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New methods of monitoring and diagnostics of the technical state of rolling mills

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New methods of monitoring and diagnostics of the technical state of equipment of rolling mills are developed. As informing parameters the torque of resiliency and vibration of equipment along the driving line is accepted. The features of transitional processes are used.

In recent years, for the diagnostics of equipment there are various types of vibration measurement devices equipped with software for process visualization and signal processing. They are designed for recording, analysis of signals and diagnostics of stationarily rotating equipment. However, shock loading conditions are inherent in rolling mills, when the impact of a driveline and stand technical condition (TC) on dynamic loads on the equipment operation is most pronounced. The application of the known systems for rolling mills meets certain difficulties, because of the different modes of their operation (strip capture by rolls, acceleration and deceleration of the mill, release of the band, idle run), a significant number of blocks and elements (rollers bearings, spindles, pinion stand, lead spindle, geared system), which need the monitoring and diagnostics. In addition, the proposed systems were not originally focused on the diagnostics of rolling mills, they do not include the new developed and tested under production-line conditions methods and ways to determine the TC, in which the design features, technologies and operation modes are used [3].

In Z.I. Nekrasov Institute of Ferrous Metallurgy (Department of process equipment and control systems) in addition to the known, the number of new methods of monitoring and diagnostics of rolling mills equipment in transient conditions was developed together with the algorithms of signal processing and TC recognition. The methods are based on numerous and mass experimental-industrial studies, primarily of broad strip mills of hot rolling 1680 (Zaporizhzhia city), 1700 (Mariupol, Karaganda cities), 2000 (Lipetsk, Cherepovets cities) and 2500 (Magnitogorsk city). The main attention was paid to the moment of elastic force measurements in the main lines of roughing and finishing stands, as well as to package units vibration along the driveline (the roll mill and pinion stand, geared system, engine). The connection between these parameters was analyzed. The basic information about the new methods are given below.

In the method 1 the record (embodiment) of the time by rolling each band is regarded as a random process, which consists of three sections (Fig. 1). Justification of the method is as follows.

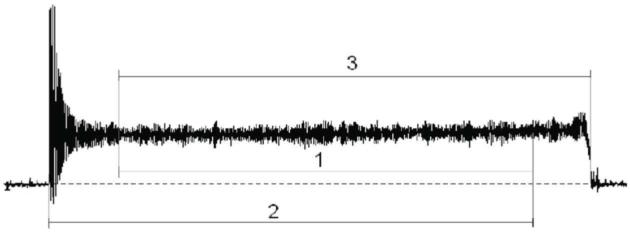

Figure 1. Recording and processing areas of the elastic force moment, being analyzed.

The greater the wear of joints and gaps, the more the dynamic forces and the greater the variation coefficient ν_2 of moment at the area 2 exceeds coefficient ν_1 at the area 1, where the technological parameters instability is primarily manifested. Over time, the wear and gaps increase, the coefficient ν_2 and the ratio ν_2/ν_1 rise respectively. Periodic measurements of the time taking into account the mix of rolling bands allow the monitor line status by the nature of ν_2/ν_1 change. For example, on Fig. 1 $\nu_2/\nu_1 = 2.19$ and $\nu_1 = 0.021$. After overhaul, i.e. at the "good" technical condition of the line of stand $\nu_2/\nu_1 = 1.23$. As we can see, this indicator is sensitive enough to the TC line.

Application of this method is particularly effective when the time measurings are in the stands of continuous group. The value of coefficient ν1 itself characterizes the stability of the technological process, taking into account the properties of semifinished rolled products [1]. At a "good" technology (stability of sheet slab heating, their submission to the mill, rolling in roughing mill group and others) the value of ν_1 is stable in all stands. If there is an abnormality in one of the stands (beating of a roller system, compression changing , fluid supply for cooling rolls, etc.), it will affect the coefficient ν1 and the ratio ν_2/ν_1 primarily in this stand. Therefore, periodic analysis of the coefficient values ν_1, ν_2 and ratio ν_2/ν_1 consistently on stands of the group and their comparison allow to assess the stability of the technological process in general and to set the change trend of the TC main lines of the stands both by the stands, and by the ratio ν_2/ν_1. Measurements of the time after an overhaul when TC is "the best", allow to determine the statistical mean values ν_1, ν_2 and ν_2/ν_1 and take them as a base for comparison.

