Influence of backlash asymmetry in the joints of rolling mill mail line on the performance of the ‘weakest’ section

Andrey Maltsev

Bauman Moscow State Technical University, Baumanskaya 2-ya str., 105005, Moscow, Russian Federation
E-mail: bauman@bmstu.ru

Abstract. The aim of this work is to study the influence of backlash asymmetry in the joints of the main line of rolling mill on the operation performance of the ‘weakest’ section (working roll spindle). The phenomenon of a backlash asymmetry in the sets of rolling mill is studied and described in the paper. The technology implying application of the NI Multisim software aimed at carrying out the analysis of the influence of mechanical gear backlash in the automatic control system of the object rotation speed and the structure of block simulating the kinematic backlash in the NI Multisim are proposed. The influence of backlash on the operation performance of the automatic system of the electric motor is studied.

1. Introduction
Both older and younger generations of scientists among which are A. I. Tselikov and V. V. Klyuev had found the solutions to the problems regarding the type and nature of the dynamic loads of large machines, the reliability issues and the service life of parts and machine components (metallurgical equipment). Mainly, there were developed methods aimed at the equipment protection from the impact stress. [1, 3, 4]

The issue of wear of parts and process tools of rolling mills operated under the dynamic loads had not been solved yet. The most problems are observed in the part related to clearances, specifically their behavior and influence, and the machine components. [4, 5, 6]

An extensive application of computers makes it possible to conduct multiple theoretical studies, bringing the components to virtual destruction.

2. Materials and methods
For high-power drives, high-speed gear motors with pinion stand are usually used to reduce the speed of rotation (Fig. 1).
The opening of clearances is related to the technological features of the rolling process and the operating modes of the machine \([2, 3, 5, 9]\):

- a sudden load drop on the rolls (strip ejection, roll slipping, etc.);
- strip grip in advance when the strip speed is greater than the roll speed;
- slow rotation of the motor to ensure strip gripping conditions when the forming roll is mechanically ahead of the neighboring unit (gear wheel or motor rotor);
- an inertial effect of the sections that take place in the machines and mechanisms of motion at variable speeds;
- an inequality of the roll diameter in case they are pressed close together (rolling with the roll cutting) and a pause between the ejection of the strip and the capture of the next one is considerable. Such situation can arise when a roll of smaller diameter tends to take the circumferential speed of the roll of a bigger diameter through the strip thus overtaking its gear wheel.

To simulate torsional oscillations, a discrete design diagram was compiled \([8, 9]\) since the rotating parts of the electric drive are endowed with inertia, elasticity and damping properties to an unequal degree. The branched structure of design diagram made it possible to take into account the backlash \((\Delta_1 \neq \Delta_2)\) and rigidity \((c_3 \neq c_4)\) asymmetry of loading of the upper and lower spindles of rolling mill, as well as the loading asymmetry by external moments of rolling \((M_z \neq M_z)\).

The differential equations of motion of massive discs in time \(t\) are compiled on the basis of Lagrange’s equations of second kind \([1, 2]\):
Theoretical study is possible only when the methods of mathematical modeling are applied. Let us compile a 5-mass torsional and vibrational analog model with the help of MathCAD (Fig. 2) to study the transition process – simulation of the torsional oscillation process that occurs in the line of individual electric drive after the rolling workpiece collapses against the roll with the presence of clearances in the drive line [2].

The most danger is caused by the angular clearances in the heavily worn spindle joints. In addition, the clearances gradually increase as the equipment wears out. [1, 3, 10]

To study the processes that take place in the backlash system, with the help of the NI Multisim environment there was developed a block structure, simulating a kinematic backlash between the electric motor and the control object when monitoring the speed of motion [10].

3. Results
Natural and experimental studies were carried out on different rolling mills, Fig. 3.

For example, for the flywheel drives of an automatic mill (Fig. 3) (a) it is typical that the electromagnetic phenomena has no effect on the dynamics of the process.
Figure 3. Kinematic diagrams of drive lines of rolling mills: a- automatic; b- three-roll; c- section; d- sheet
Figure 4. Theoretical diagrams of moments of elastic forces arising along all the sections of the automatic mill drive line.

The obtained oscillograms (Fig. 4) showed that after the tube is gripped by the rollers of an automatic mill on the safety spindle, torsional vibrations arise and last for not more than 1 sec with the frequency within the range of 21 ... 23 Hz.

The dynamic factor defined as a ratio of the maximum torque to the value of the steady state torque, varied within the following limits: 1.9 ... 2.5 in the first pass and 2.4 ... 3.8 - in the second pass.

Studies of a three-roll mill showed that there is no dynamics because of a smooth grip in the mill (Fig. 3 b).

The addition of backlash results in an additional delay in starting the movement of the object for the time necessary to pass the backlash zone, if no backlash has been selected before the reference signal was given. The electric motor in the backlash zone is not loaded; its speed increases sharply. (Fig. 5)
Figure 5. Diagram of the transient process on the rotation speed of electric motor and on the armature current in a backlash system: the speed is shown in a blue line; the red line indicates the voltage $U_{\text{total}}$ at the measuring resistance $R_{\text{total}}$ [12]

Basing on the diagrams of the object movement, it can be stated that a backlash in a system with the significant inertia of the object has practically no effect on its speed in the steady state mode; however, it creates ponderable dynamic loads on both gear and electric motor at the moment of exit from the backlash zone.

4. Conclusion
The aim of his work was to study the influence of backlash in the joints of the main line of the rolling mill on the operation capacity of parts and components of the drive line of rolling mills. Of particular interest there was the study of the backlash asymmetry in the rolling mill units. The methods of using the NI Multisim software environment aimed at carrying out the analysis of the influence of mechanical gear backlash in the automatic control system which monitors the speed of the object rotation and the block structure, simulating the kinematic backlash in the NI Multisim programming system were proposed. [10]

The issue of wear of parts and process tools of rolling mills operated under the dynamic loads had not been solved yet. The most problems are observed in the part related to clearances, specifically backlash asymmetry in the machine units.

References
[1] Kolesnikov A G, Yakovlev R A, Maltsev A A 2014 Technological Equipment of Rolling Production. Moscow: Bauman MSTU
[2] Maltsev A A 2014 Calculation of Dynamic Stresses in the Dangerous Section of the Spindle Shaft of Mill Duo in the MATHCAD environment -160. Mechanical Equipment of Metallurgical Plants 3 64-70
[3] Vafin R K, Akhmedshin R I, Maltsev A I, Maltsev A A, Alekseev P L 2001 System Design for Monitoring the Rolling Equipment 11 62-64
[4] Krause P C, Wasynczuk O, Sudhoff S D 2002 Analysis of Electric Equipment and Drive Systems: Books in the IEEE Press Series on Power Engineering. USA: IEEE
[5] Hog E, Arora Ya 1983 Applicable software modelling: translated from English. M.: MIR
[6] Coffin L F 1954 Study of Effects of Cyclic Thermal Stresses on Ductile Metal. American Society of Mechanical Engineers 76 931-950
[7] Manson S S 2009 Fatigue and Durability of Metals at High Temperatures. ASM International
[8] Krasovskiy A B 2015 Bases of Electric Drive: Manual. Moscow: Bauman MSTU
[9] Nikolaev V T 2014 Modeling of Electrical Circuits. Moscow: MIT
[10] Listopadova Yu I, Nikolaev V T, Sapozhnikova L B 2015 Modeling of electric drive backlash in the NI Multisim software environment under the Speed Control. Electronic Information Systems 2 (5) 19-30