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# ANALYSIS OF FACTORS OF THE QUALITY OF LOGS PRODUCED BY HARVESTERS

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## Abstract

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Increasing demands of the present society lead to an effort to rationalize logging operations in forest management. Therefore, multi-function logging machines are increasingly used in the course of timber harvesting. Nevertheless, the economic effectiveness of these machines is affected not only by their productivity or environmentally friendly operations but also the quality of performed work. It can be evaluated by the assessment of the quality of produced assortments. Decreasing quality of produced logs can result in the reduction of marketability and wood price. Thus, the aim of this paper is to determine some defects originating at the harvester production of assortments and specification of their potential causes.

harvesters, harvester heads, damage to log surface

In forest harvesting, a number of multi-function machines is used, however, particularly “harvester chains” brought to forest management so far unusual dynamics, changed the organization system of logging technologies and the flow of wood from the forest to a consumer. The machine efficiency reached commonly by these technologies is extreme as compared with motor-manual procedures. The use of multi-operation machines in logging or so called harvester technologies of forest exploitation brings not only previously unimaginable increase of labour productivity per one worker but also other demands on control activities, organization of work, technological preparation of workplaces, contracts and timber deliveries and transport (Neruda; 2008)

In the present always developing market economy, it is necessary lay stress on the maximalization of profit and relating minimization of losses at the sale of wood. It can be achieved by energy saving necessary for the production of assortments and reducing losses resulting from the economic devaluation of marketed wood. Losses resulting from decreased quality and thus also prices of wood are mostly caused by decreased marketability due to the occurrence of qualitative or quantitative defects originating during the production of logs. At the harvester production of wood assortments, the occurrence of these defects is mostly affected by factors, which can be divided according to their origin to natural factors and technical factors (Honsa, Neruda; 2008).

In the CR as well as in the world, many studies have been carried out dealing with the effect of harvester technologies on the natural environment or assessing economic aspects of their use. In these studies, however, minor attention is paid to problems of damage to logs produced by functional mechanisms of harvesters. Nevertheless, quality of these logs is one of the main parameters affecting economic effectiveness of the use of harvesters.

## THE LITERATURE OVERVIEW OF PROBLEMS

The first and evidently the most important (from the aspect of damage to logs) part of the harvester head are feeding rolls. In these rolls, the damage is most affected by the form of feeding rolls and their teeth, feeding rate and pressure of delimbing rolls.

In the point type of feeding rolls, the depth of the surface damage to logs increases with increasing pressure. Within the pressure range of 80 to 140 bars, points did not penetrate deeper than 8 mm although triangular points 10 mm long up to points of spherical type 18 mm long were used (Dahl, Wästerlund; 2008).

Some authors do not consider damage to logs by feeding rolls to be too serious. They consider damage caused during felling or handling operations to be more important. At damage caused by feeding rolls, particularly bark and cambium are affected. Wood is affected only at marked damage and even in this case, the depth of a defect reaches only several millimeters, seldom centimeters.

Damage caused by felling and handling occurs mostly directly in wood, most often in the stem base part, which is most valuable. Vandenberg (2002) mentions that damage to butt parts of assortments produced by a harvester deserves due attention. The most serious damage to the lower part of assortments originates during felling and the majority of studies dealing with damage to butts at felling were aimed at the felling head of a feller-buncher. There are several factors, which are considered to be the cause of damage to logs at harvester felling. These factors include the type and condition of a cutting mechanism, the harvester type, abilities/skills of the harvester operator and the size and morphology of the tree growth (Gallagher et al., 1985).

There are three types of damage, which can be caused by the used knife-type or shearing mechanism. These types of damage include: defibering the stem butt, origin of cracks and the rupture (pull-out) of wood fibres (Shaffer et al., 1990). Pulling out the wood fibres is in direct relationship to the size of a felled tree (Greene, McNeel; 1987). It means that with the increasing size of a tree the probability of damage to a butt log at felling also increases (Gallagher et al., 1985). A restrictive factor at the use of a knife-type or shearing mechanism consists in a fact that nearly every butt log will have the certain part of a log damaged (Vandenberg, 2002). In the majority of cases, it is possible to remove the damage shortening the log roughly by six inches (1 inch = 2.54 cm) (Shaffer et al., 1990). Although every butt log can be shortened, this defect will always cause a value loss. As compared to other damage caused by a shearing mechanism defibering and pulling out wood fibres was the most often occurring defect at quality butt logs (McNeel, Czerepinski; 1987).

