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Research Method and Improvement of Log Rotation in Sawmills

Tomi Tulokas and Jawdat Tannous

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Log rotation studies were performed at 14 Finnish sawmills during the years 2003–2005. In the investigation of automatic log rotation, the materialized degree of log rotation for each log was calculated from photos captured from a digital video recording. Rotation errors (Δ) for individual logs and again the accuracy of the automatic log rotator was determined from optimized angle values of the log measuring system and materialized angle values calculated from the still photos. The accuracy of the log rotation varied considerably between sawmills. The rotation error average ($\bar{X}$) of the automatic log rotation varied from –23.6° to +11.4°. This means that in some cases the logs were under-rotated and in some they were over-rotated, on an average. Standard deviation of the rotation error (*s*) of the automatic rotator varied from 4.4° to 22.9°. The results of the simulation indicated that the performance of the log rotation system can be improved by adjusting the log rotator control. In addition to the zero degree error on an average rotation (or near to zero), the corrected values have a significantly smaller standard deviation of the rotation error, and the number of correct rotations was significantly higher compared to the situation before the adjusted rotation commands. At Sawmill 1, standard deviation of the rotation error was reduced by 40.9% from 14.9 degrees to 8.8 degrees. At the same time the number of correct rotations ($-10° \leq \Delta \leq +10°$) increased 4.0 fold from 20.1% to 79.4%. At Sawmill 2, standard deviation of the rotation error was reduced by 23.8% from 10.5 degrees to 8.0 degrees. At this sawmill, the rate of accepted rotations increased 1.9 fold from 42.6% to 81.0%. According to previous research, 2.5° decrease in standard deviation of the rotation error (from 10.5 to 8.0°) in square sawing means about 0.5% increase in value yield. For example with 10 million € annual sales of sawn timber this means 50 000 € extra profit.

Keywords log rotation, sawing, optimizing, precision, standard deviation, yield
Addresses *Tulokas*, Centre for Timber Engineering, Edinburgh Napier University, 10 Colinton Road, Edinburgh EH10 5DT, UK; *Tannous*, School of Engineering and the Built Environment, Edinburgh Napier University, 10 Colinton Road, Edinburgh EH10 5DT, UK
E-mail tomi.tulokas@lut.fi
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1 Introduction

Logs are rotated and centred for maximal raw material usage and thus the best economic yield for sawmills. The accuracy and precision of log rotation systems have not, however, kept pace with the development of modern cutting machines and production control systems. Furthermore, very little is known about how the log rotation process actually works at sawmills.

The existing research information about log rotation accuracy is limited. Research results on optimal log and cant orientation for sawing are often based on different simulation models. The correctness of log rotation has been investigated because log and cant orientation equipment have a significant influence on the sawing yield (Fig. 1). It has been shown by Vesanen (2005) that the value yield increase through more precise log rotation in a primary saw machine is in the order of 3 € per sawn cubic meter of lumber. Additionally, when the logs are sawn correctly in the primary saw machine the cutting results in re-saw, with or without curve sawing, will also improve. In the case of a profiler re-saw with sideboard optimization the value yield increase was in the order of 2 € per sawn cubic meter. The annual total economic improvement for a medium size sawmill may be up to half a million euros.

Usenius et al. (2009) has investigated the correlation between standard deviation of log rotation error and loss in value yield in sawing with square and through and through sawing (Fig. 2). The figure shows the bigger standard deviation the bigger the value yield loss in sawing. The optimal log rotation and centering is more crucial with through and through sawing compared to square sawing. With square sawing the maximum standard deviation of rotation error should be near to 2°

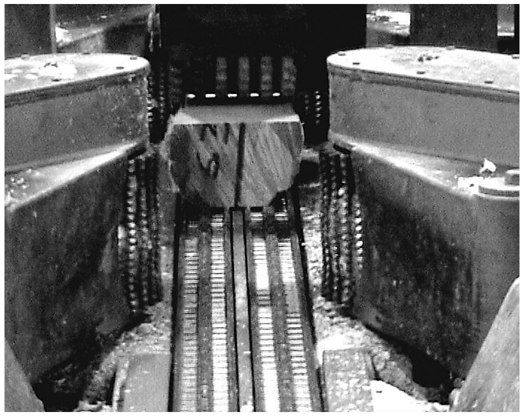

Fig. 1. Error in centering and in log rotation will affect recovery of sideboards. The recovery loss of sideboards due to rotation error is not, however, as evident as in this case.

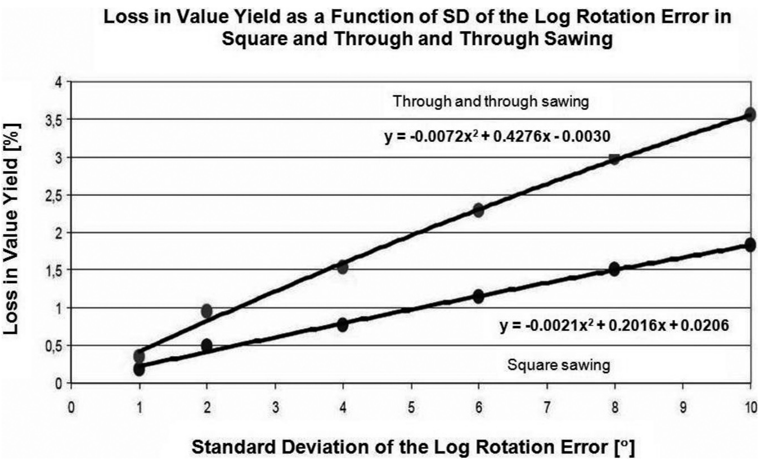

Fig. 2. The correlation between standard deviation of the log rotation error and loss in value yield in square and through and through sawing (Usenius et al. 2009).

or less to reach a log rotation accuracy level where the loss in value yield is less than 0.5%.

