Software-algorithmic System for Locating and Processing Acoustic Emission

Miraziz Sagatov[1], *Kholidakhon* Komilova[2*], *Alijon* Dadaboev[3], *Yulduz* Akkulova[3], and *Bohodir* Mamadjanov[4]

[1]Tashkent State Technical University, 100095 Tashkent, Uzbekistan
[2]«Tashkent Institute of Irrigation and Agricultural Mechanization Engineers» National Research University, 100000 Tashkent, Uzbekistan
[3]Yangier branch of the Tashkent Institute of Chemical Technology, Yangier, Uzbekistan
[4]Andijan Machine-building Institute, 170100 Andijan, Uzbekistan

Abstract. Research on the problems of creating effective control and diagnostic systems allows us to single out the following areas: development of the theory and methods for diagnosing and predicting the strength and reliability of structures, theoretical and experimental studies of fracture processes and the corresponding changes in characteristics and parameters, i.e. carriers of information about the processes occurring in the material during destruction; creation of information-measuring systems designed to register and analyze the information necessary to resolve the issue of the state of the structure; development of software for measuring equipment, including not only the main programs for generating and processing incoming information, but auxiliary subroutines that provide information compression, increase the reliability of measurement results, defect recognition, decision making. The article is devoted to the methods of acoustic-emission control of metal structures and the development of a computerized system for its implementation. The basics of organizing a software-algorithmic system for locating and processing acoustic emission signals are considered, including: methods for discretizing models of sensors and acoustic emission signals, which make it possible to obtain computational schemes such as a digital filter that provide effective algorithmic implementation; description of fragments of an experimental software-algorithmic system for processing acoustic emission signals, illustrating the principle of constructing software tools in an arbitrarily chosen computing area, the structure of the software organization of computational processes for locating an acoustic emission signal, which ensure the construction of the corresponding subsystem of a computer complex for acoustic-emission control, both in single-antenna and in a multi-antenna version.

1. Introduction

One of the characteristic trends in the development of modern technology is the increase in the scale and responsibility of structures and structures, the accumulation of large energy reserves in them. These are long-distance gas pipelines, power plants, large bridges, hydraulic structures, large-scale mobile objects associated with the transportation of a large number of people, etc. Deviations in the operating modes or accidents of such structures can lead to serious consequences, therefore it is not enough to predict the reliability of structures based on the calculation conditions their strength and testing. Most structures have been in operation for many decades, and time can make significant corrections to theoretical calculations. An attempt to take them into account when designing due to ignorance of the actual operating conditions of the structure, as a rule, leads to an increase in safety factors. At the same time, the weight of structures increases significantly, which leads to the consumption of excess metal. From the foregoing, it becomes clear that the reliability of products must be ensured and strictly controlled both during manufacture and operation. For this purpose, it is necessary to create effective monitoring and diagnostic systems that can assess a critical situation in time and take the necessary measures to prevent an accident [1].
An analysis of research and development carried out on the problem under consideration makes it possible to single out the following main scientific areas: development of the theory and methods for diagnosing and predicting the strength and reliability of structures, theoretical and experimental studies of destruction processes and the

[*]Corresponding author: komilova591@mail.ru

corresponding changes in characteristics and parameters, i.e. carriers of information about the processes occurring in the material during destruction; creation of information-measuring systems intended for registration and analysis of information necessary to resolve the issue of the state of the structure; development of software for measuring equipment, including not only the main programs for generating and processing input information, but auxiliary subroutines that provide information compression, increase the reliability of measurement results, defect recognition, decision making, etc. [2].

One of the most promising methods of non-destructive testing is the method of acoustic emission (AE), or otherwise the method of AE - control. It is based on capturing sound signals emitted during plastic deformation of solid media and the development of defects. The AE method has a number of advantages, due to which the possibilities of non-destructive testing are expanded. [3, 4, 5, 6]

It should be noted that the level of research and development results achieved so far in the field of creating AE control systems does not yet allow to fully implement the latest achievements of science and technology in specific systems and algorithms, to close the chain from the input information to the acceptance algorithms. decisions about the state of objects. At present, the mode of vibrations and the frequency spectrum of AE signals, the characteristics of their propagation in materials have not been sufficiently studied, and systematic studies on the restoration of a highly distorted AE signal have not been carried out. This complicates the solution of the problem and requires further research. The available models of AE signals and their converters are in many cases simplified and do not fully reflect the real picture. Often, experiments are not reproducible enough. It should be taken into account that in order to solve the problem of the propagation of elastic waves in a specific structure, it is necessary to build a complex mathematical model [7-13].

