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ORIGINAL ARTICLE

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Measurement of spiral grain with computed tomography

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Abstract Spiral grain is a feature of wood that affects the shape of the sawn timber. Boards sawn from logs with a large spiral grain have a tendency to twist when the moisture content changes. In sawmills the spiral grain in logs is judged manually. For research purposes the spiral grain in stems and logs is normally measured by destructive methods. In this study the spiral grain of the stems was measured nondestructively with a computed tomography (CT) scanner. Twelve Norway spruce (*Picea abies*) stems from two stands in Sweden were scanned with a CT scanner with one cross-sectional scan every 10mm along the stem. Concentric surfaces at various distances from the pith were reconstructed from the stack of CT images. In these concentric-surface images, which show various internal features of the log, the spiral grain angle was measured at different distances from the pith and at different heights in the stem. The destructive measurements of the spiral grain were carried out on disks from the top ends of the logs. On these disks the spiral grain was measured at different distances from the pith with a protractor. Finally, the results from the destructive method were compared with the results from analysis of the CT images. The nondestructive and destructive measurements were compared in pairs with the same radial and approximately the same height position in each pair. The correlations (r) between the two methods were 0.81 and 0.71, respectively, for the two stands. It was concluded that it is possible to measure the spiral grain angle nondestructively with a CT scanner.

Key words Spiral grain · Stem bank · CT images · Nondestructive measurement

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Introduction

Spiral grain is a common defect in many coniferous tree species in the world. It is well known and has been studied by many scientists. Spiral grain leads to a reduction of mechanical properties of the timber, such as the modulus of rupture (MOR) and the modulus of elasticity (MOE); but without any doubt the greatest problem with spiral grain is that timber with large spiral grain has a marked tendency to twist.[1–3] Moreover, spiral grain also can have a negative effect on surface smoothness after milling.[1]

In trees with a spiral grain the cells are not aligned parallel to the axis of the tree; they have grown in a helical structure around the pith (Fig. 1).[1,4,5] An important point is that it is common for trees to present two inclinations of the spiral grain. Most conifer trees in the Northern Hemisphere have a direction of left to right in young wood with a change to right to left in mature wood. This pattern is denoted the LR pattern. Indigenous conifers from the Southern Hemisphere have the opposite RL pattern.[1,4,6] This means that the spiral grain often changes its degree of inclination from the pith to the bark. An example of a severe spiral grain is shown in Fig. 2.

There are many theories about the origin and causes of spiral grain. One is that spiral grain has a genetic origin.[4,6,7] Tests have shown that species from the Northern Hemisphere keep their original LR pattern even when they are introduced to areas in the Southern Hemisphere. An example is the plantation-grown radiata pine (*Pinus radiata*) in New Zealand, which maintains a strong LR pattern.

A second theory is that the formation of a spiral grain depends on external factors, such as the earth's rotation, the sun, the prevailing wind direction, and the altitude.[7–10] It has also been thought that crown asymmetry in combination with prevailing winds has a major effect on spiral grain formation. Rapid growth of the trees has also been mentioned as a factor that affects spiral grain formation.[1,4]

Boards sawn from logs with a large spiral grain have a great tendency to twist when the moisture content changes. The spiral grain on boards can be measured

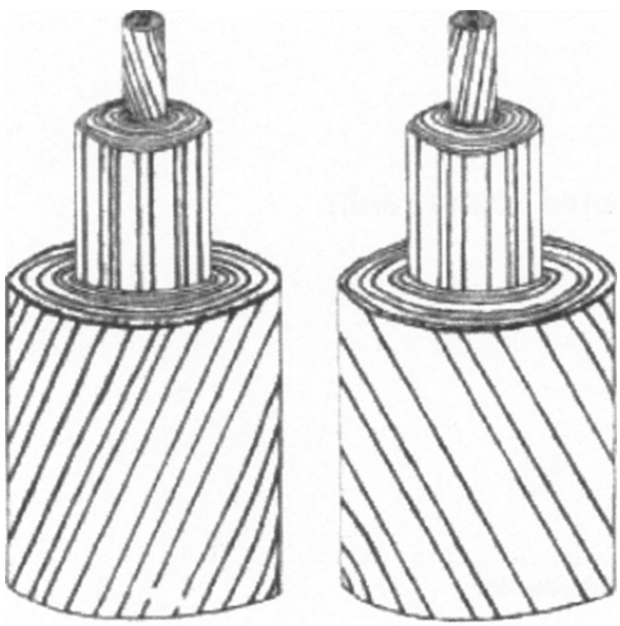

Fig. 1. Examples of how the spiral grain is seen internally. **a** LR model: in the innermost parts of the tree the spiral grain is left-handed, deviating to an angle of zero in the middle of the tree and becoming right-handed in the outermost part. **b** RL model: in the innermost parts of the tree the spiral grain is right-handed, deviating to an angle of zero in the middle of the tree and becoming left-handed in the outermost part[9]

