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Control Quality of Welded Joints by Scanning Contact Potentiometry Method

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Abstract

Conducted evaluation of technical state of welded joints, welding the collectors of the primary loop to the body of the sample of steam generator PGV 1000, located in Resource center National Research Nuclear University MEPhI at "AEM-Technologies" Atommash factory in Volgodonsk. The results of point-by-point scan shows that SLS 1000 μv and above, for almost all samples detected multiple superficial imperfections caused by the presence of certain rust spots and traces of a deep spot corrosion, and the presence of small nicks, scratches and other imperfections.

Keywords: functional electro-physical diagnostics and nondestructive testing, method of scanning contact potentiometry, non-destructive testing of welded joints, welded joint, welding of the collector of the first loop to the body of the steam generator PGV 1000.

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1. INTRODUCTION

The steam generator PGV 1000 (Figure 1) is designed to produce saturated vapor pressure of 6.4 MPa, humidity is 0,2 % at a temperature of 265°C.

The main reason of damage that may undergo to the collectors is the formation of cracks of different lengths. According to committee department specialties and technical councils, subsequently damage in collectors of steam generators caused by the combined of two effects, stress level in yield strength, and corrosive environment on collector metal, which is made of steel 10ГН2МФА. Taking into account that in many cases cracks are generated in pocket surface of the collector, and developed in the direction from node surface, according to slow deformation corrosion cracking mechanism (DCCM). Such cracks can be developed over recent years [1]. The authors of this work emphasize that there is unidentified damages, at the nodes of the collector

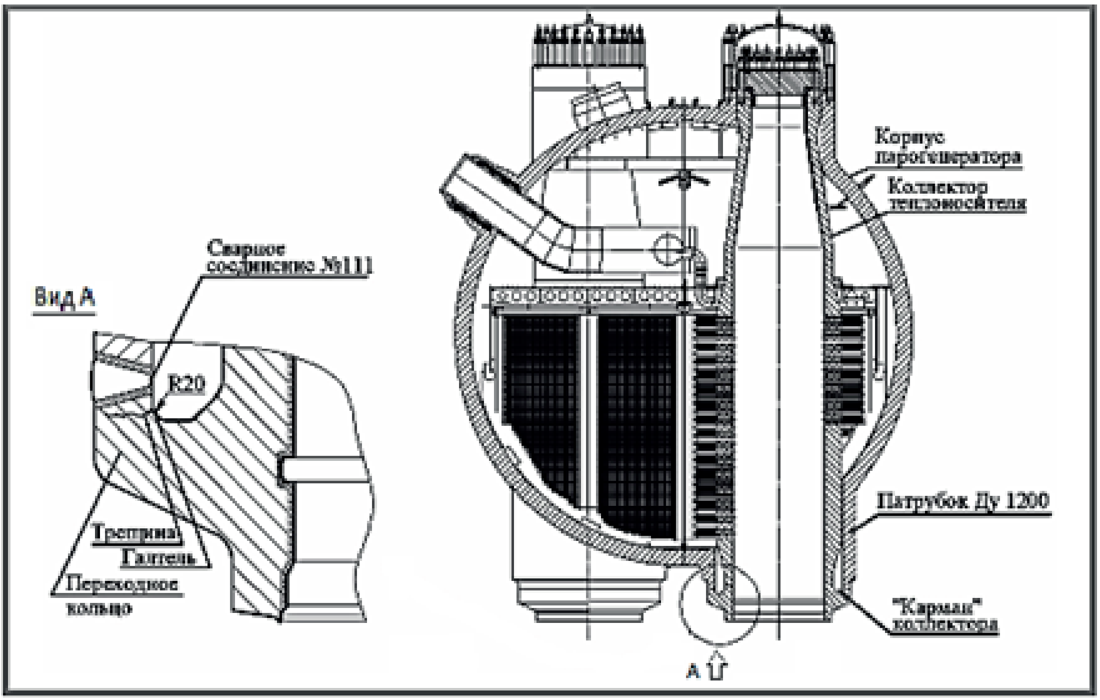

Figure 1: Sectional view of steam generator PGV 1000 and the collector with the damage in the area of welded joint № 111.

welded with steam generator, which are considered a serious problems during its exploitation.

