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Tomáš Zemánek et al.

Harvesters and forwarders in forestry

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Contents

HARVESTERS AND FORWARDERS IN FORESTRY

1. Short wood logging system as a starting point for the deployment of logging and hauling machines

In the short wood logging system (assortment method) performed by motor-manual way (i.e. with the use of portable power saw and conventional means of skidding), the woodcutter has no other option than to remove branches from the felled trees, and to cross-cut their stems into assortments directly at the stump. Then the assortments are moved (by primary extraction, skidding or forwarding) to the stack that is usually at a roadside landing. The principle of marking off stems and their subsequent cross-cutting into assortments consists in ensuring optimal utilisation of their various parts so that their maximal valorisation and monetization is achieved. The distinction of several assortments on one stem is shown in Fig. 1.

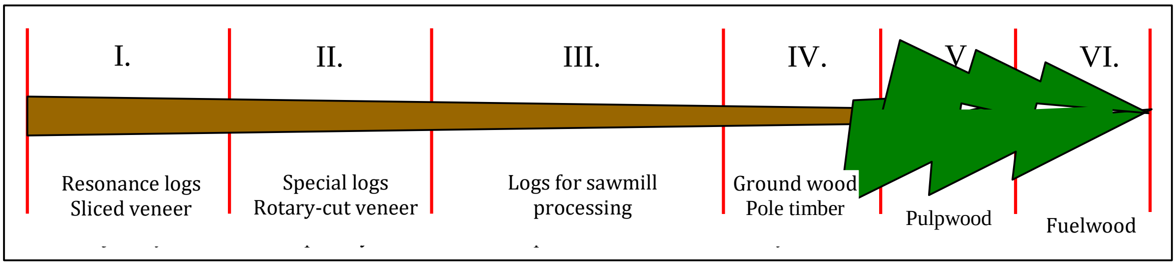


Fig. 1. Timber quality grading – Example of stem division into assortments

The method of short wood logging performed by harvester features a crucial difference as compared with the motor-manual assortment method: the felled tree is not processed immediately at the stump from which it was separated by felling, but is relocated by harvester to a chosen place (usually skidding line edge) where it is delimbed, measured, cross-cut into assortments which are then placed separately on piles. The distance to which the harvester moves the felled tree can be diverse – from usually several meters up to twenty meters in extreme cases (i.e. double the boom reach of the harvester hydraulic crane). Thus, the harvester not only produces assortments but also provides for their removal from the stump to the forest edge landing, all this in one continuous technological phase. Regarding these specific features, the logging method implemented by means of harvesters should rather be considered a separate **harvester logging method** or harvester assortment method.

Fig. 2. Timber logging by harvester node

Processing a tree, the harvester as a rule produces more than one assortment according to the customers' requirements. Basic criteria for classifying logs into assortment classes are their dimensions (species, top or butt diameter, length and technological quality, i.e. occurrence of wood defects). Producing assortments by harvester, possibilities of automatic optimization should be utilized at maximum, which is allowed by its control and measuring system, usually adjusted so that the produced timber assortments provide the best monetization, i.e. the highest proceeds. Harvester assortment methods allow environment-friendly, fast and customer-oriented timber processing. Customer's requirements are decisive to determine what assortments, in what quantities and in what term will be produced.

In the assortment method implemented by harvesters, its environmental impacts are or can be efficiently minimised thanks to the technical parameters of modern machines, proper work organisation and qualified and conscientious machine operators. Damage to tree roots can be reduced by placing branches and tree crown tops on skidding lines by harvester as the soil and the roots are better protected from the impact of travelling harvesters and namely forwarders. Nutrients remain on the site because the branches and the tree crown tops are left in the forest. Modern design principles of machines combined with qualified and conscientious machine operators and responsible preparation of production are prerequisites for logging in such a way that damage to standing trees, their root systems and natural environment are minimised.

The harvester logging technology needs only two machines in its basic and the most frequently used arrangement: harvester and forwarder which together form a so-called harvester node to carry out a number of operations such as felling, delimbing, cross-cutting, wood stacking, forwarding of timber to the deck (unloaded) at a roadside landing etc. – see Fig. 2. Optionally and with respect to actual natural and production conditions, harvesters can be combined also with other means, e.g. tractor and trailer units, cable transport installations, trough chutes etc.

Deployment of harvesters in other logging methods (whole-stem method or even full-tree logging method) cannot be advised for two main reasons. Possibilities offered by harvester technologies are far from being fully used (primary processing and measuring of trees, low time consumption for processing 1 m^3 of timber, improved labour safety etc.) and there are also technical problems, e.g. when trees are delimbed at their full length, they are often broken and the harvester working device is overloaded.

Logs made by the harvester and extracted by the forwarder remain clean, which is a significant benefit for both customers and suppliers as this is something that is as a rule financially stimulated by customers at the supplier. Moreover, the timber supplier has no problem with sanctions that may be imposed when dirty timber is transported on public roads. The harvester logging method also allows to take into account operatively special requirements of customers, e.g. production of certain dimensions of saw logs within a certain time. The timber on stacks is easy to identify because the forwarder operator sorts and places individual assortments on separate stacks at a roadside landing. Another benefit of harvester logging technologies is minimisation of transportation costs of timber haulage as timber is transported to the final user directly from the stand, i.e. timber dispatch yards are eliminated from the logistical chain of timber deliveries.

An important precondition for the successful operation of harvester nodes is a correct estimate of timber demand. Practical implementation of the programme of logging operations is then logically modified according to the need of timber. Demand fluctuation causes problems to the operators of logging and hauling machines as it affects work continuity and intensity. It is quite clear that if the logging is evenly distributed throughout the year, machine operators enjoy the increase of productivity and annual use of machines. This is why a significant prerequisite for a successful utilisation of harvester technologies is appropriate preparation of production – both at the long-term (conceptional) level and on the short-term (operational) level. The preparation of production must amongst other things include correct division of the workplace with skidding lines along which harvesters and forwarders will be moving. More details on this issue can be found in the following chapters.

2. Construction characteristics of contemporary logging and hauling machines

2.1 Harvesters

A fundamental feature of a harvester is that it is a self-propelled machine which fells the tree, removes branches, cross-cut the stem, measures the produced logs, registers them (or marks them with colours), relocates and stores them in one cycle. Logs produced by the harvester remain in the forest stand in stacked or unstacked areas/stacks but they are as a rule piled (bundled) on the edges of skidding lines. The production cycle is fully mechanised and partly automated. As a rule, harvesters and forwarders, and/or truck-and-trailer units are deployed within production flow systems and form so-called harvester nodes.

The basic classification of harvesters is based on the conception of their undercarriages (chassis): wheeled harvesters, tracked harvesters and walking harvesters. Depending on the soil surface condition, wheeled harvesters can cope with the terrains up to gradients of 25-50 % at right angles to the contour (longitudinal slope). At gradients above 50 %, wheeled undercarriages have to be equipped with tracks (a condition is however that they are provided with a double bogie axle) or the harvester is equipped with a traction winch, or a machine is used with the tracked or walking undercarriage option. Travelling across the slope, the wheeled harvester stability is max. 15 % in 4-wheel types, and 20 % in 6-wheel or 8-wheel undercarriage types. When equipped with the traction winch, wheeled harvesters can even cope with travelling on slopes nearing 75 % perpendicularly to the contours.

Fig. 3. Wheeled harvester in main felling

Fig. 4. Tracked harvester in main felling

According to the **technology of tree processing**, harvesters are classified as **one-grip harvesters** in which the whole tree is processed by the harvester head carried at the hydraulic crane boom end in one cycle, which is a standard design of temporary harvesters. **Two-grip harvesters** represent the second type of design in which the felling head carried on the hydraulic crane boom serves to fell the tree only. The tree is then placed into the swinging processor head in the rear part of harvester undercarriage, which fulfils all other operations such as delimbing, cross-cutting and log volume determination. This design was used in the first generation of harvesters and is no longer used today in European conditions.

Fig. 5. Harvester on walking undercarriage

Fig. 6. Two-grip harvester

According to engine power and basic technical parameters, wheeled harvesters can be classified as small, middle-sized and large (Tab. 1.). Other types of harvesters can be distinguished in a similar way.

Until recently, an auxiliary trait in distinguishing the size of wheeled harvesters was also the number of wheels (small harvesters 4 wheels, middle-sized and larger harvesters 6 or 8 wheels). This distinction is however no more reliable as manufacturers supply also small harvesters with a number of wheels higher than four. It should be pointed out, too, that the above-mentioned classification of harvesters cannot be considered binding; individual products may have somewhat different characteristics (some of their parameters can have lower/higher values than those mentioned for the specific machine category).

Indicative technical data of wheeled harvesters	**Unit**	**I. Small harvester**	**II. Middle-sized harvester**	**III. Large harvester**
Optimal stem volume of processed trees	m^3	0.10-0.50	0.40-0.80	0.70-2.00
Average hourly output	m^3/h	4	10	16
Engine power	kW	40-110	110-170	170-250
Width	cm	180-230	230-280	280-320
Boom reach	m	4.5-8	8-12	8-12
Max. diameter of felling level	mm	300-450	450-600	600-750
Weight	t	4-10	10-18	18-26

Tab. 1. Indicative classification of wheeled harvesters into performance classes (classification and individual parameters are of indicative character only; performance depends on local conditions)

Diagrams in Figs 7. and 8. show hourly performance values of individual categories of harvesters in dependence on the stem volume of trees and on the tree species. In addition, Fig. 8. brings a comparison of performances achieved by harvester logging and motor-manual logging. It follows from the pictures that to achieve an optimal deployment of harvesters, conditions in which the harvester is to operate have to be identified in advance, and only then a suitable harvester category can be chosen (more details in the following chapters).

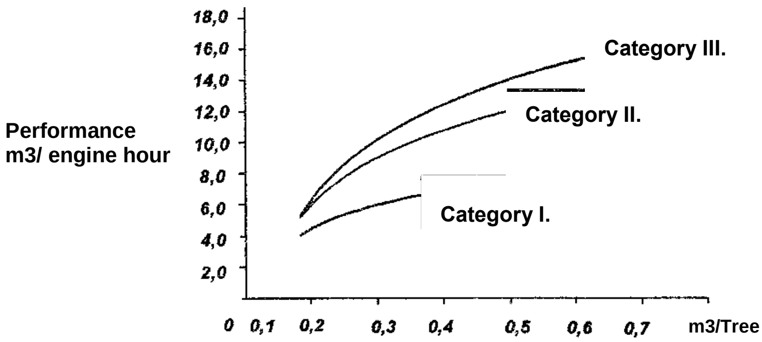


Fig. 7. Indicative values of harvester performance according to performance classes

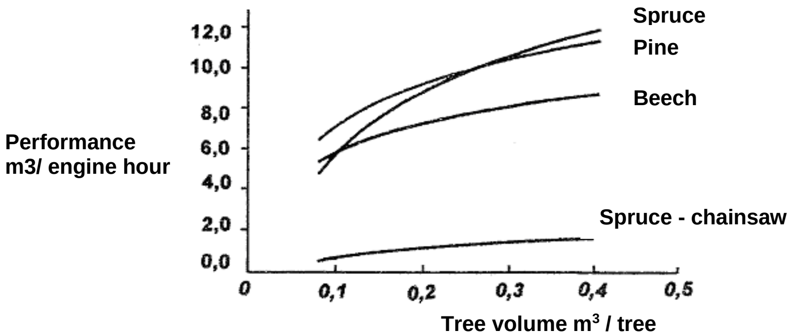
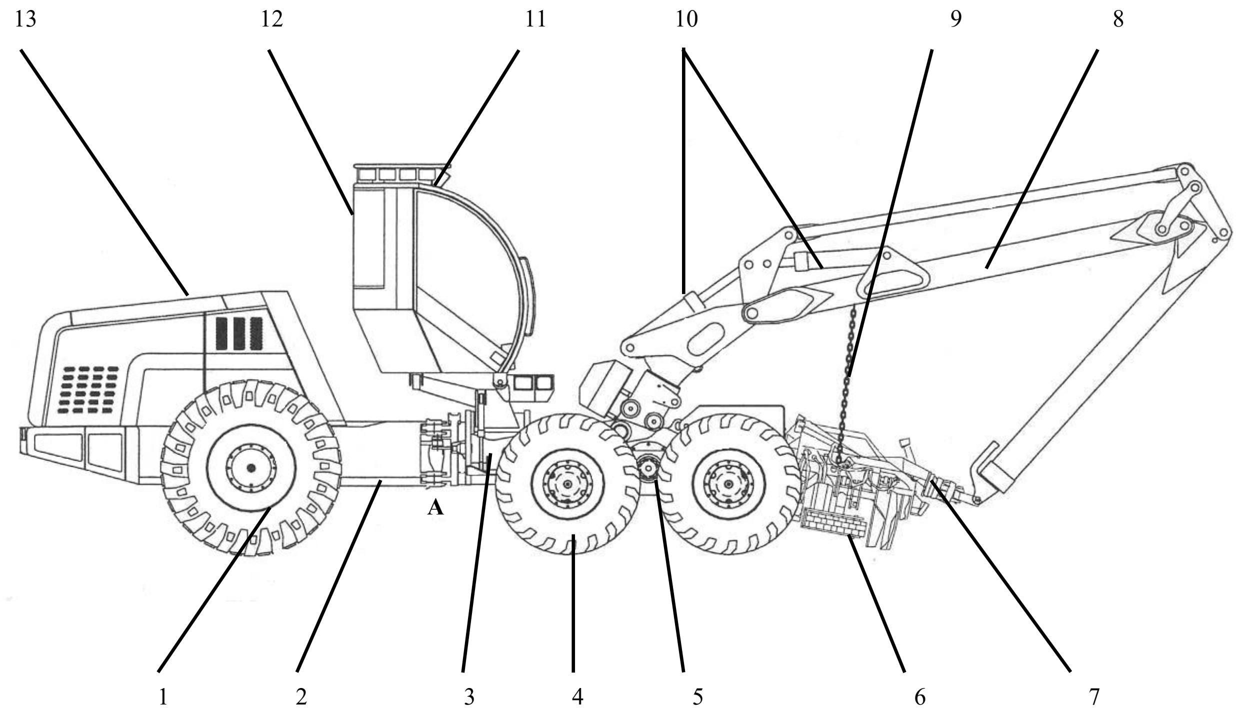


Fig. 8. Comparison of the hourly performance of middle-sized harvester and motor-manual logging (Dummel, 1999)

Main harvester parts are shown in Fig. 9. with the 6-wheel harvester with articulated undercarriage. The harvester parts include undercarriage (chassis) which is articulated in the given case, working part (hydraulic crane boom with harvester head), engine part and operator's cabin. Each of these parts consists of many other elements.

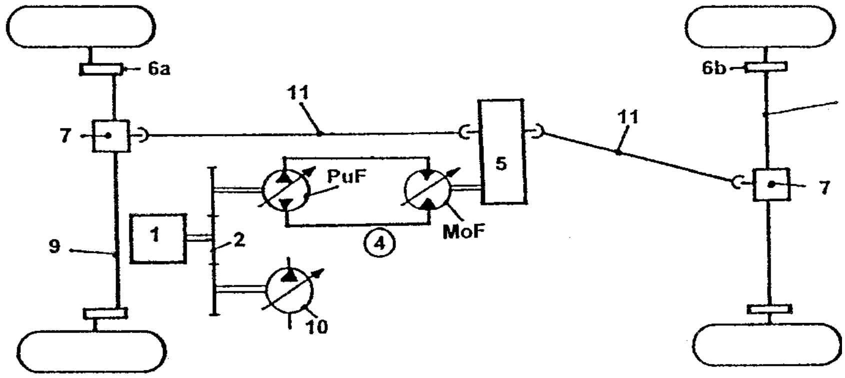


1. solid rear axle, 2. rear frame, 3. front frame, 4. front axle wheel, 5. front tandem axle, 6. harvester head, 7. rotator, 8. hydraulic crane, 9. security chain, 10. linear hydraulic motors, 11. lighting, 12. cabin, 13. harvester diesel engine

Fig. 9. Main parts of 6-wheel harvester

2.1.1 Power transmission

Harvesters and forwarders are sophisticated machines that use three basic systems for their operation – diesel engine, hydraulic system and electric system with elements of automation. The principle of their functioning is as follows: diesel engine power the hydraulic system which performs required machine operations including its travel. The two systems are then individually controlled by electronics. This electronic system currently means an interconnection of digital and analogue transmission of control information.



1- combustion engine, 2- distribution box (travel drive/working hydraulics), 3- travel clutch, 4- gearbox (drive converter), 5- distribution box of front and rear axles, 6- drive of wheels (a-transmission by spur gear wheels, b – transmission by planet wheels), 7- levelling or differential drive, 8- rear axle, 9- front axle, 10 pump of working hydraulics, 11- PTO shafts, PuF- pump of travel hydraulics, MoF- hydraulic motor of travel

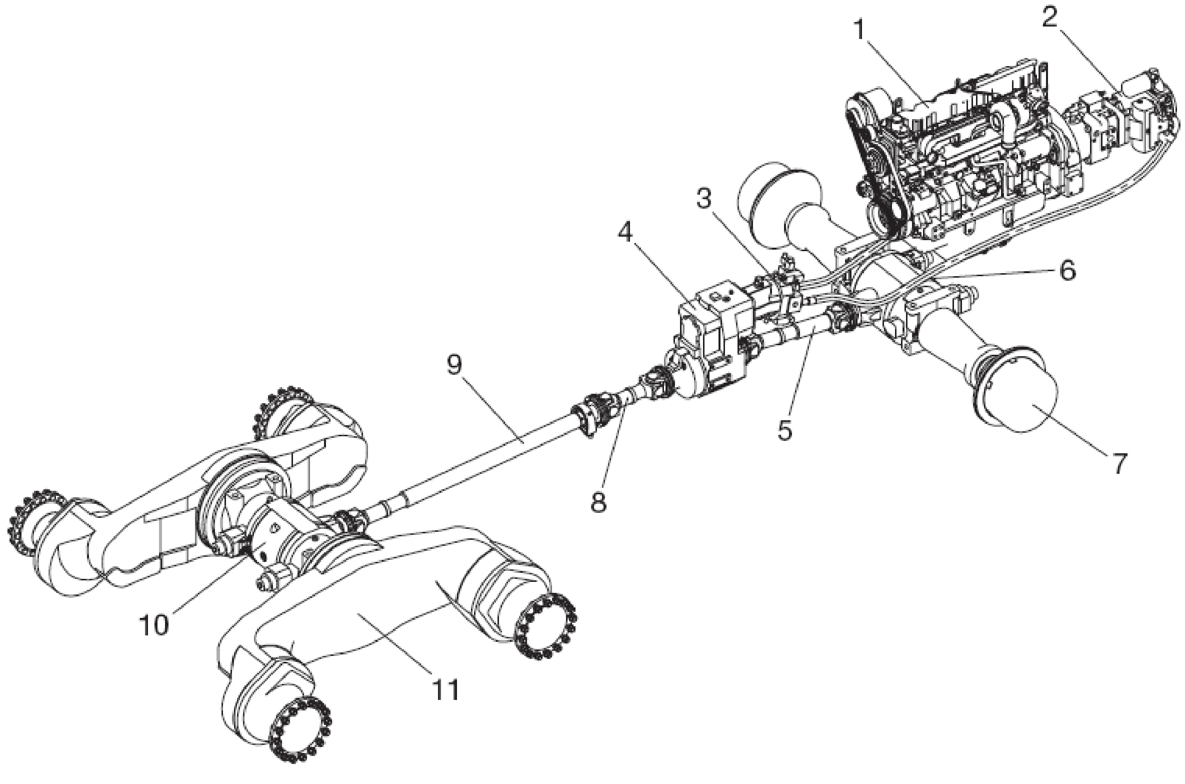
Fig. 10. System of hydrostatic-mechanical energy transmission to the travel drive

A majority of harvester manufacturers have adopted the hydrostatic-mechanical power transmission. Main advantages of the system include a possibility of the spatially economical separation of primary drive and output, a high torque at low rotations, and absence of the risk of system destruction when overloaded.

Hydrostatic-mechanical power transmission from the diesel engine to the harvester undercarriage (Fig. 10) consists of mechanical, hydrostatic and electric parts. The mechanical part includes gearbox, sets of axles, differentials and PTO shafts. The hydrostatic part includes a closed system of hydraulic pump and hydraulic motor. The work of the pump is controlled by two electrically controlled proportional valves.

In the hydrostatic part of power transmission, the speed of machine travel is continuously regulated as well as the gearing forward and back. The hydraulic pump is connected with the diesel engine, hydraulic motor which is mounted on the gearbox driven shaft and transfers power on the transmission gears, fast and slow gear. From there, the driving power is transmitted to the main drive shaft, differentials of the front and rear axles, and also on the wheel final drives.

Both the engine and the pump are of piston character and can be replaced. The direction of pump axis rotation is always constant. By means of proportional valves, the control system can change the direction and amount of oil discharge through the pump with the direction of engine rotation direction being changed accordingly (travel direction and speed). Engine rotations determine tilting of the engine axis with the board remaining in its place. Angles of pump and engine are mutually dependent. Apart from controlling direction by means of proportional valves, the pump flow rate can be changed by setting engine rotations, too. If the machine is in the still position, the pump angle is zero and the engine angle is at its maximum. When the machines are set to travel, the pump angle starts to grow. As soon as the pump angle reaches its maximum, the engine angle will start to getting smaller. At a maximum machine speed, the pump angle is at its maximum and the engine angle is at its minimum.



1. diesel engine, 2. Hydrogen generator, 3. Hydraulic motor, 4. Gearbox with distribution box, 5. PTO shaft, rear differential, 6. Rear differential, 7. Hubs of rear wheels, 8. PTO shaft, central part, 9. PTO shaft, front part (connection of middle joint and front differential), 10. Front differential, 11. Bogie axle

Fig. 11. Construction of 6-wheeled harvester undercarriage and principle of power transmission onto wheels

The arrangement of basic constructional elements of the undercarriage system of wheeled harvesters is shown in Fig. 11. It is a widely spread system of driving force transmission with a single central hydraulic motor of axial type. Forwarder undercarriages use in fact an identical system.

Manufacturers of walking undercarriages for harvesters and some manufacturers of tracked undercarriages use the system of power transmission with the hydraulic motor in each wheel (i.e. 4 wheels). Manufacturers of tracked undercarriages use the system of power transmission with the hydraulic motor in each track.

In the early stages, there is a use of the hybrid system of power transmission with the hydrostatic-mechanical drive and electric motors in the wheels of harvesters (made by ProSilva). In forwarders, this concept has been used in the Elforest brand already for some time. The manufacturer claims that one of the main advantages of this design as compared with the classic system of drive is reduced fuel consumption.

2.1.2 Undercarriage

The most common way of the movement of energy means in forestry (harvesters as well) is travelling, i.e. continual movement allowed by travel device equipped with wheels, tracks or wheel tracks. In harvesters, there is an additional principle of moving – so-called walking.

Wheeled undercarriage
Compared with all other modes of movement, the wheeled undercarriage provides the highest machine mobility. As a rule, the harvester travels over short distances (up to 30 km) along its own axis as well as along public roads, which is not feasible for tracked undercarriages that would cause damage to carriageway surface of paved roads.

Undercarriage of wheeled multi-operational machines usually consists of two parts connected with an articulated joint (turning to each other both along the longitudinal and vertical axes). The mutual lateral turning (articulation) of the front and rear parts of the frame is activated by the hydrostatic system with two linear hydraulic motors. A maximum angle of articulation of undercarriage frames while driving ranges up to 45°. The harvester Vimek 404 with a possibility of front axle turning and total turning angle of 80° is an exception. The mutual torsional movement of the front and rear parts can be blocked, which helps achieve higher lateral stability of the machine. This is important in timber harvesting with the harvester head put out on sides by the hydraulic crane boom.

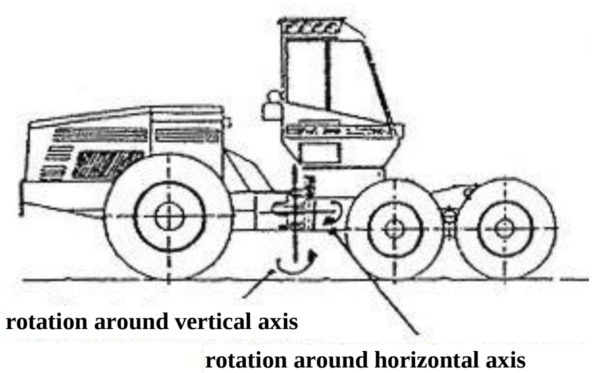


Fig. 12. Central axial joint

Four-wheeled undercarriages are fitted with two solid or (less frequently) two swing axles; six-wheeled undercarriages are fitted with one tandem (bogie) axle in the front part and with one solid axle in the rear part; eight-wheeled undercarriages are fitted with two tandem (bogie) axles. Compared with the solid axles, tandem axles have an advantage of easier overcoming obstacles in the terrain, lower pressure of machine undercarriage on the soil surface and a possibility of using so-called wheel tracks. Compared with the tandem axles, solid axles feature a shorter construction length, lower manufacturing costs and more favourable economy when the machines are moved from one site to another (lower fuel consumption). However, the vertical swing of the cabin of machine with the solid axle is greater when the left or right part of the axle hits an obstacle as compared with the tandem axles. Swing axles allow an independent swing of each wheel. The design makes possible the machine levelling to 30 % in both longitudinal and transverse direction in difficult terrains. The manufacturer informs that in this way, the harvester slope accessibility in the longitudinal direction is increased to 30 % and the slope accessibility in the transverse direction is increased to 60 %. Depending on terrain conditions, indicative values of slope accessibility of 4-wheeled harvesters equipped with standard solid axles are max. 15 % in the longitudinal direction and 40 % in the transverse direction.

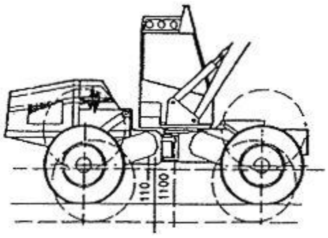


Fig. 13. Setting of individual wheels

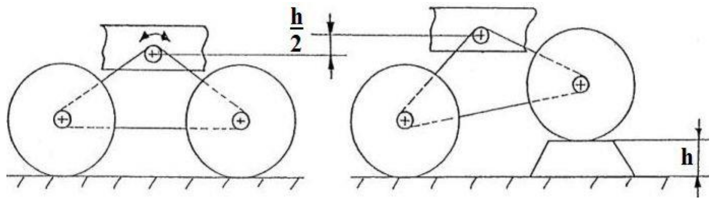


Fig. 14. Principle of tandem / bogie axle

In tandem (bogie) axles, driving force gets from the main drive shaft always to two wheels on each side of the machine through toother or chain gears located in a special box of tandem axle. The gears are in oil bath to reduce the rate of their wear. Tandem axles increase the machine stability and load forces are distributed across a larger soil surface area.

One of traditional manufacturers of tandem axles is for example the German company NAF which offers, in addition to portal tandem axles, also levelled tandem axles or tandem axles for speeds up to 65 km/h. Thanks to their design, levelled tandem axles optimize the distribution of traction force when overcoming obstacles, which improves the machine passability through the terrain and reduces damage to the terrain caused by slipping traction device. As an option, some manufacturers offer the lifting of either front or rear tandem axle to overcome local roughness's in sloping terrains.

Another construction solution is offered for 4- or 6-wheeled undercarriages by the Austrian manufacturer of harvesters Konrad Forsttechnik. Rear wheels that are height-adjustable are located on arms which extend from the basic machine frame independently on each other (maximum extension of the arm with the wheel is 1.980 mm 4WD and 1.993 mm 6WD). The front axle and rear wheels are controllable independently, which provides a relatively small internal turning radius of 3,500 mm to the machine in spite of the large front axle base and rear wheelbase.

Ground clearance of the undercarriage and **approach angle** are important technical parameters characterizing machine passability through the terrain. Ground clearance is affected by the design of axles, wheel rim diameter and by the profile number of used tyre. In harvesters, the undercarriage ground clearance usually ranges from ca. 400 mm to 700 mm. The Rottne H8 harvester is equipped with swing axles that allow to change both the wheelbase and the undercarriage ground clearance from 200 to 1.000 mm. In addition to design, the machine approach angle is markedly affected also by the axle type and by the size of wheels in the front machine section under the operator's cab. As terrain obstacles are better overcome by tandem axles, the approach angle of tandem axles is larger than in solid axles.

Fig. 15. Tandem (bogie) axle

Machine weight is a characteristic giving only indicative value on a possible extent of soil damage to the user. The significance of weight has to be at all times assessed together with the size and shape of machine undercarriage contact area and properties of base (soil, line, road) surface. The main consequence of machine weight is rutting. As a manifestation of weight and contact area size, **specific pressure of the machine** participates in the formation of ruts and damage to the soil. The value of a specific pressure should theoretically equal the value of tyre inflation pressure; it is however affected by a so-called tyre stiffness coefficient. To prevent damage to forest soils, rated footprint pressure would have to be reduced to the level of ground bearing capacity, which is unrealistic in practice. Depending on actual machine weight and total number of axles, actual specific pressure is up to 150 kPa. As compared with some other means, Ulrich et al. (2003) mentions a pressure on the soil in general-purpose wheeled tractors to be 160 kPa, 220 kPa in forest wheeled prime movers and 160 kPa in horses.

The pressure of machines onto the ground can be reduced by several ways. Except for reduced total machine weight, all have to do with the design of undercarriage. One of possibilities to reduce the pressure is increasing the contact area of machine undercarriage with the ground. This can be achieved by increasing the number of wheels, by increasing their size or by changing the tyre type. A common measure is of course the use of wheel tracks on the tandem axles. Another possibility is a new design of the undercarriage, e.g. the hydraulic lift of wheels or swing axles.

Tyres suitable for harvesters and forwarders are low-pressure large-sized tyres. An important precondition for reaching low rolling resistance on the soft ground is a shallow track. This can be achieved by reduced inflation; at the point of contact, the tyre should be yielding more than the ground, otherwise it starts to behave as a rigid wheel and the advantage of its elasticity is lost.

Slip size at the given value of transmitted driving force depends both on the type and condition of subsoil (i.e. on the mechanical properties of earth) and on the type and construction parameters of the drive train and undercarriage. It further depends on the undercarriage adhesion load, which is governed by the machine weight, load distribution onto the axles, and on the size of tracks or dimensions of tyres and their inflation.

Tyre pattern is decisive not only for the distribution of footprint pressure but also for the gentle handling of the soil surface. Arrowhead ribbing used in general-purpose wheeled tractors or on simple axles of harvesters has a great capacity of absorbing lateral forces when driving diagonally on the slope; however, damage to the soil surface is considerable. Tyres that have at the contact point with the ground the pattern rib perpendicular to the travel direction have a lower capacity to maintain stability of direction but are much friendlier to the soil surface. In practice, such a tyre pattern has to be chosen, which meets best the two requirements in specific conditions. In harvesters and forwarders, simple axles are usually equipped with the arrow pattern tyres (Fig. 16. left) while tandem (bogie) axles have tyres with so-called bent segments (Fig. 16. right), which also facilitate the operation of wheel tracks.

Fig. 16. Tyres with arrow pattern (TRS) and bent segments (ELS)

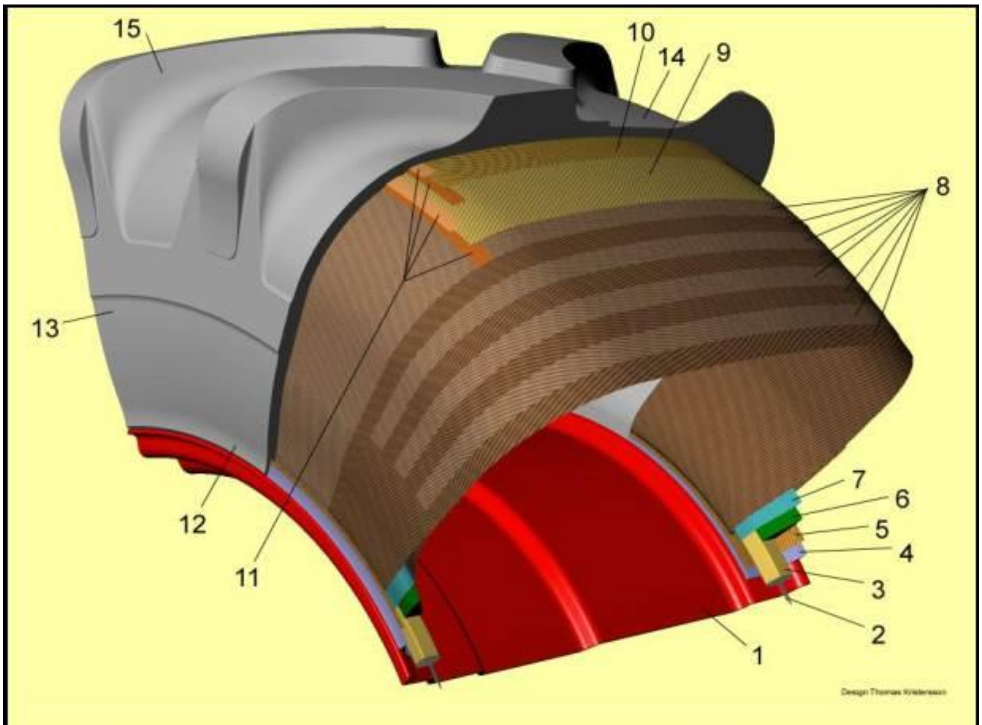
Fig. 17. Anti-slip tyre chains

Two renowned suppliers of forest tyres in the Czech Republic - Nokian and Trelleborg offer a wide range of forest tyres of both radial and diagonal design with tubes or without them. Widths of Nokian tyres are available from 500 to 800 mm for rim diameters ranging from 22.5 to 34". Widths of Trelleborg tyres are available from 400 to 750 mm for rim diameters ranging from 15.5 to 34". There are two basic types in the several produced types of patterns; in the Nokian terminology, they are referred to as TRS and ELS. Compared with the ELS pattern tyres (bent segments), the TRS pattern tyres (arrow pattern) feature better transmission of wheel traction force onto the ground surface which however suffers a greater damage (see above) when the tyre slips and wears faster when driving long on hard surfaces. Forest tyres have a special reinforced construction for working in difficult logging conditions (contain up to 14 textile layers), which prevents excessive bulging of side walls at lower tyre inflation. This is why other types of tyres (e.g. agricultural tyres) cannot be used without an increased risk of damage.

Driving with anti-slip chains requires to adhere carefully to the recommended tyre inflation and to control the chain tension so that no great sag (so-called bag) occurs on the rear side as there would be a danger of chain rotating in the link and the spike could cause damage to the tyre. It is necessary to check whether individual parts are not loose or whether sharp edges do not protrude from the chain, which could cause damage to the tyre.

For driving with the wheel tracks, the manufacturer recommends a higher inflation of tyres. The tracks must correspond to the tyre size and have to be properly tightened. The track has to be bent ca. 50 mm between the wheels. Distance between the track and tyre side wall must be ca. 15 mm. Possible damage to tracks must be inspected and removed so that sharp edges cannot cause damage to the tyre.

Regular inspection and maintenance of tyres increase their service life. Daily visual check of tyres reveal any sort of damage such as stuck splinters, large gashes, etc. that could pierce the tyre skeleton. Any such damage must be immediately repaired. All branches or wood splinters stuck between the tyre and the rim are to be removed. Pressure in tyres must be checked at least once a month. Depending on working conditions, the tyre pressure has to correspond to the terrain type and load. Lower pressure is used when the terrain is relatively free of stones and when a higher ground bearing capacity is needed. Higher pressure is used in demanding terrains with the skeleton.



1. Rim, 2. Guide wire, 3.Bead canvas, 4. Bearing surface of bead, 5. Bead protection against penetration, 6. Sealer, 7. Filling above bead rope, 8. Textile layers of skeleton, 9., 10. Steel bumper, 11. Ending of bumpers, 12. Side wall edge, 13. Side wall, 14. Tire tread, 15. Pattern

Fig. 18. Example of Trelleborg tyre design

One of the largest manufacturers of wheel tracks and anti-slip chains – Olofsfors currently offers 11 types of wheel tracks from universal (ECO-TRACK) up to wheel tracks designed for specific work conditions (ECO-BALTIC for water-logged soils) and two types of anti-slip chains in three variants of material thickness - 13, 16 and 19 mm.

In sloping terrains, the machine stability can be increased by lowering its centre of gravity through the filling of tyres with antifreeze solution (e.g. aqueous solution of $CaCl_2$). The tyre is filled with the mixture to 75 % of its volume. In the case of tyre dimensions 700x26.5 then the machine weight increases by 470 kg per one tyre. In the tandem axle equipped with these tyres, the weight of the machine increases by 1,880 kg.

Harvesters are equipped with the hydraulic **brake system** with two brake circuits. The brake pedal is controlled by brake control valve which supplies permanent variable braking pressure to a brake cylinder. For the purpose of braking, the hydraulic oil is pumped from the primary hydraulic system and stored in pressure tanks. The two working circuits are controlled by the working brake. When the machine stands still, it is applied automatically. As soon as the machine moves, the brake and the stabilization blocking are activated. The systems are constructed so that the machine can be braked in the case of engine stoppage, loss of hydraulic pressure, braking by pedal, activation of parking brake or electric failure. The parking brake and the emergency brake are controlled by springs.

a) principle **b) wheel track ECO-Track** **c) wheel track ECO-Baltic**

Fig. 19. Wheel tracks

Tracked undercarriage

Tracked undercarriage is a guarantee of excellent traction in the conditions of swampy terrains, and its benefits will show when it is deployed on soils with lower bearing capacity where low specific pressures are required. In tracked machines, high traction forces are achieved by their total weight. Tracked undercarriages have a high capacity of adhesion (adhesion coefficient of tracked undercarriages can as the only one reach a value higher than 1.0), and thus a maximum engine power can be used without excessive slip. Another advantage is great stability and slope accessibility. Disadvantages include decreasing mobility of transportation to a new workplace, damage to surface when turning, etc.

