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The Primary Converters in the Control System of the Parameters of Gear Wheels of Multiplicator of Steam Compressor for Desalination Plant

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Abstract. The aim of this work is an experimental verification of the basic operations of a contactless radio wave method for determining the technical state of gears. To implement this goal, a specially developed experimental device is used. It uses generators with frequencies of 12 GHz and 32 GHz to obtain microwave sounding radiation. The excited electromagnetic oscillations of the microwave range are channeled by means of a circulator into the path of the primary converter. It is made in the form of a circular waveguide. Non-contact radiowave method of gear working condition control is developed. This method is based on the online treatment of the signals received after detecting probing radiation of microwave range deflected from gear teeth. Dependencies of signal amplitude on distance between face of the emitting waveguide and controlled surface, received by experimental way, are presented. These dependencies was approximated. Depending on which primary transducer is to be simulated and to which of the two ranges the length of the path traversed by the reflected beam falls, one of the four dependencies is selected, which calculates the weighting factor for the specific reflected beam. As a result, the developed control system of the gears of the multipliers will allow obtaining up-to-date information on the state of the gears during the operation of the desalination plant. This in turn will reduce the probability of failure of this mechanical system and will allow you to derive an economic benefit from its use.

1. Introduction

Gear transmissions are widely used in the mechanical equipment parameters for converting rotary motion. Their service life determines the indicator of failure-free operation of the mechanism. What is one of the critical links in the tree of failures? Failures of mechanical equipment due to wear or destruction of the cogwheels result in long downtime. It is costly to restore functionality [1]. The gears, which are used in multipliers, they have high demands on reliability and accuracy of manufacture. They lead to their accelerated wear and frequent replacement. Monitoring the state of the gears of the steam compressor multiplier is an actual problem [2].

At this time, the diagnosis of defects, wear and integrity of the gear wheels is mainly in the static state. Therefore that the problem of diagnosing the technical condition of gears during their operation, in the operating mode, is very relevant. Because a non-contact radio wave method for monitoring the working state of the multiplier gear is being developed. This method is based on real-time signal processing. Which are obtained after detecting the reflected from the teeth of the probe microwave radiation.

The essence of the measurement method is that wear of the tooth changes its geometric parameters. These parameters affect one or another information part of the signal that was reflected from the controlled object of the probe microwave signal. The geometric parameters of the object under study are also influenced by the shape of the information signal. Which was isolated from the reflected probing current received by the waveguide sensor [3].

2. Problem formulation

The aim of this work is an experimental verification of the basic operations of a contactless radio wave method for determining the technical state of gears. To implement this goal, a specially developed experimental device is used. It uses generators with frequencies of 12 GHz and 32 GHz to obtain microwave sounding radiation. The excited electromagnetic oscillations of the microwave range are channeled by means of a circulator into the path of the primary converter. It is made in the form of a circular waveguide. The end of the waveguide is the transmitter of the probe flow. In a waveguide converter for a generator at 12 GHz, a wave of H11 type. In the primary converter for a generator at 32 GHz, a wave of the type E01. In figure 1, structures of the wave fields of type H11 and E01. The use of a wave of the E01 type is advisable because of its distinctive property, which is the complete circular symmetry of the field. This avoids additional operations when setting the primary converters of the mutual orientation of the field lines E and the gear tooth to obtain maximum amplitude of the information signal. Inside the round waveguide is filled with quartz glass. This makes it possible to reduce the dimensions of the waveguide. This helps to prevent clogging of its internal volume. The choice of a circular waveguide as a basis for the feeder path of a microwave primary converter is also due to the fact that cylindrical sensors from the operating position are easier to install, fix and align.
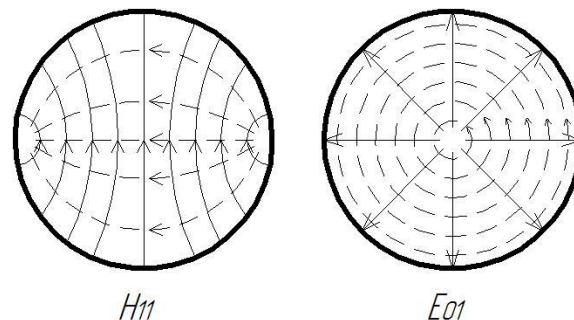

Figure 1. The structures of the fields of waves of the type E01 and H11 in a circular waveguide