To clarify the reasons of collector damage in the area welding № 111, providing a range of studies, including [2]:

- Detailed calculated study of the stress state from operational factors.
- Calculation and experimental determination of the sources of increased thermo-mechanical loading site welding "hot" collector PGV.
- Analysis of manufacturing technology, stress state experimental study of the node at the models and at nuclear power plants;
- Material science and the determination of mechanical characteristics of metal at templates cut from a defective welded joints № 111.
- Review of studies of slow deformation corrosion cracking of steel 10ГН2МФА.
- Optimization of heat treatment of the weld №111.
- Determination of permissible and critical sizes of defects (cracks).
- Development of measures to clean up "pockets" of collectors of deposits and keeping them clean during operation.
- Development of automated ultrasonic testing and the reliability of the manual.

The aim of the current work: evaluation of technical state of welded joints of the PGV 1000 steam generator sample, located in the Resource Center of the National Research Nuclear University MEPhI at the site of JSC "AEM-Technologies" Atommash in Volgodonsk city and search for structural violations by electro-physical non-destructive testing method.

2. MATERIALS AND METHODS

The evaluation of the technical state of welded joints of the steam generator sample and search for structural disturbances by electro-physical non-destructive testing (method of scanning contact potentiometry - SCP [6]) was carried out within one working day.

Before performing, the electro-physical non-destructive testing of surface sample steam generator and the controlled area has been prepared in accordance with the requirements of **GOST 14782-86**. A layer of preservative grease was removed mechanically from the surface, and then removed the traces of rust. Then the surface was degreased with solvent № 646 and rubbed with a dry cloth. The stripped surface brought to the required purity with the help of abrasive paper of different grits. Before each measurement, the electro-physical transducers, the welded joints were wiped with a cloth moistened with acetone. On the weld surface, the measurement points were marked out. For this purpose, at the top of the collector branch, along the entire welded joints, a tape with a marking was glued at a distance of 15... 20 mm from its upper edge. The circumference of the circle was uniformly divided into 22 sections with a length of the segment (18 $\pm$ 1) cm.

Performed an external inspection of the surface of each weld by a magnifying glass and measured roughness at the points of marking, device VOGEL. The corresponding results of the measurements are presented in table 1.

By SCP Method, in the area of monitoring was carried out point-by-point measurements using a portable probe and EF-sensor, and then carried out the surface scan by manual electro-physical flaw detector(defectoscope), EDSS - 1RD (Figure 2).

For the electro-physical control, a mobile information and measuring system was used on the basis of the *Asus X554L* laptop with the multimeter of *Agilent Technologies* 34401A [7]. The multimeter has all the features to perform quick and accurate tests in the information-measuring system have resolution $6^1/_2$ digits. The main 24-hour measurement error of the DC voltage is 0,0015%. The multimeter provides 1000 counts per second transmitted directly to the channel *GPIB* in *ASCII* format. In the standard

Table 1: Temperature and surface roughness of welded joints (inlet collector).

Site number. (the digit indicates the beginning of the site)	Temperature, C in the middle of the weld	Roughness R_a, µm (base 0.25 mm)	Visual defects on the surface of weld joint
0	19	0.67	Minor cratches
1	19	0.75	small potholes 6 pieces with a diameter of 1 mm
2	18	0.61	no
3	18	0.51	Minor cratches
4	18	0.65	Minor cratches
5	18	0.14	Minor cratches
6	18	0.15	Small rust spots
7	18	0.13	No major defects
8	19	0.14	Minor cratches
9	18	0.28	Small potholes
10	19	0.30	Traces of scratches, small rust
11	19	0.30	Traces of scratches, small rust
12	19	0.70	Traces of scratches, small rust
13	20	0.79	Minor cratches
14	20	0.81	Minor cratches
15	20	1.43	Dent of 4 mm in length
16	20	0.51	Minor cratches
17	20	0.52	Small rust
18	19	0.52	Focal rust
19	19	0.57	Focal rust
20	19	0.76	Minor cratches
21	19	0.80	Minor cratches
22	19	1.22	Minor cratches

configuration, the device has two interfaces: *GPIB* and *RS*-232. The signal-to-noise at the electro-physical control changes, typically in the range of 10 to 50 dB depending on the structural level signal (SLS).

Figure 2: Electro-physical flaw detector (defectoscope), EDSS - 1RD [5].