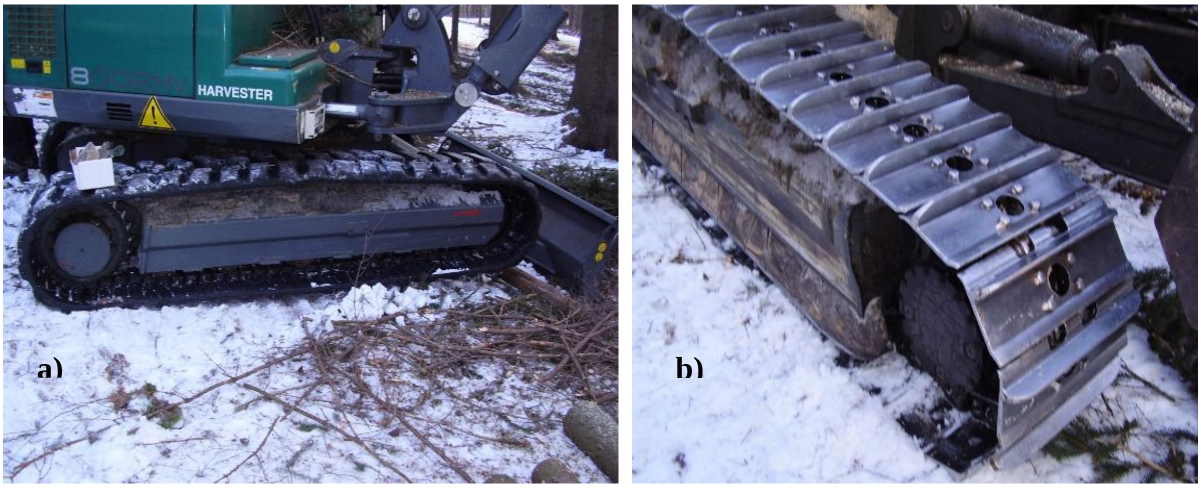


Fig. 20. Tracked undercarriage *a) rubber, b) metal*

Most tracked harvesters have the cabin superstructure and hydraulic crane with the harvesting head installed on the general-purpose excavator chassis. Tracks are made of rubber, metal or a combination of metal and rubber or high-resistance plastic material (Fig. 20.). Infinite metal tracks are composed of individual members. The members are most frequently single-edged or three-edged (higher traction). Drive is ensured from the hydraulically controlled drive wheel whose pin fall into eyes on the track. Rubber tracks are used in harvesters of lower weight classes (ca. up to 11 tons). In order to provide for a longer service life of rubber tracks, their eyes can be reinforced with metal.

Fig. 21. Metal tracked undercarriage

Fig. 22. Four tracked units of ProSilva harvester

Tracks are tightened via the chain sprocket and are led on several guide pulleys. The undercarriage is sprung by twisted rods, which maintains an optimum contact with the terrain and reaches maximum traction. The working hydraulics of the machine is separated from the drive of tracks. The hydraulic system for driving the tracks has a separate closed hydraulic circuit for the left and the right tracks, which facilitates the directional control of the machine through the changing speed of left or right tracks (up to their complete stop – which allows the machine turning on the spot).

In about 2000, another design of tracked undercarriage was first used in the tracked harvester Valmet 911.1 Snake, on the standard articulated undercarriage of which four track units of 0.5 m in width and 2.0 m in length were put on instead of tandem axles (Fig. 21). The exchange of wheels for tracks or the reverse disassembly lasts ca. 0.5 of work shift. This is a current equipment of e.g. ProSilva tracked harvesters with the standard articulated steering and four track units instead of wheels.

Walking undercarriage

The walking undercarriage is **usually based on the construction of the so-called walking excavators** (e.g. Menzi Muck – Fig. 23.) or is a superstructure on the special six-leg chassis manufactured specially for forest operations; there is currently just one prototype introduced at the end of the 1990s by the John Deere company (Plusstech) (Fig. 24).

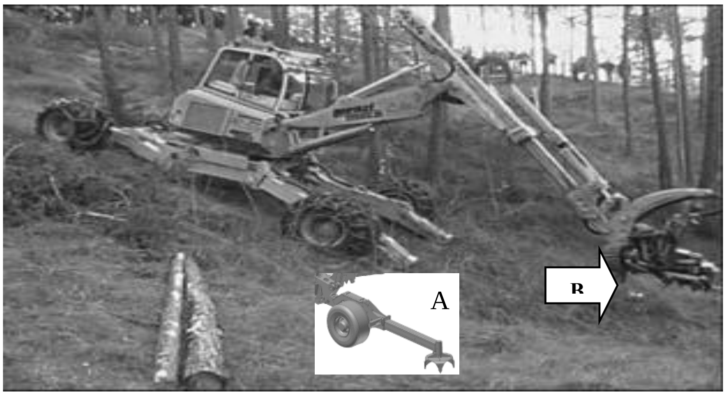
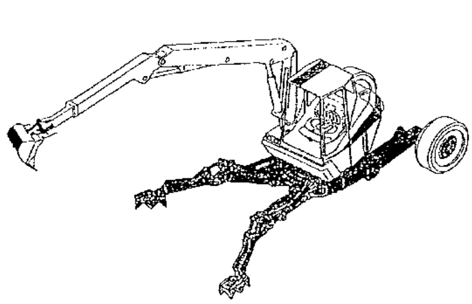


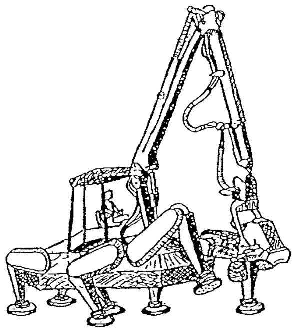
Fig. 23. Walking harvester Menzi Muck
A. stabilization supports, B. supporting base

Fig. 24. Walking harvester John Deere (Plusstech)

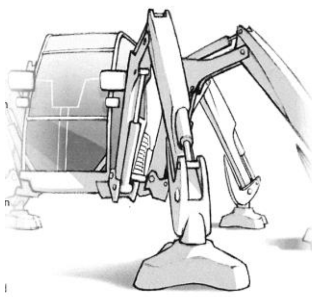
The Menzi Muck machine is normally deployed as a walking excavator (digger) in complicated terrain conditions, for example in clearing river beds, treatment of slopes, construction of roads, but currently also in mulching and forest harvesting when mulching a "Woody" harvester head is installed on the hydraulic crane boom. The undercarriage is equipped with four hydraulically controlled arms that can be set both horizontally and vertically independently on each other, and which ensure the machine stability on steep slopes. Two arms are equipped with wheels and two wheels are equipped with supports. The movement on the slope or in unpassable terrains is realized by means of hydraulic crane with the harvester head, which is equipped with a support base for the machine to dwell on during transportation similarly as the walking excavator leans on the shovel. The forward movement of the machine with this equipment is discontinued and realized by means of hydraulic crane arm reaching at maximum, leaning on the terrain with its support base, lifting the machine a bit and then pulling the chassis by articulation to the point of leaning on the terrain. After having been relocated, the machine can continue to work or further relocate by repeating the described tasks. The reverse movement is analogical, only the support base on the boom leans on near the machine which pushes away by the boom from the leaning point. An advantage of this solution is a possibility of working also in very difficult terrains with gradients up to about 90 %, on the soils of poor bearing capacity or on rugged sites. In more favourable terrain situations, all four arms can be provided wheels and the machine relocation then happens by the continual travel of these hydrostatically driven wheels. The machine speed in the field is up to 4 km/hr.



Walking undercarriage - classic design



Plusstech machine - walking undercarriage



Mantis machine undercarriage – leg detail

Fig. 25. Comparison of the principles of walking undercarriages

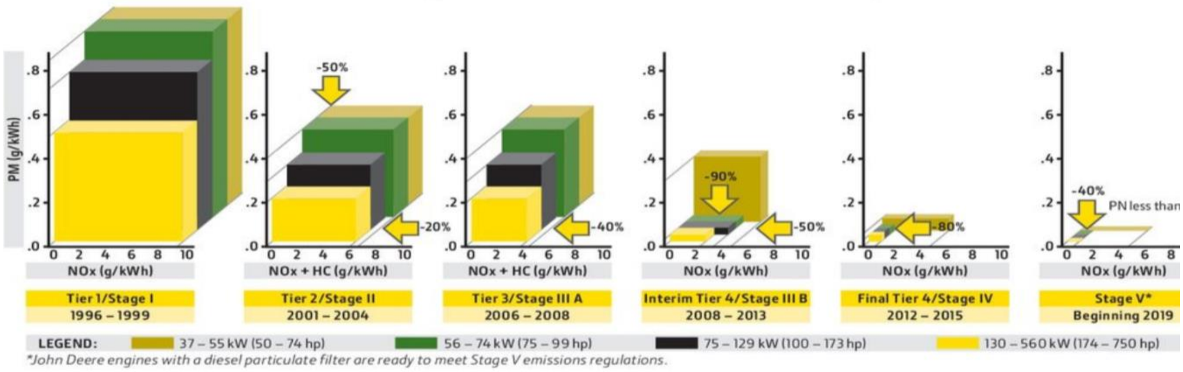
Another principle of the walking undercarriage is used in the Plusstech machine, equipped with six hydraulically driven and electronically controlled legs that are placed three on each side of the undercarriage and are mutually independent. The principle of leg movement was developed at the end of the 1990s and resembles the movement of insects; the machine relocation is thus continual. The design allows to change direction both when the machine travels or is standing still, to move forward, back and to sides, as well as machine levelling on the slope. The legs are equipped with tread surfaces with sensors which control the quality of each leg stability upon stepping on. At any moment, the machine is supported by min. four opposite legs, which provides for its stability. The movement of the legs, their position and quality of stepping on are checked and controlled by the on-board computer while the machine control by the operator happens by means of standard controllers. An undercarriage of the same principle – hexapod – is used also in the machine made by Mantis that was introduced in 2013. Even this machine is not yet in the stage of prototype.

Walking undercarriages are useful thanks to their excellent terrain passability and zero ruts in the soil. However, they cannot be used (at least at the current design level) for operations which require fast relocation, particularly in transporting materials e.g. timber skidding by carrying or hauling.

2.1.3 Engine

Harvesters are usually equipped with 4- or 6-cylinder diesel engines (50 - 250 kW, engine cylinder capacity ranging from 2.5 to 9 litres.

In 2019, the Stage V emission standard came into force. Manufacturers of engines meet these set emission limits by two methods or by their combination. The first method is a technology using the recirculation and cooling of exhaust gases - CEGR+DPF (Cooled Exhaust Gas Recirculation). Engines with this technology have a somewhat higher fuel consumption, the filter of solid particles has to be regenerated (ca. once a day) at regular intervals (time intensity of ca. 30 minutes), and the filter has to be changed after a certain time (financially expensive). The second method of reducing emissions is the technology of selective catalytic reduction - SCR (Selective Catalytic Reduction). Machines equipped with this technology must have a special tank for the AdBlue additive, which is rather demanding for the spatial design of the harvester engine part.



NO_x – nitrogen oxides, HC - hydrocarbons, PM – solid particles

Fig. 26. Development of EPA and EU emission regulations

Fig. 27. shows an example of using the two technologies (CEGR+DPF and SCR) to reduce diesel engine emissions according to Standard Tier 4 (Stage IV). This solution is used in diesel engines John Deere PowerTech PSS with cylinder capacities 4.5; 6.8; 9.0 and 13.5 l.

The engine part of harvesters can be equipped with diverse elements facilitating the machine operation and care. Independent heating is recommended particularly in winter when the outdoor temperature falls below 5 °C. The independent heating warms the engine, hydraulic oil and operator's cabin before the cold start of the harvester. By its activity, it reduces fuel consumption as well as the wear of the diesel engine and other components. Central lubrication improves the machine maintenance quality and reduces time needed for the daily maintenance of the machine. Central lubrication is usually available for the central joint of articulated frame, hydraulic crane, and system of operator's cabin levelling and turning.

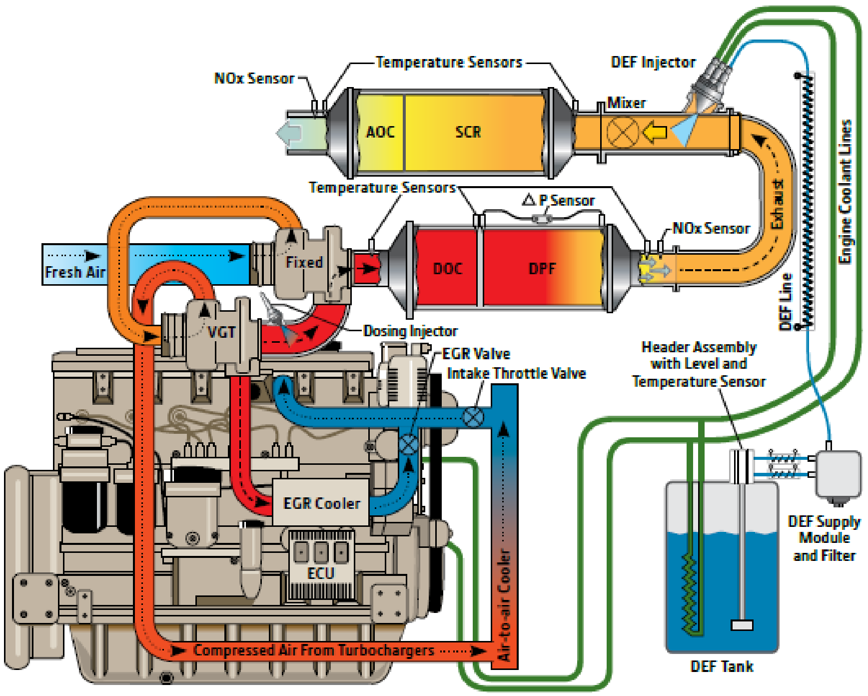


Fig. 27. Principle of reducing emissions in engines John Deere PowerTech PSS meeting Tier 4 Standard

Equipment of the engine part of the machine with an electric pump of hydraulic oil and fuel reduces the risk of the contamination of these operating fluids when pumped by external pump and reduces the time for servicing in forwarder operations. A hydraulic ventilator with the reverse mode of operation reduces noise levels and fuel consumption. Automatically at certain time intervals or manually upon the operator's instruction, the reverse operation of the ventilator can be used to release debris from its cover grid. The fire extinguishing system is usually located in the engine part of the machine. This system which is not currently mandatory for special forest machines in the Czech Republic markedly strengthens fire prevention on the machine. The system will carry out firefighting automatically if some of its sensors detects a critical temperature in the engine part of the machine.

2.1.4 Hydraulic crane on harvester

The crane is an important part of each harvester. It serves to carry the harvester head and to perform all movements required for tree processing. The crane assembly can be on the side of the harvester, in front or behind the operator's cabin. The lateral reach of the hydraulic crane booms in harvesters ranges according to the type from 7 to 12 m. According to their design, **cranes can be classified** into cranes with the main boom, articulated and/or telescopic arm; cranes with an articulated and telescopic boom, and cranes with parallel boom arms.

Crane l**ifting torque** M_j is given by the product of lifting force (kN) and the relevant boom reach (m), the result being expressed in kilonewton meters (kNm). The crane lifting torque is a basic technical parameter of the crane and is conditioned by its design characteristics (strength of beams, hydraulic system parameters). According to lifting torque, cranes are classified as small (M_j up to 100 kNm), middle sized (M_j 100-160 kNm) and large (M_j above 160 kNm).

Movements of the crane are controlled hydraulically. Working pressure of the hydraulics is between 200 – 280 bar (20 – 28 MPa). Rupture of the hydraulic line may result in a rapid oil leakage, which would jeopardize also the crane operator; this is why the individual circuits of hydraulic fluid flow are equipped with automatic hydraulic valves which block the movement of arms when the pressure in the system falls or close the fluid flow when high-pressure hoses suffer a damage.

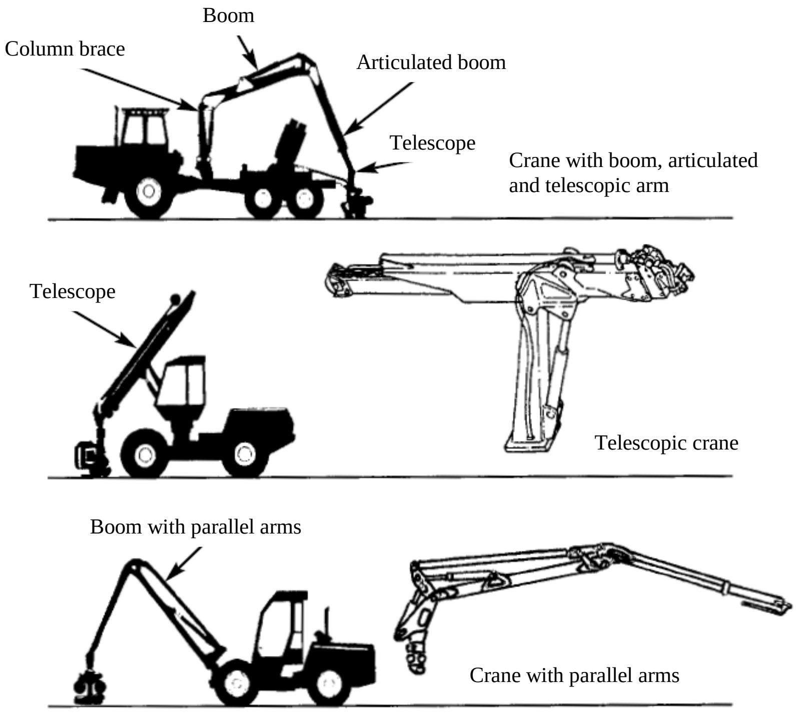
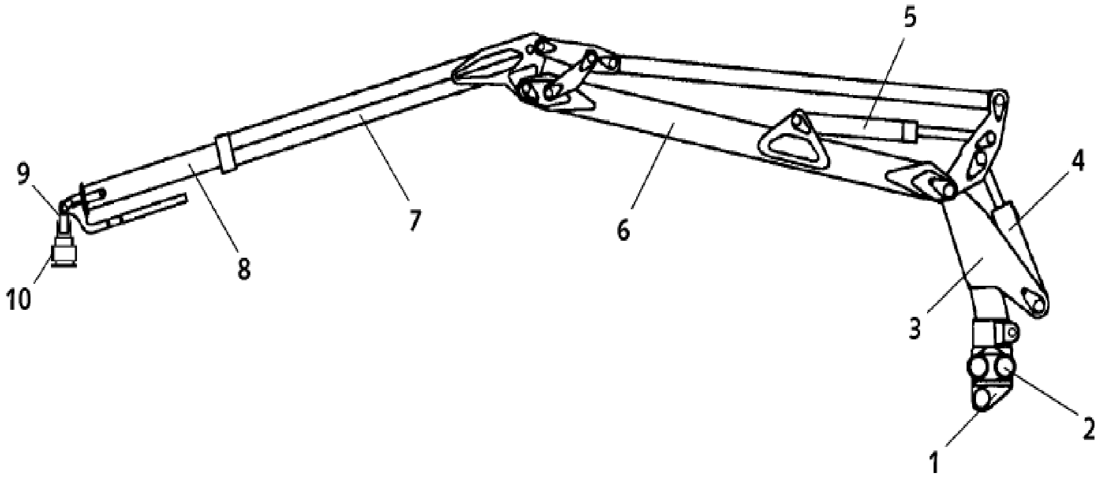


Fig. 28. Classification of hydraulic cranes on harvesters according to their design

The crane support column is installed as rotating; in some types it allows also a deflection forward and back, which increases the harvester stability and improves the working characteristics of the hydraulic crane namely when operating in sloping terrains. A good choice for novice operators is the hydraulic crane damping. This function eliminates impacts in the end positions of the crane caused by sudden movements at its control, thus extending the service life of individual components of the hydraulic crane. The function of central lubrication of the hydraulic crane speeds up and provides better quality to every-day service. A useful choice (particularly for machines in thinning's) is a hidden system of hydraulic hoses which – being protected - cannot be damaged in the dense thinning stands. In addition to working lights on the cabin or in the space under the cabin, halogen, xenon or LED lights can be installed also on the main arm of hydraulic crane for working in the dense thinning stands, which improves operator's working conditions as well as the quality of work.



1. hydraulic crane base, 2. swing bearing cylinders, 3. column, 4. main arm cylinder, 5. swing arm cylinder, 6. main arm, 7. swing arm, 8. telescope (1 or 2 telescopic arms), 9. connection of rotator, 10. rotator

Fig. 29. Design of hydraulic crane with parallel arms

2.1.5 Harvester head

The task of the harvester head is to separate the tree from the stump, tilt it into a working position, remove branches, cross-cut the trunk, measure and store logs and/or mark them.

The harvester head is provided a hanging frame that is at the end of rotator installed on two bearings placed in a cross in order to ensure both its vertical position and tilt when the tree is being processed. The working part of the head is connected to the hanging frame by two bearings on which it is tilting around the horizontal axis when in action. The position of the working part of the head towards the hanging frame (particularly when returning to its initial position) is controlled by linear hydraulic motors.

When felling, the head is put vertically onto the tree base. The tree is grasped by the closure of delimbing knives and movable feed rollers, and then it is cut off by the saw. During the cutting, the tree can be pre-stressed by the pressure of the hydraulic cylinder of hydraulic crane, and thus to lighten the saw in the cut (the saw must not be gripped tightly in the cut). When the tree falls, the working part of the head bends down in the hanging frame. The tree is pulled through delimbing knives in horizontal position by means of feeding rollers driven by rotary hydraulic motors and continually cross-cut into assortments.

Felling and cross-cutting device of the harvester head

The most frequently used tool for felling and cross-cutting in harvester heads is chain saw that replaced in the 1970s hydraulic knifes or cutting devices and circular saws. The cross-cutting unit consists of chain, guide bar, sprocket, guide bar console, chain driving rotary hydraulic motor, linear hydraulic motor (cylinder), bar position sensors and chain lubrication.

The construction of cutting device is similar as in one-man power saws. The chain with a pitch of 0.404" or ¾" consists of saw teeth (alternating left and right), chain guide links and connecting links. Bar length is over 1,300 mm in the largest felling heads, and guide groove width is 1.6 mm or 2.0 mm. All harvester bars are made of alloy steel and are equipped with a guide wheel. Guide bar movement into the cut is ensured by the linear hydraulic motor. Maximum felling level of the harvester head ranges from 350 to 750 mm according to the purpose of harvester deployment. The saw chain is driven from the chain wheel driven by hydraulic motor. Oil is driven into the groove by oil pump from a separate tank with the lubricating oil, lubrication is either dosed or continual.

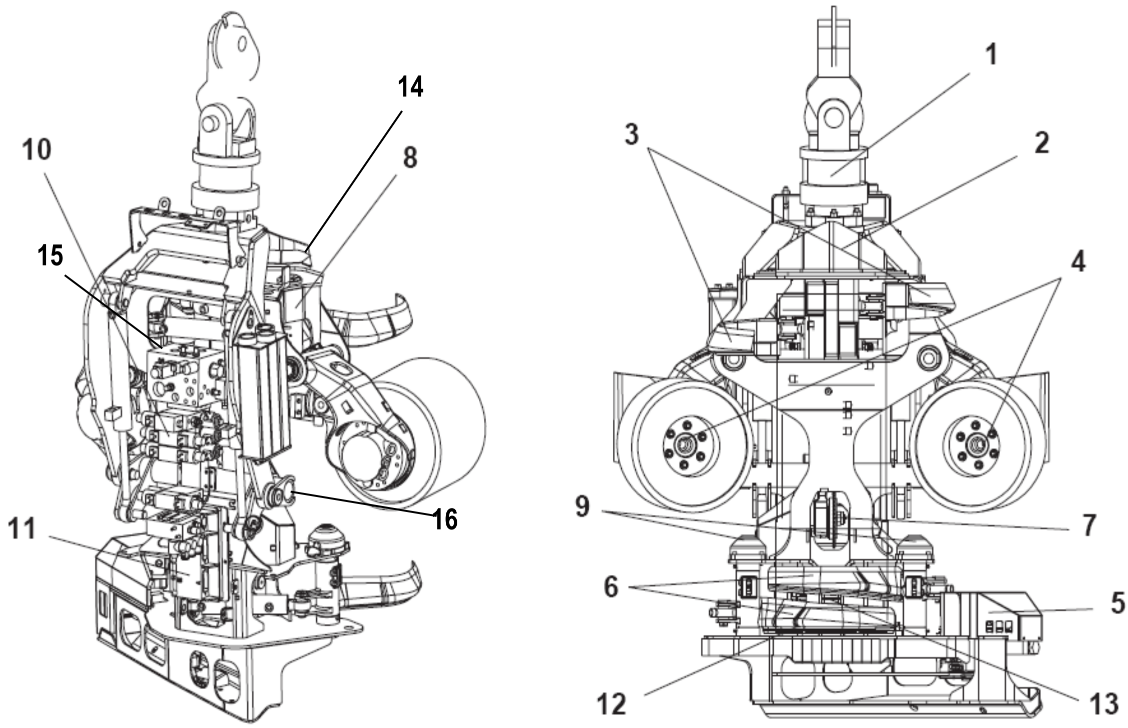


Fig. 30. Structural elements of a harvester head

The construction of cutting device is similar as in one-man power saws. The chain with a pitch of 0.404“or ¾“ consists of planer teeth (alternating left and right), chain guide links and connecting links. Bar length is over 1,300 mm in the largest felling heads, and guide groove width is 1.6 mm or 2.0 mm. All harvester bars are made of alloy steel and are equipped with a guide wheel. Guide bar movement into the cut is ensured by the linear hydraulic motor. Maximum felling level of the harvester head ranges from 350 to 750 mm according to the purpose of harvester deployment. Saw chain is driven from the chain wheel driven by hydraulic motor. Oil is driven into the groove by oil pump from a separate tank with the lubricating oil, lubrication is either dosed or continual.

Heads for cutting low-diameter trees from advance growths or plantations of fast-growing tree species can be equipped with a felling shear with one solid knife and one movable knife or with two “floating” knives moving against each other, whose edges move against each other. The felling shear has a simpler structure and is not so demanding for maintenance as the saw chain is. However, the knives can be used to fell only trees with a diameter up to 30 cm. Another disadvantage is the risk of pulling out wood fibres and wood deformation near the cut from the most valuable part when the tree is felled. Heads with the felling shear are very often combined with a device for gripping more trunks in one work cycle. The device is usually integrated into the frame of the felling head when manufactured or can be added into the space between the upper part of the head and rotator.

Felling heads of wheeled or tracked fellers often use circular saw blades as a dividing device. Their advantage is simple design and easy maintenance. A disadvantage is robustness as the diameter of the circular saw blades is more than a double when compared with the diameter of the felled tree.

Feeding device of harvester head

The main task of the feeding device is to pull the trunk of the felled tree through the harvester head. The most common equipment for the purpose are feeding rollers. Feeding can be also provided by feed tracks or by the draw feed device.

Feed rollers can be designed as movable on arms - 2 pcs (are carried and pressed against the trunk by arms that are controlled by linear hydraulic motors) or as solid - 1 pc or 2 pcs (are located in the harvester head frame). The harvester head can be equipped either with 2 (rarely 4 as a tandem) movable feed rollers, or with one solid and 2 pcs of movable feed rollers, or with 2 movable feed rollers and 2 solid feed rollers. Important for the quality of trunk processing is the design of feed rollers. In general, there are two types of rollers.

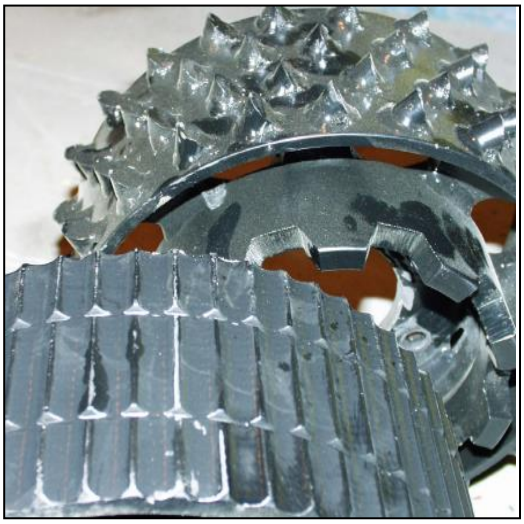


Fig. 31. Metal feed rollers with pressure tips and ribbing

Fig. 32. Tyreco feed rollers with anti-slip chains

The first type is represented by metal rollers on the surface of which there are conical or flat tips or ribs. This type of rollers is very good in transferring the feeding force onto the trunk, facilitates repeated removal of large-diameter branches occurring near the harvester head knives and has a long service life. The rollers are used when handling hard-to-trim trees of high stem volume and in cases that traces in the wood caused by the rollers can be tolerated in the further processing of the stems.

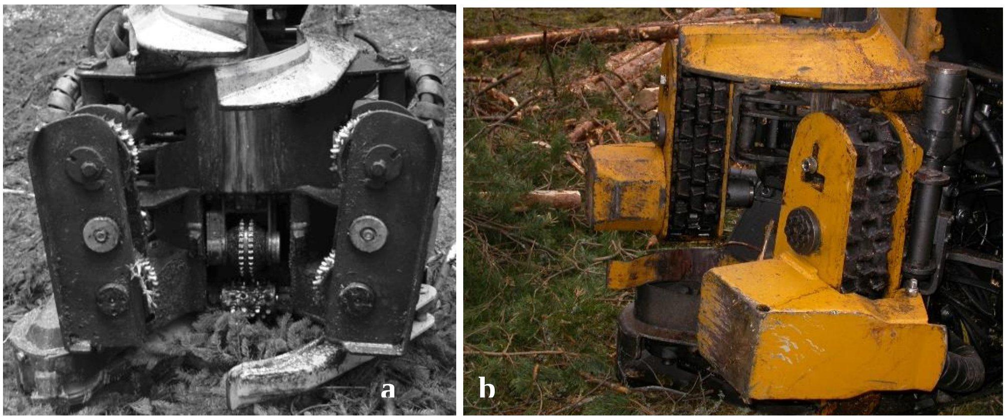


Fig. 33. Feeding device with four rollers on side (a), with tracks (b)

The second type of roller consists of a steel hoop which the rubber casing. On the rubber casing surface, sharp-edged anti-slip chains or a layer with pressure tips are stretched. The rubber casing is glued onto the cylindrical hoop, screwed or stretched under pressure. The rollers are flexible, with a sufficient transmission of feed force onto the trunk. The design reduces the effect of rollers on the trunk as well as the harvester head load at sudden impacts, which contributes to extending the aggregate service life. A harvester head with this type of rollers has a higher weight. Rollers with the rubber casing are gentler to the logs and are therefore used to process trunks in which quality of assortments is emphasized.

A **Tracked feed device** consists of two tracks made of steel links, which are carried on two cylinders. One is driven by the hydraulic motor and the second one serves to stretch the chain. Compared with the rollers, the contact area between the track and the trunk is larger, hence the risk of trunk slippage is lower, which could reflect in the accuracy of measured lengths at the time of sap flow. Compared with the rollers, a disadvantage can be considered greater complexity and larger dimensions of the installation.

There are **two basic conceptions of harvester heads** distinguished by dependence on the number of feed rollers:

Heads of Finnish type feature a more compact construction and a shorter basic frame. They are furnished with four feed rollers for feeding the trunk. This type of heads is suitable for work with crooked trunks of even broadleaved tree species as they are capable to copy better the surface of such trunks thanks to the shorter frame length. Their lower weight also allows simpler handling with the hydraulic crane.

Heads of Swedish type have a more robust construction and a longer basic frame. For feeding the trunk, they are equipped with two feed rollers whose pulling force is greater by several percent. Compared with the Finnish type of the harvester head, they can cope with trunks of smaller diameters. This type of heads is suitable particularly for working with long and straight trunks with a minimum number of irregularities.

Fig. 34. Harvester head of Swedish type Model JD H752

Fig. 35. Harvester head of Finnish type Model JD H754

Delimbing

Delimbing knives are to remove branches from the trunk when it is pulled through the harvester head. They are constructed as movable (3 or 4 pcs) or solid (1 pc or 2 pcs). Upper knives remove branches when moving forward, lower knives remove branches when moving in reverse direction. The quality of delimbing depends on the geometry and sharpness of the delimbing knives and on the setting of their pressure which can be regulated according to individual diameter classes. To overcome the stem curvature, the knives can be slightly opened during the trunk pulling. In the case of large-diameter branches or dense crowns, a so-called pre-delimbing can be adjusted in the control system, when the head pre-delimbs a preliminarily defined section (usually of 50 cm) before making the cross cut in order to clear the way without obstacles for beginning a further movement.

Measuring system of harvester head

Sensors on the harvester head send information to the harvester measuring system. Length is evaluated based on information gained from the pulser connected to the toother measuring wheel, diameter is measured based on the opening of arms of feed rollers (pulser) or based on the opening of upper delimbing knives (two potentiometers). More details in Chapter 3. The harvester head can be equipped with the FlashCut cutting system control which is able to harmonize the speed of the flipping of saw bar arm with the speed of saw engine so that the speed of chain movement is at all times optimal and the formation of cracks in the wood is minimal. The measuring system is described in details together with the control system in Chapter 3.

Other equipment of harvester heads

The equipment of harvester heads can be complemented with a device for colour marking of produced assortments, which allows the harvester operator to distinguish several assortments of similar size, and which makes the work easier and faster when putting together a load. One or two colours can be chosen that can be combined. Nozzles of colours are located either in the saw box or in delimbing knives.

A stump treatment system protects coniferous stands against rots. Agents used for the purpose are urea and biological alternatives based on specific fungi. The dosing device is in the saw bar. The SuperCut cutting unit with integrated chain lubrication and tightening is available, too.

Instead of a standard harvester head, the harvester can also use a head designed to plant seedlings. Seedlings are placed in a revolver bin with an optional size of boxes (50, 60 and 70 mm). The operator disturbs and then partially compacts the soil surface with a foot which is located under the revolver bin. Then a seedling is dropped from the revolver bin into the prepared soil by the base of the body together with a dose of irrigation and/or fertilizer. Depending on work conditions, the head performance is ca. 300 seedlings per hour.

2.1.6 Cabin

Technical and safety parameters of cabin, outlook from the cabin into the work space, arrangement of controllers and other ergonomic characteristics directly affect the operator's work performance and quality of his work.

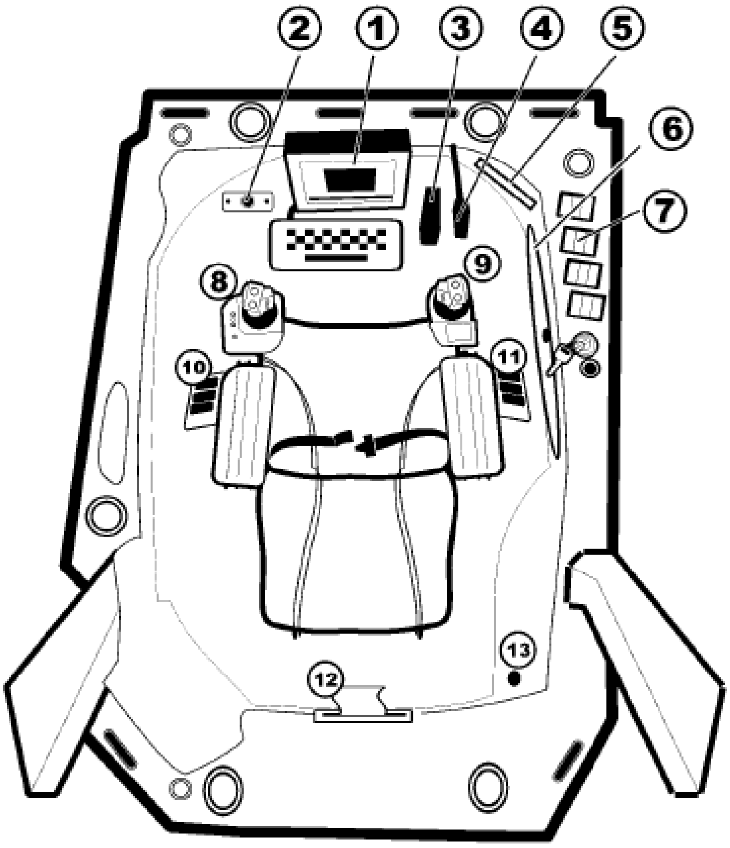
In terms of construction, harvester cabins can be solid or rotating, and/or rotating with the balancing of their position. The cabin can also be suspended on the profile frame that lifts the cabin after entry of the operator. In the case of a solid cabin, positioning of the operator at work happens by seat turning (or position balancing) in the harvester cab. Rotating cabins have in a majority of cases a limited rotation (ca. 90 - 320°). Cabin rotation happens by means of a rotating ring installed on a bearing on the machine frame. The cabin is installed on the ring. The rotating ring is equipped with a rotary hydraulic motor and rotating gear. Position balancing is realized in 4 directions (up to ca. 20° to each side according to the constructional solution of manufacturer). One of common balancing systems is cabin levelling by linear hydraulic motors. Rotation and balancing of cabin position can be manual or fully automatic.

In the upper external part of the cabin, there are work lights. In addition, lights can also be installed in the space under the cab and on the main arm of the hydraulic crane. The standard equipment of most manufacturers includes halogen lights, optionally xenon or LED lights. Compared with halogen lights, xenon lights have a more natural colour which is close to daylight, service life five times longer, and consumption of electric energy lower by a third. However, their high price is a disadvantage.

Work functions of the harvester such as manipulation with the hydraulic crane and harvester head are controlled by two mini levers on the left and right armrests of the operator's seat. The control levers work logically, i.e. the more the lever is tilted, the more the movement speed or crane boom extension is increasing. The movement of control levers can be individually adjusted according to different capabilities of the motor response of drivers working with the same machine. The lever size and shape should ergonomically correspond to hand grip. In the front part of right and left armrests of operator's seat, there are also keyboards to control the harvester head and other machine functions.

Display of the measuring and control system is controlled either by the keyboard and mouse or by touch. Further controllers (switches and push-buttons) are located on side panels in the cabin or in the ceiling part of the cabin, i.e. control of air conditioning, independent heating or wipers. When the harvester is in motion, the travel direction is controlled by a small lever controller.

Cabins of special forest machines have to comply with the EU safety standards. One of basic standards related to the mechanical damage of cabins is Roll-over Protective Structures (ROPS) - ISO 3471, Falling Object Protective Structure (FOPS) - ISO 8083, and Operator Protective Structure (OPS) - ISO 8084 – protection against the penetration of objects from sides. Other standards determine for example the operator's outlook from the cabin (ISO 5721), level of internal noise in the cabin (ISO 5128) or vibrations and impacts (ISO 2631-1). Cabins are equipped with a range of safety elements. One of basic ones is the emergency button which stops the machine, ends all machine functions and activates the parking brake in case of necessity after having been activated by the operator. There is also a central warning light and buzzer in the cabin ceiling, which signal alarm, or a safety door switch that prevents machine operation if the cabin door is not properly closed. Pursuant to regulation in force, the operator’s seat has to be equipped with a safety belt. A safety element in the cabin is also a reversing camera the image of which is shown on the display in the operator’s cabin. According to valid regulations, each cabin has to have an emergency exit which allows to enter the cabin from outside. Footboards for entry into the cabin are provided anti-slip surface and can be controlled hydraulically, too. Glasses are made of high-resistance tinted polycarbonate; their bulging reduces light reflections. In line with the legislation, there must be operating instructions in Czech language supplied with a new machine. The manual is an important part of prevention of risks and occupational accidents. Standards and directives used for the approval of technical competence for operation on roads for cabins of harvesters and forwarders in the European Union are 2006/42/EC, 2014/30/EU, ISO 14982, ISO 11850, ISO 12100, and ISO 4413.



