Radially sawn timber.

Knots - number, type and size in star-sawn triangular profiles of pine (*Pinus silvestris* L) and spruce (*Picea abies* Karst).

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Summary

This paper describes the appearance and number of knots in star-sawn triangular profiles of pine (*Pinus silvestris* L) and spruce (*Picea abies* Karst). The emphasis is placed on obtaining the volume yield of boards with a given knot appearance, together with the sizes of the fibre disturbances around the knots and how they affect the yield. The test material has been taken from three regions in Sweden and is made up of butt logs of pine and of normal and fast-growing spruce.

The results show that a large proportion of the knots found in the triangular profiles from butt logs are unacceptable in further refinement of the timber and must be cut out. Very few healthy knots can be found.

In the cutting of knot-free boards, a volume reduction of on average 8 and 21 percent is obtained for pine and spruce respectively, calculated with respect to the original profile volume. If the fibre disturbance around the knots is also cut away, a further volume loss of 5 percentage points for pine and 6 percentage points for spruce is obtained. The boards produced have a broad spectrum of lengths between 2 and 500 centimetres for pine and between 2 and 400 centimetres for spruce.

1. Introduction

The number of knots in the timber and their location, shape and nature are very important for e.g. the appearance, strength properties and susceptibility to deformation of the timber. The knots often play a decisive role for the price-setting of the timber and for its aesthetic value. Depending on the location of the sawcut in relation to the longitudinal axis of the knot, the section through the knot can be round, oval or more or less triangular. The choice of cutting pattern will thus strongly influence the geometrical appearance of the knot in the sawn timber surface.

A new sawing method for producing radially sawn timber is under development at the department for Wood Technology and Processing at the Royal Institute of Technology in Stockholm, KTH, figure 1. The method is called star-sawing and is a part of the R&D-program "Value activation" which is aimed at producing timber and boards with vertical annual rings on an industrial scale and with good profitability for products in which e.g. small and controlled moisture movements are highly valued. It is thus desirable to activate values in timber which with today's industrial technology are dormant. The R&D-program and the sawing method are described in greater detail in two articles by Wiklund (1993) and Sandberg (1996).

The star-sawing pattern gives timber sections with both rectangular and triangular cross-sections. All the timber sections have vertical annual rings and are free from juvenile wood. The term "vertical annual rings" here means that the angle between the annual rings and the flat side of the timber is greater than 60° (Sandberg 1995). In star-sawing, as in all radial sawing methods, the radial sawcuts cleave the knots longitudinally and a larger proportion of splay knots are obtained than in through sawing and block-sawing. These knots are often unacceptable from a strength viewpoint and must be removed. Star-sawing is especially suitable for large log dimensions. The top diameter should be greater than 200 millimetres to ensure that the sawn-out timber sections do not become too narrow (Sandberg 1996). A large proportion of the timber which assumes these proportions is made up of butt logs and the knots in these butt logs are often of such a nature that for aesthetic reasons they should be removed. It has been found among other things that butt logs of pine have a low proportion of healthy knots in comparison with middle and top logs (Nylinder et al 1995).

Figure 1. Sawing pattern for star-sawing.

2 Aim

The purpose of this investigation to determine the nature and number of knots in star-sawn triangular profiles from butt logs of pine and spruce. On the basis of these basic data, the yield is calculated for the production of knot-free triangular boards.

3 Materials and methods

3.1 Test material

The test material has been taken from three regions: southern, central and northern Sweden. The timber is so-called oversized which in this case means that the top diameter exceeds 35 centimeters and the selection has been made so that only timber of O/S and fifth quality (V) has been included in the study material. The timber from southern Sweden was felled during January 1994 especially for this investigation and was made up of pine and normal and fast-growing spruce. "Fast-growing" here means an average annual ring width greater than 10 millimetres. The lumber from central Sweden was made up of normally grown oversized pine and spruce which was randomly taken from the lumber catch of a local sawmill. The lumber is presumed to be representative of oversized lumber in this region. The lumber from northern Sweden is made up of normally grown pine and spruce from two sawmills and the same selection method has been used for the timber from central Sweden. All logs have been quality estimated by an authorized lumber-grader before they were sawn according to the regulations applied in Sweden (Timber Measurement Council 1990).

