UDC 629.735.063:629.7.064(045)

L. Volianska, G. Nikitina
(National Aviation University, Ukraine)

Analysis of the influence of working fluid contamination on hydraulic system operation

The analysis of sources of working fluid contamination and the influence of contaminated working fluids on the reliability and durability of hydraulic equipment is carried out.

Introduction

According to the generalized statistical data on the operational reliability of fluid systems of aircraft, a significant part of the failures and malfunctions of gas turbine engine control-fuel units are a direct or indirect consequence of fuels and oils contamination [1].

Constant and variable displacement hydraulic systems are widely used in aircraft. Currently, the most widely used airliners have a hydraulic pressure of about 210 atm. Such operating conditions lead to increased wear of hydraulic components and contamination of the working fluid.

Studies show that working fluids of hydraulic systems always contain millions of mechanical particles of different sizes and hardness, despite the presence of filters and protection systems. It is believed that it is impossible to completely protect the system from contamination [2, 3].

Sources and classification of contamination in working fluids

A number of works [1, 2, 3] are devoted to the study of penetration, composition, properties, and also the classification of contaminants. Based on the analysis of these studies, three main groups of contamination can be distinguished from among the most common. These are atmospheric contaminants (dust), operational contaminants, contaminants appeared due to poor performance of working fluids.

The first group is the most fully studied [2]. The reasons for the penetration of atmospheric dust into the working fluid, its dispersed composition, the effect on the reliability and durability of the units were investigated.

Contamination, which are generated in the units as a result of wearing of parts, should be attributed to the second group. According to [1, 2], the amount of contamination depends on accuracy of the unit running-in during preliminary tests. Also, the products of part wearing can be scale, rust, rubber, particles of abrasives, etc.

According to research, the reason for the appearance of contaminants attributed to the third group is the low performance properties of working fluids. It has been established that the presence of mechanical impurities, water, air in technical fluids, fuels, oils worsens the lubricating and thermo-oxidative properties, thermal stability. The products of wear at the time of their formation affect especially strongly the oxidation processes, which is explained by surface-active properties [2]. This leads to the appearance of oxidation products, various sediments, flakes, which are an additional source of organic pollution of fuel, oil and hydraulic systems [3]. It was also found that a large amount of contaminating particles remain after the manufacture or repair of units [1, 2]. Therefore, it is necessary to take into account that poor-quality removal of contaminants leads to premature wear of a number of working units [1, 2, 3]. At the same time, experiment and practice show that biological pollution (by various kinds of bacteria) is possible in the hydrocarbon liquids. Under the influence of favorable conditions, bacteria multiply very quickly [3, 5].

Investigation the elemental composition of contaminants in working fluids [2, 3] have shown that contamination contains not only wear products of unit parts, but also rubber, oxidation products of working fluids, other organic and inorganic particles, microbiological contamination [5].

Examination of contaminations, accumulated on filter elements during operation of a hydraulic fluid of the AMG-10 type, consist of: Si_2O_3 - 27%, Al_2O_3 - 16%, Fe_3O_4 - 8.4%, MgO - 3.4%, rubber - 7%, other inorganic substances - 7.0%, organic pollutants - 28.3% [3]. Thus, the revue of the literature has shown that it is impossible to completely protect the system from contamination entering its working cavity. It is known that, being in a suspended state and moving with the flow of liquid, mechanical particles lead to clogging and failure of filter elements, contribute to obliteration of gaps and an increase in friction forces in conjugate pairs, lead to increased wear, and in some cases to jam parts [1, 2, 3, 4]. Based on the above, we can conclude that the operation of a contaminated working fluid significantly reduces the service life of hydraulic equipment, negatively affects the service life of the technical fluid itself.

Reliability and durability of hydraulic systems, taking into account the pollution of the working fluid

Researchers in the second half of the 20th century repeatedly pointed out the dependence of hydraulic units' resource on the degree of purity of the working fluid and internal cavities of the system. The first experimental studies of the influence of contamination of the working fluid on the operation of hydraulic devices were carried out on the AMG-10 fluid, artificially contaminated with the powder of electrocorundum and carbonyl iron and on a "clean" fluid for a separate section of the hydraulic system and its units.