1. screen, 2. travel direction selector – forward/back, 3. brake pedal, 4. driving pedal, 5. radio or CD player, 6. fuse panel, 7. dashboard, 8. left control lever, 9. right control lever, 10. dashboard – left armrest, 11. dashboard – right armrest, 12. printer, 13. 12V/24V outlet

Fig. 36. Interior of harvester cabin

Air conditioning is a standard equipment of the cabin interior. In the system of air conditioning, a cooling agent circulates through compressor, condenser, tank, expansion valve and evaporator. In individual parts, cooling agent pressure and temperature change, thus generating the cooling effect. In winter or in cold periods, the air conditioning system conversely warms the cabin. The operator’s seat in the cabin is of an ergonomic design and allows comfortable whole-day long work. Individual elements of the seat such as armrests, seat itself, or lumbar support are adjustable to the operator’s body size. The operator’s seat is air-cushioned and/or air-ventilated. Cabin overwarming in summer months, particularly at work in main fellings, is considerably reduced by sun screens which can be installed on all windows in the operator’s cab. Further optional equipment of the operator’s cabin is a fixed assembly of mobile telephone with aerial located outside the cabin, printer, radio with a CD player or box to cool or warm food.

2.2 Forwarders

Forwarders are self-propelled multi-operational machines for skidding short timber assortments to the roadside landing. In a majority of cases, they work together with harvesters forming so-called nodes but they can be also used in motor-manual technologies of forest logging. The field of their activity is mainly the skidding of short assortments up to 6 m long, usually stored along the skidding line, also in more difficult terrains. A pre-requisite for their efficient use is a higher concentration of harvested timber assortments. Virtues of forwarders consist in high technical productivity (high loading capacity, good terrain passability), good ergonomic and safety conditions for the operator, flexible possibilities of grading and storing assortments by the crane boom, soil-friendly operation thanks to the low specific pressure, large ground clearance, minimal timber contamination at skidding. Even when the stem volumes are low and hauling distances longer, forwarders have an advantage over the devices for skidding long timber in their performance which ranges at distances from 200 – 400 m from 5.0 m^3/h to 12.0 m^3/h (average 8.0 m^3/h).

Basic constructional characteristics of forwarders are similar to those of harvesters. According to effective load capacity and basic technical parameters, wheeled forwarders can be classified as small forwarders (Class I), middle-sized forwarders (Class II) and large forwarders (Class III).

Indicative technical data of forwarders	**Unit**	**I. Small forwarder**	**II. Mid-sized forwarder**	**III. Large forwarder**
Effective load capacity	t	3-9	9-13	13-20
Engine power	kW	20-110	110-150	150-210
Width	cm	180-230	230-280	280-320
Boom reach	m	4.5-8	7-10	7-10
Weight	t	3-10	10-16	16-25

Tab. 2. Indicative classification of forwarders into performance classes

Manufacturers of forwarders use several systems for the transmission of driving power. The simplest of them is mechanical transmission of driving power. Advantages of the mechanical systems of driving power transmission are their simplicity and favourable price. These systems are sporadically used in small forwarders of Class I.

Most manufacturers of forwarders use the principle of hydrostatic-mechanical driving power transmission nearly identical with the drive of the undercarriage in harvesters. Main advantages of this system include a possibility of space-saving separation of the primary drive and outlet, delivery of large torque at low rotations, and absence of system destruction risk at overloading. Details of this system – see Chapter 4.1. Harvesters. It is a widely used system of driving power transmission with one central hydraulic motor of axial type.

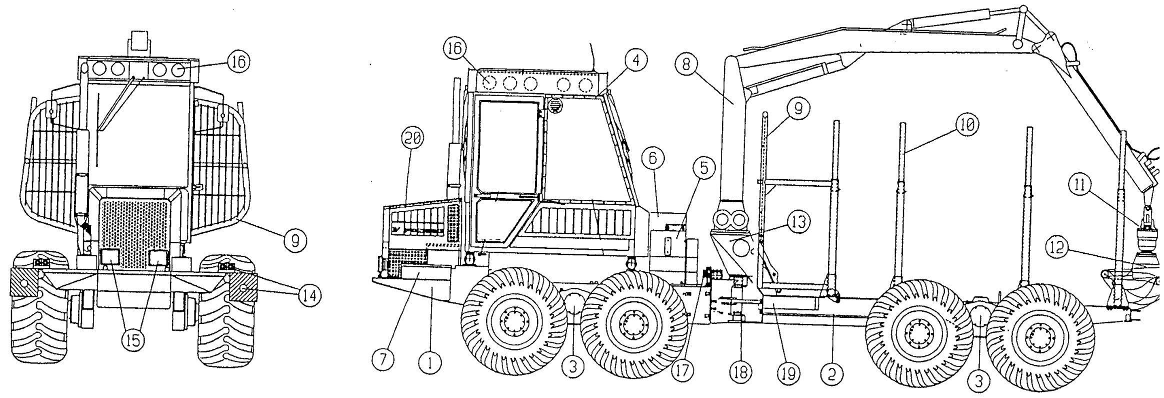
Instead of one central axial hydraulic motor, some manufacturers use four radial hydraulic motors located in each tandem axle. The company Elforest has equipped its forwarders with a hybrid hydrostatic-mechanical drive with electric motors in wheels. One of main advantages of this solution as compared with the classic solution is fuel consumption reduced by up to 25 %. Fuel savings go hand in hand with reduced emissions of forwarders with this equipment. Another advantage of this system of drive is also individual regulation of rotations in each of the driven wheels, which makes the forwarder travel more continual in difficult terrains.

In the majority of cases, forwarders are manufactured as wheeled on the articulated frame undercarriage (articulated structure similar as in harvesters) consisting of the front and rear half-frames. Less frequent in forwarders is the option of a tracked undercarriage. Half-frames are connected by axial or central joint and are mutually deflectable by means of hydraulic cylinders (as in harvesters). The front half-frame carries the engine, gear systems and cabin, the rear half-frame carries the cargo space (stanchions). Forwarders can be equipped with the Orbitrol hydrostatic steering unit which allows emergency control of the machine even when the combustion engine stops.

The forwarder can travel and manoeuvre in both directions, which is also facilitated by the swivel operator's seat in the cabin or by the rotating cabin. New types of forwarders are usually equipped with a camera to scan the space behind the machine rear for better visibility when reversing with a load. Forwarders can be equipped with a front blade that can be used to stabilize the machine on the slope, to smooth the road surface including snow raking and occasionally to relocate logs. Front blades are also used to prepare the workplace and to repair damage caused by forwarding assortments to the roadside landing.

The wheeled undercarriage of a forwarder has 4, 6 or 8 wheels. Eight-wheel undercarriages are fitted with two tandem axles, six-wheel undercarriages are fitted with one fixed axle on the front frame under the cabin and with one tandem axle on the rear frame, four-wheel undercarriages feature two fixed axles. The eight-wheel undercarriage provides better driving abilities and a large contact area of tyres ensures reduced specific ground pressure even at higher loads.

Other variants of wheeled undercarriages: Some forwarder manufacturers offer a possibility of turning fixed or tandem axles. The axle turns as a unit towards the frame and increases the total turning angle by which the turning radius of the forwarder is decreased. This solution improves machine manoeuvrability in the terrain. In their forwarders, the company Ponsse offers an assembly of fixed axle behind the tandem axle on the rear frame of the machine; thus, the number of wheels is increased to ten. In this solution, the fixed axle has the diameter of wheels smaller than the tandem axle, and can be connected in the case of need hydraulically. The manufacturer claims that the pressure of forwarder tyres on the ground surface is considerably reduced by this constructional solution.



1 … front half-frame
2 … rear half-frame
3 … double tandem axles
4 … safety cabin
5 … fuel tank
6 … hydraulic fluid tank
7 ... box for material and tools
8 ... crane rotating column
9 … protection grid
10... stanchions
11… rotator
12… grapple
13… boom support frame
14… headlights and reflectors
15… headlights for driving
16... work lamp
17… axial joint arrest
18… axial joint
19… hydraulic cylinder of articulated steering
20… engine cover

Fig. 37. Forwarder schematic

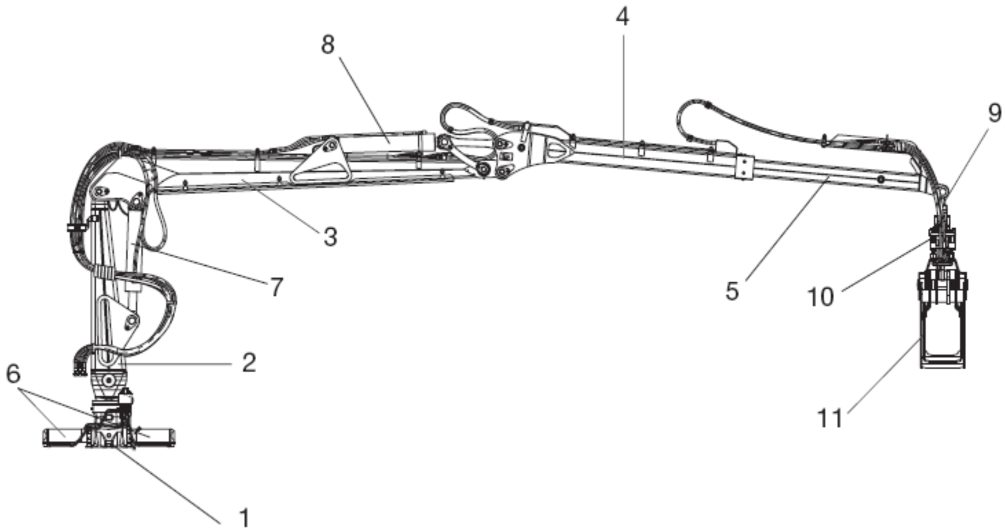
Forwarders are equipped with the **arrest of axial joint** and/or swing axles in order to increase undercarriage rigidity and hence lateral stability of the machine when loading and unloading. Thus, forwarders are not provided adjustable supports as timber transport units, which makes their work easier and faster.

Wheeled undercarriages can be equipped with **anti-slip chains** or **wheel tracks**. Anti-slip chains are used mainly in stony and muddy terrains to improve transmission of the traction force of wheels onto the ground. The main reason for using wheel tracks is machine weight distribution across a large contact area, which prevents compaction of the soil and its further damage. Other reasons are as follows: improved engagement, reduced slippage, rolling resistance decreased by up to 80 %, reduced fuel consumption, increased load capacity and machine stability both at driving and at work, enhanced slope accessibility and improved labour safety on slopes, lower machine and tyre wear, fewer losses on regeneration and shallower track. As to maximum friendliness to the forest environment, the ECO-Baltic wheel track can be pointed out, which is determined for wet, soft and susceptible subsoils. The smooth surface of crossbars allows the operation of these tracked wheels in advance growths. Thanks to the excellent distribution of weight, wheel tracks protect the soil and tree roots against damage.

The forwarder cabin has similar constructional elements as in harvester. Internal equipment of the forwarder cabin meets specific requirements for the machine function. As in harvesters, the hydraulic crane is controlled from the forwarder cabin by two control levers. Other functions of the machine such as cargo space size change, manipulation with the front grid, blade function or differential lock are controlled by means of keyboard located in the front part of armrests near the control levers. Progressive rotating cabins allow comfortable and ergonomically correct machine control.

The **forwarder hydraulic crane** with a grapple is most frequently located either on the rear half-frame near the central joint, less often on the common frame with the cabin. Basic elements of the hydraulic crane include a column, main arm, articulated arm and telescopic arm. The hydraulic crane boom reaches usually to a distance from 6 to 10 m.

Forwarder hydraulic crane is determined for another type of activity than the harvester hydraulic crane, and this is also why its geometry of movement is different. Geometry of the forwarder hydraulic crane is adapted to the predominant activity of loading and unloading, i.e. to the movement in vertical direction. In contrast, the harvester hydraulic crane works mostly in the horizontal plane when felling, cross-cutting and delimbing.



1. Hydraulic crane base	5. Telescopic arm	9. Suspension joint
2. Hydraulic crane column	6. Arm rotating hydraulic cylinders	10. Rotator
3. Main arm	7. Hydraulic cylinder of main arm	11. Grapple
4. Articulated arm	8. Hydraulic cylinder of articulated arm	

Fig. 38. Main parts of the forwarder hydraulic crane with grapple

Apart from the classic grapple, the forwarder hydraulic crane can be further equipped with the following facilities: Grapple saw with a bar and saw chain is able not only to grip the material but also cross-cut behind the grip point; it can neither fell nor delimb. Felling head is equipped with a bar and saw chain or shearing knives and is able to fell and load the tree, and after changing the felling head grip it can further cross-cut the tree, e.g. into halves for easier transport; the head cannot delimb. Felling heads of this type use to be often equipped with a device for gripping multiple trunks.

The forwarder can also be equipped with the classic harvester head which is able to fell, cross-cut and delimb. Then it is referred to as **harwarder**, the name being a combination of harvester and forwarder. In this case, the forwarder performs a similar function as a one-grip harvester, but is capable of forwarding the produced assortments by itself. This machine design could be applied particularly in the first thinning's with low amounts of harvested wood, and on small logging sites, i.e. where a presumption exists that all determined wood will be not only harvested but also loaded on the machine and hauled in a single drive along the line. Timber logging and skidding can be ensured by just one machine, investment costs are lower, driving along the line is reduced, manufacturing process is less demanding in terms of its organisation, and even lower operating costs were expected. Nevertheless, the hitherto Swedish experience does not corroborate a conspicuous reduction of operating costs of logging implemented by harwarders (Erler, 2002).

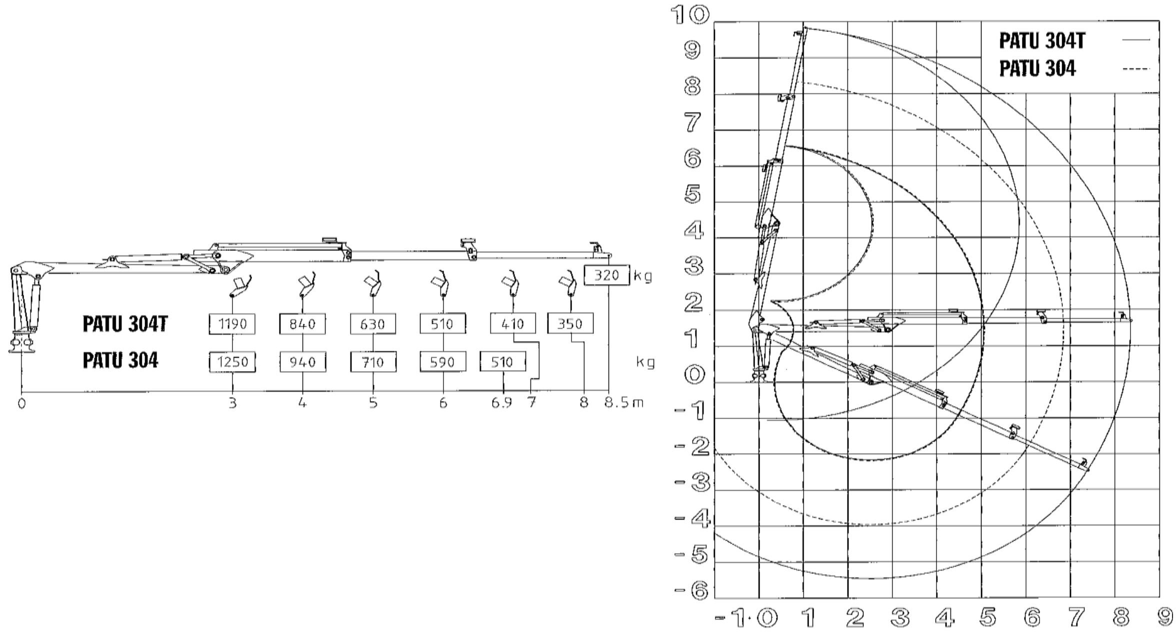


Fig. 39. Diagrams of boom lift and reach (PATU)

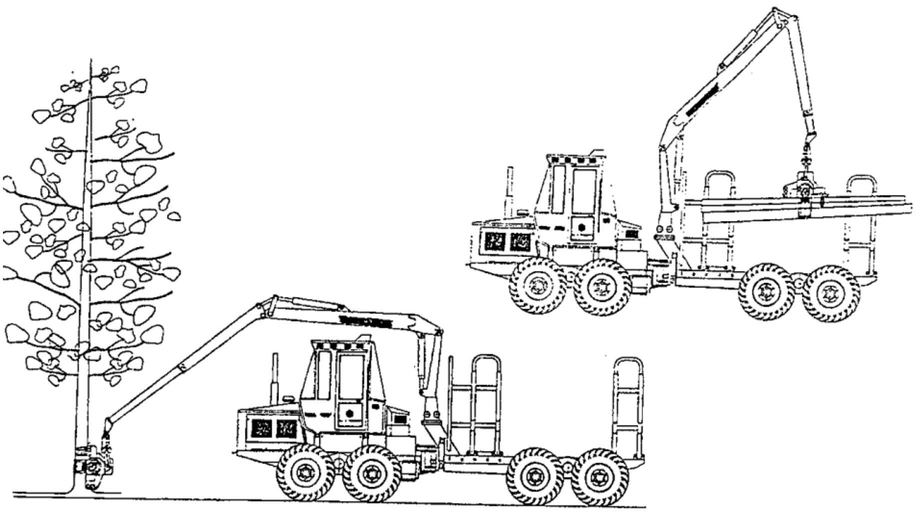


Fig. 40. Harwarder during work deployment

Forwarder **cargo space** is defined by the undercarriage frame, stanchions fixed on the frame and support grid. Stanchions of forwarders are bent towards the cargo space inside by angle that is adequate to max. cross tilt of the machine not to cause damage to marginal trees on the line when the machine travels in cross tilt. Except for length in mm, the cargo space is also characterised by cross-section area in m^2, which ranges from about 3.5 to 8.0 m^2. The cargo space is formed by a protection grid and usually by 2 x 4 stanchions. The first pair of stanchions is usually firmly connected with the protection grid while the other pairs may be sliding to be better adapted to the lengths of transported assortments. In individual types of forwarders, several combinations of cargo space width and length are available. The machine variant with a longer cargo space has a larger undercarriage wheelbase. To be permitted in the traffic on public roads, the forwarder cargo space has to have a fastening equipment preventing accidental log fallout; during the operation in the forest, the load is not fastened though. A matter of course for moving on public roads is a complete vehicle illumination (including brake and rear lights) which is however covered during the work in the forest in order not to suffer damage.

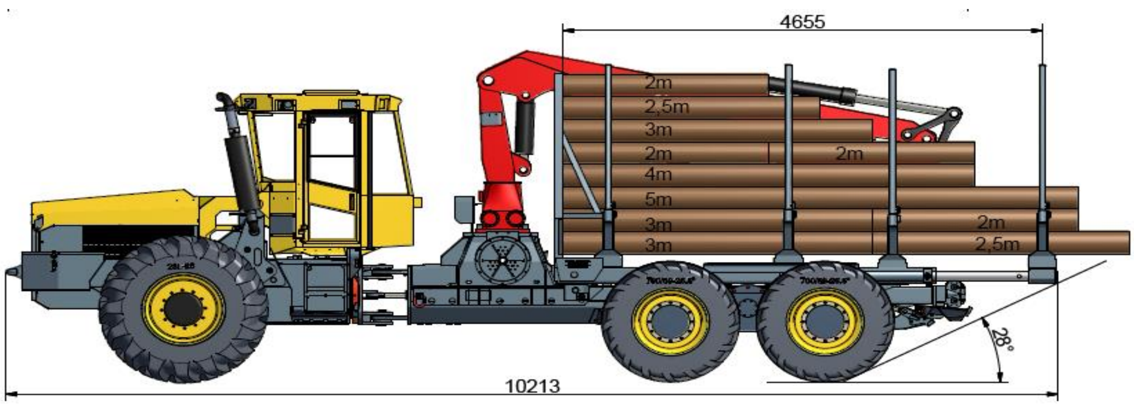


Fig. 41. Variants of arranging assortments when the cargo space length is 4.66 m (Welte)

When loading a forwarder, one has to take into consideration the tree species, its fresh or dry stem volume and dimensions of loaded assortments with respect to the machine payload. The table below shows differences in the load weight for spruce and beech with a different length of loaded assortments. In this case, the area of cargo space cross-section was 4.5 m^2. Values used for the calculation were as follows: conversion coefficient of roundwood volume 0.64, volume weight of fresh spruce wood 740 kg/m^3, volume weight of fresh beech wood 990 kg/m^3. It follows from the table that differences in the load weight when different combinations of assortments or tree species can be considerable and if the operator is inattentive, the forwarder can be overloaded. This fact will show in the unfavourable increase of forwarder ground pressures and in the increased risk of damage to individual machine components.

Parameters of the forwarder cargo space can be then modified by the operator directly in the stand, e.g. commonly in a range of forwarder types by means of hydraulically controlled forward/back sliding front grid. Another possibility of modifying parameters of cargo space right during the operation is a VLC (Variable Load Space) system – a variable load space by the means of which the cargo space can be hydraulically extended to sides by up to 64 cm. Another system is ALS (Active Load Space). The active load space is based on the hydraulically damped, extendable cargo area that can be tilted. This solution allows more continual and faster travel in the field and reduces the forwarder load. To prevent the machine overloading, VLS or ALS can be combined with the crane scale.

Assortment / Species	**Spruce**	**Beech**
2 + 2 m	8 525 kg	11 405 kg
3 + 2 m	10 656 kg	14 256 kg

Tab. 3. Forwarder load weight

In addition to the choice of forwarder cargo space length, width and cross-section area, manufacturers offer further fixed or revolving stanchions and/or clam bunk for hauling full-length stems. For the method of tree-length logging, forwarders can be equipped with one- or two-drum winch with remote control and rear hinged or fixed ramp shield. In sloping terrains, forwarders can use traction winch that can harmonize the speed of reel unwinding with the driving speed of the forwarder. Traction winches of some manufacturers can be used also for harvesting timber by the method of tree-length logging. Forwarder can be driven and controlled remotely, too, for example when using the method of tree-length logging with winches. In addition, forwarders can be equipped with a front blade that can be used to stabilize the machine on the slope, to smooth the road surface including snow raking, and occasionally to relocate logs.

Forwarder manufacturers also have a range of super-structures such as container extension for the collection of logging residues, bundler of logging residues or fire fighting superstructure to be added to the loading space or to replace it. The forwarder can be also added full compression stanchions for the collection of logging residues or application of a drum chipper with own motor.

2.3 Timber transport units

Prime mover of timber assortment transport units is as usually a general-purpose wheeled tractor 4x4 with a performance up to about 70 kW, exceptionally a special-purpose wheeled prime mover. Load-bearing part of the unit consists of a one-axle trailer with stanchions and a hydraulic crane with the grapple.

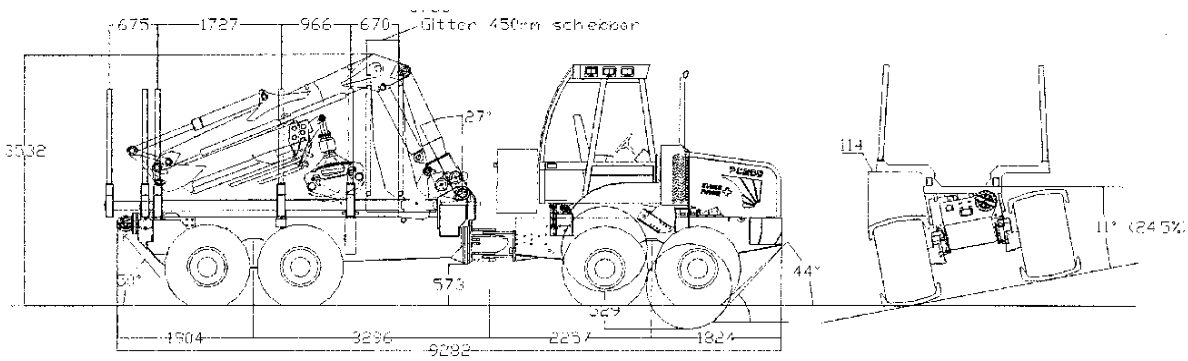


Fig. 42. Forwarder Model Forcar FC 200 with safety winch, sliding stanchions and hinged loading space

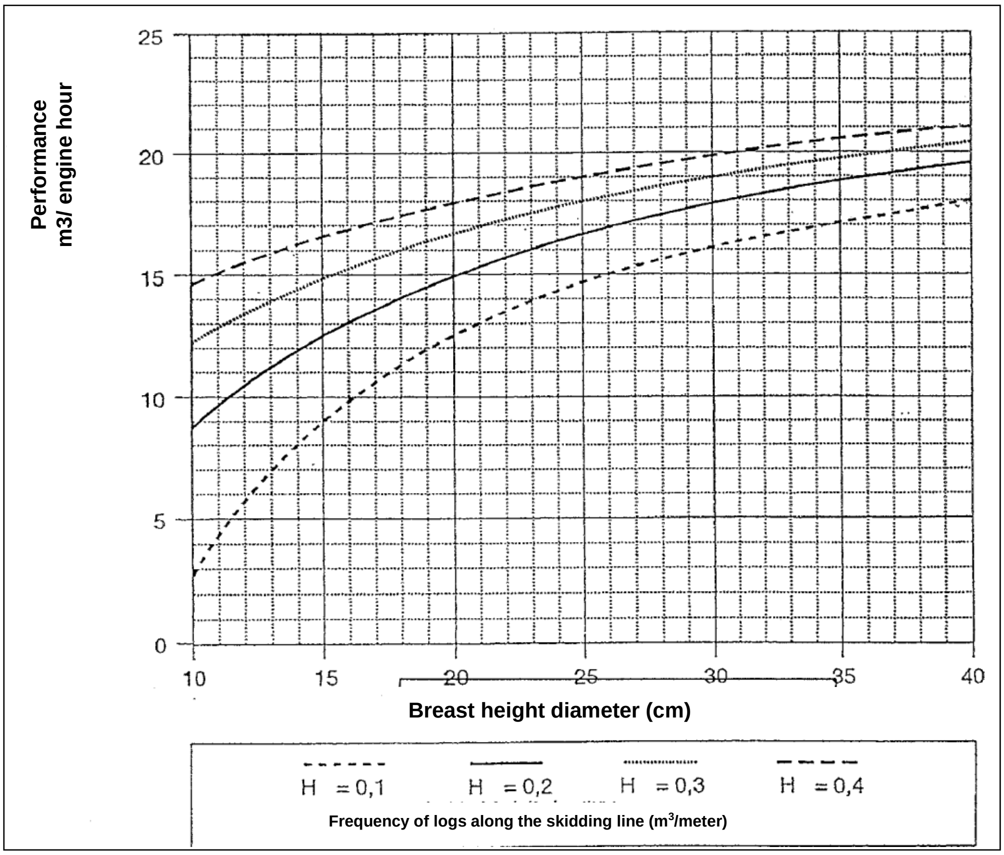


Fig. 43. Example of forwarder performance factors

The **structure of timber trailer** consists of a supporting frame which has to cope with great loads. In lighter weight trailers, it consists of backbone tube beam; trailers of more weight are provided a rigid rectangular frame of steel profiles. The undercarriage is of one-axle type, which is however equipped with four wheels as tandem axles are usually used, similarly as in harvesters. Axles are located in the rear third of the frame (in some types of trailers, they can be also longitudinally adjustable for a better load distribution between the trailer and tractor, and thus for improved stability and traction force of the tractor). Trailers with the lower payload are delivered as unbraked, trailers of higher load capacity are equipped with air or hydraulic brakes. Simpler types of trailers are manufactured without the wheel drive (which however markedly limits traction force of the unit as well as its gradeability and hence the load bearing capacity). If the trailer is equipped with the wheel drive, this can be mechanical from the tractor PTO or hydraulic with hydraulic motors in wheels, or with traction rollers as a temporary auxiliary drive. Traction rollers are inserted by the hydraulic cylinder from the outside between the wheels of the tandem axle (suitable tyre pattern is necessary). The solution allows to increase traction capabilities of the unit and to overcome more difficult carriageway sections.

Fig. 44. ALS system with the maximum and minimum areas of loading space cross-section

Fig. 45. Variability of forwarder loading space (Welte)

Connection of the trailer to the tractor is by mean of draw bar to the tractor hitch. The simplest trailers have only a fixed draw bar. Hydraulically deflectable (articulated) draw bar and interconnection of tractor rear and draw bar by double-acting hydraulic cylinder facilitate directional control of the unit including reversing. Such trailer connection is analogous to the articulated steering of skidder (LKT); deflection angle up to 60^o (following out trailer lateral deflection up to 70 cm). Some trailers are equipped also with a steering axle.

Crane booms with the grapple are driven hydraulically and the most often are fixed in the front part of the trailer behind the draw bar. Lateral boom reach is usually 6.0-10.0 m. The crane is controlled from the tractor cabin. In some types of timber trailers, the crane can be controlled also alternatively from the outside of the machine.

Fig. 46. Tandem axle driven by traction rollers

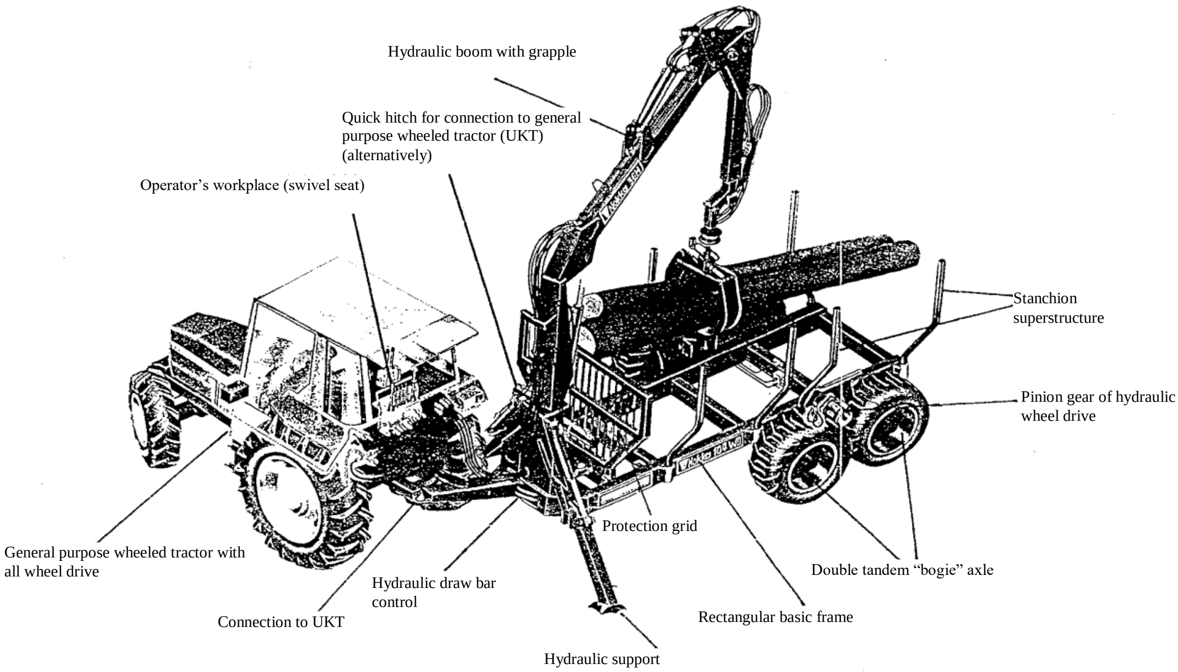


Fig. 47. Schematic of tractor and trailer unit

The trailer is equipped with hydraulically adjustable telescopic or tilting **supports** to increase the unit stability when loading and unloading; this means that the supports have to be put down before each loading and unloading, which is another characteristic difference as compared with the forwarder which has no supports. A source of pressure hydraulic oil for trailer mechanisms can be the external circuit of the tractor; however, more frequently the trailers are equipped with an own hydraulic pump which is powered by the tractor PTO.

The trailer cargo space consists of 4-8 stanchions built in the basic frame. In some types of trailers, the longitudinal arrangement of stanchions can be modified as needed. On the trailer front, there is a protection front panel (grid) to prevent load sliding down onto the driver's cabin when braking. Own trailer weight is usually from 1.0 to 6.5 t, average total trailer length from 5.0 to 6.5 m, width 1.7-2.8 m, trailer loading length is ca. 4.0 m. Load size is 4-15 t of timber. Tractor and trailer units are used mainly in simple terrain conditions. Indicative performance value is about 6-9 $m^3.h^{-1}$; skidding of pre-graded assortments is preferred.

Advantages of tractor and trailer units include great flexibility even at lower amounts of hauled timber, possibility of moving on public roads at higher speeds, machine owner is relatively mobile, tractor can be used also for other works, and the purchasing price is about a half when compared with the forwarder.

2.4 Differences and common features of forwarders and tractor and trailer units

Differences in design principles
There is a fundamental difference of meaning between the design principles of a tractor and trailer unit, and the forwarder as it directly relates to the technological application of the two machine groups.

The forwarder is a special compact machine determined for timber loading, transportation and unloading. It consists of engine section and cargo section which are built on two half-frames connected with a joint; machine steering is articulated by means of a hydraulic system, all wheels are at all times driven, the load capacity of forwarders is usually higher than that of tractor and trailer units.

The tractor and trailer unit are a temporary connection of two otherwise independent means (tractor or prime mover and trailer), each of which can be used separately for other purposes. Simple units consist of tractor and trailer with a fixed draw bar, wheel drive being not available on the trailer, or wheels are powered only by means of hydraulically driven pinion resting between the wheels of tandem axle. More sophisticated trailer designs feature hydraulically articulated draw bars which facilitate and improve trailer guidance when driving (reversing in particular). In favourable conditions, they can be a purposeful (purchasing price cheaper by up to ½) alternative to forwarders and can reach up to 90 % of their performance (which is however not a rule). Recommended annual volume of timber hauled by tractor and trailer units is 2,000 – 8,000 m^3. Although the tractor and trailer units can be in principle combined with harvesters, their lower performance compared with forwarders would have to be accepted.

Differences between tractor and trailer units and forwarders in terms of movement:
in forwarder, travel direction significantly does not affect demands for its steering (namely when unloaded, visibility from the cabin thus being not impaired)

in simple tractor and trailer units (without hydraulically articulated draw bar), reversing on lines is practically excluded, travel direction significantly affecting demands for their steering (even when unloaded and visibility from the cabin being not impaired)

in tractor and trailer units of higher technical level (with hydraulically articulated draw bar), reversing is facilitated, travel direction affecting demands for their steering somewhat less than in simple tractor and trailer units (namely when unloaded, visibility from the cabin thus being not impaired)

traction capabilities of simple tractor and trailer units with non-driven trailer wheels are significantly lower than in forwarders or tractor and trailer units of higher technical level with all-wheel drive, which results in limited gradeability of simple tractor and trailer units as well as possibility of increased slip of tractor wheels.

Common features of forwarders and tractor and trailer units
Timber hauling machines, i.e. timber units and tractors, are referred to as assortment machines (also stanchion machines) as they serve for the transport of stacked assortments or short logs usually up to 6 m long, and are equipped for the purpose with the stanchion superstructure into which the timber is loaded in its full length. For operating on public roads, they have to have a binding facility preventing accidental fall of some logs; the load is however not tied during operations in the forest. A matter of

course for moving on public roads is complete lighting of the vehicle (including brake and tail lights), which is however covered when working in the forest to prevent damage. Behind the machine cabin, there is a front panel (grid, shield) to prevent load sliding onto the driver's cabin when braking. In some types of machines, the shield is sliding to facilitate balanced load placement when loading logs of different lengths. Stanchions of hauling machines are bent towards the cargo space inside at angle adequate to the maximum cross tilt of the machine to avoid damage to marginal trees on the line when the machine travels cross tilted.

Loading and unloading is performed by hydraulic crane boom with grapple in tractor and trailer units and forwarders. This is why the crew always consists of one man and the skidding of timber-by-timber units and tractors belongs in the group of chokerless skidding.

2.5 Maintenance of logging and hauling machines

When buying a machine, its new operator is made familiar with the principles of the operational care of the machine. The principles are described in detail also in Operating Instructions which are part of the machine delivery pursuant to law. Repairs should be made as soon as possible after defects have been detected otherwise the failure may further develop, costs of service and spare parts may increase, and the repair may take more time. Apart from the economical aspects (higher cost of defect elimination and idle time of the machine), the neglected defect or regular maintenance may lead to impaired machine service life or danger to the environment due to the leakage of operating fluids.

2.5.1 Environment protection

The level of environment protection during logging works depends on the activities of harvester and forwarder operators. The most visible part of a logging site is the unloading area which is often used for the maintenance of machines. The operator of machines often leaves there a service vehicle with spare parts and tools as well as tanks with fuel and barrels with oil. Great amounts of oils, plastic materials, etc. are handled directly in the forest. Carelessness of operators may contaminate the soil and ground water for a long time. It is inadmissible to cause or tolerate leakage of oils and fuel into the environment. The condition of hydraulic hoses, tubes and couplings must be carefully and regularly visually inspected for seepage and leakages of fluids during the machine work.

The site for maintenance should be situated so that possible drainage or terrain depressions do not lead to watercourses and the site should not be near roads or paths. When the logging site is situated in the area of ground water protection, the site for the maintenance of machines must be situated outside that area.

Fuel and oil tanks must be located in such a way that no danger exists of their fall or piercing. Empty containers for fuels and oils, tubes from lubricants etc, have to be gathered and removed from the forest to an officially determined collection place for the disposal of waste.

Toxic waste has to be separated from the other waste, safely stored in relevant containers and brought to waste processing plants. Substances that may represent a potential risk for the environment are for example oils, fuels, brake fluids, filters or batteries.

2.5.2 Maintenance of machines

Acts to be performed before the machine maintenance are as follows: The machine is to be parked on a flat terrain, the hydraulic crane boom is to be put down and the harvester head or grapple are to be safely placed on the soil surface. Central placement to be ensured by means of steering lock and parking brake secured. When brakes are to be repaired, spontaneous movement of the machine must be prevented. Ignition key to the off position. If the maintenance has to be done with the engine on, the machine should not be left unsupervised. Battery switch off. Working on electric equipment, the cable should be disconnected from the negative pole of the battery. Engine to be left to cool down. To become familiar with the maintenance procedure before the beginning of servicing. To prevent the movement of unauthorised persons around the machine. To have all necessary tools and correct spare parts available.

Intervals of regular maintenance are divided into categories by the machine manufacturer, according to the reached motor-hours; for example, regular maintenance after 10, 50, 250, 500, 1000 and 2000 mth.

If the maintenance is currently made e.g. in an interval after 2000 mth, this maintenance must also include tasks of daily maintenance and maintenance required after 50, 250, 500 and 1000 mth. Regular daily maintenance tasks are performed by the operator alone while regular maintenance of larger extent is usually to be made by the unauthorised service of the manufacturer. Harvester and forwarder operators should perform on the machine the following **daily checks** and maintenance:

Daily check and maintenance of machines
Check of hydraulic oil, check of engine oil, check of cooling fluid, check of air filter indicator, removal of water and sediments from the primary fuel filter, check of the condition and inflation of tyres, check of tightening and fixation of mounted tracks or wheel tracks, check of cooler grid cleanliness, cleaning and inspection of all sealed spaces including the engine protection cover of undercarriage etc., particularly in winter it is important to clean the machine to prevent freezing of snow or dirt, inspection of possible defects and cracks on the machine.

