Diagnosis of Production Facilities of Bandsaw Mills by Sawing Accuracy

——Investigative report at Norwegian bandsaw mills——

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挽材精度による製材ラインの診断

——ノルウェーでの調査結果——

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Résumé

Sawing accuracy and straightness of cut were studied at seven Norwegian bandsaw mills. Two hundred and thirty one pieces of lumber were measured under both winter and summer conditions. Straight and thin lines were drawn on the upper face of the cants before and after secondary sawing. Thickness, width and profile of cut were measured at twenty one points from top end to bottom using a caliper and these data were analyzed statistically. Furthermore, diagnosis of the quality of production facility was intended by the analysis of correlation among profiles of side faces on boards at each mill. It was recognized that there were differences in the standard deviations of thickness and width among the seven bandsaw mills. Unexpectedly, variation of thickness was found to be significantly (5%) greater than that of width at several mills. According to the analysis of correlation for profiles of cut, mills producing boards with less variations for thickness and width do not always produce straight boards. It can be said that a bandsaw machine with carriage is superior in sawing a board straight but inferior in sawing it along a set line to a set of multiple bandsaw machines with an automatic feeding system. Bad straightness of cut was caused by only a feeding system at one mill and by tangle of sawing and feeding systems at other mills. The sawing accuracy and straightness of cut did not differ significantly (5%) between winter and summer. According to the measured contact pressure distribution between sawblade and wheel of a bandsaw machine, the parts of the highest contact pressure were mostly in the middle or back zone of the contact area at most of mills. Therefore these distributions must have been one of the causes for inaccuracy of sawing.

要　旨

ノルウェーの帯鋸製材工場で夏と冬に合計231本の製材について挽材精度と挽道の直線性を測定した。精度測定の基準線として太鼓に落とした材の挽材前後にその上面に墨つぼで直線を引き，末口から元口までの20等分点で製材の厚さ，幅，挽道の直線性をノギスで測定した。さらに製材工場ごとに製材側面の形状の相関分析により製材ラインの診断を試みた。調査した7製材工場間の製材の厚さと幅の標準偏差に差が認められ，予想に反して数工場で厚さの標準偏差が幅のそれに比べて危険率5％で大きかった。製材側面の形状の相関分析の結果，厚さや幅のばらつきの少ない製材を生産している工場が必ずしも直線性の良い製材を生産していなかった。送材車式帯鋸盤は自動送材装置付き複式帯鋸盤に比べ材を真っ直ぐに挽けるが，定められた線上を挽くのは不得手であることが分かった。挽道の直線性が悪かった原因は一工場では送材装置に，他の工場では帯鋸盤と送付装置の両方にあった。挽材精度や挽道の直線性には夏と冬とで有意な差が認められなかった。挽材精度を低下させている原因を知るために帯鋸と鋸車の間の接触圧力分布を測定した結果，多くの製材工場で接触幅の中央から後方にかけて接触圧力が高かったので，鋸身の歯側は十分安定走行していなかったと考えられる。

1. Introduction

Sawing accuracy is of great importance in the log conversion process as well as production efficiency and yield. Therefore, sawing accuracy has been investigated by Telford[1], Hallock[2], Birkeland[3] and so on in these thirty years. The method of investigation has been changed from a mere measurement of sawing accuracy to a quality control using statistics[4)-6)]. In the previous report, the measurement of sawing accuracy at seven Norwegian bandsaw mills was undertaken and sawing accuracy was clarified from various standpoints[7]. That is, though that report seemed to be a kind of mere investigative report, some additional indexes such as straightness and bow were adopted as well as a traditional index to indicate variations of thickness and width. As the data measured at seven bandsaw mills must contain a lot of information about sawing accuracy, diagnosis of the quality of production facility is intended mainly in this report using the data of profiles of cut on left and right faces of a board. The method and the tool for measuring profile of cut were explained in detail in the previous report, and briefly the profile of cut could be easily and precisely measured owing to the usage of a Japanese carpenter's tool for putting base lines on the upper face of a cant before converting.

