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Non-circular grinding of backup rolls to reduce rolling force variation

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Abstract. A common structure in hot strip mill backup roll bearings is to attach the conical sleeve of the slide bearing to the roll's shaft by a key. The key groove, cut to the conical sleeve, locally causes deformation under load. This sleeve spring is observed as rolling force variation. A new method to minimize force variations, based on 3D grinding of the backup rolls, was developed. A non-circular shape was ground on the rolls. The empirical research took place at a hot strip mill. As a result, the 3D ground non-circular geometry of the backup rolls considerably reduced the rolling force variation.

Key words: non-circular grinding, rolling mill, backup roll, rolling force variation.

1. INTRODUCTION

Contemporary steel mills are operating on a global market and the increased competition by developing countries has created a new situation. The competition has forced existing mills to focus on improved and more even quality at a higher production speed. The tolerances of steel strip profiles have become tighter. At the same time, the increased running speed brings out possible vibration problems in the rolling process, especially in a cold strip steel mill. If the thickness variation of the hot rolled steel strip can be reduced, it will be possible to increase the production speed of the cold strip mill. New harder steel alloys require increased milling force making the rolling process more sensitive to rolling force variations. These claims set new demands to the acceptable rolling force variation levels in the milling roll stands.

The steel mills built in the 1960s and 1970s and even later are looking for cost-effective means to meet the new demands. This study discusses a method of reducing the force variation in the milling stand.

Typically a rolling mill consists of 1–7 rolling stands. There are usually two, three or more rolls in each stand. In the studied hot strip steel mill all six stands consist of two working rolls and two backup rolls. The working rolls, through which the strip passes, are relatively small in diameter and have backup rolls of a larger diameter above and below to reduce the mill spring. A mill stand with two backup rolls is shown in Fig. 1.

It is known that a key-type slide bearing construction of backup rolls causes a periodic rapid drop in the rolling force [1]. The key groove is always made with a clearance in the radial direction (Fig. 2.). The clearance guarantees that there is no radial force from the key which would deform the sleeve geometry.

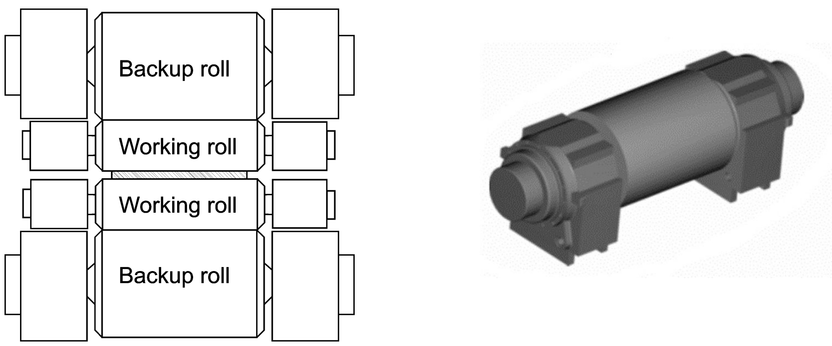
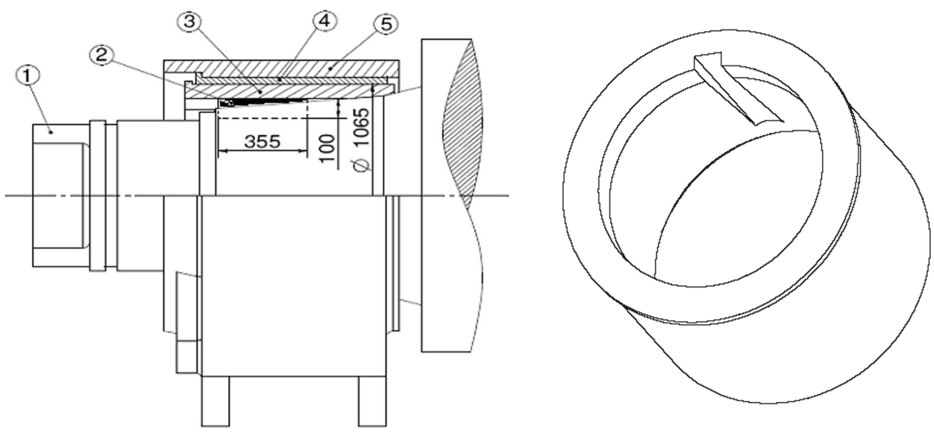


Fig. 1. A rolling mill stand with two backup rolls.