Fig. 2. Severe spiral grain on a tree. The direction of the cracks on the surface of the tree display the grain direction

nondestructively with a capacitance method or with laser methods. In practice, the spiral grain in logs is estimated manually in sawmills. For research purposes the spiral grain in stems and logs is normally measured by destructive methods.

When scanning logs with computed tomography (CT), streaks with high density can be seen on the CT images, especially around the knots. These streaks normally have an inclination relative to the longitudinal axis of the log. The objective of this study was to determine if the inclination of the high density streaks correlate with the spiral grain of the log by comparing the measurements from CT images with measurements from a destructive method. The measurements were compared in pairs with the same radial and approximately the same height position for each pair.

Table 1. Data for the sample plots from which the test material originated

Parameter	Stand 11	Stand 14
Country	Sweden	Sweden
Location	Siljansfors, Dalarna	Sannarp, Falkenberg, Halland
No. of sampled stems	6	6
Altitude (m.a.s.l.)	220	170
Latitude	60°53′30″	56°56′05″
Longitude	14°22′50″	12°47′45″
Stand age (years)	135	61
Site index (H100)	G26	G36
Mean height (m)	28	24
Stems/ha (no.)	353	719
DBH tree 1	285	258
DBH tree 2	274	271
DBH tree 3	356	398
DBH tree 4	358	392
DBH tree 5	394	435
DBH tree 6	404	442

m.a.s.l., meters above sea level; Site index (H100), height in meters for the two highest trees of the dominating species at age 100 years; DBH, diameter at breast height

Materials and methods

The study was based on data from the European Spruce Stem Bank, which is a result of the European Community (EC) project "Improved Spruce Timber Utilisation."[11] The basis of the project is the CT scanning of 150 carefully selected Norway spruce (*Picea abies* L. Karst) stems from 25 sample plots in Sweden, Finland, and France. The material in this study was obtained from two sample plots in Sweden: plots 11 and 14 (Table 1).

Six trees were selected from each sample plot: two small trees, two medium-size trees, and two large trees (Table 1). After felling and cross-cutting, the logs were scanned every 10mm along the log in a medical tomograph (Siemens SOMATOM AR.T). The X-ray beam width was 5mm. The logs were fixed at both ends and adjusted to three laser lines so all logs from a tree followed the same coordinate system during the scanning. All images were stored as 512×512 pixel images.

After scanning, a 0.1m thick disk was cut from the top end of some of the logs at different heights in the stem. These disks were sent to the Building Research Establishment (BRE) in England for destructive measurement of the spiral grain. Ten logs (disks) were measured from sample plot 11, and 13 logs (disks) were measured from sample plot 14.

The destructive measurements of the spiral grain were carried out using a method described by Brazier.[12] The disks