Sawmill personnel often have their own idea about the correctness of log rotation. This idea is often based on visual observations of the rotation process and whether the log scaler's optimized rotation angles change on the log scaler's display. Nevertheless, it has been observed during investigations that although the log scaler optimizes the log rotation angle and the log rotator rotates the log in the right direction, it is very difficult to visually observe whether the log rotates, for example, 20 or 45 degrees in the rotation process.

In this article, we present a research method for determining the accuracy and precision of log rotation. Moreover, we discuss the methods for improving the log rotation process.

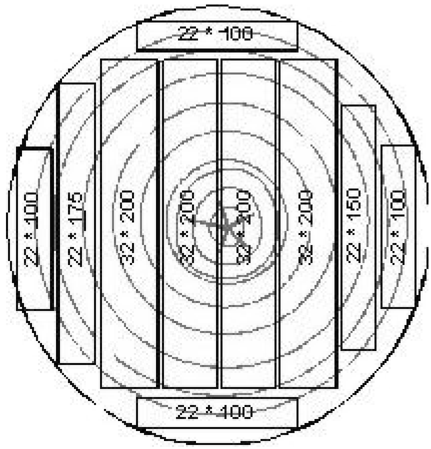

Fig. 3. Automatic optimization of primary breakdown fits the defined products in a profile model of a scanned log and employs a logical sequence of product fitting to evaluate all possible solutions at machine allowed positions.

2 Materials and Methods

2.1 Features of the Accuracy and Precision of Log Rotation

Nowadays the most common log rotation method, automatic log rotation, is based on a three-dimensional image that is constituted with an optical measurement. The image is usually rotated virtually at 5° intervals in a computer and the dimensions of boards that have been constituted for the log are investigated in every alignment of the log (Fig. 3). The alignment that gives the highest value yield determines the rotation angle of the log. After that, the log feeder and the log rotator centre and rotate the log in the best cutting position according to the rotation angle determined by optimization (Fig. 4). This is the most frequently used log rotation method at sawmills.

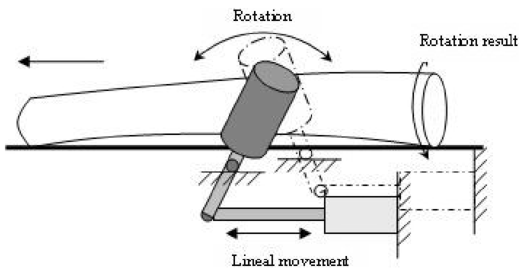

Fig. 4. Transforming a servo controlled linear movement into rotation of a log. (Vesanen 2005)

When defining a successful automatic log rotation one compares the log rotation command from the optimizer with the materialized rotation angle after rotation. The difference between the optimized rotation angle and the materialized angle gives us the rotation error Δ_i for an individual log. For a group of logs we will get the features which describe the behaviour of the whole sample, such as the log rotation error average ($\bar{X}$) and standard deviation of the rotation error (s) around the rotation error mean. Fig. 5 shows a rotation error distribution from one log rotation study.

The rotation error (Δ_i) for an individual log in the log rotation process can be calculated with an error Eq. 1:

$$\Delta_i = \left(\left| Ra_{\text{Mat}} \right| - \left| Ra_{\text{Opt}} \right| \right) \quad (1)$$

where Ra_{Mat} = the materialized rotation angle for an individual log in the log rotation process; Ra_{Opt} = the optimized rotation angle for an individual log by the log scaler.

The rotation error average ($\bar{X}$) for a group of logs can be calculated with an average Eq. 2:

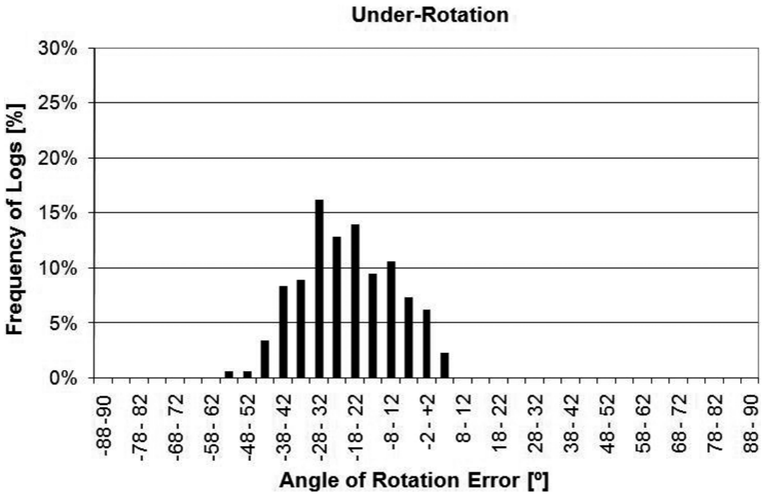

Fig. 5. In one study the rotation error average ($\bar{X}$) was –22.2°. Rotations were 22.2° under-rotated on an average. Standard deviation of the rotation error (s) was 13.0°. The rate of successful rotations was 21.1%.

$$\bar{X} = \frac{1}{n}\sum \Delta_i \qquad (2)$$

where n = the number of samples (logs); Δ_i = the rotation error for an individual log.

