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Shape of Scots pine knots close to the stem pith

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SELOSTE: MÄNNYN OKSAN MUOTO RUNGON YTIMEN LÄHELLÄ

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The shape of Scots pine knots close to the pith of butt logs was investigated. 1100 knots were split in a vertical direction, and their shape was measured. Knot diameter and branch angle were calculated at a distance of 40 mm from the pith of the stem. The mean diameter of all the knots in the material was 14 mm, and the branch angle 70°. Regression analysis was used to devise a formula for predicting branch angle on the basis of knot diameter. Knot size and branch angle were negatively correlated. Especially the shape of larger knots was curved. Knots achieved their maximum diameter at distance of 4–5 cm from the stem pith. The branch wood was almost completely situated above the formation point of the branch.

1100 männynoksan muotoa selvitettiin tyvitukin ytimen lähellä. Oksat halkaistiin pystysuoraan läpimitan, oksakulman ja oksan muodon selvittämiseksi. Kaikkien oksien keskiläpimitta oli 14 mm ja oksakulma 70°. Keskimääräinen läpimitta kasvoi oksien etäisyyden maahan lisääntyessä. Regressioanalyysin avulla laadittiin yhtälö oksakulman ennustamiseksi oksan läpimitan avulla. Oksakoko ja -kulma korreloivat negatiivisesti keskenään. Oksan muoto oli kaareva, aluksi oksat olivat alaspäin kuperia, mutta varsinkin suurten oksien kuperuuden suunta muuttui päinvastaiseksi pituuden kasvaessa. Kaarevuuden takia oksapuu oli lähes kokonaan syntypistettään ylempänä. Oksat saavuttivat suurimman läpimittansa 4–5 cm:n päässä rungon ytimestä.

Keywords: *Pinus sylvestris,* logs, knot diameter, knot shape.
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1. Introduction

11. Branch development

The height growth of Scots pine is monopodial i.e. the tree grows in height from the terminal bud. The stem is formed from the terminal bud, which usually remains more dominant than the lateral branches throughout the crown. The other buds in the crown bend to the side owing to the dominance of apical bud, thus forming branches. The same phenomenon is repeated each year in the leader shoot and the tips of the branches if they get enough light; hence the leader shoot and strongest lateral branches grow most in thickness and height (Kalela 1963).

Initially the length and diameter growth of the branches are of the same order of magnitude as the stem of the tree, although they decline within a few years compared to the stem wood. Growth of the stem and branches is interconnected, and hence the measures which increase the growth of the stem also increase the growth of the branches (Kellomäki and Väisänen 1986).

Only a few of the cells in the lower edge of the branch continue directly to the stem, and hence most of the tracheids in stemwood and branch wood are not in direct contact with each other. The cambium in the stem starts to grow earlier in the growing season than that in the branches, and it first grows around the butt cambium of the branch in the stem. Later on during the growing season the cambium of the branch butt grows on the cambium of the stem which is around the base of the branch. Thus the cambiums form a layerlike structure where the nutrients passing from the stem to the branches and vice versa move through these cells. After the branch dies it is isolated from the stemwood, which prevents pathogens from spreading along this pathway into the stemwood (Shigo 1985).

Although the anatomical structure of the branches is identical to that of the stemwood, the stemwood can be distinguished from the knot wood. This is because the wood fibers run in different directions, the branches have different proportions of different types of cell because they contain reaction wood, the cells in the branches are shorter than those in the stemwood, and the knot wood is in general more resinous than the stemwood (Kärkkäinen 1985).

As the stem increases in thickness part of the branches become immersed inside the stem, forming knots which are visible when the wood is sawn or otherwise split. Knots are considered to be defects in sawn timber because they reduce the strength of the wood - the knots are and also cause structural irregularities in the wood (Kärkkäinen 1985). Heiskanen (1954a) mentions that knottiness is the cause of almost 80% of timber defects, and is hence the major factor reducing the quality of sawn timber.

12. Grading knots in sawn timber

The main grading rules for sawn timber are given in Finnish Export Rules (Suomen... 1979), although the grading of knots in sawn timber is partly dependent on individual commercial agreements.

Knottiness always reduces sawn timber quality. The decrease in value is often defined on the basis of a number of factors used to grade the timber into different quality classes. Quality is affected by the size, location and shape of the knot in the sawn good, as well as the size of the sawn good. Larger knots are permitted in larger sawn goods than in smaller ones. Defects in the middle a sawn good have a greater effect on quality than those at the end, and if the knots are grouped together, their size and number must be smaller than individual defects.

