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Specific Characteristics of Lubricating Fluids for Optimizing Industrial Technological Systems with Electrohydraulic Actuation

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Abstract: *The lubrication process carried out by hydraulic fluids represents one of the important aspects of simple or complex industrial technological systems. The identification of hydraulic oils and the operating conditions of the component elements led to the systemic approach to the lubrication process in order to achieve an efficient productivity, to permanently keep control over the equipment used and the processes performed, but also to ensure the best conditions of development of electrohydraulic systems. There are intense concerns about reducing wear and tear, reducing maintenance costs and extending service life between repairs of machine tools and hydraulic equipment, as well as some environmental protection issues. Thus, the choice and appropriate use of lubricating fluids, the optimization of industrial electrohydraulic systems, the approach of solutions related to the quality and characteristics of the chosen lubricant, but also to the maintenance of fluid-based functional systems, are required. The hydraulic machine performance is closely related to the oil film quality, which ensures a quick and precise response of the electrohydraulic system, maintains good protection against corrosion and optimal operation of the hydraulic components.*

Keywords: *Fluids, lubrication, corrosion, electrohydraulic system, industrial machine tools*

1. Introduction

The requirements regarding the performance parameters of the drive equipment are in a continuous competition, which led to the improvement of each of these technologies and towards the maximization of these performances. The informational explosion, the rapid pace of development and accumulation of a huge volume of knowledge makes it increasingly difficult to follow, assimilate and use these informational flows. In this context, informatics represents the current technique of recording, storing, processing and transmitting information that has become indispensable to any field of activity and especially in the field of equipment and industrial CNC machine tools. This line also registers the field of hydraulic drives in order to make full use of modern analysis and synthesis techniques, to design equipment structures with constructive-functional parameters and predetermined performances. It is also aimed at streamlining the choice of implementing and using hydraulic actuation equipment in the most diverse fields of current technique and technology, and especially in the field of numerical controls (industrial robots, industrial CNC machine tools, etc.) [1]. The progress performed in various industrial fields has further highlighted the remarkable qualities of electrohydraulic actuation systems. They cover a wide range of applications, from machine tools with numerical controls to industrial robots controlled by microprocessors, capable of the most complicated and fine maneuvers. The expansion and diversification of electrohydraulic actuation equipment takes place in proportion to the increase in technical performance and their quality. The reliability of these electrohydraulic actuation equipment is one of the basic qualitative indicators, which is required to evolve simultaneously with the increase in working pressures. Research in the field has shown that one of the weak elements of a hydraulic circuit can become the hydraulic environment due to the transformations produced on the fluids used during the executed processes, which represents a significant percentage of hydraulic system failures [2]. Another element that can cause malfunctions in operation are the seals. These faults appear when the maintenance schedule is not respected. The increase in reliability and life span is conditioned by raising the precision of the execution of the components, the use of materials with superior characteristics, appropriate heat treatment methods, the hydrostatic discharge of the friction couplings, as well as the use of suitable lubricating liquids with the maintenance over time of optimal characteristics [3]. Fluids transmit energy in hydraulic actuation systems, so energy circuits can cyclically suffer significant variations in pressure, speed and temperature. They come into contact with different materials and can be exposed to the electromagnetic field, nuclear radiation, etc. [4]. The difficult conditions of use impose the following requirements on the functional fluids: lubricating qualities, good viscosity in any operating conditions of the system, stable physical and chemical properties, compatibility with the system materials, compressibility, volatility, foaming tendency, density, coefficient of thermal expansion, price and low toxicity, as well as antioxidant and dielectric qualities, easy storage and handling.