The majority of damage originating at felling was found within the first 12 inches from the butt end. It was found that damage by cross cutting were greater at logs, which were cut as dry (Shaffer et al., 1990). Greene, McNeel, 1989 also found that the damage was hardly evident if the log wood was fresh and the breakage of wood at the thicker end of butt logs would decrease its tensile strength even by 42%. Damage to logs produced by harvesters equipped with a shearing mechanism is considerable. At their use, typical volume losses reached even 4.5% while at the operation of harvesters with a cutting mechanism equipped with a saw device they reached only 0.25% (Greene, McNeel; 1989). At the use of a cutting head equipped with a knife-type mechanism, damage is negligible as compared with a shearing (scissor) cutting device. It has been found that damage to butt logs at chain felling reach only 0.64% of wood volume (Gallagher et al. 1985). According to Middleton and Munroe (1987) the total value of losses resulting from the damage to logs exceeds 13%.

A feller-buncher equipped with knives can have an advantage as against chain felling, namely in forests where the majority of cut wood reaches smaller dimensions (Hassler et al., 1999). At the use of a tree-length system, a feller-buncher does not make damage to logs produced from upper parts of a tree. Chain cutting damages both lower as well as upper parts of stems in the same way (Lamson et al., 1985).

It follows that to give precedence to defibering, production cracks and pulling out a sloven from a butt over a surface damage caused by feeding rolls or imperfect delimbing is not substantiated at the use of a knife-type felling head.

## MATERIAL AND METHODS

To evaluate the dependence of factors on the origin of defects it was necessary to divide them first according to their origin into two related groups, viz natural and technical factors. Concrete defects and factors affecting them were then determined (Tab. 1). Subsequently, general hypotheses were inductively determined on the effect of particular factors on the origin of defects. Through the statistical analysis of a background database particular hypotheses were proved or disproved.

The background databases were compiled from values obtained by field measurements. These measurements were carried out in mature and thinning spruce stands, which have to be older than 40 years in order to involve all diameter classes. Because of the elimination of undesirable effects on results, the measurements were not carried out in stands where harvester technologies were used in salvage or incidental felling.

### Measuring the factors

In each of the samplers, following parameters were measured. To determine the log volume its length and mean diameter were measured. The length was measured by a tape along the stem surface accurate to cm. The mean diameter was measured by a caliper also accurate to cm, namely using two measurements perpendicular at each other and an arithmetic mean was calculated from them. Thus, the log diameter was also obtained. Branches were divided according to diameter into classes, viz. the 1$^{st}$ 0 to 2 cm, the 2$^{nd}$ 3 to 5 cm incl. and the 3$^{rd}$ > 5 cm. Then, the number of branches of the highest class was calculated per one linear meter about in the middle of the log. If it related to a butt, it was registered in the form of binary values, viz. 0 – occur and 1 – do not occur. At delimbing knives, a cutting-wedge angle was measured, chord length and the highest deflection. On the basis of these data it was possible to calculate the radius of their curvature. To determine the chain sharpening a photo was taken of the cutting link of

Photo: Jan Honsa

1: *Medium damage*

Photo: Jan Honsa

2: *Heavy damage*

a harvester head using a camera with high resolution (at least 6 Mpix). Through the photograph analysis the cutting edge radius of a chipper link was determined

### Measuring the defects

To determine surface damage this damage had to be divided into three groups: undamaged or slightly damaged, moderately damaged and heavily damaged. Since the research was carried out under operation conditions where an effort was to ensure the continuous flow of wood, it was necessary to accelerate the measurement at the most. If there were more types of defects on a stem or more defects of the same type, the most serious and largest defect was measured, because the largest defect makes the technical quality of the wood assortments. A log the surface of which is not disturbed by feeding rolls or a log showing marks caused by feeding rolls, which, however, did not affect its technical usability and marketability, is taken as an undamaged or only slightly damaged assortment. This damage to logs is not measured but only its occurrence is registered. An assortment where at least part of bark is removed due to feeding rolls and thus, wood is exposed (however, not damaged), is considered to be a moderately damaged assortment. This damage does not decrease technical applicability of wood but depending on a consumer/customer, it can reduce its marketability or price. An assortment, where due to feeding rolls bark and phloem is removed and, at the same time, mechanical damage to wood occurs, is considered to be a heavily damaged assortment. This fact can result in the reduced marketability of wood but also decreased technical usability (Honsa, Neruda; 2007).

