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Ultrasonic method and other methods of control of undissolved gas in the working fluid

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Abstract. The power oil of the hydraulic drive plays a key role, being both an energy carrier and a lubricant. Variable pressures, speeds and temperatures effect on it. The gas presence in the hydraulic system negatively affects the operational characteristics, bearing capacity and dynamics of the system. The ultrasonic technique of the control of undissolved gas in power oils plays a significant part.

1. Introduction

The term "gas content" refers to the content of undissolved gases in the oil, determined mainly by the amount of undissolved air.

Due to the fact that the compressibility of air (gas) is significantly (thousands of times) greater than the compressibility of power oils themselves (the elastic modulus of air is approximately equal to its absolute pressure), the presence of air bubbles in significantly reduces elastic modulus. Therefore, the presence of gas in the hydraulic system negatively affects the operational characteristics, bearing capacity and dynamics of the system [1].

The ultrasonic technique of undissolved gas control is a method based on instrumental control of physical quantities that depend on the quantitative content of undissolved gas in the liquid. The basis of this method is the dependence of the phase velocity of propagation of an audio signal in a liquid with gas bubbles on its frequency and free gas concentration.
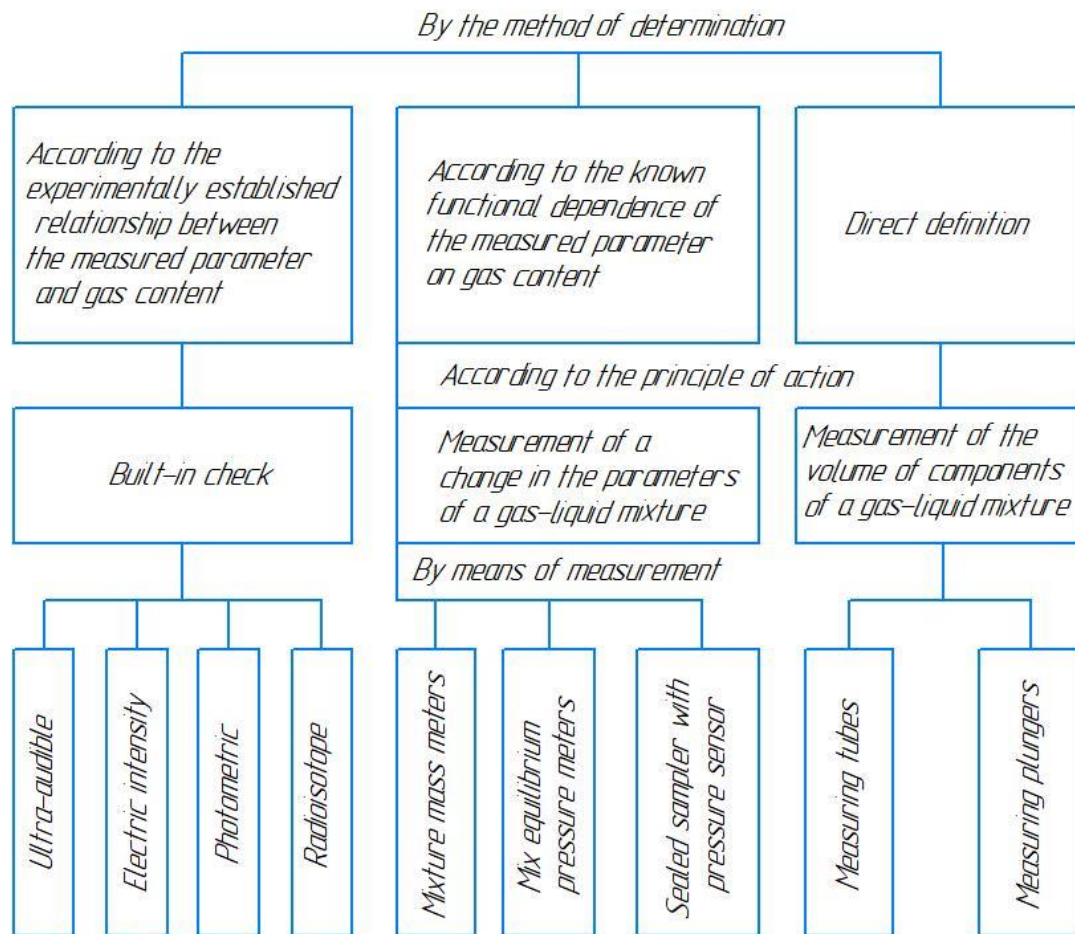
The content of known methods for determining the amount of gas dissolved in a liquid is based on a method that involves evacuating the capacity of a calibrated volume and degassing a liquid sample in it, followed by measuring the pressure released during gas degassing.

