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The device for diagnostics of condition of heat-insulation of heating systems

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Abstract. Diagnostics of the modern thermal systems is very important from the economic and reliability point of view. The paper presents the solution of the device for monitoring the isolation of the heat transmission line. The principle of its operation applies the wave model of the line. Any damage of isolation results in change of the parameters of this model and change of the measured input resistance of the line. Through the electronic system, this change is transformed to the indication of the actual state of the isolation.
Keywords: heating systems, heat insulation, diagnostics

1. Introduction

During construction of modern thermal networks, steel pipes with industrial thermal insulation of polyurethane foam in a polyethylene protective environment are used [1, 2]. Heat-supply systems based on such pipes provide excellent heat insulation due to reduction of heat losses to 1÷3% in comparison with 30% in traditional pipelines.

During operation of such heat-supply systems, some malfunctions may occur. As a result, flowing out of heat-carrier and humidifying of thermal insulation is possible. It results in heat losses, quick destruction of a steel pipe and, consequently, financial losses.

Constant diagnostics of heat-insulation conditions of heating system allows us to find out malfunctions in due time and identify their nature with the purpose of their effective elimination. For this purpose, in polyurethane foam insulation, parallel to a steel pipe, special signal conductors are established. Together with a steel pipe, they form a distributed sensitive element in the form of an asymmetric two-wire line. A diagnostic device for heat-insulation conditions of a heating system is connected to this element. Wave resistance of such a line is about 200 Ω. The line is loaded to the resistance Z_n, the value of which depends on the diagnostic device operation principle. When a pipeline is damaged, humidifying of thermal insulation or break of the signal conductor takes place. As a consequence, the input resistance of the sensitive element changes and the diagnostic device forms a signal about the pipeline damage.

2. Mathematical model of a measuring section

For the analysis, we shall divide a line into a certain number (N) of elementary sections (Fig. 1) having the length of Δl, and in an equivalent circuit we shall use the primary parameters of such a line R_i, L_i, G_i, C_i.

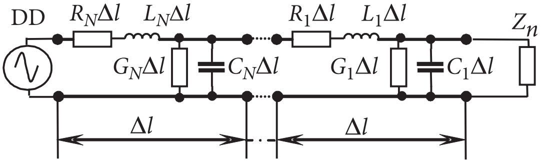

Fig. 1. Equivalent circuit of a measuring section

If we assume that $Z_i = (R_i + j\omega L_i)\Delta l$, $Y_i = (G_i + j\omega C)\Delta l$, $Y_n = \dfrac{1}{Z_n}$, then the input impedance Z_{en} can be written down as a continued fraction, Eq. (1). The quantity of elements of this fraction N, at the preset Δl, will be determined by the total length of a line and the working frequency:

$$Z_{en} = Z_N + \cfrac{1}{Y_N + \ldots + \cfrac{1}{Z_2 + \cfrac{1}{Y_2 + \cfrac{1}{Z_1 + \cfrac{1}{Y_1 + Y_n}}}}} \tag{1}$$

To test the model, there was performed calculation of the quarter-wave transformer with a factor of transformation 1:4. Divergences between the calculation done according to a strict formula and the one performed by Eq. (1) decrease from 3% at $\Delta l = 0.025\,\lambda$ to 1.3% at $\Delta l = 0.015\,\lambda$.

Detectors of defects work in a range of a kilohertz unit. Therefore, providing the condition $\Delta l << \lambda$ for the analysis of a pipeline section of 1÷2-km long is not difficult.

Figures 2 and 3 present the results of modelling the effect of the pipeline damage on the value of complex input resistance of a sensitive element 1-km long, when damage is present.

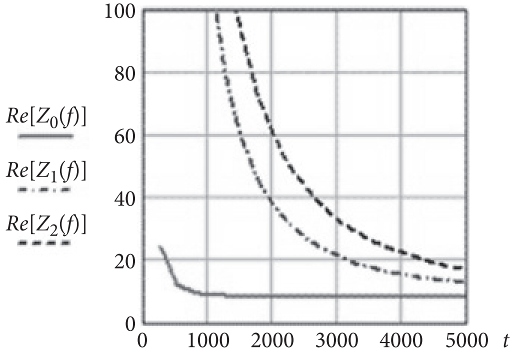

Fig. 2. Frequency dependence of the input resistance of a measuring section: an active component