(a) (b)

Fig. 2. (a) Key-type bearing assembly: 1 – roll; 2 – key; 3 – conical sleeve; 4 – bearing bushing; 5 – bearing housing; (b) conical sleeve with a key groove.

The key groove clearance is the main cause for the rapid force drop observed once per roll revolution. This phenomenon can clearly be seen in the rolling force measurement as shown in Fig. 3.

Keyless bearing construction reduces the run-out of rolls compared with a key-type arrangement. Since the majority of the world's steel works built in the 1960s and 1970s continue to use key-type constructions, solving the problem would have a major economical effect. Key-type bearings are also still used in new cost-effective mill stands. Different systems, utilizing an active control of hydraulic cylinders to compensate the roll eccentricity, have been introduced, e.g. by Ginzburg [1] and Kugi et al. [2]. The dynamics of these active control systems is not enough to compensate the rolling force variation caused by the key groove.

The aim of this study is to reduce the periodic roll force fluctuation of a roller unit resulting from the spring in the bearing assemblies of rolls by machining the external roll surface for a non-circular geometry capable of reducing the fluctuation of the roll force in the rolling process.

A new method to minimize force variations, based on 3D grinding of the mill rolls, was developed [3]. Finite element models, describing the backup roll bearings, were elaborated and applied to determine the shape and magnitude of the deformation of the sleeve, which occurs during the roll revolution. The compensation curve for the 3D grinding was constructed using these models. A non-circular shape was ground on the rolls, in order to compensate the sleeve spring.

The empirical research took place at a hot strip mill. The 3D grinding was applied to the backup rolls at the last (sixth) mill stand. The rolling force was measured using both conventional and 3D ground backup mill rolls. The analysis was carried out by using synchronous time averaging, which separates the rolling force variations caused by the upper and lower backup rolls. Each analysis includes data from 12–20 reels.

The 3D grinding method, introduced in this study, is a method to grind different pre-defined geometries to cylinders, e.g. backup rolls. The main usage is for compensating measurable systematic geometry errors, i.e. run-out, roundness errors and diameter variation of a roll. The tool path to obtain the desired geometry can be based on measurements, on mathematical analysis or on their combination, like in this study.

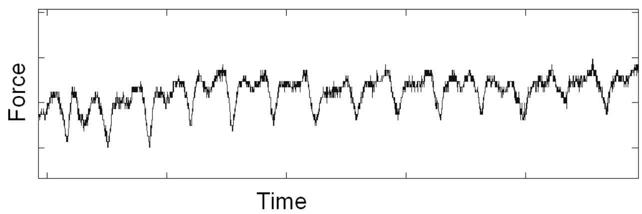


Fig. 3. A periodic force fluctuation as measured at a rolling mill stand. The figure depicts the effect of a roll key, appearing once per cycle.

The force variation errors, originating from non-systematic error sources as for example resonance vibrations, are excluded from this study similarly to systematic run-out errors like non-circularity of a neck or non-circularity of a bearing bush.

2. EXPERIMENTS

The aim of the experiments is to verify how the 3D grinding method works when applied to the grinding of backup rolls of a mill unit. The rolling force variation in a mill unit in the production environment should be reduced. The test equipment consists of measuring systems and a grinding system. The 3D grinding system controls the grinding process according to the given geometry, which is determined by the information gained from force measurements from the mill unit and FEM calculations. A roll measuring device, which measures roll geometry at low speeds with contacting sensors, is installed in the grinding machine.