Potentiometric measurements were made relative to the "mass" of the steam generator. To do this, the immobile sensor was fixed to the stator of the steam generator using magnets. Sensors with electro-physical converters made of steel 45 and steel X18H10T were used. Mechanical movement of the sensor along the sample surface was carried out along eight measuring tracks, four of which belonged to the left part of the welding (relative to the axis of symmetry of the weld) and four to the right. With an average speed of scanning on the surface weld by a defectoscope of 10... 20 mm / s, the time of one set of measurements varied within a five-minute interval.

Loading of the sample was carried out both by heating with a soldering gun and by passing an electric current. When measuring in DC modes, the current was supplied to the collector via point feeds at diametrically opposite seam points with the coordinates "2" and "15". The current strength was 600-700 mA, and the voltage was 4.2 V. The current leads were located 2-3 cm above the upper boundary of the welding joint.

Point-by-point scanning of the surface was carried out manually, and "layering" the analysis of the results at different SLS, produced on the hardware-software complex "*ElphysLAB-IDS*" mobile information and diagnostic system (IDS).

2.1. Time-frequency analysis of the diagnostic signals

To study the spectrum of mechanical waves emitted by stress concentrators, the time-frequency analysis method was used. The spectrogram $P_S f\,(u, v) = |Sf(u, v)|^2$ gives the energy value of the signal f in the frequency-time neighborhood of the point (u, v) [3, 4]. To study the ranges of the spectrogram, it is necessary to calculate the instantaneous frequencies over the local maxima $P_S f(u, v)$. The Fourier transform with the window was calculated using the symmetric window g(t) = g(–t) in the interval $[t_1, t_2]$:

$$Sf(u, v) = \int_{t_1}^{t_2} f(t) g_S(t - u) e^{-ivt} dt. \tag{1}$$

As a window function, we used the Gaussian function of the form $\exp\left[-\alpha\left(\frac{i-Mw}{Mw}\right)^2\right]$, where α – constant, Mw – width of the frequency window.

To accurately determine the localization of the ranges of the spectrogram, we used the algorithm for finding the instantaneous frequency using the Fourier transform. Leaving only correcting terms of the second order, the equation for determining the points of the stationary phase has the form [4]:

$$\frac{\partial \Phi_S(u, v)}{\partial u} = \phi'(u) - v = 0 \tag{2}$$

Where the function $\Phi_S(u, v)$ is the complex phase of the Fourier transform $Sf(u, v)$, and the function $\phi'(u)$is the instantaneous frequency of the signal in the frequency-time interval under consideration. For calculations, the number of points along the time axis was chosen from 200 to 300, the width of the frequency window varied from 5 to 100 conventional units.

3. RESULTS AND DISCUSSION

The band location of the surface defects of the welding joint of the sample of the steam generator is carried out. The fragment of the welding joint of the cold collector of the sample of the steam generator with the welded connection located on it is shown in (Figure 3) and (Figure 4.a) the inhomogeneous distribution of potentials on the surface of the welding joint is shown. Measuring sections along the x-axis, number of tracks along the y axis. The inhomogeneities are distributed mainly in the upper and central parts of the welding joint.

Using results of visual control of welding joint (table 1); it can be assumed that in upper part the heterogeneity of potential is associated with numerous scratches with deep inclusions of small rust spots. On the section №15 in the central part of the welded joint, a small dent about 4 mm in length was found, which could affect on the scan result. The results of point-by-point measurements also indicate a large number of surface defects along tracks 1-4 and 7-8. (в) A circle designates a group of defects

Figure 3: Fragment of the welding node of the cold collector of the sample of the steam generator with the welded joint.

