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## FORECASTING EQUIPMENT SHUTDOWN OF OSCILLATORY PROCESSES

**Abstract.** Free vibration problems of a flat element are investigated by all boundary value problems; generalization of the decomposition method in dynamics is given to solve boundary value problems, while it is shown that the decomposition method gives an exact solution obtained by the direct method, which in turn makes it possible to test the parts of production plants for wear leading to the shutdown of the equipment or the whole process. By checking the strength of the equipment parts, studying the degree of risk of possible breakdowns, emergency shutdowns can be predicted, and it is also possible to create controlled shutdowns.

**Keywords.** Free vibration problems, oscillatory process, decomposition method, equipment shutdown prediction, elastic and viscoelastic media.

### Introduction.

The development of science and technology, the creation of new structures, the use of high- quality materials and technologies that meet the high level of scientific and technological progress, puts forward high demands on research in the field of dynamics of deformable media. Applied

problems and the laws of the internal development of basic research in mechanics of a deformable solid revealed tendencies to sequentially take into account physical and mechanical properties of materials, the nature of their deformation in time, the effects of the relationship of mechanical deformation fields with temperature, electric and magnetic fields, and the geometric structure of bodies. Among these problems one of the leading places is occupied by the problems of theoretical analysis of oscillatory processes in elastic and viscoelastic media and structural elements that non- stationary interact with the surrounding deformable medium. The study is the subject of the general theory of oscillation and the theory of waves, which are now widely developed. Positive results of these studies are useful when considering stationary, non-stationary oscillatory and wave processes in the operation of production equipment with the aim of monitoring wear of parts and pre-warning of possible shutdowns. In modern industrial equipment materials with viscoelastic properties, in particular, polymeric ones are becoming more widespread, fundamental research in the field of unsteady processes of deformation of viscoelastic bodies and specific calculations of structural elements of viscoelastic materials are widely used in various fields of engineering practice. This includes the problems of determining strength, evaluating reliability and durability, determining frequency characteristics, choosing optimal parameters that provide effective operating conditions, stability, and some other issues related to the behavior of structural elements when exposed to dynamic effects. These studies have a wide range of relevant applications in such fields of science and technology as seismology, geophysics, acoustic flaw detection, mechanical engineering and space technology [1]. The pressing issue in current theoretical research in the field of unsteady oscillations of viscoelastic bodies, complemented by the development of new models that closely resemble the dynamic deformation of viscoelastic materials in experimental conditions, lies in the development of effective mathematical methods to study various classes of problems in both plane and spatial domains within the existing models. It is crucial to conduct a theoretical analysis of the main mechanical factors arising from the influence of viscoelastic parameters.

Despite the extensive body of theoretical and applied research in this field, many significant classes of boundary value problems and their analysis remain largely unresolved or necessitate further refinement. These encompass problems related to unsteady oscillations of roads, plates, and shells while considering rheology.

To solve such problems, approximate oscillation equations derived from three-dimensional equations of motion in the theory of elasticity are commonly employed, using different hypotheses and assumptions of mechanical or geometric nature to simplify the problem-solving process. Additionally, the original three-dimensional problem in elasticity theory is often reduced to two- dimensional or one-dimensional formulations through various mathematical techniques, including variational and asymptotic methods, power series methods, and more.

Numerous studies have been conducted to reduce three-dimensional problems to two- dimensional engineering and mathematical methods. However, these studies do not provide a complete solution. Consequently, further investigation is required to examine the dynamic behavior of circular rods interacting with a deformable medium based on vibration equations derived using rigorous mathematical techniques. This research is of significant scope, as circular rods are integral elements of various engineering structures, ranging from simple machinery, instruments, and structures to complex space technology, nuclear and hydroelectric power plants, shipbuilding, and more.

The consideration of rheological properties, material anisotropy, the shell of the interacting medium, temperature changes, varying thickness, and other factors leads to considerable complexity in studying these problems. However, accurately accounting for these factors is crucial for ensuring the strength, reliability, and durability of structures, which can result in substantial savings in material resources and minimize equipment wear [2].

Wear is a gradual deterioration of material surfaces, accompanied by changes in geometric shapes and surface layer properties of parts. Wear can be categorized as normal or abnormal,

depending on the underlying causes. Chemical wear involves the formation of thin oxide layers on parts, which subsequently exfoliate from the surface, often accompanied by rust and metal corrosion. Physical wear occurs due to excessive loads, surface friction, abrasion, and mechanical stress. It can result in the development of microcracks, cracks, or roughening of the metal surface. Normal wear is associated with short-term dimensional changes due to improper installation, operation, and maintenance practices.