Knottiness is estimated in the better face of a board at a length of 1.5 m of the worst quality, for which the largest permitted knot size and type is given in the grading rules.

13. Earlier studies

131. Branch angle

Branchiness can be depicted using the branch angle, number of branches, and the coverage of the cut surfaces of the branches (Uusvaara 1981). Branch angle refers to the angle between the stem pith and the branch pith, and is measured above the branch (Persson 1976). Branch angle and branch size are dependent on each other. The branch angle of thick branches is small, and vice versa (Uusvaara 1981). Branch angle increases with increasing age, and hence the knots become curved (Kärkkäinen 1985). This is due to the fact that as the length and mass of the branch increase, the angle of the branches becomes closer and closer to the horizontal position. Slender branches curve faster than strong ones (Huuri et al. 1987). Branch angle is also supposed to be affected by nutritional factors (Kärkkäinen and Uusvaara 1982). According to Varmola (1980), the branch angle of pines growing on OMT sites is slightly greater than that on less productive sites. Varmola also states that there is no dependence between branch angle and growing density. In contrast, Persson (1976) claims that they are weakly correlated.

132. Branch size

Branch size is considered to be a reliable measure of saw timber quality. Branch size is best explained by the stand density (Heiskanen 1965, Varmola 1980, Kärkkäinen and Uusvaara 1982, Kellomäki and Väisänen 1986, Huuri et al. 1987). The denser the trees are growing, the thinner their mean branches are. The effect may be primarily due to the fact that the branches in dense stands die before their diameter grows (Kellomäki and Väisänen 1986).

Turkia and Kellomäki (1987) found that the variation in site fertility better explained the variation in the thickness of the branches of young pines than the growing density. Branch thickness decreased as the stand density increased, but the variation in site fertility better explained the variation in branch thickness. On the other hand, Varmola (1980) did not find significant effect of site fertility on branch thickness.

The role of branchiness in reducing saw timber quality is also affected by the sawing set-ups and the concept of quality during the sawing stage, although it has to be assumed that knottiness always reduces the quality of pine sawn timber. The effect of knots on quality of the sawn timber can be reduced by selecting appropriate sawing techniques and set-ups, the parts of the log containing knots being left in goods where they have a minimum effect on quality. This can be done by producing sawn timber of maximum dimensions, or sawn timber where knottiness does not have much of an effect. However, simulations of this sort require information about the size and shape of the knots, and their predictability (e.g. Juvonen and Song 1987).

14. Aim of the study

The aim of this study was to investigate the shape and dimensions of pine knots close to the pith. The knot size and branch angle distributions, and their predictability, are studied in butt logs.

The study has been carried out on material which was originally collected for a pruning study (Pietilä 1989). The study has been supervised by Professor Matti Kärkkäinen. Jean-Baptiste Comoy, Arja Kettula, Riitta Laurila and Lauri Linnove have assisted in collecting, preparing and measuring the material. Translation into English was done by Mr. John Derome. The manuscript was read by Eero Nikinmaa and he also proposed corrections to the text which were done. I would like to extend my sincerest thanks to all who have assisted in this work.

2. Material

21. Collecting the material

The material was obtained from trees which were selected for a healing-over study (Pietilä 1989). A total of 19 trees from six different stands were obtained for the study in hand. There is no information available about the measures carried out in the stands when they were young, but it can be assumed that they have been silviculturally managed ever since their establishment (Heiskanen 1954a).

Three pruned trees were selected from each stand for the study. The first tree to be selected was the most normally pruned tree in the stand. The other two were the pruned trees situated closest to the first one. A pruned butt log was cut from each tree and then divided into 70 cm-long bolts. Discs about 5 cm thick were cut from the end of the bolts for determining growth.

The bolts were peeled to 1.5 mm thick veneers for the healing-over study. The core left after peeling had a diameter of 100 mm. The knots were clearly visible on the surface of the core. Each whorl containing knots was sawn off the core. The knots were split in half along the pith of the knot using a chisel in order to permit measurement of knot diameter.

22. Measuring the knots

The shape of the knots obtained from the core were measured in a coordination where the origin was the interception point of the stem and pith. The y-axis was the direction of the pith in the stem, and the x-axis a line at right angles to this. The distance between the upper and lower edges of the knot and the pith from the x-axis was measured at 10 mm intervals starting from the pith of the stem. Thus five measurements were obtained in principle of each knot. The branch angle was calculated as the angle between the pith of the stem and the pith of the knot at a distance of 40 mm across the stem.