Daily check and maintenance of hydraulic crane
Optical control of hydraulic crane structure, i.e. checking the tightness of the hoses, couplings, hydraulic cylinders and other structural elements, possible mechanical damage to the crane structure, lubrication with pressure lubricator according to the scheme.

Daily check and maintenance of harvester head
Check of saw chain and bar flange (sharpness, tightening, fixation, flange condition), check of the fixation and condition of diameter sensors, check of length measuring device cleanliness, check of possible oil seepage, check of lubrication function, lubrication of the rotator intermediate piece, fixation of the hydraulic cylinder of delimbing knives, placement of delimbing knives, placement of felling joint and fixation of feed rollers, fixation of saw rollers, fixation of measuring wheel in housing, placement of feed rollers, placement of hydraulic cylinders for feed rollers – arms.

2.5.3 Operating fluids

Oil
Both diesel and bio-diesel have to comply with the conditions stipulated in standard *ČSN EN 590 Engine fuels – diesel oils – Technical requirements and testing methods*. Pursuant to this standard, the cetane number must be min. 45, but a cetane number higher than 50 is preferred, namely for temperatures below – 20 °C or altitudes above 1,500 m. Temperature of filter clogging (CFPP) must be at least 5 °C below the expected lowest temperature or cloud point below the expected lowest ambient temperature. Lubricating properties of the fuel must allow passage through a crack of max. diameter 0.45 mm, measured according to standard *ČSN EN ISO 12156-1 Motor fuel – Estimation of lubricating properties using the high-frequency reversing drive instrument (HFRR) - Part 1: Test method.* The content of sulphur must be lower than 0.1 % (1,000 ppm); using diesel with a higher S content can lead to reduced intervals of oil and filter replacement.

At temperatures below -10 °C, winter diesel is recommended which has a lower cloud point and freezing point. Cloud point is a temperature at which wax starts to develop in fuel, which causes fuel filter clogging. Freezing point is the lowest temperature at which fuel movement (flow) can be observed. The use of winter diesel can impair performance and increase fuel consumption of the machine. In winter, it is recommended that the fuel tank is filled at the end of the workday to prevent condensation of water and its freezing at low temperatures. It is also advised to keep storage tanks as full as possible to minimise condensation and to check water content in the fuel regularly.

Biodiesel
Biodiesel is fuel for diesel engines based on the methyl esters of unsaturated fatty acids of vegetable origin. In the Czech Republic, it is most frequently produced from oil seed rape. Biodiesel has to comply with the requirements of standard *ČSN EN 14214 Motor fuels – Methyl esters of fatty acids (FAME) for diesel engines – Technical requirements and test methods.* Producers of fuels has an obligation to add 5 % of biodiesel to oil produced from crude oil. Biodiesel mixtures up to B20 can be stored and used within 90 days from the date of manufacture. Biodiesel mixture from B21 to B100 can be stored and used within 45 days from the date of manufacture.

Main advantages of using biodiesel are as follows. Biodiesel burns better in the process of combustion, which reduces engine smoke, emissions of flying ash, sulphur, carbon dioxide, aromatic substances and hydrocarbons in general. Pure biodiesel is not toxic, is biologically degradable and does not contain aromatic substances or sulphur. Biodiesel is manufactured from renewable resources. It has a high lubrication capacity, which reduced engine wear and extends the service life of injection units.

Disadvantages of using biodiesel are as follows. High energy consumption of biodiesel production process. Unfavourable total balance of greenhouse gases as compared with diesel. The use of 100 % of biodiesel impairs engine performance and increases fuel consumption. Possible clogging of filters (at the first switch of engine for biodiesel combustion). Biodiesel is a stronger solvent than standard diesel and disintegrates sediments in the fuel line. Possible fuel leakage through sealing and hoses. Possibly shortened service life of engine parts. Upon the contact with a larger amount of water, fatty acids develop from biodiesel that may cause fuel system corrosion. If fuel additives with the content of detergents / dispersion agents are not used, carbonization or clogging of injection nozzles may occur. Possible development of sludge and sediments. Compared with diesel, biodiesel has lower stability and shorter possibility of storage (moisture absorption, oxidation, growth of microbes).

Fuel additives

Additives are classified as production additives that are added into the mixture by the manufacturer already during the fuel production, and post-production additives that are added into the fuel by users themselves. Production additives help the fuel meet parameters required by norms. Additives for diesel engines should contain the following:

- Cetane number raisers - ensure performance and cultivated run of the engine, reduce emissions of exhaust gases.
- Antioxidants – slow down diesel ageing and ensure its stability.
- Anticorrosives – protect fuel system parts against corrosion, particularly in the presence of water.
- Detergent additives – clean hot engine parts from carbon, namely prevent clogging of nozzles.
- Lubrication additives – improve lubrication of moving parts of the fuel system, namely prevent seizing of rotary and high-pressure pumps.
- Antistatic additives – prevent development of static electricity and el. discharge during pumping.
- Demulsifiers – set the emulgated water dispersed in diesel aside to the tank bottom.
- Bactericidal and bacteriostatic additives – suppress the fuel bacterial decomposition.
- Depressants – additives enhancing the winter properties of diesel, namely its filterability at low temperatures.
- Froth-proof additives – prevent diesel overflowing when tanking, accelerate the tanking process.

Engine oils

Engine oils are mostly used as lubricants but they also fulfil cooling, sealing and cleaning functions. According to the method of manufacture, there are three groups of oils: Mineral oils are manufactured by repeated distillation of oil fractions obtained during the fractional distillation of crude oil. Semi-synthetic oils represent a mixture of mineral and fully synthetic oils. Synthetic oils are obtained by the synthesis of simple monomers similarly as plastic materials are manufactured. API, SAE and ACEA organisations stopped using this division due to its ambiguity already at the beginning of the 1990s.

Engine oil can be evaluated based on their viscosity – rate of internal friction (classification of SAE - Society of Automotive Engineers). Another possibility is their evaluation based on adequate engine performance. In this case, most countries have their own systems of norms. The currently most respected standard in the European Union is ACEA (Association des Constructeurs Européens d'Automobiles) classification.

Oil viscosity is determined by the combination of temperature - the higher is the *operating temperature*, the higher the viscosity of the used oil has to be (otherwise an inadequate thinning of lubrication film would occur and worsened lubrication), *load* – the higher the load is, the higher oil viscosity (higher viscosity class) is required, and speed – the higher is the mutual speed of moving surfaces, the lower the viscosity of the used oil has to be.

The SAE classification distinguishes 11 viscosity classes, the number describing oil properties at a temperature of 100 °C, letter W marks winter oils:

- Summer oils; Classes 20, 30, 40, 50, 60 – The higher the number of summer class is, the higher can be ambient temperature if engine lubrication is sufficient.
- Winter oils; Classes 0W, 5W, 10W, 15W, 20W, 25W – The lower the number of winter class is, the lower can be ambient temperature if oil fluidity is sufficient for easy engine start.

The most used are multigrade all-season oils; e.g. the SAE 10W-40 engine oil corresponds to the winter oil SAE 10W before engine start at low temperature and to the summer oil SAE 40 at operating temperature.

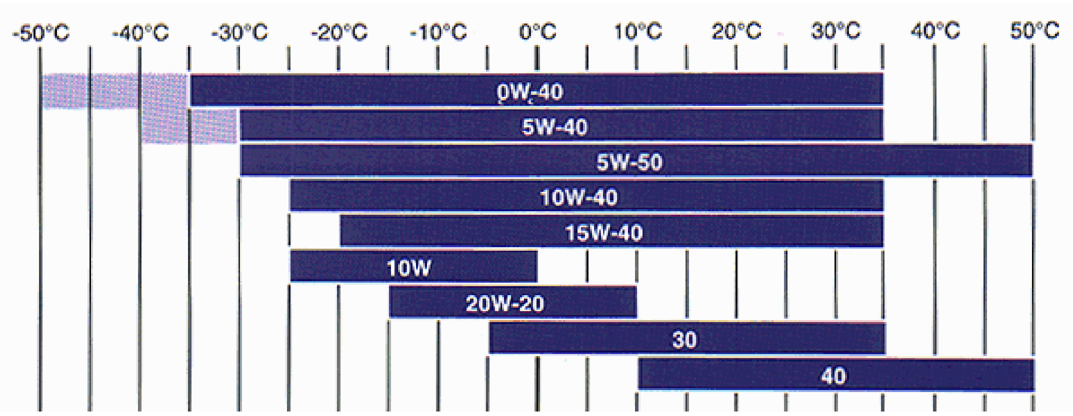


Fig. 48. Recommended viscosity classes of SAE engine oils according to outdoor temperatures (°C)

The ACEA classification distinguishes several classes, and a particular class is then added a numerical code of oil quality standard.

- ACEA A – spark ignition engines
- ACEA B – small spark ignition engines of personal and commercial vehicles
- ACEA C – small spark ignition engines with a filter of solid particles
- ACEA E - large spark ignition engines of lorries (details below)
  - ACEA E1- no longer valid since 3/2000
  - ACEA E2 – Standard oil, normal intervals of replacement
  - ACEA E3 – Oil for high load, possibility of extending replacement interval (no more valid)
  - ACEA E4 – Oil for extremely high load, possibility of extending replacement interval
  - ACEA E5 – Oil for high load, possibility of extending replacement interval
  - ACEA E6 – Highly stable oils supporting cleanliness of pistons, reducing wear (incl. by action of soot) and providing continual lubrication. The oils are recommended for modern, highly loaded diesel engines meeting Euro 1-4 emission limits.
  - ACEA E7 – Stable oils preventing sedimentation of impurities on pistons and development of mirror areas on cylinder walls, reduce wear (incl. by action of soot), development of sediments in turbocharger. The oils are recommended for modern, highly loaded diesel engines meeting Euro 1-4 emission limits.

Lubricant additives
Surface effect

- Detergents; prevent sedimentation of impurities on surfaces or dissolve the already settled dirt.

- Dispersants; prevent creation of sediments which develop primarily at low operating temperatures.
- Improving protection against high pressure and wear; protect steel parts that rub against each other under high pressure (e.g. gears) from wear.
- Improving protection against corrosion; create a protective film on metal surfaces, which prevents corrosion development.
- Reducing friction between friction surfaces to required value.

Improving oils

- Improving viscosity; stabilize lubricant viscosity which is then less depending on temperature.
- Decreasing the freezing point; suppress possible aggregation of paraffins in lubricants at low temperatures.
- Protecting elastomers; slow down ageing of plastic and rubber parts that are in contact with lubricants (e.g. sealing).

Protecting oils

- Retarders of ageing; inhibit chemical degradation of lubricants occurring primarily at higher temperatures.
- Deactivators of metals; prevent chemical reactions occurring on the surface of microscopic metal particles present in lubricants (steel, copper).
- Reducing frothiness; suppress the development of oil froth. Intensive mixing of oil with air results in the development of froth which accelerates ageing of lubricants.

Coolants based on ethylene glycol or propylene glycol

Coolant flows through the system to protect it against overheating and to take the heat produced by this system to another system where it is dissipated or used. Ideal cooler has a great thermal capacity, low viscosity, is chemically inert and does not cause or support corrosion of the cooling system. Coolants are delivered with additives ensuring the cooling system protection against cavitation and protection of metals (cast iron, aluminium alloys, copper alloys, e.g. brass).

Distilled, deionized or demineralized water is recommended for mixing with the coolant concentrate based on ethylene glycol or propylene glycol. The coolants based on ethylene glycol and propylene glycol should not be mixed as their declared properties can be lost.

Hydraulic fluids

The task of hydraulic fluids is energy transmission with as low losses caused by wear and friction as possible. Hydraulic fluids fulfil also other tasks: lubrication of movable elements, cooling of elements, corrosion control, etc.

In general, hydraulic fluids consist of water, water-based mixture (glycols) and oils (mineral, vegetable and synthetic). Advantages and disadvantages of individual hydraulic fluid types are as follows:

- water (cheap, harmless, does not protect against corrosion, low boiling point, does not lubricate)
- glycols (similar as water, suitable for large systems, better corrosion control)
- mineral oils (lubricate, protect against corrosion, do not oxidize, harmful to the environment).
- Vegetable oils (usually raffinates of oil seed rape, ecologically harmless, worse useful properties, poor thermo-oxidation stability – lower service life, additives necessary)
- synthetic oils (excellent useful and ecological properties, higher price).

Requirements for efficient energy use, reduced friction and improved mechanical effectiveness push for design changes in hydraulic systems and put increased demands on hydraulic oils. Smaller circuits and less optimal shapes and sizes of retention tanks lead to faster discharge rates in relation to the volume of hydraulic oil. Minimum clearance of hydraulically controlled elements requires the oil to be readily filterable by very fine filters even in the presence of water. This results in higher pressures ad temperatures acting on the hydraulic oils, with the increasing risk of oxidization, frothiness and cavitation. Conditions arise for the development of sludges and sediments. Valves and hydrogen generator experience a greater wear, and a more frequent replacement of block filters becomes necessary with all consequences on the economy of operation.

The quality of hydraulic oil depends on the quality of base oil as well as on the quality of the combination of additives. Hydraulic oils have to comply to the specifications stipulated in ISO 11158 and ISO 6743-4: HV. Biologically degradable hydraulic oils have to meet specifications stipulated in ISO 15380 and ISO 6743-4: HEES. Mixing of different oil types may cause degradation of their properties.

Pursuant to § 32 of the Forest Law no. 289/1995 Sb., forest owners are obliged to protect the forest against contaminants leaking or developing during their economic activities. In the forest, they are obliged to use only biologically degradable oils for the lubrication of power chain saws and biologically degradable hydraulic fluids.

For the above reasons, hydraulic fluids based on synthetic oils are used in harvesters and forwarders, which have excellent utility properties and are biologically degradable at the same time. Biologically degradable oils have to be protected against overheating (optimum 70 ^{0}C). Their service life is however lower than that of mineral oils – ca. 800 – 2,000 hours. Itis therefore necessary to respect instruction of machine manufacturers concerning intervals for the replacement of hydraulic fillings. The handling of used oils is regulated by Act no. 167/1998 Sb. on waste management.

Gear oils
The main function of gear oil is lubrication. In harvesters and forwarders, gear oils are used in gearboxes, differentials, chassis boxes, hub gearboxes and in the box of hydraulic crane boom rotation. Main requirements for gear oils include minimum wear of lubricated parts, excellent low-temperature properties, long service life, excellent corrosion control properties, low frothiness and good compatibility with sealing materials.

Lubricating greases
Plastic greases are used to lubricate various sliding and rolling bearings where oils are not possible or technically suitable. They usually consist of base oil, additives and agent.

Important additives are particularly those used for the protection against high pressure and wear, corrosion and ageing. Reinforcing agent is a chemical substance creating a grid structure the space of which is filled with oil which is released between lubricated surfaces during the lubrication. Adding a reinforcing agent to the oil changes the state of the oil from liquid to grease. Under high pressure and temperature, the reinforcing agent reacts with the metal surface of sliding area and forms a protective layer thereon. Lubricating greases are applied using pneumatic or manual lubricators.

Analysis of operating fluids
Together with the monitoring of trends in the development of fluid capacities, analysis of fluid capacities is one of the tools of so-called pro-active maintenance, i.e. maintenance which is performed based on the actual condition of the machine rather than on the basis of prescribed intervals. In this way, intervals for the replacement of operating fluids can be extended thanks to their regular analysis. The analysis of operating fluids also makes it possible to prevent situations when the premature wear of individual machine components, impaired performance or unplanned shutdown of the whole machine might occur.

The analysis of operating fluids is focused on monitoring the presence of water, solid impurities, cooler and fuel in the oil (altogether 26 components). The machine owner makes the sampling by himself. There are 10 – 15 sampling points on the machine that can be monitored by this way. Each of them is given a unique code during the first sampling, and the code is then used to identify the sample at each further sampling. Results of the analysis either signal a perfect condition, or a warning or recommendation for immediate replacement.

Filtration of oil capacities
Filtration is one of possibilities how to resolve unfavourable condition of operating oil capacities. Filtration of oil will allow to reduce contamination and to extend the service life of hydraulic system components. Mobile filtration machines can work directly in the forest where servicing is made. Built-in sensors provide information on the number of solid particles and percentage of oil saturation with

water. The machines can measure and display the contamination of oil with solid particles according to the norm ISO 4406:1999 in categories of 4, 6 and 14 microns in 90 s intervals.

Engine including oil filter	28,5 l
Cooler	28 l
Gear box	4,5 l
Wheel hubs	2 x 4 l
Rear differential	27 l
Front differential	12 l
Bogie axles	2 x 52 l
Swing bearing of hydraulic boom	14,5 l
Hydraulic oil tank, max. up to the score	220 l
Hydraulic systems incl. oil tank	290
Fuel tank	480 l
Tank for washer fluid	13 l
Tank for brake fluid	0,5 l

Tab. 4. Volumes of fluid capacities in harvester Model John Deere 1270D

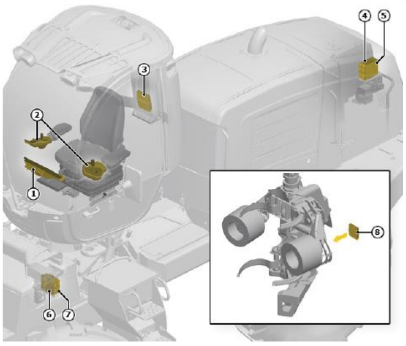
3. Control and measuring systems of logging and hauling machines

Most human activities currently increasingly apply various electronic equipment, and forest logging is no exception in this development. A typical example of the wide application of electronic measuring and control systems is highly mechanised forest logging based on the harvester technology.

3.1 Control system

Harvesters and forwarders are sophisticated machines with mechanical, hydraulic, electric and computer elements. The mutual effective cooperation of individual components cannot do without a sophisticated control system. Data for the control system are collected by an extensive system of sensors located in all functional machine elements. Based on the evaluation of these data or at the operator's command then the control system governs the mechanical and hydraulic machine parts by means of electric components. The structure of control systems in harvesters and forwarders dwells on CAN (Controller Area Network) technology and distributed control. The CAN bus can be split into several parts, which among other things facilitates simpler and faster machine diagnostics. The CAN bus provides for a mutual communication of individual independent control modules located on the machine such as engine control unit, harvester head module, cab module, hydraulic crane module of frame module. Most modules in the system are identical; this means that in the case of failure they can be swapped. Disconnection of one module has no effect on the function of the other modules. This arrangement of the system allows to create well arranged module structure and multifunctional diagnostics in different situations. Programmes of control systems are operated in the Microsoft Windows system, which makes it possible to use also other standard types of programmes such as text editor, table processor, internet browser, E-mail or map applications.

Typical data important for the machine operator are displayed by the control system in a so-called working mode on the screen display in the machine cab. They include the status of important parts of the system or exceeded limit values (condition of brakes and locks of differentials, engine speed, temperature of cooling fluid and hydraulic oil, battery charging voltage, level of fuel, parameters of harvester head and hydraulic crane, cab positioning etc. In a so-called adjustment mode, the operator can set some parameters of basic machine function on the screen display by himself (e.g. speed of the movement of individual functions of hydraulic crane, parameters of turning and cab position levelling, level of automated cutting, pressure of delimbing knives, degree of values upon the reach of which the operator should be warned about such as low fuel, high temperature of hydraulic oil etc.). Changes made in the setting of basic parameters can be saved under a specific operator's profile. This means that if there are more operators working on the same machine, each of them can have a specific setting of machine functions of his own, which is loaded together with the operator's profile at the beginning of the work shift. In the adjustment mode, the operator or serviceman can also perform diagnostics of individual functional machine components, e.g. to check the correct functioning of measuring sensors, saw sensors, or to check individual outputs on the control module of harvester head.



3. Cab module, 4. Engine control unit,
6. Frame module, 7. Hydraulic crane module,
8. Harvester head module

Fig. 49. Module structure of control system

Fig. 50. Working mode of the touch display of Rottne D5 measuring and control system

Harvester heads can be equipped with the control system of cutting. The system has a task to ensure the highest possible cutting rate, i.e. optimal pressure of saw bar in relation to the performance of saw engine. The system is used for cross-cutting, not for felling. Based on the data from sensors, the control system evaluates at each moment the information about engine speed, position of saw bar and log diameter, and regulates the optimal pressure of saw bar movement. Thus, the formation of cracks in logs is minimised.

3.2 Measuring system

Timber processed by harvesters is measured by means of harvester head suspended at the end of harvester hydraulic crane. The harvester measuring system evaluates data obtained from sensors placed on the harvester head, data entered by the operator during the production, and data from the price list stored in the computer. Based on these data, it then proposes an optimal composition of assortments in order to achieve maximum conversion into money for the processed trunk, or modifies the composition of assortments according to their required total share in the specific job. Measuring systems of harvesters meet the requirements of StanForD (Standard for Forestry Data and Communication) which is an internationally recognised standard used for production optimization by harvester technologies.

If the operator is in the process of logging, the computer display is in the working mode. In this mode, the operator has available actual information to logging just being carried out with the display of data on tree species, log quality, length, diameter and designation of the processed assortment, overview of assortments that have been already produced and assortments likely to follow. In the adjustment mode then the operator enters for example data about the stand in which he works, and may further divide the stand into several parts (blocks) according to customer's requirements, e.g. according to local names etc. By logging in his profile, the operator identifies himself when coming to the shift, and by logging out of the system he ends the shift, states reasons for interruption of working hours, selects parameters for print output etc. Production print outputs should contain identification of stand, possible division of production into blocks, information about the supplier, i.e. company identification, operator and time period of work done, a detailed specification of produced assortments by species or production groups, information about the total number of stems and their volumes, and information about the method of volume calculation and bark parameters. If the machine is equipped with satellite navigation and corresponding software, each produced log can be allocated an information about its precise location in the stand using GPS system coordinates.

Forwarders can be equipped with a measuring system, too, which in their case registers current load weight. There are two systems of load weight registration in use: pressure sensors are located either in four points under the cargo area, or are placed between the grapple and the hydraulic crane. The measuring system registers both the current weight of gripped logs and the total weight of timber in the cargo area.

3.2.1 Automated timber measurement by harvester head

The correct and flawless functioning of harvester heads is based on three types of sensors which register data about the current situation; pulser for length measurement, potentiometers or impulser for diameter measurement and induction sensors for controlling the saw bar position.

Length of logs is measured based on the rolling measuring sprocket during the movement of the processed log by harvester head with an accuracy to 1 cm or based on the rotation of feeding rollers. The length is measured based on the evaluation of data obtained from the impulser connected to the measuring sprocket. The measuring sprocket is pressed against the stem by spring or hydraulic cylinder, and as it moves, it is rolling either forward or back, with the pulser connected to it transmitting a corresponding number of pulses to the main computer. The obtained pulses are then converted to length in the computer based on the calibration value. If the system of length measuring is not calibrated correctly, resulting deviations can be only positive or negative. Thus, a situation when a positive deviation is measured in one log and immediately a negative deviation from actual length in the following log cannot happen.

Diameter (thickness) of logs is obtained based on the degree of the opening of upper delimbing knives or feeding cylinder arms with an accuracy of 1 mm. Diameter measurement based on the opening of delimbing knives dwells on the use of a pulser and uses two rotating potentiometers that are located on the locking pins of upper delimbing knives. The potentiometer is an electrotechnical component which serves as controllable resistive voltage divider. The potentiometers are located so that they respond to each opening or closing of delimbing knifes; when the knives open, the voltage running through them is increasing and when they close, the voltage running through them is decreasing. The magnitude of voltage from the two potentiometers is then decisive for the evaluation of resulting average which is calculated as an arithmetic mean of the two values.

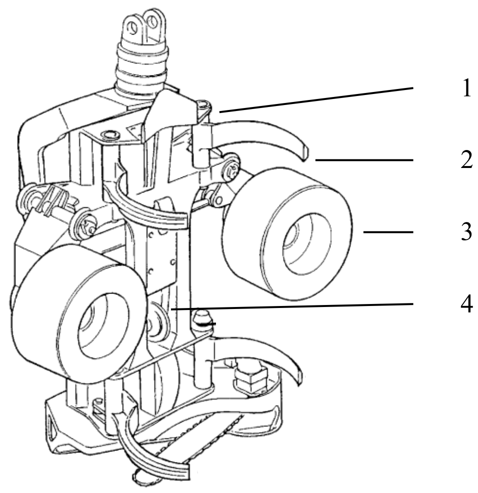


Fig. 51. Measuring mechanisms of harvester head
1 – potentiometers for measuring diameter, 2 – upper delimbing knives, 3 – feeding rollers, 4 – sprocket with the pulse sensor for length measurement

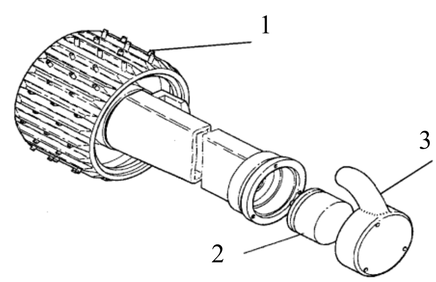
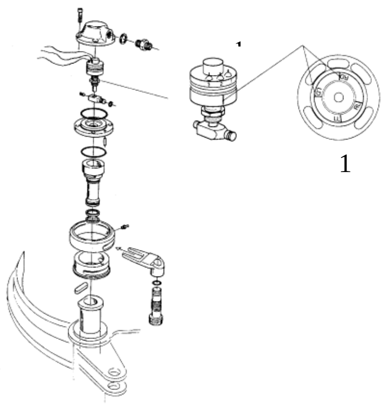


Fig. 52. Sensor of log lengths
1- sprocket, 2 – generator of measuring pulses, 3 – cable to control unit

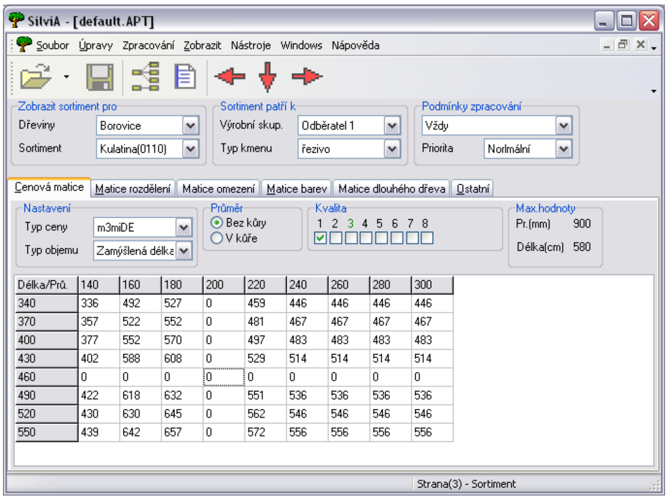
The harvester measuring system calculates the total **volume** of log based on the measured length and diameter. The log diameter is measured over bark. As the stem is not debarked for the processing, the volume of logs must be calculated using a function which is able to make a corresponding bark deduction according to the measured diameter. The allowance can be determined for individual tree species separately by two ways which should never be applied both. The first procedure is bark deduction using the zone values of stem diameters.

In the harvester measuring programme, a module is built in in which parameters are stored determining how many hundredths of a millimetre will be deduced as bark allowance provided that the stem diameter over bark falls into a certain diameter zone. The number of determined diameter zones can be from 1 – 10. Then, precise boundaries between the individual zones can be set up, and precise allowance for the given diameter zone. The second way is a bark allowance from two parametric values and allowance formula where one of the values determines a minimum deduction and the second one a progression of bark allowance size; the greater is the diameter, the more is deduced.



1- measuring potential node

Fig. 53. Sensor measuring log diameter



Délka/Prů.	140	160	180	200	220	240	260	280	300
340	336	492	527	0	459	446	446	446	446
370	357	522	552	0	481	467	467	467	467
400	377	552	570	0	497	483	483	483	483
430	402	588	608	0	529	514	514	514	514
460	0	0	0	0	0	0	0	0	0
490	422	618	632	0	551	536	536	536	536
520	430	630	645	0	562	546	546	546	546
550	439	642	657	0	572	556	556	556	556

Fig. 54. Example of price matrix in the John Deere harvester measuring system

There are several methods for calculating log volume in the measuring system. The log volume classification can be for example based on the sum of partial volumes of cylinders of given thickness, on the pin on centre diameters.

The **price list** is a file from which the measuring system obtains data about parameters of required production such as tree species, dimensions of individual assortments, their actual or more often relative monetization etc. Data are entered into the price list file by the operator or by the machine owner. Basic data entered into the price list include names of tree species and names of individual assortments to be processed for the given tree species, production group (e.g. in deliveries to multiple customers), quality classes in which the assortment can be produced, method of log volume calculation, calculation of permissible length and corresponding diameters of assortments. When the length and diameter classes are created, each matrix field has to be allocated either a relative or an actual price. If the price remains a zero in some field, the assortment with length and diameter parameters corresponding to the given field will not be produced.

Measurement of processed stem

- Operator grabs the tree stem by the harvester head at its base, and enters the tree species and/or its quality into the measuring system.
- Based on the first measured stem diameter and stem curve for the given tree species stored in the harvester computer, the measuring system predicts an optimum composition of assortments for production according to the price matrix entered in the price list file.
- The price matrix is entered into the harvester computer by the machine owner upon agreement with the customer on what assortments will be produced in the given stand. Each produced assortment is in the price matrix allocated an actual or relative price of monetization. The harvester measuring system selects the composition of assortments so that a maximum conversion into money is achieved in the processed stem or that a preliminarily agreed proportion of individual assortments is produced.
- The optimum composition of assortments for production can be changing during the stem processing according to how the measuring system continually compares the actually measured and expected stem diameters according to the stem curve.
- The stem curve for the given stand subjected to felling in continually specified based on the already converted stems.

3.2.2 Manual timber measurement, grading and takeover

Timber measurement, grading and quality control is in charge of harvester and forwarder operator. For the purposes of harvest measuring system calibration and timber assortments takeover, it is necessary to be able to properly manually measure basic dimensions of individual logs and wood stacks. If the supplier and customer do not agree otherwise, reference measuring instruments for control volume measurements are as follows: Diameter – calibrated meter with a resolution of 1 mm is usually regularly officially recalibrated (min. once in 2 years) and allows to measure with a permissible measurement error of ± 2.5 mm. Length – calibrated meter with a resolution of 1 cm is regularly officially recalibrated min. once in two years and allows to measure with a permissible measurement error of ± 0.2 % from the measured length (i.e. ± 2 cm at a length of 10 m). Results of the control measurement including the calculated diameters are not rounded.

Total log **length** is measured as the shortest distance between two log butt ends. The measuring tape must be running straight forward. The log length is measured in meters with an accuracy to 1 cm. If nominal length is mentioned, the total log length is rounded down to the nearest degree of nominal length. A nominal length degree is usually 1 m. Upon agreement between the supplier and customer, the total length of logs with a mid-diameter up to 20 cm (under bark) can be rounded down to whole meters. Allowance for bark in both coniferous and broadleaved timber logs is 2 % of nominal length. The length allowance is not to be included in the nominal length of the log.

Diameter (thickness) is given in cm in whole numbers (data behind the decimal point are not considered). Calliper has to be located at a right angle to the longitudinal stem axis. Mid-diameter is measured in the middle of the log. In specific cases it is substituted by top diameter which is measured at the top end. If the diameter is measured in one direction, the result is given in whole centimetres (data behind the decimal point are not considered). If the diameter is measured in two mutually perpendicular directions, each measurement is given in whole centimetres (data behind the decimal point are not considered), and the diameter is calculated as an arithmetic mean of the two (or four) measurements. The calculated arithmetic mean is given in whole centimetres (data behind the decimal point are not considered).

Mid-diameter is measured in the middle of the log nominal length. In logs with a mid-diameter up to 20 cm, the mid-diameter is measured (at manual measurement) once in the horizontal direction (the plane of measurement being parallel to the earth's surface). If the log has an oval cross-section, the mid-diameter is measured in two mutually perpendicular planes. In logs with a mid-diameter above 20 cm, the mid-diameter is measured in two mutually perpendicular planes.

Top diameter is measured on the thinner end of the log (on the top end). The use of top diameter for determining the volume of measured round wood must be agreed between the supplier and the customer. The measuring procedure is similar to that applied in measuring the mid-diameter.

Volume of log under bark measured over bark is calculated according to the below formula:

$$V_{bk} = \frac{\pi}{4} \times (d_{sk} - 2k)^2 \times l \times 10^{-4} \qquad 2k = p_0 + p_1 \times d_{sk}^{p_2}$$

V_{bk}	volume in m^3 with accuracy to 2 decimal points	l	nominal log length in m
d_{sk}	mid-diameter over bark in cm	$2k$	twofold bark thickness
		p_0, p_1, p_2	parameters of function

Tree species	Parameters of function		
	P$_0$	**P$_1$**	**P$_2$**
Spruce	0.5772	0.0069	1.3123
Pine - bark	0.2402	0.0019	1.7866
Pine – rough bark	1.7015	0.0088	1.4568
Beech	-0.0409	0.1663	0.5608
Oak	1.2474	0.0423	1.0623

Diameter is measured over bark or under bark. If it is measured over bark, the following procedure is used to convert the over bark measurement to the under bark measurement: Mid-diameter o.b. is used for the calculation of log volume, and the log volume is derived from tables originating from ČSN 48 0009: Tables of round wood volume u.b. according to mid-diameter measured over bark (the tables respect the bark thickness by individual tree species and the distinction is respected with the exception of larch logs which are classified in the group of pine butt logs). Supplier and customer may agree a different bark allowance by which the measured diameter is decreased.

Included are parameters of function for various tree species for the calculation the volume of log under bark, measured over bark. The log volume can be also derived according to particular volume tables upon agreement between supplier and customer.

At **measuring timber in loose measures**, the length, width and height of individual logs pile has to be determined. The dimensions are determined with an accuracy of 1 cm. Logs pile width (w) is given by the nominal length of logs or by the nominal length of the timber of standard lengths. Logs pile length (l) is the shortest distance of two marginal logs pile points measured at the logs pile foot. Logs pile height (h): Prior to height measurement, the logs pile is divided into imaginary sections. The length of individual sections is 1 m or 2 m if the logs pile length is greater than 10 m. Logs pile height is calculated as an arithmetic mean from individual height measurements in half length of each section, including the possible last incomplete section.

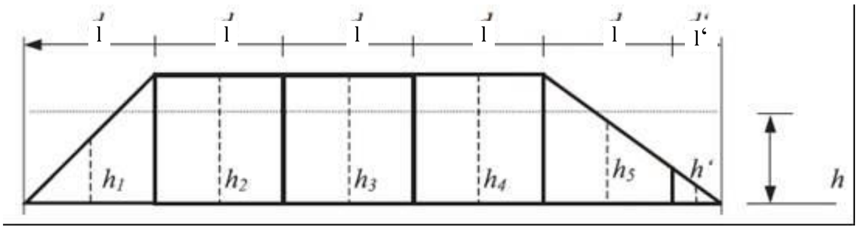


Fig. 55. Principle of logs pile measurement (according to Kolektiv, 2002)

$$h = \frac{(h_1 + h_2 + ... + h_n) + h'}{n \times l + l'}$$

h	logs pile height	n	number of sections
$h_1 ... h_n$	section height	l'	incomplete section length
l	section length	h'	incomplete section height

Timber has to be properly stored, without admixed branches, snow etc. Free access to both sides of the logs pile is a must, too. Logs pile height can be determined as an average from the height measurement of both logs pile sides. Uniform lengths of assortments are required and a diameter ranging ± 10 cm from the diameter of middle piece. Maximum logs pile height is 3.0 m.

For the purposes of **timber quality grading**, logs are classified by tree species, extent of defects and dimensions into the following quality classes: I. Resonance logs, logs for the manufacture of sliced veneers, II. Logs for the manufacture of rotary-cut veneer, other special logs, III. Coniferous and broadleaved logs for sawmill processing, coniferous logs for the manufacture of columns, IV. Timber for the production of mechanical wood pulp, mine timber and mine logs, pole timber, V. Timber for the production of pulp, wood-based panels (pulp wood) and VI. Fuelwood. As to the extent of defects, number of knots is monitored and their health, character of cracks (heat shakes, drought cracks, frost cracks, ...), growth defects (twisted growth, taper, stem curvature, ...), defects caused by fungi (soft rot, hard rot - dote, blue stain, ...) and infestation by wood-decaying insects (shallow, deep, ...). A detail breakdown see *Doporučená pravidla pro měření a třídění dříví v České republice* /Recommended rules for timber measurement and grading in the Czech Republic/ (2002) as amended.

Transfer of timber assortments often happen with the participation of supplier and contractor upon their mutual agreement at intervals of 7-30 days, depending on the progress of work. Timber produced by the harvester and skidded by the forwarder to the roadside landing is accepted by a person authorised by the contractor, who makes a number list. In case that a marking colour is used in the control reception of timber, the same colour must not be used by the contractor. A person authorised by the customer performs the control takeover (species, assortment, dimensions, allowance) and visibly provides the checked wood with a calibration mark. The correctness of data stated on the output from the harvester measuring device is formally confirmed by forest district manager or another person authorised by forest owner with his signature on each sheet of the measurement record or on each sheet of the number list – if the output from the measuring device is supplemented therewith (summarized).

Procedures that can be used for the transfer of timber assortments on the roadside landing are as follows:

- Customer accepts the production statement from the harvester without any other control measurements.
- Customer accepts the production statement from the harvester complemented by methods of mass timber measurement in loose measures. Control measurements are then performed on the agreed percentage of production at given time intervals.
- Transfers of timber assortments are performed only by the methods of mass timber measurement in loose measures.

3.2.3 Measuring system calibration

The harvester measuring system should be checked for the accuracy of length and diameter measurement at least once a day. If the actual values of log lengths and diameters do not agree with data provided by the harvester measuring system, it is necessary to calibrate the measuring device. Measurement calibration is also made if logging conditions change, e.g. stem volume of the felled stand or if the harvester head or the measuring system have to be repaired. The measuring of length and diameter directly affects results of log volume calculation. Correct adjustment of the harvester measuring system is essential. Logs that do not correspond to parameters agreed between the manufacturer and customer are automatically reclassified into a lower quality class with a lower rate of monetization. This is how considerable financial losses may occur at high daily outputs of the harvester and absence of measurement control.

Before calibrating the measuring system, it is advised to check the sprocket for length measurement, diameter sensors and/or pressure of delimbing knives. The calibration of the measuring system should use data min. from 3 felled trees. The measured length is checked first and then the measured diameter. Calibration of length and diameter can be performed separately for each tree species and for the lower stem end. It is performed on round standard stems without unusual bends or large branches.