Further analysis of the ratio ν2 / ν1 shows the contribution to the process of rear area of the band (degree of its cooling, or thickening or how the thickness is aligned at this area squeezing).

In the method 2 according to the results of periodic measurements of moment of elastic forces during each band rolling, made for 2...4 hours of mill operation, the correlation field (Md, Mst) of the values of maximum dynamic Md and average static Mst loadings (fig. 2) is constructed. The field is approximated by a linear dependence Md(Mst).

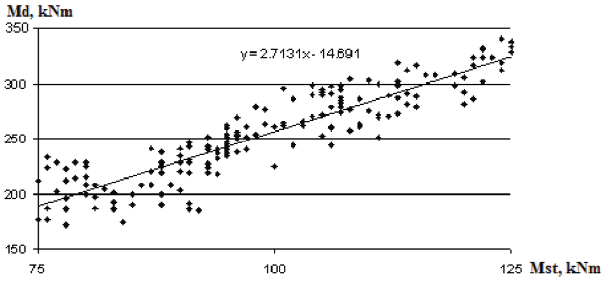

Figure 2. Correlation field Md, Mst as measured in the stand 6 of mill 1680.

Two unexplained rules are used. Firstly, the greater the Mst, the more the Mg. Secondly, the greater the spread of the wear of joints and angular gaps in the driveline, the wider, more scattered the correlation field. With increasing of the mill operation time the wear and clearances rise and thereupon increase the level of correlation field (fig. 3).

Here the method efficiency significantly also increases, if the measurements are carried out simultaneously in the stands of continuous group.

Consistent rolling in stands of one assortment bands production runs and monitoring of correlation fields, and therefore maximum dynamic loadings on the stands, allow to determine the real picture of loading changes of main lines and their TC.

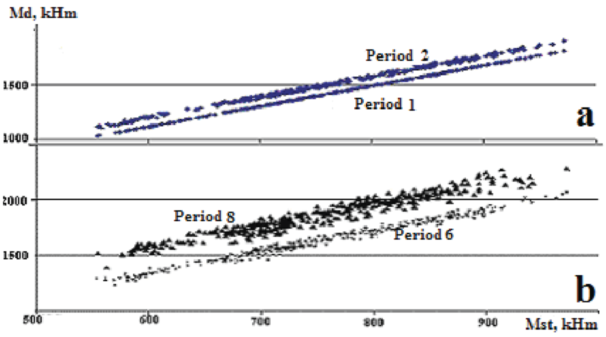

Figure 3. The calculated correlation fields: 1 - at the initial period of stand operation after the installation of spindles with new livers (minimum clearance), 8 - before the replacing of spindles with worn livers (wear and gaps are maximum).

Method 3 is based on the experimentally and theoretically established connection between the motor drive torque and the elastic forces torque. With the increasing of the wear of gear joints and angular clearance at the motor-geared system area the period between the first two peaks of the torque increases. A similar increase in the period occurs in the electromagnetic torque of the motor drive (Fig. 4).

