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Condition monitoring of cylinders between their examinations

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Introduction

In different industrial branches, thin-walled metallic vessels – cylinders are widely used to store fluids and gas. In general, cylinders can be classified into groups according to the substance stored in them and its characteristics (see Fig. 1). It is obvious that the more dangerous or deleterious substance is stored in the cylinder, the higher requirements are raised for its technical state.

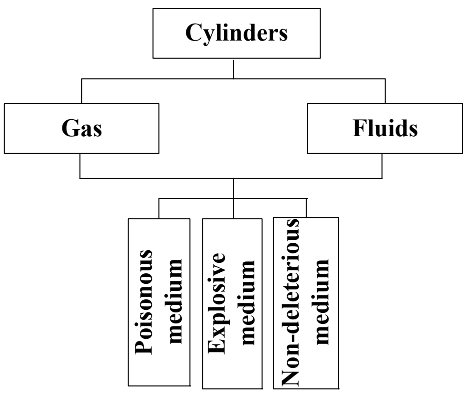

Fig.1. **Cylinder classification**

This induced us to examine a current situation of a cylinder technical diagnostics and control and try to suggest new possibilities for its improvement.

Problem formulation

The out analysis carried showed that there is an insufficient number of cylinder technical state diagnostics and control procedures during cylinder exploitation between two examinations or there are no procedures at all. After the cylinder is manufactured, its technical state is determined and evaluated by the manufacturer who, considering the purpose of the cylinder, indicates the term after which the cylinder must be repeatedly checked. For example, in case of carbonic acid cylinders, a verification period is 5 years. Suppose, we have two cylinders manufactured at the same time and filled with carbonic acid. One was used 1000 times between two examinations, another – only once. Is their technical condition the same? On the other hand, will the cylinder stored in a deleterious environment and improperly transported last till its indicated verification time? In addition, we must take into account that an enterprise receives the cylinder for filling with the parameters of its technical state (verification date, weight, volume, etc.); however, it has rarely the sufficient information about the history of cylinder exploitation. The answers to these questions form the essence of the problem, i.e., how to evaluate the technical state of the cylinder and a residual resource of the cylinder during the period of time between examinations. There we can separate two aspects of the condition monitoring problem of cylinders:

1. A current express analysis and suitability evaluation of the technical state of the cylinder between their examinations;
2. Forecasting and evaluation of the residual resource suitability of the technical state of the cylinder between their examinations.

In the first case, we must find a suitable non-destructive testing method, in the second, we must develop an evaluation methodics.

Research method

Considering the practical use, we have made the first step towards the solution of the problem, executing the search of monitoring possibilities of JSC "Achema" (Lithuania) carbonic acid cylinders. The enterprise annually fills with carbonic acid more than 60 thousand of cylinders, which are manufactured in different years (see Fig. 2).

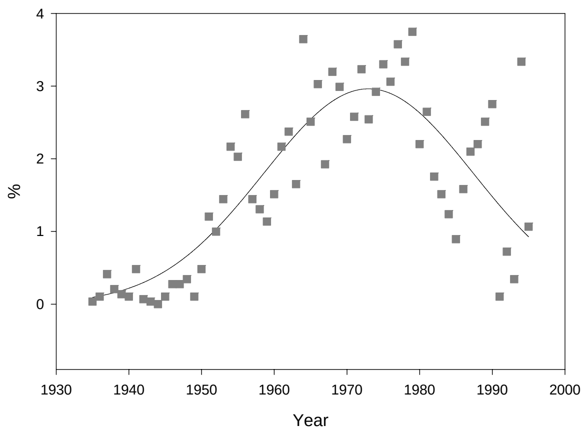

Fig. 2. **Distribution of cylinders by manufacturing years**

As we see, the exploitation period of the cylinders, received for filling, considerably varies and their specific weight y may be calculated by percent in the annual program according to the year of the cylinder manufacturing x:

$$y = ae^{-0{,}5\left(\frac{x-x_0}{b}\right)^2}, \qquad (1)$$

where a=2,9621; b=14,4384; x_0=1972,97.

Technological process analysis of filling of JSC "Achema" carbonic acid cylinders showed that monitoring procedures can be carried out at a hydraulic test of the cylinders as well as after filling them with carbonic acid. In addition, after performance of a suitability study of different non-destructive testing methods, we found out that the method of acoustic emission (AE) is the most suitable, which is known for its integrity in defect evaluation. It means that the main diagnostics and control problems of the cylinders and their solutions depend on the received integrated AE information and its evaluation. Considering this, the following tasks are formulated:

1. AE examination of the cylinders during the hydraulic test process and assesment of their technical state;
2. AE examination of the cylinders filled with carbonic acid and assesment of their technical state;
3. Development of residual resource evaluation methodic of the cylinders.