In summary, addressing these wear-related factors and studying the dynamic behavior of viscoelastic bodies, especially in the context of circular rods interacting with deformable media, presents complex challenges that require further investigation to ensure structural strength, reliability, and durability.

Physical wear can manifest in various forms, including confluent pitting, fatigue, abrasive erosion, and erosion. Thermal wear, on the other hand, occurs when molecular bonds within the metal appear and subsequently deteriorate due to temperature fluctuations. Several factors influence wear, which are as follows:

Material quality of the parts:

The wear resistance of parts is generally higher when the surface hardness is greater, although this relationship is not always linear.

Materials with high hardness exhibit higher wear resistance, but there is an increased risk of particle detachment. To mitigate this, parts require high viscosity to prevent particle separation. When two parts made of homogeneous materials undergo friction, an increase in the friction coefficient leads to accelerated wear. Therefore, more expensive and complex parts should be made from harder and better-quality materials, while simpler and cheaper parts can be made

from materials with lower friction coefficients.

Surface treatment quality:

Wear of a part occurs in three stages: initial wear, steady wear, and rapid-increasing wear. Optimizing the first stage through precise and clean part processing, maximizing the second stage, and preventing the third stage helps to increase the service life of parts.

Lubrication:

Introducing a layer of grease between rubbing parts fills surface roughness and unevenness, significantly reducing friction and wear.

Speed of movement and specific pressure:

Experimental data suggests that within certain specific loads and speeds (0.05 to 0.7), the oil layer remains intact, allowing parts to operate for extended periods. Increasing the load drastically increases part wear [3].

Rigidity infringement in motionless parts. Violation of fit.

Violation of relative part positions in joints.

Currently, most industrial equipment is equipped with automated control systems for monitoring process parameters. These systems collect data on equipment operating modes, store process parameters, and provide notifications for emergencies and malfunctions. The development of methods to determine equipment conditions based on process parameters is crucial for modern equipment assessment [4].

During operation, automated control systems may encounter various incidents such as sensor malfunctions, communication line breakdowns, controller/computer failures, or process parameter deviations beyond established boundaries. To ensure process continuity, the control system must include means for detecting and handling such emergency situations. Tracemode6 provides tools for this purpose, such as:

Automatic identification of hardware failures or data exchange issues by setting an unreliability sign for a channel associated with Input/Output equipment.

Automatic identification of program unreliability when channel values exceed set limits.

Monitoring FLOAT channels (analog alarms) by setting boundaries to detect abnormal process states.

Monitoring events and accidents using event class channels.

Trace Mode 6 also offers actions to prevent or mitigate accidents during ASM operation, such as alarms, operator recommendations, and blocking mechanisms. Process status information can be stored in archives and alarm reports.

### Experimental.

To numerically analyze oscillatory processes in elastic and viscoelastic media, an effective approach is to apply the approximate method based on the decomposition method developed by Professor G. Pshenichny [5, 6] for static problems. In this context, we focus on examining the oscillation problems of flat rectangular elements under arbitrary boundary conditions along the element edges to determine the natural frequencies using the decomposition method. Initially, we present the method's formulation for the case of an elastic flat element, with future applications planned for viscoelastic materials. Figure 1 illustrates the frequency variations of natural vibrations for a viscoelastic plate.

7

*β*

τ0=0,5

τ0=1

τ0=5

6

5

4

3

2

1

0 2 4 6 8

10 *γ*

Fig. 1. Сurves of changes in the frequencies of natural vibrations for a viscoelastic plate at τ0 = 0.5, τ0 = 1.0, τ0 = 5.0, v1 = 0.34, v2 = 0.3

For a flat element made of elastic material, we express the approximate equation of transverse vibration as a fourth-order equation in the form

2 2

4*W*

2*W*

*W*  *D*0 *t* 2 *W*  *D*1

*t* 4

 *D*2

*t* 2

#  0,

(1)

where the coefficients *D*0, *D*1, *D*2 are determined by the geometry and material properties

of the flat element. Seeking a solution to the equation in the form (1), we introduce the equation

*W*  exp*i b* *W* *x*, *y*

(2)

#   0

*h*

 

by substituting (2) for *W*0 , yielding equation (3):

 *b* 2

 *b* 2 

 *b* 2 

2*W*

2

0

 *D* 

  2*W*

  2 

 *D* 

  2  *D* *W*  0

(3)

0 0  *h* 

0  *h*  

1 *h*  

To facilitate the decomposition method, it is advantageous to introduce new independent and dependent variables as follows:

   *x*;

*l*1

   *y*; *l*2

4

*W*  1 *v*;

*l*

0

 4

(4)

  *l*1 ;

*l*2

  1

*h*

*l*

1

Expressed in these variables (4), equation (3) takes the form:

#  4*v*

2 4*v*

4 4*v* 

2  *b* 2 2

 4

 2

 

 2 2

 4   1 *D*0  *h*   



#  2*v*

2 2*v* 



# 4  *b* 2 2 

 

#  *b* 2 2 

(5)

  2    2   1  *h*   *D*1 *h*    *D*2 *v*  0

       

The decomposition method in the theory of oscillations follows a general procedure [7].