Leaving branches or their parts on a stem or pulling out the branches from a stem is considered to be imperfect delimbing. Cracks caused during felling but also by pulling out a solven from the butt or stump are considered to be production cracks. Production cracks and imperfect delimbing were registered similarly as a butt, namely by a binary code 0 and 1, i.e. they occur or they do not occur.

A difference between length measured by a harvester and actual length is considered to be erroneous measurement. This difference is expressed in % in every assortment. The actual length is measured by a tape along the stem surface.

### Analysis of data

With respect to the considerable amount of measurements it was necessary to use Statistika 8 program to process the data. In this program, the Shapiro-Wilk's test of normality was carried out (if it was necessary). Then, a box diagram was created showing extremes and distant values. Checking the validity of hypotheses was carried out by means of multi-factorial ANOVA.

## RESULTS

### Hypotheses

#### *Natural factors*

1. **Season** of harvesting affects surface damage
2. **Diameter of branches** affects surface damage
3. **Number of branches** affects surface damage
4. **Log diameter** affects surface damage
5. **Log diameter** affects imperfect delimbing
6. **Number of branches** affects imperfect delimbing
7. **Diameter of branches** affects imperfect delimbing
8. **Log volume** affects the origin of production cracks
9. **Butt** affects the origin of production cracks
10. **Season** of harvesting affects the erroneous measurement of length

Photo: Jan Honsa

3: *Imperfect delimbing*

11. **Number of branches** affects the erroneous measurement of length
12. **Diameter of branches** affects the erroneous measurement of length

### *Technical factors*

13. **Cutting-wedge angle** affects the surface damage
14. **Chain sharpening** affects the origin of production cracks
15. **The curvature radius of delimbing knives** affects imperfect delimbing.

cant statistical deviation among these values. It also proves that **hypothesis 1 is valid**. The diameter of branches (the size of knots) affects both medium and heavy surface damage. A slightly increasing trend in the diagram shows that with the increasing diameter of branches the damage also increases. It follows that **hypothesis 2 is valid**. According to Fig. 1, the trend of a curve describing effects of the number of branches (knots) on surface damage is steady or ranges about the same values (at medium damage) thanks to a repeating decreasing and increasing tendency. A deviation is also evident at the number of knots ≥ 10. This deviation is caused by the low number of sample trees where such a high number of branches occurred and thus, it is insignificant from statistical aspects. Therefore, on the basis of these data, **hypothesis 3 is invalid**. The curve trend illustrating the surface damage dependence on a diameter class in Figs. 2 and 3 shows a slightly decreasing character. Exceptions are as follows: diameter class 34, at medium damage also diameter class 46 and at heavy damage diameter class 50. Nevertheless, between these values and other values there is no statistically significant difference. However, it is noted at diameter class 10 at medium damage. This difference proves that with an increasing diameter class the surface damage is lower and thus, **hypothesis 4 is valid**.

I: *Determination of factors and defects*

| | Natural factors | | | | | | Technical factors | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Logging season** | **Log volume** | **Log diameter** | **Number of branches** | **Branch diameter** | **Butt** | **Cutting-wedge angle** | **Curvature radius** | **Chain sharpening** |
| **Surface damage** | ✓ | • | ✓ | ✓ | ✓ | • | ✓ | • | • |
| **Cracks** | • | ✓ | • | • | • | ✓ | • | • | ✓ |
| **Imperfect delimbing** | • | • | ✓ | ✓ | ✓ | • | • | ✓ | • |
| **Erroneous measurement of length** | ✓ | • | • | ✓ | ✓ | • | • | • | • |

## Results

Resulting confirmation or refusal of particular hypotheses was carried out on the basis of diagrams, examples of which are part of an appendix. In the majority of cases, these diagrams are the graphical output of multi-vector ANOVA carried out in the Statistika program. View of *p*-values by multi-vector ANOVA is contained in Table II.