3.2 Sawing and drying

All logs were sawn according to the star-sawing method. Cutting patterns were chosen so that the sides of the triangular profiles were 120 millimetres (dried measurement) and the rectangular timber had a thickness of 50 or 63 millimetres (dried measurement). In each cutting pattern, a pith-catcher was sawn away. The width of the pith-catcher was at least 50 millimetres and the thickness was the same as for the rectangular timber. After the sawing, the timber was stacked and dried according to a conventional drying schedule in a drying chamber. Table 1 presents a compilation of the extent of the test material.

Table 1. The extent of the test material and the lengths of the profiles.

Test group	Total length (m)	Number of profiles	Average length (m)	Number of butt logs
pine central Sweden	221	46	4,8	8
pine northern Sweden	189	39	4,9	9
pine southern Sweden	109	24	4,5	3
total pine	519	109	4,7	20
spruce central Sweden	176	35	4,9	7
spruce northern Sweden	129	24	5,0	5
spruce southern Sweden	167	38	4,4	5
fast*				
spruce southern Sweden	47	12	4,4	7
total spruce	519	109	4,7	24

*fast = fast-growing spruce with an average annual ring width of 10 mm

3.3 Measurement method

For each triangular profile, the relative positions and extensions of the knots were determined on the three sides of the profiles. In addition, the lengths of the profile which must be removed to obtain, on the one hand, knot-free timber boards where only the knot is removed and, on the other hand, boards where the fibre disturbance around the knot is also removed, were determined. Each knot was classified according to shape and type according to the assessment rules applied in the Nordic sorting rules for sawn timber goods (Timber Grading Committee 1976).

4. Results and discussion

4.1 Timber quality

The quality of the timber used in the investigation is shown in table 2. For the timber from central and northern Sweden, the distribution between O/S and fifths is very similar, whilst the normally grown pine and spruce timber from southern Sweden has an over-representation of fifths. Compared with the official statistics over the distribution of timber grades, the timber from northern and central Sweden has a higher proportion of O/S. Table 3 gives the quality distributions for pine and spruce timber according to the Swedish Forestry Statistics for 1994. The down-grading of the timber from the best quality to fifths is related mainly to the knot distribution in the logs. The difference between O/S and fifths from a knot viewpoint is primarily that the healthy knots can be 15-20 millimetres larger in fifths than the healthy knots in O/S. The maximum number of knots in both classes is equal. Besides this, knots with rot must not occur in O/S, whilst these knots can occur in fifths. The assessment of the logs has been made with the assumption that they will be block-sawn.

Table 2. Quality of the timber in the investigation.

Test group	Quality of log							
	1	2	3	4	5	6	7	8
pine central Sweden	O/S	O/S	V	O/S	V	V	V	O/S
pine northern Sweden	V	O/S	V	V	O/S	O/S	O/S	
pine southern Sweden	V	V	V	V	V			
spruce central Sweden	O/S	V	O/S	O/S	O/S	O/S	V	
spruce northern Sweden	O/S	V	O/S	O/S	V	V	O/S	V
spruce southern Sweden	V	V	O/S	V	V	V	V	
spruce southern Sweden fast*	O/S	V	O/S					

*fast = fast-growing spruce with an average annual ring width greater than 10 mm

Table 3. Quality distribution of sawn timber in Sweden according to official statistics.