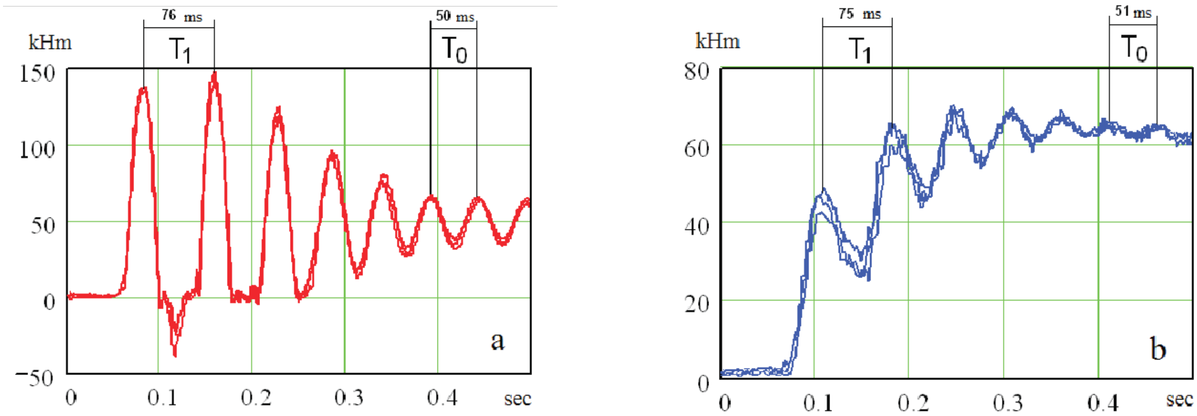

Figure 4. The actual difference in T_1 and T_0 periods between the time the first two peaks of the elastic forces moment (a) and the engine (b) from the results of measurements.

The difference in the periods T_1, when there is an open gap, and T_0 (there is no gap) is quite significant - T_1/T_0 = 1.05 ... 1.7 and very informative. Results of statistical modeling confirm the marked contrast in periods and the digital imposition of multiple processes about their repeatability. The application process is the periodic determination of period T_1, the ratio T_1/T_0 monitoring and its comparison with the calculated dependence $T_1/T_0(\delta)$ on the angular gap δ. Advantage of the method is that almost in all stands there is a time measurement of the main drive, which facilitates its practical use.

Method 4. With the development of the joints wear at the motor-geared system area, except that at the band capture the period between the first two peaks of the time increases, after the band release several same consecutive bursts (peaks) appear (Fig. 5). Accumulated potential energy expressed in elastic twisting and relative displacement of the masses is released rapidly due to removal of loading. Shafts unwinding leads to the relative movement of masses - roll system of rolling mill, rolls of pinion stand, geared system and drive. The masses move towards each other. If there is an angular gap wear, the first blow with the opposite, negative value of the moment occurs. Thereafter masses move in opposite direction, the re-closure of the gap, accompanied by impact. The duration of impact impulses repetition after the band release depends on several factors.

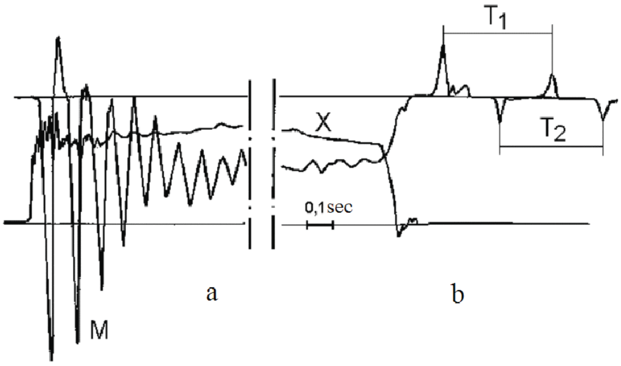

Figure 5. The transient in rollers drive line on the intermediate shaft between the engine and geared system (moment M of elastic forces) and the stand elastic system (deformation X of housing post) at the capture (a) and after the output (b) of the band from the rolls.

The driveline dynamical system, being in a loaded state at the band release significantly changes its structure due to the presence of gaps, the inertial forces from the unwinding concentrated masses and the absence of external influences other than friction forces. The system is divided into partial components, the main among which is the moment of inertia of the geared system, the elastic connection with clearance, and the moment of inertia of the drive rotor. The stored potential energy, expressed in the angles of elastic relative twisting of masses and depending on the load, transmitted by line during rolling is of considerable importance.

In this method there are two diagnostic features - the period T_1 or T_2 between the first (or second) peaks of torque and the number N of peaks. After determining the measurement data T_1 and N, modeling results for the release of the stand, the actual value of the angular wear is set.