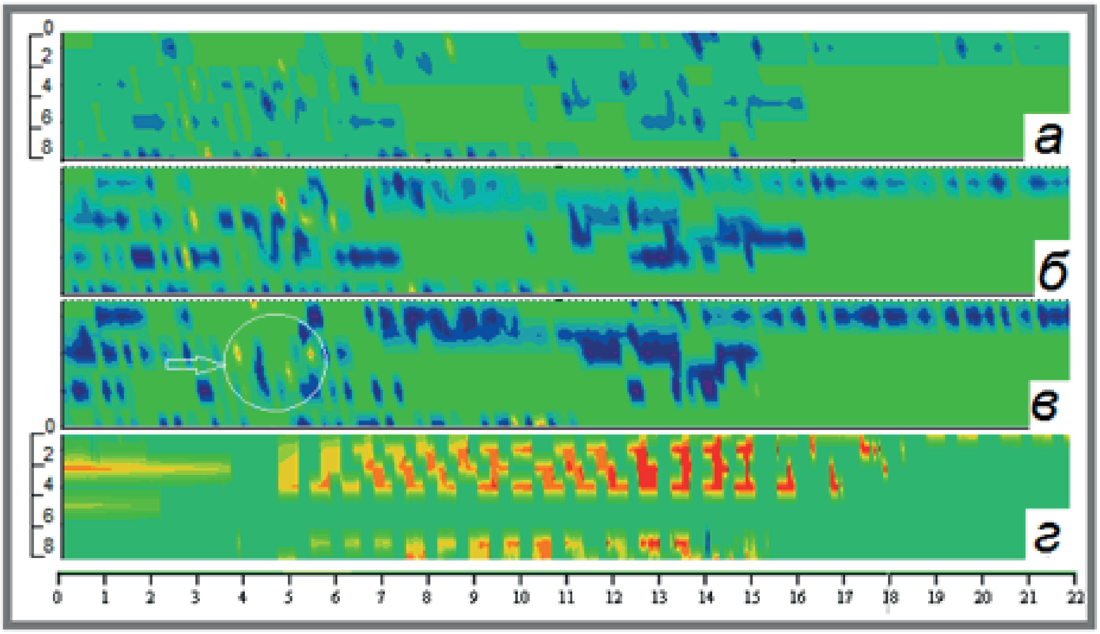

Figure 4: Surface potentiogram - a scan of the welding seam of the hot collector of the primary loop to the body of PG-52 sample, constructed for different SLS: a - 17 μV; b -9 μV; в - 5 mV; d - the results of point-by-point scanning, the level of 70 μV.

detected at high structural levels, which should be qualified as discontinuities, located in the subsurface welds. These defects are shown separately in Figure 5.

The results of the electro-physical control of the welded joint of the cold collector of the primary loop to the body of the sample of the steam generator are shown in Figure 6 Attention is drawn to a number of surface defects concentrated along the axis of the welded joint. Visual inspection of the seam shows the presence of the same defects

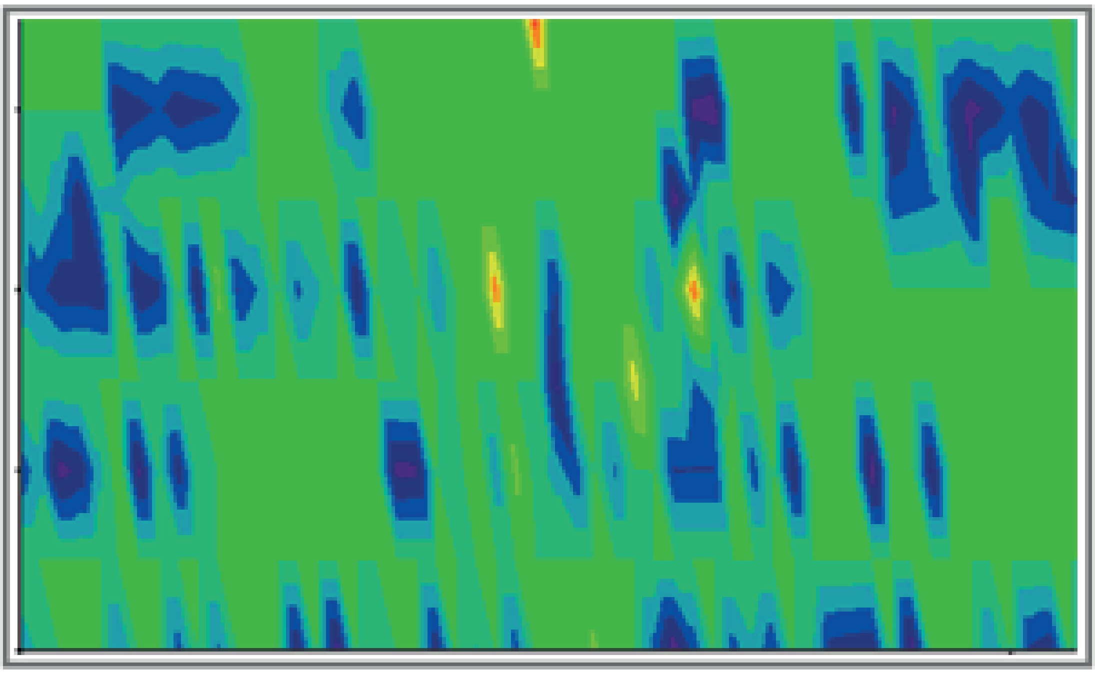

Figure 5: Group of surface defects (red spots) belonging to the structural level of 5 μV, in sections 5 and 6 in an enlarged view.

