Integrated Diagnostic Method Analysis of Use in the Inspection of Rolling Mills

S N Rednikov¹, E N Akhmedyanova² and K T Akhmedyanova³

¹South Ural State University, 76, Lenin prospekt, Chelyabinsk, 454080, Russia
²South Ural State Agrarian University, 13, Gagarin street, Troitsk, 457100, Russia
³Kazan State Power Engineering University, 51, Krasnoselskaya str., Kazan, 420066, Russia

E-mail: srednikov@mail.ru

Abstract. Organizing maintenance of equipment in accordance with its technical condition is a way to reduce production costs in the metallurgical industry. Equipment condition assessment is possible by various methods, but one of the most promising is the method of monitoring the thermal fields of devices. The method of monitoring the equipment temperature fields is not new and is often used for diagnostics of metallurgical equipment. This article analyzes the economic efficiency of the applied method in comparison with the method of vibration diagnostics, control current signal, a method of condition monitoring of hydraulic fluids. The authors describe their experience in equipment diagnostics.

1. Introduction
Creating modern technological units, designers strive to increase the unit capacity of machines in an effort to reduce the cost of producing a production unit. But the growth of specific indicators leads to the creation of products with limiting characteristics and a slight change in operating parameters increases the number of equipment failures, which means that equipment downtime and reduces production efficiency. Thus, an increase in pressure in hydraulic control systems leads to a reduction in their service life and requires improving the quality of cleaning the working fluid. The use of advanced technologies does not guarantee itself an increase in production efficiency. You can significantly increase efficiency by properly organizing the operation of systems and using the optimal maintenance system of metallurgical production. Under the performance indicator use methods of diagnosis in this work is the ratio of the costs of diagnostic procedures using existing certified methods, the costs for applying the developed methods of complex diagnostics primary with a medium probability of defects to be detected rolling mills.

The method of thermal fields analysis has a high efficiency index at a low cost of diagnostics[1, 2, 3, 4, 5, 6, 7, 8]. Its application in a complex of methods of vibration diagnostics, acoustic vibration assessment, analysis of test signals, analysis of wear products increases the level of forecast reliability.

2. Problem
Considering the accidents that occur at metallurgical plants in our country and abroad, we can see that the distribution of accidents is uneven by type of equipment and by primary causes. An analysis of accidents at metallurgical enterprises in our country shows that they are mainly associated with a violation of the functioning of cooling and control systems. Since the problem of equipment failures...
exists and to increase production efficiency, it is necessary to introduce advanced technologies and improve maintenance, so it is necessary to consider the types of maintenance and their use. Since the 18th century, the main thing in the metallurgical industry was repair by failure, which was typical for small enterprises of a periodic cycle or for equipment with a small and chaotic load.

In some cases, this approach is still found today. The maintenance method, in which equipment is repaired or replaced only if it fails or runs out of service, is often referred to as reactive maintenance.

Reactive maintenance has a number of disadvantages: the possibility of unscheduled downtime due to sudden equipment failures, and expensive and lengthy repairs due to the severity and extent of defects. At the same time, this approach did not allow to plan repair activities and optimize the repair personnel, to plan the spare parts fleet with high efficiency, since there is a possibility of sudden failure of several different units at the same time, so the need for repair work may exceed the capabilities of the repair service of the enterprise. In addition, an emergency failure of one element in metallurgical equipment is often accompanied by an avalanche destruction of serviceable elements in the process chain, and this leads to significant production costs.

3. Solution approach
The thermal type of non-destructive testing is based on the registration of changes in the thermal or temperature fields of controlled objects. It is applicable to objects made of any materials. According to the nature of the interaction of fields, there are methods of passive or natural radiation (the object is not affected by an external energy source) and active (the object is heated or cooled from an external source). The measured informative parameter is the temperature or heat flow.

When monitoring by the passive method, heat flows or temperature fields of working objects are measured in order to determine malfunctions that occur in the form of places of increased heating.