Region	Pine			Spruce		
	O/S	V	Others	O/S	V	Others
northern Sweden	0,28	0,68	0,04	0,38	0,61	0,01
central Sweden	0,34	0,62	0,04	0,69	0,30	0,01
southern Sweden	0,25	0,67	0,08	0,69	0,27	0,04

4.2 Distribution of knot types and their nature, dimensions and accompanying fibre disturbance.

Tables 4 and 5 show the distribution between knot types, their nature and the extent of fibre disturbance in the longitudinal direction of the profiles. For the tangential surface of the triangular profile (a) and its radial surfaces (b, c), the proportion of each type of knot is indicated for each test group with regard to the total number of knot surfaces. For each knot type, the proportions of the total number of knot surfaces having a certain nature is also indicated. The sides of the triangular profile are observed separately, which means that the same knot can appear simultaneously on three sides of the profile and thus be observed as three different knots. Also indicated are the average length of the removals required to remove only knots (L knot), the average value of the extension of the fibre disturbance in the length direction of the timber on the root side (L root) and top side (L top) of the knots, and the removal required to obtain knot-free timber boards without fibre disturbances (L tot). For the measurement of the lengths L knot, L root, L top and L tot, the extension of the knots in the whole triangular volume has been taken into account, i.e. consideration has been given to the knot extension on all sides of the profile. Where values are lacking in the table, the proportion is less than 0.005.

Table 4: Knot distribution in pine

Test group		Proportion		Number of knots with a certain nature								Knot extension (mm)					
				barkringed knot		healthy knot		loose knot		rotten knot		dead knot		L knot	L root	L top	L tot
	Knot type	a	b,c	a	b,c	a	b,c	a	b,c	a	b,c						
central Sweden	spike knot		0,15		0,04		0,01				0,09			37	15	18	70
	knot cluster	0,03	0,06		0,01					0,02	0,04	0,01		208	15	11	234
	splay knot		0,10		0,04						0,05			49	19	16	84
	edge knot	0,02	0,24	0,01	0,08		0,04		0,01	0,01	0,05		0,05	35	15	24	74
	oval knot		0,15		0,04		0,02		0,01		0,07			30	12	18	60
	pearl knot	0,03			0,01						0,02			8	5	8	21
	round knot	0,16	0,05	0,05	0,01						0,11	0,03		18	11	16	45
northern Sweden	spike knot		0,11		0,01		0,02		0,01		0,06		0,01	33	19	21	73
	knot cluster	0,06	0,09	0,02	0,01				0,01	0,01	0,04	0,03	0,02	205	15	19	239
	splay knot		0,06		0,01		0,01				0,02		0,01	64	24	23	111
	edge knot	0,03	0,20		0,03		0,01		0,01	0,01	0,05	0,01	0,11	30	18	21	69
	oval knot	0,03	0,21		0,06		0,01		0,01		0,11	0,03	0,03	26	18	18	62
	pearl knot	0,03	0,01	0,02	0,01						0,01			6	14	19	39
	round knot	0,14	0,01	0,03							0,08		0,02	20	9	13	42
southern Sweden	spike knot		0,09		0,02		0,02		0,01		0,03		0,01	51	27	30	108
	knot cluster	0,01	0,02	0,01	0,01					0,01	0,01		0,01	264	11	9	284
	splay knot		0,15		0,05		0,02		0,01		0,06		0,02	70	42	30	142
	edge knot	0,05	0,24	0,02	0,04	0,01	0,08	0,01		0,02	0,02	0,01	0,10	44	40	45	129
	oval knot	0,05	0,14	0,03	0,08		0,04	0,01		0,02	0,02			36	27	37	100
	pearl knot		0,03		0,02		0,01							9	12	13	34
	round knot	0,17	0,04	0,08	0,01	0,01	0,01		0,01	0,08	0,01	0,01		23	56	53	132

Table 5. Knot distribution in spruce.

