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Technical Diagnostics and Features of Measuring NPP Power Equipment Parameters

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Introduction: *The task of nuclear energy at the present stage is to assess the technical condition and extend the life of existing power units of nuclear power plants.*

Problem Statement and Purpose: A test program is proposed to determine the flow rate of cooling water (distillate) in the cooling circuit of the stator winding rods of the TVV-1000 turbogenerator, which establishes the composition, content and sequence of work on the examination of the turbogenerator using the ultrasonic control method.

Materials and Methods: *Based on the analysis of scientific and technical documentation, a hydraulic calculation method for the cooling water flow in the cooling circuit of the stator winding stems of the TVV-1000 turbogenerator stator winding is presented, which determines the theoretical justification for the inspection of the turbogenerator. The numerical results of computational studies of the cooling water flow rate in the contour of the turbine generator stator winding rod for the South Ukrainian and Khmelnitsky NPPs are presented.*

Results: *It is shown that with timely technical diagnostics, it is possible to identify violations of turbogenerators and to eliminate them in a timely manner to ensure safety and operational efficiency.*

Conclusions: The program of technical diagnostics of stator rods of the turbogenerator gives the chance to define volume of necessary operations on increase of efficiency and safety of its operation. And at systematic carrying out of the offered technical diagnostics of a condition, on the basis of the program of tests and the calculated analysis of rods of a winding of a stator of the turbogenerator, to provide reliability of operation of the equipment.

Keyword: *turbogenerator, nuclear energy, technical diagnostics, measurement*

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I. INTRODUCTION

In Ukraine, the demand for electricity is increasing every day, due to economic and social changes in the country. Increasing needs and the impossibility of increasing energy capacity force to increase the efficiency of existing energy facilities. One of the main factors of inefficient electricity production at nuclear power plants is damage to turbogenerators (TG), which significantly reduces electricity generation.

Tests to determine the flow rate of cooling water (distillate) in the cooling circuit of the stator winding rods of the TVV-1000 turbogenerator are an important component of technical diagnostics during scheduled capital repairs. The purpose of the tests is to obtain objective data on the flow of cooling water in the cooling circuit of the stator winding rods of the turbogenerator by the ultrasonic method, which is used to assess the technical condition of the stator coil cooling systems and the turbogenerator as a whole.

The introduction of the technical parameter "cooling water flow in the stator coil cooling circuit" to assess the state of the turbogenerator is due to:

- the lack of diagnostics of this parameter (the design of a turbogenerator of the TVV-1000 type, operated at power units of Ukrainian NPPs, does not provide for the installation of sensors for measuring the flow of cooling water in the cooling circuit of the stator winding rods);
- triggered protections when the stator winding temperature is exceeded;

- triggered the increased number of violations of the conditions for the normal functioning of individual nodes and parts of the turbogenerator (damage to the stator winding, disconnection of the spacer-wedge assemblies of the frontal parts, fractures of the elementary conductors of the rods at the places of their soldering to the tips, violation of the tightness of the water cooling system of the stator winding), which are caused by electrical and thermomechanical processes .

Obtaining reliable data on the flow of cooling water in the cooling circuit of the stator winding rods of a turbogenerator is necessary to solve the following problems:
- assessment of the technical condition of the turbogenerator;
- increase operational reliability;
- determination of permissible operating parameters of the turbogenerator;
- optimization of the structure of the repair cycle;
- cost optimization for repairs and equipment upgrades.

II. ANALYSIS OF LATEST RESEARCHES AND PUBLICATIONS

The task of nuclear energy at the present stage is to assess the technical condition and extend the life of existing power units of nuclear power plants. Currently, many scientific and technical works are devoted to solving this problem. As mentioned in the article [1], turbogenerators type TVV-1000-2UZ are one of the most unreliable turbogenerators operated in power units of Ukraine and offers technical diagnostics of turbogenerator defects and their impact on local overheating. This study focuses on the generator stator winding, its thermal defects, and not on coolant consumption issues. However, the flow of cooling water into the cooling circuit of the stator coil, as mentioned above, affects the overheating and operation of the protective system.

The approach to the evaluation of technical equipment, which is based on the comparison of measuring and calculation, is described in [2, 3]. The authors propose to compare the calculated and measured values of the thermal state (temperatures) of spent nuclear fuel and in case of coincidence of these results, normal operation continues. The absence of coincidence of measured and calculated data indicates a violation of normal operating conditions and requires corrective action in the operation of the equipment and additional verification for further normal operation. It is proposed to adapt this approach to determine the normal operating conditions of the consumption of chilled water in the cooling circuit of the stator winding rods of the turbogenerator.