At calibrating the diameter, calibration points are distributed along the entire course of diameters. A "basic curve" is created using these calibration points. In the final stage, only several of these points are used for the conversion from a certain value of voltage to a final diameter. It follows that relying on the accuracy of harvester measurement without checking the measurement of the whole range of diameters would be risky. The control of harvester measurement accuracy should be therefore focused on the measurement accuracy in diameter zones at a distance of ca. 50 mm – optimally then 100, 150, 200, 250, 300, 350 mm, etc., logically in dependence on the volume of stems in the given stand. This means that the more stems with large volume occur in the stand, the more control zones the check should include. During the calibration, one or several calibration points may be changed if needed. During one measurement checking, the diameter correction should not exceed more than 5 mm. A greater correction done at once can deform the shape of the diameter curve and make the calibration more difficult.

A **database of control measurements** can be acquired by electronic calliper or by manual entering of measured results. The system automatically evaluates the results during data import and recommends calibration in the case of need. Measured data are automatically ignored during the calibration if the difference between the displayed and measured data is too big.

In the manual entering of measured results, results from the measurements are recorded into a so-called calibration protocol. As soon as the operator ends the processing of stems by harvester that were selected for the control measurement, he will enter their manually measured lengths and diameters into the calibration protocol. Length is rounded down to the nearest whole cm. Upper log diameter is measured crosswise over the bark. The measuring system of the machine can process only descending diameters, which is to be taken into account when entering the measured values. Mid-diameter is calculated and the data are entered into the harvester measuring system. After calibration, the given log length and diameter in the computer measuring system should correspond to dimensions of the actually produced log.

Calibration of the measuring system has to be made also in the **forwarder**, if it is equipped with the system of load weight registration. The calibration of pressure sensors located on four points under the forwarder cargo space is performed on the flat terrain and with the empty cargo space. When a zero point of the system is set up, a reference cargo of known weight is loaded, and if the value given by the measuring system differs, calibration is made.

When the pressure sensors are located between the grapple and the hydraulic crane, a so-called static calibration is made first. Static calibration of scale is a base for the measurement and is usually necessary only when the scale is used for the first time or after a long machine shutdown. After entering the zero point with the empty grapple, a burden of known weight is grasped in the scale and the grapple is left to stabilize. Then the calibration is performed in the case of need. Dynamic calibration as a tool for reliable measuring results is more important than static calibration. By means of dynamic calibration, the inaccuracy of weighing caused by the different type of forces acting during loading and unloading can be reduced. Dynamic calibration has to be performed with a reference burden of known weight. The point is to carry out 20 cycles of loading and unloading so that the measuring system can calculate the coefficient of calibration for both directions from the mean value of individual movements. As the coefficient of dynamic calibration is specific for the operator, the calibration should be made always when a new operator starts working with the crane scale for the first time. As in the preceding cases, the zero point of the scale has to be reset before starting the calibration.

3.2.4 Accuracy of the harvester measuring system

The production statement provided by the contemporary versions of harvester measuring systems fully answers with its contents and accuracy of given parameters to the operational needs of forestry if the calibration of the measuring system is correct. Possible deviations in the individual parameters of products are caused either by human factor (intentional or unprofessional handling with the measuring software, or by specific working conditions such as stem unevenness, logging in times of frost or sap, or work in calamities. The wear of length measuring sprocket or failure of one of two potentiometers for diameter measurement can affect the correct length determination, too, thus impacting the volume of production.

The forest owner has knowledge about the average **stem volume** in the stand that is under his management. If the stand will be subjected to logging by harvester technology supplied by contractor, a basic problem for the forest owner is to set up the price at which the service is received. The basic three parameters of the price are skidding distance from the clear-felled area to the roadside landing, stem volume and type of cut. Skidding distance is a quantity that can be easily determined by measuring the average distance from the logging site to the roadside landing. The type of cut is given – thinning, main felling. A problem arises at the moment when a correct stem volume has to be determined, especially in situations when the stem volume in the stand reaches limit values.

The number of stems and the amount of felled timber are decisive for the determination of stem volume. In fact, the stem volume could be determined by a mere quotient of these two data. The procedure is however not acceptable in operational practice with respect to a possible current situation. In a stand without broken tops and individual trunks damaged by bayonet (spiked) tops, the situation is clear – resulting stem volume is determined as a ratio of timber volume and number of stems. Here, the number of stems counted by the harvester should be the same as the number of actually felled stems. Contrariwise, in a stand with top breakages (and requirement for the processing of both the standing part of the stem and the top part laying on the ground), one has to take into account that the number of stems counted by the harvester will be always higher than the number of stems that were felled in reality. Measuring systems are namely based on a presumption that any piece of timber grasped by the head and cut into assortments is a stem without any distinction between the standing part of the stem or the top lying on the ground. The logic of this system is based on the number of operations. For the operator, this situation means that he must grasp the standing part of the stem, fell it, process it, and then go back for the top breakage, grasp it and process it again. In terms of machine performance, it is not only one operation but two operations. Moreover, it is usually only max. one pulpwood log of 2 m in length that can be produced from the tops, which is then the most expensive log produced from the given stem.

In forest stands with the occurrence of breakages, forest owners should always take into consideration the above facts in determining the objective value of average stem volume.

Current practice in determining timber volumes in the Czech Republic allows each of the parties participating in the logging process to take their measuring methods for the only correct ones. Suppliers of harvester works request the output from harvester measurements to be accepted as the only correct ones. Customers of services (usually forest owners) refer to the amount of timber measured at a roadside with the use of conversion coefficients, and customers purchasing timber force and accept only outputs from the electronic takeover of timber in their own receiving depot measured on their own measuring equipment. This complicates relationship between suppliers, contractors and customers.

There is no institution in the Czech Republic that would unify the timber measuring systems and that would deal with disputes about supplied or purchased amount of wood and services. An example could be the Swedish system in which an independent company exists in which all four main participants in timber trade are represented – state, forest owners, suppliers of services (operators of harvester technologies, logging truck-and-trailer units, etc.) and customers. The company is then responsible for the management of measuring sites where independent measuring of timber volume takes place. All invoicing among the parties is then governed by volume detected there. The measuring sites are mostly located at the final customer's but they are under management of an independent agency which dispels all doubts about the correctness of measurements. The output from the measuring system of the harvester then serves as a primary working document for the organisation of timber transport from the roadside landing to the place of destination.

3.3 Systems of performance monitoring

Working hours of the machine and information about the machine use and availability are a precondition necessary for any high-quality calculation of costs. This is why manufacturers of harvesters and forwarders offer the possibility to monitor all performance and operational parameters of machines required for the calculations. Regular checks of the results of monitored parameters easily reveal changes in the technical status of machines and in the consumption of operating fluids. As all functions are monitored continually, the operator can swiftly react to any changes in the machine performance and thus to maintain high productivity and economy of operation in all areas of machine activities. The evaluated data can also be used in the training and schooling of operators and in the development of their work skills.

Information from sensors placed on the machine are gathered by means of CAN bus. During the working hours, the system is able to identify individual work stages such as machine transportation, hydraulic crane handling, felling, harvester head movement, operator's work breaks, servicing, etc. When the harvester head is in action, these time quantities are allocated fuel consumption or can be broken down according to the volume of processed stems.

A change in the diagrams of productivity or consumption is the first symptom of problems with the technical condition of the machine. The obtained values can help monitor and determine performance and economic indicators. In this respect, the most important factors are production productivity and the share of production stage in the total time of machine operation. All these data should be monitored regularly. Hourly machine output can be estimated by multiplying production productivity (m^3/h) and percentage of production stage (%). Another important monitored element is fuel consumption (l/m^3). Low fuel consumption informs us about high productivity and good technical condition of the machine. Results of the achieved goals logically depend on many different factors such as stand density, representation of individual tree species, stem volume or topography. Outputs and measurements can help estimate those factors and develop work procedures. Peak output assumes optimal setting of the machine in dependence on work conditions, i.e. adjustment of the pressure of delimbing knives and feeding rollers, feed rate, adjustment of the pressure of hydraulic crane and of the working speed of combustion engine. Using the information, it is possible to find optimum values for such a machine setting related to various work conditions.

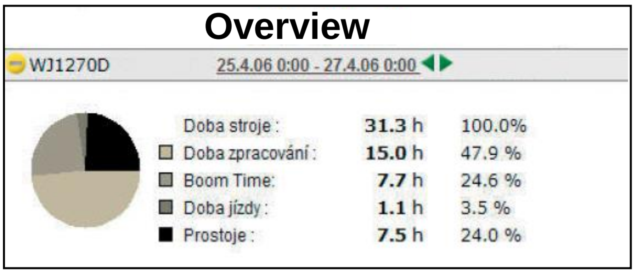


Fig. 56. Division of machine working time monitored by the TimberLink programme
(John Deere)

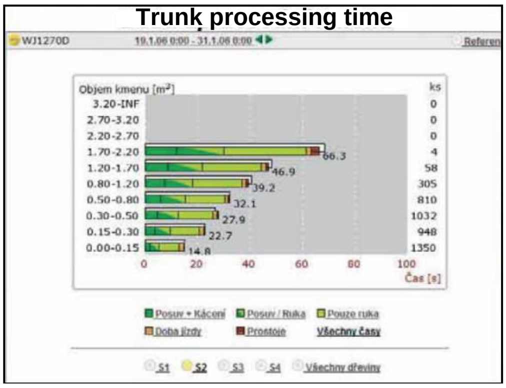


Fig. 57. Individual production stages monitored by the TimberLink programme
(John Deere)

3.4 Telematics

The principles of telematics are increasingly applied in harvesters. This technological field deals with the combination of data transfer and processing with imaging and other communication systems and equipment. Thus, the machine owner can send or receive information about operational characteristics of harvester or forwarder remotely via own communication facility. The system of telematics in harvesters and forwarders combines possibilities of systems for machine output monitoring and global system for mobile communication - GSM (Groupe Spécial Mobile), and/or satellite positioning system for remote localities with no GSM signal.

The systems for machine output monitoring are offered only by bigger manufacturers of harvesters and forwarders, and they are at all times based on the same design principles. The GSM system is the most widely spread standard for mobile telephones in the world and is currently used by more than 5 billion users in more than 200 countries. The currently most frequently used satellite positioning system is GPS (Global Positioning System) which is a military global satellite positioning system operated by the US Ministry of Defence. To enhance accuracy and availability of the satellite positioning system, it is possible to use at the same time also the GLONASS system (Globalnaja navigacionnaja sputnikovaja sistěma) which is a global satellite positioning system operated by the Russian army. Additionally in 2017, the European project of the Galileo satellite positioning system became functional and aims to be fully functional by 2030.

The process of telematic communication can be as follows. Modular telematic hardware (A) uses the GPS signal (B) to determine the actual position of the machine. GPS data and actual operational data of the machine are joined in the controller of the modular telematic gate. The data are regularly sent via the GSM mobile network © or optionally via the satellite network (D) to the data server of service provider company (E). There they are processed and made available in the programme application which is accessible by means of personal communication tools (F).

The possibilities for using the telematic system are wide. The machine owner can for example remotely obtain information about the actual position of the machine or its movement in the terrain in a certain time period, information related to diagnostics of service parameters and to error messages of harvester. The telematic system ensures the performance of initial diagnostics, to control diagnostic error codes or reprogramme CAN buses and controllers of machine in the field at a distance of many kilometres. Remote diagnostics helps servicemen get prepared for service at machine owner’s and reduce costs and time required to eliminate the problem. When the preset machine parameters are exceeded, persons concerned can be automatically sent messages by email or SMS. The warnings may relate to security breaches, error codes of the machine or may simply inform the operator that fuel is low. The machine owner can further be informed about total fuel consumption or about fuel consumption during individual machine operations, the parameters of implemented logging, felling site position, etc. The system also allows to monitor in detail activities of the operator during his working hours.

Example of GPS system use in logging

- Machine owner receives from the customer requirements for the production of assortments and enters them into the harvester measuring system.
- In the digital stand map, forest manager lays out skidding lines in the stand taking into account the stand situation (slopes up and down, watercourses, marshes etc.), which then do not need to be set out in the stand; all lines run in the same direction and have the same distance.
- During the production, the harvester stores information on produced assortments in electronic form including GPS system coordinates for each produced log.
- At the end of the work day, the harvester sends the production data to the machine owner and to the forwarder operator by means of GSM network.
- The forwarder receives the data from the harvester, and based on them, its operator sets up an optimal plan for forwarding. In winter, the forwarder does not need to follow the harvester immediately to take away everything because even the logs hidden under snow are shown on the display. Thus, no forgotten logs are left in the forest.
- The machine owner informs the customer or carrier about GPS coordinates of individual timber stacks at the roadside landing.
- Based on the need for diverse assortments, the machine owner or carrier organize deliveries of produced assortments to customers.
- The machine owner has an immediate information about the position of the machine in the stand and about the size of the already felled area.

The whole process of timber flow should be controlled by only one organisation (always the state forests in other countries); individual parts of the process can be assigned to contractors. The first step of the process = planning of felling must be drafted on the basis of the so-called logistic logging projects where felling operations are carried out by one specific firm as to organisation and data transfer. Current practice in the state forests: Finland and Sweden – complete data transfer by means of satellite technology including the graphical display of forest timber loads for carriers. Austria – data transfer via SMS, options for the cartographic satellite transfer of data about forest timber loads for carriers are being finalized.

Navigation of logging and hauling machines by GPS using digital stand maps
The system of controlling the technology of forest logging carried out by logging and hauling machines allows us to make use of digital stand maps with the marked skidding lines along which the machines will be moving (Fig. 59.). The maps are loaded up to the on-board computer memory and when the machines work, the GPS system marks their actual position or even shows the placement of produced assortments in the map. The updated stand map then facilitates the work of the forwarder whose operator uses the marked locations of individual produced assortments (Fig. 60.) to optimize the forwarding procedure. As mentioned above, another function of this system is a possibility to control the activities of the machines by relevant entities.

4. Planning of tree felling by logging and hauling machines

The flow of timber from the stump to the processing facility in proper assortments, species and in the right time should be as continual or fluid as possible. Only in such a way, requirements of customers for certain assortments can be met efficiently and profitably. The stock of stands chosen for harvesting should cover all required assortments in the planned season of the year. This is why the principles of logistics have to be used along with the planning of logging and timber supplies.

4.1 Criteria for the selection of stands suitable for CTL logging technologies

Selection of stands plays a crucial role in the resulting damage to stand and economic efficiency of the measure. This chapter specifies technological conditions of the workplace allowing the deployment of harvester technologies.

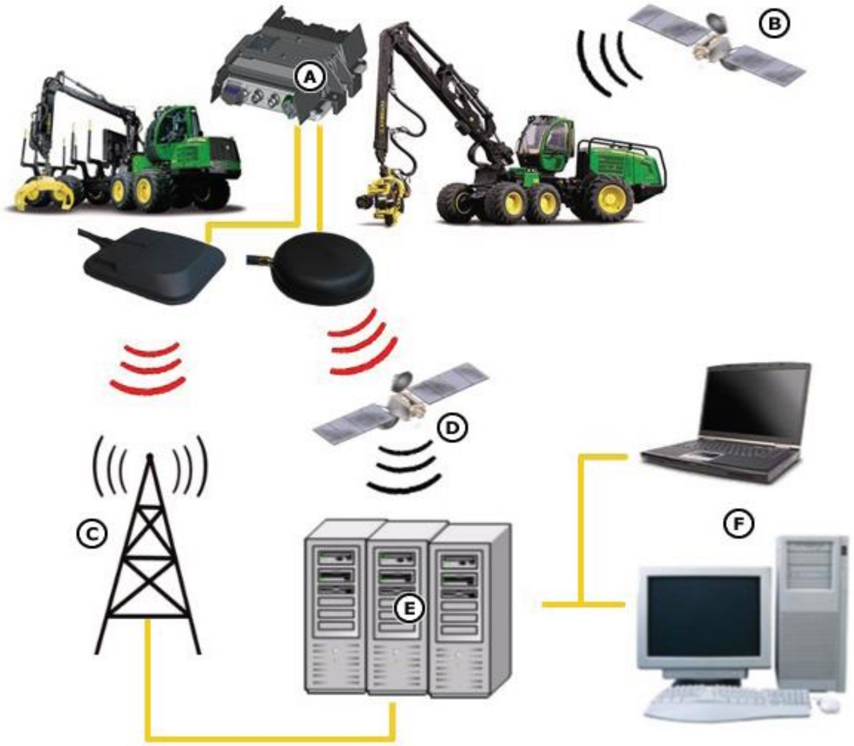
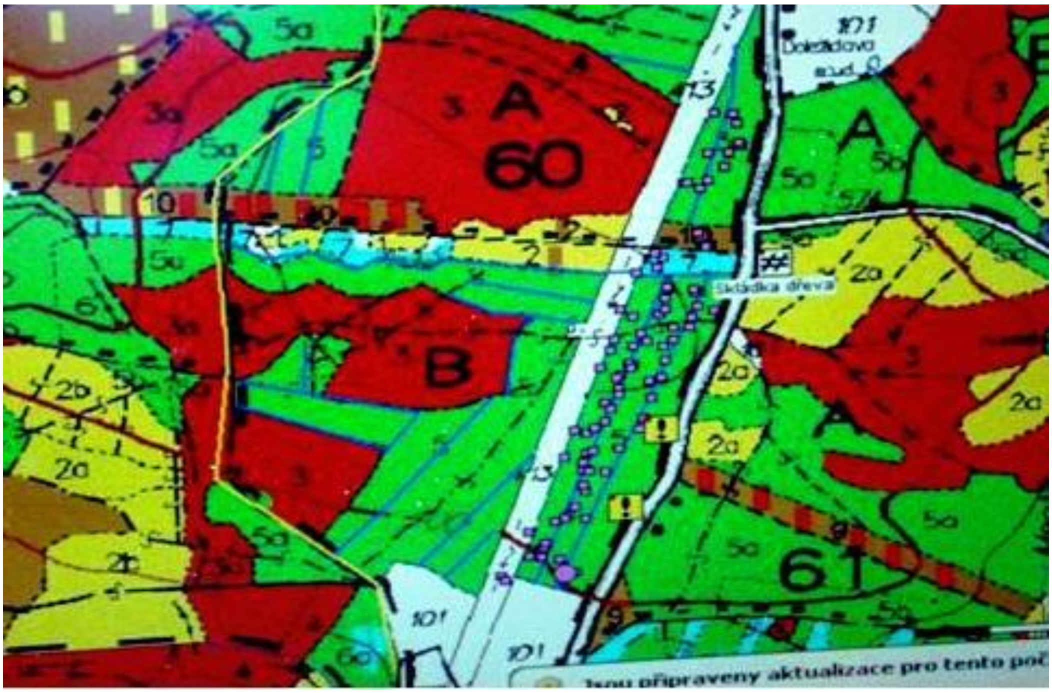


Fig. 58. Principle of telematic communication (John Deere)



Squares represent actual work positions of the harvester proceeding along the blue skidding line on the harvester PC. Lower larger circle – position of harvester during the break.

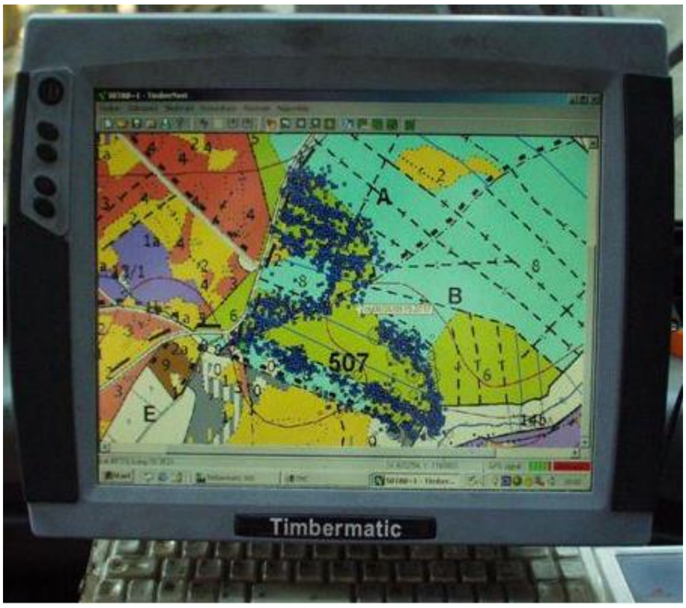
Fig. 59. Marking of skidding lines in a digital stand map and recording of harvester movements

Terrain articulation

When judging terrain navigation, the size of obstacles (elevations and depressions) and distance between them are important for the deployment of logging harvester technologies.

Table 5. shows a Swedish system for the classification of terrains suitable for logging harvester technologies. Heights of elevations and depths of depressions are allocated possible distances between

them. The table also presents a comparison of the Swedish classification system with a common terrain typification of ÚHÚL (Forest Management Institute – FMI).



Where the circles are missing, the assortments have already been forwarded to the roadside landing.

Fig. 60. Circles on the display of an on-board harvester PC show the position of stored assortments prepared to be brought to the forwarder (John Deere 810D).

Elevations (mounded earth, stony surface, scattered stone blocks) and depressions in Class 1 are passable without decreasing speed, at greater depths already with respect to the size and frequency of obstacles with adequate caution of the operator with respect to the stability and strength of the harvester or forwarder structure. The effect of obstacles increases with the increasing slope gradient.

Ground bearing capacity

In the ÚHÚL typological classification, the boundary pressure between bearing and non-bearing terrains is considered a pressure of 50 kPa in the track of the transport means (pressure corresponding to the sinking human leg). Decisive for the deployment of harvester technologies is in this case the pressure of the forwarder which has to pass over skidding lines several times. Forwarders with 8 wheels and tracks on individual axles are preferred to reduce the pressure on the soil. Tab. 6. presents indicative values of pressure on the soil in various John Deere forwarders with 6 and 8 wheels, with the tracks and without them. When travelling without a load, the rear axle does not exceed a pressure of 50 kPa. With the load, the value is exceeded always even with using the tracks. This is why harvesters should be used on poor load bearing soils only in favourable conditions (frost, long-term drought). The table shows that tracks and larger tyre width efficiently reduce pressure on the soil, and this is why their use is desirable in terrains with the low bearing capacity.

Characteristics of the ruggedness of terrains suitable for harvester technologies						
Class	**Elevations (cm)**		**Depressions (cm)**	**Distance between obstacles (m)**		**Passability by harvester and forwarder**
	Sweden	**ÚHÚL CR**	**Sweden**	**Sweden**		
1	0 - 15	**Terrains without obstacles (UKT up to 30 cm, SLKT up to 50 cm)**	0 - 20	> 20	**individual**	**without reduced speed**
2	16 - 25		21 - 40	11 - 20	**sparse**	**with reduced speed**
3	26 - 40		41 - 60	6 - 10	**less dense**	
4	41 - 60		61 - 90	2,6 - 5	**dense**	
5	> 60	**Terrains with obstacles**		0 - 2,5	**multiple**	

Tab. 5. The system of Swedish classification of terrains suitable for harvester technologies

Soil bearing capacity is characterised by terrain type which includes, with a certain inaccuracy, edaphic categories from the group of forest types (forest site complex). For indication, these edaphic categories can be sorted into several groups according to bearing capacity given by soil texture and effect of water. If conditions for the deployment of harvesters are unfavourable, the risk of damage to soil in the otherwise identical stands will be lower in the stand classified in the edaphic category with a higher bearing capacity. Edaphic categories of a generally very good bearing capacity are those that are characterised by the higher content of skeleton which can efficiently distribute the vehicle pressure on the soil (J, X, Y, Z, C, N, A, F).

Specific pressure on the soil in forwarders										
Forwarder characteristics					Without load		With load			
Brand	Chassis	Tire width		Load	front	rear	front	rear	rear (tracks)	
		front (mm)	rear (mm)	(t)	(kPa)	(kPa)	(kPa)	(kPa)	(kPa)	
John Deere 1110 D	6w	600	600	11	71	37	71	100	63	
		700	700		62	32	62	90	55	
	8w	600	600		54	37	54	100	63	
		700	700		47	32	47	90	55	
John Deere 1410 D	6w	600	600	14	78	40	86	118	68	
		700	700		67	35	74	101	60	
	8w	600	600		59	40	65	118	68	
		700	700		51	35	55	101	61	
John Deere 1710 D	6w	700	650	17	67	40	74	120	68	
		700	750		67	35	74	105	61	
	8w	650	650		56	40	60	120	68	
		750	750		49	35	53	105	61	

(deep grey fields – pressure up to 50 kPa, light grey fields – pressure up to 100 kPa, i.e. pressure comparable with general-purpose wheeled tractor model Horal equipped with forestry completion)

Tab. 6. Pressure on the soil in some John Deere forwarders

Terrain gradient

Harvesters and forwarders have slope accessibility given by their design. Terrain across a slope is much more dangerous to both machine types and their overturning should be prevented already in laying out skidding lines. A general rule stipulates that the **line across a slope should not exceed 10 %**. The effect of terrain inclination for the deployment of harvesters is shown in Tab. 7. Slopes without problems can be considered those up to which a harvester can get without using differential lock and on which it does not slip down the slope at felling a tree when braking. If such a situation occurs, a further operation of the harvester can be considered risky, and waiting is advised for more favourable conditions (drought).

Effect of terrain gradient on the deployment of harvesters					
Terrain type	11, 21, 31	12, 22, 32	13, 23, 33	14, 24, 34	15, 25, 35
Gradient (%)	0 - 8	9 - 15	16 - 25	26 - 40	> 40
Laying out of lines	**Laying out of lines regardless of slope**	**Laying out of lines down the slope**			
Type of harvester chassis	**Extent of using wheeled chassis (in dependence on subsoil condition)**		**(during drought)**	**(during drought on skeletal soils)**	**(on short slopes)** 60 - 80 %
	Extent of using tracked and caterpillar chassis			50 - 60 %	

Tab. 7. Effect of terrain gradient on the deployment of harvesters

Age of the harvested stand

The age of the stand is related to dimensions of trees in the stand and their spacing (planting distance). Harvesters mostly move only along the lines in between of which there is a working field of ca. 20 m in width. However, technological procedures with a greater spacing of working lines are known, when the harvester moves inside the working field.

In order to prevent excessive damage to stands, a sufficient free space should be left on the machine sides. A survey focused on the spreading of rots showed that there is a danger of damage to the trunk by rot if such a damage occurs at a distance up to 0.5 m from the trunk. Therefore, none of the machines can be used for moving inside the working field at respecting the used tending models if more than 1 450 trees per hectare remain on the site. While following the tending models, the machines cannot be used inside the working field in stands aged below 40 years.

Harvested tree species and their dimensions
Harvester heads are designed particularly for coniferous tree species. Spruce is very good to be processed. Older pines have large-diameter branches in their crowns, and problems occur when pulling trunks through delimbing knives. This is why heads with 4 pull-through rollers are suitable in such cases. The heads have a shorter frame and accommodate better to the trunk shape. Trunk forking complicates the work in all tree species, and this is why forest stands with a higher representation of crooked and forked trees are not good for harvesters.

4.2 Organisation and logistics for the short-term planning of timber felling

Short-term planning is for a period of about 1 year. The planning will be successful provided that following operational data are assured and measures adopted:

4.2.1 Obligations of the contracting authority

- Organisations should estimate the harvesting needs according to predicted requirements provided by wood-processing companies.
- Total timber volume to be harvested should be determined according to prevailing stem volumes based on the forest management plan (FMP) regulation while respecting the profile and subsoil of stands, i.e. inclination, type and drivability. The soil bearing capacity must be at least 5-7 % CBR for the drivability of logging and hauling machines.
- The condition of access roads to stands to be thinned should be determined; both the current skidding lines and the truck roads should be checked.
- The number of assortments to be produced should be determined with respect to market requirements. More than three assortments cause difficulties in putting timber away in the stand and the machine performance is reduced thereby.
- Depending on the season and special felling tasks (calamities), machine operators can have their logging capacities filled 1 to 6 months in advance. Therefore, forest stands should be inspected timely for the contractors, their bids evaluated and contracts concluded.
- Marking of lines and trees for felling and/or promising individuals that must not be felled and have to be preferably protected against injury must be assured.
- Timber felled during the wet / summer season should be transported to the conversion as fast as possible and should not be left at a roadside stack for long. In this period, transport from the stump to the customer should optimally take from a few days up to max. two weeks. Timber felled during the dry / winter season can be left lying for a longer time.

4.2.2 Obligations of the operator of logging and hauling machines

- The practical implementation of the programme of felling operations is modified by the need of timber, which changes during the season. Productivity and annual use of machines increase if the felling operations are evenly distributed throughout the year. One of goals in planning is to know (in advance if possible) the programme of felling for both machines and their operators.
- For entrepreneurs with one or two chains of machines, felling compartments should be planned at least a month ahead. The monthly programme is broken down into logical series of felling units in order to meet all felling tasks. Daily felling volumes are estimated in advance.
- Logging blocks should provide several days of work for one logging chain. A minimum volume of logging works in one block should range from ca 1000 m^3 in thinning up to 3000 m^3 in main felling. Sound planning will reduce non-productive machine time and movements of machines. The two machines are usually moved to the site together, but the also can be transported individually if needed. Movements along the machine's own axis should not be longer than 20 km. The programme of operations is also affected by machine repairs and staff leaves.

- The machines should be operated only by properly trained persons. Invested costs of training will pay back several times in lower machine operation costs (maintenance, machine work) and in the higher performance of the operator. The initial training of operators may take 6 – 12 months in dependence on their capabilities. Only then a greater chance exists that they will work friendly to the forest environment.
- Following the inspection of stands, the machine operator should select a machine type suitable for the site and stem volume of trees to be felled.
- With the machines working in the stand, emphasis should be put on the zero-damage logging operations.
- Contract price derives from the costs of machine operation and job parameters, i.e. terrain character, stem volumes felled, skidding distance, number of assortments, self-seeding etc.
- For the job to be done in time, it is necessary to decide upon the shift operation of the machine. Two shifts per day are considered a minimum. In Scandinavian countries, three shifts per day are a common pattern with respect to the ergonomic load on the operators.
- Service has to be ensured for small and big repairs on the harvester and forwarder.
- Alternative employment should be assured for machine operators in the case of repairs or harsh weather conditions.

4.2.3 Joint obligations of contractors and machine operators

Tasks to be performed together by the contractor and machine operator are as follows:

- demarcation of lines for the movement of harvester and forwarder in the stand map (1:10 000 or 1:5 000), and/or on a technological sketch or in the digital stand map
- selection of site most suitable for assortment dumps on the truck road and spacing of skidding lines (technological sketch, Fig. 61.); search of sites suitable to store fuels, to park the accompanying car and personal vehicles
- selection of person to be responsible for deployment of machines and site preparation
- to ensure transport of persons in case of accident
- to propose measures on the site in order to protect visitors to forest
- to take over the workplace before and after felling.

The mutual collaboration of contractor and operator of logging and hauling machines should be in the written form, e.g. in the form of handover protocols. Examples of such protocols are presented below:

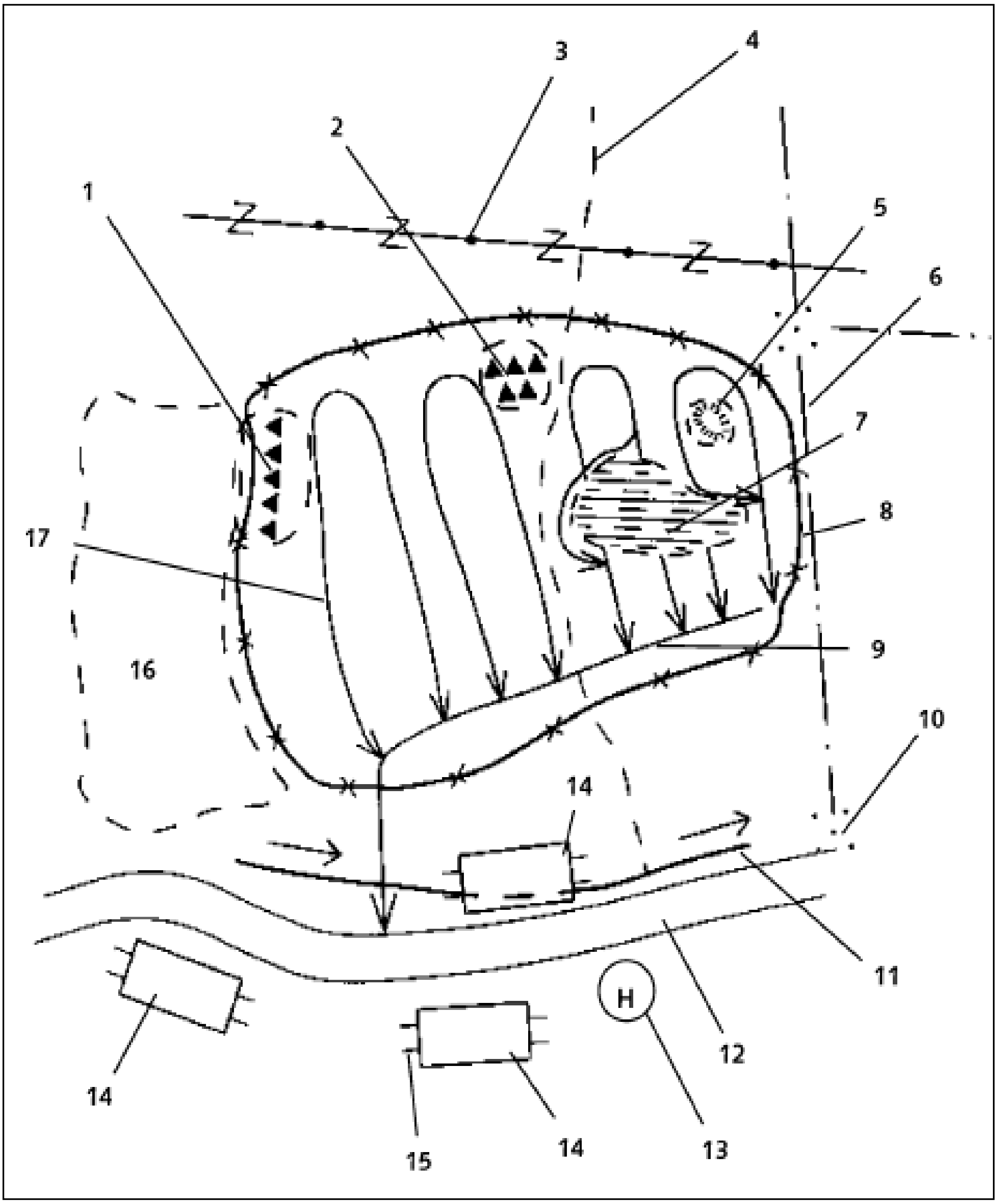
- protocol on workplace handover and takeover (Tab. 8.)
- handover protocol on the performed felling

4.3 Access to forest stands through the system of forest roads

4.3.1 Technological preparation of the stand (workplace)

Research and operational practice of international forestry as well as Czech forestry confirm that access to forest stands is a basic precondition for their management. The main benefit provided by the system of access for timber logging consists in the fact that it mitigates unfavourable conditions for timber skidding following out from the stand density, from the requirement on the measure selectivity, and also from the low stem volume of harvested trees in the intermediate felling. It should be pointed out at the same time that relative economical and zero-damage timber skidding needs preparation before extraction, directional felling or cross-cutting of trees (trunks) before extraction or manual piling of stacked wood and poles.

Prior to logging, it is therefore necessary to prepare the stand (workplace) technologically, to determine transport divisions in the terrain (according to terrain configuration and selected technology), to break down the stand by means of skidding or hauling lines into working fields (in accordance with silvicultural goals and planned technology), to determine a place and area size for timber storage (depending on the logging method), and to determine the direction of felling, skidding and haulage. The technological preparation of the stand has to be performed in time and in a direct link to the chosen technology because the workplace preparation for a certain technology can be only a compromise or entirely inappropriate if another technology is finally used. A part of the technological preparation of the workplace is also technical preparation of the workplace, representing necessary technical modifications of the workplace before proper felling, e.g. local surface reinforcement of lines, treatment of approaches from the lines to landings, etc.



1. Key site - slope
2. Key site – stony soil
3. Above-ground lines
4. Footpath
5. Exposed rock
6. Land borders
7. Marshy ground
8. Stand boundaries for felling
9. Main skidding line
10. Border stone
11. Ditch
12. Truck road
13. Maintenance place
14. Loads
15. Load base
16. Young stand
17. Collection skidding line

Fig. 61. Technological sketch

Protocol on workplace handover and takeover

Comp.:		Age:		Tree species:	
Stand:		Stand density:		Slope:	
Area:		Av. stem volume:		Parent rock:	

<u>Stand preparation</u>

Spacing of skidding lines: [m]

Width of skidding lines: [m]

Minimum height of brash: [cm]

Assumed maximum diameter of cut trunk: [cm]

Acquaintance with the specific features of the workplace (e.g. condition of stand and possible current skidding lines, terrain load bearing capacity etc.):

Provision of first aid:

Schematic technological sketch:

Required assortments
- saw logs:
- aggregate:
- pulpwood:
- other:

Estimated thinning measure: [m^3 / ha] Total: [m^3]

Species	Assortment	Small end diameter over bark [cm]
Spruce		
Pine		
Larch		
Other conifers		
Beech		
Birch		
Other broadleaves		

Remediation of subsoil and damaged trees:

Work start date: Work completion date:

Customer: Work contractor:

Tab. 8. Protocol on workplace handover and takeover

The contact point of road and line is covered with slash to prevent damage to the surface by the turning chassis of the forwarder. Logs lying on the stand edge serve as bumpers to prevent disturbance to the road ditch. **Fig. 62. Extraction line connected to the truck road with the bituminous surface.**

Fig. 63. By temporarily filling the ditch with logs, the harmless passage of machines into and out of the forest is enabled

Principles for the access system construction

Practical insertion of the network of skidding lines into the specific forest stand is affected namely by:

- terrain (relief, gradient, bearing capacity, obstacles)
- existing network of truck roads and location of permanent landings
- development stage of the stand
- hitherto access
- expected technology for the intended felling measure and considered means of mechanisation.

Access system goals

- to provide an even access to the entire stand area
- to allow fast movement of vehicles with as much load as possible in the shortest possible direction to the landing at the roadside
- to allow as high as possible utilisation of technical parameters and technological properties of methods used for efficient work.

4.4 Practical findings

- In large areas without an appropriate network of truck roads, fast transport to greater distances is resolved by secondary strip (slope) roads to which the skidding lines are connected only.
- In cases that a truck road is lined with a high excavation or mound making the technological connection of the stand impossible, a collection skidding line or strip road is routed in parallel to the road, which is opening onto the truck road at a convenient place.
- The pattern of former roads for skidding by horse can be used inside the forest stand only if their parameters comply with current technologies, which is usually only in the flat terrains. In mountain conditions, the old network of roads is better to be abandoned and the same holds for sunken roads.
- At providing access, we take into account an area that is larger than the stand in which the felling will take place. The access to neighbouring stands is useful particularly if they have the same direction of skidding and the same roadside landing (basic production units, blocks).
- The routing of lines in the terrain requires to follow its relief. Although the total terrain inclination may be safe (e.g. as determined from the map or by measuring inclination in the entire slope length), there may be critical points markedly exceeding the inclination. Such places are useful to bypass and provide access to them only by extraction lines.