2. Industrial machinery with electrohydraulic actuation

Hydraulic actuation is still current and preferred in the field of high powers and sometimes becomes irreplaceable in the case of heavy industrial machinery (machine tools - CNC), characterized by large dimensions and own weights, large working space, large manipulated loads, difficult working environment. The advantages of using these CNC industrial devices mainly consist in the automation of manufacturing processes, improvement of the finished products quality, increase in productivity, handling of heavy weights, multi-functionality, flexible programming, adaptability, avoidance of toxic environments, harmful atmosphere and noise. The electrohydraulic actuation consists of a set of technical functions through which the relative movement of some process elements is achieved. The non-mechanical energy source of the actuation system is hydraulic type. The choice of the actuation system is made taking into account a series of factors such as: operating conditions, handling capacity, workspace, temperature and degree of pollution of the working environment, positioning precision, control and management possibilities, etc. Each actuation system must be dynamically sized to support and drive all structural elements, including the object to be handled or the work device, in motion. The main advantages of hydraulic actuation are:

- the working agent, hydraulic oil at high pressures, up to 700 bar [5], develops forces, respectively high torques at small dimensions of hydraulic motors, being a good energy index;
- the reduced compressibility of the hydraulic agent; it provides the necessary rigidity to the drive system, and the strokes size can also be determined by the phase shift of the oil volume;
- reduced wear of moving elements, because the hydraulic agent is a good lubricant, which contributes to improving the reliability index;
- use in humid, irradiated environments, with high intensity magnetic fields without danger of accidents;
- the possibility of obtaining variable speeds of the execution element, stops at fixed points with high precision;
- technological developments in various fields, especially in the fields: space, military, and medical;
- the provision of new techniques, principles and control devices such as servo valves and proportional directional control valves, which are key elements in the field of precision hydraulic drives.

There are a number of disadvantages of electrohydraulic drive systems such as:

- lower global yield than in the case of electric drives;
- the need for additive hydraulic fluids with special characteristics, which increases the complexity and raises the cost of the actuation;
- requires specific seals for high pressures, qualified personnel for maintenance and repairs;
- the need for cooling installations for the actuation system.

Electrohydraulic systems combine the special qualities of electrical and electronic systems in terms of automatic controls with the remarkable advantages of hydraulic systems, under the transmission aspect of large energies. The association led to the realization of electrohydraulic systems of automatic tracking and in general automatic regulation, with superior performances. The expansion of electrohydraulic actuation and control systems has led to remarkable successes regarding the realization of servo systems, some complex interface elements, as well as the manufacture of proportional equipment with a wide application in the control and actuation of industrial CNC machine tools. The appearance of these servo systems allowed the development of hydraulic

systems applicable in situations where the repeatability of cycles is required, the programming of forces, displacements and speeds, the provision of different functions for switching from one speed level to another and a great flexibility in programming. This type of equipment ensures the ordered electrohydraulic actuation that meets the requirements imposed on industrial devices in terms of positioning precision, reliability, speed control range, etc. Starting from this type of electrohydraulic actuation control system, two types of actuation systems used by various industrial equipment have been developed, namely:
- electrohydraulic actuation, analog servo control (hydraulic tracking systems);
- digitally servo-controlled electrohydraulic actuation (with numerical control).

The electrohydraulic actuation remains a basic solution in the case of heavy machinery, for which the other modes of actuation do not meet the requirements due to the large size and high energy consumption. Although the solutions seem more complicated, electrohydraulic actuation systems are cheaper than electric ones at the same installed power, because with low power servo elements hydraulic powers hundreds of times higher can be commanded. The electrohydraulic actuation has taken full advantage of the remarkable advances in electronics and microelectronics and through an intelligent technological tandem it was possible to achieve high-performance mixed electrohydraulic equipment. The control and regulation equipment achieves at the output a flow rate proportional to the size of the input electrical signal, through throttling (reducing the flow section).

3. Specific characteristics of hydraulic fluids used for machine tools and industrial equipment

Currently there is a wide range of functional fluids, chemically belonging to several classes, but none of them present all the qualities required for a given transmission. As a result, the choice of hydraulic fluid is generally a compromise that ensures the satisfaction of the essential requirements, but imposes restrictions on the structure of the system and the conditions of use.

The main necessary elements with a role in choosing a lubricating fluid are:
- the range of temperatures for use and storage, normal and accidental;
- the range of pressures to which the liquid is subjected in normal and accidental mode;
- the requirements of certain materials or components of the system;
- safety requirements;
- economic conditions.