The specimens were two backup rolls of a mill unit. The empirical research took place at the hot strip mill of the Ruukki Raahe factory in Finland. The force variation was analysed before and after the 3D grinding by force measurements of the mill unit.

2.1. Equipment

2.1.1. Mill stand force measuring device

The rolling force of the mill stand was measured from the drive and operator sides of the mill by Millmate PFV100 Pressductor the resolution of which is 24.4 kN (12 bit AD converter, measuring range from –50 000 kN to +50 000 kN) [4]. The sampling rate was set to 400 Hz. The resolution of the rolling force measurement device is diminished by the noise of the measuring device and averaging. The calculated resolution of averaged force variation measurement is heavily dependent on the number of measurements, but it is less than 0.5 kN when $N > 1000$ samples with a certainty of 95% ($k = 2$).

Triggering sensors were installed on the backup roll chocks and sensors were located at 45° angle relative to the key groove of the shaft sleeve. The data from the sensors was sampled simultaneously with the rolling force measurement data.

2.1.2. The grinding system

The grinding machine in this study had been upgraded with a 3D grinding system and a four-point measuring system for large scale rotors (Fig. 4). The prototypes of both of the equipments were developed in the Laboratory of Machine Design at the Helsinki University of Technology, but the control and measurement systems in this machine are a commercially available as retrofit for existing roll grinding machines. The grinding machine can grind large scale backup rolls up to about 100 t. The maximum length of these rolls can be about 5 m and the maximum diameter 2 m. In both traditional and 3D grinding, normal operating parameters of the grinder were used.

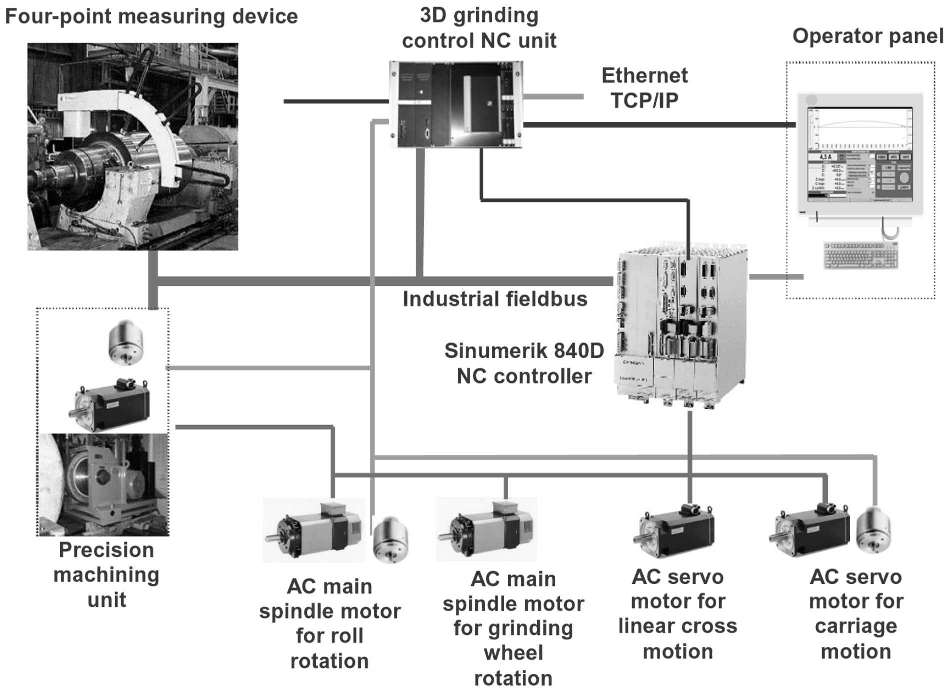


Fig. 4. Generic description of the 3D measuring and grinding system.