3. Analytical expressions

When constructing a mathematical model for the interaction of the primary converter with the monitoring object, some sampling of the processes is introduced, when the radiation region of the sensor is divided by a rectangular grid into fragments with a certain step, which is specified in advance. In the same way, the step of the angle of rotation of the gear, and the step of the beam rotation within the limits of the directional pattern are set in advance. To account for the intensity of each sounding and reflected beam, the corresponding weight coefficient. Which is determined by the angular position of the beam in the radiation pattern of the sensor. The weight coefficient decreases with increasing angle of incidence relative to the normal to the receiving-emitting end face of the sensor. The directivity diagram of the primary converter in Cartesian coordinates will be a Gaussian pulse. Accordingly, weight coefficient for the rays are discrete values of the function which describes the Gaussian pulse. Accordingly, increasing or decreasing the sampling steps, you can increase or decrease the accuracy of calculations. In addition, it is necessary to solve the transcendental equation for calculating the weight coefficients, it is given in expression (1), which is not solved in the analytical version. Because it is necessary to use numerical methods to solve it.

$$e^{-x^2} = kx + b \qquad (1)$$

In constructing the model for the interaction of the probing microwave flow from the gear elements of the multiplier for the effect of the radiation pattern of the primary device, as well as the influence of changes in the distance between the primary transducer and the reflecting surface is necessary to introduce weight coefficients for each beam.

For experimental studies, model gears with a predetermined tooth geometry were designed and manufactured. During the experiments it was established that the size of the gap between the receiving-transmitting end of the waveguide and the controlled object exerts a strong influence on the shape of the information signal and its amplitude [4].

Figures 2 and 3 show oscillograms of the detected high-frequency signal at different gaps between the end face of the waveguide radiator and the monitored surface. In this case, a probing electromagnetic flux of a microwave band with a frequency of 12 GHz was considered. The scale along the abscissa axis for the graphs shown in Figures 2 and 3 is 2 ms/division, the scale along the y-axis is 500 mV/division.
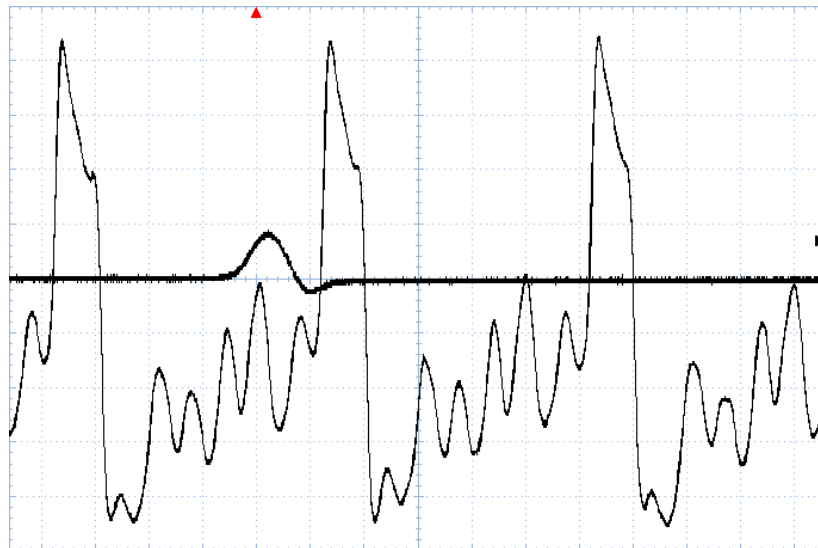

Figure 2. Information signal and the signal of the reverse mark with the gap between the primary converter and the object being monitored is 2.5 mm
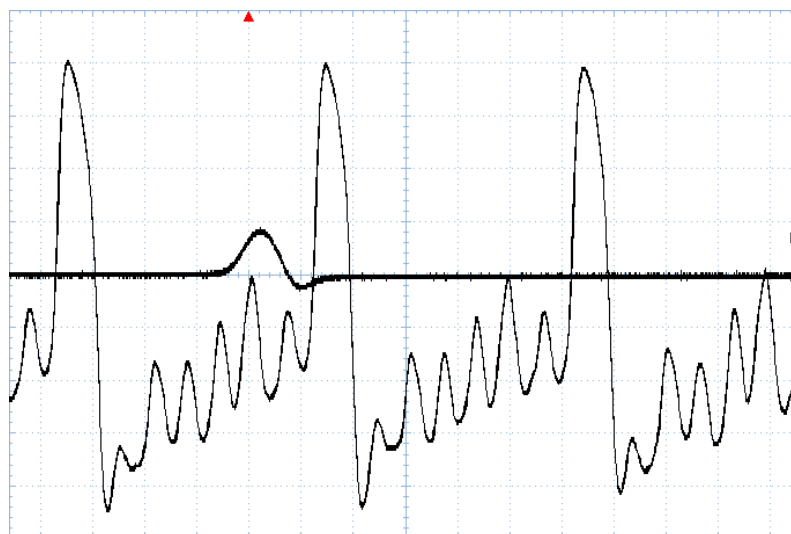