We state the auxiliary problems as follows:

Problem 1: Determine a solution to the equation

subject to boundary conditions

4*v* 

 4

1

*f* 1,  

(6)

*L*1 ,    0;

*L*2  ,    0;

  0; 

(7)

Problem 2: Determine a solution to the equation

subject to boundary conditions

4 4*v*2 

 4

*f* 2 ,  

(8)

*L*3  ,    0;

*L*4  ,    0;

  0; 

(9)

The specific boundary conditions at the plate edges depend on the fixation conditions or the presence of free edges, which may involve stresses.

### Results and Discussion.

The remaining part of equation (5) is denoted as

4*v*3

 *b* 2

2  2*v*3

2 2*v*3 

4  *b* 2

2 2

2  *D*0 

  

2  

2   1 *D*0   

 

 *h* 



 

 

 *h* 

(10)



 2   *b* 2  2 

1

  2  

 *D*1 *h* 

 *D*2 *v*3  *f*

,  *f* ,  0,

   

where *f*  *j*,   represents arbitrary functions whose specific form depends on the

boundary value problems being solved. Following the decomposition method, we assume that

*v*  1 *v*  *v* 

(11)

3 2 1 2

must also satisfy certain conditions at designated points of the plane element. The general solutions of the auxiliary problems' equations (6) and (8) can be expressed as

     3      2          

*v*1 *f*1 , 6 1 2 2

3 4 ;

(12)

*v*1 

*f*1  ,

   3 

# 6

    2 

1 2

2     3

 

4  ;

where  *j* , *j* represents arbitrary functions of the arguments determined by the boundary

conditions (7) and (9). We then represent the arbitrary functions in a general form as

*f*  *j* ,    

*n*,*m*

*n*1

*a*





*j*1

*a* *j* sin*n*sin*m*,

(13)

where

 *j*  *n*,*m*

represents arbitrary constants, and the functions

*f j* ,  

in the general

solutions (12) are equal to

  *a* *j* 

*f*1 ,     *n*,*m* sin*n*sin*m*;

*n* 1 *j* 1 *n*4



*f*2  ,   





*n*1





*j*1

*a*2

*n*,*m* sin

*m*4

*n*sin

*m*.

(14)

By using particular solutions to problems under given boundary conditions and employing

the approximate representations (11) to determine the unknowns *a* *j*  , we obtain a homogeneous

*n*,*m*

linear system of algebraic equations. A nontrivial solution of this system leads to a frequency equation, enabling us to determine the natural frequencies of flat elements. The problems related to viscoelastic materials in flat elements are solved in a similar manner.

The concept of a software and hardware complex forms the basis of automated systems for monitoring the state of equipment. This concept has emerged relatively recently in the field of computer technology and fiscal devices. One popular example of a software and hardware complex is "Cruise" with Trace Mode software. "Cruise" is an automated process control system that combines hardware and software components and is designed to implement automatic, automated,

and remote control of industrial facilities. The structure of the "Cruise" software and hardware complex is depicted in Figure 2.

The main objectives of creating an automated process control system are as follows: Ensuring the management of technological processes in normal, emergency, and post-

emergency conditions.

Providing operational personnel with sufficient, reliable, and timely information about operating modes, the course of technological processes, equipment conditions, and technical controls.

Optimization of technical and economic indicators. Increasing the reliability of equipment.

Improving working conditions for operating personnel.

Working with the software and hardware complex involves addressing various tasks such

as:

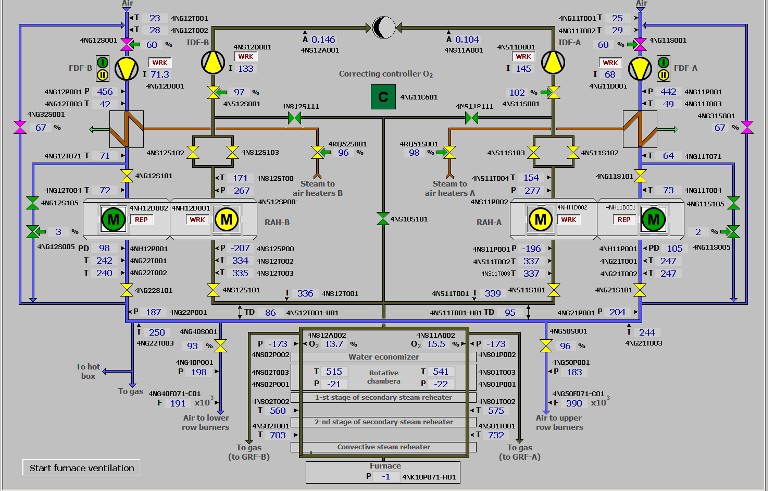
Collecting and primary processing of information. Monitoring the reliability of received information. Receiving and storing retrospective information.