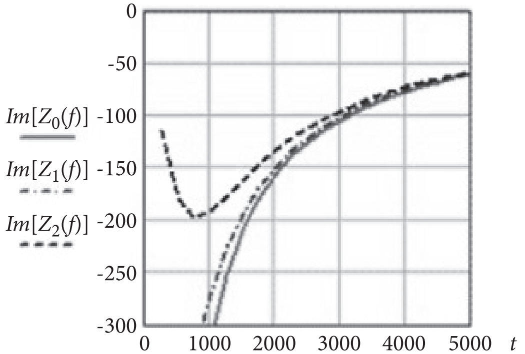

Fig. 3. Frequency dependence of input resistance of a measuring section: a reactive component

Modelling is carried out in a range of frequencies of 250÷5000 Hz. Damage was simulated by inclusion of parallel resistance on the middle of a sensitive element model. In Figs. 2 and 3, a continuous line shows frequency dependences of active and reactive components of a sensitive-element input resistance of an in-service pipeline. A dot-dash line shows frequency dependencies during imitation of failure using resistance 300 Ω; a dotted line — using 150 Ω.

The model allows us to analyze simultaneously the influence of a series of damages being locally distributed in a pipeline due to a corresponding choice of resistance of the loading Z_n, the primary parameters R_i, L_i, G_i, C_i and the character of their distribution along a line.

3. The block diagram of the device

The block diagram of the device [3] is shown in Fig. 4.

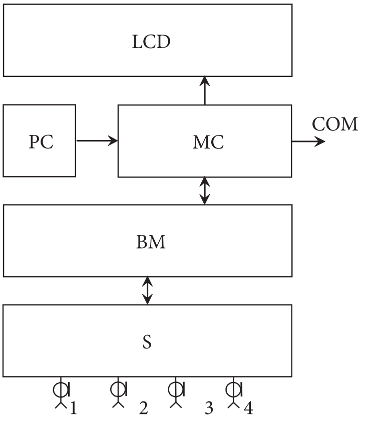

Fig. 4. The block diagram of the device

The device consists of a liquid crystal display (LCD), a control panel (CP), a microcontroller (MC), the block of measurements (BM) and the switchboard (S). The device has the following characteristics:

- quantity of controlled sections — four;
- length of a controlled section ≤ of 2000 m;
- output of information — LCD (№ of a controlled section, a condition of a heating system with the description of the type of failure, date of failure, resistance of insulation);
- archive of data: memory of the last 25 found defects (failures) with the possibility of their revision on the device display and an opportunity to archive these data on computer using COM port and RS-232 trunks;
- power supply — 220 V, 50 Hz, the maximum current consumed — 50 mA;
- range of working temperatures — from −30°C to +50°C;
- humidity — not more than 98% at $t°$ = 25°C and atmospheric pressure 750 ± 30 (mm);
- overall dimensions 220 × 155 × 80 (mm).

Appearance of a control device of heat-insulation condition of heating systems is presented in Fig. 5.

Fig. 5. Appearance of the device

The control device distinguishes, fixes and outputs on LCD the following technical conditions of the heating systems heat-insulation:

— "S. C." — "Short circuit";
— "Moisture";
— "Serviceable";
— "S. C. Break-down";
— "Moisture, Break-down";
— "Moisture-free break-down".

4. Principle of operation of the device

The principle of operation of the device lies in sequential determination of the value and character of changes of active and reactive components of input resistance of the measured line of each of the four controlled lines relative to their rated value.

For this purpose, measuring lines of each section of control are loaded to capacity. When defects are absent, complex resistance of such a line is known and it is equal to 120÷150 Ω. If any defects occur in a heating system line, the active and reactive components of the line input resistance change.

The functional diagram of the diagnostic device (Fig. 6) consists of a microcontroller (MC), a conditioner of sine wave signal (CSS), an amplifier of power (AP), phase-shifting elements C3, R3, C4, R4, four comparators K1… K4, eight analogue keys S1-S8, an insulation resistance measuring instrument (IRMI), a timer (T) and a liquid crystal display (LCD).