The accuracy of the grinding process is heavily dependent on the accuracy of the control system, which gets the feedback from the information, gained through the measurements. The manufacturer of the grinding control system has announced the accuracy for the hard roll grinding. Accuracy in cross direction (CD) compensation (diameter variation) is ±2.5 μm and in machine direction (MD) compensation (roundness profile) ±2 μm.

To achieve the above accuracy there are prerequisites for proper grinding conditions. The most important one is that the environment and coolant temperature is stable within ±0.5°C and there is no direct sunlight or great temperature differences. Before grinding, the temperatures of the roll and grinding machine must be stabilized [5].

2.1.3. The roll measuring system

The grinding machine is equipped with an automated roll geometry measuring device. It is a four-point measuring system as shown in Fig. 5. The four-point measuring method uses four sensors in a combination of a three-point method and a two-point method [6]. The two-point method has been used, for example, in caliper rules or measuring devices for conventional roll grinders and lathes. The three-point method can be used for roundness measurements [7]. The four-point method combines them in a more accurate way [8].

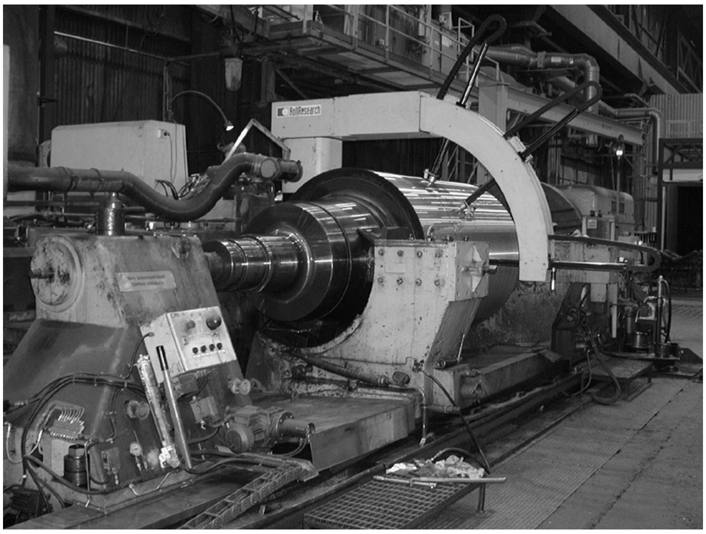


Fig. 5. The measuring device and the 3D grinding system installed on a grinding machine.

The measuring device is capable of measuring the diameter variation (CD-profile) and the roundness profile (MD-profile) of a large-scale cylinder, for example, of a backup roll. The measuring accuracy is ±1 μm. According to the manufacturer, the optical length gauges in the device have a measuring accuracy of ±0.2 μm.

For data acquisition, the measurement system acquires and stores the raw measurement data in a database. The measurements can be accessed, filtered and displayed on a computer display or printer, or used for geometry error compensations while grinding.

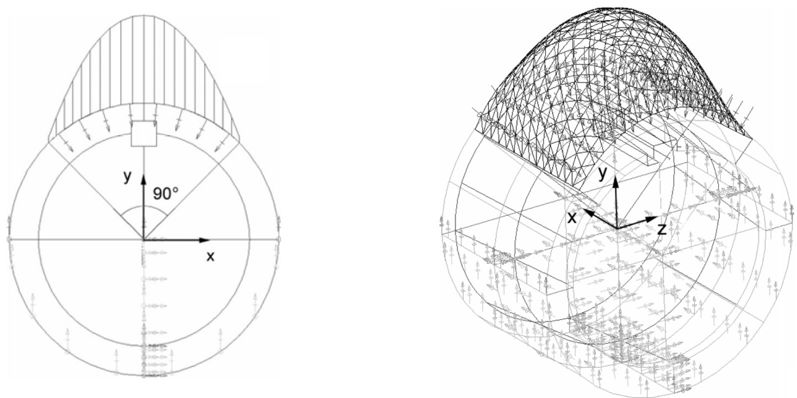
2.2. Calculation of the sleeve spring compensation profile

The compensation profile for 3D grinding is based on four separate finite element models of the bearing arrangement to study the shape and order of magnitude of the spring as a function of the rotational angle of the roll. A simple model of the sliding bearing was used to determine the load distribution. A load of 10 MN (given by the operators of the mill) was applied for each bearing.