Test group	Knot type	Proportion		Number of knots with a certain nature										Knot extension (mm)			
		a	b,c	barkringed knot		healthy knot		loose knot		rotten knot		dead knot		L knot	L root	L top	L tot
central Sweden	spike knot	0,08	0,02			0,01		0,01		0,03		0,01		26	11	14	51
	knot cluster	0,11	0,16	0,05	0,05	0,01		0,01		0,05	0,04	0,01	0,05	235	10	14	259
	splay knot		0,06		0,03					0,01		0,02		36	12	18	66
	edge knot	0,04	0,13	0,01	0,02	0,01	0,01	0,01	0,01	0,01	0,01	0,07		25	11	16	52
	oval knot	0,01	0,15	0,01	0,05	0,02		0,01		0,05		0,02		29	12	16	57
	pearl knot	0,02	0,02	0,01	0,01					0,01	0,01			8	7	8	23
	round knot	0,19	0,02	0,05	0,01			0,01		0,10	0,01	0,03		18	9	11	38
northern Sweden	spike knot		0,03							0,01		0,02		41	26	29	96
	knot cluster	0,15	0,20	0,03	0,03	0,01				0,04	0,07	0,06	0,08	262	13	18	293
	splay knot		0,08		0,01	0,02	0,01			0,02		0,04		47	20	21	88
	edge knot	0,05	0,13	0,01	0,01					0,02	0,02	0,03	0,10	31	22	24	77
	oval knot	0,03	0,17		0,03	0,01				0,06		0,02	0,07	36	19	17	72
	pearl knot	0,02	0,02							0,01	0,01			36	6	6	48
	round knot	0,12		0,02				0,01		0,05		0,04		13	10	10	33
southern Sweden	spike knot		0,14		0,03	0,01		0,02		0,07				18	11	18	47
	knot cluster	0,12	0,18	0,03	0,04	0,06	0,01	0,01	0,04	0,03	0,04	0,04		286	17	22	325
	splay knot		0,02		0,01	0,01		0,01		0,01				40	18	20	78
	edge knot	0,02	0,10	0,01	0,03	0,03	0,01	0,01	0,01	0,01	0,01	0,02		22	14	16	52
	oval knot	0,02	0,12	0,02	0,05	0,03		0,01	0,01	0,01		0,01		24	15	23	62
	pearl knot		0,03		0,03									7	7	13	27
	round knot	0,22	0,02	0,09	0,01	0,01	0,01	0,02	0,01	0,08		0,02		19	9	13	41
southern Sweden	spike knot		0,07		0,02	0,02				0,02		0,01		34	17	18	69
	knot cluster	0,12	0,16	0,01	0,02	0,02	0,01	0,02	0,05	0,04	0,04	0,06		207	13	19	239
	splay knot		0,12		0,01	0,03		0,01		0,01		0,06		60	25	29	114
	edge knot	0,07	0,14	0,01	0,01	0,01	0,03	0,01		0,01		0,03	0,09	41	20	26	87
	oval knot	0,01	0,09	0,01	0,01	0,03				0,02		0,01	0,03	35	18	20	73
	pearl knot	0,02	0,01		0,01					0,02				13	9	11	33
	round knot	0,18	0,01	0,02		0,01		0,02		0,05		0,08		35	17	20	72

*fast = fast-growing spruce with an average annual ring width greater than 10 mm

4.3 Yield of boards with healthy knots and knot-free boards.

When cutting the triangular profiles to boards with a certain knot appearance, consideration must be given to the shape and nature of the knot on all profile surfaces. The location of the cut is determined by the total extension of the knot in the profile volume, with or without taking the fibre disturbance into consideration. Table 6 shows volume yields for both knot-free material and material with healthy knots. Table 4 and 5 show that a large proportion of the knots in this timber are either loose, dry or contain rot. Few healthy knots can be found. Table 6 shows that there is little difference in volume yield between knot-free material and material with healthy knots. A certain increase in the yield could be expected, however, if the proportion of healthy knots were considered, as shown in tables 4 and 5. The explanation of why this is not the case is obtained if the whole extension of the knot is observed. Closest to the pith, the knot is often healthy and well grown into the surrounding timber material. Further from the pith, the knot often becomes dry, bark-drawing or damaged by rot as a consequence of the natural pruning. In the triangular profiles, this corresponds to healthy edge knots on the radial surfaces and a dry, loose or bark-drawing round or oval knot on the tangential surface of the profile. The change from healthy to dry knot is often clearly visible on splay knots which are usually healthy closest to the pith but deteriorate towards the sap-timber side. Table 4 and 5 only take into consideration the nature of the knots on one side of the profile, independently of the appearance on the other sides. This means that we overestimate healthy knots in table 4 and 5 when we wish to produce boards with healthy knots on all sides. The yields produced in table 6 take into consideration the nature of the knots on all sides in the determination of the length of the removed section, so that there is only a small difference in volume yield between knot-free boards and boards with healthy knots.

