INTEGRATED DIAGNOSTIC MONITORING OF HAZARDOUS PRODUCTION FACILITIES

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In modern economic conditions, reduction of costs for technological equipment operation and rectification of accident consequences is one of the main methods to improve profitability of enterprises of continuous production cycle in gas-and-oil, petrochemical and chemical branches of industry. Integrated sets of measures are developed and applied with the main purpose to provide in maximal degree the efficient and safety operation of equipment.

One of such measures provides installation of the integrated diagnostic monitoring systems at the most responsible facilities. It resolves the following tasks:

- Timely detection of structural defects with high completeness of testing;
- Acquisition and storage of data on technical diagnostics and prediction of changes in the technical state of structure in the course of time;
- Automation of technical diagnostics and reduction of the human factor role during evaluation of diagnostic results.

Determinant attributes for the necessity of application of the diagnostic monitoring are as follows:

- Structure destruction can lead to significant material and ecological losses and even to human losses;
- There is no access to perform periodic inspection and testing of structure or such access is difficult;
- Considerable volume of preparatory work and work related with periodic facility testing requires partial or complete stoppage of such a facility;
- Structure is of low operational survivability;
- Runtime between repairs of equipment must be increased;
- Requirements of regulative documents.

1. Conception of integrated diagnostic and corrosion monitoring

The conception of monitoring systems' construction involves incorporation of a wide range of the following components into a united system:

- Tracking the operational characteristics of the technological process;
- Monitoring the factors that influence the object's damageability (on the basis of which the methods of the nondestructive examination are selected);
- Monitoring by the means of methods of nondestructive examination;
- Warning personnel on the problems and instructions on the implementation of the activities that eliminate those problems.

Integrated diagnostic monitoring includes the following basic methods:

- Method of acoustic emission;

- Tension-stress state meters;
- Corrosion ratio meters;
- Vibration-based diagnostics;
- Ultrasonic method;
- Displacement meters and dipmeters;
- Temperature fields measurement;
- Devices for the estimation and analysis, in accordance with the measurements' results.

As a rule, acoustic emission is the main method implemented in the systems of stable objects' monitoring.

Presently, method of acoustic emission is one of the most sensitive methods, and it detects the following types of defects: cracks, microcracks, all types of corrosion damages, leakages; detects the zones of tension-stress state. Besides all the above listed, it is worth mentioning that work on investigation of new possibilities of the present method (evaluation of material's degradation and pitting corrosion rate) is actively implemented.

Besides all those advantages it is worth mentioning that this method is integral, that means that the surface of the whole object is being monitored, while under the periodical monitoring attention is paid to separate elements of the structure.

Ordinary periodical monitoring requires certain conditions for the implementation of the method – the change of the objects' operation modes during the monitoring (the measuring of pressure, temperature, or mechanical effect on the object that causes the increase of the existing defects). In the monitoring mode it becomes unnecessary because tracking is being performed within 24 hours and the incoming signals from defects appear because of the operational loads and the external actions.

Despite all the advantages of the acoustic emission method, the other monitoring methods mentioned above need to be implemented to provide a more accurate and objective evaluation of the object's condition.

1.1. Construction of the monitoring system

The classification of monitoring according operation types is as follows:

- Integrated monitoring;
- Permanent monitoring;
- Periodical monitoring;
- One of the methods of non-destructive examination.

The integrated monitoring system shall provide complete information on the object's condition and have the calculation and analysis program to estimate the monitored object's condition.

Permanent monitoring is preformed uninterruptedly within 24 hours.

Periodical monitoring is performed when the sensors are installed on the object and their readings are periodically taken and analyzed.

It is often reasonable to use only one monitoring method, for example tracking of the existing defect up to its critical value.

1.2. Operating principle of monitoring systems

Key point of the continuous monitoring consists in automatic mode which the system functions in during the whole period of operation. Diagnostic data enter continuously into modules where they are converted into digital form, pre-processed and then are transmitted to the central computer for final processing and presentation in real-time mode on a display in the control room. Display contains the main informational windows to output the following: monitored facility mnemonic diagram indicating locations of measuring and controlled devices, locations of defects (when they occur), values of measured parameters, detailed protocol of monitoring system and personnel actions, forecast of the current technical state of facility and recommendations on further operation.

The slide contains the structural diagram of the integrated diagnostic monitoring system that includes the following:

- Data collection and data processing modules
- Concentrators
- Marshalling box of galvanic isolation
- Central computer
- Display panel

The next slide contains functional diagram of the integrated diagnostic monitoring system.

Software of the integrated diagnostic monitoring system implements the following tasks:

- Reception and processing of the information coming from the hardware of the integrated diagnostic monitoring system to the central computer;
- Automatic saving of primary data and results of the analysis using a special recording device with the ability of data reading for their additional processing on a remote terminal;
- Visualization of the incoming information and the results of its analysis, displaying the objects' current condition on the screen of the central computer and the display panel;
- Giving alarm sound messages, light indication messages and recommendations on personnel actions in case off-nominal situations with different hazard levels. Generation and transmission of the monitoring signals to the actuated equipment;
- Consolidated mutual multifactor analysis of the received diagnostic data with the purpose of defining the current technical condition of the objects and detecting the trends of their operation.