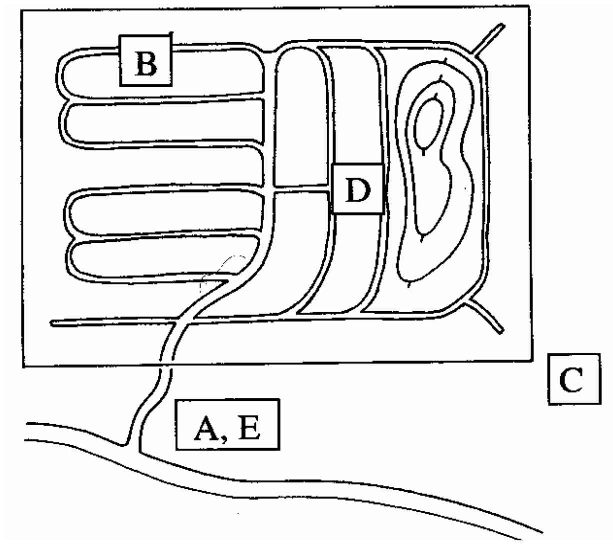
- Insurmountable obstacles in the terrain (poor bearing capacity, rocks, short ad steep terrain faults, deep rills) exceeding technical (or ecological) limits has to be resolved individually. The most common is running a circular line along the edge of unpassable terrain, and the inside of the area is then resolved by extraction lines combined with purely technological facilities (e.g. extraction by cable, combined skidding, extended manual piling etc.). Extraction distance can be longer than usual (2-4 times greater than the length of extracted tree) in these cases.
- If the terrain inclination is up to the lateral operational stability of the vehicle, there are other criteria deciding on the insertion of lines. At inclinations exceeding the limit of vehicle lateral stability, the lines are to be led only along the right angles to the contour.
- Lines that are inserted into the terrain on the limit of permissible cross-slope are to be used only for travelling without the load, if possible.
- The routing of lines in the broken terrain is affected by technical properties of machines and vehicles that may differ. In this respect, the greatest attention should be given to forwarders and tractor-and-trailer units.
- The network of lines for forwarders and tractor-and-trailer units must be interconnected with connecting lines because reversing of tractors and units into the lines is very difficult.
- In most stands situated in tractor terrains, the basic access scheme is enough to provide access into the forest inside.
- In planning the scheme of travels, we make sure that primary extraction is implemented up the slope if possible (labour safety, load control, erosion) and skidding down the slope. Travelling up the slope should be restricted only to travels without the load.
- The developmental stage of the stand and its conditions significantly affect the insertion of access networks. Gaps in the stand (broken canopy) should be used only if corresponding to our intentions.
- Effort to avoid promising trees and their groups is justified only at the late stand age. In younger stands with a high number of individuals, the effort is not substantiated as it always means complications in laying out the lines, accumulation of horizontal breaks of the route, and finally a greater damage to the stand by skidding. This is why the schematic routing of lines can be recommended when dividing the youngest stands and providing access to them wherever allowed by terrain conditions. Linear routing of lines then will suit best even technologies with multi-operational machines.
- The length of skidded timber and technical parameters of machines and vehicles affect details of skidding lines (line width and its extension in the bend). A guideline for the line width is a principle that the line width should equal the width of machine/vehicle increased by min. 0.5 – 1.0 m on each side (by 1 m on each side in assortment forwarders as it is considered that each log extracted to the line has to be pulled out 0.5 m into the line to be able to be loaded by the hydraulic crane without scratching the marginal trees of the line). In the line bends, one has to count with an adequate extension (up to a width of 7 m in timber lengths of 15 m, and up to a width of 10 m for skidding timber of 20 m in length). The line should be similarly extended at places where lateral tilt of vehicle/machine occurs.
- Too much anxiety in selecting the line width and effort to avoid individual trees clearly lead to subsequent considerable damage to marginal trees of the line. (In addition, timber skidding is slowed down and financial costs increase).
- Taking into account that the access system remains preserved up to the stand felling age, it is necessary to count on its use also for only developing technologies. Therefore, LDS parameters should be designed so that they would fit also the future technologies or could be at least adapted to them. It is absolutely unacceptable to make access routes to the stand several times during the rotation period, at all times for another technology which is coincidentally available to the current forest management entity.
- Access to stands that are subject to thinning is a logical and basic precondition for the implementation of any logging technology. Seemingly less logical is then the requirement for access to the youngest stands in which the harvested wood remains unused so far. The movement of workers and machines, as well as organisational and control reasons require however that even these stands are equipped with a perfect access network. The network has

understandingly some different parameters (lines are narrower but their density is higher), but its routing and orientation must be in accordance with the future requirements of technologies in the intermediate felling. When regenerating forest artificially on large areas, a basic access network can be created already at establishing the stand by appropriately selected direction of rows, and choose a spacing for a simple creation of skidding lines in suitable direction by mere schematic harvesting of one or more rows of trees.

- When an access network is created in the youngest stands, a question arises whether the access system would not become obsolete before the stand reaches the felling age. The danger is however not too big because a correctly created access system is based not only on factors that are valid permanently (terrain characteristics, network of truck roads, traffic direction), but also on presumptions of long-term character (prevailing land transport of timber and in fact a final number of timber forms to be transported – trees, raw stems, short logs, chips).
- On larger forest properties, it is useful to have one person for the proposal and laying out of access systems, who is familiar with the technologies of logging and silvicultural activities as well as with the technical parameters and technological characteristics of both used and prospective means and technique of their operation. The concentration of this conceptual work in one person guarantees that the entire area will be treated in a uniform manner. Delegation of the task of access to a wide range of technical persons does not bring the best results.
- A necessary pre-requisite for designing the network of lines is a detailed knowledge of the stand and the goal of the felling measures. During the first errand through the stand, cardinal points have to be marked in the terrain (roadside landing, terrain faults, obstacles, current communications) that will serve at laying out the system of lines. During the proper laying out, the first to be marked are lines whose insertion into the terrain is clear and unchangeable, i.e. mainly those by which we resolve complicated points. Only then the network is complemented with more or less schematic lines to the required density. Attention should be given to all bends, connections and openings of lines in accordance with the direction of skidding, skidded assortments and considered machines/vehicles. It is useful to mark the lines before marking the felling in order to facilitate easy orientation.

Fig. 64. Marking the marginal trees of the line with a tape *is properly visible, the layer of logging residues on the line is sufficient to prevent disturbance of root system in marginal trees*

- The network of lines is marked using the simplest aids (tape line, range-finder, ranging poles, inclinometer, magnetic compass) and temporary marking is made with the use of plastic marking tapes. Only the definitive marking is made using yellow stripes of paint slanting in the skidding direction. The width of the line is fixed by marking the marginal trees of the line with a tape. To prevent an error in the identification of line walls, the tape is bound so that the knot and tape ends face the line inside.



A, E – main hauling road
B – collection hauling road
C – return hauling road
D – connection hauling road

Fig. 65. Distinction of skidding lines

- Workplaces where the movement of timber only along the marked lines is extremely important (regenerated stands, selection system) should be subject to commission transfer including a detailed drawing of the network in the technology card which then serves as a basis for the assessment of subsequent damages in the case of dispute.
- Felling of lines should not be in terms of time separated from the proper felling; it is however necessary to strictly follow flush cutting in the line tracks.
- Concluding we have to emphasize that final results of timber skidding (technical, economic and ecological) depend not only on the access to the forest stand but also on the technical parameters of used machines and vehicles, qualifications of executives and operators of logging and hauling machines, and on the level of forest production management. The result will be always proportional to the weakest link of the chain.

4.5 Skidding lines

Distinction of skidding lines and their functions can be seen in the scheme of Fig. 65. The main hauling line (A) should be able to bear a fully loaded forwarder several times. Collection hauling lines (B) are loops starting and ending in the main hauling line. Return hauling lines (C) are used when loops are not suitable, e.g. in narrow stripes between natural obstacles or near electric lines. Connecting hauling links (D) can be used to connect long collection hauling lines. It is however recommended that their use is given up wherever possible.

High-quality main hauling lines (E) should be used preferably as they can haul timber much faster than common lines. The E-type hauling line is usually a forest road or another road along which timber is forwarded to the landing. Sometimes a repaired seasonal road can be used as an E-type hauling road.

If there is no E-type of hauling line from the felling site to the landing, it would be possible for example to reconstruct a part of the main hauling line to increase timber haulage efficiency. Optimization of the length of collection hauling lines is based on the idea that the forwarder can travel along such a hauling line as many times as possible.

Methods to enhance bearing capacity of lines on less bearing subsoils

Hauling (skidding) lines should be situated on solid ground with corresponding bearing capacity. Logging sites with poor bearing capacity of the subsoil occur in various forms namely as loose and drift sands, wet sands, permanently waterlogged sites, approaches to replacement bridging in inundation areas of watercourses, bottoms of fords, marshy or peaty terrains, deck areas etc. Clayey soils are particularly endangered as they absorb large amounts of water and their bearing capacity becomes problematic during spring and autumn months. Roads on the slopes serve temporarily as drainage troughs and water erosion disturbs their profile.

In practice, a low bearing terrain can be made passable using the following variants:

- Travel route is reinforced with additional materials.
- Treatment will temporarily pave the roadway surface as follows:
  - fascine bundle
  - plastic mobile mats
  - plastic mobile boards
  - reinforcement with rails (recycled construction waste or borrow pit)
  - meshes (old used fences as a bottom layer into rails)
  - grates from logging residues
- Technical measures used on machines (low-pressure tyres, tracks, caterpillars)

Extent of area reinforcement depends mainly on:

- machine axle pressures
- road construction and stiffness
- mechanical and physical properties of the terrain
- required number of machine passes.

Slash which is left behind the harvester increases the bearing capacity of the skidding line. A slash layer of 35 – 40 cm in height (after compression) is already capable of reducing soil compaction on the line. Waterlogged and low-bearing subsoils can be also reinforced using bark or chips. The material is suitable for peaty soils, too, provided that correct technological procedures are used. The choice of other materials for subsoil reinforcement is affected by the delivery distance.

4.6 Marking of the felling measures

Harvester operators often work under conditions of certain stress which can be induced by climatic, natural and technical factors. Their work can be made easier especially by the correct marking of trees and lines, which is an obligation of the forest owner. The marking is made with reflective spray colours (orange, yellow, light green). The marking of lines, trees for felling and promising individuals should be distinguished. From the harvester operator's point of view, the most advantageous method of marking is taping.

In principle, the marking of lines should be always made by the responsible forester after a possible consultation with the operator to be in charge of the measure. Marks on the trees may even be different, according to practice used by the forest owner.

Marking of the lines

A line is marked from its connection to the truck road towards the stand. The tree is marked with a longitudinal oblique line or arrow giving the direction of timber movement from the stand by forwarder. Marking can be made also with plastic, nature-friendly tapes which weather within a year and fall. Tapes have an advantage that they can be seen from all sides. In the youngest thinning stands, tapes are hung vertically so that the future line is clearly visible in the terrain both to technical workers and for harvester operators at felling.

The line is delimited by means of three ranging rods, tape line and compass. The effort is to have the line straight, and only in exceptional cases the lines can be running in bends (sloping terrain – limited impact of later erosion). If the parallel character of lines is measured only at the beginning and is later checked only visually, the spacing usually becomes narrower after some 100 m. The line width is measured as a distance of its margins. The spacing of lines is measured either from the line axis or by the width of intermediate zone. If the line is narrowed due to an obstacle, it is preferred to remove one tree more than to restrict the movement of harvester or forwarder.

The experience indicates that the marking of lines per 1 ha of stand takes 1.5- 2.5 hours, according to stand density. Timber hauling from the stand to the deck at the roadside landing should not be planned along a distance longer than 200-250 m, otherwise the share of travel times is too high.

Marking of the trees

Trees to be felled are marked with at least two dots of ca. 7 cm in diameter (at a height of about l.20 m, located on the opposite sides of trunk), perpendicularly to the line, or with a transverse line long about 1/3 of trunk circumference (less appropriate, poor visibility from both lines). In high density stands, spray bars can be used (e.g. Sterzik type). Promising trees (which are not commonly marked in the Czech Republic so far) are best marked with a tape (disintegrating plastic material) which is properly visible from all sides.

4.7 Selection of the season for logging by harvesters

If the stand size suffices for several days of felling only, it does not have to be divided into blocks. At planning for more than several days of felling, stands have to be divided into blocks: for a so-called moist (usually summer) season and a dry (usually winter) season of the year. The stand is broken down into the blocks in cases that the felling season, felling method or structure of timber assortments are changed. In stands or felling blocks singled out for the moist period, prescribed improvement felling or main felling is supposed in localities where low damage to the soil can be expected. Areas on sites that are highly risky in terms of damage to trees and soil during the moist season of the year are therefore classified into blocks and intended to be felled during the dry (winter) period when the bearing capacity of the soil is expected to be increased due to reduced moisture content or freezing. Felling on steep slopes should be avoided during moist periods because of the risk of erosion damage. Stands or felling blocks intended to be felled in the dry period can be felled only if the soil is without excessive moisture and its bearing capacity is sufficiently high. Sites in stands or blocks of dry season include tree species susceptible to damage by logging, e.g. by the mechanical damage to trunk.

Planning of felling should take into account current weather changes. A long and moist autumn can delay the dry (winter) season of thinning stands. In this case, timber should be harvested from the standby stands determined for felling also in more difficult climatic conditions.

4.8 Determining the need for machines and time sequence of their deployment

Managers of the operation of logging and hauling machines should be able to estimate actual monthly felling volume according to stands in the given area, and to find out existing requirements of customers according to various assortments, and subsequently to calculate the need for machines. Detailed and accurate inventory of data on the parameters of logging units, e.g. ratio of main felling and thinning, is very important for a precise estimate of the need for machines. Imperfect planning causes among other things financial losses both to the machine operator and to the customer (e.g. late delivery of the required volume of certain assortments).

Large machines for the main felling should not be used in improvement measures, particularly not in the first thinning as the ratio of their productivity and costs is never cost-effective in such cases. Also, damage to young stands by large logging machines and damage to the site are undesirable consequences of the wrong choice of machines. Therefore, the planning of machines required for prevailing situations should take into consideration the following factors:

- technical feasibility (correct size of the machine)
- economic feasibility (machine performance relation to total investment costs of the machine)
- social acceptability (whether the mechanised felling is a good alternative for the given site).

Determination of the required number of machines, their deployment in time (sequence) as well as economic parameters are based on the technical and economic parameters of specific machine types working in expected natural and production conditions.

5. Felling and forwarding of timber by logging and hauling machines

5.1 Occupational safety principles

Occupational safety and health protection (OSH) must be understood as an integral part of the production process and its principles must be observed by all its participants. The employer is responsible for health and safety of the staff and must adopt all possible measures to minimise the risk of damage to health or property. Prevention is the crucial approach to the issues of occupational safety;

therefore detection, elimination or mitigation of workers' occupational hazards is one of the basic tasks of the employer. Amongst other things, the employer is obliged to ensure adequate professional and occupational health and safety training for the employees, so that the employees may know correct work procedures, the maintenance and repair plan and general OHS guidelines. The employer is responsible for using correct work procedures, is obliged to provide work clothing, protective work equipment, first aid equipment, etc. The employee is obliged to use the work clothing and the protective work equipment.

The safety principles are legally binding and can be included in the documents of the contract between the employer and the worker, as well as in the contract between the supplier and the contracting authority. To work with a harvester or a forwarder, the operator must have a driver's license of group T, a driver's license for operating the hydraulic crane, and must pass a training course organised by the machine supplier, where the operator is familiarised with the machine operation and maintenance.

In the case of mechanised timber logging, prior to deploying the means of mechanisation for timber harvesting, the workplace must be prepared as follows: the stands must be divided, the number and direction of skidding lines for timber logging and the corresponding handling and storage areas, including their marking, must be determined; at the same time, stability of the means of mechanisation for timber logging must be ensured. When more methods of mechanisation for timber logging are deployed at one workplace, their operation must be coordinated.

When using a machine for timber logging, a danger area is understood to be a circular area with the radius of at least twice the height of the felled tree, increased by the length of the machine arm.

There are two health risks when working with a logging and hauling machine: physical risk, caused by the machine itself, and mental risk, which is of human origin. Physical risks are minimised by harvester technologies compared to motor-manual logging. Most injuries occur during the maintenance and repairs, when entering or exiting the machine cabin. Safety boots, anti-slip surfaces and functional handrails reduce the risk of injuries. Falling is one of the most common causes of injury. When getting on or off the machine, it is always necessary to keep contact with the steps and the handrail in three points, to be facing the machine and not to use control elements as grips. Always keep the floor, steps and walking surfaces clean, free of oil, ice, mud and loose objects. There are also significant risks resulting from increased psychical demands due to the necessity for high accuracy of labour, permanent concentration and monotonous work, feeling of loneliness, working in dim or dark, etc. Therefore, the care for the mental health of workers should become an important task for the managers of owners of the logging and hauling machines. All these aspects should be taken into account in the planning stage of the production process, together with aspects related to the technique of timber logging and hauling.

Prior to starting work on a new site, machine operators should receive map documents and written work instructions from the forestry company responsible for the logging area and should become familiarised physically with the stand. All dangerous zones should be clearly marked on the map and also directly in the forest, e.g. power lines, soft unbearable soil or steep terrain, roads and recreational trails. Recommendations concerning suitability of hauling roads should also be marked on the map, as good driving technique and optimal load size reduce the risk of an accident in difficult terrains and improve performance parameters. Prior to starting the work, it is necessary to make sure that the necessary warning symbols are in appropriate places, both in the forest and on the machines. It is important to keep a safe distance between the working machines. In practice, the safe distance means at least two - tree lengths plus the length of hydraulic crane boom reach, but at least 90 m from the harvester and 70 m from the forwarder. During the operation, other persons may be neither inside the safety zone of the machine nor in the cabin. A sudden change in the direction of the falling felled tree or break and ejection of the saw chain of the harvester head represents a danger for persons staying at the workplace of the logging and hauling machines.

Timber storage areas and hauling roads should not be situated near power lines. Lines that must be situated under them should be marked clearly on the map and on the site, and these obstacles must be visible even during the operation at night. Minimum distance of the forwarder (hydraulic crane) from the power line is three meters for voltages of 1 to 50 kV and five meters for voltages of 50 kV and more. If the machine comes into contact with the power line and the engine is running, it is safer to stay in the cabin and back out. The unloading should be planned so that the forwarders can move and stack the wood without driving the load on public roads. When unloading, the forwarders should be able to move from one storage edge to the opposite one without any problems. There should therefore be enough space and adequate visibility provided.

Prior to work start, the new operator should read the harvester manual, become familiar with the safety guidelines and the daily maintenance schedule. It is essential to know the layout and method of using all safety features of the machine. The emergency button stops the machine, terminates all functions and activates the parking brake. It is usually located on the side control panel in the operator's cabin. If the cabin door is open, the door safety switch shuts off the basic machine functions. The central warning light and a buzzer signal alarm in case of acute malfunctions. Every cabin is equipped by law with an emergency exit and a first aid kit. It is forbidden to use a device containing a radio transmitter (e.g. a mobile phone) in the cabin, when the antenna of which is located inside the cabin. Such equipment must be permanently installed in a proper manner with an antenna on a suitable grounded plate outside the cab.

Machine operators should always perform difficult maintenance work and repairs together. Machine engines should be switched off during the maintenance and repairs. For greater safety of servicing, it is necessary to use safety devices such as the central steering lock or the cab lift lock mechanism. Pressure can remain in the hydraulic systems long after the engine and the pump have been shut down. Use work gloves and a piece of cardboard or wood to locate the leak. Never search for a possible leak with bare hands.

Due to the risk of fire, the areas for machine maintenance should not be located near timber stacks. As an integral part of fire and explosion prevention, it is necessary to observe the following principles. Keep the machine clean, and inspect and clean all closed spaces. Remove dust and small logging residues especially from around the exhaust pipe, clean the cooler grid and the cooling pipe regularly. Check the condition of electric cables and connectors, as well as the condition of the fuel lines and the hydraulic system. Remove any excess grease and oil, find out causes of their leakage and repair them immediately. Store cleaning rags on a safe place where they cannot be ignited. Store flammable materials outside the areas with a risk of fire. Do not burn or puncture pressure vessels. Before starting repairs, such as welding, it is necessary to clean surroundings around the welded area. Always have a fire extinguisher ready for use (located in the operator's cabin or in the box near the engine part of the machine. An automatic fire extinguishing system with sensors located in the engine part of the machine is an important fire preventing element.

Fig. 66. Location of emergency button on the side control panel (No. 10)

Fig. 67. Door safety switch (A)

In urgent cases related to accidents or machine malfunctions, clear information must be given to the appointed person, and the arisen situation must be resolved immediately and prudently. All operators should know the basics of first aid. A previously common trauma plan is still maintained on some forest properties. It is a system of contact points in the field (mostly intersections of hauling roads or stacks), which are characterised by GPS coordinates, availability for individual rescue means, etc. The operator, contracting authority and units of the rescue system have a detailed map of these points in the field at their disposal. In case of an accident, it is enough for the affected entity to report only the number of the contact point where the affected entity is located or which it is heading for.

Cabins of harvesters and forwarders are adapted and approved for one person only, the operator's seat is equipped with a safety belt, which has to be used. When driving the machine on a public road, it is necessary to ensure that the machine is equipped properly for this purpose (front and rear running lights, side mirrors, direction indicators, reversing lights and a warning triangle for slow-moving vehicles). When driving on public roads, it is permitted to use neither the tracked wheels nor the anti-skid chains due to the risk of damage to the road. When driving, or when transporting the machine on a semi-trailer, it is necessary to consider total height of the vehicle, e.g. in the case of bridges, overpasses or tunnels. During transport, the hydraulic crane and head of the harvester or the grapple of the forwarder must be secured in the transport position. Avoid driving and parking on frozen water areas. For reversing, the machines are equipped with the reversing alarm.

5.2 Work shift organisation

Planning of the shift schedule shall be an integral part of the planning of logging measure, because it is linked to the logging plan in connection with the schedule of wood deliveries to buyers. However, the shifts can be adjusted operatively during the operation, as need be.

Long work shifts are mentally and physically exhausting for the machine operators. The operators are also exposed to a great deal of social isolation during the long shifts in weekly work cycles. The operator's work requires great precision and many quick decisions. Therefore, the operator can be recommended to get out of the machine cabin from time to time and take a short personal walk in the stand to familiarise himself with its specific features and think through the next detailed progress of work. The operator can thus relax mentally, specify the next progress and can continue working.

Under normal conditions, the logging and hauling machines work in one- or two-shift mode with the shift duration from 8-10 hours. During the two-shift operation, approximately 1 hour is reserved for taking over the machine by the incoming operator and, if necessary, for common maintenance of the machine. This allows the operators to share information about the progress of production, machine problems, etc.

If the works are performed in the classic two-shift mode, two operators work in each shift (one on the harvester and the other one on the forwarder). The morning shift works, for example, from 6:00 a.m. till 3:00 p.m. and the afternoon shift from 1:00 p.m. till 10:00 p.m. The time from 1:00 p.m. till 3:00 p.m. is reserved for both morning shift operators and both afternoon shift operators for maintenance, handover of the machine and workplace, and for lunch. The work teams change the shift order weekly.

work 7 h	maintenance 1 h	food 1 h	**operator 1**
operator 2	maintenance 1 h	food 1 h	work 7 h

Tab. 9. Two-shift work system for one machine

The split shift system is almost identical to the system developed in Canada. Compared to the previous shift system, breakdown of the work into two time-separated cycles brings a lower health and psychical burden for the operator and thus increased safety of labour. The first operator starts his 11-hour shift at 5:00 a.m. instead of 6:00 a.m. This allows the second operator (starting after him) to finish work already at 8:00 p.m. and not at 9:00 p.m. The shift allows the first operator to do felling for 4 hours, when his working abilities are at their best. Then he has a one-hour meal break. By that time, the second operator already starts his workday with a three-hour shift on the same machine.

<table>
<tr><td>work 4 h</td><td>food 1 h</td><td>non-harvesting work 2 h</td><td>maintenance 1 h</td><td colspan="2">work 3 h</td><td>operator 1</td></tr>
<tr><td>operator 2</td><td colspan="2">work 3 h</td><td>maintenance 1 h</td><td>food 1 h</td><td>non-harvesting work 2 h</td><td>work 4 h</td></tr>
</table>

Tab. 10. Split work shift system

After the meal, the first operator spends two hours for instance by grinding saw chains or other maintenance work, or by performing various tasks such as marking sorted wood at the stack, walking to the next block to schedule the next harvesting, etc. After the second operator's 3-hour shift, both operators perform maintenance on the harvester for one hour, followed by a second operator's meal break, while the first operator continues his shift with 3 hours of logging, allowing him to end his shift at 4:00 p.m. After the meal, the second operator performs “non-logging activities” for 2 hours and then ends his work day with 4 hours of logging activity, ending at 8:00 p.m.

It is necessary to respect the fact that night work is generally by 30-50% less productive than day work, because in the dark, especially during the thinning operations, it is much more difficult for the operator to follow the trees and make decisions. At night, it is also necessary to consider longer time consumption for storing assortments into stacks at the roadside landing. Therefore, unless absolutely necessary, night shifts are not organised.

5.3 Harvester work procedures

Before starting a new job order, it is necessary, upon agreement with the contracting authority, to enter into the measuring harvester system the structure of tree species, manufactured assortments, limit lengths and diameters, oversize allowance, etc. Instructions for execution of the work, technological maps, identification of the stand boundaries, etc., all this has to be agreed in advance on the spot. The operator must familiarise himself with the complete information.

When producing assortments of quality classes I to IV, the following rules shall apply, unless the supplier and customer agree otherwise:

- remove branches and their residues (knots) in the plane of the trunk surface
- align the log butt end perpendicularly to the longitudinal axis of the log
- remove irregularities created during harvesting (keys, chips, torn fibres, etc.)
- remove buttresses so that their height above the round surface may not exceed 3 cm
- remove visible foreign bodies
- log butt ends may not be dirty, covered by snow, ice, etc. for good visibility of defects (note: in case of delivery of the wood with the butt ends coloured due to aging - oxidation, when some defects may not be distinguishable, it is advisable to include in the contract the requirement for cutting butt ends by a fresh cut)
- production of logs of combined qualities is possible upon agreement between the supplier and the customer.

The machine should always be positioned so that as many trees as possible are felled from one location before the machine is moved to the next position. At first, the safest tree felling is as close to the machine as possible. For a beginner, it is always safer to fell the trees on the left or on the right side, depending on the direction of travel, at an angle of 45 to 90 degrees. This will reduce the risk of trees falling on the machine due to the operator’s error or failure during harvesting. Delimbing takes place in the middle of the forwarding line in front of the machine. If the trees to be felled are at a distance greater than about 4 m from the machine, they are delimbed in the stand and the logs are stored as close as possible to the line. The operator should avoid placing the brash on the butts (stems) of trees that will be harvested later. Brash reduces visibility, which can result in damage to the harvester head and the trees standing around that are not intended for harvesting.

The trees on or near the forwarding line are harvested at first to increase the space for handling the felled trees, the trees farther away are felled afterwards. Pulling the trees with a higher stem volume just by moving the harvester pull-through head rollers has to be restricted. Poor stacking of assortments along the line means reduction of performance of the forwarder. The logs should be arranged in parallel to each other, differentiated according to their belonging to the assortment classes, and piles of wood should not be created close to the forwarding line, because it is difficult for the operator of the forwarder to load wood stored in this way. The processed wood should not be stored against the standing trees, as further handling would thus be much more difficult and complex.

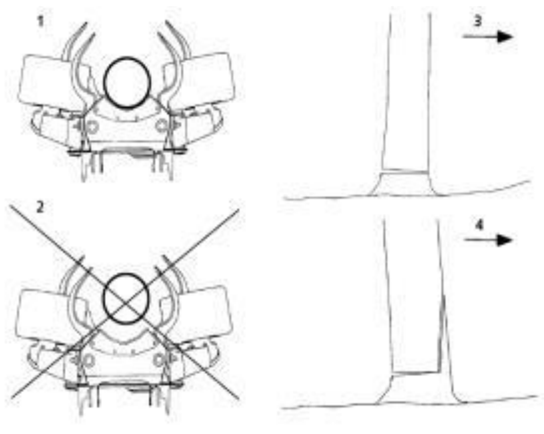
Whenever possible, the operator should position the harvester head so that he could see the guide bar moving toward him when felling. Work of an experienced operator is characterised by smooth transition from driving to grabbing the tree, its processing and placement of logs.

Felling, delimbing and cross-cutting
The basic principle when harvesting is that felling is performed towards the inside of the harvested stand. The factors that affect where felling should begin in the logging unit are as follows: layout of stacks, character of the terrain, roads, power lines, boundaries, ditches, watercourses, prevailing wind direction, areas of the stands that should not be harvested, etc. When felling trees, the operator should always consider the prevailing wind direction. If possible, the operator should always cut in the direction of the wind and not against it. When felling, the effort should be to create the lowest possible stumps. The separation cut should be made immediately above the highest buttress, namely in such a way that breaks and cracks at the site of the cut are avoided. The harvester head should be seated close to the trunk of the felled tree.

In trees with the diameter corresponding to the parameters of the relevant harvester head, the tree felling requires just a single cut. At first, the head is seated onto the tree trunk and centred. The cutting height is then set, the tree trunk is clamped tightly with the delimbing knives, and the operator issues a command to the cutting system to make the main cut for separating the tree from the stump. After cutting, the crane pulls the log from the stump. In larger trees, more than one main cut may be needed to separate the tree from the stump. If the head must be moved to make a second cut, the operator should place it at the same level or preferably a little bit higher. The second cut may never be made below the level of the first cut. If the main cut is made, the stem must always be cut continually until the entire stem profile is cut through, because if the cut is terminated prematurely, then the stem may crack at the butt end and the first log is thus devalued.

No hydraulic crane function may be performed while the tree is being cut. However, trees with a higher stem volume can be pre-tensioned a little by moving the main arm of the crane slightly upwards before felling. When the main cut is complete, the tree should not be lifted by the harvester, but instead it should be pulled by a short distance away from the stump to the side opposite of the felling direction. The result is that the centre of gravity of the tree is shifted and the tree begins to fall in the desired direction. It is very important not to lift the tree by means of the harvester, especially in the case of large trees. Otherwise, the stem slips inside the head and the cutting bar can be easily damaged.

On slopes, it is always advisable to start at the bottom (at the foot) of the slope. The direction of travel of the machine is therefore uphill (upwards). The trees are felled so that their tops fall upwards in the direction from the machine. The trees are then hauled downslope (downhill) for processing, with gravity facilitating their delimbing. When felling on a slope, the height of the cut is set so that cutting the trunk may not reach the ground.



1 – correct 2 – incorrect, 3, 4 – direction of felling
Fig. 68. Details of felling with the harvester head

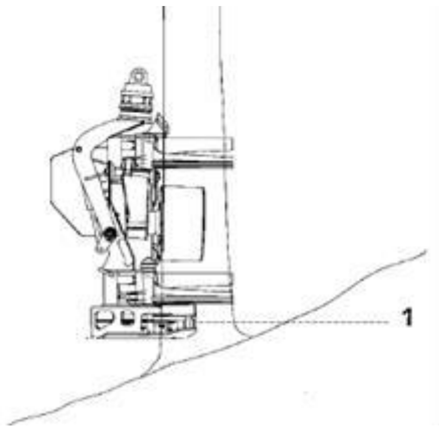
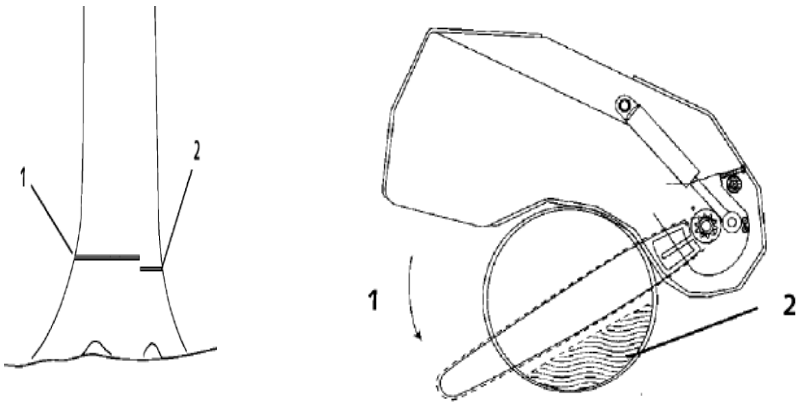


Fig. 69. Correct cutting height (1) when felling on the slope

One of the methods for felling trees with large buttresses is to make a directional cut. The cut is made in the direction in which the stem is to be felled. The harvester head is then rotated round the stem and the stem is cut off. If the head does not rotate round the stem sufficiently, the stem profile will not be cut through and the stem will not fall in the desired direction.

During the time when the tree falls to the ground during felling, its movement in the harvester head for the purpose of delimbing can already be started. Advantage of this operation consists in the fact that delimbing is made easier, as the own weight of the tree contributes to its pulling through the harvester head. During this procedure, after the tree has fallen to the ground, the first log is already cut. This procedure requires some experience, but can be applied without any problem after a relatively short period of practice.



1 – main cut, 2 – directional cut
Fig. 70. Making directional and main cut with the harvester

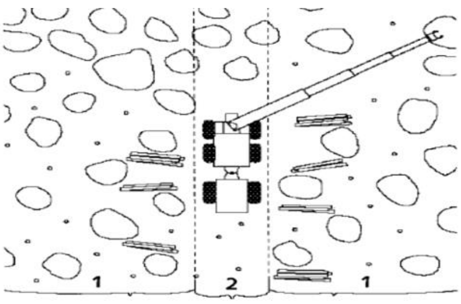
When cutting the logs and moving the stem, the head must be as close to the ground as possible, but the feed rollers must not rub against the stones, for example. When cross-cutting, it is advisable to lean the stem against the surface of the ground in order to prevent the formation of cracks and breaks on the stem, especially in the case of higher stem volumes. If the small end of the log points downwards, the grapple should not be held too high, as this would induce a heavy load on the hydraulic crane boom and the grapple. There is also a risk that the tree stem will break when it falls to the ground.

If the tree is branched heavily or if the branches are thick, the movement functions of the hydraulic crane can be used to improve the delimbing performance (pulling force of the rollers). The pre-limbing length can also be set in the harvester computer, making it easier to start movement of the following log.

Work procedures in improvement felling
Work procedures of improvement felling, using the harvesters, can have several variants. These variants are mainly dependent on the density of the forwarding lines that are available (or that can be created during the progressing work).

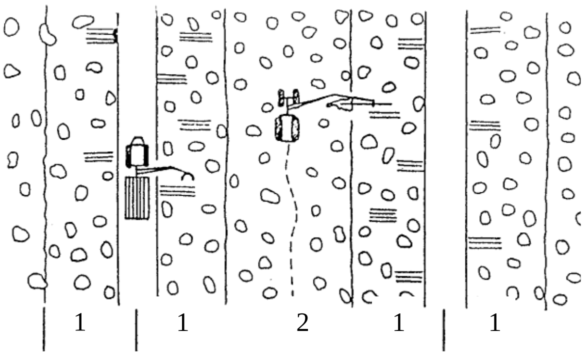
A. Improvement felling performed only by harvester with the subsequent forwarding by forwarder
In the first modification of this method, the harvester drives strictly only along the forwarding lines. It is assumed that the width of working fields will be roughly twice the maximum reach of the harvester crane boom, i.e. the spacing between parallel lines will be approx. 20 m. The forwarding line is cut down first. Trees will be delimbed on the forwarding line and the roadway or its sections (less load-bearing places) will be covered with brash. Buttresses of trees and roots that can be damaged easily are also covered with brash. If necessary, the brash is spread, using the harvester head, on the necessary places of the line. The forwarding line width should be about 4 meters. Trees are processed preferentially on the forwarding line and logs are stored on its opposite side, namely perpendicularly to it. To minimise the back-and-forth travel of the machine, the trees can be felled alternately on the right and left side of the line. Direction of felling the trees and storing the produced assortments should be determined with regard to the subsequent selection of assortments from the piles and their loading on the forwarder. Small trees at the outer limit of the reach of hydraulic crane boom are best processed on the forwarding line (the obtained brash is preferably used as coverage on the forwarding line).

In the second modification of this method, the harvester moves along the forwarding lines, and in the axial line of the working field. It is assumed that the width of the working fields will be greater than twice the maximum reach of the harvester crane boom, i.e. that the spacing of parallel lines will be approx. 30-35 m. It is also assumed that the spacing of trees in the axis of the field is sufficient for passage of the harvester or that an auxiliary line is cut through (in this case it does not need to be exactly straight, the machine can use suitable gaps in the stand). The produced wood is stored by the harvester in a standard way along the actual forwarding lines. If possible, the harvester will process timber in the axis of the field at first and places it in direction towards the line (alternatively, it just cuts and places the trees towards the line in the reach zone of the crane boom). This modification cannot be recommended for normal use, as it is complicated, with reduced performance and requires the harvester to drive mainly across the stand area.



1- harvester reach, 2- line width 3.5 – 4.0 m

Fig. 71. Thinning with the harvester– travel only on lines



1- zones within reach of the harvester from the line, 2 – zone processed by travelling in the field axis

Fig. 72. Thinning with the harvester– travel on lines and in the axis of the working field

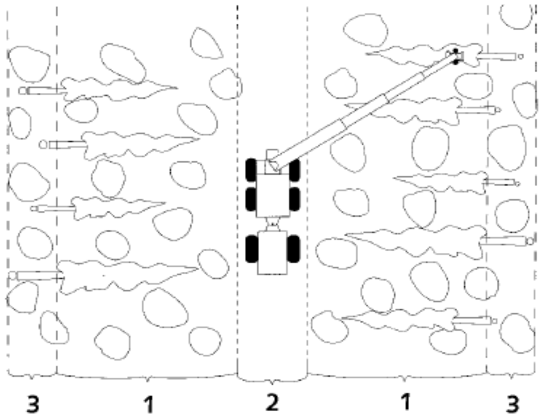
B. Improvement felling with a combined technology (harvester and power saw)
The work group consists of harvester operator, forwarder operator and woodcutter. Advantage of this method is that trunks of large stem volume are cut towards the forwarding line with a power saw and can be further processed with a harvester. The method has been also proven in steep terrains, or if the forwarding line lies at a greater distance from the other one (width of the field is significantly greater than twice the reach of the harvester crane).

At first, the harvester works on the forwarding line within the reach of the hydraulic crane. The power saw may not be used for felling until the harvester is at a safe distance. After the parts of the working fields within the reach of the harvester have been felled, the motor-manual felling of the trees on the far side of the working field(s) is started. There must be an effort to cut the trees with the power saw perpendicularly to the forwarding line. Felling the trees in a group should be avoided, as it increases damage when the harvester brings them down, making it difficult to grab individual stems. The risk of stem break is also increased. As soon as the manual measure is completed, the manually felled and otherwise unprocessed trees can be processed by the harvester. If the manually felled trees are to be cut to regular lengths, the harvester head should return to the buttresses and perform a flush cut so that the machine can process the tree from the correct direction. In case of a sufficient length of the felling site, every other forwarding line can be felled manually using the power saw.