Table 6. Volume yields for boards of triangular profiles.

Test group	Share of total profile volume			
	Knot-free boards with fibre disturbance	Boards with healthy knots and fibre disturbance	Knot-free boards without fibre disturbance	Boards with healthy knots without fibre disturbance
pine central Sweden	0,90	0,90	0,85	0,85
pine northern Sweden	0,92	0,93	0,89	0,89
pine southern Sweden	0,94	0,95	0,89	0,89
spruce central Sweden	0,84	0,84	0,79	0,79
spruce northern Sweden	0,74	0,74	0,69	0,69
spruce southern Sweden fast*	0,74	0,74	0,69	0,69
spruce southern Sweden	0,83	0,83	0,77	0,78
average pine	0,92	0,92	0,87	0,88
average spruce	0,79	0,79	0,73	0,74

*fast = fast-growing spruce with an average annual ring width greater than 10 mm

When the knots are removed, a wide spectrum of boards of different lengths is obtained. Figures 2 and 3 show the cumulative volume distribution for the knot-free lengths. Figure 2 shows the distribution for knot-free material where the fibre disturbance around the knot has not been removed. Figure 3 shows the corresponding distribution without fibre disturbance. Figure 2 and 3 show that pine has a larger volume proportion of knot-free boards over a given length of the corresponding boards than spruce. As an example, the proportion by volume (with regard to the original triangular profile volume) of the knot-free pine material without fibre disturbance from central Sweden and shorter than 25 centimetres is 0.08. The corresponding proportion for spruce from central Sweden is 0.15. Further, the proportion by volume of knot-free boards of pine with a length greater than 200 centimetres is 0.27, but only 0.02 for spruce. For the same tree type, however, there is no clear difference in length distribution for the knot-free boards between the different felling areas. It may seem natural to assume that the proportion by volume of knot-free boards will increase with increasing growth rate of the tree because of an increasing distance between the branch whorl. For spruce, this does not seem to be correct since the yield for fast-growing spruce from southern Sweden is of the same magnitude as that for spruce from northern Sweden, table 6.

The investigation has been carried out with only one dimension of triangular profile, a 120 millimetre side. The dimension of the profile will probably influence both the nature and frequency of knots in the surfaces of the profiles. The dimension investigated here is the largest which is now sawn and it is improbable that any considerably larger dimension will be sawn. Compared with profiles with a side of 120 millimetres, smaller profiles will show a higher proportion of loose and dry knots. This is a consequence of the fact that these profiles will be sawn out further from the pith, i.e. the smallest distance between the pith and the profile will increase if the same log diameter is used for the different cutting patterns. On the other hand, the consequence of a smaller profile dimension may be that the distance between the knots increases because it is less probable that a small dimension cuts through a branch whorl than it is for a larger dimension. This must be investigated more closely, however.

Figure 2. Cumulative volume distribution of knot-free boards with fibre disturbances from knots.

Figure 3. Cumulative volume distribution of knot-free without fibre disturbances from knots.

5. Conclusions

Triangular profiles produced with the star-sawing method have vertical annual rings and are free from juvenile wood. This means that the timber becomes straighter and flatter, has considerably more uniform dimensions and has a more predictable movement as a result of moisture variation. From a knot point of view, the triangular profile has the advantage compared with conventionally sawn timber that there can be no completely hidden knots in the profile which will appear at a later treatment stage. A knot in a triangular profile will always be visible on one of the three sides of the profile. The two radial surfaces of the profile can, however, contain splay knots which are unacceptable from a strength and aesthetic viewpoint.

Judging from these results, it seems evident that triangular profiles of pine and spruce from butt logs constitute a good starting material for the manufacture of knot-free boards with very good properties, which in a later refinement step can either be jointed into greater lengths or be used directly in manufacture.

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