Evaluation of the object's technical condition and issuing recommendations on its operation is being implemented by the expert system that includes the following elements:

- Knowledge base, algorithms for the classification of the object's conditions in accordance with certain criteria.

- Database, structural diagrams of storage data on the object, operational practices, influence of supplementary factors and deviations of the operational parameters of the process mode.
- Block for making decisions on the basis of the object's classified condition forms recommendations on its operation.

When the data on the object's damages or off-nominal situations come into the system the expert system performs operative evaluation of the object's current technical condition and forms recommendations on its further usage, for example:

- To continue the operation with fixed operating parameters.
- To perform additional examination of the defected area.
- To track the development of the defect and to be ready for the emergency object shutdown.
- To reduce the operational pressure or operational temperature.
- To perform the emergency object shutdown.

2. Planning of the monitoring

2.1. Main stages of planning

2.1.1. The planning of the monitoring complies with the preliminary stage of the development of the project for carrying-out the monitoring of the technical condition of hazardous production facilities, within the framework of which the following is implemented:

- Determination of the failure risk value in accordance with its two components (accident rate –damage);
- Determination of the types and mechanisms of the technical condition change;
- Determination of the monitoring type and equipment for the technical condition monitoring according to the possible mechanisms of the technical condition change;
- Feasibility for the expedience of the implementation of technical condition monitoring to reduce failure risk indicators;
- Defining the methods and mechanisms of registration and processing of monitoring results;
- Feasibility study for the expedience of the technical condition monitoring project.

2.1.2. Expedience of the implementation of the monitoring of the object's technical condition is substantiated by the following:

- Necessity of uninterrupted control of the key technical condition parameters whose change may not be detected under the periodical monitoring;
- Necessity to control separate sections of the structure inaccessible for periodical diagnostics, or the whole structure;

- High level of responsibility for hazardous production facilities when the system of monitoring of one or several technical condition parameters is added to other types of control.

2.1.3. Expedience of carrying out the monitoring is implemented by the comparison of the object's failure indicators with the installation of monitoring tools or without them.

2.1.4. Feasibility study of the technical condition monitoring efficiency is based on the comparison of economical efficiency indicators of the object's operation in accordance with two options: with monitoring tools or without them.

2.1.5. As a result of planning the monitoring of the object's technical condition the following must be provided:

- Feasibility study for necessity to control technical condition parameters (parameter) in the monitoring mode;
- Determination of technical condition parameters controlled in the process of monitoring, on the basis of types and mechanisms of the technical condition change;
- Determination of equipment scope, places for installation, service personnel, providing the maximum efficiency of the technical condition control in the monitoring mode;
- Form of registration and processing of monitoring data, the expert system of decision-taking in accordance with monitoring data;
- Cost evaluation for technical condition monitoring;
- Feasibility of economic efficiency of monitoring.

2.2. Classification of monitoring systems

2.2.1. The classification of monitoring systems used in the present document is based on resource loss mechanisms and ability of the applied physical method of control to remotely detect the damaged areas in the elements of the structure of hazardous production facilities.

2.2.2. The classification of the monitoring systems based on the mechanisms of changing technical condition parameters and technological parameters includes the following:

- Diagnostic monitoring systems – detection of developing defects and leakages by means of the acoustic emission method;
- Corrosion monitoring systems – the control of corrosion rate, hydrogen absorption processes, the chemical composition of the media;
- Parametric monitoring systems – the control of the object's parameters not related directly to the defects' development and corrosive wear (leakages' control by the pressure drop method, the change of the object's geometry and location, the mechanical stress, technological processes' parameters).

2.2.3. The classification of monitoring systems based on mechanisms of changing the technical condition parameters and the technological parameters includes the following:

- Diagnostic monitoring systems – detection and determination of operational defects' coordinates;
- Corrosion monitoring systems – detection of corroded areas and evaluation of corrosion rate and chemical composition of the media;
- Parametric monitoring systems – control of the object's parameters not related directly to the defects' development and corrosive wear but preceding the occurrence of hazardous defects of the structure (leakages' control by the pressure drop method, change of the object's geometry and location, technological processes' parameters).
- Integrated monitoring systems combine all the abilities of the diagnostic, corrosion and parametric monitoring systems.

2.2.4. Classification of monitoring systems based on the ability of remote detection of defects includes the following:

- Local monitoring systems that detect the defects in the measurement place (in the place of installation of measuring devices);
- Integral monitoring systems that allow to detect the defects located outside the measurement place (outside the place of installation of measuring devices).

2.2.5. A possibility of remote detection of defects allows to monitor extended areas of hazardous production facilities and depends on the physical method implemented in the monitoring devices. The description of diagnostic methods in accordance with measured parameters and evaluation of the method's ability to perform remote control is described in Annex 3.

2.3. Feasibility study.

2.3.1. The feasibility study of economic efficiency is implemented under the planning of carrying-out the monitoring of the technical condition of hazardous production facilities.