Standard deviation of the rotation error (s) for a group of logs can be calculated with standard deviation Eq. 3:

$$s = \sqrt{\frac{1}{n-1}\sum (\Delta_i - \bar{X})^2} \qquad (3)$$

The rotation error average describes the accuracy of the process on an average. Standard deviation of the rotation error describes the precision of the system. In other words, a standard deviation describes how exactly the process is "in a cluster".

2.2 Determination of Successful Log Rotation

The correct rotation with softwood can be "sweep up" for the log position that yields the best solution. For the log rotation to be well in control the rotation error average should be close to 0° and standard deviation of the rotation error should be as small as possible (0°). The effective control of log rotation is a critical success factor in sawmill. The yield (the volume of lumber per used log volume) can decrease substantially if the log is not rotated to its best cutting position. The required rotation precision (standard deviation, around the rotation error average) by experts is often stated as better than 5°.

However, the analysis of log rotation success should not be limited to the features ($\bar{X}$) and s. It is of interest to examine how many of the rotations hit an acceptable range. The acceptable range can be defined as an area in which the Δ is small enough, such as ($-10° \leq \Delta \leq +10°$). In log rotation process the maximum deviation value of 10° between optimized and materialized angle means standard deviation value of 3.3° and a rotation error mean value of 0° when 99.7% of rotations hit the target. That is a challenging objective to current log rotation technology. Allowed standard deviations from the target value and the number of logs that must hit the target range are matters which each sawmill must decide individually.

The average rotation error can be reduced by recalibrating of the rotation mechanism or with a programmable constant correction coefficient, which is applied to all rotations. However, one cannot simply adjust the mean of the rotation angles with a constant correction value. A more serious problem

Fig. 6. Measuring situation during the log measurement, before rotation.

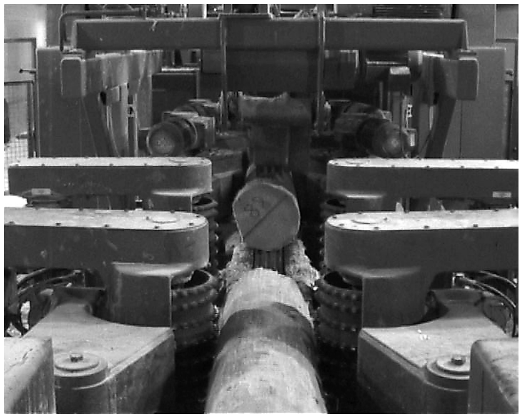

Fig. 7. Measuring situation after rotation.

in rotation is the control of standard deviation of individual rotation angles around the mean.

2.3 Measuring Method for Accuracy and Precision of Log Rotation

Log rotation studies were performed at 14 Finnish sawmills during the years 2003–2005. Each sawmill used 3D log scanner with an automatic log rotator. The rotator mechanism in sawmills varied from single or double tilt rotators to single ring framework rotor rotator. The sawmills were processing Norway spruce logs when the investigation was carried out. The investigation of automatic log rotation, the materialized degree of log rotation angle for each log was calculated from photos captured from a digital video recording.

A study of the accuracy of automatic log rotation was based on the use of two or three digital video cameras. 50–300 logs were chosen on the log field for each measuring batch.

The logs were numbered (for analysis of the results) and alignment lines were drawn on the butt-ends or the top ends of the logs, depending on camera positions. The aim of the alignment lines was to verify the materialized degrees of the log rotations. The alignment lines were drawn with optical alignments of the logs or randomly. After that, the logs were transported through the log measuring system to the sawing machine by conveyor.

Fig. 8. Shooting the alignment line from the cant.

The first camera shot the log during the measurement, before rotation (Fig. 6), and the second camera shot the log after the rotation (Fig. 7). In many cases the log alignment line was shot (2nd camera) from the cant after the rotation and primary sawing step (Fig. 8). Rotation angles measured by the log measuring system and the order of arrival of the logs (for helping result analysis) were recorded.

2.4 Analyzing the Results

Still photos from each measured log, before and after the rotation, were captured from the video

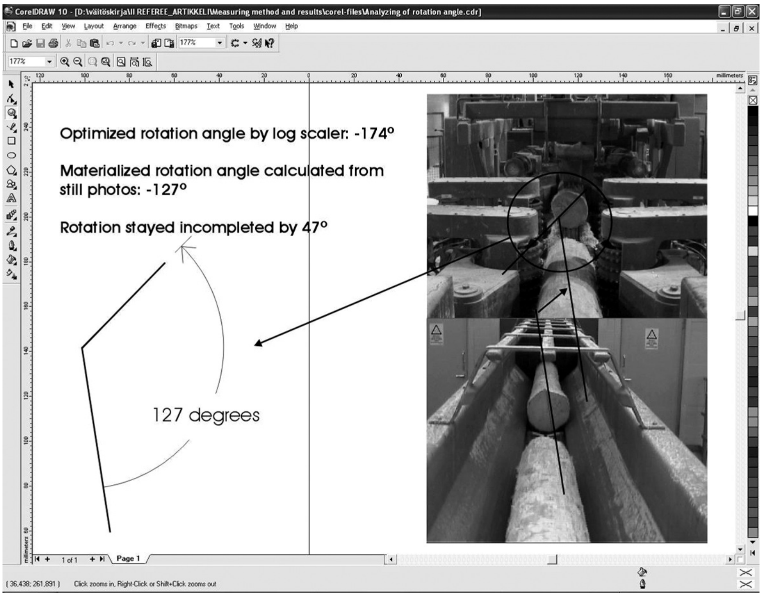

Fig. 9. Analyzing the materialized rotation angle: The optimized angle value by log measuring system was –174°. The materialized rotation angle calculated from still photos was –127°. The rotation error Δ for a log was –47°. The rotation fell short of the target angle by 47°.

with a video image processing program. Still photos of each log were set to the same template (Fig. 9). The photos were rotated with the assistance of reference levels determined in the measuring process so that the vertical and horizontal alignments were the same in both photos on the template. Determining the rotation angle from the photos was required for drawing assistance lines with an image processing program in the same place where the alignment lines were in the photos. The program automatically calculated the angle between drawn assistance lines and the calculated angle was the materialized rotation angle of the log in degrees.