Two of the four FE models were 2D and two 3D models. The parabolic tetrahedron element type was used in 3D models. Plane stress linear triangle elements were used in the first 2D model and plane stress linear quadrilateral elements in the second one.

The results from the FE models were analysed. The result from the model with the plane stress triangle elements was chosen as the basis of the sleeve spring compensational profile (Fig. 6a). This result was chosen because it has no points of discontinuity and is therefore suitable for grinding. The result, as shown in Fig. 7, was transformed into a control curve by filtering, inverting and expanding the result to cover the whole perimeter of the roll shaft. The final curve was scaled to 30 μm (Fig. 8). The value was obtained from the FE analysis and verified by a test run of the mill stand.

The calculated 3D compensation profile was sent to the NC unit controlling the tool axis and used as a tool path while grinding the roll to achieve the desired cam-like geometry of the backup roll.



(a) (b)

Fig. 6. Two models in the FE analysis: plane stress linear triangle (a) and solid parabolic tetrahedron (b) elements.

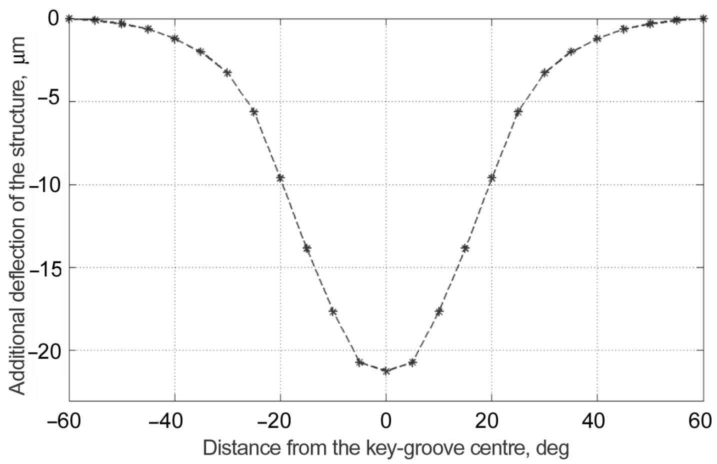
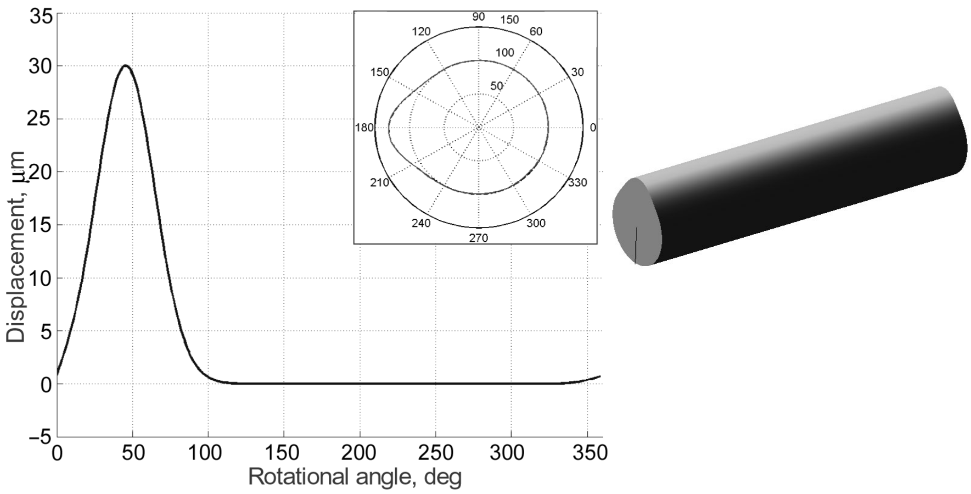


Fig. 7. Result of the plane stress linear triangle element analysis.