In rare cases, when the working field is extremely wide, this technology can be supplemented with a conventional skidding device (winch), which is used to pull whole trees felled with the power saw into the reach of the harvester. However, this modification significantly reduces the overall performance. An overview of individual technological variants of improvement felling can be seen in Tab. 11.

C. Improvement felling in broadleaved stands
Logging by harvester when thinning broadleaves (e.g. beech) is possible with some restrictions. Harvester facilitates a timely, correctly performed and economically acceptable measure. Damage to standing trees is reduced is case of conscientious work compared to the motor-manual technologies. It is necessary to use stronger machines (higher weight of trees). To overcome irregularities on the trunk, it is advisable to use harvester heads with 4 feed rollers and a shorter basic frame. Nevertheless,

problems with cutting the overgrown branches are possible. The date of the measure must be chosen only and exclusively in the period outside the growing season. Despite high investment costs, the technology of improvement felling by harvesters in broadleaved stands is more effective than the motor-manual harvesting (Erler, 2002). The technical productivity of labour depends mainly on the stem volume, tree species, branching, intensity of thinning, volume of fallen unusable dendromass (wooden matter), sorting, terrain conditions, layout of the stand and skills of the operator.



1- harvester reach, 2- line width 3.5 – 4.0 m, 3- area of manual felling

Fig. 73. Work procedure when thinning with harvester and power saw

Opera-tion	Spacing of forwarding lines		
	small – 20 m	**medium – up to 35 m**	**large – up to 45 m**
1.	tree processing on the line and in the boom zone along the line	tree processing on the line and in the boom zone along the line	tree processing on the line and in the boom zone along the line
2.	wood forwarding	a) inter-zone processing by harvester *) b) motor-manual processing of the inter-zone (additional felling of trees), and/or tree skidding from the inter-zone *)	motor-manual additional felling of trees in the inter-zone
3.		processing of additionally felled trees	cable skidding from the inter-zone to the boom zone
4.		wood forwarding	processing of additionally felled trees
5.			wood forwarding

Tab. 11. Examples of the composition of technological variants using harvesters in improvement felling
*alternatively (Erler, 2002)

Tree parameter		Time consumption (min/tree)		Productivity (m^3/h)	
$d_{1,3}$ (cm)	stem volume (m^3)	straight trees	forked trees	straight trees	forked trees
10	0.07	0.8	1.3	5.6	3.3
20	0.31	1.2	1.8	15.3	10.3
30	0.88	2.5	3.5	20.7	15.1
40	1.55	4.8	6.4	20.0	14.6

Tab. 12. Example of performance and cost parameters in beech thinning (Erler, 2002) Share of duration of individual operations: vehicle passages 10.3%, placement 9.5%, felling 19.5%, tree processing 60.7%.

The workflow when processing forked trees is as follows; normal delimbing up to the first fork, delimbing is then stopped and the stem is cut through. Re-gripping and re-grabbing the tree above the fork and continuation in the tree processing. After successful delimbing of one part of the fork - cutting away, re-gripping and finishing the other part of the fork.

Work procedures in main felling

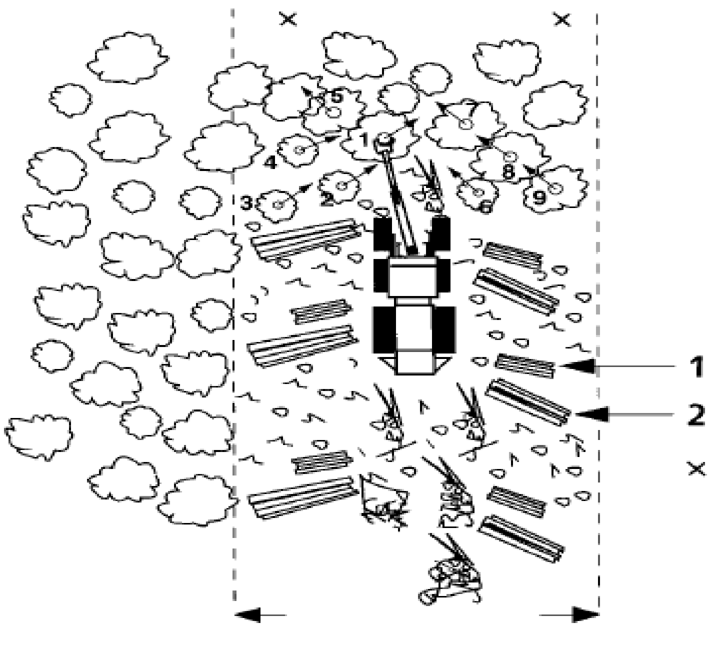
In the main felling, it is sometimes better to cut down the tree in the direction to in front of you, away from the machine. Delimbing then takes place on the forwarding line immediately in front of the machine. Advantage of this is that defects on the stem, such as curvature or rotten spots, can be detected much more easily than when felling on the sides of the machine. In regeneration felling, if the terrain allows, the principle is to fell a strip 8-12 m wide and process it directly in one harvester run.

When the logging site is opened in the direction of marking, the felling will be directed to the stand inside, as well as in the case of younger stands, near power lines, etc. Furthermore, this method will be preferred when the stems are of large diameters or where a side wind prevails. By applying this method, we get a felled area, in which the machine can work. The trees are felled in the direction away from the work site, especially if they stay on the edge of the stand and if there is a risk of stand damage.

In dense stands, felling only in one direction is more practical. However, when felling trees on both sides, movements of the hydraulic crane are reduced. At first, trees are felled left from the central line of the work zone and then right. Unnecessary movements of the hydraulic crane can thus be avoided. Using this method, the brash remains on the forwarding line, the load capacity of which is thus improved. The wood should be placed diagonally to the machine. Brash and the top parts of the tree crowns are thus not mixed into the piles of logs placed on the opposite side. Distant trees of high stem volume, weight of which is at the limit of the load capacity of hydraulic crane at its maximum reach, can be left for the next logging procedure, when the machine can travel closer to the given tree and cut it down at a more favourable distance in terms of the boom load capacity.

Work procedures in salvage felling

Salvage logging, caused by climatic impacts, i.e. mainly by wind and snow, is currently gaining importance both in the Czech Republic and in other European countries, both as to the frequency of their occurrence and volume of the harvested timber. To solve the tasks of salvage felling, standard technological procedures, proven over the years and based on motor-manual labour, are available. These conventional technological procedures are extended by new technological variants utilising logging and hauling machines, especially harvesters and forwarders. For the management of forest operations, it is always a difficult task to choose the most suitable work procedure from a large number of options. Moreover, there are also procedures and techniques that have not been applied yet in the given forestry region and for which own experience does not exist yet. The adopted decisions almost always represent a compromise between operational goals, safety of labour and ergonomics, between the care and quality of performed works, as well as profitability of production.



1. Pulp wood, 2. Round timber

Fig. 74. Two-sided felling and system of log placement in main felling

Too much haste in felling stands affected by disaster is undesirable. It is necessary to design a well-founded strategy very responsibly, assess the current situation continuously and respond to it by adopting appropriate measures. As early as when suitable procedures for dealing with a disaster are decided upon, we must take into account the strategy for forest regeneration. In particular, felling with the use of harvester reduces the need for later skidding of the areas, because brash has already been concentrated on or near the skidding trails. Total costs of the measures associated with logging must be taken into account. For example, logging with the forest cableway is more expensive, but more environmentally friendly which, in the longer time horizon, can reduce the costs for after-logging site treatment, road maintenance, etc.

When deciding on the choice of a certain technological and work procedure, requirements for safety of labour must have priority. In salvage felling, advantages of harvesters are clearly highlighted as these machines are more efficient and safer when deployed in salvage felling, compared to conventional methods. One of the basic attributes of harvester logging technologies consists in avoiding the direct contact of workers with harvested trees and timber. In the Federal Republic of Germany, this effort to reduce the risk of injury to the workers caused by harvested timber after salvage felling is expressed by the principle: "*Neither hand on wood, nor foot on soil*", which can be unquestionably agreed upon also in our conditions.

Progress of logging works in stands affected by disaster is usually faster than expected. For highly mechanised processes, we can count on the performance of 250 or more cubic meters per day. The speed of processing a disaster depends on wood haulage. Especially in sloping locations, only limited capacities are available on roadside landings. Continual wood hauling is therefore desirable. However, forest logging roads are often not designed for such a high traffic load. Therefore, it is necessary to plan their continual maintenance.

Technological procedures are not determined by the contractor, but rather by the owner or administrator of the forest property (forest company). The often-used statement "*there is no other way*" cannot be accepted by the forest company without proper justification. Therefore, the forest staff must have adequate knowledge for the relevant decisions and, if necessary, turn to more creative contractors. Before concluding a contract for salvage felling, it is necessary to familiarise work suppliers in greater details with the required technological procedures and standards of quality, measurement and wood records. The contractor is obliged to use only the machines specified in the quotation and confirmed in the contract or comparable machines. Not every machine is equally suitable for use in certain conditions. Insufficiently dimensioned logging machines (with small lateral reach and carrying capacity) encourage the contractors to move the machines outside the specified areas, accessible by the lines. When choosing the machines then, when in doubt, it is always necessary to decide in favour of a more powerful machine class.

Even when using harvesters, the framework procedure of salvage felling has to be adhered to, the deployment of harvesters is only one of several activities that have to be performed after a disaster:

- acquire map documents and locate the affected areas, find out numerical data about the amount, structure and location of damaged wood
- analyse terrain conditions and accessibility of territorial units and stands
- choose the optimum disaster processing technologies with regard to the extent, location, structure of affected stands, after-felling treatment and rehabilitation of areas affected by the disaster
- propose measures to suppress the development of insect pests
- elaborate a proposal for regeneration of clearings arisen due to salvage felling
- solve the storage of harvested wood, its hauling and sales with the aim to achieve optimum monetization.

Practical principles of salvage felling

Soil-friendly practices can be increased by concentrating machine travels: prohibited movement of machines across the whole site during wood logging and skidding. Use of the existing transport accessibility system. Strictly observed travel routes. The spacing of skidding lines kept at 40 meters on the soils sensitive to traffic. The resulting higher production costs are justified due to soil protection. Do not allow increased density of the access system so that the spacing of forwarding lines may fall below 20 meters on a flat and on a slightly sloping terrain, and below 30 meters on the slopes with gradients over 30%. New forwarding lines should not be established just because the trees in a given location are more difficult to access. Higher production costs are justified and morally compensated for by increased soil-friendliness. Width of the forwarding line must correspond to the selected machine, but may not exceed 4 meters. Proper maintenance of forest roads is important, as timely repair of damage to primary logging roads will prevent high costs afterwards.

Passability of the forest machines through the terrain can be improved and the negative impact of the wheeled chassis on the ground can be reduced by the consistent use of wide (low-pressure) tyres. Put a layer of brash on the surface of the lines, especially on their lower load-bearing sections and near the edge trees. Choose appropriate connection of the lines to the roads, or even partially reinforce (pave) them, but always place firewood or low-quality logs of minimum length of 4m or more in the ditches at the first passage, and remove the logs during the last travel with the load, treat the ditch and place the logs in the appropriate stacks on the roadside landing by assortments.

In motor-manual technologies, direct contact of the worker and the power saw with the felled (cut) tree is necessary, which is associated with an increased occupational risk in such a situation. Therefore, trees on the stump site should only be cut down if possible (i.e. trunks separated from stumps). All other works should be done on a different site, in case of the whole-tree logging method on the roadside landing. In the Federal Republic of Germany, using a sufficiently powerful crawler excavator equipped with a grapple proved effective on large areas in the flat terrain affected by disaster for loosening the trunk separated from the stump by power saw and for its relocation (skidding). Gripping the tree with a grapple on the excavator boom increases safety and prevents the trunk from cracking. Use of winches on tractors and prime movers is less suitable in such cases. In less extensive areas affected by disaster and on gentle slopes, it is possible to deploy more powerful tractors equipped with rope winches and stackers. On steep slopes, wood is gathered, using a cable transport installation. Trunk delimbing and cross-cutting take place close to the main logging road.

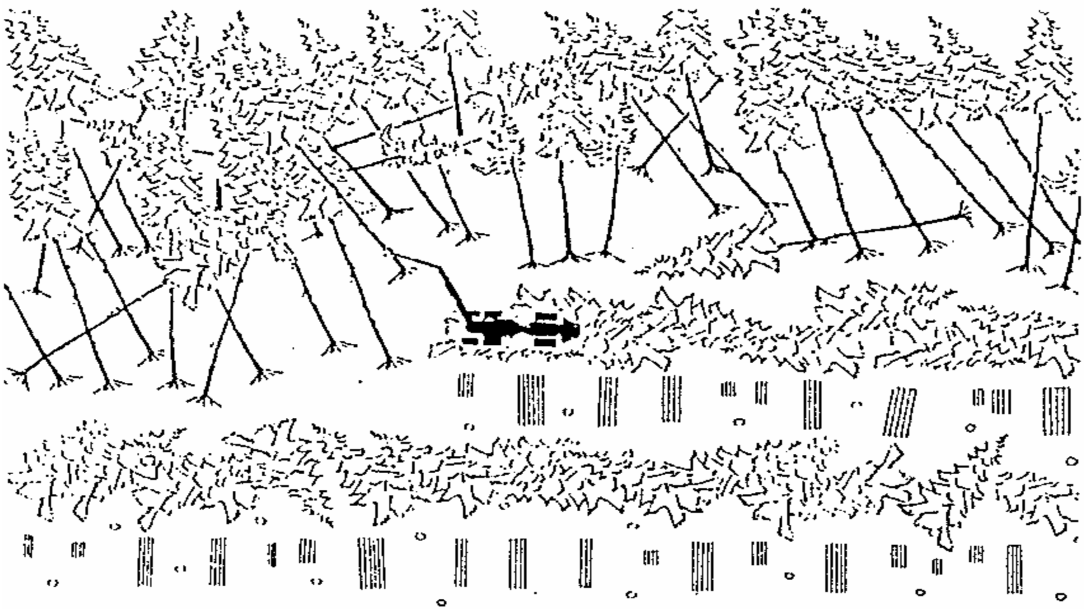


Fig. 75. Progress of harvester working in the stand affected by disaster

For particularly dangerous uprooted trees, it is recommended to cut the stem from the stump so that a longer stub (min. root plate height) may be left to prevent the root plate from tipping over onto the worker cutting the stem from the stump. Particularly dangerous root plates are secured with cable tractors or crawler excavators. Prioritize cutting of the root plate by harvester (this solves the most dangerous operation when processing uprooted trees).

When producing long timber, the harvester should enter the salvage felling site from the side, when producing short timber - perpendicularly to the main wind direction. Attention must be paid to possible transfer of strong tensile and impact force moments onto the harvester, arising from cutting tensioned trees. The performance of the harvester during salvage felling is reduced due to the higher labour intensity of separate processing of the standing tree stumps and broken off crown parts, which requires manual control and sorting instead of automatic operations. It is advisable to equip the staff (machine operators and workers in the stand) with radio stations to improve their mutual communication.

Technological procedures presented

Technological procedures that are suitable for the processing of timber from salvage felling are presented in the following tabular overview. Amongst other things, documents from the Research Institute of Forestry in Freiburg, Germany were used for its preparation. The procedures are compiled into groups taking into account terrain conditions; the basic machine elements of technological operations are characterised, as well as their productivity and typical features. For each of these procedures, the area of application, widths of the working fields (line spacing), indicative performance data and the most important advantages and disadvantages are given. The performance ranges are created by average values for coniferous and broadleaved trees and for all age classes, and can therefore be used only as rough estimates within larger salvage felling areas. At the same time, it should be emphasized that many of the principles shown below are also valid for planned cutting.

I. Work procedures in mainly flat terrains with the slope of up to 30%

Processing of the salvage felling should be preferably performed using highly mechanised procedures. This means that powerful harvesters are deployed for harvesting both coniferous and broadleaved timber. A crawler harvester is particularly suitable for this purpose, as in contrast to a wheeled harvester it usually has the necessary power reserves. In wheeled harvesters, only the higher performance classes give satisfactory results. Due to a high risk of injuries after cutting the uprooted trees, it is advisable to level and remove the root plates of uprooted trees, usually by harvesters, or by crawler excavators equipped with grapples.

II. Work procedures on slopes with inclinations from 30% to 50%

Processing of salvage felling can be expected mainly by work procedures with a small degree of mechanisation. Though the technology using crawler harvesters is suitable, for the time being it is available within a small scope, i.e. it can be designed and used in rare cases only. Harvesting is performed mainly motor-manually. Timber skidding is performed by prime movers equipped with cable winches. Wood processing is usually also performed using the motor-manual method on suitable sites. Trees are not delimbed on the stump site, with the exception of very small volumes of logging (isolated trees).

III. Work procedures on slopes with inclinations exceeding 50%

Harvesting is usually performed motor-manually. Extraction and skidding are in principle performed by cable crane. Processing is performed by processor or motor-manually. Capacities of the stacks are usually a big problem; therefore, continual timber hauling is an effective solution.

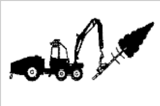
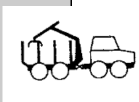
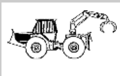
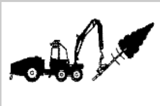
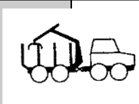
Work procedures are illustrated in Tab. 13., which can be found on the following pages.

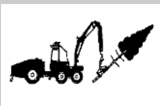
I. FLAT TERRAINS WITH THE SLOPE OF UP TO 30 %

a) Motor-manual logging technologies using the power saw

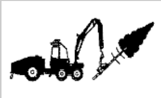
Felling	Release and extraction	Delimbing	Cross-cutting	Skidding	Stacking	Technological procedure no. 1
						
4 – 12 m^3/h	**4 – 15 m^3/h**	**2 – 5 m^3/h**		**6 - 15 m^3/h**		
Area of application:		• large area damage > 1 ha • coniferous and broadleaved tree species, not low-diameter timber				
Advantages:		• line spacing > 20 m • standard machines and procedures				
Disadvantages:		• organisational complexity, difficult coordination of capacities				

b) Mechanised technologies

Works within the reach of harvester boom						Technological procedure **no. 2**
Felling	Release and extraction	Delimbing	Cross-cutting	Skidding	Stacking	
						
Large wheeled harvester 8 – 20 m^3/h				**Forwarder 10 – 20 m^3/h** **Tractor + clam bunk 10 – 30 m^3/h**		
Works inside the working field outside the reach of harvester boom						
Felling	Release and extraction	Delimbing	Cross-cutting	Skidding	Stacking	
						
4 – 12 m^3/h	**4 – 15 m^3/h**	**Medium-sized wheeled harvester 8 - 15 m^3/h** **Large wheeled harvester 8 – 20 m^3/h**		**Forwarder 10 – 20 m^3/h** **Tractor + clam bunk 10–30 m^3/h**		
Area of application:		• individual windthrows, small plot and large area damages • mainly conifers (broadleaves within a limited scope only)				
Advantages:		• brash on the lines, most of felling residues removed • soil-friendliness, line spacing > 20 m				
Disadvantages:		• high organisational demands • risk of work during manual felling • production costs				

Felling	Release and extraction	Delimbing	Cross-cutting	Skidding	Stacking	Technological procedure **no. 3**
						
4 – 12 m^3/h	**Medium wheeled harvester 7 - 20 m^3/h** **Large wheeled harvester 10 – 25 m^3/h**			**Forwarder 10 – 20 m^3/h** **Tractor + clam bunk 10 – 30 m^3/h**		
Area of application:	• large area damages > 1 ha • mainly conifers (broadleaves within a limited scope only)					
Advantages:	• great processing performance • great skidding performance • possible short travels along the machine own axis					
Disadvantages:	• intensity of travel on the site, spacing of lines 10 – 20 m • risk of work during manual felling					

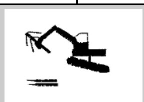
<table>
<tr><td>Felling</td><td>Release and extraction</td><td>Delimbing</td><td>Cross-cutting</td><td>Skidding</td><td>Stacking</td><td rowspan="6">Technological procedure

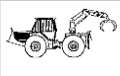
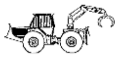
no. 4</td></tr>
<tr><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td colspan="4">**Large wheeled harvester 8 – 20 m^3/h**</td><td colspan="2">**Forwarder 10 – 20 m^3/h
Tractor + clam bunk 10 – 30 m^3/h**</td></tr>
<tr><td colspan="2">Area of application:</td><td colspan="4">• large area damages > 1 ha
• mainly conifers (broadleaves within a limited scope only)</td></tr>
<tr><td colspan="2">Advantages:</td><td colspan="4">• high safety of labour (manual work during felling is eliminated)
• high processing and skidding performance
• possible short travels along the machine own axis</td></tr>
<tr><td colspan="2">Disadvantages:</td><td colspan="4">• higher risk of malfunctions, wear of the cutting device
• intensity of travel on the site, spacing of lines 10 – 25 m</td></tr>
</table>

<table>
<tr><td>Felling</td><td>Release and extraction</td><td>Delimbing</td><td>Cross-cutting</td><td>Skidding</td><td>stacking</td><td rowspan="6">Technological procedure

no. 5</td></tr>
<tr><td></td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>**4 – 12 m^3/h**</td><td colspan="3">**Medium wheeled harvester 10 - 25 m^3/h
Large wheeled harvester 10 - 30 m^3/h**</td><td colspan="2">**Forwarder 10 – 20 m^3/h
Tractor + clam bunk 10 – 30 m^3/h**</td></tr>
<tr><td colspan="2">Area of application:</td><td colspan="4">• large area damages > 3 ha
• mainly conifers (broadleaves within a limited scope only)
• in case of terrain slopes over 30% - skidding with a winch cable or a cableway</td></tr>
<tr><td colspan="2">Advantages:</td><td colspan="4">• higher safety of labour
• high processing and skidding performance
• great lifting forces, sufficient boom reach
• spacing of lines up to 25 m</td></tr>
<tr><td colspan="2">Disadvantages:</td><td colspan="4">• cannot be used on paved (consolidated) roads
• organisational complexity, transport by low trailer</td></tr>
</table>

<table>
<tr><td>Felling</td><td>Release, extraction</td><td>Delimbing</td><td>Cross-cutting</td><td>Skidding</td><td>Stacking</td><td rowspan="6">Technological procedure

no. 6</td></tr>
<tr><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td colspan="4">**Medium wheeled harvester 8 - 20 m^3/h
Large wheeled harvester 8 - 25 m^3/h**</td><td colspan="2">**Forwarder 10 – 20 m^3/h
Tractor + clam bunk 10 – 30 m^3/h**</td></tr>
<tr><td colspan="2">Area of application:</td><td colspan="4">• large area damages > 3 ha
• mainly conifers (broadleaves within a limited scope only)
• in case of terrain slopes over 30% - skidding with a winch cable or a cableway</td></tr>
<tr><td colspan="2">Advantages:</td><td colspan="4">• higher safety of labour
• high processing and skidding performance
• great lifting forces, sufficient boom reach</td></tr>
<tr><td colspan="2">Disadvantages:</td><td colspan="4">• intensity of travel on the site, spacing of lines 16 – 20 m
• cannot be used on paved (consolidated) roads
• organisational complexity, transport by low trailer</td></tr>
</table>

Felling	Release, extraction	Delimbing	Cross-cutting	Skidding	Stacking	
						Technological procedure **no. 7**
3 – 10 m^3/h	**4 – 12 m^3/h**	**2 – 5 m^3/h**		**6 - 15 m^3/h**		
Area of application:		• individual windthrows, small plot and large area damages, • conifers as well as broadleaves, not low-diameter trees • access by skidding lines				
Advantages:		• all parts of the machine fleet represent the standard equipment for forest operations • simple organisation of work for operative deployment • spacing of lines > 20 m				
Disadvantages:		• lower performance • higher safety risk				

II. SLOPING TERRAINS WITH INCLINATION FROM 30 TO 50 %

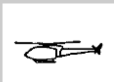
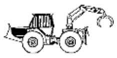
Felling	Release, extraction	Delimbing	Cross-cutting	Skidding	Stacking	
						Technological procedure **no. 8**
3 – 10 m^3/h	**Medium wheeled harvester 7 - 20 m^3/h**			**Forwarder 10 – 20 m^3/h** **Tractor + clam bunk 10 – 30 m^3/h**		
Area of application:		• large area damages > 3 ha • mainly conifers (broadleaves within a limited scope only) • in case of terrain slopes over 30% - skidding with a winch cable or a cableway				
Advantages:		• high processing and skidding performance • wood harvesting and skidding can take place separately • great lifting forces, sufficient boom reach				
Disadvantages:		• intensity of travels, spacing of lines 16 – 20 m • high risk of work during felling • cannot be used on paved (consolidated) roads • organisational complexity, transport by low trailer				

III. SLOPING TERRAINS WITH INCLINATIONS OVER 50 %

Felling	Delimbing	Cross-cutting	Skidding	Stacking	
					Technological procedure **no. 9**
1 – 3 m^3/h			**3 – 15 m^3/h**	**6 – 15 m^3/h**	
Area of application:	• large area damages, harvesting volume > 500 m^3 • conifers as well as broadleaves, not low-diameter trees • skidding distance 150 – 600 m, cable skidding up to 200 m				
Advantages:	• common requirements for organisation, processing of trees and timber skidding can take place separately • soil not burdened by movement of machines				
Disadvantages:	• higher risk when working manually with a saw • lower performance, higher production costs • brash is left in the stand				

Felling	Release, extraction	Skidding	Delimbing	Cross-cutting	Stacking	
						
3 – 9 m³/h	**3 – 10 m³/h**		**2 – 5 m³/h**		**6 – 15 m³/h**	
Area of application:	• large area damages, volume of timber harvested >500 m³ • conifers as well as broadleaves, not low-diameter trees • skidding distance 150 – 600 m, cable skidding up to 250 m					Technological procedure **no. 10**
Advantages:	• higher safety of work • soil not burdened by movement of machines, brash removed					
Disadvantages:	• organisational requirements, a larger cableway is desirable • brash cleared from the stand • low-value assortments are also forwarded • a larger area of the roadside landing is required, or the need for continual removal of timber					

IV. INACCESSIBLE LOCALITIES

Felling	Delimbing	Cross-cutting	Skidding	Stacking	
					
1 – 3 m³/h			**Medium-sized helicopter 20 - 45 m³/h** **Large helicopter 45 – 65 m³/h**	**6 – 15 m³/h**	
Area of application:	• inaccessible and particularly sensitive locations • time period of a turn < 3 min. • conifers as well as broadleaves, not low-diameter trees				Technological procedure **no. 11**
Advantages:	• high performance of skidding • minimum requirements for making stands accessible • soil not burdened by movement of machines				
Disadvantages:	• higher risk when working manually with a saw • organisational complexity • high requirements for skidding • noise, dependence on weather conditions				

grey coloured parts of the table = works performed in the stand	uncoloured parts of the table = works performed outside the stand

Tab. 13. Overview of variants of technological procedures used in salvage felling

5.4 Forwarder work procedures

Timber forwarding is a technological stage that can consist of two operations (i.e. timber extraction and timber forwarding itself) or of one operation only (forwarding), and both operations are ensured by a single mean of mechanisation, i.e. by tractor-and-trailer unit or by forwarder.

Since both tractor-and-trailer units and forwarders are equipped with the hydraulic crane with the grapple, it is indeed possible, but only on a theoretical level in the improvement felling, to choose such a technological procedure that the timber is extracted from the stand, from the stump, using only this crane, namely at a distance given by its maximum reach of approx. 6 – 10 m, and continually loaded and forwarded afterwards. This technological alternative is technically possible in the improvement and main felling, but in the improvement felling it is not economically advantageous due to the low performance of the machine, when extracting individual pieces of timber with a grapple on the hydraulic crane boom of the forwarding mean as well as due to the limited boom reach into the stand.

Therefore, an absolutely predominant alternative in the improvement felling is the concept of timber forwarding understood as a technological phase consisting of a single operation, for which the timber is extracted from the stand in advance (directly by the harvester in the case of harvester technologies), and prepared on piles at the edges of the extracting line, where it is then loaded and forwarded by the relevant machine.

Benefits and disadvantages of timber skidding technology by forwarding
The main advantage is a significant reduction in physical effort of workers compared to lashing the choker, less dependence on the weather, elimination of some unpleasant and dangerous works (choker lashing and unlashing in mud or snow, going through weeds, undergrowth and brash), accidents caused by the damaged, e.g. frayed rope and by timber itself. The advantage also consists in possible substantial increase in daily labour productivity per worker up to 60 or more m^3 of skidded wood (in favourable conditions even over 200 m^3), which is absolutely unattainable when binding the chokers manually and pulling the winch rope into the stand. A very important factor of the forwarding operation is that the transported timber is not damaged and polluted by dragging on the ground (which has a high commercial importance from the point of view of supplier-customer relations – for supply of contaminated wood, many customers request significant deductions from the purchase price), and there is neither impairment of the soil surface by digging the log butt ends into the soil surface, nor damage to the standing trees by contact with the dragged timber.

There is a specific difference in the impact of transported load on the amount of traction force in forwarders and units with the all-wheel drive, compared to the impact of load dragged by skidding tractors and prime movers. It can be stated that the adhesion force of the forwarding means is increased significantly due to the forwarded load, and the driving resistance, caused by the rising rolling friction of wheels, is increased only slightly. However, in the case of dragging the load behind the tractor, the adhesion force of the tractor is increased only negligibly (or may even be decreased due to the lightening of the front driven axle), and the resistance force of the shear friction of the load (dragged timber) is increased significantly.

Therefore, the risk of wheel slippage is not as imminent for the forwarding vehicles as it is for the tractors and prime movers when dragging timber, and this important type of soil damage (filling of furrows by the slipping wheels) becomes less serious. However, the risk of soil compaction increases due to greater load on the soil during the travel of the forwarding machine. Nevertheless, this problem can be solved by modifying design of the machine, i.e. by increasing the number of wheels, doubling the wheels on the axle (bogie axles), by tracked wheels and by increasing the width of tyres. Soil compaction by the movement of machines can also be reduced by organisational measures, as identified elsewhere in this manual.

Objective disadvantages of tractor-and-trailer units and forwarders are as follows:

- slope of the terrain is suitable without major problems only up to approx. 40-45% when skidding the timber at right angles to the contour. At greater inclinations, the machine stability is already threatened and its manoeuvrability is significantly reduced
- high centre of gravity of the vehicle (bottom of the loading area is up to 145 cm above the ground in larger types of machines), is reducing lateral stability of the loaded machine, and therefore it is necessary to choose travel direction of the loaded forwarder perpendicularly to the contour line on higher slopes. By using the ALS cargo space option, the loading area is tilted towards the slope by the hydraulic system, which results in a favourable change in the transverse position of the centre of gravity and an increase in transverse stability. Tying the machines to the traction winch ropes is an effective measure to increase longitudinal stability when driving down the slope
- on higher terrain slopes, the fact that vehicles, due to their larger turning radius, are unable to cope with exits from the sloping road to the terrain and vice versa points out that these exits must be prepared appropriately

- in case of significantly concave and convex terrains, there can be a problem with the length of the vehicle (with the load, this length is approx. 10 m).

Overview of model forwarding technologies
Harvester + forwarder is currently the most typical example of the timber forwarding technology. They are used in the improvement and regeneration felling. The harvester cuts down the trees and pulls them onto the line, where the machine debranches them and makes assortments of them, which are stored outside the passable profile of the line in the improvement felling, and on piles on the felling area in case of regeneration felling. Forwarding is realized by forwarder (not by tractor-and-trailer units, as a rule, performance of which is significantly lower than that of the harvester.

As the forwarders and tractor-and-trailer units are nowadays used even in some other technologies, we present some examples of them for completeness, although these technologies are not widely spread. Power saw + manual timber skidding + tractor-and-trailer unit or forwarder is used in the improvement felling, in the motor-manual assortment method, variant of standard lengths, where the wood cutter extracts (clears) the produced short logs to the line, on which the subsequent forwarding is performed by the assortment forwarding machine. It is expedient to use hydraulic cranes with an extended reach of approx. 10 m. The spacing of forwarding lines is approx. 20 m, after 6-8 m lines for the hydraulic crane are connected at right angles, on which the timber is prepared, the forwarder ensures clearing and forwarding. This technology can be used in younger and middle-aged coniferous stands.

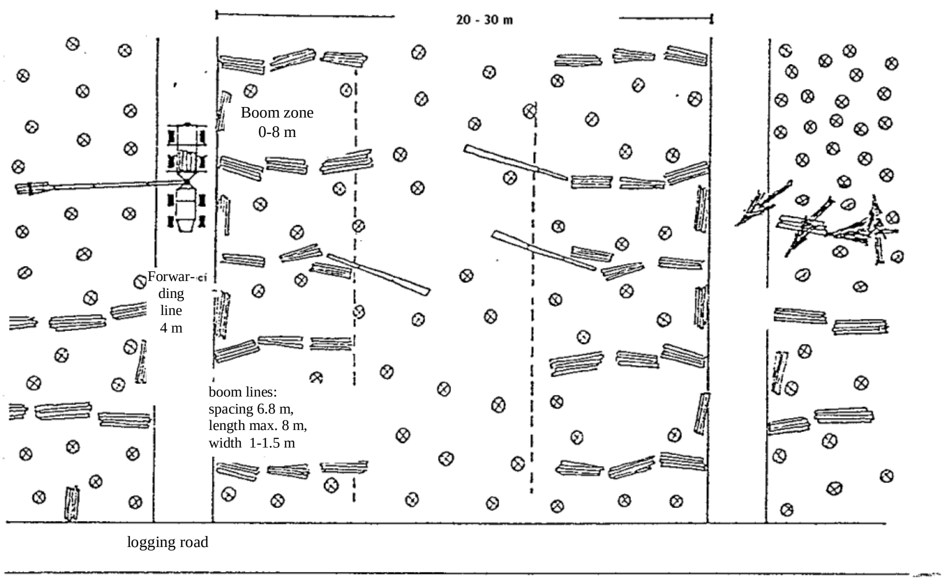


Fig. 76. Method of timber extraction and forwarding by forwarder in motor-manual felling

Motor-manual felling of long timber and its handling, distribution and storage on stacks by the forwarder with a **grapple equipped with the cross-cutting device**. This technique enables a combination of loading of the prepared assortments with raw logs, the maximum trimming diameter being 60-90 cm.

Use of a combined forwarder with the technology of timber extraction from the stand with a winch rope, which the forwarder is equipped with, and then timber loading onto the forwarder loading area. The loading can be complete (short wood) or only partial (storing the butts of long timber between the rear stanchions and securing the load with a winch rope) - the timber is thus transported in a semi-trailer. This technology solves the need for skidding short and long timber with a single machine. The technical solution comes in two variants: a folding part of stanchions, sliding chassis and removable stanchions.

Power saw + horse + processor + tractor-and-trailer unit or forwarder are used in the improvement felling, when whole trees are extracted by horse to the line, followed by their processing by processor and storage of the made logs to the line. The logs are then forwarded by forwarding machine.

Power saw + mobile winder + processor + tractor-and-trailer unit or forwarder are used in the improvement felling, when whole trees are extracted to the line by mobile winder and, when processed by the processor, the logs are forwarded by tractor-and-trailer unit. Instead of mobile winder, a tractor winch can be used, then we can speak about the use of integrated felling with the simultaneous clearing of extracted timber.

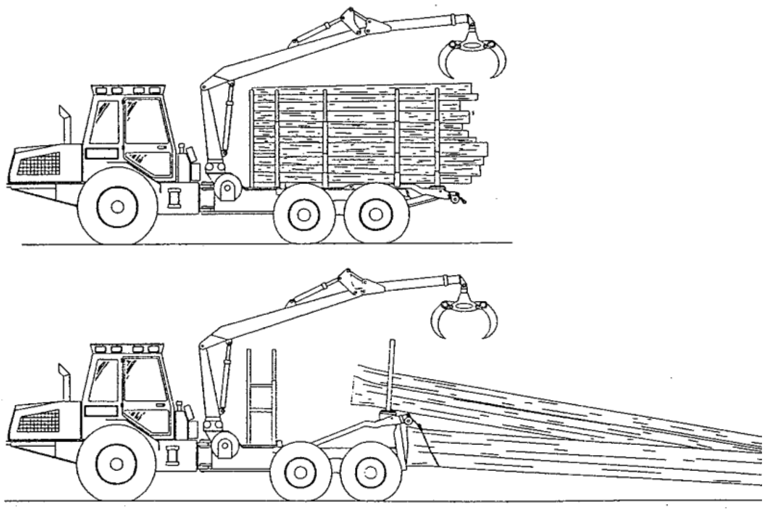


Fig. 77. Timber forwarding by combined forwarder
(equipped with a winch for extraction and skidding by dragging)

Start of timber skidding
It is necessary to check and ensure that the area for the planned timber storage is clean and free from any obstacles. Furthermore, it is necessary to verify complexity of the terrain conditions, whether or not the logging area is in the state after motor-manual or mechanised felling, etc. After mechanised felling, the extracting lines are usually passable and clear, i.e. the forwarder can move freely. This is not always the case of motor-manual felling with a power saw. The main forwarding line must be designed with great care, especially if high timber volumes are transported, as this transport route must ensure the majority of transport of the harvested timber. If the forwarder travels over a drainage ditch during forwarding, it is necessary to protect it against damage, usually by filling it with the round wood. When forwarding is completed, it is necessary to restore the ditch and its initial condition.

When using the forwarder, loading is started on the farthest place from the storage area, and the forwarder proceeds smoothly towards it. Such a timber forwarding procedure is suitable, where felling by the harvester has already been completed, i.e. if the felling is completed before the start of the forwarding. The forwarder therefore does not need to turn on the line, which is difficult especially when thinning high-density stands. Low-bearing, steep or rocky terrain in the middle of the stand can be crossed with a partially loaded forwarder, and loading can be completed closer to the storage area. However, this measure reduces full loading of the forwarder, which affects the machine performance, as we do not use its full capacity. Improper preparation of the site can significantly reduce the daily production volume. In steep terrains, timber loading and forwarding in the direction down the slope is always preferred. This way, energy consumption of timber transport by forwarder is reduced, and smooth and uniform loading of timber between the stanchions is ensured.

Load assembly and skidding
When extracting short logs with forwarders, clearing and assembling of the load differs depending on whether we consider the large area main felling or about the improvement and/or selection felling. In the large area felling, clearing can be integrated into a single operation with load assembly, as movement of forwarders is usually possible on the lines distributed at adequate density on the whole logging area. In the improvement felling, the movement of the forwarder tractor is limited to the lines only, and therefore timber extraction to them has to be realized by other means (e.g. harvester, horse, winch, manual felling, etc.). Piles must be placed in gaps between the trees, outside the passable profile of the line! The forwarding machine then assembles the load by loading the preliminarily prepared piles of logs.