2. Experimental Method

Sampling

Seven bandsaw mills were selected from various mills with a variety of equipment and size after a consideration of both technical and practical factors involved. Table 1 shows the outline of selected bandsaw mills. Of these mills, two were small (up to

Table 1 Outline of selected bandsaw mills.

Mill	A	B	C	D	E	F	G
Consumption of log m^3/year	145,000	6,000	100,000	54,000	100,000	8,000	42,000
Type* and number of machines	Tw-2 Si -1	Sc-1	Cc -2 Tw-2 Tr -1	Cc -1 Tw-1 Tr -1	Cc -2 Tw-2 Tr -1	Sc-1	Cc -1 Qu -1 Tr -1

* Cc Chipper canter, Si single bandsaw machine, Sc single bandsaw machine with carriage, Tw twin saw, Tr triple saw and Qu quad saw.

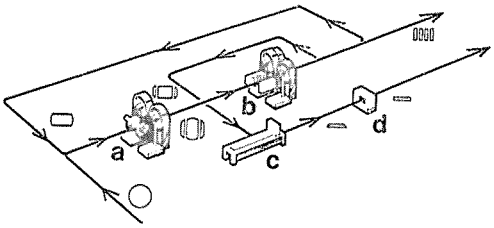

Fig. 1 Typical layout of modern Norwegian sawmill. (a) chipper canter and twin saw, (b) triple saw, (c) optimizer and (d) double edger.

10,000 m^3 per year), four mills were classified as medium (10,000 m^3 to 100,000m^3 per year) and the remaining one as large (over 100,000 m^3 per year).

Figure 1 shows an example of a layout of production facilities at one of the seven bandsaw mills. A log enters from lower left of the figure after barking and is converted to a cant by the chipper canters and the twin saw in group (a). The cant is fed back again to the starting point and cut into two or four boards by machines of groups (a) and (b). The side strips derived from the primary sawing and resawing are edged to boards by the double edger (d) after positioning of the strip by the optimizer (c). The average yield of lumber and chip per log was 55 % and 35 %, respectively. Mills B and F have only one single bandsaw machine with carriage, but the remaining five mills have more than two machines among from single to quad saws and an automatic feeding system. Mills A, D, E and F have a log sorting line. Mills C, D and E convert mostly spruce (*Picea abies* Karst.), Mills A, B and G 60-80 % spruce and 40-20 % pine (*Pinus sylvestris* Linn.) and Mill F pine only. Typically the bandsaws used at the mills were 180 mm in width and 1.47 mm in thickness, had teeth (2.4 mm kerf width) spaced at 40 mm and were driven at 40 m/s. Average feed per tooth in winter, 0.688 mm was 13 % lower than that in summer, 0.790 mm.

The sampling of a few logs was generally done at least twice a day in the morning and in the afternoon just after preparation for measurement. The same procedure was used at each mill in both winter and summer. The total number of samples taken was 231 boards from 98 logs of which 32 logs were pine. Four-in-a-set boards were produced from 16 logs and three-in-a-set boards from 3 logs and others were two-in-a-set boards.

Measurement

After a sampled log was sawn to a cant by the primary sawing, the same number of parallel lines as boards which will be produced afterwards were drawn on the upper face

from the top end to the bottom using a sumi-tsubo, a kind of ink-pot marker[8]. This tool can make a straight line of 0.5 mm wide over 5 m long of which the range of straightness was the ±1.0 mm at the 95 % confidence interval depending on to the operator's skill.

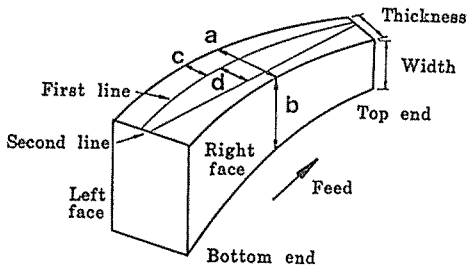

Fig. 2 Measurement locations method on board. (a) thickness, (b) width, (c) distance between left face and the first line and (d) distance between both the lines.