According to the results of measurements in the mill 4 of stand 1700 of Ilyich Iron and Steel Works at a consistent 28-rolled bands, the repeatability of the process of impacts emergence after the band release is established. The average values of the periods are determined: $T_1 = 0.536$ sec ($\sigma_{T1} = 0.002$ sec), $T_2 = 0.526$ ($\sigma_{T2} = 0.001$ sec) at sufficiently small dissipation. $\delta_M \approx$ 0,05 rad corresponds to the value $T_1 = 0.536$ sec. The ending of time recording after the release was carried out arbitrarily. Therefore, it is impossible to estimate the number N of impacts as a diagnostic feature. The fixed value N was from 2 to 5. Furthermore the moment at a steady rolling state remained unknown. In this regard, the informativeness of impacts number is subject to greater scrutiny in practice.

Method 5. It is taken into account that the torsional shear load in steel cylindrical body extends at a constant rate, independent of its size. According to [1], this speed is constant and equal to Vo = 3200 m/sec. The presence of gaps in the driveline joints and local compliance at the contact points (oil of different viscosities, microcracks and so on) leads to the fact that the speed of distribution of the torsional load front decreases from the band gripping by rollers at the areas.

The larger the gap δ_{sp}, the more time of its sampling (closing), and the lower the speed of the front propagation of torsional load velocity of the spindle area. The rate of the load passage is $V_L = dS / dt$, where S - the distance between two points along the driveline, where the delay time is measured.

To implement the method the vibration sensors are installed in the rolling mill and along the line and the distance between them is determined. In the beginning of reaction the areas delay time is calculated.

In Fig. 6 there are the measured average values of delay time of three areas at three different technical conditions of the line relative to the vibration sensor signal on the stand and the estimated speed of the areas. A series of measurements are carried out at intervals of 9 days. The increase in delay times indicates the change of areas state. It was noted previously how to define a gap δ_{sp} by the measured value τ_{MV}, using the calculated dependence $\tau_C(\delta_{sp})$ [3].

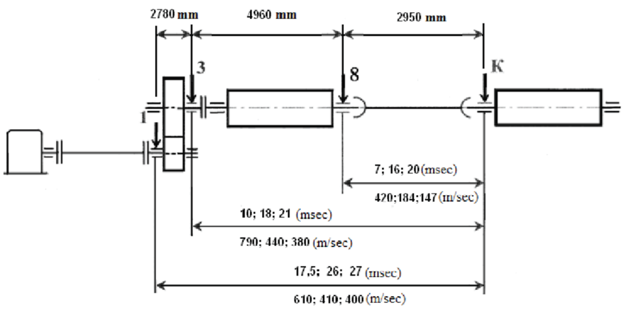

Figure 6. The measured values of the delay time of three areas and the estimated speed of the shock pulse passage of areas.

Using the speed of the shock pulse passage of areas allows to quantify directly the differences between the actual speed and the reference one by the ratio $V_0 / V_L = 3200 / dS_i/dt$ and then by periodic measurements to track the trend of its change during the mill operation. In Fig. 6 the pulse driving at the spindle area $\tau_8 = 7$ msec consists of the time required to close the gap $\tau_{SP}(\delta_{sp})$ and natural time τ_{SP0} of the area passage when the gap is closed or absent. It is τ_{SP0} = 2.950 m / 3.200 m/sec = 0.9 •

10^{-4} with ≈ 1 msec. Hence the closure of the gap itself lasts 6 msec. Determination of TC areas by τ_i and dS_i/dt is equivalent. However, in those cases when the measurements are carried out for the first time and there are no data on them on the rolling mill, the method 5 allows to obtain a sufficiently reliable information about the status of the driveline areas.

Thus, a gamma of techniques and methods of diagnostics of the technical condition of the main drivelines of rollers is designed. They use transients at the capture and release of the band by rolls. The application of developed methods, along with the well-known, in which the parameters in a rolling steady state are used, gives a great opportunity for improving the technology, equipment, operation modes and maintenance of mills in the normal technical condition.

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