Figure 3. Information signal and the signal of the reverse mark with the gap between the primary converter and the object being monitored is 3.5 mm

4. Results and discussions

To study the reason for the transformation of the shape of the detected envelope of the high-frequency signal, graphs of the dependence of the signal amplitude on the distance between the end face of the radiating waveguide and the monitored surface were plotted. The graphs of the dependence of the amplitude of the signal on the distance between the end of the radiating waveguide and the controlled surface, which were described in [5], were obtained experimentally. In figure 4, amplitude characteristic for the primary converter, which emits an electromagnetic microwave stream at a frequency of 12 GHz. In figure 5, amplitude characteristic for the primary converter, which emits an electromagnetic microwave stream at a frequency of 32 GHz. The amplitude response shown in the graph is normalized to the amplitude value of the signal. When analyzing the obtained dependences, it can be noted that the shape of the signal is affected by the nonlinearity of the amplitude characteristic. Because when the gear wheel rotates, the distance between the monitored surface and the end face of the primary transducer will not be constant. This will be especially pronounced in places of local minima of amplitude characteristics. The first of which is 0.25 of the wavelength of the probe microwave current.
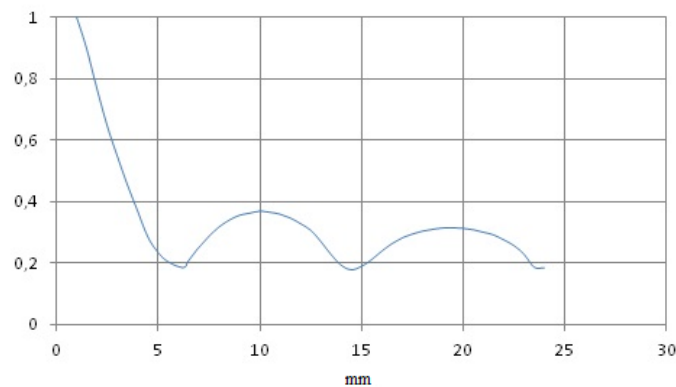

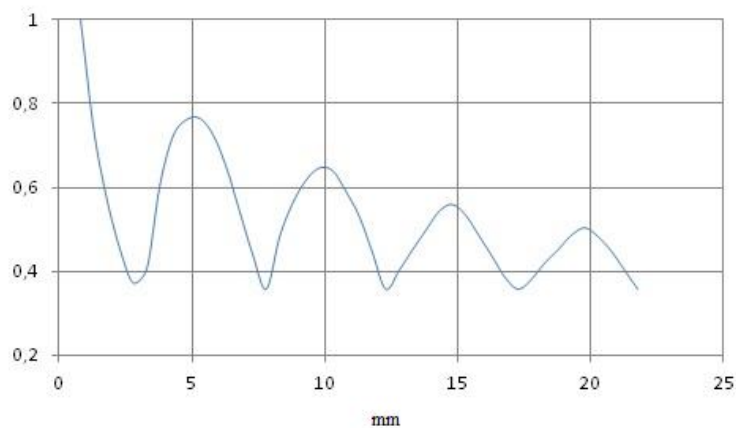**Figure 4.** Amplitude characteristic for a 12 GHz primary converter

Figure 5. Amplitude characteristic for a 32 GHz primary converter

The range of working clearances between the monitored surface and the end face of the waveguide primary transducer is selected by the amplitude characteristic, which is illustrated in Figures 4 and 5.

Based on the above material, we can formulate the criteria for selecting the working region of the amplitude characteristic in terms of the degree of its nonlinearity, the unambiguousness of the measurements and the maximization of the amplitude of the output signal.

From the point of view of increasing the amplitude of information signals, it is necessary to recommend gaps that do not exceed a quarter of the wavelength of the probing radiation.