2.5 Inaccuracy Factors of the Measuring Method

The method of determining the precision of log rotation has several drawbacks. These can cause errors in measurement results. Hence the marginal error of the method is hard to determine. Sometimes some logs have to be excluded from the results because of inaccuracy factors.

In the research method based on digital video camera technology, the purpose is that both cameras are set at the same distance from the focus (log top) and vertically and horizontally at the same level with the focus.

Determining the angle of the alignment lines from the logs requires determining vertical or horizontal reference levels from the constructions of the sawmill or sawing machine. The reference levels are determined with a spirit level which might cause inaccuracy. Determining the log rotation angle from the photos requires drawing lines. All drawings with an image processing program are based on observations with the human eye and drawing by hand (with a computer mouse), which causes inaccuracy.

The marking of the log is done with a felt pen, and therefore, the marks are not always uniform due to the irregularities of the log surface. This increases inaccuracy when we are drawing assistance lines in the same place as the alignment lines on the templates. Furthermore, a possibly dirty, snowy or frozen log end and an often irregular log surface make the observation of alignment lines more difficult. Therefore, the “bad” logs are not even marked or analyzed. A skew log top, crooked stem and oval shape of the log also cause inaccuracies in this method because the cameras are not always perpendicular to the log top. In addition, still-photos are often darker compared to video clips, which sometimes hinders the observation of the alignment lines in still photos.

An independent inaccuracy factor for the measuring method may be the log’s unstable performance on the conveyor. The log position may change radically when the log moves from the measuring conveyor to the positioning conveyor. Thus the first camera shot should be taken just before the log rotator and the second one just after the rotation. Then we could establish the accuracy and precision of the log rotator. However, the log rotation process begins from log measuring, and therefore, it’s also important that log doesn’t sway on the conveyor between log scanner and log rotator.

It is very difficult or maybe even impossible to scientifically determine the absolute accuracy of the measuring method. In addition, the accuracy factors concerning the measuring process vary individually between sawmills and measuring conditions. Based on experiences obtained from investigations, the maximum error for a measured rotation angle for an individual log has been estimated to be 2°, on an average.

3 Results

3.1 Log Rotation at Sawmills

A very typical situation at most sawmills was that the rotation error average often deviated clearly from zero: log might have been under-rotated by 20° on an average (Fig. 5) or they could be over-rotated from the target rotation angles. Additionally, standard deviation of the rotation error was often large, sometimes over 30°. An average deviation from zero and large standard deviation decrease the rate of successful rotations ($|\Delta| \leq 10°$), which decreases the volume yield of sawing.

Table 1 shows a summary of the log rotation results on the tilt roll rotator study at Sawmill 1. The minimum log top diameter was 277 mm and the line speed was 100 m/min. Table 2 shows automatic log rotation features from 14 sawmills.

Even if the number of sawmills studied was 14 only one sawmill (No. 6) had the log rota-

Table 1. Log rotation summary on the tilt roll rotator study at Sawmill 1. The rotation error average deviates clearly from zero and standard deviation of the rotation error is large.

Log rotator type: double tilt roll rotator — *Line speed* (m / min): 100
Log class (mm): 277 — *Log length* (m): 4–6
Cutting pattern: heartwood 32 × 225 × 4; boards 32 × 150 × 2

Log number	Rotation angle [°]		
	Optimized (Ra_{Opt}) by log scanner	Materialized (Ra_{Mat}) by calculation	$\|Ra_{Mat}\| - \|Ra_{Opt}\|$ Rotation error Δ [under (–) / over (+)]
1	–91	–45	–46
2	93	64	–29
3	–175	–122	–53
.	.	.	.
.	.	.	.
.	.	.	.
173	–153	–106	–47
174	–54	–31	–23
175	73	60	–13
Rotation error average [°]			23.6
Std. deviation of log rotation angle [°]			14.9

Table 2. Log rotation features at 14 sawmills.

Sawmill	Rotation error average [°]	Std. deviation of log rotation angle [°]
1	–23.6	14.9
2	11.4	10.5
$3_{\text{sawing line 1}}$	3.7	13.2
$3_{\text{sawing line 2}}$	5.7	16.7
4	–8.1	8.4
5	2.4	8.5
6	–2.9	4.4
7	–4.0	14.7
8	–1.4	9.6
9	–1.1	15.8
10	–10.6	13.6
11	–15.8	22.9
12	–1.8	14.9
13	3.1	22.9
$14_{\text{log size 1}}$	–6.2	9.1
$14_{\text{log size 2}}$	–8.4	7.1

tion process under good control when standard deviation of the rotation error was graded at 4.4 degrees. A few sawmills had the log rotation process fairly in control when standard deviation of the rotation error was graded at 8 degrees. At most of the sawmills, standard deviation of the log rotation error was over 10 degrees and in only a few sawmills the log rotation error average was near to zero.