Experimental research

For solution of the first task, we proposed a diagnostics scheme of the cylinder at the hydraulic test (Fig. 2) and carried out AE examination, using the standard AE measurement procedures.

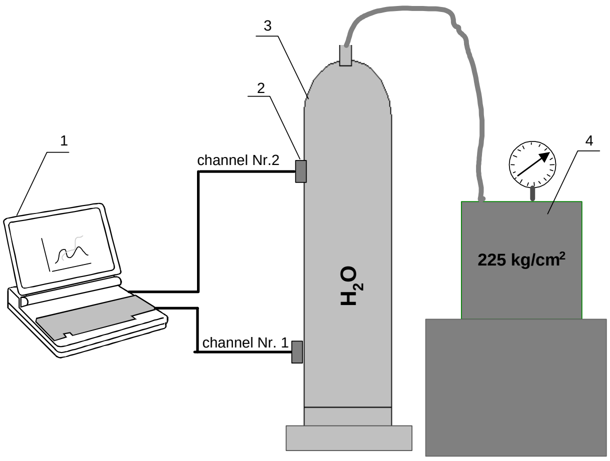

Fig. 2. **A diagnostics scheme of the cylinder at the hydraulic test: 1 – AE system Aline 32D; 2 – transducer GT200 with a magnetic carrier; 3 – cylinder; 4 – hydraulic test stand**

The experimental investigation was executed as follows. First of all, AE transducers were fixed at the specifically prepared spots of the cylinder surface (roughness Ra<6,3 μm) with the help of a magnetic carrier and their calibration was performed in accordance with a standard artificial HSU-NIELSEN excitation. During the hydraulic test of the cylinder, i.e. increasing water pressure in the cylinder up to P_B=225 kg/cm^2, all AE information was stored in the computer. In addition, in order to separate plastic deformations of the cylinder metal from a developing possible defect, using Keiser effect [1], after the primary increase of water pressure in the cylinder up to P_B and maintaining it for 10 minutes, the pressure was reduced in half and then increased again up to the limiting pressure, simultaneously registering AE parameters.

Some of the experimental results are given in the charts Fig. 3-5.

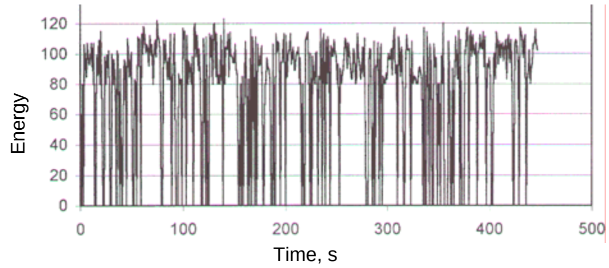

Fig. 3.

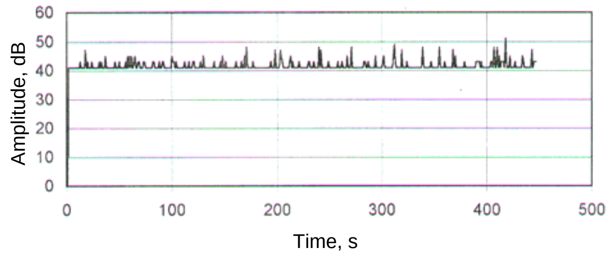

Fig. 4.

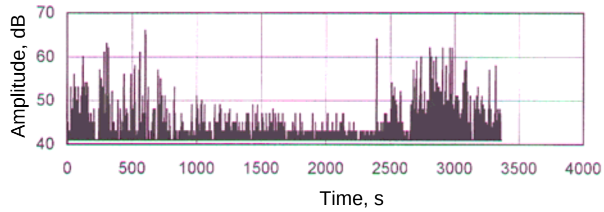

Fig. 5.

For solution of the second task, we made up a testing scheme of two cylinders filled with carbonic acid (Fig. 6) and selected two cylinders filled with carbonic acid for experimental investigation. Analogically as in the first experiment, we fixed transducers, performed their calibration and registered the received AE information in the computer. Some of the experiment results are presented in the Fig. 7 and 8.