(a) (b)

Fig. 8. (a) The calculated 30 μm 2D correction profile for each cross section of the roll; (b) the same profile applied to the whole length of the backup roll (not in scale).

3. RESULTS

The results of the roll force variation measurements are shown in Figs. 9 and 10. The results are presented as force variation percentage of the total load level. The rolling force, measured at each end of the mill stand, varies between 4500 and 7000 kN, making the total rolling force variation from 9000 to 14 000 kN. The thickness of the steel strip was with traditional ground backup rolls 2.2 mm and with 3D ground rolls 2.0 mm. The results are synchronous time averages

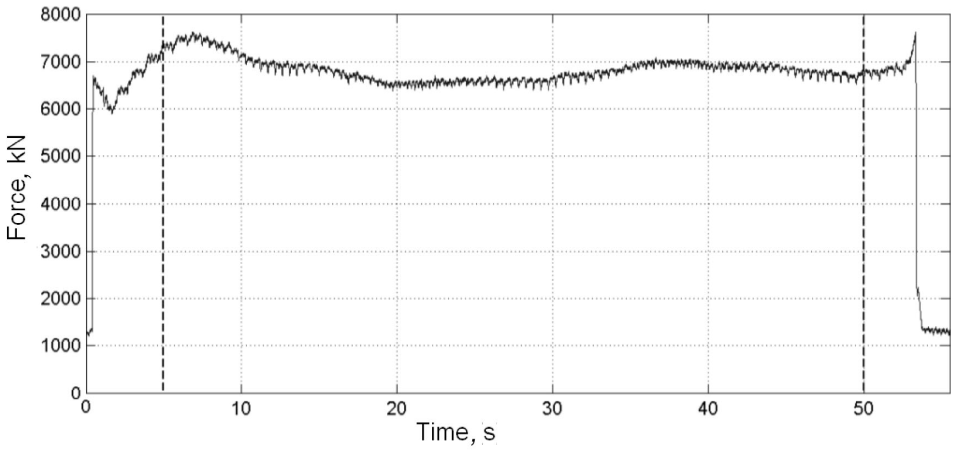
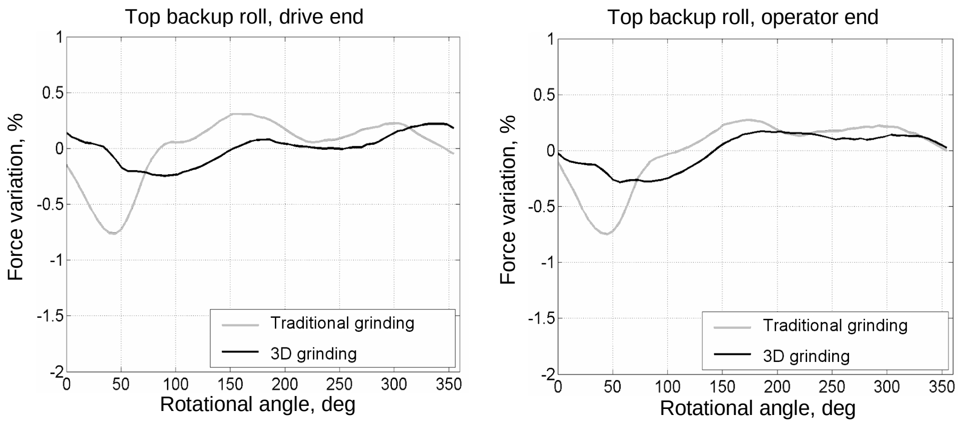


Fig. 9. Beginning and end of the data was excluded from the analysis.