It should also be noted that solving the problem of restoring the original AE signal shape allows us to reduce the further problem of fracture prediction to the problem of mechanics with its powerful physical and mathematical apparatus, apply existing computational mathematics tools and ensure the creation of the required control and prediction algorithms [14, 15, 16].

The study of acoustic signals emitted by areas of plastic deformation or zones of cracking of solids under mechanical loading and the use of AE signals for monitoring the state and predicting the strength of mechanical engineering objects form the conceptual basis of the AE method [17, 18, 19-25].

2. Research Methods

Control systems for metal structures based on AE signal processing, depending on their area of application, functional and communication capabilities, accuracy characteristics, can differ significantly in complexity and equipment composition. However, despite the differences, all such systems must satisfy some general requirements, namely:

1) to process incoming information in real time;
2) ensure long-term trouble-free operation in continuous operation;
3) have the means for documentary registration, large amounts of information in a form convenient for storage and subsequent machine processing;
4) to carry out operational analysis (express analysis) and display of measurement results;
5) maintain performance under various external influences (industrial noise, vibration);
6) operate at a significant distance of the equipment from the test object.

In addition to these requirements, when creating acoustic emission control systems, the principle of modularity should be observed, and the systems themselves should have a hierarchical structure. The hierarchical system of acoustic emission control, the structure of which is shown in Figure 1 contains sensors S that can be combined into groups (antennas), a device for preprocessing the results of measurements of location parameters (DPRM-V), a device for preprocessing the results of measurements of diagnostic parameters (DPRM-D), a specialized coordinate calculator (SCC) of AE sources, a specialized calculator of diagnostic parameters (SCDP), recorder (R), interface device (ID) with a computer for intermediate processing of diagnostic information (COMPUTER - I), computer for statistical processing and decision making (COMPUTER-D).

AE sensors are electroacoustic transducers and are one of the main elements of acoustic emission diagnostic systems. DPRM-V registers and converts into a code the time parameters of the AE signal, for example, the time of the beginning of the mode, the time of the end of the mode, the arrival time difference (RTD) modes for different sensors. A mode is a part of the AE electrical signal envelope at the output of the receiving transducer, located between two adjacent minimum values and having one maximum in this interval [20]. DPRM-D pre-amplifies, limits and converts the AE electrical signal into digital form. In DPRM-V and DPRM-D buffering (intermediate storage) of pre-processing results is also carried out.

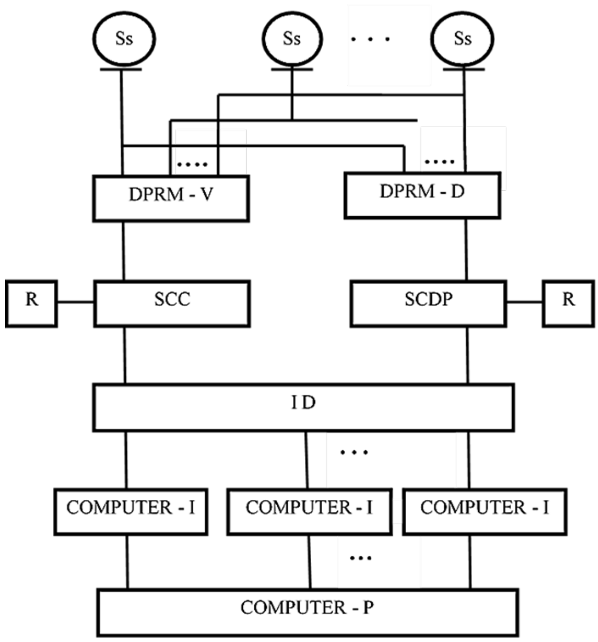

Fig. 1. Hierarchical system of acoustic emission control

The SCC of AE sources and SCDP carry out the calculation of the coordinates of sources and express analysis of AE signals in real time, as well as the operational registration and display of processing results on the recorders R. ID is designed to ensure the coordinated operation of SCC and SCDP in combination with upper-level computers and provides telecommunication access to them. Low power computers or blocks are used as intermediate processing computers, while more powerful computers are required for static processing and decision making.

Localization of sources allows separating information from different defects and performing spatial filtering, which means that the display of AE signals associated with a developing defect is concentrated at its location, while signals caused by extraneous, non-local phenomena, for example, noise, as a rule, either does not have a specific location, or is concentrated in pre-known places, due to the specific layout of the receivers and the features of the controlled design.