The aim was to obtain at least three diameter measurements of each knot. In cases where this was not possible, the knot was not used in analyzing knot shape. These knots were used, however, in calculating branch angle and diameter if the diameter and location of the pith were known at a distance of 40 mm. This is the reason why the size of the material varies in different tables. Further omissions were caused by the fact that the knots did not always split exactly along the pith, and that some of the knots were destroyed when splitting the other knots in the whorl. The knots were numbered using the same system as in the healing-over study. Each knot was given a six-digit code, indicating the stand, tree, whorl and bolt number. In addition, the code also indicated the knot number in the whorl. The height of the knot in the tree could be determined to an accuracy of 70 cm on the basis of the bolt number.

A total of 1103 knots were measured for this study. The distribution of the knot material between the stands is shown below:

Stand	1	2	3	4	5	7
No. of knots measured	91	138	226	197	213	238

No material was obtained from Stand no. 6. However, the numbering was not changed so as to maintain uniformity with the previous study.

23. Calculations and analyses

The data were analyzed using BMDP software. The aim was to determine the properties of the knots when the height of the knot in the tree and the stand were varied. The dependence of knot shape and branch angle on knot diameter was also investigated, correlation analysis being carried out on the last-mentioned variables. An equation was devised by means of regression analysis to depict the dependence between branch angle and knot diameter. The distribution of the knots into different diameter classes in different parts of the butt was investigated using cross-tabulation. Although the knots were grouped so as to give at least 50 measurements for each class, this was not always successful. The diameter at a distance of 40 mm from the pith of the stem was used when the knots were grouped according to knot diameter.

3. Results

31. Grouping the trees by stand

The mean knot diameter at a distance of 40 mm from the pith of the stem, the branch angle and mean growth of the logs are presented for each stand in Table 1. Growth was determined at the butt of the tree as the mean width of the 25 annual rings closest to the pith. This procedure was adopted because, according to Heiskanen (1954b), growth close to the pith best depicts the wood quality (knottiness). Growth was measured in random directions with respect to the pith.

The mean diameter of all the knots was 14 mm and the branch angle 70°. The corresponding figures according to site fertility were : OMT 24 mm and 69°, MT and corresponding 12.7 mm and 69° and VT and less fertile 13.2 mm and 71°. A clear dependence between knot diameter and tree growth can be seen from the results. The better the tree grows, the larger are the knots in it. In contrast, the dependence between branch angle and growth was not as clear. Neither did the site type explain knot diameter and branch angle very well.

Table 1. The mean knot diameter, the branch angle, mean growth and forest site type for each stand.

Taulukko 1. Keskimääräinen oksan läpimitta, oksakulma, kasvu kannon korkeudella ja metsätyyppi metsiköittäin.

Stand *Metsä*	Mean knot diameter *Oksan läpimitta* mm		Branch angle *Oksakulma* degrees *astetta*		Ring width *Luston leveys* mm/y *mm/v*	Forest site type *Metsätyyppi*
	x̄	s	x̄	s		
1	24	14	64	14	3,5	$h_{100}=28$
2	15	9	64	15	2,6	VT[1]
3	12	5	71	11	2,0	ClT[2]
4	9	4	69	11	1,3	MT[3]
5	17	9	64	16	2,4	MT
7	13	7	69	16	2,3	PyT[4]

1) *Vaccinium* site type
2) *Cladina* site type
3) *Myrtillus* site type
4) *Pyrola* site type

Table 2. The cross-tabulating between knot diameter and angle, N=1044, and distribution of the material into different diameter classes without knots in stand 1, N=958.

Taulukko 2. Oksakulmien jakautuminen läpimittaluokittain, N=1044, ja oksien jakaantuminen läpimittaluokkiin ilman metsikön 1 oksia, N=958.

Branch angle *Oksakulma* degrees *astetta*	Diameter class *Läpimittaluokka* mm							
	–5	6–10	11–15	16–20	21–25	26–30	31–	Total *Yhteensä*
–50	0,0	0,2	0,7	2,0	3,6	5,1	3,0	11,6
51–60	0,2	1,9	5,3	4,1	2,3	2,7	2,2	16,5
61–70	0,7	7,1	8,2	4,7	1,9	1,1	0,2	23,8
71–80	3,4	10,9	4,3	2,2	0,6	0,0	0,0	21,5
81–	8,9	11,0	3,7	1,7	0,8	0,4	0,1	26,6
Tot/ *Yht.*	13,2	31,1	22,3	14,8	9,2	3,9	5,5	100,0
Without stand 1 *Ilman metsikköä 1*								
	13,8	33,0	23,0	14,9	8,8	3,5	3,0	

The variation in branch angle between different trees in the same stand can be large. In one stand the difference in the branch angle of the trees was 10°, while in another it was only a few degrees. The variation in branch angle between stands was investigated on knots with a diameter of 10–20 mm. In this case the maximum variation between the stands was 7°. The variation in the means of the knot diameters of each class did not explain the difference.

