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Floor board quality assessment with the use of control charts

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Abstract: *Floor board quality assessment with the use of control charts*. The aim of the article was to describe quality control of the floor board production process. A statistic method was used for the purpose of the assessment. Based on the measurements obtained and the required computations, the X''_{av}, R and the cusum chart for board width were designed and analysed. In the control chart analysis, correctness of the board production process was assessed, while C_p and C_{pk} indicators served as a basis for the process capability assessment.

Key words: sawn timber, process capability, average values chart, range chart, cusum chart

INTRODUCTION

Timber has been known and used as raw material for ages, and remains unchangeably popular, especially now, when consumers are becoming increasingly aware of the impact of natural products on the quality of their lives [Tesařová and Čech 2011]. The material is very susceptible to ambient conditions, which highly affect its shape and quality. In the process of production of wooden boards, preparatory actions performed by specialised machines, needed for the boards to achieve the final shape, are of particular importance [Bombin and Mordvinov 2010, Wieloch 2012, Wieloch and Zbieć 2012]. In Poland, wooden board production is on the rise and is dominated by native companies [Kosycarz 2013].

Constantly growing needs of the contemporary consumers set a challenge to producers. Together with the increase of customers' needs grows their awareness, which determines their selection and assessment of the products offered. Wishing to meet customers' requirements, producers give their products innovative properties and make sure to enhance their technical parameters [Dahlgaard et al. 2000] by introducing new technologies on each stage or production. Yet another element of quality maintenance, aimed at minimisation of errors and undesired factors, is the control of processes and goods with the use of a variety of methods [Cyrankowski and Wrotek 2010].

Quality control at the stage of production permits early discovery of potential irregularities in the process [Czyżewski 1999]. Duly performed quality control increases profits of the company. Depending on the method used, the activity of undesired factors can be counteracted still during the process or right after its completion and avoided in subsequent processes [Hamrol and Mantura 2005, Pająk et al. 2014]. Products with quality below the required standards can be dangerous to users. All this makes quality control a very important stage of production. Depending on the type of the product, a defect or error discovered in good time makes room for its correction, reclassification or elimination.

The article proposes a statistical process control in timber processing companies. The quality of floor boards was controlled with the use of average values charts (*X*), range charts (*R*) and cusum charts. The controls were based on measurements of a parameter which is of particular importance to the customers, i.e. floor board width.

Control charts are used for: assessment of process stability, indication of reasons causing increasing process variability, presentation of normal run of the process and extraordinary cases, which require adjustments, or establishment whether the improvements introduced are correct.

Control charts are created with the use of the parameters calculated based on previously selected data. Individual points on the chart make a curve, the trajectory of which is later analysed. The central line (LC) represents an average of all average values for samples collected from the process and serves as a graphic reference for individual samples. Average values for samples that are positioned outside of the bottom and top external control line (DZLK and GZLK) indicate process instability. If only single average values are located outside of the lines or if several average values make a sequence, this is indicative of one-time or permanent occurrence of non-standard factors. The internal bottom control line, DWLK, and the internal upper control line, GWLK (monitory thresholds) are lines which, when exceeded, suggest the necessity to examine the process analysed more thoroughly [Czyżewski 2010a, b].

MATERIAL AND METHODS

The process of control chart designing started with the selection of the controlled feature. The feature should be material to the quality of the end product. Concurrently, it should also be impactable by means of changing the production process parameters. Having defined the number and size of the samples, the different types of control charts for measurable features were analysed and the appropriate chart was selected (given the parameter, sample size and nature of the process). Consequently, the average values chart (X''_{av}) and the range chart (*R*) were selected as the most appropriate charts for a small sample and mass process. The samples were collected directly from the production line and measured, whereupon all the required computations were made in the MS Excel spread sheet. After the central line, threshold lines and monitory lines were inserted into the control chart, the average values and ranges obtained in the calculations were marked thereon as well. The so created control charts were subjected to analysis, giving due account to the maladjustments of the processes and points located outside of the control thresholds or close to monitory lines. Subsequently, the average values charts (X''_{av}) and range charts (*R*) were supplemented with cusum charts. Then, the process capability indicator (C_p) was established, denoting the dispersion of the process in relation to the thresholds, and the C_{pk}, i.e. process adjustment and dispersion indicator. As a result of the analyses carried out, corrective actions were established and the potential process maladjustment sources were defined.

