Analysis of technical condition and development of practical recommendations to improve the reliability of steam turbine control system

M M Sultanov¹, V S Lunenko² and Y M Chubko¹

¹ Department of Energy Engineering of Heat Technology, Branch of the National Research University "MPEI", Lenin Avenue, 69, Volzhsky, 404110, Russia
² Department of Automated Control Systems, Branch of the National Research University "MPEI", Lenin Avenue, 69, Volzhsky, 404110, Russia

Abstract. Questions of ensuring reliability and safety of operation of complex technical systems are relevant during the operation of power equipment of thermal plant (TPP). The paper presents a generalized statistical analysis of defects and damages over the past 15 years in the control systems of steam turbines of types ET (extraction turbine) and IET (industrial extraction turbine), with an installed capacity of 50 to 135 MW. As a result of the calculation study, the main cause-and-effect relationships of the resulting defects that lead to an emergency stop of the turbines were identified. This paper presents the results of the analysis of defects in steam turbine control systems and provides recommendations for eliminating and preventing unplanned downtime due to an emergency shutdown of turbine units.

1. Introduction

Reliability theory is developed to select optimal technical solutions related to the need to preserve the main technical characteristics of equipment and its elements for the required period of time in certain operating conditions and avoid failures. The main reasons for the failure of technical systems such as steam turbines are sudden (accidental) failures, failures due to deterioration of the characteristics of elements (aging, wear), as well as hidden manufacturing defects characteristic of violation of operating conditions. Aging of equipment is accompanied by a decrease in its reliability and an increase in operating costs [1]. An increase in the failure rate of technical systems is usually associated with stricter conditions for their functioning (operation) and insufficient qualification of service personnel [2].

In modern conditions, when most of the equipment of the domestic heat and power complex has exceeded the standard service life, it is important to ensure the safe and efficient operation of generating enterprises. When managing operation and repair modes, it is necessary to take into account the actual level of reliability of power equipment, taking into account the impact of real operational factors [3]. In this work, generalized statistical analysis of damages in the control systems of steam turbines is performed based on the data of operation statistics for a 13-year period.

2. Methods

For the quantitative assessment of equipment reliability in the heat power industry, a number of complex indicators are used (table 1) [4].
Table 1. Analytical dependencies of reliability indicators calculation.

| Criterion                                | Label | Dimension | Equation |
|------------------------------------------|-------|-----------|----------|
| Average load                             | Nal   | MW        | $N_{al} = \sum \frac{Pr}{Tr} \cdot 100$ |
| Production                               | Pr    | million kWh | - |
| Runtime                                  | Tp    | h         | - |
| Coefficient of working hours             | Kp    | %         | $K_p = \sum \frac{T_p}{T_k} \cdot 100$ |
| Calendar time in the reporting year (8760 or 8784 hours in leap) | $T_r$ | h | - |
| Coefficient of technical use             | $K_{tec}$ | % | $K_{tec} = \frac{\sum T_p + \sum T_{over} + \sum T_{av.r} + \sum T_{cur.r} \cdot 100}{\sum T_k}$ |
| Duration of downtime in forced (emergency) repair | $T_f$ | h | - |
| Duration of idle time in reserve         | $T_{res}$ | h | - |
| Duration of dependent downtime           | $T_{dep}$ | h | - |
| Coefficient readiness                    | $K_r$ | h | $K_r = \frac{\sum T_p}{\sum T_p + \sum T_{over}} \cdot 100$ |
| Coefficient of scheduled downtimes       | $K_{sch.d}$ | % | $K_{sch.d} = \frac{\sum T_{over} + \sum T_{av.r} + \sum T_{cur.r} \cdot 100}{\sum T_k}$ |
| Duration of downtime in overhaul         | $T_{over}$ | h | - |
| Duration of downtime in average repair   | $T_{av.r}$ | h | - |
| Duration of idle time in current repair  | $T_{cur.r}$ | h | - |
| Coefficient of not scheduled downtimes   | $K_{n.sh}$ | % | $K_{n.sh} = \frac{\sum T_f + \sum T_{dep} \cdot 100}{\sum T_k}$ |
The complex of quantitative indicators allows estimating and analyzing the reliability of equipment and determining the expediency of measures aimed at increasing the reliability, including the expediency of repair [2] of equipment.

For estimation of probable damage from failures/accidents and for forecasting of investments, capital expenses, insurance volumes the analysis of the risk of operation of the equipment according to requirements of GOST 51.901.1-2002 is carried out. By means of collection and processing of information on the reliability of equipment the following problems are solved:

1. Determination of failure/accident causes
2. Identification of those parts and components of the equipment that limit its reliability
3. Identification of operating conditions and modes that affect reliability
4. Determination of economic efficiency of reliability improvement measures

The analysis of rejections is based on the investigation of rejections and other reporting forms. In order to increase the reliability and comparability of the performed assessments, the risk analysis should be performed using the same methodology [5], the same working group, and the same source of source data.

In this paper, we consider control systems with the following types of speed controllers:

**Table 2. Brief description of station control systems.**

| Type (brand) of the turbine | PT-61(65)-115(130)/13 | T-48(50)-115(130) | T-97(100)-115(130) | PT-133(135)-115(130)/15 |
|----------------------------|-----------------------|------------------|--------------------|------------------------|
| Manufacturer               | Leningrad metallurgical plant | Ural metallurgical plant | Ural metallurgical plant | Ural metallurgical plant |
| Regulatory system          | hydrodynamic          | hydrodynamic      | hydrodynamic        | hydrodynamic           |
| Turbine speed regulator    | SR-3000-6             | hydraulic membrane - tape SR | hydraulic membrane - tape SR | hydraulic membrane - tape SR |
Figure 1 shows a T type turbine control system with a single control diaphragm and hydraulic connections (simplified) [5].