For the time being various methods have been developed for determining undissolved gas in the power oil. The classification is shown in figure 1.

According to mechanism these methods can be classified [2, 3]:

- instrument control using ultrasonic, electric capacity, radioisotope, photoelectric and other physical methods;
- volumetric control method using measuring tubes or compressing the liquid till the complete dissolving of gases in it;
- control over parameter variation of the gas-liquid mixture flow (pressure and flow rate along the length, pressure in the closed volume, density of the gas-liquid mixture).

Figure 1. Classification of methods and means for determining the gas content in the working fluid.

According to the methods for obtaining the determination result, they can be divided into three groups [4, 5].

The first group of methods includes methods based on instrumental control of physical quantities that depend on the quantitative content of undissolved gas in liquid. One of these methods is based on the dependence of the phase velocity of the acoustical signal in a liquid with gas bubbles on its frequency and free gas concentration. This method allows rapid analysis of the content of undissolved gas. Another method is based on the dependence of the resonant frequency of mechanical vibrations of the hollow cylindrical resonator on the ratio of the volumes of liquid and gas filling the resonator. It was found that self-resonant frequency linearly depends on the volume of the gas and does not depend on the nature of the distribution of this volume in the resonator.

This method allows measuring the concentration of undissolved gas phase in the range of 1 to 100% to a precision of ± 10%. The electro-capacitive determination method is also known. It is based on the measurement of the dielectric constant of the mixture having various gas contents.

The second group of methods is based on changing parameters of the volume or flow of a gas-liquid mixture depending on the amount of undissolved gas. A method of "hydrostatic scales" is also known. It uses the dependence of the density of the mixture on the ratio of gas and liquid in it. The content of undissolved gas in liquid is defined here as the ratio of the displaced mass of oil with gas bubbles to the displaced mass of free of bubbles oil when a sphere filled with lead is plunged into the oil. It is advisable to measure the gas content only in an open sump using this method. The absolute accuracy when measuring gas content using this way is ±0.5%. Another way of determining the gas factor is based on a change of gas-liquid head when the amount of undissolved gas in it changes. The

value of the gas phase in the mixture is determined the magnitude of the pressure drop in the upward fluid flow in the control section of the vertical tube. This method can be used only in laboratory conditions. Besides, the accepted assumption when calculating the gas content of the equality of friction losses for a gas-liquid mixture and a clean liquid that does not contain gas inclusions leads to an inaccuracy of the measured results. The inaccuracy grows with an increase of the content of undissolved gas. There is also another method and apparatus for determining the content of undissolved gas is known. It is based on measuring pressure of a gas-liquid mixture in a cut-off and hermetically sealed space of a pressure line, which changes in time due to the dissolution of the gas phase.

The third group of techniques relies on methods for directly determining the volume of the components that make up the gas-liquid mixture. Those methods include techniques recommended by Hayward. One of these methods is to measure the volume of liquid in a measured sample of a gas-liquid mixture. To do this, measuring tubes are used in which sedimentation of the working fluid sample is carried out. When gas bubbles completely disappear the volume of liquid in the sample is measured and the content of undissolved gas in the power oil is determined by the difference i between the volumes of the sample and the liquid in it [6].

Estimating methods for monitoring undissolved gas in the power oil of hydraulic systems in general, it should be noted that most part of the developed methods and devices can be used only in laboratory conditions [7, 8].

2. Ultrasonic technique for control of undissolved gas in the power oil

The ultrasonic technique of undissolved gas control is based on instrumental control of physical quantities that depend on the quantitative content of undissolved gas in the liquid. The basis of this method is the dependence of the phase velocity of propagation of an acoustical signal in a liquid with gas bubbles on its frequency and free gas concentration.

Ultrasonic testing technology is based on the ability of high-frequency oscillations (about 20,000 Hz) to penetrate the working fluid and to be reflected from the gas. An artificially created, directed diagnostic wave penetrates the tested compound and, in case of gas detection, deviates from its normal propagation. The ultrasound operator sees this deviation on the instrument screens and, according to certain data readings, can assess the gas content.

One of the main characteristics of elastic waves is the wavelength λ. It is proportional to the size of the detected defect and is determined by the formula [9]:

$$\lambda = \frac{C}{f}, \tag{1}$$

where λ - the wavelength (m); C - the speed of propagation of ultrasound in the material (m/sec); f - wave frequency (Hz).