Assessment of the technical condition of power unit equipment requires a comprehensive approach. Such a comprehensive assessment is proposed by the authors to determine the quality of operation of pipeline systems, taking into account the peculiarities of their stress-strain state and seismic stability [4]. Research methods: calculations using a mathematical model; comparison of calculation results, forecasting of limiting parameters of technical condition and monitoring of mechanical properties of material of the main pipeline; inspection, qualification, determination of the residual resource of buildings, structures, foundations and metal structures taking into account geotechnical and seismotectonic conditions. This research algorithm can be used as a basis for assessing the technical condition, namely its general model.

To ensure safety beyond the design term and the quality of operation of the power unit, it is necessary to create an effective mechanism for examining the technical condition, which would optimize its operation as much as possible, based on the favorable ratio of economic indicators and safety. In particular, such a mechanism will allow for a smooth transition to the operation of the power unit, without stopping it for a long time and the associated economic losses, in over-design periods [5].

STATEMENT OF THE MAIN MATERIAL

In accordance with the requirements of [6] carry out special tests of the stator winding for hydraulic and gas density, because leaks in the water path lead either to the ingress of hydrogen into the cooling water system, which disrupts the normal circulation of water and causes overheating of the insulation of the rods, or to the ingress of water into the stator housing, which reduces the dielectric strength of the stator winding.

It is necessary to check the parameters characterizing the initial state of the cooling system of the stator winding rods, namely:
- distillate pressure in the water cooling manifold;
- distillate temperature of each rod;
- distillate quality pH, R, Cu, O_2;
- hydrogen content in the trap;
- mechanical impurities;
- technological alarm.

If the parameters that characterize the initial state of the cooling system of the stator winding rods differ from the accepted standards (table 1), a decision should be made on further testing.

Table 1 Indicators of quality parameters of the distillate

Designation	Parameter Name	Parameter Values
R, kOhm / cm^2	Electrical resistivity at a temperature of 25 ° C	Less than 200
pH	PH at 25 ° C	8,5 ± 0,5 %
O_2, mcg / kg	Oxygen content, not more	400
Cu, mcg / kg	Oxygen content, not more	100

Accept the following characteristics of the measurement location:
- fluoroplastic pipe, outer diameter 28.0 mm, wall thickness 3 ± 0.5 mm;
- available straight section up to 200 mm;
- pressure of cooling water from 1.0 kgf / cm2 to 5.0 kgf / cm^2;
- the surface temperature of the rods on a stopped TG from 25 ° C to 30 ° C.

Measurements are carried out using a portable time-pulse flow meter-liquid meter FLUXUS ADM F601 (F) by FLEXIM. The main functional characteristics of the flowmeter are:
- graphic LCD display;
- RS232 / USB interface;
- 4-20 mA output;
- the ability to work as a heat meter and measure the wall thickness of the pipeline;
- two ultrasonic laid on sensors;
- measurement accuracy - 0.1% of the measured value ± 15 µA;
- memory of more than 100,000 measuring points;
- frequency output - range 0 ... 5 kHz.

The flowmeter technology allows accurate bi-directional flow measurement by using the non-invasive method with patch sensors and to withstand adverse factors such as electrical interference to the system from nearby power cables and short-term interference with the acoustic signal.

Water flow measurements should be performed on the drain of cooling water (from the turbine side) on the hydraulic branches of 42 stator winding stems of the turbogenerator into the drain manifold (total number of drain pipes 84 pcs.) And on the hydraulic branches of 60 stator winding stems of the turbogenerator (total number of drain pipes 120 pcs.).

In addition to measuring the flow rate, perform measurements of the cooling water flow rate at the exits from the water chambers of each core of the stator winding of the turbogenerator, the cooling water flow rate in the outlets from the drain manifold, the temperature of the cooling water in the outlet (drain) manifold, and the wall thickness of the fluoroplastic pipelines.

The results of each measurement should be summarized in the table of the test report.

Start measurement operations after conducting high-voltage tests on the insulation of the stator windings of the turbogenerator and filling the cooling system of the winding rods with distillate. Having chosen one of the hydraulic branches of the winding rods, install measuring overhead ultrasonic sensors on the fluoroplastic pipe. Install on a straight section of the pipeline, at the outlet of the distillate from the water chambers of the heads of the winding rods, having previously prepared the surface of the pipeline (gel application). Connect the FLUXUS ADM F601 (F) to the installed surface sensors.