If several liquids comparably satisfy these requirements, the final choice is determined by the fulfillment of the other criteria. The liquids used in electrohydraulic systems are practically incompressible fluids, they do not have their own shape, they are perfectly elastic to the compression effort. Liquids in small quantities take the spherical shape and in large quantities take the shape of the container, presenting a free surface. Lubricating fluids must have parameters that ensure the maximum requirements of the technology. Modern trends in the development of electrohydraulic systems aim at the following aspects:
- increase in working pressure and temperature;
- increase in power in relation to the mass of the hydraulic fluid;
- reduction of the working space of the system elements;
- increase in the operating period of the lubricant.

Lubricating fluids must fulfill the following characteristics:
- thermooxidative stability - resistance to oxidation reactions that occur at high temperatures;
- filterability - the ability to extract possible chemical impurities from the liquid with a filter;
- anti-wear properties – the hydraulic oil must protect the actuation device of the machine tool;
- hydrolytic stability - protection of equipment elements against corrosion and chemical attack;
- anti-foam properties – the fluid must not foam under various operating conditions.

Fluids used in electrohydraulic actuation systems cyclically undergo significant variations in pressure, velocity and temperature.

The difficult conditions of use impose certain specific requirements on these fluids:
• good lubrication properties;
• optimal viscosity throughout the range of temperatures used;

• stability over time of physical and chemical properties;
• high mechanical resistance of the film;
• high flash point;
• compatibility with the materials of the hydraulic system, especially with the sealing elements;
• reduced compressibility and foaming tendency.

Table 1[1]: Presentation of the most important performance classes for hydraulic oils

FLUID CODE	MINERAL BASED HYDRAULIC OILS
HLP DIN 51 524 T.2	Mineral oils with antioxidant and anticorrosive additives, with extreme pressure properties
HVLP DIN 51 524 T.3	HLP oils, superior quality, with high viscosity indices (IV>150) and multifunctional characteristics
HLP-D HLP	Detergent oils, with additional absorption properties of water and keeping the hydraulic circuit clean
HVLP-D HLP-D	Oils with a high viscosity index (IV>150), detergents, with additional water absorption properties and keeping the hydraulic circuit clean
FLUID CODE	HYDRAULIC OILS WITH FAST BIODEGRADABILITY
HEES VDMA (Hydraulic oil Environment Ester Synthetic)	fluids with rapid biodegradability, based on synthetic esters, with high performance properties
HEPG (Hydraulic oil Environment Polyglycole)	fluids with rapid biodegradability, based on polyglycols, for special uses (must not be mixed with other hydraulic fluids)
HETG (Hydraulic oil Environment Triglyceride)	rapidly biodegradable fluids based on vegetable oils with reduced (limited) performance properties

The density changes as a function of pressure and temperature; if the change of density with pressure can be considered negligible, the change of density as a function of temperature takes into account the volume coefficient of thermal expansion. The change in the volume of fluids depends on the increase in pressure, so if the force acting on the liquid is removed, it returns to its original volume without suffering residual deformations, therefore fluids can be characterized by means of the modulus of elasticity (ε). This parameter increases linearly with pressure. For most oils used in hydraulic drive systems, ε = 17000-18000 daN/cm^2 [6]. Due to the high values of the modulus of elasticity for liquids, it can be considered that at pressures up to 2x104 kPa the fluids used in hydraulic systems are incompressible. The situation changes dramatically when undissolved air is found in the liquid mass, in which case the modulus of elasticity decreases greatly, with negative influences on the operation of the system. Viscosity is also an important parameter that determines the fluidity of the hydraulic oil and characterizes the sliding resistance of the liquid layers. The amount of viscosity varies significantly with temperature, which affects the lubrication capacity of the drive system elements. The viscosity of hydraulic fluids gives the ability to optimize, by developing tangential efforts. Many hydraulic oils, especially synthetic ones, contain additives with high molecular weights, due to which they have a non-Newtonian character, so their viscosity decreases with the increase of their deformation speed. The addition of additives changes the properties of the oil, so it makes it possible for these fluids not to liquefy at higher temperatures or to crystallize at low operating temperatures. The optimum viscosity value for each mechanism is its own, the permissible viscosity index is assigned by the unit manufacturer. Viscosity is an essential characteristic of hydraulic fluids because it provides lift to the bearings, limits liquid losses through the sealing elements and generates forces that dampen the oscillations of the functional parameters. The viscosity of fluids increases with pressure.
At high temperatures, the internal leaks of bulky machine tools with electrohydraulic actuation and distribution elements alter the efficiency of transmissions. At the same time, the decrease in the