3.2 The Relationship between the Rotation Error and the Optimized Angle

As we stated, by recalibration, the average of the rotation error can be set near to zero by using a constant correction angle, which is applied to all rotations. A greater problem in log rotation is to control the standard deviation of individual rotation angles around the mean.

At most sawmills, the studies indicated that when using a fixed line speed and roll pressure the error of rotation Δ was at least, to some extent, dependent on the magnitude of the optimized angle due to the mass of the logs and the clearance and the flexibility of the mechanics. The larger the targeted optimized angle, the more probable and frequent was the occurrence of rotation errors and the wider the angle of error (Δ). There seemed to be a near linear relationship between the angle of error and the magnitude of the rotation command, for example in analysis linear function gave higher R^2 values compared to 2nd degree functions. This proportional rotation error could even be visually observed on the sawing line. It was often quite clear that a log with a large optimized rotation angle did not rotate enough (Fig. 10, Sawmill 1) or rotated too much (Fig. 11, Sawmill 2).

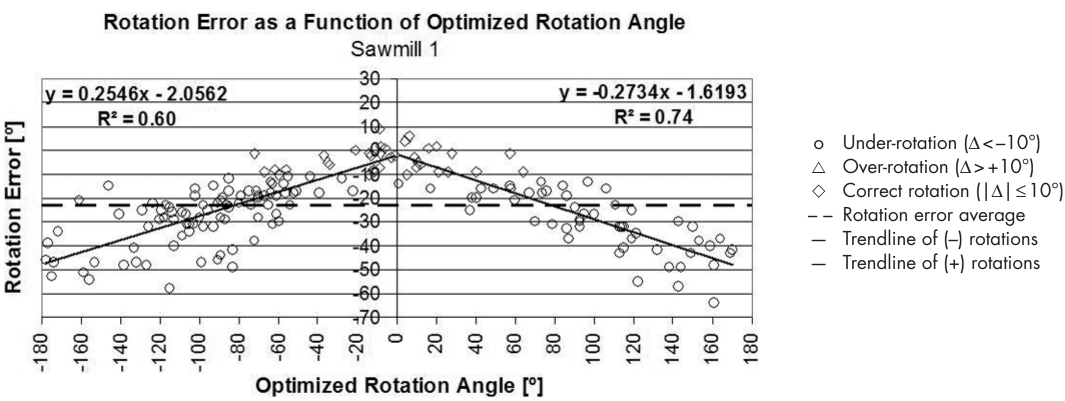

Fig. 10. The relationship between the optimized rotation angles and the materialized rotation errors at Sawmill 1. The rotation error average ($\bar{X}$) was –23.6°. Logs were under-rotated by 23.6°, on an average. Standard deviation of the rotation error (s) was 14.9°. The rate of successful rotations was 20.1%.

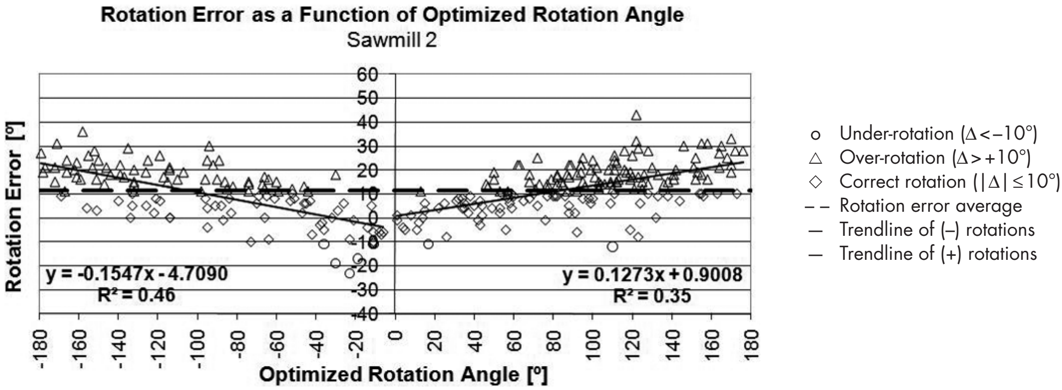

Fig. 11. The relationship between the optimized rotation angles and the materialized rotation errors at Sawmill 2. The rotation error average ($\bar{X}$) was +11.4°. Logs were over-rotated by 11.4°, on an average. Standard deviation of the rotation error (s) was 10.5°. The rate of successful rotations was 42.6%.

3.3 Correction of Log Rotation Process by Calculation

The performance of the log rotation system can be improved by using information from the log rotation measurement and analysis. Correction equations for the log rotation at all sawmills, such as in Fig. 10 (Eq. 4 and Eq. 5) and Fig. 11 (Eq. 6 and Eq. 7), were calculated using the following linear functions:

Correction equations for Sawmill 1:

$$y1_{(1)} = 0.2546x - 2.0562 \quad (4)$$

$$y1_{(2)} = -0.2734x - 1.6193 \quad (5)$$

Correction equations for Sawmill 2:

$$y2_{(1)} = -0.1547x - 4.709 \quad (6)$$

$$y2_{(2)} = 0.1273x + 0.9008 \quad (7)$$

In Fig. 12 and Fig. 13 the original materialized rotation values have been corrected with correction angles calculated from linear function equations where x is optimized rotation angle. The y values derived from the correction equations are added to the counter-clockwise rotations and deducted from the clockwise rotations.

The results of the simulation indicated that the performance of the log rotation system could be improved by adjusting the log rotator control. In addition to the zero degree error on an average rotation (or near to zero), the corrected values have a significantly smaller standard deviation of the rotation error and the number of correct rotations was significantly higher compared to the situation before the adjusted rotation commands.