Measure the distillate flow rate in the pipe of the selected rod. Measurement time - until a steady signal is received, but not less than 30 s. To minimize errors during operations, the flow rate should be fixed per second throughout the entire process of receiving a steady signal.

Measurements should be taken on all hydraulic branches of the stator winding rods of the turbogenerator. Accounting for the difference in height of the place of measurement of water flow relative to the place of measurement of water pressure will be implemented when performing hydraulic calculations.

It is proposed to perform hydraulic calculations based on the measurement results for the cooling water flow rate, heat transfer and heat transfer intensity, and a comparative analysis of the design parameters and data obtained experimentally during the measurement of the cooling water flow in the cooling circuit of the stator winding rods of the turbogenerator is carried out. Conclusions are drawn about the dynamics of changes in the state of the internal surfaces of the cooling pipelines of the stator winding rods of the turbogenerator, about the technical condition and, accordingly, the sufficiency of heat exchange of the cooling circuit for each rod of the stator winding of the turbogenerator is estimated.

III. RESULTS AND DISCUSSION

The purpose of this calculation is to conduct a comparative analysis of the values of the cooling water flow obtained during the measurements in the cooling circuit of the stator winding rods of the turbogenerator with the calculated (theoretical) data and the results of previous measurements to further determine the dynamics of changes in the state of the internal surfaces of the cooling channels of the stator winding rods and hollow conductors winding rods. In the absence of data from previous measurements, the results of the current measurement in the calculations will be considered as the source.

The hydraulic calculation depends on the flow regime, the type of fluid and its temperature, as well as on the roughness of the pipe. The calculation of friction is described by one equation with a variation of its parameters and the introduction of various correction factors.

The stator winding rods of the turbogenerator are cooled by supplying water through an annular collector to rectangular conductors. With a developed turbulent flow with a sufficient degree of accuracy in determining λ, one can use the formulas for a round pipe with the diameter *d* replaced by four hydraulic flow radii Rg (d = 4Rg). The concept of "hydraulic radius", despite its name, the hydraulic diameter is not equal to two hydraulic radii and is calculated by the formula:

$$R_r = w/c \qquad (1)$$

where *w* is the area of the "live" section of the flow, c is the "wetted" perimeter of it (the perimeter of the "live" section at the liquid – solid contact). The area of the "live" section of the flow is determined by the perimeter of the rectangular section ab / (a + b); Reynolds number by the ratio (4υab / (a + b) ν); coefficient of hydraulic resistance (64 / Re) (8a / b) / ((1 + a / b) 2K), coefficient K = 0.12.

At the branching point of the channels A, for all parallel sections, the pressure head will be the same, since one pressure point is the same in all directions. Also, the pressure at point B will be the same for all channels. Therefore, the pressure loss in all parallel sections will be the same

$$h_k = H_A - H_B. \qquad (2)$$

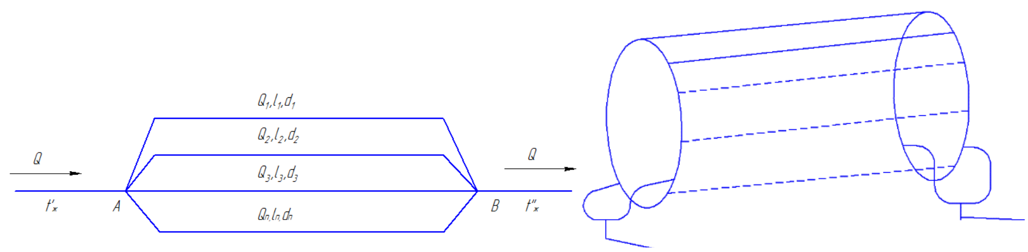

Figure 1. *Fluid flow chart*

Since the channel lengths and diameters are the same, the costs in these areas are the same.

From here

$$Q = Q_1 + Q_2 + Q_3 + \cdots + Q_n. \qquad (3)$$

The flow rate in each channel will be respectively equal to:

$$Q_1 = Q/n \qquad (4)$$

where n is the number of channels.

For the fluid flow rate in the channel υk, we present the expression for the pressure loss along the length in the form:

$$h_k = \lambda \frac{l}{d} \cdot \frac{\upsilon_k^2}{2g} = \lambda \frac{l}{d} \cdot \frac{Q_1^2 \cdot 16}{2g\pi^2 d^4} \qquad (5)$$

where λ is the hydraulic coefficient of friction, depending on the relative roughness Δ / d and the Reynolds number; l is the length of the channel; d is the diameter of the channel; υk — flow rate in the channel; g - acceleration of gravity; π is the Ludolph number; Qn flow rate in the channel.