II: *View of p-values by multi-vector ANOVA* ($\alpha = 0{,}05$)

| | Natural factors | | | | | | Technical factors | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Logging season** | **Log volume** | **Log diameter** | **Number of branches** | **Branch diameter** | **Butt** | **Cutting-wedge angle** | **Curvature radius** | **Chain sharpening** |
| **Surface damage** | 0,00000 | • | 0,00007 | 0,19897 | 0,01602 | • | 0,00000 | • | • |
| **Imperfect delimbing** | • | • | 0,00000 | 0,00000 | 0,00000 | • | • | 0,00000 | • |
| **Erroneous measurement of length** | 0,00000 | • | • | 0,92045 | 0,65290 | • | • | • | • |

### *Surface damage*

Results demonstrating effects of a season on the surface damage show that at heavy damage, there is the evident decline of the trend only between spring – summer and autumn – winter couples. At medium damage, there is a marked decline of the trend in winter months and then a considerable increase in spring months. There is a signifi-

According to results depicting the effect of a cutting-wedge angle on the surface damage, it was not possible to confirm this dependence at heavy damage. On the other hand, there is a marked ascending trend and a statistically significant difference occurs at all values of medium damage. It follows that with the increasing size of a cutting-wedge angle the size of medium damage also increases. Therefore, it is possible to state that **hypothesis 13 is valid**.

### *Imperfect delimbing*

A curve illustrating the dependence of imperfect delimbing on a diameter class shows a decreasing trend. An exception occurs at diameter class 46 where the value of imperfect delimbing slightly increases. On the basis of that it is possible to note that with an increasing diameter class the imperfect delimbing decreases and thus, **hypothesis 5 is valid**.

Fig. 4 shows that the trend of a curve illustrating the dependence of imperfect delimbing on the number of branches is ascending. In case of the number of branches ≥ 10, marked changes of the trend are evident. It is caused by the small number of sample trees where this high number of branches occurred. Therefore, these data are insignificant from the aspect of statistics. In case of < knots, an increasing trend with significant statistical differences is evident. Thus, it is possible to claim that **hypothesis 6 is valid** and a statement holds good that with the increasing number of knots the occurrence of imperfect delimbing increases.

In Fig. 5, the ascending trend is evident of a curve depicting the dependence of an imperfect delimbing on the diameter of branches. There is a significant difference between classes of knots 1 and 2, 3. Thus, it is possible to state that **hypothesis 7 is valid**. It follows that imperfect delimbing is dependent on the diameter of branches.

According to Fig. 6, the curve trend depicting the dependence of imperfect delimbing on the curvature radius is increasing. There is a significant statistical difference between values 23 and 27 as well as between values 28 and 29. Thus, we can say that with the decreasing radius of curvature of delimbing knives the imperfect delimbing will be lower but only till then the radius of curvature will be equal to the radius of the delimbed part diameter of a stem. Thus, **hypothesis 16 is valid**.

### *Production cracks*

It is evident from the results of statistical analysis that the larger the log volume the larger probability of the origin of production cracks. On the basis of these data it is possible to note that **hypothesis 8 is valid**. A dependence of the origin of cracks on the occurrence of a butt shows an ascending trend. A marked turn occurs if the butt occurrence is equal to 40%. At this value, rapid increase in the probability of the origin of cracks occurs. Based on this results it is possible to note that **hypothesis 9 is valid**. Comparing an ascending character and illustrates probability of the origin of cracks and a curve illustrating measured values of radii of a sharpened chain, which is rather of steady character, there is no marked detectable dependence between them. On the basis of these data it is possible to say that **hypothesis 14 is invalid**.

### *Erroneous measurements of length*

According to a diagram in Fig. 7 describing the effect of a season on erroneous lengths, there is a marked increase between autumn and spring. Then, the curve is of declining trend and at comparing winter and summer, rather a steady trend. A significant statistical difference occurs between autumn and spring. Thus, it is possible to state that **hypothesis 10 is valid** and in spring, the probability of erroneously measured lengths increases. A trend expressing the dependence of erroneously measured length on the number of branches in Fig. 8 is rather steady. Its changes occur at the number of branches ≥ 13. It is probably caused by the low number of sample trees where these high numbers of branches occurred. Therefore, it is possible to say that **hypothesis 10 is invalid**. Similarly if we observe a trend expressing the dependence of erroneously measured length on the diameter of branches it is possible to term it as steady without significant statistical differences. It shows that **hypothesis 12 is invalid**.

## DISCUSSION

### *Surface damage*

On the basis of the effect of a season on the origin of the medium surface damage it is possible to note that the quantity of sap is an important factor affecting this damage. During the period of sap, the adhesion of bark to wood is considerably reduced and thus, the assortment is more liable to the origin of damage. Damages of logs caused by harvester in the spring season are more stronger as in the winter season. Thus, a statement is also confirmed that damage in the course of dormancy is lower than in the growing season because in the winter season, the cohesion of bark and its adhesion to wood is about 2 times higher than in the period of sap (Simanov, 1999). Heavy damage is not any more affected by this factor because it refers to the zone of wood under cambium. At large-diameter branches, the amount of energy necessary for their proper cutting off is increased.