Due to the high centre of gravity, it holds for the movement of all extracting machines in the terrain as well as on the lines that they are more sensitive to the transverse slope than the tractors forwarding the timber by dragging. The lines with combined longitudinal and transverse slopes are therefore driven without any load only, travelling with a load is limited only to lines without the transverse slope! If it is not possible to avoid driving the forwarding machine along the contour, the machine is "balanced" by extending the hydraulic crane boom against the slope (or alternatively, a load, e.g. a log, is grasped in the grapple to increase the counterweight). When driving the forwarding machine along the contour line, timber should only be loaded onto the cargo area from above the line, to eliminate the risk of overturning the machine due to the tipping moment of the crane and load.

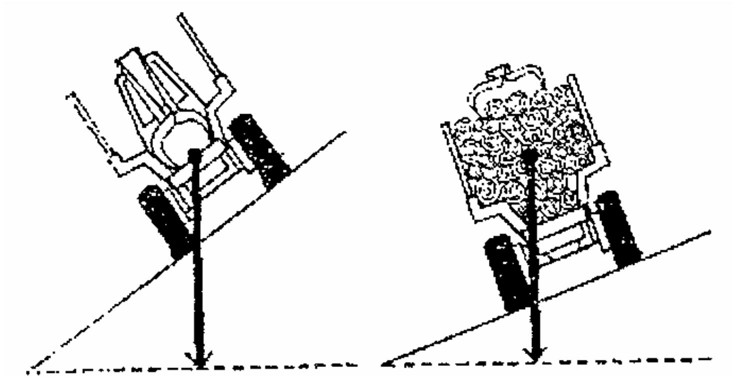


Fig. 78. Change of the forwarder gravity centre before and after loading

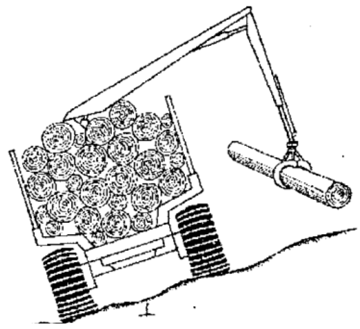


Fig. 79. Compensating the forwarder lateral tilt

It is typical for tractor-and-trailer units (especially simpler and cheaper versions) that the connection of the towing machine with the trailer is loose and does not allow its active directional control when reversing. With respect to the fact that capability of such tractor-and-trailer units to reverse into a dead-end line is very limited if not even impossible, it is advisable or even necessary to route the forwarding lines as continuous. Reversing with the forwarder, as well as with more advanced types of tractor-and-trailer units, is easier, because the principle of their driving is the same or similar to the described so-called articulated steering. That is why forwarders can also use the access network made up partly of blind-end lines. In terms of traffic optimization and increased soil-friendliness, even in this case the lines should be designed as passable, to eliminate the unnecessarily increased number of machine travels along the same track.

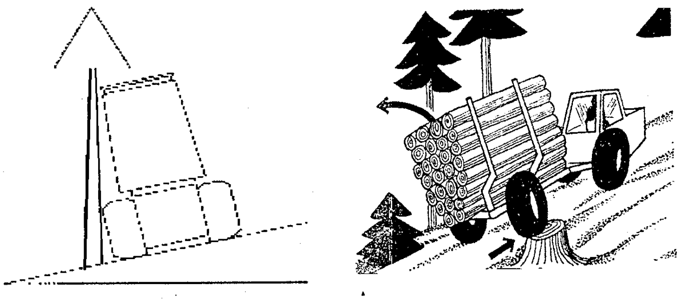


Fig. 80. Increased risk of the forwarder and tree collision: when driving along the contour line (left), when driving over a higher tree stump (right)

If the forwarding machine gets stuck while driving with the load (e.g. on a low-bearing place of the line), there is often nothing else to do but to unload one part of the load next to the line and take it only during the next travel with the load (provided that the forwarding machine is not equipped with its own recovery winch).

In some cases, it can be advisable to use the tractor-and-trailer unit even for timber haulage. This is the case, for example, if the hauling distance is so short that by eliminating one loading and unloading, more time is saved than the difference in time consumption for hauling with the tractor-and-trailer unit compared to the time consumption for hauling with a slower forwarding unit. In some European regions, hauling of short logs using an assortment forwarding unit is a completely common technology in the mountain areas, where the haulage network is dimensioned just for the forwarding units, and does not allow the operation of larger tractor-and-trailer units at all.

The main woody plant is usually forwarded first. The sequence of the forwarded timber assortments depends on the felling technology. If the wood cutter working with the power saw places all assortments separately next to the hauling road, the sequence of clearing is not important. However, if the pulp wood is stored on the top of the sawn round wood pile, then it should be removed first. In the motor-manual felling, saw logs are often scattered on the forwarding line and should be extracted as a single assortment within the forwarder load. Here, the operator must apply his skill and readiness to assemble the load with minimal movements of the forwarder.

Fig. 81. Load with mixed assortments

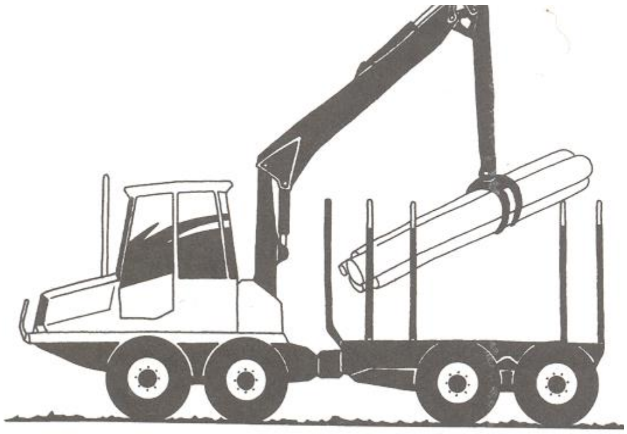


Fig. 82. When lifting the load, its front part should be slightly overbalanced

A beginner, whose skills in operating a hydraulic crane have not been developed fully yet, should not be forwarding mixed assortments. He can thus avoid wasting time on sorting the assortments at the stack. In low stand density or unfavourable terrain on some places (low-bearing capacity, steep or rocky), all timber can be taken at once. Then it is possible to avoid this area in the future. For mixed assortments, sorting is performed during loading, i.e. pulp wood is placed on one side of the loading surface and saw logs - on the other one. Mixing of assortments on the top and bottom part of the load should be avoided, due to their poor visibility in certain parts of the cargo area, which then slows down sorting at the deck. When loading mixed assortments of a mixture of wood species, it is necessary to ensure that they are visually easily distinguishable from one another. Distinguishing of assortments with similar parameters can already be done by the harvester operator during felling, using colour marking.

Whenever possible, as early as on the way from the storage area towards the stand, one assortment is loaded between the stanchions, e.g. softwood pulp wood, and on the return way another assortment is placed on the top of the load, e.g. hardwood pulp wood. The main timber is forwarded first and the other types of timber later. Systematic forwarding is important, because it leads to a so-called clean route without any logs left. On large areas, it is not advisable to spend unnecessary time on local collection of rotten and low-value timber as doing so would reduce the machine performance. If the snow covering the logs is continuous, the areas already extracted must be clearly marked.

The load of timber grabbed by the grapple should not be too large. This puts too much strain on the hydraulic crane, the logs often get released from the grapple and roll away, and the lost time rises by collecting them again.

If the load held by the grapple is lifted, its front part should be slightly dropping. The load is then easily swung against the face of the loading area (formed by the supporting stop grid) and ends of the logs are aligned with the grapple jaws slightly ajar. Experienced operators align the ends of the logs by swinging them against the ground, opening the grapple a little. The correct size of one grapple is such that the hydraulic crane can easily handle its weight and the timber is properly gripped by the grapple jaws. Other aspects affecting work with the crane are the length of the assortment and the type of logs (saw logs or pulp wood).

Timber unloading on the roadside landing

When starting logging operations at a new site, the operator should familiarise himself with the layout of stacks, and whether the timber unloading should be made from the forest road (preferably) or from the side of the forest stand. The deck is usually pre-determined and the operator has little influence on its location. Good stack planning has a decisive impact on all aspects of hauling. Information about tree species, assortments and volume of timber in the stand should be known in advance. Load-bearing capacity of roads and of the unloading surface for the trucks has to be assessed. All of these factors affect requirements for timber stacking. The base for the stacks should be prepared, levelled and supplemented with rafters, any snow should at first be compressed and smoothed. Stacks should be in rows and levelled, even if the log ends are not aligned.

At the stacking area, the forwarder is positioned in such a way that unloading may be carried out at an angle of 90° to both sides and 2-3 m from the wheels. This position requires only lifting, turning and slight movement of the rotator.

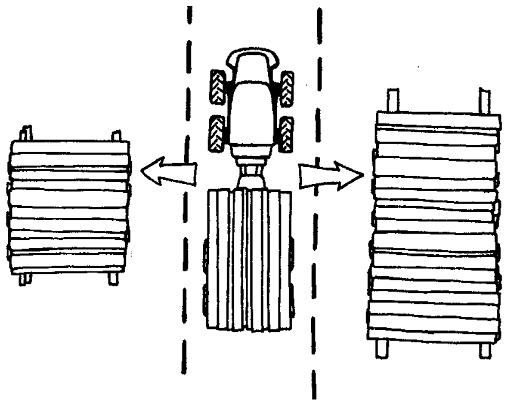


Fig. 83. Example of correct forwarder positioning at the deck

Main principles governing the stack layout are as follows:

- When deciding on the stack layout, it is necessary to consider the needs of the logging truck-and-trailer unit. The driver of the vehicle needs to start loading, load the cargo and drive away without undue delay. Hydraulic cranes of truck-and-trailer units are best controlled if the stacks are located 1 - 3 m from the vehicle.
- The layout of stacks should be planned, e.g. pulp wood and saw round wood stacks should be clearly separated, but close to each other. All this facilitates and speeds up unloading, sorting and placement of diverse loads. The machine movement at the stack piles is thus reduced and the site is kept clean, tidy and well-functioning.
- If the wood is stored on both sides of the logging road, the stacks should be 4-5 m apart along the entire length of the deck. If the stacks are placed closer, the moving forwarders can easily cause them to fall.
- The stacks should not be located between growing trees, stones, tree stumps or near any other objects and also not under power lines or phone lines. The stacks should not contain logging residues, stones or other foreign objects.
- Each assortment should be placed in as large and separate stack as possible. The logs should be placed in parallel and at right angles to the road, pulp wood in particular. This will speed up their loading. However, large and long saw logs can be stored parallel to the road.
- The assortments that should be taken fresh or only in the wet/winter season must be placed in the most favourable part of the deck. Other assortments (small volumes, subsidiary wood species) may occupy less favourable places of the deck.

- Special logs, such as large veneer logs, should be stored in stacks so that they can be easily loaded from the logging road upon arrival on the deck.
- Skidded timber can be stored across the trenches, which should be cleaned, when the logging activities are completed. Unloading can be implemented from the logging road or from the side of the forest stand.

The height of the stacks is limited by the possibilities for their development by the forwarder. If the wood is measured at the storage area, the logs should be measurable from the usual worker's position (i.e. from the ground without any special tools) – this way the stack height is defined. If the wood at the storage area is measured in stacks, the top side of the stack should be as flat as possible, which contributes to the accuracy of measurement. For saw logs, small ends of the logs should be visible to measure the small end diameter.

5.5 Logging and hauling machines in mountain conditions

Sites situated in mountains and steeply sloping territories represent a specific area of application of highly mechanised forest harvesting technologies. Slope accessibility is a significant and indeed limiting factor in the deployment of mobile logging and hauling machines, such as harvesters, forwarders, tractor-and-trailer units, but also conventional mobile machines (especially tractors and prime movers). Therefore, in conditions where the slope reaches 40 % or more, the only alternative in the Czech Republic is de facto a technology based on the motor-manual felling, usually also on the motor-manual delimbing and cross-cutting of trees into logs with the subsequent timber skidding with the use of forest cable transport installations. In areas with a higher-density network of transport roads, these cable transport installations can be replaced by land-based skidding vehicles (tractors and prime movers with winches).

Currently, however, technical and technological development allows the deployment of more sophisticated means of forest production mechanisation even in these challenging terrain conditions. Although nowadays the methods and vehicles shown below have almost never been used in the Czech Republic, it can be expected that special technologies of highly mechanised felling will be extended over time even to the conditions of mountainous and heavily sloping territories. According to the terrain classification, approximately 85% of forest stand areas in the Czech Republic are passable by wheeled mobile vehicles; on the remaining 15%, other methods should be used (at least theoretically), led by forest cableways. The current reality does not correspond to these facts, but the situation can change in the future in favour of greater use of the standard cableways or the machine aggregates mentioned below.

The highly mechanised felling technologies applicable in mountainous and heavily sloping areas can be broken down into two groups:

- technologies based on the use of so-called mountain harvesters
- technologies based on the use of so-called mountain processors.

Mountain harvesters
The basic feature of the mountain harvesters is their **increased off-road accessibility and passability**, enabling them to drive in the stand even in the demanding terrain with a steep slope. The principles mentioned above in this chapter apply to access, harvesting and forwarding of timber. A special emphasis must be given on appropriate routing of lines, i.e. their routing perpendicularly to the contours with the possibility of vehicle turning at places with a lower terrain slope, e.g. at the foot of the slope or on its peak. Compared to wheeled harvesters, tracked harvesters have a larger width (3.0 - 3.5 m), and the width of the line has to be adapted accordingly. When felling and handling the stems, extra care must be taken to avoid the loss of machine stability and machine overturning. Harvesters equipped with tracked or walking undercarriage are capable of felling even in inaccessible terrains, from where it may be financially or technically difficult to skid the timber to the roadside landing (use of cable transport installations, forwarders with traction winches and tracked-wheel vehicles, etc.). The method of harvesting must always be planned comprehensively, also with regard to the method of timber forwarding or, for example, subsequent reforestation.

Fig. 84. Tracked harvester Neuson Ecotec

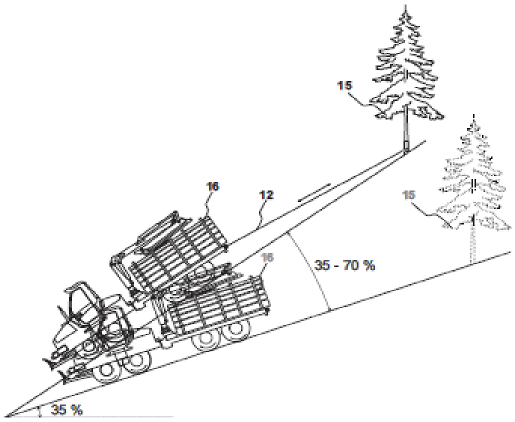
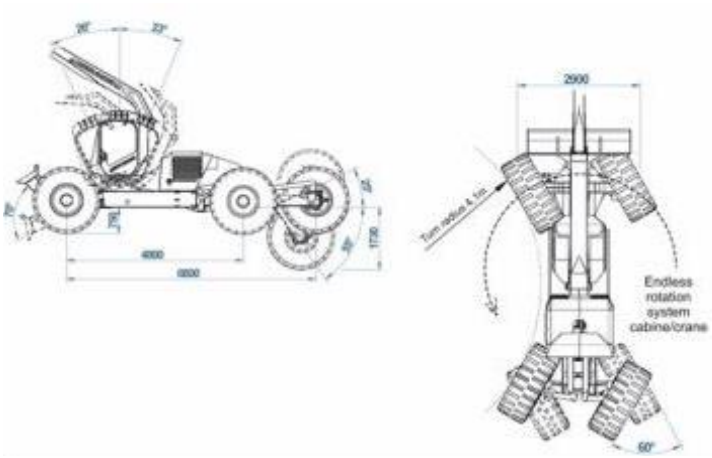


Fig. 85. Deployment of the forwarder with a traction winch

The increased off-road accessibility and passability of mountain harvesters is facilitated by specific features of their design, especially the machine undercarriage - chassis. The harvesters in question are primarily those on tracked undercarriages. The typical modern types include for example the machines of the Neuson series (models 9002HV, 132HVT, 182HVT, 242 HV, 242 HVT), Königstiger, or Valmet 911.3 Snake. Another group of machines for mountain conditions are walking harvesters, e.g. based on the MenziMuck machine. Their principles of design and useful properties are described in Chapter 4. The Highlander wheeled harvester of the Austrian origin is characterised by a special type of design which has a very low centre of gravity and a hydraulically adjustable wheelbase (individually, on each side of the machine - Fig. 87). Some parameters of these machines are given in Tab. 14.

Fig. 86. Harvester Königstiger



Fir. 87. Mountain harvester Highlander

Machine type	Engine power (kW)	Boom reach (m)	Weight (t)	Harvester head
Neuson 9002HV	74	9	11	diverse (e.g. Keto 51, Waratah HTH240)
Neuson 132 HVT	104	10	14.4	diverse (e.g. AFM 45/50, Keto 150, Waratah HTH250HD)
Neuson 242HVT	183	12	24.7	diverse (e.g. AFM 60HD,75, Logmax 7000, 9000, Waratah H290)
Köngstiger	153	15	28	diverse (e.g. LAKO 53, 63, 83
Menzi Muck A71T2 Mobil	70	8.5	8.7	diverse (e.g. Woody 50)
Highlander	172	10	18.5	Woody H50/Woody H60

Tab. 14. Parameters of some mountain harvesters

The performance of mountain harvesters is a subject of research by many authors, especially from Austria (Stampfer, 1998, 1999, etc.) or from Switzerland (Heinimann, 1998). The performance of the Königstiger harvester, which can also be used in the main felling, is shown in Tab. 15. The performance of the Neuson 11002HVT harvester (now an upgraded version designated as 9002 HVT), which is intended for the improvement felling, is shown in Tab. 16 (phs = machine working hours, i.e. 45 minutes of work).

Stem volume (m^3)	Performance (m^3/phs)		Stem volume (m^3)	Performance (m^3/phs)	
	Slope			Slope	
	25 %	45%		25 %	45 %
0.15	9.55	9.35	1.03	29.80	27.92
0.26	13.65	13.25	1.14	31.30	29.23
0.37	16.98	16.35	1.25	32.69	30.44
0.48	19.79	18.95	1.36	33.98	31.56
0.59	22.25	21.19	1.47	35.19	32.60
0.70	24.43	23.15	1.58	36.32	33.57
0.81	26.39	24.91	1.69	37.39	34.47
0.92	28.17	26.49	1.80	38.39	35.33

Tab. 15. Performance of Königstiger harvester

Stem volume (m^3)	Slope (%)		
	20	40	60
0.06	3.67	3.61	3.53
0.09	4.90	4.79	4.67
0.12	5.94	5.78	5.60
0.15	6.83	6.62	6.38
0.18	7.60	7.34	7.05
0.21	8.28	7.98	7.63
0.24	8.89	8.54	8.14
0.27	9.43	9.04	8.59
0.30	9.92	9.49	9.00
0.33	10.37	9.90	9.37
0.36	10.77	10.27	9.70
0.39	11.15	10.61	10.00
0.42	11.49	10.92	10.28

(m^3/phs) – *improvement felling, intensity 20 %*

Tab. 16. Performance of Neuson harvester 11002HVT

Wheeled harvesters or forwarders equipped with a traction winch can only drive in a straight line. The traction winch cable anchored at the beginning of the line will not allow these vehicles to turn, this fact, as well as any terrain faults that could damage the cable, must be considered when routing the lines for this way equipped machines. When felling on a slope, it is necessary to pay attention to correct location of the harvester head and to the height of the cut - if the cut is set too low, there is a risk of damage to the saw chain of the harvester head when cutting into the ground, if the cut is set too high, tall stumps remain in the stand.

Mountain processors

Mountain processors are sets of machines in the combination of a forest mast cableway and a hydraulic crane equipped with the harvester (processor) head. Both machines are placed together on the truck platform. The set, where the mast of the cableway is placed as a superstructure on the harvester, is intended for thinning operations. In this case, the harvester head is used only for cross-cutting and delimbing.

Almost all mountain processors have a closed technological cycle. After felling the trees with a portable power saw, the cableway performs skidding of the whole trees to the storage area within the reach of the hydraulic crane. The hydraulic crane equipped with a harvester (processor) head takes the tree for further processing into final assortments, which, when delimbed and cross-cut, are stored at the stacks within the reach of the hauling vehicle.

Fig. 88. Workplace of mountain processor

It is characteristic for mountain processors that they are mostly used for the logging method of whole trees, when only the motor-manual felling of trees takes place in the stand and their connection to the main line of the cableway. When a tree is skidded to the processor, it is delimbed and cross-cut into assortments.

Under certain circumstances, e.g. on fertile sites or on the sites endangered by soil erosion, the processors can also be used in the tree-length logging method (branches and tops of the trees being left on the spot for natural decay after motor-manual delimbing). However, by applying this method, useful parameters of the machine are not used adequately.

Fig. 89. Cableway mast as a superstructure on the harvester

Wanderfalke mountain processor

Work application of the light mountain processor Wanderfalke lies primarily in the improvement felling. Performance of the processor depends mainly on the stem volume, extraction and skidding distance and slope, and ranges from approx. 2.0 m^3/h to 7.0 m^3/h at an inclination of 60°, extraction distance of 11 m and skidding distance of 150 m (Lukáč, 2002).

Syncrofalke mountain processor

For the regeneration felling, an extraordinary energy potential is required, which is adequate to the stem volume of the felled stand, as well as to demanding terrain conditions. One of the representatives of such high-performance processors is the Syncrofalke processor.

Hourly performance of the Syncrofalke processor is higher than that of the Wanderfalke processor, namely due to the possibility of skidding larger volume trees. Performance of this machine also depends on the stem volume, extraction and skidding distance and on the slope, and ranges from approx. 3.0 m^3/h to 11.0 m^3/h at an inclination of 60^o and skidding distance of 100 to 300 m (Lukáč, 2002).

Processor assembly	**Indicator**	**Value**	**Unit**
Total assembly	Weight	24 000	kg
Driving unit – truck ÖAF 25.331	Engine power	243	kW
Hydraulic crane V-Kran 20.88	Reach Lifting moment	9 192	m kNm
Cableway Wanderfalke	Max. load capacity Max. car speed Height of the mast Working drum diameter Aerial line diameter Main line diameter Auxiliary line diameter	1 500 6 9 508 16 10 6	kg m.s^{-1} m mm mm mm mm
Processor Woody 50	Weight with rotator Max. cut diameter Delimbed tree diameter Grapple opening Stem movement speed Tree movement force	750 550 500 950 0-3 28	kg mm mm mm m.s^{-1} kN
Cableway car Sherpa U-1,5t	Loading capacity Weight	15 250	kN kg

Tab. 17. Parameters of Wanderfalke processor

Fig. 90. Syncrofalke mountain processor

An average decrease of hourly performance with the increasing length of the skidding distance by 100 m is approx. 0.5 m^3. Performance of the used cableway system also depends on the time required to rebuild the cableway to a new route. Time consumption is different if it is a complex preparation of the cableway for deployment on the first route, or if it is only conversion of the cableway to the next working field.

Mounty 4000 mountain processor

The Mounty 4000 processor is designed for timber processing in the main felling of coniferous trees in mountain conditions. The advantage of the Mounty 4000 processor is that most of its components are produced by the machine manufacturer, which guarantees their mutual alignment. In case of anti-gravity skidding, this machine is usually equipped with a cable car with the internal combustion engine that is controlled remotely by the operator. Using this car allows very considerate extraction, as the operator controls the stem movement from the stump to the cableway route precisely. Sherpa Mot, Woodliner, Moko 250 are cars suitable for anti-gravity skidding. Performance achieved when using this machine in Slovakia was 120 m^3/cm (Lukáč, 2002).

Processor assembly	Indicator	Value	Unit
Total assembly	Weight	24 000	kg
Driving unit – truck ÖAF 33.322	Engine power	235	kW
Hydraulic crane V-Kran 20.88	Reach Lifting moment	8.97 232	m kNm
Cableway Syncrofalke	Max. load capacity Max. car speed Height of the mast Working drum diameter Aerial line diameter Main line diameter Auxiliary line diameter	3 000 9.2 10.4 1000 18 11 8.5	kg $m.s^{-1}$ m mm mm mm mm
Processor Wolf 50 B	Weight with rotator Max. cut diameter Delimbed tree diameter Grapple opening Stem movement speed Tree movement force	830 500 400 850 1.8 45	kg mm mm mm $m.s^{-1}$ kN
Cableway car Sherpa U-3t	Loading capacity Weight	30 380	kN kg

Tab. 18. Parameters of Syncrofalke processor

Technology of felling with the mountain processor using the whole-tree method

Felling is performed by a power saw using a typical whole-tree method, whole trees are transported by the cableway, or the tops of the trees are cut off in the stand. In the improvement felling, there are two men in the stand (feller, cable fastener), in the regeneration felling, one worker performs both felling and load fixing. In the skyline logging, the trees are felled principally at an angle to the slope, namely in gravity skidding with the crowns towards the route and with the crowns away from the route in the anti-gravity skidding. The direction of felling should be practically identical to the direction of wood extraction, the steeper the slope, the sharper the angle of cable pulling out. The width of the cableway working field depends on the slope, direction of felling (pulling out) and also on the height of the stand in the gravity skidding. For ergonomic and performance reasons, the rational length of the cabler pulling out to sides should not exceed 30 m. The width of the working field when skidding trees against the slope should not exceed 40 m, including a 3-4 m wide line. When skidding down the slope, the width of the working field should be in the range of 60-80 m. Marking of the felling measure is standard, but the technological preparation of the site for the mountain processor is complex with regard to the processing of skidded logging residues. On the narrow slope roads, the storage capacity near the cableway processor is limited, therefore timber haulage must be synchronized with timber logging.

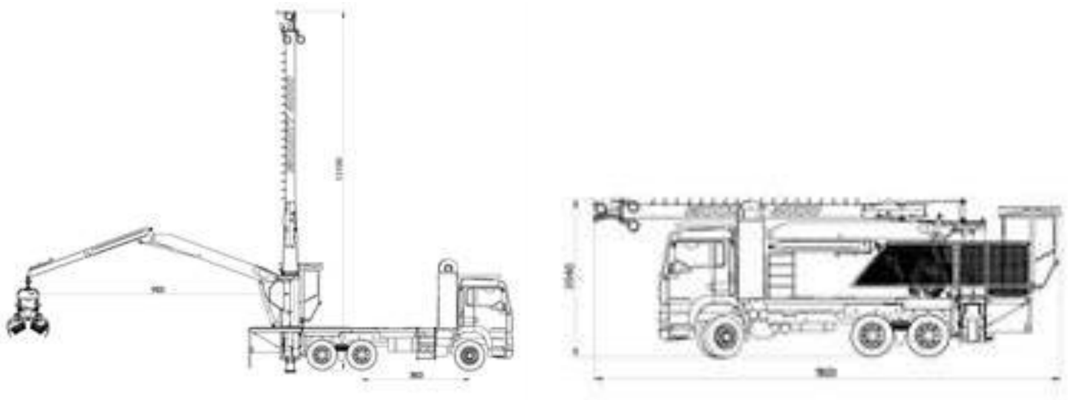


Fig. 91. Mounty4000 mountain processor

Technology of felling with the mountain processor using the whole-stem method

Technological preparation of the site is simpler than in the whole-tree method. With respect to performance parameters of the processor, it is necessary that felling and motor-manual delimbing be performed by at least two workers, another worker fastens the load (min. 4 workers are required in total). In case of short routes (up to 200 m), it is necessary to cope with the time disproportion between the motor-manual harvesting and timber skidding and sorting by the processor. The mass of small wood is left in the stand, only the Derbholz is processed. The logging measure is marked in a classic way.

Processor assembly	Indicator	Value	Unit
Total assembly	Weight	28 500	kg
Driving unit – truck Man/ÖAF 27.417 DFAC 6x6	Engine power	301	kW
Hydraulic crane Penz 2080M	Reach Lifting moment	9,6 200	m kNm
Cableway Mounty 4000	Max. load capacity Max. car speed Height of the mast Working drum diameter Aerial line diameter Main line diameter Auxiliary line diameter	4 000 5 (10) 12 10 12 20	kg $m.s^{-1}$ m mm mm mm
Processor WOODY 60	Weight with rotator Max. cut diameter Delimbed tree diameter Grapple opening Stem movement speed Tree movement force	830 650 600 1250 0-4 36-45	kg mm mm mm $m.s^{-1}$ kN
Cableway car Sherpa U-3t	Loading capacity Weight	30 350	kN kg

Tab. 19. Parameters of the Mounty 4000 processor

Symbol of the operation	Description of the operation (activity)	Average time consumption in min.
A1*	Travel of the empty car into the stand	0.93
A2*	Pulling the cable into the stand and fixing the load	1.50
A3*	Pulling the load from the stand under the main line	0.70
A4*	Skidding the load under the main line	1.03
A5	Lowering of the load onto the processor platform	0.43
A6	Releasing of the load and anchoring of the car	0.48
A7	Delimbing and production of assortments	2.18
A8	Sorting of the assortments and their storing on piles	0.88
* felling and operations A1 – A4 are running together with operations A7 – A8		

Tab. 20. Average time for work operations and activities with the Mounty 4000 (*Lukáč, 2002)*

6. References

- JOHN DEERE COMPANY. 2002. *Timberjack A John Deere Company (Příručka harvestorových technologií)*. Timberjack Oy, Tampere, 35 p.
- BARTOŠ, L., MÁCHAL, P., SKOUPÝ, A. 2009. Possibilities of using price analysis in decision making on the use of harvester technology in forestry. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 57(4), 31-36.
- BARTOŠ, L. 2009a. Kolik místa zbývá v našich lesích pro harvestory? *Lesnická práce*, 88(5), 22-23.
- BARTOŠ, L. 2009b. Možnosti využití harvesterových technologií těžby dříví na základě analýzy rozhodujících faktorů. Disertation Thesis. Mendel University in Brno.
- ČERMÁK, J., NERUDA, J., NADĚŽDINA, N., ULRICH, R., MARTINKOVÁ, M., GEBAUER, R., POKORNY, E., PRAX, A., HRUŠKA, J., NADĚŽDIN, V. 2006. Identification of tree root damage caused by heavy machinery using new measurement technology suitable for precision forestry. In: *Precision Forestry in Plantations, Semi-Natural and Natural Forests*, p. 291--304. ISBN 0-7972-1121-7
- DOLEJSKÝ, V. et al. 2006. *Projektování výroby a prodeje dříví*. LS Telč.
- DOUDA, V. 1986. *Nepříznivý vliv techniky na lesy*. Praha VŠZ Praha.
- DOUDA, V. 1988. *Poškozování lesních porostů těžební a dopravní technikou*. Lesnictví, 34(1), 29-50.
- DUMMEL, K. 1999. *Hochmechanisierte Technologien der Forstnutzung*. Speech on International Conference Formec, Delnice, Chorvatsko. Unpublished.
- ERLER, J. et al. 2002. *Forsttechnik*. Skriptum. TU Dresden.
- HEINIMANN, H. R. 1998. *Produktivität und Einsatzbedingungen verschiedener Harvestertypen – eine statistische Auswertung aufgrund von Leistungsnachweisen*. ETH Zürich.
- HEIJ, W., LEEK, N. A. 1981. *Impacts of wood harvesting technology on soil and vegetation*. Proceedings XVII. IUFRO Japan, p. 21-32.
- JOHN DEERE FORESTRY. 2015. *Operator's Instructions 1070E/1170E*. Tampere. Worldwide Construction and Forestry Division. F074164.
- JOHN DEERE FORESTRY. 2016. *Operator's Instructions H414*. Tampere. Worldwide Construction and Forestry Division. F074202.
- JOHN DEERE FORESTRY. 2016. *Operator's Instructions 810E*. Tampere. Worldwide Construction and Forestry Division. F684808.
- SVAZ ZAMĚSTNAVATELŮ DŘEVOZPRACUJÍCÍHO PRŮMYSLU, SPOLEČENSTVO DŘEVOZPRACUJÍCÍCH PODNIKŮ V ČR, ČESKÁ ASOCIACE PODNIKATELŮ V LESNÍM HOSPODÁŘSTVÍ, LESY ČESKÉ REPUBLIKY. 2002. *Doporučená pravidla pro měření a třídění dříví v České republice*. Svaz zaměstnavatelů dřevozpracujícího průmyslu, Společenstvo dřevozpracujících podniků v ČR, Česká asociace podnikatelů v lesním hospodářství, Lesy České republiky, Praha – Hradec Králové.
- MZČR. 2006. *Zpráva o stavu lesa a lesního hospodářství České republiky v roce 2005*. 1st Edition. Praha: Ministerstvo zemědělství, Výroba a dovoz lesnické techniky, p. 110-114. ISBN 80-7084-550-3
- MZČR. 2009. *Zpráva o stavu lesa a lesního hospodářství České republiky, stav k 31. 12. 2008*. Praha: Ministerstvo zemědělství ČR. ISBN 978-80-7084-861-6
- MZČR. 2012. Výroba a dovoz lesnické techniky. In: *Zpráva o stavu lesa a lesního hospodářství České republiky v roce 2011*. 1st Edition. Praha: Ministerstvo zemědělství, p. 123-125. ISBN 978-80-7434-063-5
- MZČR. 2013. Výroba a dovoz lesnické techniky. In: *Zpráva o stavu lesa a lesního hospodářství České republiky v roce 2012*. 1st Edition. Praha: Ministerstvo zemědělství, p. 121-127. ISBN 978-80-7434-112-0
- ULRICH, R. et al. 2006. *Harvestorové technologie a jejich optimální užití v praxi*. MZLU v Brně, p. 87. ISBN 80-7375-012-0
- LASÁK, O., NĚMEC, K. 1996. Víceoperační těžebně-dopravní stroje. *Les. Práce*, 75(12), 447-449.
- LUKÁČ, T. 2002. *Viacoperačné stroje v lesnom hospodárstve*. TU ZVOLEN. ISBN 80-228-1348-6
- MALÍK, V., DVOŘÁK, J. 2007. *Harvestorové technologie a vliv na lesní porosity*. Forestalia 5. Lesnická práce. ISBN 978-80-86386-92-8
- NADEZHDINA, N., ČERMÁK, J. 1998. Responses of sap flow in spruce roots to mechanical injury. In: Proc. *Int. workshop EFI, MUAF IUFRO "Spruce Monocultures in Central Europe: Problems and Prospects"*. Brno 22 25 June 1998, p. 51.
- NADYEZHDINA, N., ČERMÁK, J., NERUDA, J. et al. 2006. Roots under the load of heavy machinery in spruce trees. *European Journal of Forest Research*, 125(1), 111-128.
- NERUDA, J. 2000. Theorie und Application der Methode zur Auswertung der Forstbeständeschäden nach der Holznutzung. In: *Proceedings of the International Scientific Conference Forest and Wood Technology vs. Environment- FORTECHENVI 2000*. Brno, pp. 255-260. ISBN 80-7157-471-6

- NERUDA, J. et al. 2013. *Technika a technologie v lesnictví*. Brno: Mendelova univerzita v Brně. ISBN: 978-80-7375-839-4
- NERUDA, J., SIMANOV, V. 2006. *Technika a technologie v lesnictví*. Brno: Mendelova zemědělská a lesnická univerzita v Brně. ISBN 80-7157-988-2.
- NERUDA, J., ULRICH, R., VALENTA, J. 2006. Analýza faktorů výkonnosti středních harvestorů. In: PUCHOVANOVÁ, I. *Trendy lesníckej, drevarskej a enviromentálnej techniky a jej aplikácie vo výrobnom procese*. Zvolen: Technická univerzita vo Zvolene, Fakulta enviromentálnej a výrobnej techniky, p. 156-163. ISBN 80-228-1648-5
- NERUDA, J., VALENTA, J. 2004. *Determinace poškozování lesních porostů těžebními technologiemi*. Monografie. Folia Universitatis Agriculturae et Silviculturae Mendelianae Brunensis. Brno: MZLU. ISBN 80-7157-820-7
- NERUDA, J., VALENTA, J. 2004. *Faktory výkonnosti harvestorových technologií lesní těžby. Monografie*. Folia Universitatis Agriculturae et Silviculturae Mendelianae Brunensis. Brno: MZLU.
- SALANCI, J. et al. 1989. *Teória polnohospodárskych strojov*. Alfa Bratislava.
- SCHÄTTLE, S., PFEIL, C. 1999. *Anweisung zur Aufnahme von Bestandesschäden nach der Holzernte (Entwurf)*. Forstliche Versuchs- und Forschungsanstalt Baden – Württenberg, Freiburg a.Br, p. 1-14.
- SCHLAGHAMERSKÝ, A. 2003. Zjišťování poškození půdy harvestory v probírkách. *Lesnická práce*, 82(10), 85-87.
- SIMANOV, V. 1998. *Harvesterové technologie. Podmínky jejich provozního využívání a perspektivy dalšího rozvoje v ČR*. Study. Brno.
- SIMANOV, V. 2004. *Soudobé technologie těžby a dopravy dříví ve smrkových porostech. In Smrk – dřevina budoucnosti*. Svoboda nad Úpou: Lesy České republiky, s.p.
- STAMPFER, K. 1998. *Harvester leistungs Daten*. Untersuchungsergebnisse aus Aufnahmen bei Geländeneigungen von 20 – 60 %. Report. Wien: Universität für Bodenkultur.
- STAMPFER, K. 1999. Influenceš of terrain conditions and thinning regimes on productivity of a track-based steep slope harvester. In: *Proceeding of the International Mountain Logging and 10th Pacific Northwest Skyline Symposium*. Oregon, pp. 78 – 87.
- ULRICH, R. et al. 1999. *Zjišťování škod ve smrkových probírkových porostech po harvestorech a vyvážecích traktorech: výzkumná zpráva*. Brno: MZLU LDF.
- ULRICH, R. et al. 2006. *Možnosti uplatnění sortimentních technologií ve správě LČR, s.p.* Brno: LČR, s.p. Hradec Králové, MZLU v Brně. ISBN 978-80-7375-051-0
- ULRICH, R., NERUDA, J., VALENTA, J. 2003. *Vliv podvozků těžebních strojů na podloží*. Read on IX. International Symposium Use of film and video – computer techniques in agricultural research. Zakopane, Polsko, 12.-13.6.2003.
- ULRICH, R., SCHLAGHAMERSKÝ, A., ŠTOREK, V. 2003. *Použití harvestorové technologie v probírkách*. MZLU v Brně. ISBN 80-7157-631-X
- ULRICH, R., NERUDA, J., KUPČÁK, V., KNEIFL, M., KLIMÁNEK, M., VALENTA, J., HÁNA, J., MORAVEC, P. 2006. *Možnosti uplatnění sortimentních technologií ve správě LČR, s.p.*. Výzkumná zpráva. Brno.
- ULRICH, R., VALENTA, J. 2006. Kriteria výběru porostů vhodných pro harvestorovou techniku. In: *Perspektívy vývoja ťažbovo-dopravného procesu a využitia biomasy v lesnom hospodárstve*. Zvolen: Technická univerzita vo Zvolene, p. 277-281. ISBN 80-228-1661-2

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