The principle of operation of the device is as follows. When any defect in a heating system occurs, the active and reactive components of sensitive element

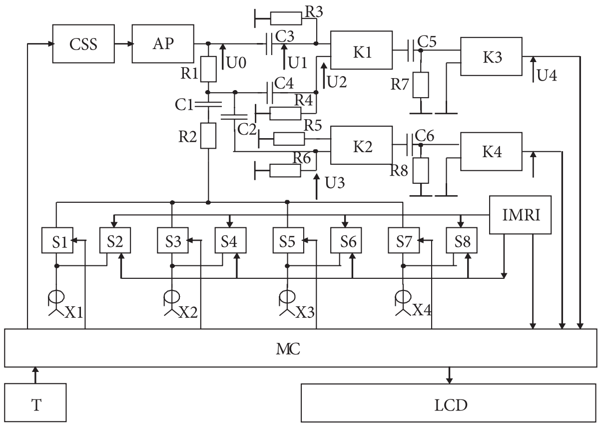

Fig. 6. A functional diagram of the diagnostic device

input resistance of the corresponding pipeline change. Each sensitive element is connected to one of the device's four connectors X1…X4. According to the change of resistance and the change of phase shifts between the reference and output signals, the conclusion is made about the character of defects in the line. For this purpose, the signal of rectangular form with the frequency of 3 kHz from the microcontroller (MC) comes to (CSS) where it is turned into a sine wave signal by filtration. In the amplifier of power (AP), this signal is amplified and through matching the resistance R1 and the element C1, R2 is applied to analogue keys S1, S3, S5, and S7 through which, in turns, it is connected to the corresponding measuring channel. The condenser C1 blocks the passage of a signal constant component to the measuring channel. The amplitude- and phase-stable reference signal U_1 is applied from the amplifier AP to non-inverting input of the comparator K1 by means of the condenser C2. The signal U_2, coming from loading through differential element C4, R4, by means of which some advancing of AP signal (a positive phase shift) is carried out, is applied to an inverting input of this comparator.

The amplitude and a phase of this signal can change depending on the change of active and reactive value of line resistance caused by the character of defect in the measuring channel of a heating system line. The signal U_3 is applied through the differential element C2,R6 to an inverting input of the comparator K2. The signal at the output of this comparator does not depend on the amplitude of U_3 and responds only to the voltage phase shift U_3 relative to the reference voltage U_1 depending on the change of reactive component of the measuring channel resistance.

To increase the accuracy of measurement, the results of measurement for each measuring channel are averaged. Depending on the results of measurement, in accordance with the program used in MC, the character of the defect of the corresponding channel is defined and the information is output on LCD. After that, additional measurement of isolation resistance is done by means of the in-built isolation resistance measuring instrument, which is sequentially connected to the corresponding channel through the keys S2, S4, S6 and S8. The keys S1, S3, S5, and S7 are disconnected. The results of measurements come to MC, and, accordingly, to LCD screen.

The signal from loading can change both by amplitude and by phase depending on the change of active and reactive components of resistance of the sensitive element caused by the character of the defect. Therefore, quadrature processing of a signal is used in the device.

When a defect in a controlled part of a heating system is present, in accordance with the program used in MC, the character of this defect is defined. The information on the character of the defect and the number of the channel is displayed on LCD screen. In addition, the result of measurements of thermal insulation resistance of this link on a direct current is output to LCD screen.

The timer (time/calendar) is used in the device. The timer depicts on LCD screen the current time and date as well as the time and date of the 25 previous emergency operations. By means of COM-port and RS-232 trunks, these data can be stored in a computer.

5. Conclusions

The offered model allows us to analyze the influence of concentrated and locally — distributed discontinuities on the value and character of a change of measuring line input resistance.

The developed device provides monitoring of heating systems' sections up to 2 km long and is compatible with similar devices of foreign origin.

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I. PRUDYUS, V. STOROZH, G. TURKINOV, V. SHKLIARSKIY

Układ diagnostyczny do badania stanu cieplnej izolacji systemu przesyłania ciepła

Streszczenie. Diagnostyka izolacji w systemie linii przesyłowych ciepła odgrywa ważną rolę w ekonomice przesyłu i pewności działania systemu grzewczego. Praca przedstawia układ diagnostyczny pozwalający stwierdzić uszkodzenie izolacji. Zasada działania urządzenia wykorzystuje model falowy linii przesyłowej. Uszkodzenie izolacji powoduje zmianę parametrów modelu linii i związaną z tym zmianę rezystancji wejściowej. Zmiana ta poprzez układ elektroniczny czujników jest przetwarzana na sygnalizację LCD uszkodzenia. Praca przedstawia szczegóły rozwiązania takiego układu.
Słowa kluczowe: systemy grzewcze, izolacja cieplna, diagnostyka