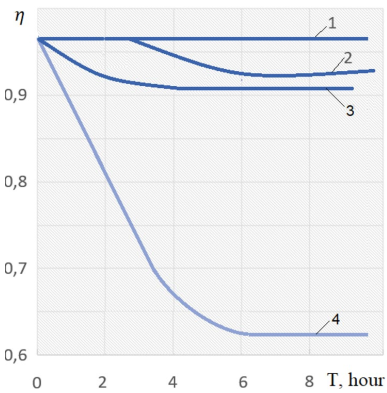

Fig.1. Dependence of the relative efficiency η of an axial piston pump on the test time T of AMG-10 fluid of various contamination: 1 – clean fluid; 2 - 1 μm; 3 – 7-13 μm; 4 – 20-30 μm.

All the authors came to the identical conclusion after analyzing the data of these studies. It was found that contamination of the working fluid during operation leads to a decrease in pump performance, a deterioration in its volumetric efficiency [2] Fig.1, 2. This is explained by the abrasive effect of solid particles of impurities that have entered the working cavity. The sizes of the window openings in the nozzles and throttling washers increase, the geometry of the edges of the control spools changes, which leads to a deterioration in the characteristics of the entire system. For this reason, the volumetric flow rate of the pumps decreases, the characteristics of hydraulic engines, hydraulic boosters, control and distribution devices deteriorate.

The total number of contaminant particles and their concentration in the working fluid increase with an increase in the operating time, while tending to a certain limit due to the filtering characteristics of the filter elements. Those, after a certain time of the hydraulic system operation (about 2000 hours), the time of pollution stabilization comes [2, 3]. This fact is confirmed by the analytical dependence, which allows us to analyze the contamination of the working fluid of hydraulic systems and give a qualitative assessment of the results of the experiment [2]:

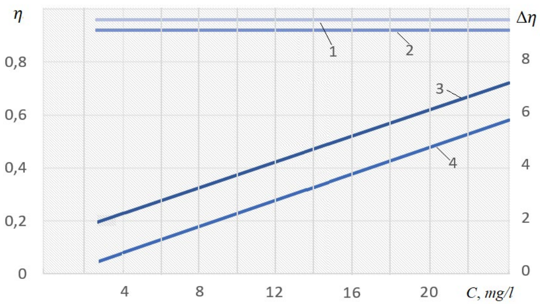

Fig.2. Influence of electrocorundum particles on the relative efficiency η (1, 2) of the pump and the intensity of its reduction $\Delta\eta$ (3, 4) at changing particles concentration: 1, 3 - 1-3 μm; 2, 4 - 7-13 μm.

$$n = n_0 e^{-\psi \frac{Q}{v} T} + \frac{n_n}{\psi}\left(1 - e^{-\psi \frac{Q}{v} T}\right), \tag{1}$$

where n is the contamination of the hydraulic system fluid; n_0 is the number of contaminating particles of a certain size per unit volume of fluid at the beginning of operation (initial pollution); n_n is the number of a certain size per unit volume of a fluid of contaminating particles generated during one complete passage; ψ - filtration coefficient of pollution particles; $\frac{Q}{v}T$ - the number of fluid passes during time T; Q - mass flow rate of fluid in the system.

When distribution devices operate on a contaminated liquid, in comparison with a “clean” one, the forces of breakaway increase, unstable work of the distributors, jamming of the plungers appear [1, 2, 3]. The presence of solid pollution particles, a change in their concentration leads to an increase in the friction forces between the surfaces of conjugate pairs [2, 3], Fig. 3.

The maximum friction force caused by contamination of the fluid, in this case, can be determined by the formula [2]:

$$F_{\max} = (4....5)\pi dh \Delta P n, \tag{2}$$

where πdh – the channel cross-sectional area (S); ΔP – pressure drop; n – the number of plunger belts separating cavities with different pressures.

