A technique for monitoring content of undissolved gas in a hydraulic drive of a self-propelled vehicle

A S Lunev, V I Afanasov, A A Nikitin, D A Sokolov, V A Ionova and V Y Obvintseva
Siberian Federal University, 660041, Krasnoyarsk, 79, Svobodny Avenu, Russia

E-mail: Allynev@mail.ru

Abstract. This paper considers a technique for monitoring the content of the undissolved gas in hydraulic systems. This technique is suitable for a self-propelled vehicle, forestry, lifting, and transport equipment. The paper presents an influence of gas content in the hydraulic fluid on the physical properties of hydraulic oils. The work is important because the hydraulic fluid is a mixture of liquid and undissolved gas. The measure test bench presenting in this paper makes it possible to understand the mechanism of monitoring the content of the undissolved gas in the hydraulic fluid.

1. Introduction
Currently, there are various techniques to determine the content of the undissolved gas in the hydraulic fluid. According to the principle of operation, these techniques contain:

- hardware checks. In this case ultrasonic, electro capacity, radioisotope, photoelectric and other physical methods are used for monitoring;
- a volumetric method by using measuring tubes or by compression of fluid to complete the dissolution of the gas in it;
- a technique for monitoring changes characteristics of a flow of a liquid-gas mixture (pressure and flow rate depending on the pipe length, a pressure in enclosed volume, the density of the mixture).

Papers [1, 2, 7] contain the theoretical dependence of the bulk elastic modulus of the mixture (liquid and undissolved gas) on the pressure and gas factor. The bulk modulus of the mixture is given the following expression

\[ B_{\text{mix}} = -V_{\text{mix}} \frac{dp}{dV_{\text{mix}}}, \tag{1} \]

where \( B_{\text{mix}} \) – the bulk elastic modulus of the mixture under unrestricted pressure \( p \); \( V_{\text{mix}} \) – the volume of the mixture under unrestricted pressure \( p \); \( dp \) – an infinitesimal increment of pressure; \( dV_{\text{mix}} \) – an infinitesimal increment of the volume of a mixture.

The volume of a mixture \( V_{\text{mix}} \) is defined as the sum of the volumes of the liquid component \( V_l \) and the gas one \( V_g \)

\[ V_{\text{mix}} = V_l + V_g. \tag{2} \]
The infinitesimal increment of the volume of a mixture is interpreted as the sum of increments of the volumes of the liquid component \( dV_l \) and the gas one \( dV_g \)

\[
dV_{\text{mix}} = dV_l + dV_g. \tag{3}
\]

After substituting \( V_{\text{mix}} \) and \( dV_{\text{mix}} \) from equations (2) and (3) into equation (1), the formula is deduced

\[
B_{\text{mix}} = \frac{V_l + V_g}{dV_l + dV_g} \cdot dp. \tag{4}
\]

Expressing parameters included in the formula is more convenient for practical use in terms of the value of the parameters under atmospheric pressure \( p_0 \). When the pressure changes from \( p_0 \) to \( p \), the process of gas-phase compression is considered to occur by polytrope in papers [1, 2, 7]

\[
V_g = V_{g,0} \left( \frac{p_0}{p} \right)^{\frac{1}{n}}, \tag{5}
\]

where \( V_{g,0} \) – the volume of gas under atmospheric pressure \( p_0 \); \( n \) – polytropic exponent.

In this case, the formula for the bulk elastic modulus of gas can be deduced using the equation

\[
B_g = np. \tag{6}
\]

When the pressure changes from \( p_0 \) to \( p \), the dependence of the bulk elastic modulus of the hydraulic fluid on the pressure becomes linear [2, 7, 8]

\[
B_l = B_{l,0} + Ap, \tag{7}
\]

where \( B_{l,0} \) – the bulk elastic modulus of the hydraulic fluid under atmospheric pressure \( p_0 \); \( A \) – coefficient that depends on the type of liquid and temperature.

**Figure 1.** The linear dependence of the bulk elastic modulus of the hydraulic fluid on the pressure.

Figure 1 shows that empirical formula (7) describes changes of the bulk modulus of the hydraulic fluid.

It is promising to determine the quantity of the undissolved gas based on measuring the volume of the liquid-gas mixture compressed until complete the dissolution of the gas in it.

2. **Description of the measure test bench for monitoring the content of undissolved gas in a hydraulic drive of a self-propelled vehicle**

The measure test bench presenting below can help to monitor the content of undissolved gases in hydraulic systems while in operation [8].
Figure 2 shows the hydraulic circuit diagram of the measure test bench for measuring the volume of undissolved gas in hydraulic fluids.