The production process is never carried out in perfect conditions and is always interfered by different factors. Therefore, it is impossible to obtain two identical products. Because of the disturbances, variability is an inherent element of each and every process. The disturbances can be divided in two categories, i.e. random disturbances and extraordinary disturbances. Random disturbances are those that occur naturally and make a part of the process, and are frequent and difficult to recognize. Extraordinary disturbances, in turn, occur unexpectedly and affect the process from the outside, causing maladjustments. It is very important to eliminate them on an ongoing basis. Extraordinary disturbances which induce signals that can be seen on the control chart have been assessed here in the manner proposed by Konarzewska-Gubała et al. [2006]:

- points not contained between the threshold lines: this indicates excess wear and tear of the machine or an element thereof or operator's error;
- 9 consecutive points located on the same side of the central line: this means that the values are far from the average;
- 6 consecutive points showing an upwards or downwards trend: signal of a permanent disturbance of the process;
- 14 consecutive points located alternately on top and on bottom: presence of a factor that makes the parameters cyclical;
- 2 out of 3 consecutive points on the diagram located between GZLK and GWLK or between DZLK and DWLK: the points outside of the monitory line suggest that the process should be looked closer at;
- 4 out of 5 points located between the central line (LC) and below GWLK or above DWLK; the points are closer to the threshold lines than to the central line: this means deviation of the values in one direction from the average value for the process;
- 15 consecutive points located close to the central line: the distribution of values differs from normal distribution;
- 8 consecutive points located below and above the central line (LC) but not close thereto: this indicates significant departures from average values.

The following dependencies were used in the calculations (1–9):

$$X_{av} = \frac{\sum_1^n x_i}{n} \tag{1}$$

$$X''_{av} = \frac{\sum_1^m x_{av}}{m} \tag{2}$$

$$GZLK = X''_{av} + \frac{3\sigma}{\sqrt{n}} \tag{3}$$

$$GWLK = X''_{av} + \frac{2\sigma}{\sqrt{n}} \tag{4}$$

$$DWLK = X''_{av} - \frac{2\sigma}{\sqrt{n}} \tag{5}$$

$$DZLK = X''_{av} - \frac{3\sigma}{\sqrt{n}} \quad (6)$$

$$\sigma = \sqrt{\frac{\sum (x_i - X_{av})^2}{N}} \quad (7)$$

where:
- n – number of observations in the sample;
- x_i – measured value;
- m – number of samples;
- σ – standard deviation;
- N – total number of observations.

For the purpose of floor board evaluation with the use of cusum charts, it was necessary to calculate average values for the samples, from which the nominal value of the parameter (board width, 8) was deducted, whereupon the result was cumulated (9). Values of the cumulated sums were marked on the diagrams.

$$X'_{av} = X_{av} - x_{nom} \quad (8)$$

$$C = \sum X'_{av} \quad (9)$$

where:
- X'_{av} – average departure from the nominal value;
- x_{nom} – nominal value (production assumption);
- C – cumulated sum.

