The Monitoring System of the Operating State of the Gear Wheels of the Torque Multiplier of the Desalination Plant Steam Generator

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Abstract. The article describes a noncontact operational control method based on the processing of a microwave signal reflected from the controlled teeth of the wheel. In this paper describes the influence of wear patterns on the characteristic information parameters of the analyzed signals. The block diagram in section 3 shows the experimental system for monitoring the operating state of the gear wheels of the steam compressor torque multiplier. The design of the primary converter is briefly described.

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 cog wheels result in long downtime. It is costly to restore functionality.

To the torque multipliers that are used in the desalination plant vapor compressors, high demands are placed on the reliability, precision of the production of gears and the economy in operation. These torque multipliers provide an increase in the number of revolutions up to 32,000 per minute. Gears used in this mechanism are under heavy loads. This factor leads to their accelerated wear and tear and frequent replacement. Therefore, control and diagnostics of the gears in the torque multipliers during their work is an actual problem.

At this time, the diagnosis of defects, wear and integrity of the gear wheels is mainly in the static state. In the dynamic mode, a wide application was made of the spectral method of analysing vibrational signals obtained from a controlled mechanism. But the spectral method of diagnosis has many serious drawbacks. Diagnosis by the envelope spectrum of the signal is complex for the physical interpretation of the defects in the gears. It usually requires good theoretical skills of the engineer or the presence in his technical arsenal of a specialized computer expert system. A very great influence on the accuracy of the assessment of the current technical condition and on the reliability of the diagnosis of defects in the state of gear pairs is provided by the personal practical experience of the engineer and his knowledge of the internal arrangement of the monitored equipment [1].

2. Our method
For operational monitoring and diagnostics of the operating state of the gear of the torque multiplier of the steam compressor, a non-contact radio-wave method [2, 3, 4]. It is based on real-time processing
of signals obtained after detecting the reflected from the teeth of the probe microwave radiation. The parameters of the information signals are compared with the reference signals that were obtained at the start of the operation of the gear wheel. This method allows you to obtain information directly about the degree of wear of each tooth and the appearance of defects in it, in a dynamic mode. The parameters of the probing signal are determined by the geometrical dimensions of the teeth and the technological configuration of the control zone. The microwave radiation can exist in the oil environment in which the torque multiplier gears work. The advantages of this method include the absence of a large number of sensors and the need for their accurate alignment. Also, there is no need for frequent maintenance of the sensor. Who works in a fairly aggressive environment?

The following variants of tooth fracture are distinguished: tooth breakage, tooth chipping, and damage to the ends of the teeth, abrasive wear, and the appearance of defects in the form of cracks, flaking or deep contact destruction of the material [1]. During the diagnostics, the reflected probing flow is converted into an electrical signal. From which several information parameters are distinguished. Of all the above types of damage using the proposed method, it is not possible to diagnose only the appearance of cracks in the teeth if they are not located on the surface under investigation.

The need to develop a mathematical model for the interaction of the probing flow and the object of investigation appeared during the development of the method. The process of developing a mathematical model can be divided into several stages, characterizing its complication in order to improve the metrological characteristics of the results obtained. The first stage is the model in the plane, the second stage is the spatial model [5].

The first step of building a model in the two-dimensional coordinate system. The basis is the laws of geometrical optics.

A simplified tooth model is a trapezoid. A simplified model of the radiator is a segment, each point of which is both a radiator and a receiver. By varying the position of the emitter relative to the gear can observe the change in the output signal and thereby select an optimum sensor arrangement, a relatively controlled gear. The mechanism of interaction between the sensor and the surface is illustrated in Figure 1. From each radiation point of the sensor, within a linear angle determined by the direction diagram, rays emerge with a certain angular pitch specified in advance. The weighting factor for each beam is used to take into account the angular position in the radiation pattern of the sensor. The weight coefficient decreases with increasing angle of incidence relative to the sensor radiator normal. In figure 1, this is shown in the example of ray 1.

![Figure 1. The mechanism of interaction.](image)

Then investigated and determined by the intersection points of the rays with the surface. From the points of intersection, straight lines perpendicular to the surface under investigation are restored. In the figure 1, this is the perpendicular 2 for ray 1. After this, reflected rays with reflection angles equal to the angles of incidence with respect to the normal restored to the surface are constructed. The specified weight coefficients are also used for reflected rays. After that, the intersection points of the
reflected rays and the sensor surface are calculated. For each reflected ray intersecting the emitter segment, a certain weighting factor is assigned according to its intersection point.

The resulting weight coefficients from the reflected rays are summed and stored. Further, there is a rotation of the functions describing the cogwheel, relative to its center by a certain step set in advance and everything is repeated anew. Based on the number of intersections of the reflected rays with the sensor surface, a reflected signal is constructed. The construction of a mathematical model in a two-dimensional coordinate system is a necessary step of simplification for the subsequent construction of a three-dimensional model in space (figure 2) [6].