32. Knot shape and size

The distribution of the whole material into different diameter classes with a class interval of 5 mm is presented in Table 2. The knots of Stand no. 1 are omitted from the end of Table 2 because the knot size in this stand was exceptionally large.

Knot shape is shown by diameter classes in Figs. 1–3. When the knot diameter was below 20 mm, the knot grew evenly out from its formation point and finally curved slightly downwards (Fig. 4). The direction of the pith in the larger knots was, in contrast, clearly two-directional. Initially the pith was downward-facing convex and then upward-facing convex (Fig. 5). The larger the knot, the clearer was the change in the direction of convexity. The variation in convexity is not as clear at the extremities of the knot as in the pith, because the growth in thickness of the knot compensates for the change in convexity. The knot is at almost all points higher than its formation point. The shape of different-sized knots is the same close to the pith of the stem, where the diameter increases at an even rate. The branch angle of larger knots with a diameter of over 20 mm was approximately the same, even though the size of the knots was different.

The mean shape of the knots situated at two heights (0–70 cm and 420–490 cm) in the tree is presented in Fig. 6.

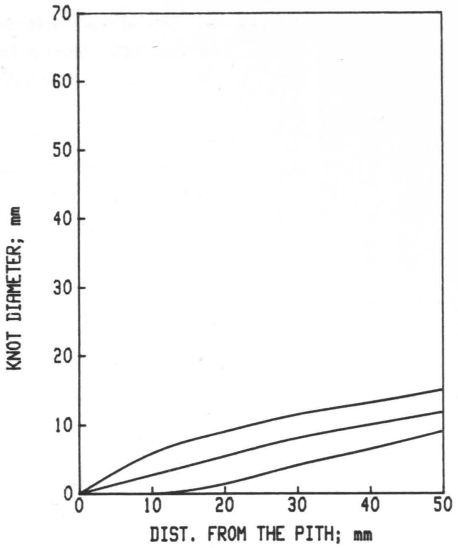

Fig. 1. The mean shape of the knot with a diameter of 1–10 mm. The horizontal axis is the distance from the pith and the vertical axis the knot diameter. Branch angle is 76°.
Kuva 1. Oksan keskimääräinen muoto, kun oksan läpimitta oli 1–10 mm. Vaaka-akselilla on etäisyys ytimestä ja pystyakselilla oksan läpimitta. Oksakulma on 76°.

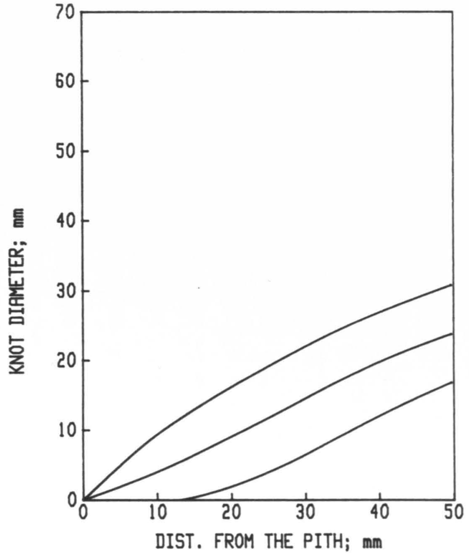

Fig. 2. The mean shape of the knots with a diameter of 11–20 mm. Branch angle is 65°.
Kuva 2. Oksan keskimääräinen muoto, kun oksan läpimitta oli 11–20 mm. Oksakulma on 65°.

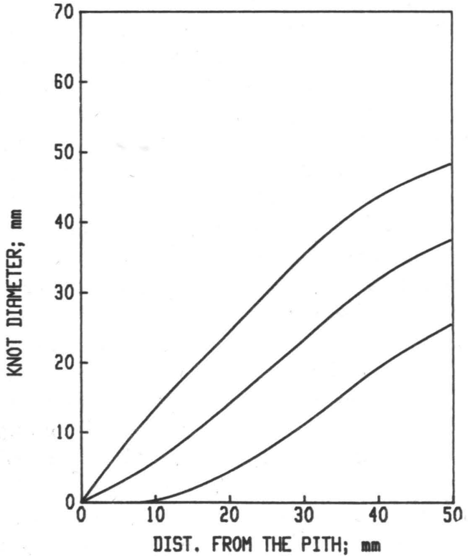

Fig. 3. The mean shape of the knots with a diameter of 21–30 mm. Branch angle is 54°.
Kuva 3. Oksan keskimääräinen muoto, kun oksan läpimitta oli 21–30 mm. Oksakulma on 54°.