The penetration of mechanical particles into the gap between the parts is the main cause of friction failure in them. The predominant wear in hydraulic systems is abrasive wear. With internal fluid overflows, hydroabrasive wear is possible, but its role is less significant [2].

The degree of wear is determined mainly by the mass, size and hardness of the pollution particles Fig. 4 [2]. Mechanical particles commensurate with the gaps of precision pairs are a frequent cause of jamming of the latter [1, 2, 3].

Using the studies [1, 2, 3, 4], it can be argued that contamination in working fluids contributes to: increased wear of the most critical parts with the progression of abrasive and hydroabrasive wear; obliteration of cracks in small-section canals; the appearance of cavitation in working fluids, oxidation of fluids and deterioration of their physical, chemical, operational properties; an increase in the frictional forces in the plunger pairs and an increase in the force required for starting and moving the plunger; overheating and destruction of hydraulic mechanisms; jamming of parts moving relative to each other.

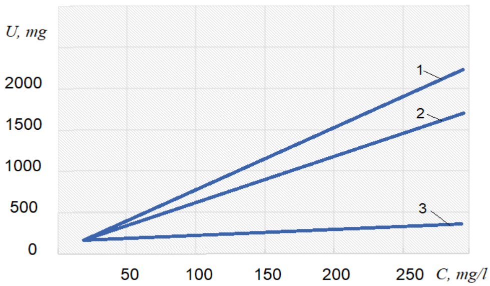

Fig.3. Influence of wear of vane pump parts depending on the size and concentration of contamination particles: 1 – 10-20 µm; 2 – 30-40 µm; 3 – more than 40 µm.

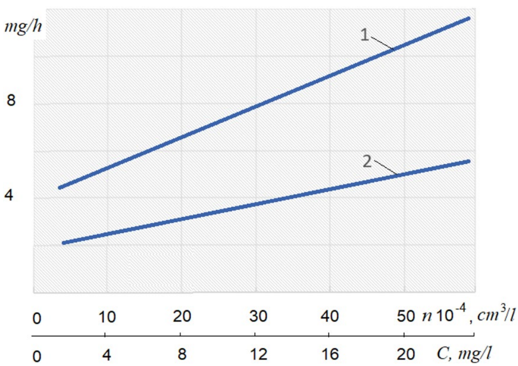

Fig. 4. Dependence of the intensity of wear of the end surface of the cylinder block on the concentration of alumina particles of size: 1 – 10-20 µm; 2 – 30-40 µm; 3 – more than 40 µm.

Conclusions

From this, it can be concluded that contamination of the working fluid during the operation of hydraulic systems, both for general industrial purposes and aviation, increases the probability of malfunction and failures of a number of hydraulic equipment units, and, consequently, reduces the reliability of the hydraulic system as a whole. However, in order to guarantee the requisite reliability and durability of the modern systems units, and, therefore, flight safety, a comprehensive study of the influence of operating factors on the characteristics of the reliability of hydraulic systems, including the effect of the liquid pollution, is required. To study the effect of the level of pollution, it is necessary to develop a mathematical model of the hydraulic system operation.

Raising awareness of the consequences of excessive fluid contamination can play a vital role in achieving reliable hydraulic system performance.

References

1. А.Г. Никитин. Состояние трибообеспечения современных ГТУ. Резервы повышения надежности и экономической эффективности// Газотурбиные технологии. - 2010. - №1(82). - С. 26-29.
2. Белянин П.Н., Данилов В.М. Промышленная чистота машин. – М.: Машиностроение. 1982. - 224 с.
3. Венцель Е.С. Улучшение эксплуатационных свойств масел и топлив: монография / Е.С. Венцель. – Х.: ХНАДУ, 2010. – 224 с.
4. Т.В. Тарасенко, В.Г. Романенко, В.Н. Бадах. Возникновение кавитации в объемном насосе // Гідравлічні машини та гідроагрегати. Вісник НТУ «ХПІ». – 2015. - №3(1112). – С. 112-120.
5. Passman F.J. Microbial contamination and its control in fuels and fuel system / Internacional Biodeterioration and Biodegradation, 81. – 2013. - P. 88-104.