2.3.2. The basis for feasibility study of economic efficiency is the technical and economic estimation of two options of the object's operation: when the object is equipped with the technical condition monitoring system and when it is not equipped with additional devices.

2.3.3. The basic indicators defining the expedience of the implementation of the technical condition monitoring system and products' cost reduction are as follows:

- Projected reduction of failure risk value;
- Reduction of products' prime cost due to the economic effect under technical maintenance.

2.3.4. The efficiency of the monitoring system implementation is evaluated on the ratio of the value of the reduction of the total financial loss caused by possible accidents happened within the forecasted period of operation of the object equipped with monitoring system, to the value of its implementation and maintenance costs within the same period.

2.3.5. In case of insufficient economic efficiency the repeated development of monitoring system is implemented for receiving economic indicators acceptable for the Customer, upon condition that the level of the object's safety characterized by the risk indicator does not reduce.

2.3.6. Evaluation of failure risk reduction under the implementation of the monitoring system

2.3.6.1. The risk of the failure of hazardous production facilities**,** R_0 without the implementation of the monitoring system is calculated by multiplying the failure frequency per annum, Γ_0 by the average total value of the financial loss caused by one failure W_0:

$$R_0 = \Gamma_0 \cdot W_0 \ (2.1.)$$

2.3.6.2. The failure risk R (2.2.) after the installation of the monitoring system is calculated multiplying the failure frequency Γ by the average total value of the financial loss caused with one failure W

$$R = \Gamma \cdot W \ (2.3.)$$

$$\Gamma = \left(1 - \frac{\gamma}{100}\right) \cdot \Gamma_0^1 \cdot W + \Gamma_0^2 \cdot W \ (2.4.)$$

$$\Gamma_0 = \Gamma_0^1 + \Gamma_0^2 \ (2.5.)$$

where γ % is the probability of the failure detection by the monitoring system that depends on its operation time; Γ_0^1 is the number of failures detected by the monitoring system; Γ_0^2 is the number of structure failures not provided by the monitoring system.

2.3.6.3. Efficiency of the monitoring system depends on the following:

- Equipping the system with devices allowing to control active and indirect factors of the resource loss, causing failures;
- The quality of the monitoring system providing high level of defects' and damages' detectability, and supporting the required operational capability in the process of operation.

2.3.6.4. Expedience of the monitoring system implementation is calculated by the reduction of the risk indicator within the period of further operation

$$R(t) \prec R_0 \ (2.6.)$$

where t is the time after the monitoring system implementation, t<T; T is estimated

time of the object's operation (resource) after the monitoring system implementation.

2.3.7. Costs of the monitoring system implementation

2.3.7.1. The main costs of the monitoring system implementation include the following:

- Purchase and installation of the monitoring system on the object;
- Organization of the information control room for the work with monitoring data;
- Purchase of appropriate computer equipment for the information center;
- Recruiting of specialists for the monitoring system maintenance.

2.3.7.2. Additional costs depend on the correlation between the guarantee service life of the monitoring system equipment and the designed service life of the object T equipped with this system.

2.3.7.3. In case if the service life of the monitoring system equipment does not exceed the designed service life of the object, it is required to take into consideration the depreciation costs of the monitoring system equipment.

2.3.8. Estimation of the economic efficiency of the monitoring system

The indicators of comparative economic efficiency of the capital investments into the installation of monitoring system in accordance with different reviewed options may be evaluated taking three parameters into consideration.

2.3.8.1. Estimation of the payback period
The payback period of additional capital investments

$$T_{ok.c} = \frac{(K_2 - K_1)}{(C_1 - C_2)} \quad (2.7.)$$

where $T_{ok.c}$ is the payback period of additional capital investments defined by saving on the prime cost, K_1 and K_2 are the capital investments for the options when the object is equipped and not equipped with the monitoring system (under estimation the financial loss caused by a possible accident risk is taken into consideration); C_1 и C_2 is the prime cost of production per annum according to the compared options. The value $T_{ok.c}$ is compared with the regulatory value of the enterprise $T_{ok.c\ n}$ accepted at the enterprise. If $T_{ok.c} < T_{ok.c\ n}$, additional capital investments are efficient.

2.3.8.2. Estimation of additional capital investments' efficiency
Comparative efficiency of capital investments:

$$E_{.c} = \frac{(C_1 - C_2)}{(K_2 - K_1)} \quad (2.8.)$$

The estimated value E_c is compared with the regulatory value E that is the regulatory value of capital investments' efficiency accepted at the enterprise. If $E_c > E$, then the additional capital investments are efficient.

2.3.8.3. If several equal options are available, the most efficient option is selected in accordance with the minimum of reduced costs:

$$З_i = C_i + EK_i = \min \qquad (2.9.)$$

where $З_i$ are reduced costs for every option;
C_i are operating costs (prime cost) for the same option;
K_i are capital investments for the same option;
E is regulatory value of capital investments' efficiency.

The slides contain several examples of the implemented integrated diagnostic monitoring systems.