In this regard, the construction of SCC AE sources operating in real time is a priority task in the creation of systems for acoustic emission control and diagnostics.

DPRM is designed for detecting an AE signal and extracting information features from it by analog-digital processing for subsequent mathematical processing using a computer.

DPRM-V location signs, a variant of the structure of which is shown in fig. 2, contains $n \geq 3$ measurement channels, where n is the number of sensors Ss used in the AE control system, each of which consists of an amplifier A, a comparator C, a detector (Dr), a selector S, registers Rg. The DPRM-V also includes the control unit CU and the interface unit IU with the SCC. The connection of the DPRM with the sensors Ss is carried out via cables. Amplifier A is designed to amplify the signal coming from sensor Ss. Comparator C is designed to highlight the part of the AE signal that exceeds the discrimination level u_{Δ} , the choice u_{Δ} depends on the noise level during the control.

The detector Dr performs the formation of a pulse, the beginning of which coincides with the moment of registration of the next mode of the AE signal by the sensor, which has a duration equal to the duration of the mode. Selector S generates short pulses at times corresponding to the beginning and end of the mode, the beginning and end of the mode registered in the selected channel, etc. The registers Rg are used for intermediate storage of location features for their subsequent transmission through the IU interface unit for processing the SCC. The CU control unit is used to synchronize pre-treatment processes in a given mode, which is set from the control panel via external communication lines.

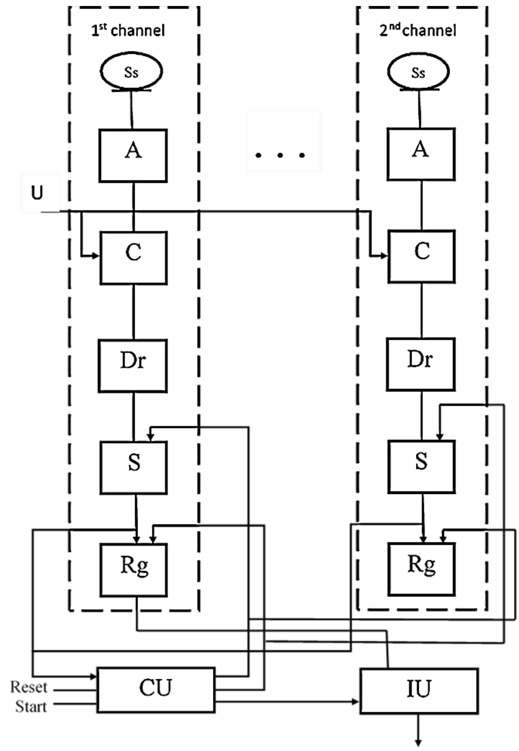

Fig. 2. Device for preliminary processing of results of measurement of location parameters (DPRM-V)

DPRM-V, whose structure is shown in Figure 2 works as follows. After the "Reset" signal arrives at the second input of the CU control unit, zero signals are set at its outputs, and all units of the device are set to their initial state. After the "Start" signal arrives at the third input of the control unit, current time codes begin to be continuously issued from its first output, which are fed to the second inputs of the Rg registers of each measurement channel $i(i = 1,...n)$. The AE signal recorded and converted by the sensor Ss, after amplification in the amplifier A, is fed to the input of the comparator C. In the comparator C, the part of the AE signal that exceeds the noise is isolated by limiting the lower limit to the voltage level u_{Δ}, the value of which depends on the operating conditions. At the same time, in each measurement channel $i(i = 1,...n)$, the time of appearance of the next mode of the AE signal will be different, depending on the location of the sensor Ss relative to the source of AE signals. At the output of the comparator C, "packages" of pulses of the level of a logical unit of digital elements are formed, the pulse repetition period in the "package" is equal to the oscillation period of the high-frequency filling of the resonant sensor Ss, and the duration of the "package" of pulses is equal to the duration of the mode at the level limited by the comparator C. The signal from the output comparator C is fed to the input of the detector Dr, in which the "packages" of pulses are converted into a continuous signal of the level of a logical unit, having a duration equal to the duration of the mode at the limiting level. Through the edge of the signal generated by the Dr detector, a short pulse of the beginning of the mode is generated in selector S, and a short pulse of the end of the mode is generated by the signal decay.