The cusum chart is used to discover minor departures in the data of the process controlled, as it is highly sensitive to changes. The data on the diagram are presented in such a way as to distinguish accidental changes and tendencies from factual ones. Process capability is assessed through comparison of the tolerance interval width for the process with the process variability thresholds. Processes controlled with statistical control measures always deliver two pieces of indispensable information, i.e. whether the machines and devices used in the process ensure the necessary quality parameters of the product and whether it is possible to manufacture products of the required quality with the technology used. These capabilities can be calculated based on two indicators: C_p (potential capability) and C_{pk} (perfection). Potential capability reflects in numbers the dispersion of the process in relation to the external monitory thresholds:

$$C_p = \frac{GZLK - DZLK}{6\sigma} \quad (10)$$

The other of the process accuracy indicators, C_{pk}, is used to assess whether the average value for the process has not shifted in relation to the assumed nominal value, i.e. whether the process is statistically adjusted.

$$C_{pk} = \min\left(\frac{GZLK - X''_{av}}{3\sigma} \text{ or } \frac{X''_{av} - DZLK}{3\sigma}\right) \quad (11)$$

If indicators C_p and C_{pk} are lower than 1, this means that the process subjected to the analysis is incapable of ensuring satisfaction of certain requirements. Indicators above 1, in turn, show process capability, which means that the process variability thresholds are within the tolerance interval and the process is statistically regular [Muhlemann et al. 1995].

RESULTS

The quality control was performed for oak boards of different lengths and invariable nominal width and thickness. Only one dimension of the boards was tested, i.e. width, which is one of the most important quality parameters of floor boards, as discrepancies to this end make correct and aesthetic floor laying impossible. Width measurements were performed with an electronic slide caliper, with accuracy of 0.01 mm. Amount of 100 samples (size 4) were collected from each tested lot. The boards were taken off the planer every 10 min and measured. As specified in the production assumption, all desks were 20 mm thick and 95 mm wide. The boards were produced in 3 length variants: D1 – 850 mm, D2 – 800 mm and D3 – 1,005 mm.

The analysis of the measurement data shows that the process is accurate, which is indicated by the average value of 94.95 mm, which only negligently departs from the expected value (95.00 mm), and by a low standard deviation of 0.07 (Table 1).

All points located on control charts for board variant D1, which suggest the occurrence of extraordinary circumstances (Fig. 1) are shown in Table 2. Average values of measurements of samples 61 and 78, which depart the most from the external monitory thresholds, make very characteristic points on the *X* chart. Additionally, the range chart (Fig. 1, Table 3) shows impact of an extraordinary event, as sample 61 is situated above the internal monitory threshold and close to the external monitory threshold. This may suggest a random incident connected with board measurements.

TABLE 1. Results of *X* and *R* control chart parameter computations

Data/Oak timber lot	Marking	Units	D1	D2	D3
Nominal value (production assumption)	x_{nom}	mm	95.0	95.0	95.0
Double average (average of the averages)	X''_{av}	mm	94.95	94.96	94.96
Average departure from nominal values	x_r	mm	–0.05	–0.04	–0.04
Standard deviation	σ	mm	0.070	0.071	0.072
Top external threshold line	GZLK – X	mm	95.06	95.04	95.07
	GZLK – R		0.28	0.26	0.26
External bottom threshold line	DZLK – X	mm	94.85	94.85	94.85
	DZLK – R		0.01	0.01	0.01
Top internal threshold line	GWLK – X	mm	95.02	95.03	95.03
	GWLK – R		0.21	0.19	0.19
Internal bottom threshold line	DWLK – X	mm	94.88	94.89	94.89
	DWLK – R		0.03	0.03	0.03
Indicator	C_p	–	0.50	0.50	0.50
	C_{pk}	–	0.50	0.50	0.50