After processing of the cant by machines, boards were picked out from the converting line and the second straight line was drawn on the same upper face along the first line as shown in Figure 2. The thickness (a), the distance between the left face and the first line (c) and the distance between the two lines (d) were measured by a digital caliper at twenty one points at equal intervals from top end to bottom. The width (b) was measured only at the outside face of the two outer boards.

In order to measure the pressure distribution on a wheel, a pair of special "prescale" papers were inserted between the sawblade and upper wheel by reversing the wheel slowly by hand. The prescale develops red color corresponding to the pressure.

Analysis

All measured values of each board were entered into a computer. In addition, information such as top and bottom diameters of the log, target sizes of the board, sawing conditions and identification codes of the machines which processed each face of the board were also inputted. The identification code consists of three-digit figure as follows. The hundreds digit shows the order of the arrangement of main machine groups along a converting line at a mill. Figures 1 and 2 at the tens digit denote a chipper canter and a bandsaw machine, respectively. The units digit represents the position of a machine in the same machine group from left to right and from front to back. For example, 223 indicates the back left bandsaw machine in the second group. The distance between the right face and the first line was calculated by subtraction of the distance between the left face and the first line from the thickness. The profile of cut on each face was expressed by the distance between the face at a point and the idealized location. The idealized location was determined by a linear regression of the twenty one points measured along the length of the board. Straightness of a sawn surface along the idealized location was indicated by the standard deviation of each profile of cut in this report. Size difference was calculated by subtraction of a target size from the average of measured size.

In the cases of evaluating correlation coefficient, testing for correlation coefficient, comparing variances and performing an analysis of variance, each variable was first tested individually for normality with the Kolmogorov-Smirnov method[9]. In order to evaluate the profiles of cut, the so-called correlation analysis was done between the two

faces produced by a machine and between any two faces sampled out from all faces produced by the machines in a same group. More than half of numerical calculations were executed by a Norsk Data ND-500 mini computer and the rest by a FACOM M-382 large-scale computer at Data Processing Center of Kyoto University.

3. Results and Discussion

Figure 3 gives an example of the values measured on boards cut from the same cant. These figures show variations of thickness (a) and width (b), profiles of cut along the left face of the boards (c) and bow (d). The abscissa indicates the distance from the top