![Figure 2. General view of the three-dimensional model.](image)

Here the sensor from the segment is transformed into a circle. The tooth of the wheel is a trapezoidal parallelepiped. The radiation area of the sensor is divided by a rectangular grid into fragments with a certain step specified in advance. From each fragment rays are built with a certain angular pitch. To take into account the direction diagram of the sensor, a weighting factor is used for a group of rays having the same solid angle. The weight coefficient decreases inversely proportional to the increase in the solid angle relative to the normal. To construct the interaction of beams with a cogwheel in space, the results obtained for the model in the plane are used, with appropriate changes for the possibility of their application in the spatial model.

Mathematical model allows: to create a theoretical basis for the planning of practical experiment, to justify the optimal relative position of the sensor and the test gear, consider the impact properties of the medium between the sensor and the object under study.

For the experiments, was developed an experimental stand, presented in figure 3, and manufactured by exemplary gear with the desired geometry of the tooth.

![Figure 3. Appearance of the experimental stand.](image)
The results of theoretical and experimental studies have shown that the received reflected signal after detection has the form of a quasi-bell-shaped pulse \[5, 6, 7\]. Information parameters on the basis of which the evaluation of the degree of wear of the gear wheel is made: signal amplitude, normalized signal edge lengths, and normalized signal duration, absence of signal.

Each of the types of wear affects certain information parameter, extracted from the reflected flux. So the absence of a signal indicates a broken tooth. Chipping of teeth affects the following information parameters:

- signal amplitude;
- normalized signal duration.

Abrasive wear of teeth affects the following information parameters:

- amplitude of the signal;
- the normalized duration of signal edges.

Thus, each of the types of wear of the teeth of the controlled wheel affects several measured information parameters.

3. Our device
The block diagram of the control system of the gears of the torque multiplier is shown in figure 4.

![Figure 4. Structural diagram of the experimental device.](image)

The signal reflected from the surface of the teeth is received by the antenna-feeder device (AFD). It is channeled through the circulator into an amplitude detector. The detected signal enters the active filter. In the active filter, high-frequency noise is separated and amplified. Next, the peak detector (PD), fixes the maximum value of the pulse. With the help of ADC, this value is read and stored in the memory of the microcontroller (MC). After filtering and amplification, the information signals fall into the comparators 1 and 2, which act as the drivers of the rectangular pulses.

In the MC, the duration of the pulses and their fronts is determined. With the help of a revolving sensor there is a period of rotation of the cogwheel, which is used to normalize the time parameters of the information signal. In addition, the presence of a reverse pulse and its time position allows each tooth of the controlled gear to be identified.

AFD is a coaxial transmission line, one end of which is connected to the generator module, and the other to a modified waveguide radiator. The modified waveguide radiator consists of two parts: a waveguide-coaxial junction and a waveguide with a dielectric filling, for example, quartz glass. The modified waveguide radiator is screwed directly into the gearbox case, perpendicular to the gear ring of the controlled wheel. The use of dielectric filling makes it possible to reduce the dimensions of the waveguide while maintaining the wavelength. Dielectric filling prevents splashing of oil into the waveguide and formation of carbon deposits there. The design of such a primary converter is shown in figure 5.
The signal from the detector output has an amplitude of 0.2 V. To use the ADC effectively, it is necessary that the signal level aspire to the source of its reference voltage. The reference voltage for the ADC is 2.5 V. Therefore, to amplify the signal and to filter it from high-frequency noise, this monitoring system uses a third-order Butterworth active filter. The active filter is designed on two operational amplifiers. The monitoring system uses a Butterworth filter because it has the most smooth amplitude-frequency response within the bandwidth. Analog Devices ADA4062 are used as operational amplifiers.

Comparators are used to form the boundaries of measured intervals. The information signal arriving at the input of the first and second comparator from the output of the active filter has the form shown in figure 6. The comparator 1 is set to operate at a level of 0.1 from the amplitude of the reference information signal. Comparator 2 is set to operate at a level of 0.7 from the amplitude of the reference input signal (figure 6).
4. Conclusion
The proposed system for monitoring the working state of the gear wheels of energy-loaded multipliers can be used for diagnostics in operation in any dynamic modes.

Ultimately, the proposed system allows automating the control process, objectively evaluating and recording its current operating state, and reducing the number of device preparations. The monitoring system generates a pre-emergency signal of the torque multiplier and thereby significantly reduces the probability of failure of a complex and responsible mechanical system and ensures operation of the torque multiplier of the steam compressor based on its actual technical state.

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