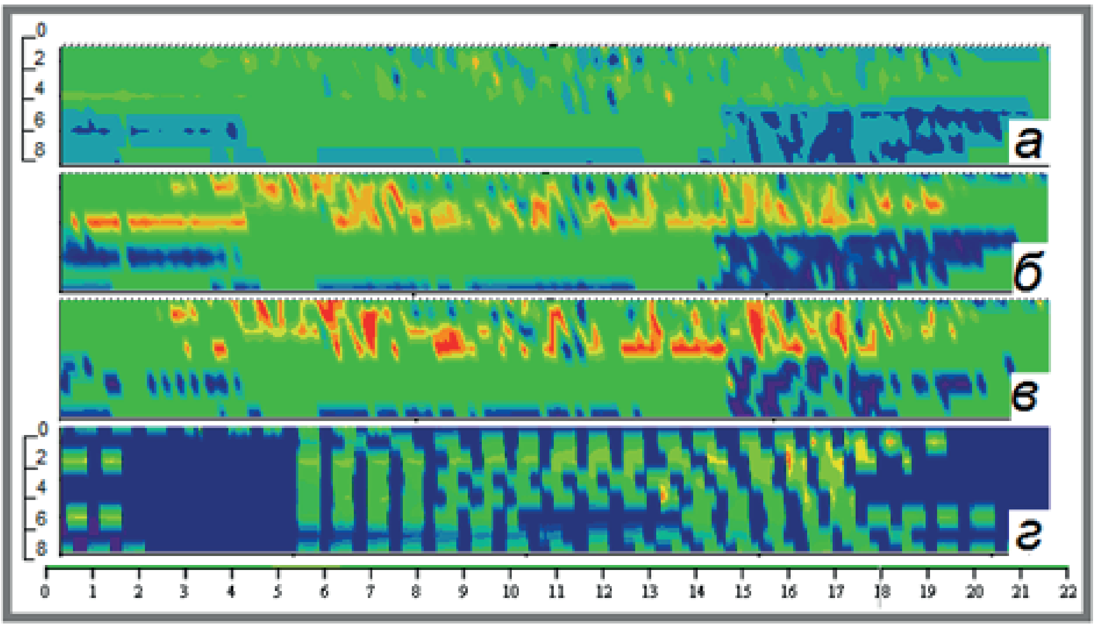

Figure 6: Surface potentiogram - a scan of the welding seam of the cold collector of the primary loop to the body of PG-52 sample, constructed for different SLS: a - 17 μV; b -9 μV; в - 5 mV; d - results of point-to-point scanning, level 100 μV.

as in the first case. The potentiogram of this weld was constructed at a structural level of 2 μV (Figure 7).

On the spectrogram shown in (Figure 8), the time in seconds is plotted along the x-axis, and the frequency in conventional units along the y-axis.

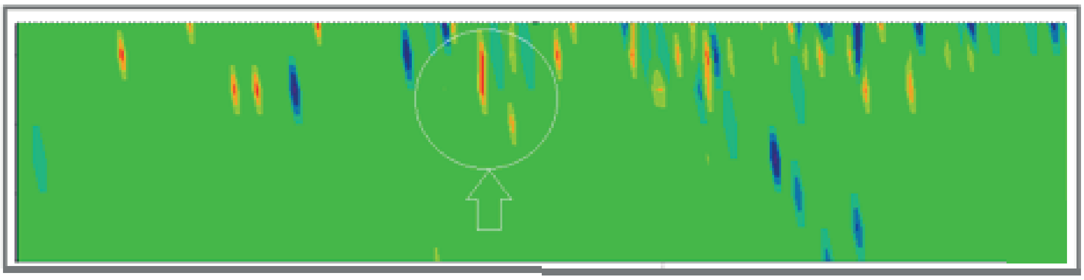

Figure 7: Surface potentiogram - scan welding joint of cold collector of the primary loop to the body of steam generator sample. Circle indicates surface defects detected by electro -physical flaw detector, *EDSS-1RD*.