![Figure 2. The measure test bench for monitoring the content of undissolved gases in hydraulic fluids](image)

The coupling 2 transmits rotation from the driving motor 1 to the hydraulic pump 3. The hydraulic fluid containing undissolved gas bubbles flows through suction tube 4, and it comes in the hydraulic pump 3. The flow meter 7 and the ultrasonic flow meter 12 set to the suction tube 4, and they fix the value of the volume of the liquid coming in the hydraulic pump 3. The pressure gauge 16 measures the pressure in the suction tube 4. The hydraulic fluid under pressure leaks out of the pump 3. After that, it flows through the discharge pipe 5, the adjustable orifice 6 using for changing the pressure in pipe 5, and then the hydraulic fluid comes into the hydraulic motor 20. The pressure gauge 17 measures the pressure in the section of the discharge pipe 5 to the adjustable orifice 6, and the pressure gauge 18 measures the pressure in the rest of the pipe 5. Flow meters 8, 9, 13, 14 show the value of the flow rate. The pressure gauge 21 uses to measure the change of pressure in the critical section of the adjustable orifice 6. Then the hydraulic fluid drains from return line 11 into tank 22. The pressure gauge 19 measures the pressure and flow meters 10, 15 shows the value of flow rate in the return line 11. The thermometer 23 takes hydraulic fluid's temperature in the tank.

Flow readouts from ultrasonic flowmeters 12, 13, 14, 15 compare with readings from flowmeters 7, 8, 9, 10. Pressure gauges 16, 17, 18, 19 and flow meters allow obtaining the measurement accuracy in the dynamic process, the measurement parameters before compression of undissolved gas and liquid, and after compression becoming possible.

The measure test bench is taken readings of values below in real-time mode:

- the pressure in 4 different points (suction tube, the section of the discharge pipe before the adjustable orifice, the section of the discharge pipe before the hydraulic motor and the return line);
- the flow rate in 4 different points (suction tube, the section of the discharge pipe before the adjustable orifice, the section of the discharge pipe before the hydraulic motor and the return line);
• the temperature of the hydraulic fluid (the tank contains the thermometer 23).

The compressibility of the liquid is taken into account by measuring the flow rate of the hydraulic fluid before the adjustable orifice and after that. The hydraulic fluid passing through all flowmeters 7, 8, 9, 10, 12, 13, 14, 15, the values of its volume are made simultaneously. The difference between the flow rate of the mixture contained uncompressed bubbles of undissolved gas and the flow rate the one with the gas compressing estimates the volume of this gas of hydraulic fluid with account for volume efficiency of hydraulic pump 3.

According to the proposed technique, it is possible to monitor the content of the undissolved gas- and-air phase of hydraulic fluid on any section of the hydraulic system with various hydraulic elements.

Besides, the measure test bench helps to analyze the characteristics of individual hydraulic elements included in the hydraulic system and to plot them.

3. Conclusion
Generally, assessing the evolution of techniques for monitoring undissolved gas factor in a hydraulic fluid of hydraulic systems, it is worth pointing out that most of the available methods and devices find use only in laboratory conditions. Thus, it is very important to develop diagnostic aids for monitoring the content of undissolved gases in the hydraulic system while in operation.

References
[1] Popov D N 2002 Mechanics of Fluid and Pneumatic Actuators (Moscow: Bauman Moscow State Technical University Press)
[2] Metlyuk N F, Avtushko V P 1980 Dynamics of Fluid and Pneumatic Actuators of Vehicles (Moscow: Machinery Construction)
[3] Nikitin A A, Mandrakov E A 2014 Influence of undissolved gas in the hydraulic liquid on the dynamics of logger’s hydraulic drive Proc. of Tomsk Polytechnic University. Math. and mech. Phys. vol 325(2) 65–71
[4] Popov D N, Panaiotti S S and Ryabinin M V 2002 Hydromechanics ed D N Popov (Moscow: Bauman Moscow State Technical University Press)
[5] Gamynin N S 1972 Hydraulic Drive of Control Systems (Moscow: Machinery Construction)
[6] Danilov Y A, Kirillovskii Y L and Kolpakov Y G 1990 Equipment of Fluid Power Drive: Work Processes and Characteristic (Moscow: Machinery Construction)
[7] Gorbeshko M V 1997 Development of Mathematical Models for the Hydraulic Machinery of Systems Controlling the Moving Components of Water Development Works Hydrotechnical construction vol 31(12) 745–50
[8] Lunev A S, Nikitin A A 2008 The Adjustable Orifice: Pat. RU №73714 pub. 27 May 2008 9 p
[9] Mihaïlov A A, Lunev A S and Pilugaev I N 2007 Power Unit of Hydraulic Drive: Pat. RU №67203 (Moscow: Rospatent)
[10] Gordeev A S, Kulgnek G I, Domogatskiy V V, Folimonov V M, Dmitriev F A, Mahonin V A and Kravtsov A I 1978 A Technique for Measuring the Volume of Undissolved Gas of Hydraulic Fluid: Pat. SU №802869 (Moscow: Rospatent)