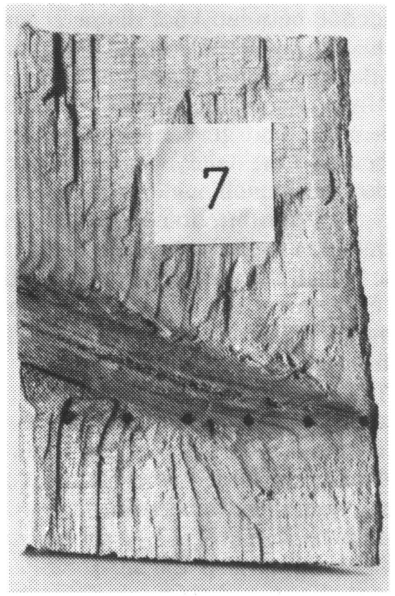

Fig. 4. A normal knot whose diameter is about 10 mm (edge 5 cm).
Kuva 4. Normaali pieni oksa, jonka läpimitta on noin 10 mm (särmä 5 cm).

Fig. 5. Thick knot with unclear lower edges, large branch angle, in which the direction of convexity of the knot pith has clearly changed (edge 5 cm).
Kuva 5. Paksu oksa, jonka alareuna on epäselvä, oksakulma suuri ja oksan ytimen kuperuussuunta vaihtuu selvästi (särmä 5 cm).

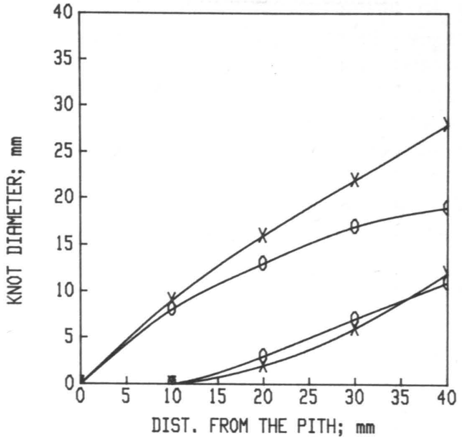

Fig. 6. The mean size and shape of the knots at two different heights above the ground, 0–70 cm (0) and 420–490 cm (X).
Kuva 6. Oksien keskimääräinen koko ja muoto kahdella eri korkeudella maan pinnasta, 0–70 cm ja (O) 420–490 cm (X).

Table 3. Dependence of mean knot diameter and branch angle on height above ground.
Taulukko 3. Oksan läpimitta ja oksakulman riippuvuus oksan etäisyydestä maasta.

Height above ground *Etäisyys maan pintaan* cm	Knot diameter *Oksan läpimitta* mm		Branch angle *Oksakulma* degrees *astetta*	
	$\bar{x}$	s	$\bar{x}$	s
– 70	9	5	71	14
70–140	12	8	71	16
140–210	13	8	74	20
210–280	16	9	68	18
280–350	15	9	70	19
350–420	16	10	68	18
420–490	17	9	66	17
490–560	19	11	70	24

On the average, the lower edge of the knot curved in the same way irrespective of the position of the knot and the growth in diameter is visible at the upper edge of the knots. The phenomenon was the same irrespective of the height of the knot in the tree, and the same in the case of different-sized knots.

The extent to which the knot diameter at a distance of 4 cm explains the diameter of the knot at its pruning point (on average at a distance of 6.5 cm from the pith) was tested (Fig. 7).

There was a clear positive correlation between these two diameters. It can be concluded that the dependence between these two diameters is approximately linear, and that knot diameter does not change very much over this distance. Smaller knots with a diameter of under 20 mm attain their maximum thickness at an early stage already, and hence their diameter is easily predicted.

The mean size of the knots and the mean branch angle at different heights above the ground are presented in Table 3. The mean knot size is at its minimum at the base of the tree, from where it increases by about 10 mm towards the top of the butt log. The largest knots were in region at a height greater than 4 m, and their mean diameter was 17 mm.