At Sawmill 1, standard deviation of the rotation error was reduced by 40.9% from 14.9 degrees to 8.8 degrees. At the same time the number of correct rotations (–10° ≤ Δ ≤ +10°) increased 4.0 fold from 20.1% to 79.4%. According to Usenius et al. (2009) 6.1° decrease in standard deviation of the rotation error (from 14.9 ° to 8.8°) means about 1.2% increase in value yield in square sawing. For example with10 million € annual sales of sawn timber this means 120 000 € extra profit.

At Sawmill 2, standard deviation of the rotation error was reduced by 23.8% from 10.5 degrees to 8.0 degrees. At this sawmill, the rate of accepted rotations increased 1.9 fold from 42.6% to 81.0%. According to Usenius et al. (2009), 2.5° decrease in standard deviation of the rotation error (from 10.5° to 8.0°) in square sawing means about 0.5% increase in value yield. For example with 10 million € annual sales of sawn timber this means 50 000 € extra profit.

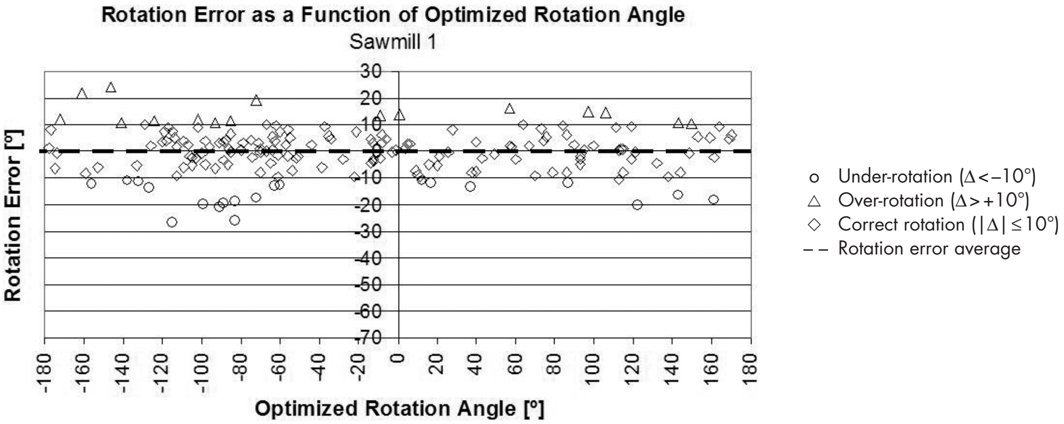

Fig. 12. Corrected rotation results at Sawmill 1. The rotation error average ($\bar{X}$) was –0.2°. Standard deviation of the rotation error (s) was 8.8°. The rate of successful rotations was 79.4%.

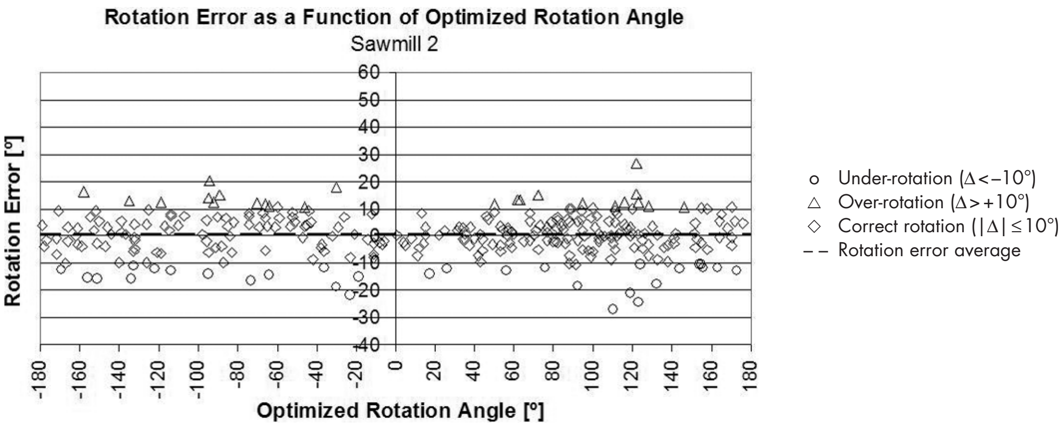

Fig. 13. Corrected rotation results at Sawmill 2. The rotation error average ($\bar{X}$) was –0.1°. Standard deviation of the rotation error (s) was 8.0°. The rate of successful rotations was 81.0%.

3.4 Incorrect and/or Mistimed Movement of Tilt Rolls

In tilt roll rotators with one or two pairs of rolls, the tilt rolls rotate the log. Therefore, it is important that the rolls position themselves correctly before the rotation, and that they move and rotate correctly and on time during the log rotation.

Because of high standard deviation values of the rotation error, we examined the relationship between the optimized rotation angles and the materialized rotation errors with linear function in which (+) and (–) rotations were considered separately. And the results were surprisingly informative at Sawmills 12 and Sawmill 13 (Fig. 14 and Fig. 15). The figures show that the tilt rolls moved incorrectly and/or untimely. The reason for this was a detected position error of the tilt rolls.