Since this energy is transferred to a processed tree by feeding rolls their slipping can occur when certain limits are exceeded. This results in damage to a butt in the place of contact of these feeding rolls with a stem (Honsa, Neruda; 2008). Since effects of the number of branches on surface damage were not proved in this paper it is possible to say that feeding rolls have to transfer more energy on the tree stem at cutting off one large branch than at cutting several small branches. It can be also caused by a fact that there is small probability to cut off several small branches at the same time them to cause the same resistance as one large-diameter branch. It has been found that with a decreasing log diameter the surface damage increases. It is caused by the higher occurrence of large-diameter branches in these areas. This event can be also affected by the problematic gripping of small-diameter branches by a harvester head or by bark thickness, which decreases towards the tree top. At the results obtained, effects of the cutting-wedge angle of delimbing knives were evident only at medium damage. Thus, it is possible to say that the higher the cutting-wedge angles the higher the surface damage. To optimize their sharpening it is necessary to take into account that with the decreasing cutting-wedge angle its faster blunting will occur.

### *Imperfect delimbing*

The dependence of imperfect delimbing on a diameter class is given by a fact that with the increasing log diameter the number of branches decreases. There is also a condition that at small-diameter logs the transmission of energy by means of feeding rolls is insufficient. It results in the deceleration of feeding rate and thus, problems occur at delimbing. It is also proved by Dahl and Wästerlund (2008), who urge that good gripping affects productivity and feeding rate. It has been also found that with the increasing number or diameter of branches demands of quality delimbing increase.

On the basis of measured values it is possible to state that the cutting-wedge angle of delimbing knives does not affect the quality of cutting off branches. It is possible to suppose that this quality is rather affected by the pressure of delimbing knives or by their sharpening (the size of the edge curvature radius) or delimbing rate. These hypotheses will be the subject of follow-up research. Imperfect delimbing is markedly dependent on the radius of the delimbing knives curvature. It is also possible to declare that with the decreasing radius of the delimbing knives curvature the occurrence of imperfect delimbing is reduced. This can be caused by better copying the stem surface at lower diameter classes. Therefore it is very important to optimize the harvester head size in relation to thickness of trees in the stand.

### *Production cracks*

Production cracks result from the different resistance of wood at stress along and across the grain. The smaller strength of wood across the grain results in its longitudinal split at flexural stress. The higher the volume of a cut off assortment the higher the log weight and thus also the flexural stress of wood and the subsequent origin of production cracks. It is also possible to say that the occurrence of production cracks is more frequent in butt parts. It is caused by wood cracking at its pushing in the direction of felling. However, it is also the consequence of using a harvester head the cut of which does not reach the tree diameter at the stump. In this case, the whole stem diameter is not cut off at felling or cross-cutting. The stem will remain connected with a butt through a sloven, which will cause stress in the wood and subsequently its splitting or the rapture of wood fibres.

The effect of chain sharpening on the origin of production cracks was not proved in this paper.

Since the measurement was carried out under operation conditions when an endeavour occurred of the owners of harvester technologies to use always sharpened chains and not under laboratory conditions, it was not possible to determine the effect of a blunted chain on the origin of cracks. Nevertheless, on the basis of these measurements, it is possible to say that in spruce stands and under favourable field conditions, sufficient chain sharpening will endure for the period of one working day, ie 8 hours of work. As against motor-manual felling, this difference is caused by controlled pressure on a cutting bar, controlled pre-stress in a stem in the course of its felling, low contact of a stem with ground and resulting cutting the polluted wood and, last but not least, by larger chipper links of the harvester head chain as against chains of a power saw.

### *Erroneous measurements of length*

If wood is felled in the period of sap sufficient energy transfer on the stem is not always ensured by means of feeding rolls. It results in the occasional stopping of delimbing at slipping feeding rolls or even repeated return at attempts to cut off large-diameter branches. In the period of sap, there is higher probability of slipping the measuring mechanism. Thus, an error increases at the measurement of length. In case the slipping of feeding rolls and a measuring mechanism will be prevented it is possible to say (on the basis of data obtained) that the diameter or the number of branches do not show direct effects on the size of an error at the measurement of length.