Creating process equipment monitoring teams and presenting information to operational

and engineering personnel through mnemonic representations, diagrams, graphs, and histograms.

Logging and documentation.

Registering emergency events and analyzing protection actions. Monitoring and displaying the state of the hardware and software complex.

The complex operates as a distributed control system with a two-level organization, utilizing the standard Ethernet protocol for communication between different system levels. This approach allows for the incorporation of extensive experience in building fault-tolerant systems and leveraging the latest advancements in distributed computing and redundancy.

**Fig. 2. DCS “Cruise” structure**

Overall, the automated control system represents a decentralized human-machine system in which control tasks are partly performed automatically and partly through remote automated

control with human involvement. In urgent cases, emergency tools and individual control keys installed on the backup control system's remote controls can be used for process control. Individual control and monitoring tools are employed to ensure a safe shutdown of equipment in the event of a functional failure of the software and hardware complex. Each level of the process control systems is equipped with corresponding control posts where operational personnel are stationed. Information is generated and displayed automatically by the technical means of the software and hardware complex, while management decisions are made and implemented by the operator. The operator interacts with the control system through the information presentation subsystem [8].

In Trace Mode 6, the automatic creation and configuration of the channel base for controllers is accompanied by the automatic construction of the operator's graphical interface using monitors. Equipment control algorithms are also selected. Figure 3 illustrates the recording of emergency stops based on technical parameters in Trace Mode. Monitors within the system can generate messages in various situations during the operation of an automated control system. For instance, when a channel value of the FLOAT class exceeds a set limit or when there are changes in employee status. These messages are logged in a dedicated text file called the alarm report (AR), which is configured for each node. AR messages are logged on channels for which the corresponding flag is set. The configuration of the AR allows monitors to generate messages. Message texts for events can be defined in dictionaries. If a channel is linked to a dictionary, messages from the dictionary will be generated; otherwise, monitors will generate default messages. For some channels, the criteria for generating messages are dependent on specific channel parameters. The dictionary can also be configured to transmit messages through additional means, such as SMS messages to a specified mobile phone number via a console network. Graphic elements used in the development of graphical screens allow operators to input arbitrary messages into the alarm report and view all AR messages, as well as acknowledge them [9].

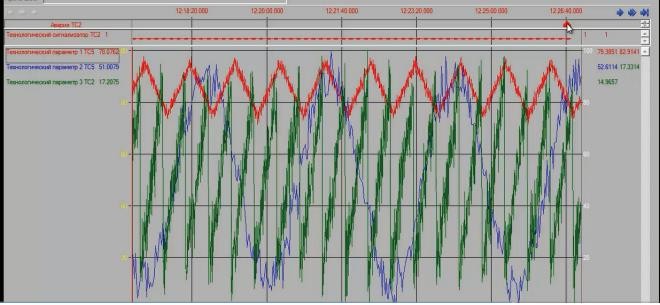


Fig. 3. Registration of emergency stops based on technical parameters in the Trace Mode.

To exit the alarm state for a variable, its value must decrease by an amount known as the deadband, such that it falls below the threshold. Similar interpretations apply for lower pre-alarm and emergency alarms. These conditions hold for alarms of the deviation type. The set value of a variable can be modified by either the operator or the program. The alarm is triggered when the variable value exceeds the tolerance limit. Alarms determined by the rate of change of a parameter occur if it exceeds the maximum permissible value or falls below it. The concept of a "deadband" does not apply to alarms of this type [10].

### Conclusion.

The findings and analysis presented in this study regarding the natural oscillations of planar rectangular elements and the propagation of harmonic waves in planar elements demonstrate the applicability of the decomposition method for obtaining precise solutions to oscillatory processes in both elastic and viscoelastic media. These results provide valuable insights for predicting equipment shutdown. Based on the theoretical outcomes, boundary-value problems concerning the natural vibrations of rectangular plane elements were formulated and successfully solved using the Trace Mode program [11-12].

By employing the decomposition method, a comprehensive examination of free oscillation problems in flat elements was conducted, encompassing various boundary value problems. The generalization of the decomposition method in dynamics was applied to solve these boundary value problems, resulting in exact solutions comparable to those derived through direct methods. This enables the testing of production plant components for wear, which can potentially lead to the shutdown of individual equipment or even entire manufacturing processes.

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