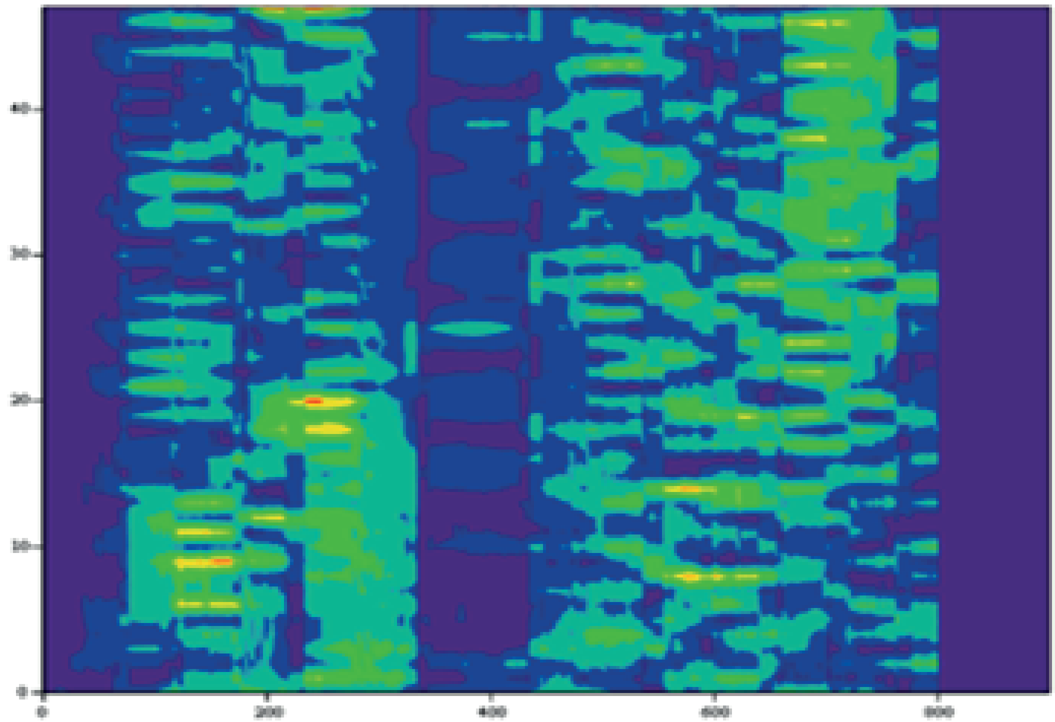

Figure 8: Spectrogram of the signal obtained by electro-physical control of the welding weld of the cold collector of the first loop to the body of the sample of the steam generator (time interval from 600 s to the end of the measurement set).

4. CONCLUSIONS

1. The object of nondestructive testing was the welded joints of the primary loop to the steam generator PGV 1000 sample, located in the Resource Center of the National Research Nuclear University MEPhI on the site of the JSC AEM-Technologies «Atommash» in Volgodonsk city.

2. To carry out this work, the technical conditions for testing were formulated; sensors and electro-physical control devices were developed, as well as a measurement methodology adapted directly to the factory conditions.

3. The technical state of the welded joint of the sample of the steam generator is evaluated. The results of point-by-point scanning show that multiple superficial imperfections are found on the 1000-μV or higher SLS, due to both the presence of individual rust stains and traces of deep focal corrosion, as well as the presence of small potholes, scratches and other imperfections. On potentiograms, they appear in the form of individual small dots and bright color spots, passing into large patches of large diameter or wide bands.

4. Surface discontinuities in the welding joints of the hot and cold collectors of the first loop to the body of the steam generator sample, at a level of 5 μV, which are identified as transverse or longitudinal-transverse small-size discontinuities, were detected. With the zone location of the welded seam of the cold collector, in the regime of direct current transmission, a singularity is detected.

5. The spectrograms show the presence of imperfections in the welds of the sample of the steam generator in a wide range of low frequencies.

6. As a result of the work carried out, the technical state of the welded joints of the primary loop collectors to the body of the sample of the PGV 1000 steam generator is estimated as satisfactory. In order to improve the quality of welded joints production, the method of scanning contact potentiometry is recommended to be used as an additional highly effective express method of NDT for already applied NDT methods, and also for developing new measuring means and methods of electro-physical NDT for the operation of NPP power equipment.

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