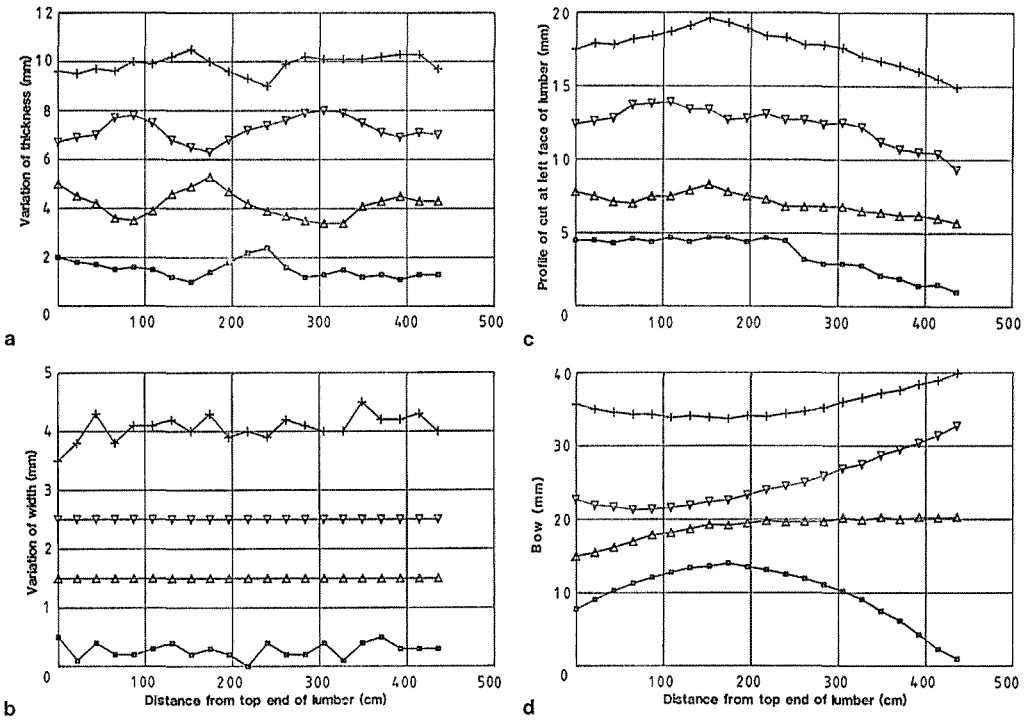

Fig. 3 Typical figures made from data sets of a board. (a) variation of thickness, (b) variation of width, (c) profile of cut on left face of board and (d) bow. □ left side board, △ middle left board, ▽ middle right board and + right board.

end of the boards in cm and the ordinates indicate the variation of variables in mm. The raw values of each ordinate plotted on Figure 3 contain an arbitrary offset which is removed in the data processing. With the data in this form, the following matters were analyzed at each mill : variations of thickness and width, straightness of sawn surface, size difference from target size and contact pressure distribution between sawblade and wheel.

Variation of Thickness and Width

Figure 4 shows the mean value of the standard deviations for the thickness and

width at each mill and their ranges. Mills E and G had significant differences (5 %) between the mean values of the standard deviations for thickness and width. Mill C also appeared to have the same tendency, but the mean value of the standard deviations for the thickness variation at Mill F was greater than that for the width. Furthermore, Mills B, C, D and F seemed to produce lumber with larger variations for thickness and width. Therefore, the difference of variation between thickness and width is considered to differ with mills. It is very difficult to find the main cause but it seems to come from the adjustment of individual machines and the global adjustments between groups of machinery. It may safely be said from this figure that mills using single bandsaw machines with carriage belong to the group with relatively larger variations of thickness and width and the age of mill had no statistical connection with the variation.

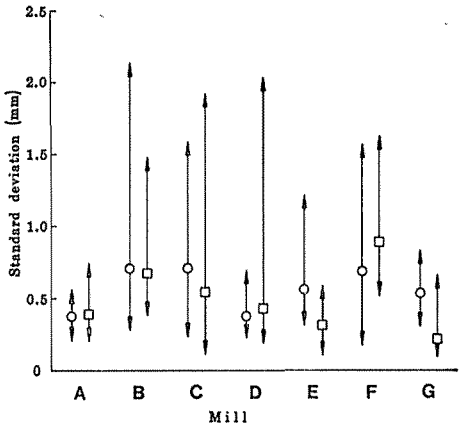

Fig. 4 Variation of thickness and width indicated by standard deviation at each mill. ○ mean of standard deviations for thickness and □ mean of standard deviations for width. A line with arrow heads indicates range of standard deviations.

In order to evaluate the quality of machines in a group in detail, the method to calculate so-called standard deviation within boards and between boards seems to be available and in fact this method is used widely[10]. As the author has an enigma about this method, the method of analysis of variance with repeat is exemplified in Table 2 to clear not only the quality of machines in a group but the quality of boards produced by Norwegian bandsaw mills in this case. The letter a denotes position of a board (left or right outside board) in a cant, the letter b indicates position of the measured point along a board and e represents error from disagreement of repeated data. S.S., D.F., M.S. and F mean sum of squares, degrees of freedom, mean square and variance ratio, respectively.

Table 2 Analysis of variance for variation of thickness and width of lumber produced by machines in the same group.

a) Thickness variation

Factor	S.S.	D.F.	M.S.	F
Sa	7.441	1	7.4405	31.2**
Sb	1.158	20	0.0579	0.24
Sa×b	3.040	20	0.1520	0.64
Se	10.013	42	0.2384	
Total	21.652	83		

** 1 % level of significance

b) Width variation

Factor	S.S.	D.F.	M.S.	F
Sa	0.048	1	0.0476	0.04
Sb	10.956	20	0.5478	0.42
Sa×b	0.838	20	0.0419	0.03
Se	54.928	42	1.3078	
Total	66.770	83		

It became clear from this analysis that there was a difference for thickness variation between boards at 1 % level of significance but no difference for width variation. Therefore it may be safely concluded that the thickness variation of boards produced by Norwegian bandsaw mills is not the same as the width variation even if the lumber was processed by machines in the same group. As the result, the greater part of lumber produced by Norwegian bandsaw mills can be said to have larger variation of thickness than that of width, but the cause of this phenomenon could not be found at all.