Kemppinen (2005) has observed the same that, seen from the feed direction, the first right hand tilt roll was in an angle of 2.3° towards the feed direction at Sawmill 13. Kemppinen noticed also that a 2° failure of one tilt roll alignment can affect a 5° increase in standard deviation value

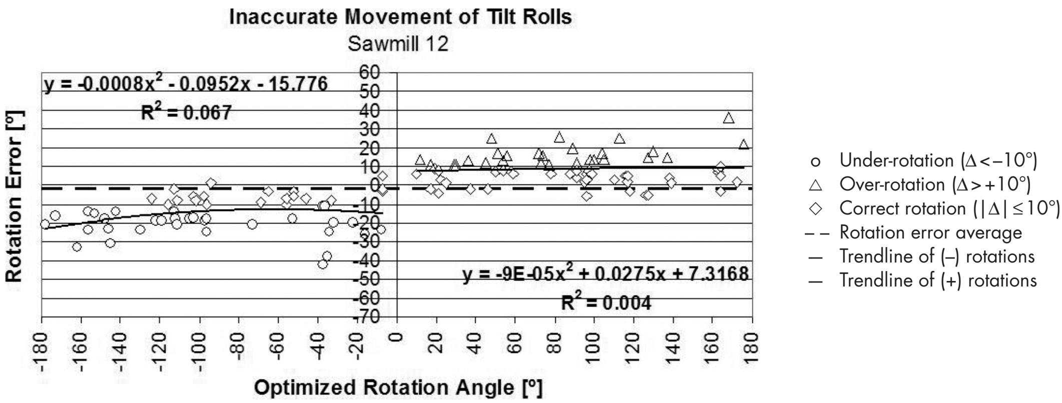

Fig. 14. In Sawmill 12, the logs were over-rotated 8.8° clockwise, whereas counter-clockwise they were under-rotated 15.1°, on an average. Standard deviations of the rotation angle were reasonably small (8.3° and 9.8°) when the clockwise and counter-clockwise rotations were examined separately. The inaccurate movement of the tilt rolls increases standard deviation of the rotation error (14.9°).

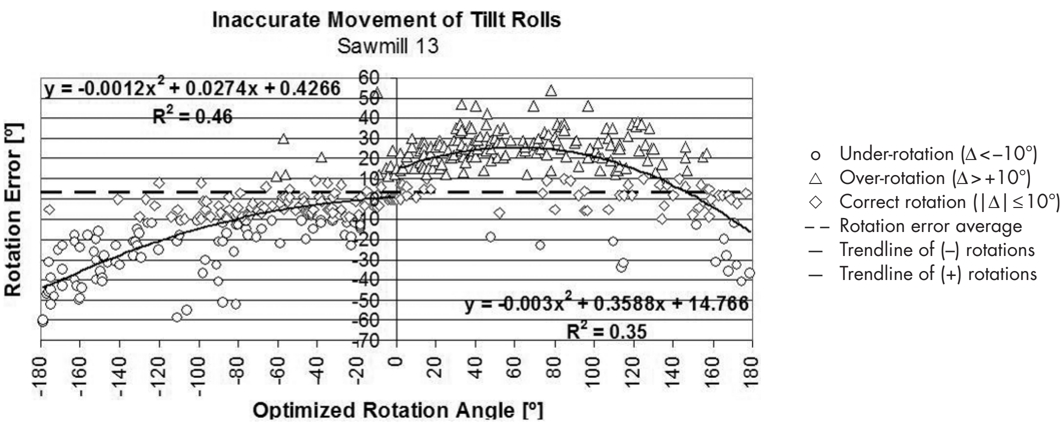

Fig. 15. In Sawmill 13, the logs were over-rotated 17.0° clockwise, whereas counter-clockwise they were under-rotated 13.1°, on an average. Standard deviations of the rotation angle were large (17.0° and 17.8°) when the clockwise and counter-clockwise rotations were examined separately. An inaccurate movement of the tilt rolls significantly increases standard deviation of the rotation error (22.9°).

of the rotation angle. The incorrect alignment of the tilt roll can also be observed as an abnormal distribution of rotation errors (Fig. 16).

Fig. 17 and Fig. 18 show the relationship between the optimized rotation angles and the rotation errors with two different log sizes at Sawmill 14. During the study the till rolls of the log rotator did not operate synchronously. The figures show that the relationship between the optimized rotation angles and the rotation errors might differ with different log sizes. Therefore, the investigation of the relationship between the optimized rotation angles and the rotation errors is necessary with various log sizes even if the log rotators were mechanically in good condition.

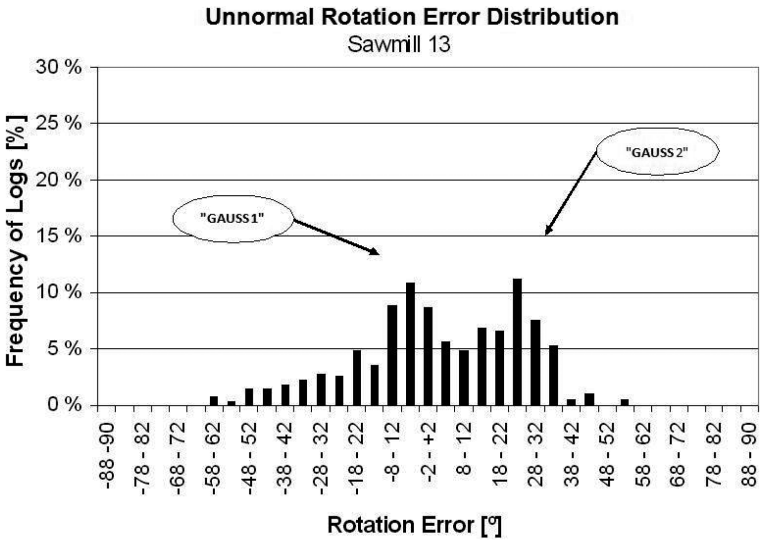

Fig. 16. The frequency of logs with different values of rotation errors. The figure clearly shows two distributions of rotation error caused by incorrect positioning of the tilt rolls.