The usage of ultrasonic and other methods for estimating the amount of undissolved gas in the power oil of a hydraulic system offers the greatest promise although it requires complex equipment: the readings of the devices depend on the parameters of the gas-liquid mixture flow, experimental determination of calibration characteristics is necessary. These methods are used mainly in the laboratory when conducting research.

The proposed method for measuring the amount of undissolved gas allows measurement using ultrasonic fixation devices. An ultrasonic method for determining the concentration of undissolved gas in a liquid involves generating an ultrasonic wave, irradiating the test medium, recording a wave that has passed through it, and then comparing the signals.

In order to provide the possibility of measuring the concentration at any sizes of gas bubbles, with a varying dispersed composition, the acoustic wave is pulsed at a frequency exceeding the resonant frequency of the smallest bubbles, and the average statistical value of acoustic signals that have passed through different distances in a liquid with gas bubbles is measured, the concentration of undissolved gas in the liquid is judged by the change in the attenuation coefficient.

In the course of performance the control there is a weakening of acoustic energy in the power oil, associated with several loss mechanisms: viscous, scattering, thermal and resonant. The attenuation coefficient of acoustic energy when there is no hydrodynamic interaction between particles can be represented as the sum of the corresponding coefficients [10]:

$$\alpha = \alpha_0 + \alpha_{disp} + \alpha_{visc} + \alpha_{therm} + \alpha_{res}, \qquad (2)$$

where α_0 - absorption coefficient; α_{disp} - dispersion coefficient; α_{visc} - viscosity coefficient; α_{therm} - thermal conductivity coefficient; α_{res} - resonance absorption coefficient.

In the non-resonant frequency zone, where the wavelength is comparable or smaller than the particle size, the geometric scattering plays a key role among all the mechanisms of attenuation of acoustic waves, which leads to a linear relationship between the coefficient of additional attenuation and the concentration of gas bubbles.

$$\Delta a = n2\pi r, \qquad (3)$$

where n - concentration; r - gas bubble radius.

The system under study is irradiated with pulsed 5 MHz ultrasonic waves. This frequency is more than by times higher than the resonance frequency of the smallest gas bubbles arising in a liquid. The coefficient of additional attenuation is found by the difference between the coefficient of attenuation of the investigated gas emulsion and the absorption coefficient specific for a given liquid α_0

$$\Delta a = a - a_0, \qquad (4)$$

where

$$a = \frac{\left(\ln P_2 - \ln P_1\right)}{(x_2 - x_1)}, \qquad (5)$$

where P_1, P_2 - average statistical values of acoustic signals that have passed the distance; x_1, x_2 - respectively in a liquid with gas bubbles.

The fractional concentration of gas bubbles is determined by the ratio of attenuation coefficients. The absolute concentration values are determined using preliminary calibration.

The method provides the ability to measure the concentration of undissolved gas phase in two-phase dynamic systems for any size of gas bubbles, with a varying dispersed composition, in various, including small, volumes of the studied systems.

The advantages of the ultrasonic control method are the possibility of application in laboratory and field conditions; the absence of the need of determination the isothermal modulus of the bulk elasticity of the liquid, which is included in the formula for calculating the gas content, as well as the limited scope of its application (only in pressure headlines); speed of the test; simplicity of accounting for temperature changes; the invariance of the rate of displacement of air bubbles from a liquid.

3. Conclusion

The ultrasonic technique of undissolved gas control has advantages over others, i.e. methods for determining the amount of undissolved gas, based on changing the parameters of the volume or flow of the gas-liquid mixture depending on the amount of undissolved gas, can only be used in laboratory conditions, and the assumption made when calculating the gas content is that friction losses are equal for a gas-liquid mixture and a clean liquid that does not contain gas inclusions leads to an inaccuracy in the measured results, which grows with increasing of undissolved gas content. Also, the disadvantages of this method is necessity of determination the isothermal bulk modulus of elasticity of fluid entering the formula of calculations values of gas content, and its limited field of use (pressure lines only).

The method of direct determination of the volume of the components that make up gas-liquid is inferior to the ultrasonic method as the tube filling time is long (from 10 to 25 s); difficulty of

accounting temperature changes; a long measurement time (several hours, and under certain conditions characterized mainly by bubble size and viscosity) of the liquid, the rate of displacement of air bubbles from the liquid may decrease as much that the gas will be mixed with the liquid for several days); and the necessity of usage a measuring tube of relatively large capacity.

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