Straightness of Sawn Surface

The information about straightness of the left and right faces of lumber from each mill is shown in Table 3. Most of the mills appear to produce lumber with faces that have almost the same straightness though it is clear that Mill B produces lumber with significantly (1 %) different straightness between left and right faces. Furthermore

Table 3 F-test for straightness of left and right faces at each mill.

Mill	A	B	C	D	E	F	G
Left*	2.117	0.1711	0.8211	0.6165	2.058	0.5780	0.7288
Right*	2.068	0.6707	0.9104	0.5833	1.997	0.9493	0.7225
d.f.	27	25	30	36	29	23	38
F	1.02	3.91*2	1.07	1.06	1.03	1.64*3	1.01

* Values in these lines are indicated by unbiased estimates of variance
*2 1 % level of significance
*3 25 % level of significance

Mill F seems to produce lumber with different straightness of cut. Both mills use a single bandsaw machine with carriage. At other mills, no significant straightness between left and right faces was recognized. The above mentioned analysis was executed to grasp the profiles of cut of boards at each mill, and diagnosis of the quality of a production facility is as follows.

The first step is to check percent defectives of straightness of both faces of boards at each mill, and the results were obtained in Figure 5 judging from the value of 5 % of target thickness as the criteria. Comparing this figure with Figure 4, Mill A with small standard deviations and narrow ranges for thickness and width produced a lot of boards with bad straightness, while Mill B had the opposite tendency. Typical profiles of cut sawn by Mill A were shown in Figure 6. It is clear from this figure that the variation of thickness of these two boards are very small even if straightness of the profiles of cut are very bad. Four mills showed worse straightness in summer than in winter. Percent defectives of Mill B and F were under the average defective of all mills. These mills are the only mills which use a single bandsaw machine with carriage.

The second step of diagnosis is to analyze whether two profiles of cut of a board sawn by a processing machine are correlated or not. Figure 7 shows the percentage of

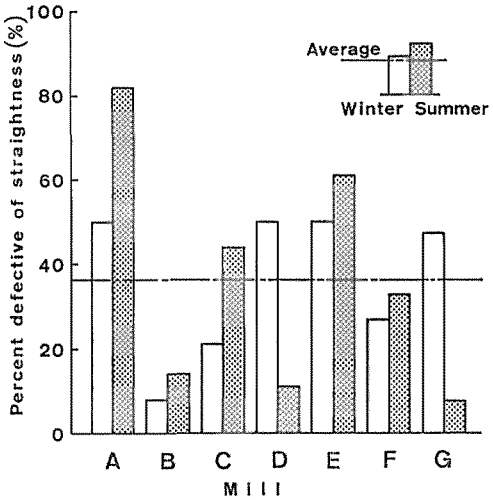

Fig. 5 Percent defective of side faces of boards from the point of straightness of profile of cut at each mill. A face was judged bad if three times of the standard deviation is over 5 % of the width.

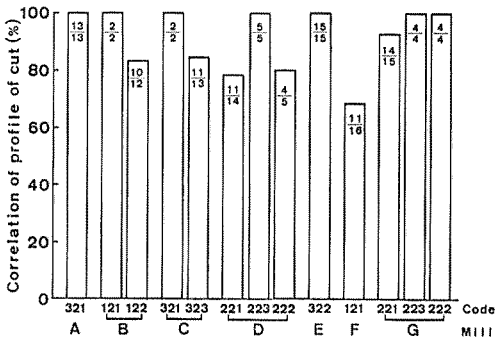

Fig. 7 Result of analysis of correlation between both profiles of cut sawn by a processing machine at each mill. A numerator in a bar graph indicates the number of cuts with 1 % significant profiles on both sides.