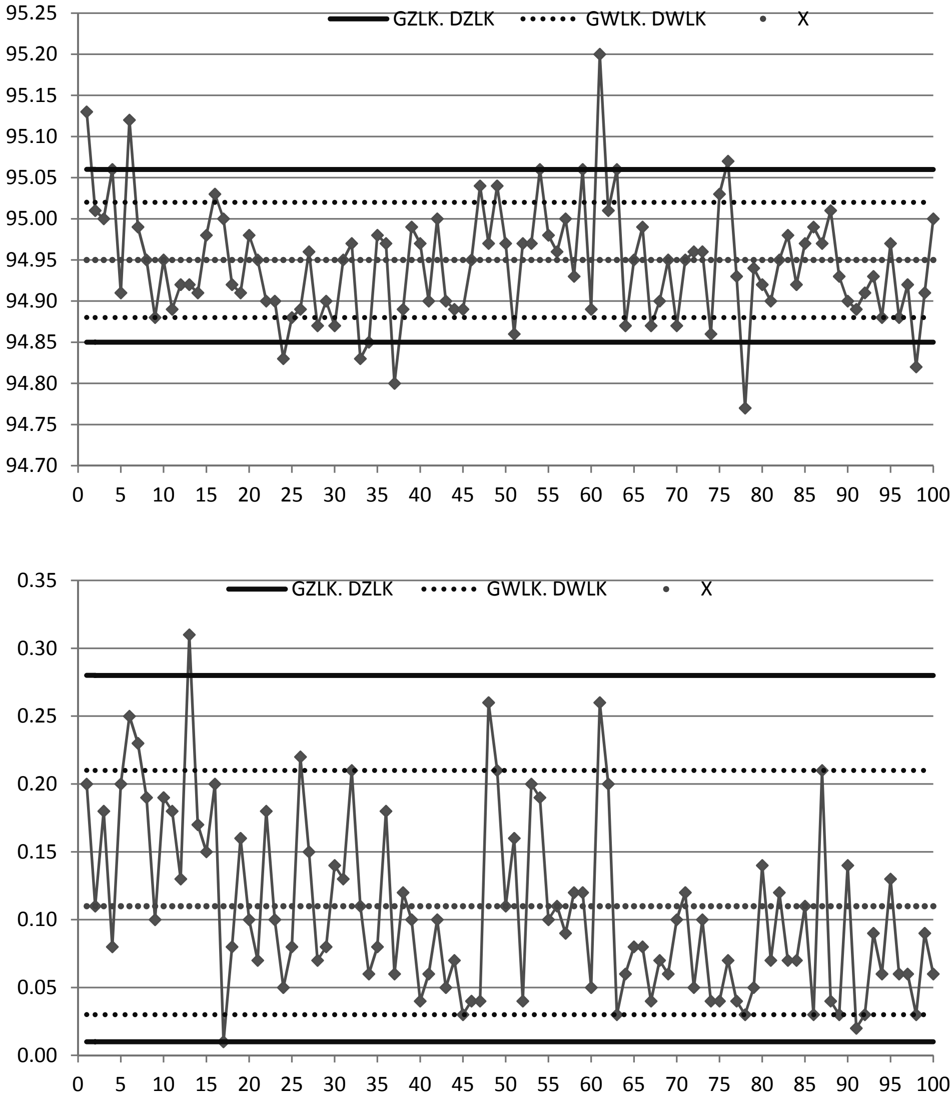

FIGURE 1. X''_{av} and R control charts for process 1

Additionally, Table 2 shows all points marked on control charts for D2 boards, which are signals induced by extraordinary factors (Fig. 2). As can be seen from the X control chart, the most characteristic points are points 48 and 84, which significantly exceeded the top external monitory threshold. This may be due to an extraordinary event such as, for instance, damaged planer spindle.

Table 2 shows all points marked on control charts which make sequences

TABLE 2. Analysis of *X* control charts for floor boards (D1, D2, D3)