After calculating the pressure loss along the length of the channel, we calculate the fluid velocity in each channel

$$\upsilon_k = \sqrt{h_k 2g \frac{1}{\lambda} \frac{d}{l}} \qquad (6)$$

Table 2 presents the initial data for calculating the speed of water for the TG of power unit No. 2 of the OE KNPP.

Table 2

Volumetric flow Q, m^3/s	Channel length l, m	Channel perimeter M	Acceleration of gravity g, m/s^2	Ludolph number π	Kinematic viscosity coefficient ν, m^2/s	Roughness k_e	Arithmetic mean temperature t, ^oC	Number of channels n
119,12	8	$12 \cdot 10^{-3}$	9,81	3,14	$0{,}658 \cdot 10^{-6}$	0,04	37,4	84

According to the formula (4), the hourly volumetric flow rate in the channel will be equal to:

Q1 = 119.12 / 84 = 1.418 m^3 / h

Second consumption

$Q1 = 3.93 \cdot 10^{-4}\ m^3 / s = 0.3939\ l / s$

Find the Reynolds criterion from the expression (1):

$Re = 4\upsilon ab / ((a + b)\ \nu) = (4 \cdot 1.36 \cdot 2 \cdot 4\ 10^{-3}) / ((2 + 4)\ 0.658 \cdot 10^{-6}) = 11023$

where a = 2mm is the height of the channel; b-4 mm — channel width.

The Darcy coefficient is found by the formula:

$\lambda = 0{,}3164\ Re^{-0{,}25}\ (8a / b) / ((1 + a / b)^2 K) = 0{,}1922$

Head loss (14):

$h_k=0{,}1922\cdot(8/0{,}022)((3{,}939\cdot10^{-4})^2 16)/(2\cdot9{,}81\cdot3{,}14^2 \cdot0{,}022^4)=4{,}9837$

The calculated speed in the conductor is determined by the formula

$\upsilon = \sqrt{4{,}9837 \cdot 2 \cdot 9{,}81 \frac{1}{0{,}19} \frac{0{,}022}{8}} = 1{,}43\ m/s$

The measurement data on the water velocity in the rods are presented in the diagrams (Fig. 2, 3).

Table 3

Volumetric flow Q, m^3 / s	Channel length l, m	Channel perimeter, M	Acceleration of gravity g, m / s^2	Ludolph number π	Kinematic viscosity coefficient ν, m^2 / s	Roughness $k_э$	Arithmetic mean temperature t, °C	Number of channels n
20,01	8	$12\cdot10^{-3}$	9,81	3,14	$0{,}658\cdot10^{-6}$	0,04	28,5	120

Table 3 presents the source data for calculating the speed of water for the TG of power unit No. 1 of OE SU NPP.

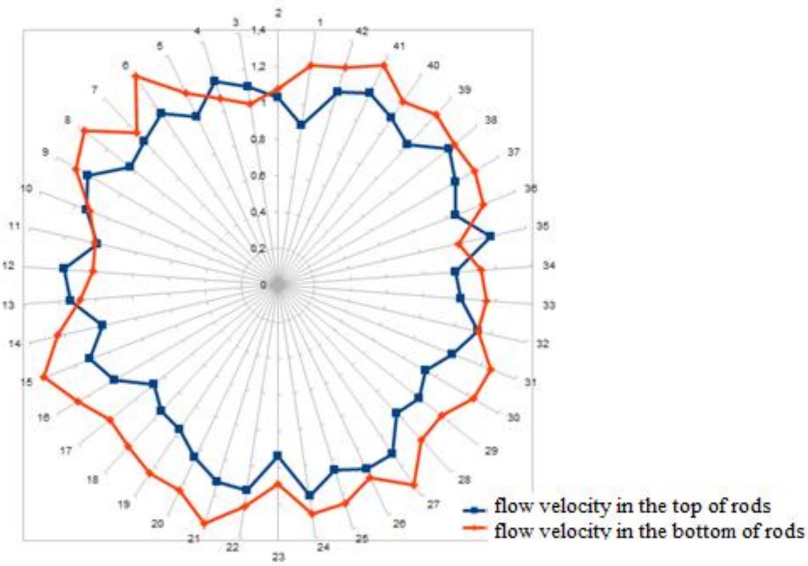

Figure 2. Diagram of the speed of water in the rods (block No. 2 of the OE KNPP).

Having calculated the theoretical velocity of the fluid, we compare with the measured velocity in each channel. A decrease in the velocity in the channel by an order of magnitude indicates the appearance of additional friction in the channel or a decrease in the diameter of the channel due to deposits.