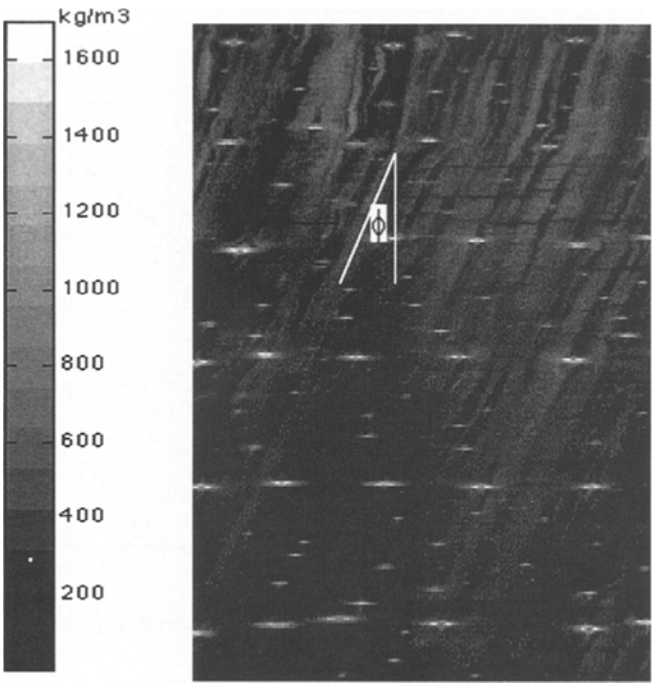

Fig. 3. Concentric surface reconstructed from a computed tomography (CT) image stack. The horizontal direction (x-axis) corresponds to the tangential direction of the concentric surface (CS) and the vertical direction (y-axis) corresponds to the distance from the root to the top of the log. Resolution in the horizontal direction is 1 degree/pixel and in the vertical direction 10mm/pixel. The leaning pattern in the image probably corresponds to the spiral grain. The image was taken 35.6mm from the pith. Its gray level is given kilograms per cubic meter in (kg/m^3)

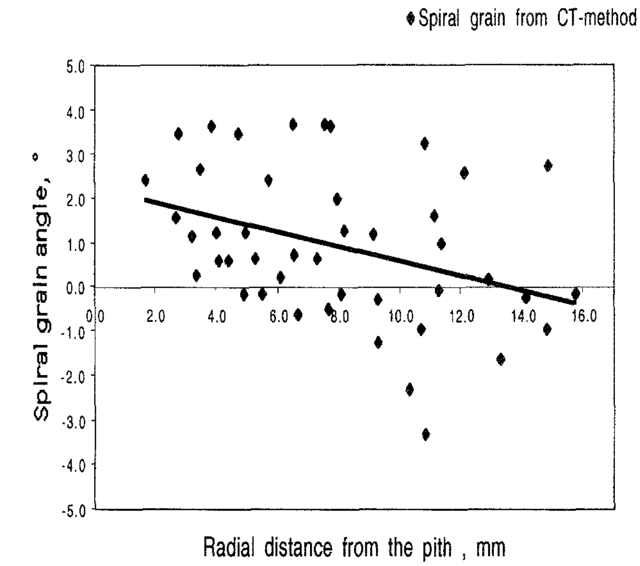

Fig. 4. Spiral grain angle for stand 11 as a function of the radial distance from the pith. Spiral grain values were measured with the CT method

were first split along an east–west diameter through the pith. The spiral grain was recorded along the west radius and the east radius 10, 30, 50, 70, 90, mm (and so forth) from the pith.[13] At a certain distance from the pith the mean value of the east and west measurements were calculated and used in the comparison with the nondestructive method.

Measurements

The CT images from a log were consolidated into a CT image stack with one image every 10mm along the log. Stack concentric surfaces (CSs) around the pith were created from the CT image with the aid of "Image" software (Fig. 3). A CS image has 360 pixels, corresponding to one pixel per degree in the horizontal direction and one pixel per 10mm along the log in the vertical direction. Ten CSs on different radii from the pith were reconstructed. The five innermost CS images were formed within the heartwood and CSs 6–10 were reconstructed within the sapwood. A high density streak pattern can be observed in the CS images (Fig. 3).[14] The hypothesis of this study was that this pattern might be a spiral grain pattern. The angle of this pattern in relation to the longitudinal axis was defined as the spiral grain angle in the CS images. The angle was measured in the CS images with the aid of the "Image" software.[15] Four measurements were made in each CS image, and the mean value was calculated.

To be able to compare the values of the spiral grain obtained from the CS images with the measurements of the spiral grain obtained from the destructive method, it was necessary to calculate the radial distance from the pith to the various CSs. The angle measured for the spiral grain pattern in the CS image had to be converted to the true spiral grain in the log, as the longitudinal scale (Y) and the tangential scale (X) in the CS image are not the same and, in addition, vary among CSs. The following expression was used for the conversion.

$$\Phi_{\log} = \text{Arctan}\left(\pi * D * \tan(\Phi_{\text{CS}}/360)\right) \tag{1}$$

where $\Phi_{\log}$ is the spiral grain angle in the log; Φ_{CS} is the spiral grain angle in the CS image; and D is the diameter of the CS in pixels.

Results

For Stand 11 the measurements showed a general tendency to have an LR pattern, beginning with a left inclination near the pith and concluding with a right inclination near the bark (Fig. 4). This change of inclination of the spiral grain takes place at approximately one-half of the diameter of the tree, although the variations among trees and logs are large.