Signal on *X* chart	D1 sample number	D2 sample number	D3 sample number	Comment
Points located outside of monitory threshold	1, 6, 24, 33, 37, 61, 76, 78, 98	23, 29, 48, 54, 57, 59, 70, 84	9, 12, 21, 27, 32, 34, 44, 62, 66, 80, 94, 96, 97	the process is unstable
9 points on the same side of the LC	–	–	–	–
6 points showing an upwards or downwards trend	–	32–37	–	the process needs adjustment
14 points located alternately on top and on bottom	–	–	–	–
2 out of 3 points between GZLK and GWLK or between DZLK and DWLK	28, 30, 47, 49	88, 90, 65, 67	10, 11	the process needs adjustment
4 out of 5 points located between the central line (LC) and below GWLK or above DWLK	85–88, 41, 43–45, 11–14, 49, 51–53	–	–	deviation of the average value in one direction; adjustment needed
15 consecutive points located close to the central line	79–93	–	–	abnormal distribution of values
8 consecutive points located below and above the central line (LC) but not close thereto	–	–	–	–

TABLE 3. *R* control chart analysis for oak (D1, D2, D3)

Signal on *R* chart	D1 sample number	D2 sample number	D3 sample number	Comment
Points outside of monitory thresholds	13	–	–	–
9 points on the same side of the LC	39–47	–	–	–
6 points showing an upwards or downwards trend	–	–	–	–
14 points located alternately on top and on bottom	–	–	–	–
2 out of 3 consecutive points between GZLK and GWLK or between DZLK and DWLK	6, 7	18, 19, 48, 49, 77, 78	–	the process needs adjustment
4 out of 5 points located between the central line (LC) and close to GWLK or DWLK	–	1–4, 6–9	21–24, 70–73, 92–95	deviation of the average value in one direction; adjustment needed
15 consecutive points located close to the central line	–	–	13–27	–
8 consecutive points located below and above the central line (LC) but not close thereto	–	–	–	–