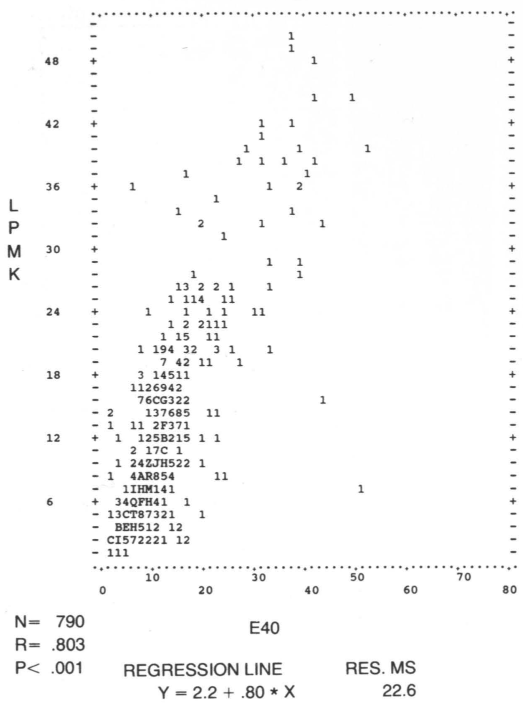

Fig. 7. Correlation between the diameter of the knots at the pruned point (LPMK) and at a distance of 40 mm from the pith of the stem (E40).

Kuva 7. Oksan kahden läpimitan, katkaisukohdassa (LPMK) ja 40 mm:n päässä ytimestä (E40), keskinäinen korrelointi.

The branch angle decreases slightly as the distance to the ground increases, but the change is not as clear as for the knot diameter.

The average number of knots per whorl in the whole material was 5.2, the variation range being 3.7–6.3. The mean number of knots per whorl and the distance between the whorls are presented by stand in Table 4. The variation in the whorl interval and in the whorl knot number between trees in the same stand was small.

The height of the whorl in the tree had no effect on the number of knots in the whorl but the deviations of the diameters of the knots in the same whorl were greater in whorls situated higher up than those lower down. The distance between the knot whorls was usually smaller at a height of less than one meter. Stand no. 4 was an exception to this because there was a considerable number of whorls throughout the length of the butt log. This is explained by the slow growth of the stand.

Table 4. The mean numbers of knots per whorl and the distance between the whorls.

Taulukko 4. Kiehkuran oksien määrä metsiköittäin ja kiehkuroiden väli.

Stand *Metsikkö*	Knot/whorl *Oksaa/kiehkura*	Whorl interval *Kiehkuroiden väli* cm
1	4,7	40
2	5,1	33
3	5,2	26
4	3,7	24
5	6,3	40
7	6,3	48

Table 5. Branch angles in different heights above the ground, knot diameter is 10–20 mm.

Taulukko 5. Oksakulman vaihtelu oksan korkeusaseman mukaan oksan läpimitan ollessa 10–20 mm.

Height above ground *Etäisyys maasta* cm	Branch angle *Oksakulma* degrees *astetta*
– 70	62
70–140	66
140–210	73
210–280	68
280–350	72
350–420	69
420–490	70
490–	68

33. Dependence of branch angle on knot diameter

The knot diameter and branch angle are cross-tabulated in Table 2. The branch angle decreases as the mean knot size increases.

The change in branch angle as the height of the knot in the tree increases was investigated in the next stage. In order to eliminate the effect of changes in knot size, the analysis was restricted to knots with a diameter of 10–20 mm. The results are presented in Table 5.

It can be concluded from the table that the height had no effect on branch angle if the knot diameter remains constant. The reduction in the mean branch angle along with growth is thus affected by the growth in knot size as the distance to the ground increases, and not the height of the knot in the tree.

Regression analysis was used to construct a model for predicting branch angle on the basis of knot diameter. The dependence was best depicted by a straight line with the following equation

$Y = 83 - 0.94 \cdot X$, where
Y is the branch angle in degrees, and
X is the knot diameter in mm.

The coefficient of determination of the model was 47%. The model slightly underestimated the size of knots below a height of 1.5 m. An attempt was made to improve the model by omitting the lowest knots, but this had no effect on the coefficient of determination.

As the deviation of branch angle and diameter were greatest in Stand no. 1, a model was also tested which did not include the knots from this stand. The equation was

$Y = 86 - 1.1 \cdot X$, where
Y is the branch angle in degrees, and
X is the knot diameter in mm.

The coefficient of determination of this model was 41%.

4. Discussion

41. Knot size

When the mean knot diameter is compared with the results of the pruning study of Pietilä (1989) it can be seen that the mean knot size in this study was 0.2 mm smaller. This would suggest that the diameter of the knots did not apparently influence which knots were in fact split.

Comparison of the knot size obtained in this study with those reported in other studies is made difficult by the fact that sites are of different quality and measurement methods of branch angle and knot size are partly unknown. Knot diameter measured across the knot gives different results than diameter measured to stem pith direction.