Depending on the operating mode set from the control panel through the control unit of the control unit, selector S can generate pulses of the beginning and end of the mode registered in any other selected measurement channel, an impulse corresponding to the maximum value of the mode duration (used when analyzing the reliability of time intervals). According to the pulses coming from the output of the selector S to the first inputs of the register Rg and the control unit CU, control signals are generated for writing to the register Rg, in which, depending on the mode of operation, either the start / end times of the mode, or the RTD for the selected sensors, or the maximum RTD in the corresponding channel. According to the signal coming from the third output of the control unit CU to the control input of the IU interface unit, the information recorded in the registers Rg of the measuring channels is transmitted for further processing through the IU interface unit.

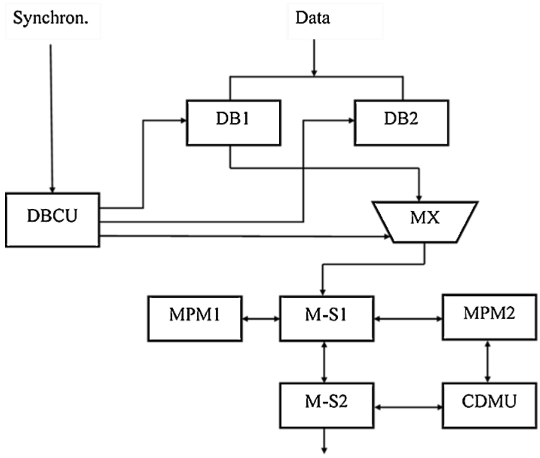

Fig. 3. The structure of the SCC, which implements the single-antenna processing algorithm

Calculation of the coordinates of AE sources is carried out by the SCC. The structure of the SCC, which implements the single-antenna processing algorithm, is shown in Figure 3. The SCC contains a control unit CU for data buffers DB1 and DB2, microprocessor modules MPM1, MPM2, an MX switch, multiplexers-selectors M-S1 and M-S2, a common data memory unit CDMU. Two data buffers DB1 and DB2 are introduced to increase the throughput of the SCC and alternately operate in write-read modes. While the data from one buffer is being processed, the other one is being filled with new data.

SCC works as follows. According to the synchronization signal arriving at the first input of the data buffer control unit DBCU, from the first output of the DBCU control unit, signals for setting the operating mode are issued to the control inputs of the data buffers DB1 and DB2. Moreover, if the "Write" mode is set for the DB1 buffer, then the "Read" mode is set for the DB2 buffer and vice versa. According to the readiness signals of the microprocessor modules MPM1 and MPM2, arriving at the second and third inputs of the control unit DBCU, at the second output of the control unit DBCU, a control signal for the MX switch is generated, which connects the corresponding data buffer (DB1 or DB2) to the input bus of the M-S1 multiplexer-selector , which can carry out data transmission on four bidirectional buses with multiplexing and selection under the control of microprocessor units.

So, for example, according to the readiness signal of microprocessors, data is transferred from the corresponding buffer to the common memory of the CDMU, and according to the last processing command, information is issued from the data memory of the CDMU through M-S2 for further processing or display. In specialized devices, processing algorithms, as a rule, do not change. Therefore, programs can be written to ROM or PROM. To provide some functional flexibility of a specialized SCC, it is possible to ensure the interchangeability of the program memory through the use of appropriate structural elements for fixing ROM chips (PROM).

The use of a common data memory of the CDMU requires taking into account possible conflict situations that arise during the operation of microprocessor systems, such as, for example, simultaneous access to memory, invalid modification of the contents of memory, etc. avoid conflicts. The expansion and complication of tasks solved on a specialized multiprocessor system with a shared data memory puts forward the requirements for increasing its flexibility. In this case, the problem of unresolvable conflicts may arise. To avoid this, it is necessary to introduce a priority system for servicing requests, blocking memory in case of unauthorized access, etc., which leads to an increase in hardware and can significantly reduce the efficiency of the system as a whole due to waiting for permission to access memory. These shortcomings are devoid of a multiprocessor system in which each microprocessor module MPM has its own (local) data memory. In fact, such a module can be considered as a stand-alone processor equipped with means for high-speed data exchange and synchronization of operation with other similar processors. The block diagram of such block is shown in Figure 3.

3. Results and Discussion

Calculation of the power of information flows according to the AE methodology. The processing of acoustic emission signals in order to determine the location of a defect before its identification requires a large amount of computational work, which is associated both with the complexity of the processing algorithms and the amount of information being processed.