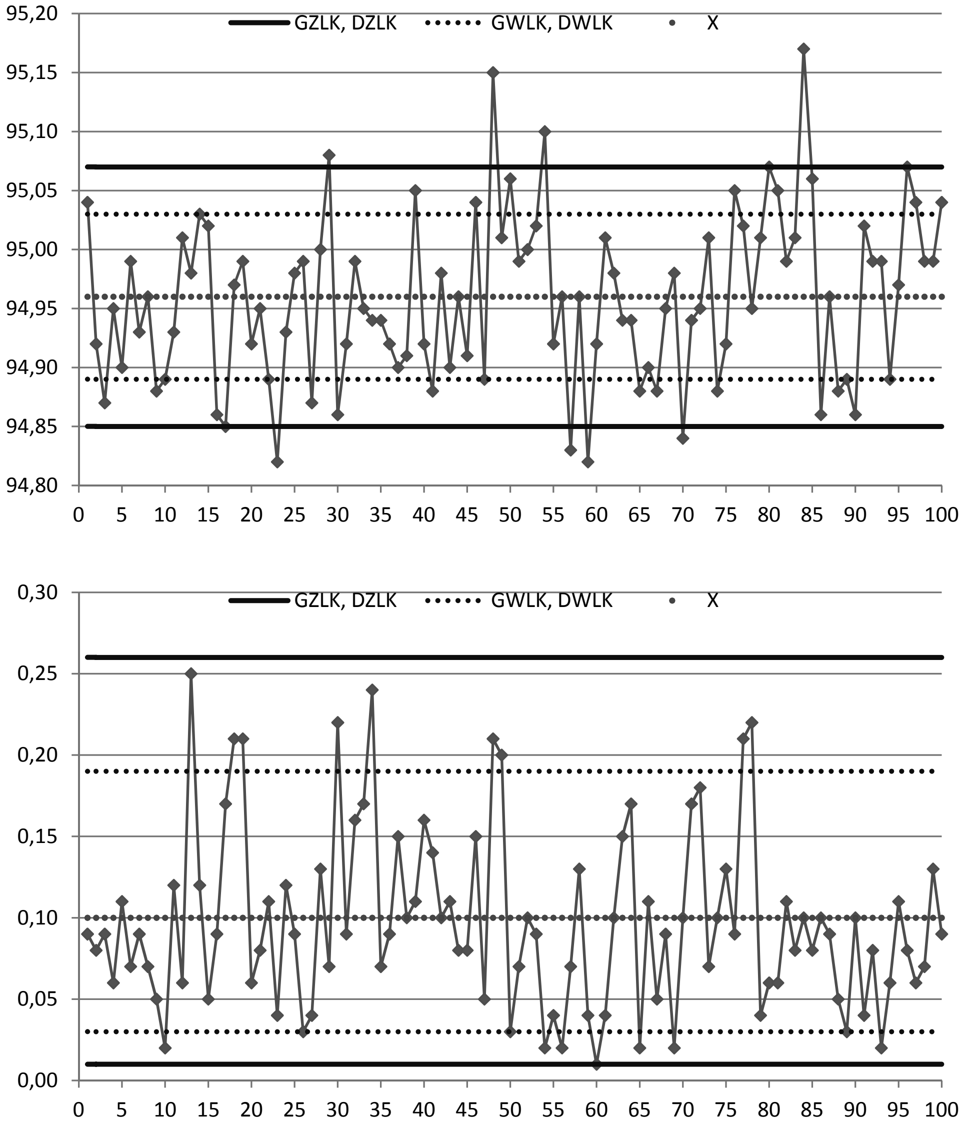

FIGURE 2. X''_{av} and R control charts for process 2

created due to extraordinary events for D3 boards (Fig. 3). The most characteristic points on the *X* chart are points representing average measurements for samples 12 and 62, which are the furthest from the external bottom monitory threshold. Significant sample deviation from the nominal value can be due to processing of inadequately dried wood.

The Duncan test performed (Statistica 10) showed no significant differences between the average values and