(a) (b)

Fig. 10. Force variation, caused by top backup roll after traditional grinding and 3D grinding at the drive side (a) and at the operating side (b).

from 12 to 20 reels and the backup rolls rotate during one reel about 160–200 rounds. This means that the results presented are averages of about 2000 to 4000 backup roll rounds.

In the beginning and end of the measurement of a strip there are rapid level changes in the milling force, therefore about 5 s from the beginning and from the end of the measuring data was excluded because of possible interference (Fig. 9). The data was then divided into periods, which represent one revolution of backup roll. Equivalent measuring points were combined with averaging. Finally all the steel strips were combined again with averaging. This method is called synchronized time averaging.

The top backup roll after traditional grinding caused a drop of about 0.75% in the measured force. After geometry compensation, the sharp drop cannot be seen and mainly 1st harmonic eccentricity is present, as seen in Fig. 10. The bottom backup roll caused a 1.2–1.4% drop in the measured force with the traditional grinding method. In this case the 3D grinding with the same control curve reduced the force variation by about 40%, but the force drop still exists (Fig. 11).

Because there is some difference in the diameters of the rolls in the mill stand, the relative rotational position of the rolls changes with time as shown in Fig. 12. Together with roll eccentricity, this causes a beat phenomenon – a long term fluctuation in the rolling force variation. The frequency of fluctuation depends on the relative positions of the key grooves and the rolling speed. Relative positions of the grooves depend on the diameters of the backup rolls in the stand.

The beat phenomenon of the measured force was also decreased by 3D ground backup rolls, which can be seen in Fig. 13. The peak-to-peak value of rolling force variation was reduced from 300 to less than 200 kN.

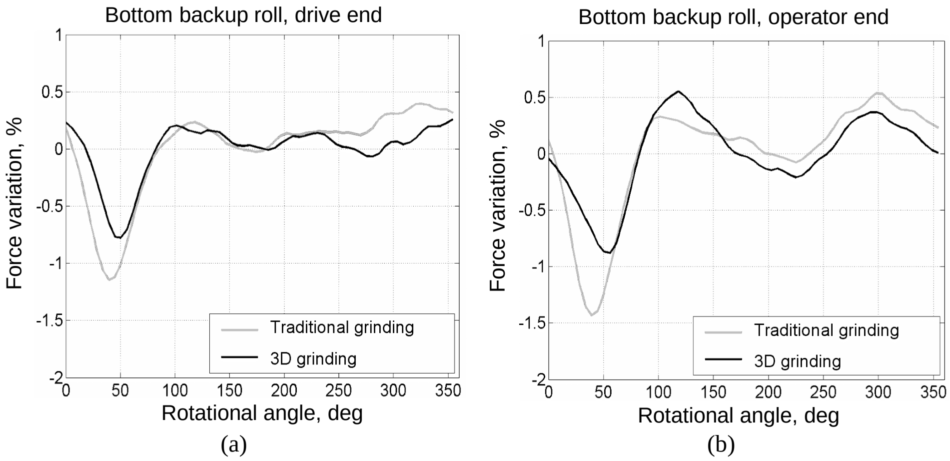


Fig. 11. Force variation caused by bottom backup roll after traditional grinding and 3D grinding at the drive side (a) and at the operating side (b).

