MINIMIZING FORCE VARIATIONS IN A ROLLING MILL BY 3D GRINDING

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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 deflection under load. The deflection 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 the hot strip mill. As a result of 3D grinding of the backup rolls the rolling force variation reduced significantly.

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

1. INTRODUCTION

1.1 Background
The dominant trend in steel industry is improved and more even quality. At the same time, the vibrations have frequently limited maximum running speed both in hot and cold rolling mills. The running speeds in hot rolling mill can be even 15 m/s. Those coexistent claims set new demands to the acceptable force variation level in the milling roll stands.

1.2 Research problem
The rolling assembly or roller unit consists of a set of rollers and its support structures. A rolling mill comprises a number of units complemented by various control devices and drive units. There are usually two, three or even more rolls in a roller unit.

Major rolling operations are performed by means of four-roll mill (Fig. 1) for attaining required roll forces.

Fig. 1. A mill stand unit design, including working rolls 1 and backup rolls 2 with bearings chocks and rolled product.

The working rolls, through which the metal passes, are relatively small in diameter and have backup rolls of a larger diameter above and below transmitting a force to the working rolls.

It is known that in a key-type slide bearing construction, the key or keyway causes periodic fluctuation (Fig. 2) which is synchronised to the roll. The gauge control process of a web is hampered by this. The keyway required by a key must always be made with a clearance. As the roll is rotating, the load-carrying force working in the bearing transmits across the bearing bush, whereby the bush deforms when in line with the keyway.
A keyless bearing construction reduces the run-out of rolls with respect to a key-type arrangement.

Fig. 2. A periodic force fluctuation 1 as measured from a rolling mill stand. The figure depicts the effect of a roll key appearing once per cycle 2 [1].

Since a majority of the world's steel works built in the 60's and 70's continue to use a key-type construction, solving the problem would have a major economical significance. Different systems utilizing active control of hydraulic cylinders to compensate roll eccentricity have been introduced for ex. by Ginzburg [1] and Kugi et al. [2].

1.3 Aim of the research
The aim of this study is to reduce the periodic roll force fluctuation of a roller unit resulting from elasticity variation in the bearing assemblies of rolls by machining the external roll surface for a non-circular geometry capable of reducing the fluctuation of a roll force in rolling process. The study was realized as a master’s thesis of Jari Uusimäki [3].

1.4 Research methods
In this research a new method to minimize force variations, based on 3D grinding of the mill rolls was developed. Finite element models describing the backup roll bearings were prepared, and those models were used to determine the shape and magnitude of the deflection, which occurs during the roll's revolution. Using these models the compensation curve for the 3D grinding was constructed. A non-circular shape, 30 µm in height, was ground on the rolls, in order to compensate the deflection.

The empirical research took place at the hot strip mill. The 3D grinding was applied to the backup rolls at mill stand number six. Triggering sensors were installed on backup roll chocks and sensors were located at 45° angle relative to the key groove of the shaft sleeve. The rolling force was measured using both conventional and 3D grinded mill rolls. The analysis was done by using synchronous time averaging, which separates the rolling force variations caused by upper and lower backup roll. Each analysis includes data from 15...20 reels.

1.5 Scope of the research
The force variation errors originating from non-systematic error sources, for example resonance vibrations, are excluded from this study. In addition, systematic run-out errors like non-circularity of a neck or non-circularity of a bearing bush are not examined in this study.

2. EXPERIMENTS
The aim of experiments is to verify how the 3D grinding method works when applied to the grinding of the backup rolls of a mill unit. The force variation in a mill unit in the production environment should be reduced. The system consists of measuring systems and a grinding system. The 3D grinding system controls the grinding process according to curve, which is determined according to the information gained from force measurements from 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 Rautaruukki Rahe factory. The force variation was analysed before and after the 3D grinding by force measurements from mill unit.
2.1 Equipment
The equipment consists of four-point measuring system and 3D turning system (Fig. 3). It can be installed for any commonly used roll grinding machine. The generic equipment was developed in the Laboratory of Machine Design at the Helsinki University of Technology (TKK) and further developed applications are nowadays commercially available.

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

2.1.1 Measuring system
The roll-measuring device used in this study is a four-point measuring device (Fig. 4) developed in the laboratory of Machine Design at TKK. The four-point measuring method uses four sensors as a combination of a three-point method and the two-point method, that has been used in for example caliper rules or measuring devices of conventional roll grinders or lathes, and combines these to a more accurate method [4].