According to the formula (5), the hourly volumetric flow rate in the channel will be equal to:

$Q_1=20{,}01/120=0{,}167$ м^3/h

Second consumption:

$Q_1=4{,}632\cdot10^{-5}\ m^3/s=0{,}04632\ l/s$

Find the Reynolds criterion from the expression (1):

$Re=4\upsilon ab/(a+b)\nu)=(4\cdot0{,}14\cdot2\cdot4\cdot10^{-3})/(2+4)\cdot0{,}658\cdot10^{-6}=1012$

where a = 2mm is the height of the channel; b = 4 mm - channel width.

The Darcy coefficient is found by the formula:

$\lambda= 0{,}3164\ Re^{-0{,}25}\ (8a/b)/((1+a/b)^2K)=1{,}596$

Pressure loss (5):

$h_k=1{,}596(8/0{,}028)\cdot((3{,}939\cdot10^{-4})^2\cdot16)/(2\cdot9{,}81\cdot3{,}14^2\cdot 0{,}028^4) =0{,}9634$

The calculated speed in the conductor is determined by the formula

$$\upsilon_k = \sqrt{0{,}9634 \cdot 2 \cdot 9{,}81 \frac{1}{1{,}596} \frac{0{,}022}{8}} = 0{,}1825 \text{ m/s}$$

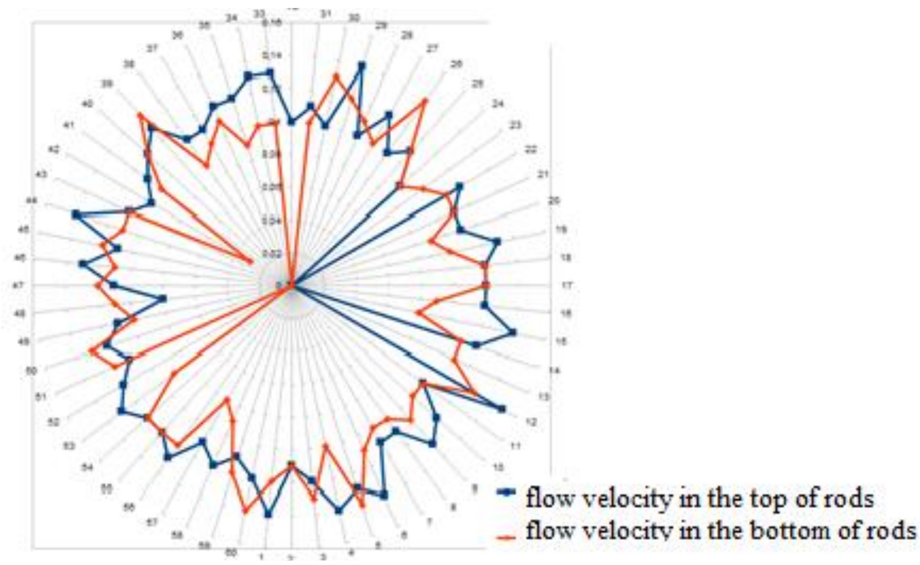

Figure 3. Diagram of the speed of water movement in the rods (block No. 1 of the OE of the SU NPP).

Having calculated the theoretical velocity of the fluid, we compare with the measured velocity in each channel. A decrease in the velocity in the channel by an order of magnitude or longer indicates the appearance of additional friction in the channel or a decrease in the diameter of the channel due to deposits.
According to the calculation data (Fig. 2), one can judge the normal operation of the generator stator cooling system. The diagram (Fig. 3) shows processes with clogging of channels and zero flow rates. It is necessary to clean such channels. Channel 32, 52 lower rods; channel 13, 23 upper rods.

IV. CONCLUSION

The proposed test program to determine the flow rate of cooling water (distillate) in the cooling circuit of the stator winding rods of the turbogenerator TVV-1000, which establishes the composition, content and sequence of inspection of turbogenerators using ultrasonic control.

To perform a comparative analysis of the obtained values of cooling water flow in the cooling circuit of the stator winding rods of the turbogenerator with calculated (theoretical) data and results of previous measurements to subsequently determine the dynamics of the state of the inner surfaces of the cooling channels of the stator winding rods calculation analysis.

The program of technical diagnostics of stator rods of the turbogenerator gives the chance to define volume of necessary operations on increase of efficiency and safety of its operation. And at systematic carrying out of the offered technical diagnostics of a condition, on the basis of the program of tests and the calculated analysis of rods of a winding of a stator of the turbogenerator, to provide reliability of operation of the equipment.

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