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lubrication capacity of the film in the hydraulic contact areas can cause malfunctions at the level of the mechanism [7].
The excessive viscosity that occurs at low temperatures generates high pressure losses that create suction difficulties for pumps (cavitation), reduce engine speed and transmission efficiency.
These phenomena explain the major interest in fluids whose viscosity varies little with temperature. Several "viscosity indices" have been proposed to evaluate this quality. The influence of temperature must be taken into account, because the transport of energy between the pump and the motor takes place with irreversible losses, accompanied by the release of heat that changes the temperature of the oil/fluid. According to performance characteristics, hydraulic fluids are divided into several groups:
1 - oils without additives, applicable in lightly loaded hydraulic systems;
2 - additive oils to prevent oxidation and corrosion reactions, designed for medium load hydraulic systems;
3 - fluids that inhibit oxidation reactions, reduce corrosion processes, prevent mechanism wear, operating at temperatures above 90 ^{o}C.

4. Interactions between the structural elements of the tribological system

The strains that appear on the structure of the hydraulic system from a tribological point of view are contact processes and relative movements between the structural elements due to the dynamic action of friction and wear, of a physical and chemical nature, but also processes in the intense areas of contact, which lead to energy and efficiency losses. The set of strains is imposed by the physico-chemical parameters that affect the structure of the system, but also by techniques that ensure its operation. The most important characteristics of these strains can be determined by variable elements such as: type of movement, cycle of movement, loads, temperature, contact time, nature of the fluid used. The wear process is influenced by the parameters that depend on:
- construction: dimensions, shape;
- operation: energy, environment, lubrication.
Appreciation amounts of wear and tear depend on:
- constructive and operating parameters;
- the level of noise or vibrations produced as a result of the increase in the clearance between the elements (bearing),
- speed, applied or transmitted load, received or developed energy;
- parameters related to the material (technological and temperature);
- operating parameters (magnitude of the load, characteristics of the lubricating fluid and of the working environment, type of contact) etc.
The wear process can be influenced/accelerated by fluid mass action, fluid pressure, travel speed and temperature. For optimal results from the technological and economic point of view, mechano-hydraulic processes must form a unitary functional system of the following components: operating equipment, operating environment, process parameter settings, type of fluid used.
Fluids used by hydraulic systems must demonstrate a series of characteristics that allow them to satisfy a wide variety of requirements depending on the operation for which they are used. There is a wide variety of uses of the machine tools depending on the special requirements of the various activities undertaken. During the use of electrohydraulic actuation systems, fluids can change their characteristics as a result of changes in some of their physico-chemical parameters. These changes also occur as a result of the environment of use, foreign bodies and the mechanisms involved. In order to optimize the fluids used and expand the possibilities of operating the machines, additives are added that change both the physical and chemical characteristics of the base fluids. The categories of added substances are: anti-wear additives that favor the formation of a lubricating film, high-pressure additives, anti-foaming agents, anti-corrosive agents, etc.
The entire technological flow is directly or indirectly influenced by the characteristics and composition of the fluids used, as such aspects can be established regarding:
- the effectiveness of the process (minimum wear and tear);
- productivity (adequate operating time);
- process safety (type of activity).

5. Conclusions

Irregular operation, oxidation, contamination with water or foreign particles, leaky gaskets, lead to degradation and shortening of the service life of the hydraulic oil.
Tribological assessment criteria can establish methods for optimizing the selection of lubricating fluids in relation to the nature of the execution process and can provide methods for estimating its degree of wear.
Through the tribological study at the level of the industrial technological system with electrohydraulic actuation, relevant data can be provided for the formulation of lubricating fluids, for the estimation of functional stability and for the assessment of the life span of the oil and industrial equipment.

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