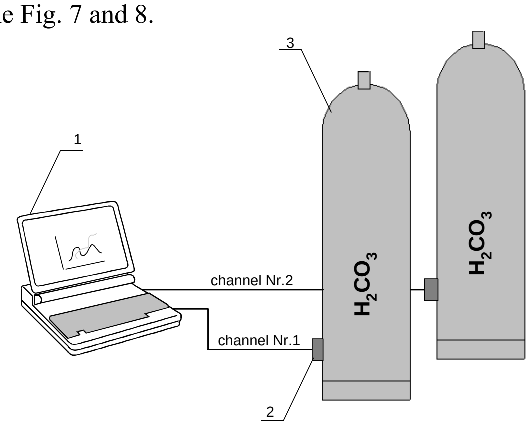

Fig. 6. **A control scheme of two cylinders filled with carbonic acid: 1 – AE system Aline 32D, 2 – transducer GT200 with a magnetic carrier, 3 – cylinder**

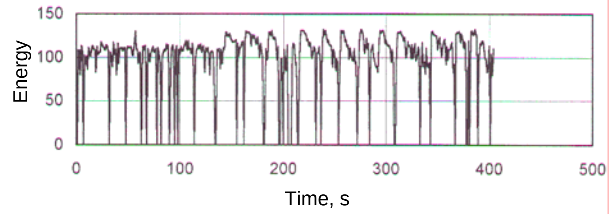

Fig. 7.

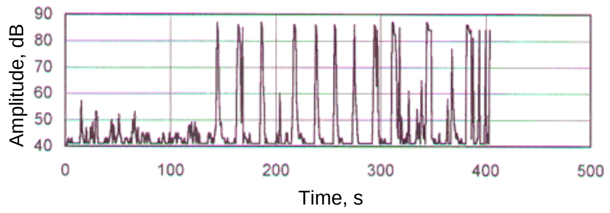

Fig. 8.

Analyzing the received results in general, we can state that no deleterious AE sources were registered in the range of the cylinders tested. Considering that the analysis was carried out according to the standard AE parameters, we may suggest some evaluation criteria of a technical state used in this field (see Table 1).

Theoretical analysis

For solution of the third task, we analyze relationship between a metal fatigue process and AE. In general, complexity of the metal fatigue effect leads towards diversity of AE sources, i.e. AE can be generated:

1. when a break appears and develops, a zone of plastic deformation expands;
2. when the length (area) of the developing break expands;
3. due to interfriction of the edges of the developing break.

Considering this, we can assume that the integrated AE signal N consists of components N_i from each factor of the metal fatigue process. Therefore, it is important to find a possibility to evaluate the influence of these factors in the integrated AE signal, which we may express as follows:

$$N = f\left(\sum N_i\right). \qquad (2)$$

It is obvious that it may be implemented only by an experimental method and the obtained expressions are empirical. As it is known [2], velocity of break development is defined as follows:

$$l' = \frac{dl}{dn}, \qquad (3)$$

where l is the length of the break, n is the number of load cycles, in our case, it may be a number of filling the cylinder with carbonic acid.

Velocity of break development in the cylinder wall can be empirically related to the coefficient $\overline{K}$ of the tension intensity change by a gradual expression:

$$l' = C\overline{K}^{q}, \qquad (4)$$

where

$$K = f\left(\sigma, l, x^*, y^*, z^*\right),$$

$$\overline{K} = K_{\max} - K_{\min},$$

C, q are the coefficients of the metal, σ – nominal tensions; x^*, y^*, z^* – relative values of geometric parameters of the break and the cylinder.

Then, due to the break development, AE component can be expressed as follows:

$$N_1 = f\left(\overline{K}^{n}\right). \qquad (5)$$

Due to the development of the plastic deformation, AE component N_2 can be expressed as follows [3]:

$$N_2 = f\left(V_p\right), \qquad (6)$$

where V_p is the current substance volume in the plastic deformation.

As it is known [4], due to a small increase of the break length, a released energy U is proportional to an amplitude A_p square of a peak AE signal, then we can state that

$$N_3 = f\left(A_p\right) = f\left(U^{\frac{1}{2}}\right). \qquad (7)$$

The influence of AE component, due to the interfriction of the break edges, in the integrated AE signal is the least, as this process is indirectly related to the velocity of break development and therefore, creates a weak background. Thus, in order to evaluate a residual resource of the cylinder, we must carry out the experimental research, determine levels of critical parameters and receive empirical expressions 4, 5, 6 and 7, with the help of which we are able to separate the integrated AE signal into components and evaluated them. As a complex criterion to evaluate durability of the cylinder, we suggest to use the value of the angle β (see Fig. 9) between the linear tendency energy change of the integrated AE signal, calculated using the algorithm [5].