## CONCLUSION

For the determination of the effect of factors on the origin of defects on assortments produced by harvesters 1961 sample trees were measured. In each of the sample trees, both natural (season of felling, volume of logs, log diameter, number of branches, diameter of branches, butt) and technical (cutting-wedge angle, radius of the curvature of delimbing knives, chain sharpening) factors were determined. Subsequently, hypotheses were determined of the dependence of particular defects on these factors. By means of statistical programs, these hypotheses were either proved or disproved and subsequently, causes of the dependence of defects on these factors were deductively derived.

On the basis of these measurements it has been found that the size of surface damage is dependent on the suitably chosen season and the related period of sap, diameter of branches and the diameter of logs, which correlates with the occurrence of large-diameter branches and thick bark. On the other hand, the number of branches does not affect the origin of surface damage to the extent as it could be supposed. It has been also proved that there is higher probability of the occurrence of production cracks at felling than at following cross cutting. The dependence of the origin of cracks on the volume of logs was also proved. Based on data obtained the dependence is also evident of imperfect delimbing on the number and diameter of branches and even on the log diameter. The erroneous measurement of length was significantly affected only by the season of felling when again negative effects on felling showed the period of sap. Assumptions were also disproved that the number and diameter of branches affected erroneous measurements of length.

It is also evident that with the increasing cutting-wedge angle of delimbing knives energy necessary to cut off branches increases. However, this fact does not become evident by imperfect delimbing but by higher requirements for the transmission of energy by means of feeding rolls and, thus, the origin of surface damage. It has been also proved that the curvature radius of delimbing knives shows a marked effect on the quality of delimbing and that it is necessary to pay attention to copying the stem shape in narrower parts of the stem where there are more branches. On the basis of measurements carried out within this research effects of chain sharpening on the origin of production cracks were not proved. However, it is logical that this effect would be proved under controlled laboratory conditions or where it would be possible to evaluate defects on logs produced by a harvester with a blunted cutting mechanism.

A group of those factors of the origin of defects at assortments that are related to a "human factor" can be evaluated as very significant. These factors include, for example, wrong work of the harvester operator, badly selected type and size of a harvester points/nodes with respect to the age, species and spatial structure of stands, their bad preparation etc. It is possible to suppose that these factors could be most important out of all three groups. Already at present, it is possible to say that they show the greatest effect on the productivity of harvester technologies. Unfortunately, in practice, this group of factors is quantifiable only with difficulties.


## SOUHRN

### Analýza faktorů kvality výřezů vyráběných harvestory

Pro určení vlivu faktorů na vznik vad na sortimentech vyráběných harvestory bylo změřeno 1961 vzorníků. U každého vzorníku byly zjišťovány jak faktory přírodní (roční období těžby, hmotnatost výřezů, tloušťka výřezu, počet větví, tloušťka větví, oddenek), tak i faktory technické (úhel břitu, poloměr zakřivení odvětvovacích nožů, nabroušení řetězu). Následně byly stanoveny hypotézy závislosti jednotlivých vad na těchto faktorech. Tyto hypotézy byly pomocí statistických programů buď potvrzeny či zamítnuty a následně byla deduktivně odvozena příčina závislosti vad na těchto faktorech.

Na základě těchto měření bylo zjištěno, že se velikost povrchového poškození odvíjí od vhodně zvoleného ročního období těžby a s tím souvisejícím obdobím mízy, od tloušťky větví a od tloušťky výřezu, která koreluje s výskytem silných větví a se sílou kůry. Oproti tomu počet větví neovlivňuje vznik povrchového poškození takovou měrou, jak by se dalo předpokládat. Také se potvrdilo, že je větší pravděpodobnost výskytu výrobních trhlin při kácení stromu než při jeho následném přeřezávání. Byla také prokázána závislost vzniku trhlin na hmotnatosti výřezu. Ze získaných údajů je také patrná závislost nedokonalého odvětvení na počtu a tloušťce větví a dokonce i na tloušťce výřezu. Chybné změření délky bylo prokazatelně ovlivněno pouze ročním obdobím těžby, při kterém na ně mělo opět negativní vliv období mízy. Byly také vyvráceny domněnky, že má počet a tloušťka větví vliv na chybné změření délky.