In accordance with GOST, single and complex reliability indicators are used to quantify the reliability of power equipment. Individual indicators of reliability are parameter flow of failures, the average time between failures, mean time to repair; as complex indicators are used - the coefficient of readiness, coefficient of technical use, utilization of installed capacity, the ratio of unplanned failures and more. Figure 2 shows the control scheme of a PT-type turbine with hydraulic connections (simplified) [6].

For calculations in research dot estimates of parameters of the most applied in the theory of reliability laws of distribution are used and the corresponding methods of finding approximate trust estimates are applied. The structural scheme of reliability of the regulating system is represented in the form of a set of consistently connected subsystems, assembly units, units, mechanisms, etc., failure of each of which leads to failure of the system as a whole. Each subsystem of the structural scheme, in turn, includes a set of elements, which have their own intensities of failures [7-9].

When element-by-element assessing the reliability of calculated point estimates:
- time between failures of i-th component (i-th element)
- failure rate of i-th element
- time between failures of the system in operation or testing
- time between failures point estimation variance of i-th system component
- time between failures point estimation variance of the system
- time between failures point estimation of system ensemble and its variance

Complex indicators of system reliability are also calculated - availability, technical use factors and assessment of system failure rate as a whole is calculated [10].

The paper presents a generalized statistical analysis of defects and damages over the past 13 years in the control systems of steam turbines of types T (extraction turbine) and IIT (industrial extraction turbine), with an installed capacity of 50 to 135 MW.
3. Results and Discussion
Figures 3 and 4 show statistical data on defects that occurred in the control systems of steam turbines manufactured at LMP and UMP, respectively.

![Figure 3. Statistics of defects in the regulatory system of LMP turbines.](image)

![Figure 4. Statistics of defects in the regulatory system of UMP turbines.](image)

As a result of the design study, the main causal relationships of the resulting defects leading to the emergency shutdown of turbines of types PT-61 (65) -115 (130)/13, T-48 (50) -115 (130), T-97 (100) -115 (130) and PT-133 (135) -115 (130)/15 were identified. It has been established that in the vast majority of cases, faults arise as a result of violations during equipment operation, installation defects after completion of current and major repairs, as well as physical and moral wear of units and assemblies.

| Failure                                    | Solution                                                                 |
|--------------------------------------------|-------------------------------------------------------------------------|
| Industrial side steam out of control       | Side steam regulator takedown, screw joint jam fixing, stem making and stem gear joint restoration |
| Industrial and heat side steams out of panel control | Pressure regulator actuator shaft and manual control arm shaft alignment |
| Pressure regulator actuator shaft and its manual control arm shaft malalignment |                                                                         |
Industrial side steam out of control. Cumulative valve doesn’t rotate in full swing
Heat side steam not working (doesn’t maintain pressure), steam emission near pressure regulators. Seal failure of heat side steam pressure regulator steam section (bellow damage)
Feedback cone connecting rod oil leak in lower pressure actuator. Bronze bushing wearing
Unstable turbine generating unit operation under load and idle motion

Restoring bellow connection rod moving according to the turbine data sheet, making an M6 retention screw
Takedown, bellow replacement, pressure testing
Takedown, blushing to make with gaps according to the turbine datasheet, assembly
Takedown, replacement with newly manufactured ones. Linear dimension adjustment according to technical drawing

4. Conclusion
In this paper, we analyze the evaluation of reliability indicators of technical systems, including indicators of reliability of TPP equipment. The risk analysis of equipment operation is given. The principles of operation of control systems for steam turbines of thermal power plants are considered. Automatic control systems for T type turbines and PT type turbines are described. The analysis of methods for collecting and processing information used to assess the reliability of equipment of existing thermal power plants under operating conditions is performed. The generalized statistical analysis of damages in the systems of steam turbine regulation based on the statistical data for the 13-year period was made.

According to the results of the study, it was determined that the main defects arise due to contamination of the working fluid and failure of the control system elements (bellow, slide valves). To eliminate situations that occur due to clogging of the liners and the oil pipeline, it is recommended to flush the system every time the turbine unit is put out of operation, as well as carefully monitor the quality of the oil and fill the oil filters. Stops of the turbine unit associated with deficiencies in the operating parameters of the control system and operational characteristics are associated with the resource output of the control system elements beyond the design limits. It is recommended to replace the hydraulic part of the system with an electronic one in order to completely eliminate the defects that occur with the turbine control systems in use. These measures will help to reduce the number of nodes that fail during operation, as well as increase the accuracy of setting and triggering the control system. The modern electro-hydraulic control system meets the requirements of reliability, safety and trouble-free operation of generating facilities.

The study found that the failure of the regulation system can not only lead to delays and accidents but in the current job affect the mode of operation of the turbines, the quality of issuance of electric and thermal power, industrial and cogeneration turbines, stability of pressure and temperature, work on the market of electric energy and power according to the set schedule of the load, which greatly complicates the work of operational staff and impact on technical and economic indicators of the station.

References
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