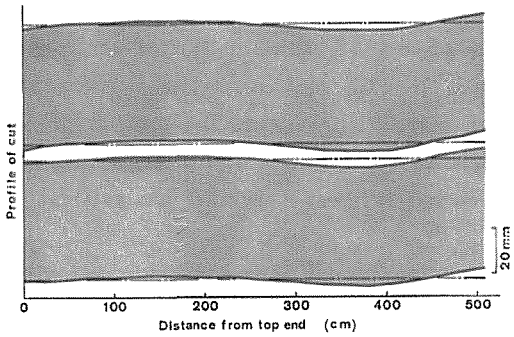

Fig. 6 Typical bad profiles of cut of two boards produced at Mill A in summer.

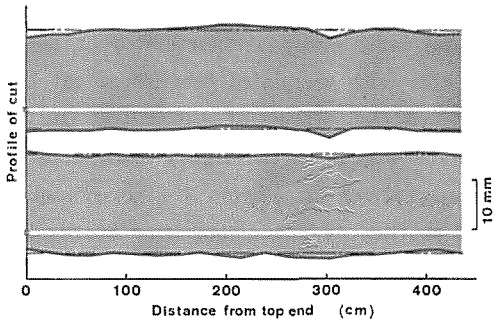

Fig. 8 Typical profiles of cut without 1 % significant profiles on both sides sawn at Mill F.

the number of cases with correlated profiles of cut to the total number analyzed at 1 % significant level at each bandsaw machine of the mills. The two codes of Mill B denote going and returning of the carriage of a double cutting bandsaw machine, respectively. The coefficient of correlation between two profiles of cut produced by a bandsaw machine must be almost one generally if the sawing is done normally. But there are six cases that could not reached the line of 100 % in this figure. Two profiles of cut with a low correlation suggest the vibration of a sawblade or unsymmetrical swaged sawteeth. An example of Mill F among them is shown in Figure 8 which shows the change of a kerf width along the longitudinal direction. These cases are not a serious problem because there was no such case among profiles of cut with bad straightness in this analysis.

The third step is to analyze whether any two profiles of cut produced by machines

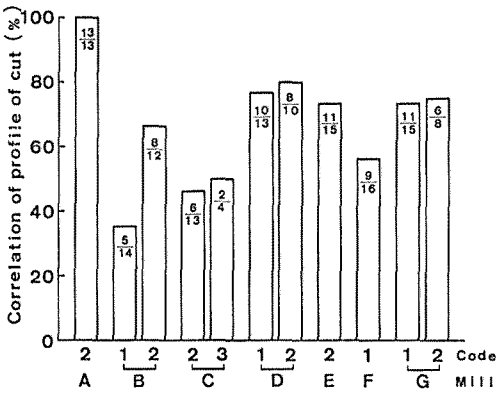

Fig. 9 Result of analysis of correlation between any two profiles of cut among boards sawn by processing machines in the same group at each mill. A numerator in a bar graph indicates the number of 1 % significant result.

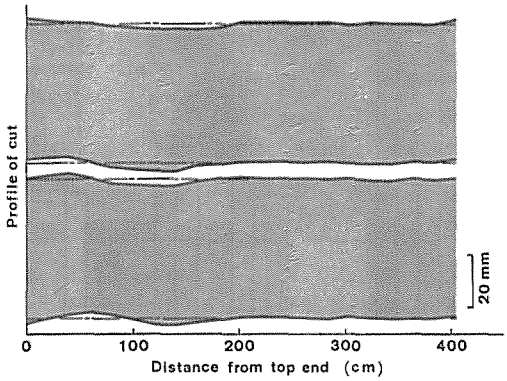

Fig. 10 Typical profiles of cut without 1 % significant profiles among boards sawn at Mill E.

in the same group are correlated or not. Figure 9 shows the percentage of the number of cases with correlated profiles of cut to the total number analyzed at 1 % significant level at each group of the mills. Only the machines in the second group of Mill A produce boards with highly correlated profiles of cut of which a typical example is already shown in Figure 6. An example of Mill E with low correlation between any two profiles of cut among two boards and high correlation between the profiles of cut produced by a sawing is shown in Figure 10. The cause of bad straightness in this case may come from bad feeding and bad processing on outer faces. A further analysis can be executed by FFT analysis.