Z výsledků je také patrné, že se zvyšujícím se úhlem břitu odvětvovacích nožů se zvyšuje energie potřebná k odříznutí větve. To se však neprojevuje nedokonalým odvětvením, nýbrž opět většími požadavky na přenos energie pomocí podávacích válců, a tudíž na vznik povrchového poškození. Také se potvrdilo, že poloměr zakřivení odvětvovacích nožů má výrazný vliv na kvalitu odvětvení a že je potřeba klást větší zřetel na kopírování tvaru kmene v užších částech kmene, kde se vyskytuje více větví. Vliv nabroušení řetězu na vznik výrobních trhlin se na základě měření provedených v rámci tohoto výzkumu nepotvrdil. Je zde ale logický předpoklad, že by se tento vliv potvrdil v řízených laboratorních podmínkách nebo tam, kde by bylo možné hodnotit vady na výřezech vyrobených harvestorem s otupeným řezacím ústrojím.

Jako velmi významnou lze nesporně hodnotit skupinu těch faktorů vzniku vad na sortimentech, jež jsou spojovány s tzv. lidským faktorem. K těmto faktorům patří např. špatná práce operátorů harvestoru, špatně zvolený typ a velikost harvestorových uzlů vzhledem k věkové, druhové či prostorové skladbě porostů, jejich špatná příprava a jiné. Dá se předpokládat, že by tyto faktory mohly být ze všech tří skupin nejvýznamnější a už nyní lze konstatovat, že mají největší vliv na produktivitu harvestorových technologií. Bohužel v praxi je tato skupina faktorů jen velmi obtížně kvantifikovatelná.


harvestor, harvestorová hlavice, poškození výřezů

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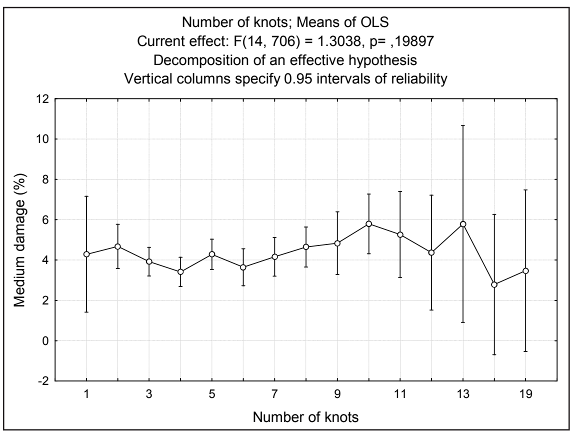
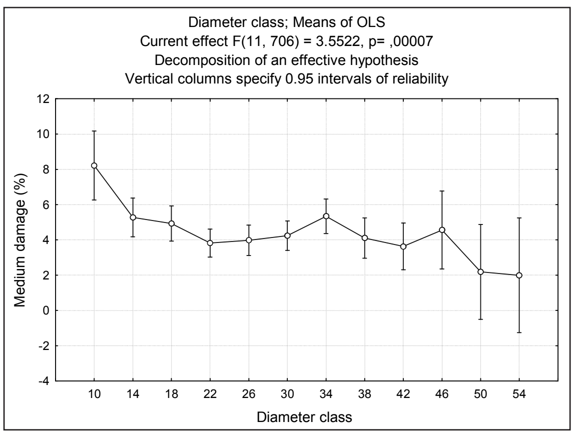
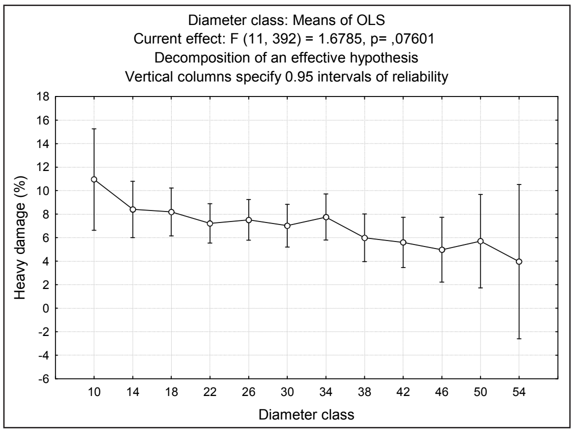
## APPENDICES




1: *Multi-factorial ANOVA – Dependence of the mean surface damage on the number of branches*




2: *Multi-factorial ANOVA – Dependence of the mean surface damage on a diameter class*