A comparison in pairs between the CT method and the destructive method is shown in Fig. 5. The correlation (r) between the two methods was 0.81. The average difference

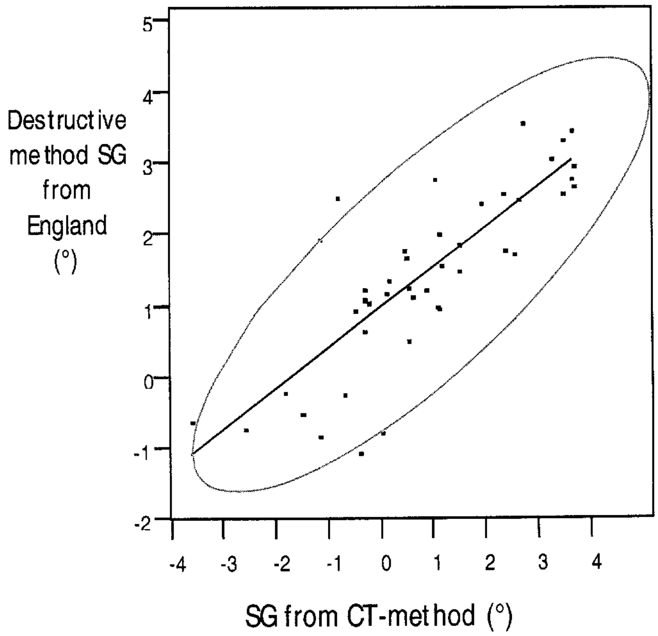

Fig. 5. Comparison in pairs of spiral grain angle (*SG*) measurements between the CT method and the destructive method for Stand 11. SG corresponds to the spiral grain angle in the log

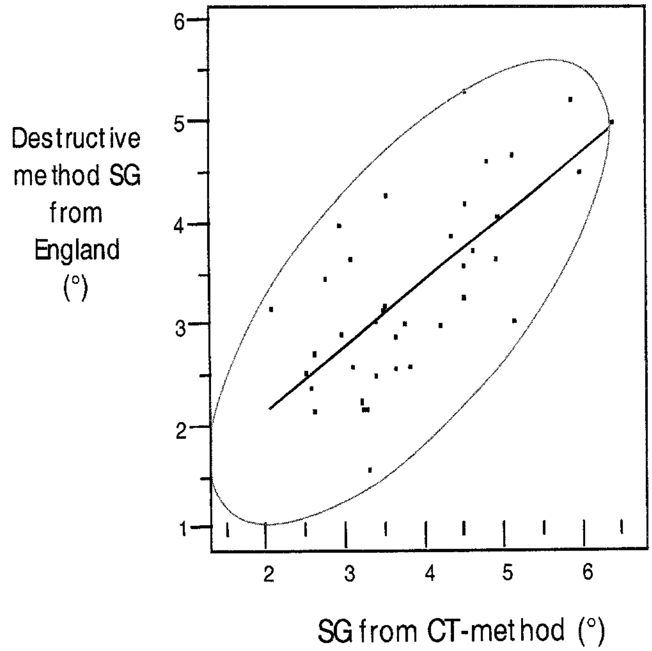

Fig. 7. Comparison in pairs of the SG measurements between the CT method and the destructive method for Stand 14

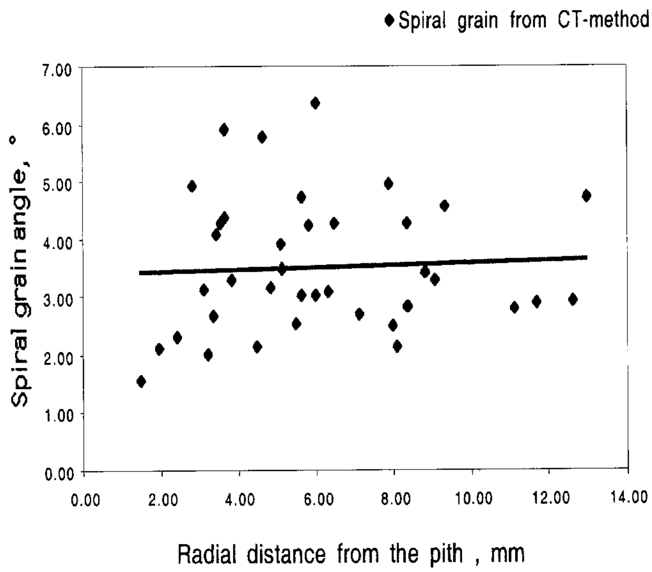

Fig. 6. Spiral grain angle for Stand 14 as a function of the radial distance from the pith. Values were derived from the CT method

between the destructive method and the CT method was 0.8 degrees with a standard deviation of 1.0 degree.