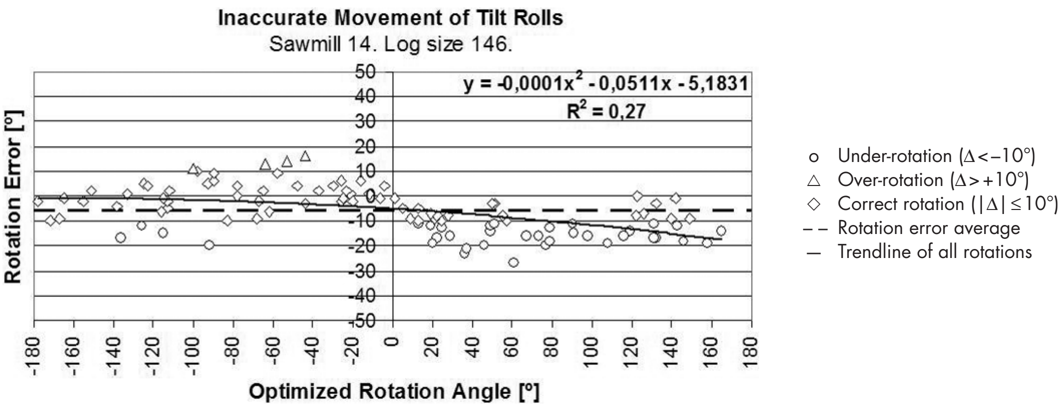

Fig. 17. The relationship between the optimized rotation angles and the materialized rotation errors with minimum log top diameter of 146 mm at Sawmill 14 based to the 2nd degree function. The rotation error average ($\bar{X}$) was –6.2°. Standard deviation of the rotation error (s) was 9.1°. The rate of successful rotations was 61.8%.

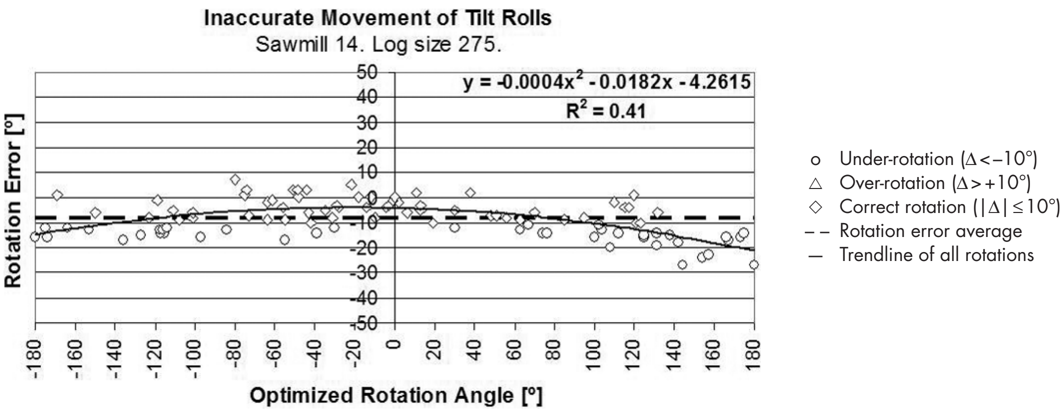

Fig. 18. The relationship between the optimized rotation angles and the materialized rotation errors with minimum log top diameter of 275 mm at Sawmill 14 based to the 2nd degree function. The rotation error average ($\bar{X}$) was –8.4°. Standard deviation of the rotation error (s) was 7.1°. The rate of successful rotations was 60.2%.

4 Discussion

The results of log rotation studies show that there is much room for improvement both in the mechanical and data transmission systems in this most basic and important stage of cutting logs.

The interdependency between the rotation error and optimization angle shows that successful rotation is not only a question of the accurate operation of rotator mechanics or other components involved in the rotation process. Thus the solution to log rotation quality improvement could also be in the control of the rotator mechanism when a clear interdependency between the rotation error and optimization angle is detectable.

The rotation error trend lines with 1st degree polynome examined separately for clockwise and counter-clockwise rotations show directly if the rotation direction has any effect on the success of the rotation.

If interdependency is observed between the rotation error and optimization angle, the relationship does not necessarily behave the same way for different log sizes or line speeds. Thus the use of the correction algorithm in optimization requires researching the dependency in as many log sizes and/or line speeds as possible. Our investigation was carried-out at sawmills processing Norway spruce and it is possible that the wood species may influence log rotation results but we do not have data to support or refute this assumption.

Additionally it should be considered after measurements whether to correct optimization angles at all if the absolute value of angle is ≤ 10°. If the trends of the clockwise and counter-clockwise rotations are not similar, there is first the need to correct the faulty operation of mechanism before any correction algorithm to correct the rotation may be used.

Some modern systems utilise 2D and 3D scanner data to control the correctness of log rotation and optimisation by continuously comparing the current log position with the optimum position. In addition to correcting the systematic log rotation error, the system will also measure other parameters such as centring error and log in-feed angle, this is done by employing a scanning unit located after the primary breakdown. The cost of this type of system is about 55 000 €, this means it will pay back (for 10 million € turnover) in less than two years if, for example, the interdependency between the rotation error and optimization angle, as shown in this article, is established.

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