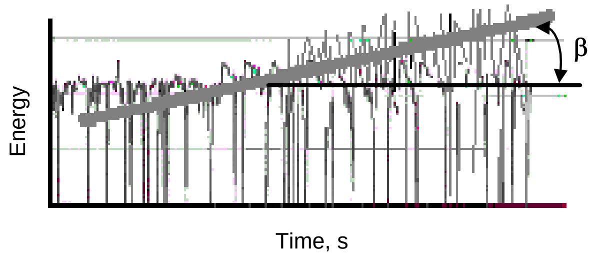

Fig. 9.

In general, this complex criterion β_i would be restricted:

$$0 < \beta_i < \beta_{kr.} \qquad (8)$$

Here β_{kr} is the critical value of the criterion.

In a concrete case of cylinder monitoring, the critical value of the complex criterion may be determined in the experimental way, additionally considering the substance characteristics $\varphi(m)$ and the thickness of the cylinder wall b, i.e. determining dependence:

$$\beta_{kr.} = f\left[\varphi(m), b\right]. \qquad (9)$$

This would set the preconditions, after measuring the integrated AE energy in the tested cylinder, to select a complex critical parameter β^*_{kr} according to the Eq. 9, and, considering the exploitation time of the cylinder, to evaluate its residual operating resource.

Table 1.

No	Evaluation criteria	Value	Significance
1.	Quantity of AE events registration during a load confinement period	No more than 10 pulses per one transducer, starting calculating from the second minute of load confinement	AE occurred during the load confinement shows the developing break defect
2.	Felicity ratio F>0,85	During the repeated load, there are no AE pulses up to 85% of a previous load pressure	The occurred AE shows a considerable defect
3.	Local - dynamic	Paragraph 1.3 from AE control organization and execution rules of vessels, apparatus, boilers and technological pipe network	Plastic deformation or defect development is identified
4.	AE event energy	No increase of AE event energy during the test	Increase of AE event energy shows a considerable defect
5.	AE activity	No increase of AE intensity during the test	Increase of AE activity shows the expansion of the defect zone

Conclusions

The research carried out during the hydraulic test of the cylinders and after filling them with carbonic acid showed that the received AE information is sufficient for a current evaluation of the technical state of the cylinders and the standard criteria presented in Table 1 may be used for the condition monitoring.

The carried out investigation and analysis in the determination field of a residual resource of the cylinder showed that solution of this task is complex and requires an additional research. However, using the suggested methodics, it is possible to forecast the residual resource of the exploited cylinder between examinations.

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Balionų techninės būklės monitoringas laikotarpiu tarp bandymų

Reziumė

Įvairiose pramonės šakose skysčiai ir dujos daugiausia laikomi plonasieniuose metalo induose – balionuose. Situacijos analizė parodė, kad nepakanka ar visai nėra balionų techninės būklės diagnostikos ir kontrolės procedūrų baliono eksploatacijos laikotarpiu tarp bandymų. Tai paskatino mus patyrinėti esamą balionų techninės diagnostikos ir kontrolės situaciją bei pabandyti pasiūlyti naujų būdų jai pagerinti. Problemai spręsti, t.y., baliono techninei būklei ir liekamajam resursui laikotarpiu tarp bandymų nustatyti sprendžiami šie uždaviniai:

1. baliono techninės būklės laikotarpiu tarp bandymų einamoji ekspresanalizė ir tinkamumo vertinimas;
2. baliono techninės būklės laikotarpiu tarp bandymų prognozavimas ir liekamojo resurso vertinimas.

Pirmuoju atveju pasiūlytas tinkamas neardančiosios kontrolės metodas, o antruoju –vertinimo metodikos kūrimo koncepcija.

Straipsnyje pateikiami kai kurie šios problemos sprendimo rezultatai, gauti atlikus AB”Achema” angliarūgštės balionų monitoringo galimybių analizę. Pasiūlyta taikyti akustinės spinduliuotės (AS) metodą ir tuo tikslu atlikti eksperimentiniai balionų AS tyrimai hidraulinio bandymo procese taip pat angliarūgštės pripildytų balionų AS tyrimai.

Atlikti baliono techninės būklės laikotarpiu tarp bandymų prognozavimo pagal gaunamą AS informaciją teoriniai tyrimai ir pasiūlytas naujas sprendimas, pagrįstas kompleksinės AS energijos kitimo parametro vertinimu.

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