The development of an appropriate control system (CS) requires a preliminary assessment of the power of the processed information flows that arise when using the AE technique. The main purpose of such assessments is to substantiate the structure and composition of the CS.

In the process of testing a product according to the AE method, the main characteristics that determine the amount of information processed are the following:

- f_{fl} – the average frequency of outbreaks of AE acts;
- Ψ_{fl} – average flash duration;
- *N* – the number of modes in one burst;
- Γ_m – the duration of the mode;
- f_γ – the upper frequency of the AE signal (in the case of a broadband sensor) or the resonant frequency of the AE sensor (for resonant type sensors);
- *n* – the number of ADC samples for the period determined by the frequency f_γ of the AE signals;
- T_{test} – product testing time;
- K – the number of channels of the AE signal processing system (the number of "fours" of multi-element acoustic antennas).

The presence of the indicated characteristics of AE signals that arise during testing makes it possible in principle to organize the solution of location problems, as well as the identification of defects through appropriate processing.

The presence of two main tasks of processing AE signals - identification location - determines two groups of processing algorithms, while algorithms for solving the location problem are characterized by a small amount of processed information and the requirement for fast processing, due to the need to obtain location results in real time.

When solving the location problem, we obtain the characteristic of the information flow in the form of an upper estimate for the total number of data processing operations of one mode. Consider the main subtasks of the location problem.

I. Determining the angle of direction to the AE signal source (wave front - flat)

$$\varphi = arctg\frac{t'_{4.1} - t'_{2.1}}{t'_{3.1} - t'_{1.1}} + \Delta\varphi$$

where

$$\Delta\varphi = \begin{cases} 0^0, when\ m = 1 \\ 90^0, when\ m = 2 \\ 180^0, when\ m = 3 \\ 270^0, when\ m = 4 \end{cases}$$

m - the serial number of the sensor in the antenna that received the signal first.

$$\left.\begin{matrix} t'_{j,1} = t_{j-m+1, when\ j \geq m} \\ t'_{j,1} = t_{5-m+1, when\ j < m} \end{matrix}\right\} or \begin{cases} circular\ shift\ of \\ T_1(4)\ array \\ to\ the\ left\ by\ (m-1) element \end{cases}$$

$$(m-1)max = 3$$
$$\min = 0.$$

$t_{j,i}$ - registration time j - with type i wave sensor

$$\begin{pmatrix} i = 1 - \ longitudinal\ wave \\ i = 2 - shear\ wave \end{pmatrix}$$

II. Determining the distance to the AE source by the difference in the type of waves (the wave front is flat).

$$v_i = \frac{B}{\sqrt{(t'_{4,i} - t'_{2,i})^2 + (t'_{2,i} - t'_{1,i})^2}}; B = b\sqrt{2},$$

B – base of a multi-element acoustic antenna.

III. Determining the distance to the AE source by the triangulation method (the wave front is flat).

$$T_1 = \frac{b}{(t_3 - t_4) - (t_2 - t_1)} \times$$
$$\times \sqrt{\frac{[(t_3 - t_1)((t_2 - t_1)(t_2 - t_3) - (t_2 - t_1)(t_3 - t_4))]^2 + [(t_4 - t_2)((t_2 - t_1)(t_3 - t_4) - (t_4 - t_1)(t_2 - t_3) - (t_3 - t_1)]^2}{(t_3 - t_4) - (t_2 - t_1)}}$$

here $t_j = t_{j,1}$.

As can be seen from the above descriptions of the stages, the solution of the location problem, the amount of initial data is:

- with a combination of A and B - N - the number of the sensor that received the signal first; B - antenna base; $T_1(4)$ - array of times of longitudinal wave registration by antenna sensors;
- with a combination of A and B (as well as A, B and C - $T_2(4)$ - an array of shear wave registration times by antenna sensors.

The obtained estimates of the characteristics of information flows in solving the problems of location and identification of defects by analyzing acoustic emission signals make it possible to constructively formulate certain requirements for computing facilities.

4. Conclusions

On the basis of the formulated transformations to the functioning and composition of the computerized acoustic emission control system, its structure of a hierarchical type is proposed, the creation of which implies the use of the principle of modularity. The structure provides for the construction of a control system in the form of software-algorithmic tools implemented on a serial computer, or in software and hardware form using special processors. To determine the resource of the used computer (hardware) part of the monitoring system, a method is proposed for calculating the power of information flows that display computer analysis of AE signals.

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