To ensure an unambiguous correspondence between the signal value and the working gap, it is necessary to exclude ranges of gap variations corresponding to the extreme values of the amplitude characteristic.

The nonlinear properties of different parts of the amplitude characteristic can be conveniently considered by their deviation, for example, from a linear function or to estimate the degree of correlation with a linear function.

To do this, it is necessary to approximate the amplitude characteristic of the transducer by some power polynomial, and to estimate the quality of the approximation by the coefficient of determination (R^2).

As a result, in the section $0 < \lambda \leq 0.25$ of the probe microwave stream with a frequency of 12 GHz, the dependence of the amplitude on the distance can be described by the approximating polynomial of the third degree represented by the expression (2). The coefficient of determination (R^2) is equal to 0.9997.

$$y = 0,0033x^3 - 0,0118x^2 - 0,2238x + 1,2368 \tag{2}$$

Similarly, the approximating polynomial for the second section of $0.25 \leq \lambda \leq 0.5$ is represented by the expression (3). The coefficient of determination (R^2) is 0.9976.

$$y = -0,0006x^3 + 0,0025x^2 - 0,1383x + 0,6188 \tag{3}$$

For the amplitude characteristic in the range of normalized wavelengths $0 < \lambda \leq 0.25$ for the probe flow with a frequency of 32 GHz, the approximating polynomial is given in expression (4). The coefficient of determination (R^2) is 0.9985.

$$y = -0,0248x^3 + 0,2579x^2 - 0,9764x + 1,6279 \tag{4}$$

Similarly, the approximating polynomial for the second section of $0.25 \leq \lambda \leq 0.5$ is represented by the expression (5). The coefficient of determination (R^2) is equal to 0.9997.

$$y = 0,106x^4 - 1,7941x^3 + 11,12x^2 - 29,695x + 29,198 \tag{5}$$

For an example, the graphs of the experimental dependence and the approximating function for the range $0 < \lambda \leq 0.25$ for the 12 GHz probing current are shown in figure 6.
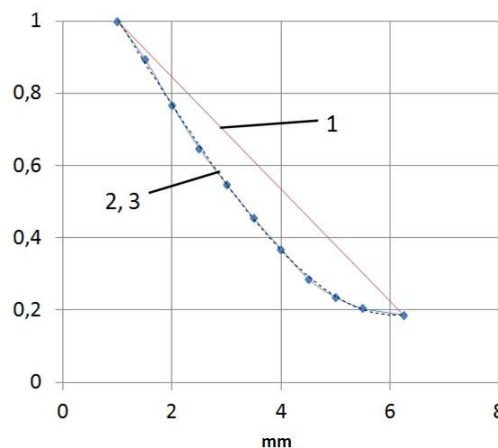

Figure 6. The section of the amplitude characteristic of the primary converter for 12 GHz in the section $0 < \lambda \leq 0.25$. 1 - linear function; 2 - experimental dependence; 3 - approximating function

Similar graphs for the range $0 < \lambda \leq 0.25$ for a 32 GHz probe flow are shown in figure 7.
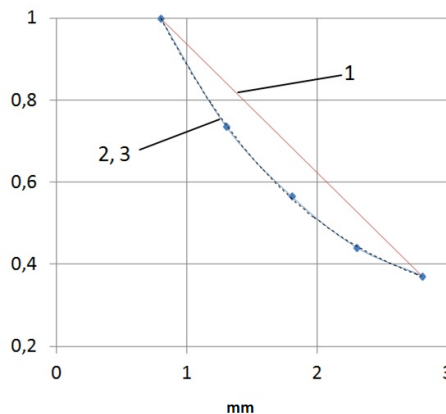
Figure 7. The section of the amplitude characteristic of the primary converter for 32 GHz in the section $0 <\lambda \leq 0.25$. 1 - linear function; 2 - experimental dependence; 3 - approximating function

The distance traveled by the reflected beam is calculated using expression (6).

$$|\bar{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2} \qquad (6)$$

Depending on which primary transducer is to be simulated and to which of the two ranges the length of the path traversed by the reflected beam falls, one of the four polynomials presented above is selected, which calculates the weighting factor for the specific reflected beam.

5. Conclusions
As a result, the developed control system of the gears of the multipliers will allow obtaining up-to-date information on the state of the gears during the operation of the desalination plant. This in turn will reduce the probability of failure of this mechanical system and will allow you to derive an economic benefit from its use.

Acknowledgments

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