The measuring device is capable of measuring the diameter variation (CD-profile) and the roundness profile (MD-profile) of a large-scale cylindrical object, for example a backup roll. The measuring accuracy is ±1 µm. This was verified by reference disks [5]. According to the manufacturer, the optical length gauges in the device have a measuring accuracy of ±0.2 µm.

For the rotational position of the roll (C-axis) a rotary encoder with 1024 pulses per revolution was used. In addition, the linear cross (Z-axis) movement was equipped with a similar rotary encoder.

The C-frame of the device was made of carbon fibre. This ensures stability against thermal expansion and overall stiffness combined with low weight of the frame.

For the data acquisition the control unit reads and stores the raw measurement data in a database. From there the measurements can be fetched, filtered and displayed on a computer display or printed out.

2.2 Accuracy of the 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 accuracy values for hard rolls. 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 mentioned accuracy there are prerequisites for the proper grinding conditions. The most important one is that the environment and coolant temperature is stable ±0.5°C and there is no direct sunlight or great temperature differences. Before grinding, the temperature of the roll and grinding machine must be stabilised. [6]

2.3 Calculation of the 3D correction profile
The correction profile for the 3D grinding is based on four separate finite element models.
of the bearing arrangement to study the shape and order of magnitude of the deflection as a function of rotational angle of the roll. A simple model of the sliding bearing was used to determine the load distribution. A load of 10 MN was used for each bearing.

Fig 5. Plane stress linear quadrilateral (top) and solid parabolic tetrahedron elements were used in finite element analysis of the bearing arrangement to study the shape and order of magnitude of the deflection curve under typical load passing by the key groove.

The result from the FE-models are analyzed and transformed to a control curve by filtering, inverting and expanding the result to cover the whole perimeter of the roll shaft as shown in Fig 6. This calculated 3D correction profile is sent to the PC 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.

Fig. 6. Calculated 2D correction profile for each cross section of the roll.

3. RESULTS

Results from roll force variation measurements are shown in Figs 7 and 8. Results are presented as force variation percentage of the total load level. The top backup roll after traditional grinding caused approximately 0.75 % notch in the measured force. After geometry compensation the sharp notch cannot be seen and mainly 1st harmonic eccentricity is present, as seen in Fig 8.

Fig 7. Force variation caused by top backup roll after traditional grinding and 3D grinding at drive side (top) and at operating side (bottom).
Fig 8. Force variation caused by bottom backup roll after traditional grinding and 3D grinding at drive side (top) and at operating side (bottom).

The bottom backup roll caused close to 1.5 % notch in the measured force, when traditional grinding method was used. In this case the 3D grinding with the same control curve reduced the force variation by approximately 0.5 percentage units, but the notch still exists. Because there is some diameter difference in the rolls of the stack, the relative rotational position of the rolls changes all the time, as shown in Fig 10. Together with roll eccentricity, this causes a beat phenomenon which causes long term fluctuations in rolling force variation.

Fig 10. Diameter differences of the rolls cause the relative phase shift of the key grooves. The roll force reaches its minimum, when both key grooves are under load at the same time, as shown in left: a) 0°.

Fig 11. The beat amplitude of the rolling force was reduced from 300 kN to 200 kN by 3D grinding.

The beat phenomenon of the measured force was also decreased by 3D machined backup rolls, which can be seen in Fig 11. The maximum amplitude of rolling force variation was reduced from 300 kN to less than 200 kN.

4. DISCUSSION

As seen from the results this method can significantly reduce systematic errors deriving from key-type bearing design. The calculated control curve resulted in geometry of the top backup roll that compensated the deflection caused by the key groove.
There was some rolling force variation left caused by the bottom roll. 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 rolling force, which can be compensated by trial and error calculations of some test geometry and applying this geometry in 3D grinding.

5. CONCLUSIONS

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 deflection under load. The deflection 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 the hot strip mill. As a result of 3D grinding of the backup rolls the rolling force variation reduced significantly. The technology developed can be used to compensate any systematic errors which are synchronous to the rotating components like rolls.

In further studies focus should be set to apply the used method to all mill stand units in a rolling mill. As a consequence of that the thickness variation of the end product should reduced.

6. REFERENCES


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