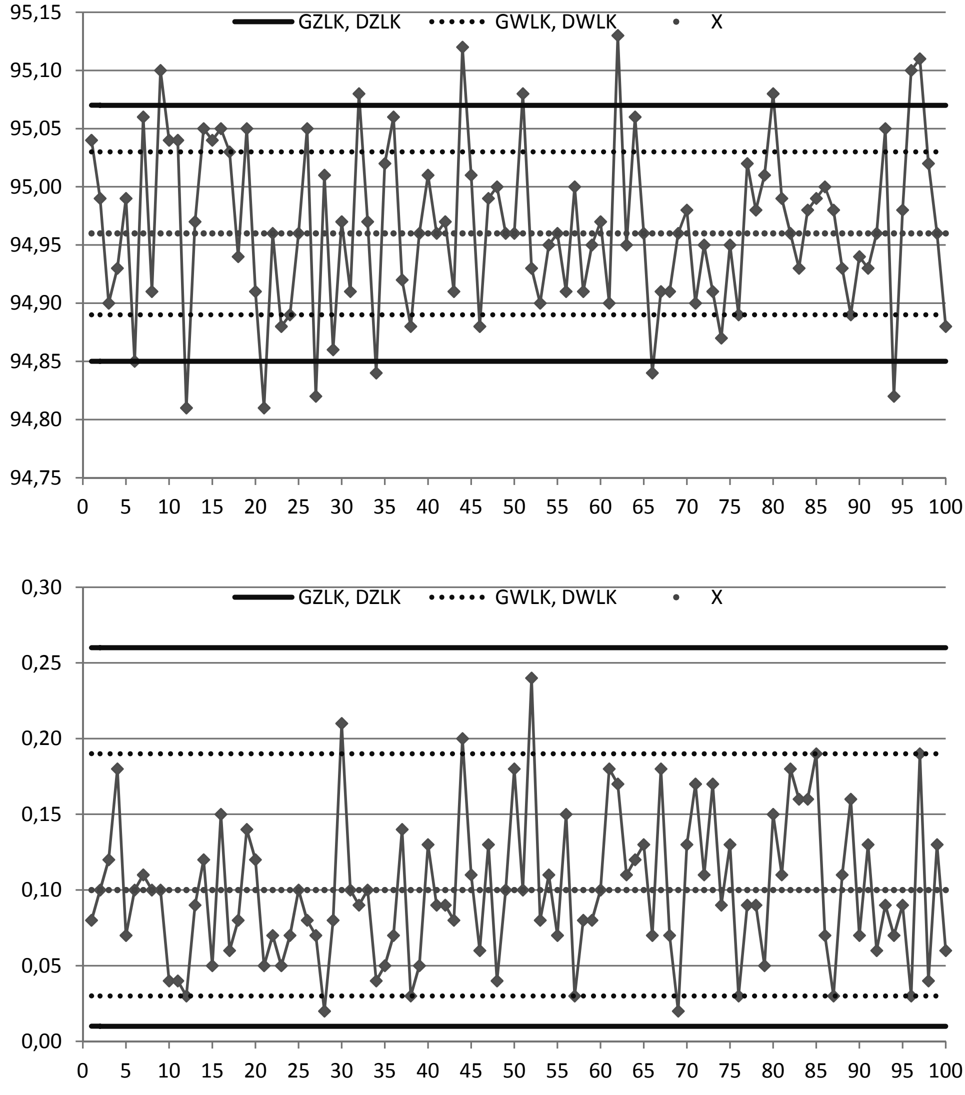

FIGURE 3. X''_{av} and R control charts for process

ranges of widths for the three oak board lots tested, which means that all boards subjected to the test can be classified as the same population.

The cusum chart presented on Figure 4a shows deviations of the values read out in the process from the expected value (95.00), while Figure 4b shows deviations of such read-out values from the double average, i.e. 94.95 (D1) and 94.96 (D2, D3) respectively. A horizontal line of tendencies at the beginning and at the end of the process shows that the values measured are close to the pre-set