As a result, bad straightness of side faces on boards was caused by only a feeding system at Mill A and by a tangle of sawing and feeding systems at other mills. Therefore, it seems to be necessary to check straightness of a board in order to find defects of a production facility even if the variation of thickness or width is very small. It can also be said that a bandsaw machine with carriage is superrior to saw lumber straight but inferrior to saw it along a set line.

Size Difference from Target Size

Information about size difference from target size is shown in Figure 11 where mean values of size differences from the target thicknesses and widths are indicated with their standard deviations. Each data set was recognized to have a normal distribution. An F-test to compare variances of size difference for thickness and width from the target sizes found that all mills except Mills D and F had differences between the two variances. Two kinds of t-tests were performed in order to compare the mean values of thickness and width differences from the target sizes. As a result, Mills F and G were recognized significantly (1 %) to produce lumber with the same grade of size difference

from the target size for thickness and width. Other mills seemed more or less to produce lumber with different size difference. In particular, Mills B and C seemed to produce lumber which have widths much more oversized than the thickness. Because of this large variation, the machines in the mills have been adjusted to produce oversized lumber in order to insure acceptable finished sizes. Only Mill F could be evaluated to produce lumber with the same grade of size differences between thickness and width from the standpoints of the mean value and the standard deviation. From these results, it became clear that machine adjustments are set with larger oversize for the primary sawing (decision of width) than for resawing (thickness) at all bandsaw mills which were judged to produce lumber with different size variations of thickness and width.

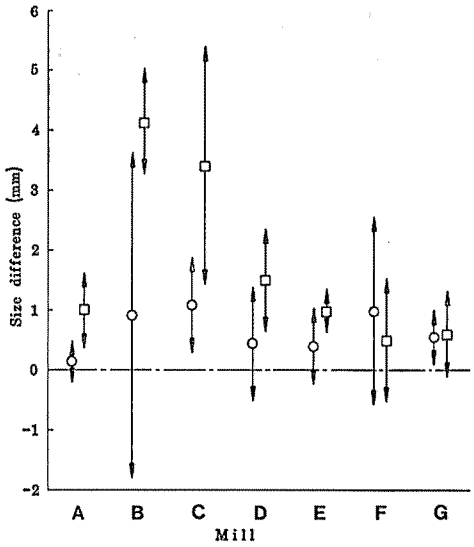

Fig. 11 Size difference from target size at each mill. ○ mean of size differences for thickness and □ mean of size differences for width. A line with arrow heads indicates ±1 standard deviation.

Contact Pressure Distribution between Sawblade and Wheel

Pressure distributions between the sawblade and upper wheel were measured on most of the bandsaw machines at the seven mills with the prescale paper. Most of the wheels had a small curvature on their surfaces. Figure 12 shows a few examples of the measurements. The darker parts mean higher pressure in this figure. From this figure, it was recognized that the highest pressure part is not at the front edge of the contacting area but a little inside of the front zone as shown in the case of a-1, a-3 and so on or middle zone (a-2 and b-2) or back zone (b-3, c and d). If a sawblade is only a belt that transfers force to the other wheel, this pressure distribution is acceptable. But if this blade has teeth at the front edge and is tensioned to stabilize the blade especially in the teeth zone, the highest pressure part should be at the front edge of the contact area, somewhat lower pressure part should be in the back zone and the least pressure in the middle according to the shape of cross section of a sawblade on the wheel as shown by Sugihara[11]. Furthermore, it became clear that there are irregular pressure distributions in the front zone along the longitudinal axis of the blade as shown in a-2 and a-4 and that the teeth are in the contact area (b-3 and c-1). The first undesirable situation is considered to be caused by poorly tensioned sawblades or wear of the wheel while the second was caused by incorrect inclination angles of the upper wheel which also caused irregular pressure distributions. From these results of the contact pressure distri-