For Stand 14 the measurements always showed the same inclination of the spiral grain. Its inclination was to the left (L), from the pith to the bark (Fig. 6). A comparison in pairs between the CT method and the destructive method is shown in Fig. 7. The correlation (*r*) between the two methods was 0.71. The average difference between the destructive method and the CT method was 0.4 degree with a standard deviation of 0.9 degree.

Discussion

The two stands included in this study show different spiral grain patterns. The LR pattern, so well known from the literature, is shown for Stand 11, whereas the spiral grain in Stand 14 shows no tendency to change with the distance from the pith. One reason for this discrepancy between the results obtained for Stand 14 and the "normal" pattern may be that the trees in Stand 14 are only 61 years old. Maybe the "normal" pattern will show up when the trees in Stand 14 become older. No general conclusions can be made from these results, as the number of trees in this study was limited. The only thing that is clear is that different stands and different trees can have different spiral grain patterns.

A comparison in pairs shows that there is fairly good correlation between the destructive method for spiral grain measurement and the nondestructive CT method, although the values from the destructive method are in most cases slightly higher than the spiral grain values from the CT method. The discrepancies between the two methods may depend on errors in both methods. The variation interval for the spiral grain was rather small for the test sample, which can have had a negative effect on the correlation between the two methods. It can be concluded that it is possible to measure the spiral grain angle nondestructively with a CT scanner, and that this measurement can be performed at arbitrary positions in the stem.

It is not clear what the pattern with high density streaks means anatomically. The hypothesis is that they are resin streaks around the knots that follow the grain of the wood and thereby display the grain direction. This hypothesis must be confirmed or rejected in a new study.

Both methods used in this study are laboratory techniques. The goal for the future must be to develop an industrial method so logs with considerable spiral grain can be sorted out or treated separately. Therefore, the next step is to study the possibility of using an industrial X-ray LogScanner for spiral grain measurements.

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References

1. Harris JM (1969) Spiral grain and wave phenomena in wood formation. Springer, Berlin Heidelberg New York
2. Danborg F (1994) Drying properties and visual grading of juvenil wood from fast grown *Picea sitchensis*. The Royal Veterinary and Agriculatural University, Frederiksberg, Denmark
3. Tsehaye A, Walker JCF (1996) Spiral grain in Canterbury *Pinus radiata* within- and between-tree variations and effect on mechanical properties. School of Forestry, University of Canterbury, NZ
4. Tian X, Cown DJ, Lausberg MJF (1996) Modelling of *Pinus radiata* wood properties. Part 1. Spiral grain. Journal of Forest Science 25(2):200–213
5. Skatter S, Kucera B (1998) Spiral grain – an adaptation of trees to withstand stem breakage caused by wind induced torsion. Norwegian Forest Research Institute, Ås, Norway
6. Skatter S, Archer RR (1997) Within-stem growth stress distribution in the case of spiral grain. Norwegian Forest Research Institute, Ås, Norway; Department of Civil and Environment Engineering, University of Massachusetts, Watertown, MA
7. Hansen JK, Roullund H (1997) Genetic parameter for spiral grain, stem form, pilodyn and growth in 13 years old clones of Sitka spruce (*Picea sitchensis* (Bong). Car). Silvae Genet 46:107–113
8. Keller R, Oukda M (1996) Influence of green pruning on grain angle in Norway spruce (*Picea abies Kanten*). Laboratoire de Recherches en Sciences Forestiéres Nancy, France
9. Skatter S, Kucera B (1998) The cause of the prevalent directions of the spiral grain patterns in conifers. Norwegian Forest Research Institute, Ås, Norway
10. Rouvinen S, Kvuluvainen T (1997) Structure and asymetry of tree crowns in relation to local competittion in a natural mature Scots pine forest. Can J For Res 27:890–902
11. Anonymous (1996) Improve spruce timber utilisation. EC FAIR II Project. PL96-1915, Uppsala, Sweden
12. Brazier JD (1965) An assessment of the incidence and significance of spiral grain in young conifer trees. For Prod J 15:308–312
13. Moore GL, Maun KW (1998) Improved spruce timber utilisation: sub-task AB 1.6: measurement of spiral grain on disc
14. Grundberg S, Grönlund A, Grönlund U (1995) The Swedish stem bank. Division for Wood Technology, Skellefteå, Sweden
15. National Institutes of Health (1996) NIHImageVersion1.61. NIH, Bethesda, MD, USA