Thermal imaging diagnostics consists of two stages. The first is thermal imaging. The second part-image processing and analysis of anomalies and defects is the most important part and requires high qualification. At this stage, images are interpreted, object temperatures are determined, and the reasons for temperature deviations from the norm are analyzed. To do this, determine the temperature of objects based on the results of thermal imaging and compare with the standard temperatures or thermal fields, determine the cause of losses, temperature deviations from the norm.

The solution of two and three-dimensional heat conduction equations by modern computing systems has been repeatedly described in [1, 8, 9, 10, 11, 12, 13]. For an axisymmetric problem, a solution in a cylindrical coordinate system is often sufficient. The system of equations in this case can be presented in the classical version:

\[(1-s)\rho_k c_k \frac{\partial T}{\partial t} = \alpha_v (T-t) + \lambda_c (\frac{\partial^2 T}{\partial R^2} + \frac{1}{R} \frac{\partial}{\partial R} \frac{\partial T}{\partial R}) \]  \hspace{1cm} (1)

\[-(s)uc_s \frac{\partial T}{\partial x} = \alpha_v (T-t) \]  \hspace{1cm} (2)

boundary condition: \( \tau = 0; t = t(x,R), \ R = 0; \ \frac{\partial T}{\partial R} = 0; T = T_g, \ x = H; \ \frac{\partial T}{\partial x} = 0, \ R = R'; k(t-t_b) = \lambda_c \frac{\partial T}{\partial R}. \]  

where: \( \alpha_v \) — given heat transfer coefficient; \( s \) - parameter of the heat flow direction; \( \rho_k c_k \) — the material density and heat capacity; \( \lambda_c \) — the material thermal conductivity; \( c_g \) — heat capacity of the gas at the border; \( k \) — heat transfer coefficient to the environment; \( R, R' \) — respectively, current and external radii; \( H \) — height; \( t \) — material temperature; \( u \) — coolant velocity; \( t_b \) — ambient temperature; \( T, T_g \) — coolant temperature at the border; \( \tau \) — time.
Methodology of integrated primary diagnostics was successfully applied to the inspection of the equipment in the rolling mill at Ural steel (Novotroitsk). We used complex diagnostics to assess thermal fields with the calculation of temperature distribution in the volume of the most important equipment, vibration diagnostics, current diagnostics, assessment of contamination and chemical stability of working environments.

The cost of work on metallurgical equipment technical diagnostics includes: the cost of materials used; salary of diagnosticians; deductions from the payroll; the electricity cost; overhead costs; other expenses. When determining the cost of materials and electricity used in the diagnosis process, the current prices are applied and reasonable amounts of expenditure are laid down. The payroll is calculated based on the analysis of real time expenditures or according to the time standards for carrying out diagnostic activities, taking into account the hourly rate of diagnosticians. Thus, according to [14, 15, 16, 17, 18, 19, 20, 21], the standard time for analyzing documentation per unit of equipment is 0.8 man-hours, 1.8 man-hours are allocated for analyzing accidents, 8 man-hours are allocated for evaluating the remaining resource, and 10 man-hours are allocated for preparing a technical conclusion. These time expenditures are common both for complex diagnostics and for diagnostics using vibration analysis methods, thermal fields, current methods, acoustic methods, and when using equipment condition assessment by analyzing the state of working fluids.

The analysis of actual time spent directly on carrying out measures for diagnostics of metallurgical equipment by methods of analysis of external thermal fields showed the average time spent per unit of equipment in the amount of 0.75 man-hours. Moreover, the work included preparing and configuring the device, removing the distribution of external temperature fields, fixing the results of measurements, and analyzing the results of thermography.