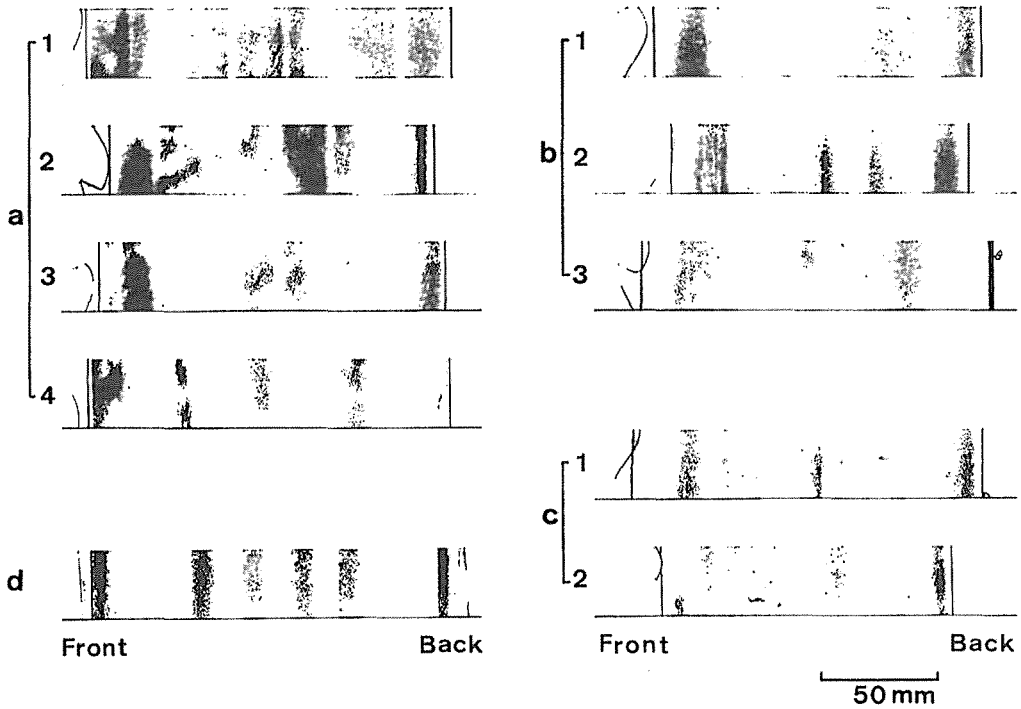

Fig. 12 Some examples of pressure distribution between sawblade and upper wheel of bandsaw machine. (a) quad saw, (b) triple saw, (c) twin saw and (d) special type of single bandsaw.

bution, it may be suspected that a wheel with some curvatures or special grooves on its surface demands stronger tensioning than that with flat surface and that such wheels are not suitable to stabilize the front side of a sawblade between both saw guides.

4. Conclusion

In order to diagnose the quality of production facilities of mills, sawing accuracy was investigated at seven selected Norwegian bandsaw mills. This was quantified by measured variations of thickness and width, straightness of cut, size difference from the target size and contact pressure distribution between sawblade and wheel of a bandsaw machine.

Variation of thickness was unexpectedly found to be significantly (5 %) greater than that of width at two mills even if the sawing condition of primary sawing is supposed to be worse than that of resawing because of the irregular shape of log and larger depth of cut. More than half the mills seemed to produce lumber with larger variations for thickness and width.

It was found that the mill using single bandsaw machines with carriage produced lumber with significantly (1 %) different straightnesses of cut between left and right faces. But these mills produced better straight boards than mills using multiple bandsaw

machines in a set and automatic feeding systems.

Size difference of thickness from the target size was recognized to be less than that of width at most of mills. This means that the adjustment of the target size for the primary sawing is relatively greater than for resawing. A noticeable point is that averages of size difference of width from target sizes were over 3 mm at two mills, while all other averages were around 1 mm.

Contact pressure distributions between sawblade and wheel of bandsaw machine at most of the mills were recognized to be unsuitable to stabilize the tooth side of a blade based on the fact that the parts of the highest contact pressure were mostly behind the front edge of the contact area. Also, there were some cases with irregular pressure in the front zone of the contact area.

In order to check the quality of production facilities, it is obvious that the analysis of correlation between profiles of side faces on boards is necessary as well as the analysis for thickness and width variations.

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