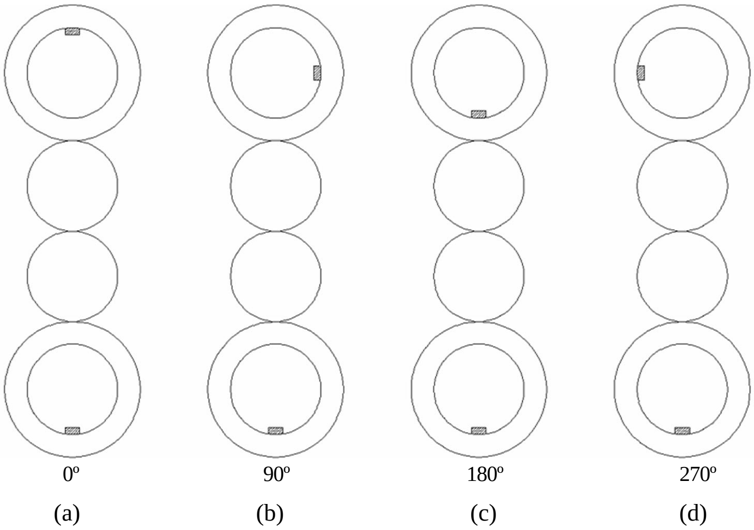


Fig. 12. Differences of the diameter of the backup rolls causes a relative phase shift of the key grooves; the roll force variation reaches its maximum, when both key grooves are under load at the same time, i.e. the relative groove positions are close to the situation as shown in (a).

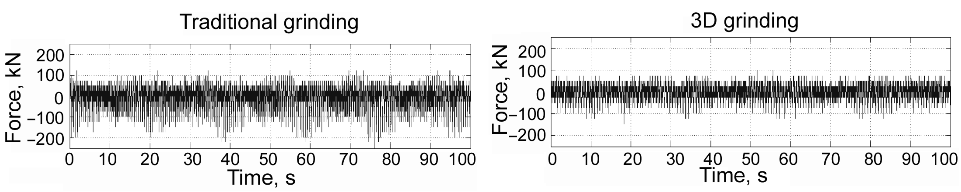


Fig. 13. The beat peak-to-peak value of the rolling force was reduced from 300 to 200 kN by 3D grinding.

4. DISCUSSION

As seen from the results, the 3D grinding method can considerably reduce systematic errors due to the key-type bearing design. The calculated control curve resulted in a top backup roll geometry that compensated the spring, caused by the key groove.

Some rolling force variation, caused by the bottom roll, remained. The residual error in the rolling force variation can be used to optimize the 3D geometry of the backup rolls. One should notice that there are also other systematic errors in the rolling force, which can be compensated by 3D grinding.

5. CONCLUSIONS

A common construction of hot strip mill backup roll bearings is to attach the conical sleeve of the slide bearing to the roll shaft by a key. The key groove, cut to the conical sleeve, locally causes spring under load. The spring is observed as rolling force variation.

A new method to minimize force variations, based on 3D grinding of the backup rolls, was developed. A non-circular shape was ground on the rolls. The empirical research took place at a hot strip mill. The rolling force variation was considerably reduced as a result of 3D grinding of the backup rolls. The technology developed can be applied to compensate other systematic errors, which are synchronous with the rotating components such as rolls.

In this study the 3D grinding method was applied to the last stand in a hot rolling mill. The focus in further studies will be application of the method to all mill stands. Another focus can be the study of the effects of this method on the thickness variation of the steel strip. If the method reduces the thickness variation of the strip, then its application on all the mill stands should reduce thickness variations in the lower frequency band. The variation, caused by the previous stands, is moved to a lower frequency band because of the reduction of the strip.

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Tugivaltside mitteümarlihvimine valtsimisjõu kõikumise vähendamiseks

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Lehtribamaterjali kuumvaltspingi tugivaltside laagrikonstruktsioonis on üldlevinud lahenduseks liugelaagri koonilise hülsi kinnitamine valtsrulli teljele kiilliitega. Koonilisse puksi lõigatud kiilusoon on aga koormuse rakendumisel lokaalse deformatsiooni allikaks, kusjuures puksi läbipaindel on täheldatud muutusi valtsimisjõus. Jõu kõikumiste vähendamiseks on välja töötatud uus meetod, mis põhineb tugivaltside 3D lihvimisel. Valtsidele antakse lihvimisel mitteümar kuju. Eksperimentaalne uuring kuumvaltspingil näitab, et tugivaltside mitteümara geomeetria puhul on valtsimisjõu kõikumine oluliselt vähenenud.