If the diameter is measured at a specific distance from the stem then the measuring points will not, owing to stem tapering, follow a line parallel to the pith, but in fact gradually approach it. This may further increase the effect of crown shape at the measuring instant on the measured knot diameters owing to the different degree of tapering of different-sized branches.

42. Branch angle

In this study the mean branch angle of all the knots was 70°. This is 9° greater than the treewise mean in Varmola's (1980) material. The standard deviation of the angles was also greater in this material. Similarly, the angle is larger than that presented by Persson (1976) and Huuri et al. (1987). The difference can be explained by the fact that, in the last mentioned studies, the branch angle was measured on the thickest branches, while in the study in hand it is in principle the average of all the knots. In this study the trees were pruned and it is assumable that pruned trees were best in quality whose branch angle was large.

The difference may also be partly due to the measuring technique. Since the angle of all the knots was measured at the same distance from the pith, the development stage of the knots situated at different heights may have been different. Evidence supporting this is that the branch angle of the larger knots decreased as their size increased, i.e. the knots gradually attained a horizontal position. How branch angle is defined and the method used to measure it have an effect on its magnitude, and hence the branch angles obtained in different studies cannot as such be compared directly.

The branch angle inside the stem may be greater than that correspondingly measured outside the stem because curvature of the branch does not usually start right next to the stem. The branch angle may in reality be smaller than that of the knot in the trunk. The knots in the butt especially had adopted a horizontal position already at a distance of 4 cm from the pith. Thus the branch angle of the smallest knots became greater than that of the larger knots because the branch angle was measured at a constant distance from the pith.

The branch angle can be satisfactorily predicted on the basis of the knot diameter, as was to be expected on the basis of earlier studies. If the knot diameter is small, then the branch angle is probably large. In contrast, the branch angle of knots with a large diameter varies much more, i.e. their branch angle cannot be predicted as well on the basis of the diameter. The reason for this appears to lie in the fact that large branches can grow vigorously throughout their whole lifetime or, on the other hand, they can reduce their growth slowly and gradually curve down.

Small diameter knots can also be divided into two groups with respect to their branch angle. The branch angle of branches growing close to the ground is small and their diameter is also small because, despite their small size, the branches grow well throughout their lifetime. In contrast, small branches situated higher up the trunk die off sooner after they are formed, at a time when they are almost horizontal.

In these stands in study knot diameter reached its maximum already at a distance of 4 cm from the pith. Evidence for this was obtained by comparing this diameter with that at the cut face, as well as the shape of the knot. As was the case with the stem, knot diameter increased fastest when the branch was young. This is also affected by the fact that if the knot diameter is measured parallel to the pith in the stem, then curvature of the knot towards a horizontal position decreases its measured diameter.

43. Sources of error

The largest source of error in this material was the sampling. Tree selection was done subjectively out of the pruned trees. It is also supposable that those were not the average trees in stands concerning quality, but they were the best ones and that underestimates the knot size and overestimates the branch angle compared with the average in the stand. Silvicultural history, which has great effect on branchiness of trees, is unknown, and thus it is not possible to generalize these results. The measurement results are based on only a few trees per stand, and it is therefore not possible to determine how large the variation was between the individual trees.

The other fact is that the trees had been pruned. Diameter growth of the branches had not ceased in the upper part of the logs especially. This may have resulted in underestimation of the knot diameter in the upper part of the log compared to the results which would have been obtained if the trees had not been pruned. Comparison of the diameter distribution according to the height of the knot in the tree with the results presented by Uusvaara (1974) suggests that this may have been possible. Underestimation of the knot dimensions may, in addition, have also weakened the dependence between knot diameter and branch angle.

Unfortunately the direction of the knots was not taken into account when the knots were being measured. This would have made it possible to carry out a more detailed analysis of the location of the knots in the whorls and along the logs.

There were problems especially in measuring the diameter of those knots which had grown the most vigorously. This was due to the fact that the stemwood especially below the knot, curved so gradually towards the knot that it was difficult to determine where the stemwood stopped and the branch wood started (cf. Shigo 1986). However, there were presumably no systematic errors in the measurements.

44. Conclusions

The material represented Scots pine plantations but the results may also be applicable to naturally regenerated stands. The frequently made finding that the branches in poorly growing trees are slender was true in this study too. Slow growth also resulted in an increase in the number of whorls per unit length, but there were less knots in the whorls. The quality of the timber obtainable from well growing trees is reduced by the knot size, while in slow growing trees the short distance between the whorls would reduce the quality of the timber.

