Simulation of the interaction of the primary microwave converter with a control object based on the laws of geometric optics

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Abstract. In this article, the features of constructing a mathematical model of the interaction of the primary converter and the object of control are given. Also, a brief assessment of existing methods for controlling energy-loaded gearbox systems is given. Expressions approximating the amplitude characteristic are given. The equation is given to take into account the directional pattern in the construction of the model.

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].
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 is being developed to monitor the operating state of a gear wheel, based on real-time processing of signals received after detecting the probe radiation reflected from the teeth of the microwave range.

2. Simulation

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. The reflected beam is constructed using an imaginary point source of radiation. For this, a point source of radiation is constructed symmetrically with respect to the reflection plane (controlled surface). This point source of radiation is imaginary. There are two points. The first point A' is an imaginary point source of radiation. The second point O is the intersection of the beam from a real point source of radiation with the plane of reflection. The plane of reflection is the segment FG. A ray is drawn through these two points. Figure 1 shows this process. According to the rules of geometry, the angle β' is equal to the angle β'', because the angle α is equal to the angle α'. It follows that the constructed beam, when continued, will be the reflection beam.

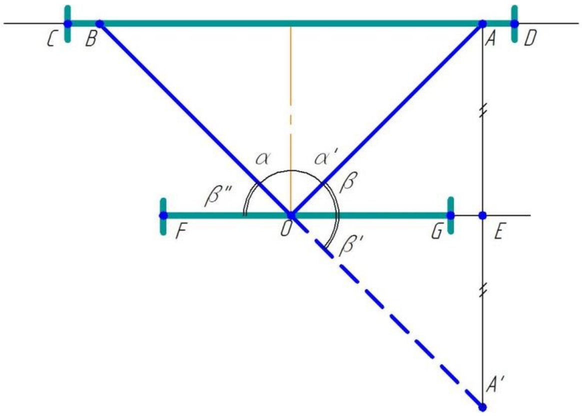

Figure 1. The process of building a reflected beam.

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.

$$e^{-x^2} = kx + b \tag{1}$$

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.

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 [2], were obtained experimentally. In figure 2, amplitude characteristic for the primary converter, which emits an electromagnetic microwave stream at a frequency of 12 GHz. In figure 3, 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.

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 2 and 3.

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.

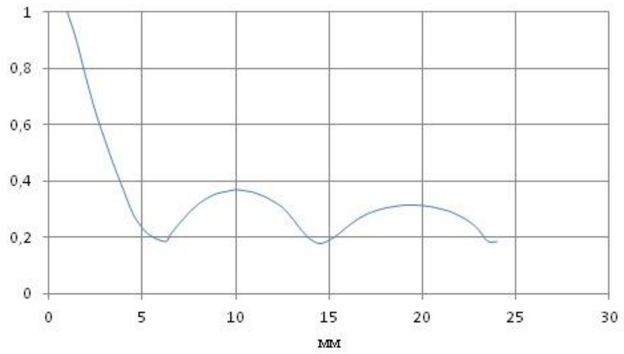

Figure 2. Amplitude characteristic for a 12 GHz primary converter.

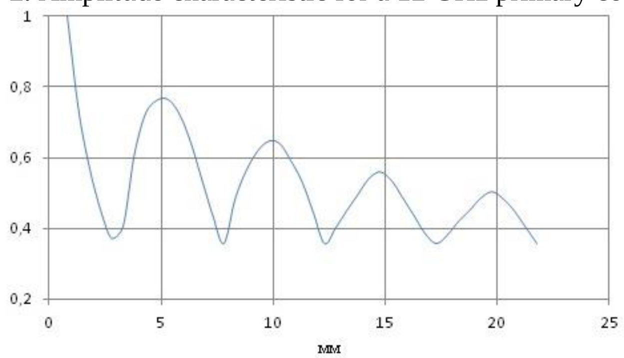

Figure 3. Amplitude characteristic for a 32 GHz primary converter.

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.

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

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.

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

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.

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

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.

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

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

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

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.

3. Conclusion

This mathematical model of the interaction of the primary microwave converter with the control object will allow to correlate the theoretical study with the experimental results. This mathematical model will increase the efficiency of designing systems for monitoring the operating state of gears.

4. References

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