Development of Damage Evaluation Methods in Uneasily Accessible Units of Oil and Gas Equipment

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Abstract. The article represents the issue of the possible identification of uneasily accessible assemblies of oil and gas equipment. Sensitivity of the system as a whole to changes occurring in its individual sections was hypothesized and tested. The work was based on the study of the output voltage of the electromagnetic signal with the eddy current control method. A special feature of the experiment was the use of a standard sample for low-cycle fatigue, but with an elongated end, a “tail,” that does not experience deformations. Measurements of the output voltage were carried out with a certain periodicity at four different frequencies of alternating current: 15, 30, 60 and 100 Hz. Analysis of the results showed that the “tail” part of the sample responds to the accumulation of damage in its working area, which made it possible to talk about the possibility of development of a method for remote diagnostics of equipment and structures.

1. Introduction
Most of the equipment of the oil and gas industry is operated in difficult conditions: overpressure, high temperature, external influences, etc. During operation in such conditions, the material of gears and machines accumulates certain damages which become critical over time [1-2].

Modern discoveries in non-destructive testing give prompt and reliable assessment of the condition of the equipment thereby eliminating possible emergencies and accidents. However there are cases when the diagnosed area is unavailable for various reasons: interfering isolation, high location above the ground level, walls or floors of buildings or structures, or simply an underground section [3-4].

The inability to diagnose in inaccessible places conditionally increases the risk of emergencies which may cause at least large economic and environmental losses and at most casualties [5].

In order to study the possibility of remote diagnosing the state of structural material, at first it is necessary to understand whether the whole system responds to its local changes. This article is dedicated to solving this issue.

2. Researches review
Fundamental data for the development of methods for remote control of structural materials is a number of scientific studies [6-13], describing the sensitivity of the whole system to certain changes in its individual parts.

Considering the pump-and-compressor equipment of the enterprises of the oil and gas industry, it can be noted that the majority of them have an electric drive. A distinctive feature of electric drive
Pump-and-compressor equipment is that the reliability of this equipment is determined by the reliability of the combination of the elements of the mechanical part and the electric drive. The system of the electric drive contains two channels - power and informational. The first channel transports the converted energy, the second controls the flow of energy, as well as collecting and processing the information about the state and functioning of the system, diagnosing its failures [6].

In [7] it was shown that the condition of the mechanical part of pump-and-compressor equipment with an electric drive can be estimated by the parameters of the harmonical components of the currents and voltages of the direct and reverse sequences, and the condition of the electric part by the parameters of the harmonical components of the currents and voltages of the zero sequence.

One more example although it does not describe the assessment of the condition of an object but reveals the essence of the remote control is the pulse scanning of pipelines to detect leakages [8–9]. The safe operation of trunk pipelines is associated with the observance of operating rules and timely repair. However during past decades environmental safety has been violated due to unauthorized pipeline tie-ins to steal oil and oil products.

The method proposed in the study [8] is based on scanning the pipeline with pulses of a given frequency response function and detecting the reverse pulse arising in the pipeline at break.

In studies [10–13] during testing for low-cycle fatigue it was found that the degree of change in the magnetic field strength $H_n$ / $H_0$ time (the ratio of the normal component of the magnetic field strength of the $i^{th}$ loading cycle to the same magnetic characteristic at failure) along the length of the steel sample load cycles have several distinct peak values. Upon subsequent loading, only one peak remains determining the potential zone of destruction of the sample.

These examples clearly indicate that the system as a whole is capable of responding to changes occurring in its narrow local zone. The explanation is as follows – the system applies redundant mechanisms of adaptation to external influences. Therefore, it was decided to check this statement on the model of a real object from the point of view of the remote removal of information about its condition.

### 3. Experimental method

In order to record changes in the condition of the material at a remote distance from the zone of potential destruction, a standard sample for low-cycle fatigue was used as a test specimen one end of which had an elongated part - a “tail” (Figure 1).

![Figure 1. Geometrical dimensions of the sample with a “tail” and the location of measurement points.](image)

The sample was subjected to cyclic loading in the field of low-cycle fatigue. Figure 1 shows that the specimen experienced deformations only in the operating area (points 1-3), and the “tail” part (points 4-11) moved freely without deformation.

The output voltage of the electromagnetic signal was chosen as the parameter under study, based on the interaction of an external electromagnetic field with the electromagnetic field of eddy currents induced by the exciting coil in the studied sample. For these purposes the TiePie SCOPE HS801 oscilloscope was used with a built-in signal generator. The advantage of this method is the ability to study the material at different depths due to changes in the frequency of alternating current.

The recorded signal has the form of damped harmonical motion (Figure 2). Earlier in the studies [14–18], it was shown that the peak values of these oscillations may be sensitive to changes in material properties, therefore at this stage it was decided to investigate the peak values of the first three maximum amplitudes of the recorded signal - $A_1$, $A_3$ and $A_5$. 
4. Analysis of the obtained results

The dependences of the output voltage of the electromagnetic signal on the number of cycles for the first three maximum amplitudes at four frequencies: 15, 30, 60, 100 Hz were constructed based on the obtained peak values of the recorded signal. At the same time the constructed dependences showed an identical character of their changes for all three studied amplitudes.

All the dependencies obtained showed the sensitivity of the “tail” points of the sample to the accumulation of damage in its operating area. But due to the complexity of displaying a large number of points on one dependency and overlapping them, it was decided to build dependencies in relative units: \( U_{a2} / U_{a3} \), \( U_{a2} / U_{a4} \), \( U_{a2} / U_{a7} \). Such relations were chosen in order to compare the output voltage of the electromagnetic signal at different points of the sample with the values in the potential zone of destruction (point 2).

The dependences constructed in relative units also showed the sensitivity of the entire sample volume to damage accumulation in the deformation zone. Figures 3-5 show the example of dependences for the frequencies of 30, 60, and 100 Hz respectively.
Figure 4. The dependence of the relative output voltage of the electromagnetic signal on the number of loading cycles for the amplitude A1 at a frequency of 60 Hz.

Figure 5. Dependence of the relative output voltage of the electromagnetic signal on the number of loading cycles for the amplitude A1 at a frequency of 100 Hz.

As can be seen from Figures 3–5 the nature of the change in the dependences of the relative stress is identical which means that the entire volume of the sample material responds to changes occurring in the zone of potential destruction.

At the change of the alternating current frequency from 30 to 60 Hz and from 60 to 100 Hz in the loading range from 2000 to 3000 cycles some features are observed that the authors associate with the reaction of the hierarchical structure of the material [19–21].

5. Conclusion
Analyzing the obtained dependences it could be argued that the system responds as a whole and adapts to external influences in its full blast due to the “use” of redundant mechanisms.

Sharp drops in output voltage values at some points may be a “warning” about the beginning of structural changes in the material. Destroying the sample and building dependencies in a relative coordinate system (degree of accumulated damage) it becomes clear what exactly the resulting bursts mean.
The results obtained clearly showed the possibility of remote measurement of accumulated damage. To quantify the damage, it is necessary to carry out additional measurements and expand the range of used AC frequencies.

6. References

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