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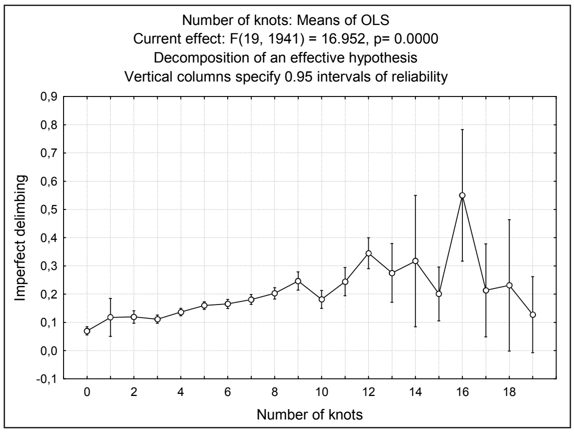
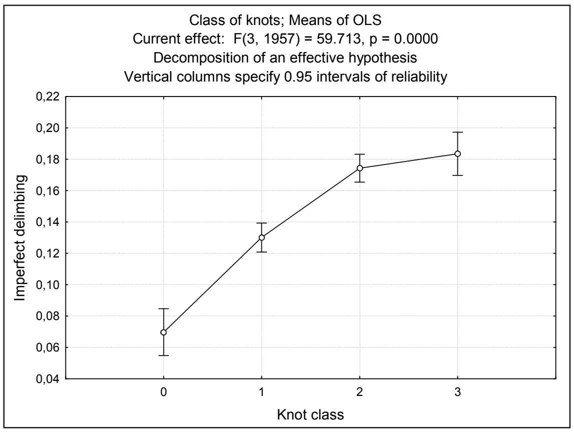
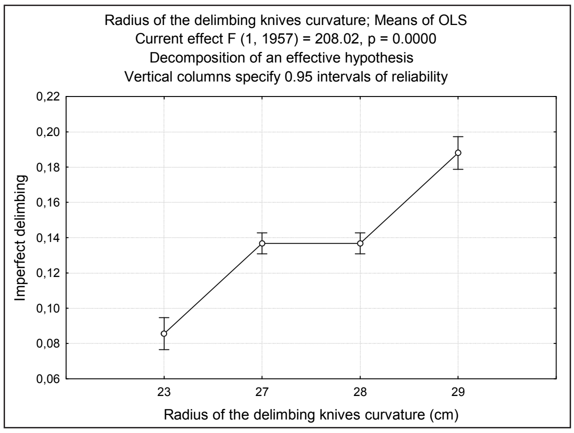


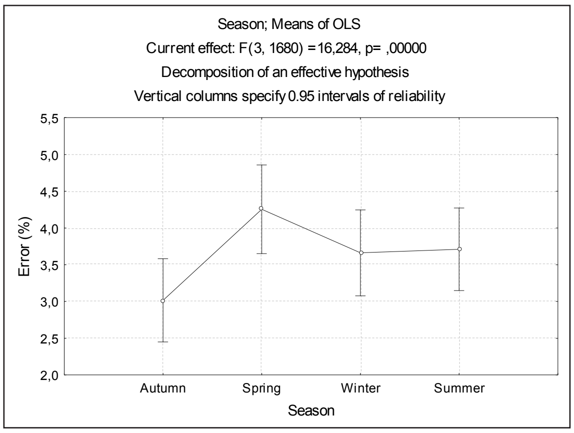

4: *Multi-factorial ANOVA – Dependence of the imperfect delimbing on the number of branches*



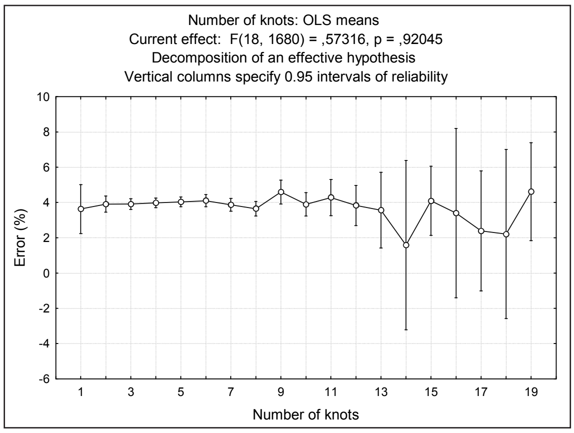

5: *Multi-factorial ANOVA – Dependence of imperfect delimbing on the diameter of branches*




6: *Multi-factorial ANOVA – Dependence of imperfect delimbing on the curvature radius of delimbing knives*




7: *Multi-factorial ANOVA – Dependence of the erroneously measured length on the season*




8: *Multi-factorial ANOVA – Dependence of the erroneously measured length on the number of branches*

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