The variation in the size of the knots in the same whorl was greater higher up in the stem than lower down. This may be due to the fact that when the trees are small, shading by other trees does not have as much effect on the growth of the branches as when the trees are older. Another reason is that the branches of lower whorls do not grow overall to such an extent that considerable differences in size would develop. Higher up the tree it may be that the branches which increase in thickness are selected at a relatively early stage, and the suppressed branches die off rapidly.

The branch angle increased especially in the case of larger knots as the distance from the pith increased, i.e. the knot became curved. There may be a number of reasons for this.

Reason for the straightening out of the knots may be that the part of the branch lying outside the stem and the weight of the needles start to press the knot down, and hence the branch angle increases. At the same time, the increase in knot thickness declines, and hence the area of the surface supporting the knot in the stem decreases with respect to the mass to be supported. This would explain the increase in the branch angle of vigorously growing branches. The large branch angle on the slenderest branches is caused by the fact that their photosynthesis is insufficient for growing branch wood through their lifetime, and hence they are not directed strongly toward the light.

On visual examination, the branches of pine are thus attached to the trunk in the way presented by Shigo (1985). At the upper edge of the branch the border between the stem and the branch is clear. The cells are pressed tightly against each other and the angle between the stemwood and the branch wood is large. In contrast, the change from stemwood into branch wood at the bottom edge is unclear because the fibers in the stem are slightly bent towards the branch, and there are no signs of compression of the cells against each other (Fig. 8).

Fig. 8. Branch attachment to stem with pine.
Kuva 8. Männyn oksan kiinnittyminen runkoon.

A branch almost always grows higher than its formation point. Slender branches which can be either horizontal or lie even completely below their formation point form an exception to this. Similarly, the lower edge of vigorously growing branches can be below the formation point of the branch right close to the pith.

The shape of a knot can be depicted using two cylinders according to the stage of its development: a strongly opening cylinder, and a slightly closing curved cylinder. The cylinder changes from an opening to closing one at a distance about 2–4 cm from the pith of the stem, i.e. at the stage where its diameter growth ceases or declines and it attains a horizontal position.

If the first sawing to the butt log is done at distance of 4–5 cm from the pith, it is possible to determine the knot size in outer part of the log with help of visible cross cut knots. This could help in determining set-ups for further sawing because at least rough knot size classification is possible. Sawings after the first one could also base on the best first cutting face -simulations, e.g. Adkins et al. (1980) and Richards et al. (1979).

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Seloste

Männyn oksan muoto rungon ytimen lähellä

Tutkimuksessa selvitettiin männyn oksan muotoa tyvitukin ytimen lähellä. Tutkimusaineistona oli noin 1100 oksaa 19 eri puusta, jotka saatiin kuudesta eri pystykarsitusta metsiköstä. Oksat halkaistiin pystysuoraan, ja niiden ala- ja yläreunan sekä ytimen sijainti mitattiin rungon ytimen suuntaisesti 10 mm:n välein. Tulosten perusteella laskettiin oksien läpimitta ja oksakulma 40 mm:n päässä rungon ytimestä sekä piirrettiin oksien kuva läpimittaluokittain. Aineiston kaikkien oksien keskiläpimitta oli 14 mm ja oksakulma 70°, mutta puittainen vaihtelu oli suurta. Mitä paremmin puu kasvoi, sen suuremmat oksat siinä olivat. Sen sijaan kasvun ja oksakulman välinen yhteys ei ollut selvä, eikä metsätyypinkään perusteella voinut ennustaa oksien oksakulmaa. Oksien keskimääräinen läpimittta kasvoi oksien etäisyyden maahan lisääntyessä ja oksakulma pieneni. Oksakulman muutos ei kuitenkaan ollut niin selvää kuin läpimitan muutos. Regressioanalyysin avulla laadittiin yhtälö oksakulman ennustamiseksi oksan läpimitan avulla. Oksakoko ja -kulma korreloivat negatiivisesti keskenään. Oksan muoto oli kaareva, sillä aluksi oksat olivat alaspäin kuperia, mutta varsinkin suurten oksien kuperuuden suunta muuttui päinvastaiseksi oksan pituuden kasvaessa. Oksapuu oli lähes kokonaan syntypistettään ylempänä. Kiehkurassa oli keskimäärin 5,2 oksaa, metsiköittäinen vaihteluväli oli 3,7–6,3. Oksat saavuttivat suurimman läpimittansa 4–5 cm:n päässä rungon ytimestä. Aineiston heikkoutena oli se, että koepuita oli vähän ja ne oli karsittu. Tämä aiheutti luultavasti aliarviota metsiköiden keskimääräiseen oksakokoon verrattuna ja yliarviota oksakulmaan.