Thermal imaging systems showed the lowest diagnostics cost with defects, high detection probability (no less than 0.67) and minimal time expenditures. High time costs and higher diagnostics cost, but with a higher (0.72) detection probability of defects, were demonstrated by vibration diagnostics methods. Methods for assessing the state of units for working fluids, analysis and lubricants using the spectrometric method when studying the maximum cost gave a reliable minimum time forecast.

The applied control by the current signal, by the reaction mechanisms, methods, ultrasonic control were used selectively and gave intermediate results. When using the greatest efficiency was achieved at the preliminary stage with vibroacoustic and current diagnostics by methods of further refinement.

An analysis of the time spent on diagnosing a unit of metallurgical equipment by various methods of assessing the state of aggregates is given in table 1.

To determine the efficiency coefficient, it is necessary to find the cost of conducting diagnostic measures. The typical scope of activities performed during diagnostics includes analysis of technical documentation for the object being diagnosed, visual monitoring of the state of aggregates, directly carrying out diagnostic activities, analysis of the results of diagnostics and evaluation of the residual resource of the object, preparation of a technical conclusion. Analysis of the tables shows a twofold reduction in the required time spent on diagnostics using thermal fields compared to other types of diagnostic measures at a lower cost of diagnostic measures.

To assess the effectiveness of the applied methods of technical condition assessment, it is necessary to consider the probability of detecting defects during diagnostic measures. When carrying out measures to diagnose the state of metallurgical equipment, statistics of confirmed and not confirmed by control disassembly of equipment and failures of defects were recorded. Based on the ratio of detected anomalies and confirmed defects during monitoring, a conclusion was made about the probability of establishing a correct diagnosis of the equipment condition assessment. Diagnostic measures were performed by a single group of diagnosticians, which eliminated the need to introduce an amendment to the different probability of detecting defects with different qualifications of personnel. Diagnostic measures were performed at monthly intervals.
Table 1. Time spent on diagnostic measures.

| Time spent on | Vibration diagnostics | Analysis of external thermal fields | Current signal analysis | Analysis of working fluids |
|---------------|-----------------------|-------------------------------------|-------------------------|---------------------------|
| working with technical documentation | 20.6                  | 20.6                                | 20.6                    | 20.6                      |
| Time spent on performing diagnostic measurements | 10                    | 7                                   | 4                       |                           |
| The time needed for processing of measurement results | 10                    | 0.75                                | 5                       | 10                        |
| Time spent on analyzing the received data | 8.1                   | 8.1                                 | 8.1                     |                           |
| Subtotal     | 48.7                  | 21.35                               | 40.7                    | 42.7                      |
| Standard time| 56.98                 | 24.98                               | 47.62                   | 49.96                     |

Table 2. Probability of detecting defects.

| Months before the audit of mechanisms | Vibration diagnostics | Analysis of external thermal fields | Current signal analysis | Analysis of working fluids |
|---------------------------------------|-----------------------|-------------------------------------|-------------------------|---------------------------|
| 5                                     | 0.2                   | 0.1                                 | 0                       | 0.03                      |
| 4                                     | 0.49                  | 0.35                                | 0.1                     | 0.05                      |
| 3                                     | 0.72                  | 0.67                                | 0.4                     | 0.2                       |
| 2                                     | 0.92                  | 0.86                                | 0.605                   | 0.41                      |
| 1                                     | 0.93                  | 0.9                                 | 0.74                    | 0.8                       |

4. Method of solution
The diagnostic interventions efficiency ratio was determined by the study in progress. A primary complex external field analysis method was applied. The efficiency is compared with the most effective of the certified methods - the vibration diagnostic method. During the research, the coefficient of effectiveness of diagnostic measures was determined by methods of complex primary diagnostics using the method of analysis of external thermal fields. The resulting efficiency coefficient is compared with the most effective of the certified methods, the method of vibration diagnostics. Calculation results

The diagnostic effectiveness ratio of measures from the moment of diagnosis is shown in Figure 1. The results of using the complex diagnostics method. The efficiency coefficient was determined three months before equipment failure. Combined diagnostics efficiency exceeded vibration diagnostics efficiency by 34% ($K_{eff} = 1.41$, $K_{ev} = 1.06$).