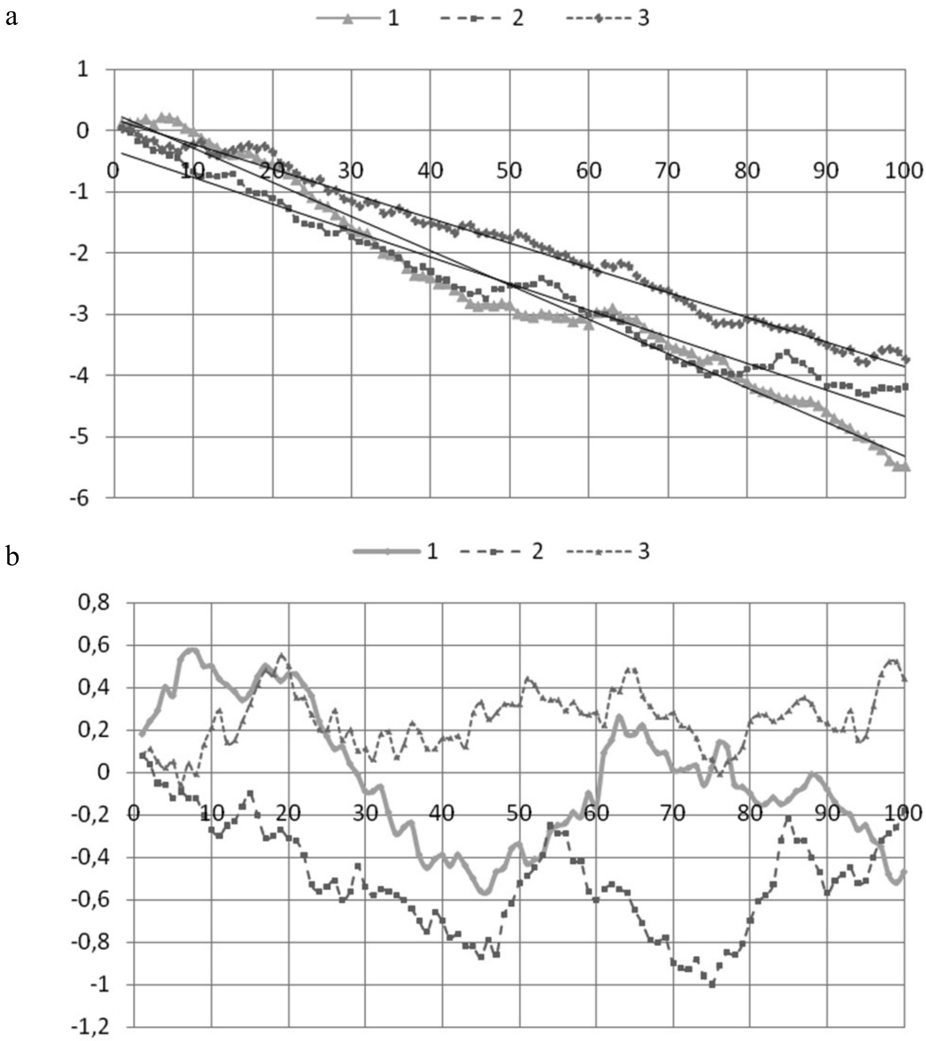

FIGURE 4. Cusum chart for D1, D2, D3 board production process: a – for a value equal to the expected value, b – for a value equal to double average

value. Finally, a declining line of tendencies shows that the collected values are lower than the expected value.

The line of tendencies marked on the chart diagram suggests deviations of the measured value from the nominal value. If the line trajectory is horizontal, this means that the values measured correspond to the nominal value. A declining line of tendencies shows that the values read out during the measurement are lower than the nominal value, while an ascending line means that the measurements are higher than the nominal value [Hamrol and Mantura 2005, Montgomery 2009].

The indicators C_p and C_{pk} for each of the three processes have been presented in Table 1. All are lower than 1, which means that the process requires intervention and adjustment.

CONCLUSIONS

Quality of wooden floor boards was controlled based on the pre-determined production assumptions and with the use of an average values chart (X''_{av}), a range of R chart and a sucum chart, which represent statistical process control methods.

The parameter tested was the width of floor boards, which was considered a significant factor for customers. The tests were performed for three processes, in which round, oak wood was sawed into boards. Control charts were created and analysed for each product and the capability of the processes controlled was established.

The following conclusions have been drawn based on the analysis conducted:

- the three processes in which 95-mm wide boards were obtained are not stable, which is indicated by the points located outside of the external monitory thresholds on the chart of average values (X''_{av}). Certain sequences on each control chart have been created as a result of extraordinary circumstances, which are indicative of permanent maladjustment or major disturbances of the process. As the processes have no self-regulatory properties, they need adjustments. The variability in the samples is stable, i.e. values on the R range chart do not exceed the threshold lines. None of the processes is statistically capable of manufacturing products of the required properties, as the capability ratios are much lower than the monitory values;
- irrespective of the length of individual boards produced, their width does not differ significantly, which is confirmed by the results of the Duncan test;
- although the results obtained indicate maladjustment of the processes subjected to the test (boards narrower or wider than the assumed 95 mm), this has no significant impact on the quality of the products manufactured, as they still satisfy customers' requirements.

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Streszczenie: *Ocena jakości desek podłogowych metodą kart kontrolnych*. W artykule opisano statystyczną kontrolę jakości procesu produkcji desek podłogowych. Wybrano metodę kart kontrolnych. Na podstawie uzyskanych pomiarów oraz potrzebnych obliczeń zaprojektowano i przeanalizowano karty kontrolne X''_{av}, R oraz kartę sum skumulowanych dla szerokości desek. Analiza kart kontrolnych pozwoliła ocenić prawidłowość przebiegu procesu produkcji desek. Zdolność procesów oceniono, używając wskaźników C_p i C_{pk}. Mają one wartości mniejsze od 1, co oznacza, że proces wymaga ingerencji i regulacji.

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