Diagnostics combined external thermal analysis fields time cuts troubleshooting in half. Failure of operating time forecast for 2-3 months before the critical state is received. Failure detection combined diagnostics reduces costs. Failure detection reduces costs. Procedure planning and maintenance and repair combined unit diagnostics simplifies.
Figure 1. Results of calculating the coefficient of effectiveness of diagnostic measures by analyzing external thermal fields.

References

[1] Brovman M J 2007 Continuous casting of metals (Jekomet) p 484
[2] Krivandin V A, Filimonov Ju P 1986 Theory of construction and calculations of metallurgical furnaces (Moscow: Metallurgy) p 479
[3] Lisienko V G, Lobanov V I, Kitaev B I 1995 Thermophysics of metallurgical processes (Moscow) p 240
[4] Mastrjukov B S 1978 Theory, designs and calculations of metallurgical furnaces. Volume 2. Calculations of metallurgical furnaces (Moscow) p 272
[5] Plahtin V D 1983 Reliability, repair and installation of metallurgical machines (Moscow) p 415
[6] Alekseeva T V, Babanskaja V D, Bashta T M 1989 Technical diagnostics of hydraulic actuators (Moscow) p 264
[7] Rednikov S N, Akhmedyanova E N, Zakirov D M 2018 Experience in Using Combined Diagnostic Systems for Assessing State of Metallurgical Equipment Global Smart Industry Conference Online. Available: https://ieeexplore.ieee.org/document/8570148
[8] Sherkunov V G, Rednikov S N, Vlasov A E 2016 Mathematical modeling of galvanic coating deposition processes at different speed modes Bulletin of the Magnitogorsk State Technical University. G.I. Nosova 14 2 101–106.
[9] Rednikov S N, Muromcev N N 2011 Determination of the temperature of the medium under study at high pressures Bulletin of the Samara Scientific Center of the Russian Academy of Sciences 13 1–3 620–622
[10] Rednikov S N 2015 Viscosity characteristics of hydrocarbons at high pressures Procedia Engineering 129 839–844
[11] Bataev V A 2007 Methods of structural analysis of materials and quality control of parts (Moscow) p 224
[12] Zedginidze I G 1976 Planning an experiment in the study of multicomponent systems (Moscow) p 390
[13] Kashsheev I D 2004 Properties and application of refractories (Moscow: Teplotehnik) p 352
[14] Kazancev E I 1975 Industrial furnaces. Reference Guide for Calculation and Design (Moscow) p 368
[15] Smirnov A N, Piljushenko V L, Minaev A A 2002 Continuous Casting Processes (Doneck) p 536
[16] Grebenik V M, Ivanchenko F K, Pavlenko B A 1991 Mechanical equipment of metallurgical plants. Mechanical equipment of converter and open hearth shops (Kiev) p 287
[17] Pavlova G A 2011 Statistical analysis of accidents and injuries at metallurgical plants Technosphere safety technologies Online. Available: http://ipb.mos.ru/ttb
[18] Rednikov S N, Rahmatullin B B 2012 The method of express diagnostics of hydraulic system units Dynamics of machines and work processes
[19] Fominyh A V, Chinjaev I R, Shanaurin A L 2016 Pipe fittings as the basis of passive protection systems *Valve construction* 4 58–63

[20] Rednikov S N, Zakirov D M, Platov S I 2018 *Complex diagnostics of metallurgical equipment* (Magnitogorsk) p 75

[21] Sherkunov V G, Rednikov S N, Vlasov A E 2016 Influence of the dynamics of the electrolyte movement in a galvanic bath on the uniformity of the applied coating *Bulletin of the Magnitogorsk State Technical University. G.I. Nosova* 14 3 32–38