Analysis of the Behavior of Fluids Specific to Electrohydraulic Systems and the Performance of Industrial Machine Tools

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Abstract: *Hydraulic oils play a major role in the performance of high-precision industrial machine tools. The share of hydraulic oils on the market is significant and constitutes an important group within lubricants. The decision to use a certain type of hydraulic oil from a certain range can sometimes be very difficult. The difference in use and operation is the main reason why great attention must be paid to identifying that hydraulic oil formulation with specific additives for each type of machine-tool or equipment in the targeted industrial segment. The main properties of state-of-the-art hydraulic lubricating fluids are aimed at the reliability and performance of the drive system. The big companies especially dedicate all the technology and research in obtaining the ranges for professional use, therefore, the study of modern and innovative lubricating fluids, specially dedicated, with synergies that give life to products with extraordinary qualities, able to offer and satisfy the best performance in the most difficult situations of using hydraulic drive systems.*

Keywords: *Austenitic steels, CNC, depassivation, hydraulic oil*

1. Introduction

The performance of properly used lubricating oils has led to the solution of some technically demanding problems in the field of hydraulic actuation. The specialized literature provides important data regarding the constant development of hydraulic fluids, taking into account oils or hydraulic fluids such as:

- ✓hydraulic fluids based on mineral oil;
- ✓fluids under synthetic pressure;
- ✓biodegradable hydraulic fluids;
- ✓fire-resistant hydraulic fluids.

New hydraulic oil technologies aim at environmentally friendly formulations as an alternative to hydraulic oils containing zinc and ash, biodegradable hydraulic fluids. Emphasis is placed on the development of food-grade hydraulic oils, synthetic base fluids for multi-grade hydraulic oils, and new fire-resistant water-glycol hydraulic oils. Advances are being made in the area of hydraulic fluids with a special anti-wear capability, but also for the compatibility of hydraulic oils and oil filter sockets, as well as cooling lubricants of machine tools, low viscosity fluids. These types of high-efficiency and energy-enhancing hydraulic fluids offer solutions that take into account new requirements for thermal, oxidative and shear stability, with a quick response for smooth operation.
The special operating conditions for industrial machines raise particularly severe restrictions and require a rigorous selection of fluid categories that meet most of the requirements imposed on them. Among the most important requirements that are imposed and based on which these working fluids are chosen, the following are worth mentioning:
- excellent lubricating properties and high mechanical resistance of the liquid film;
- high chemical and thermal resistance and stability to prevent its oxidation, decomposition and degradation;
- minimal variation of viscosity with temperature;
- not to release vapors at normal operating temperatures and not to contain impurities that facilitate the release of vapors;

- not to contain, not to absorb and not to release air beyond the amount allowed by the technical prescriptions;
- not to cause corrosion and damage to the sealing elements;
- have a high flash point and a freezing point as low as possible;
- minimum content of mechanical and technical impurities.

2. Case Study - Performance of industrial CNC machine tools with the selected hydraulic fluid

The study consists of analyzing the behavior of an industrial CNC numerical control machine tool, EMCO/MCX-600, a lathe used for mechanical splintering processes.

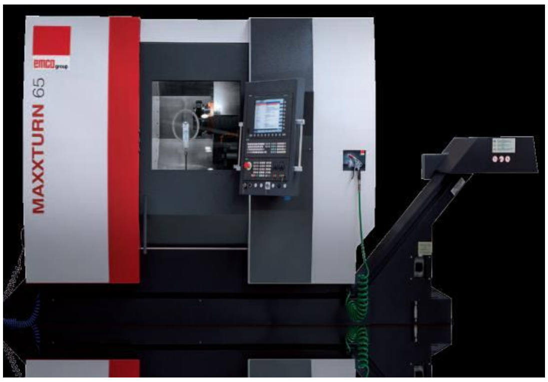

Fig. 1. Machine tool EMCO/MCX600

The hydraulic actuation system used to manufacture the parts of some assemblies and subassemblies is from the category of special purpose steels that differ from tool steels for the splintering process of technological flow. The choice of steel for exploitation in optimal conditions is an important stage that currently applies both to the material and to the technology used. Alloys of non-ferrous metals have chemical, physical, mechanical and technological properties superior to pure metals. Compared to iron alloys, non-ferrous alloys show a much higher resistance to the corrosive agents' action. Due to the high corrosion resistance and cold deformability, stainless steels are used in various fields, being found in the chemical, food, construction, household industries, etc. The concern regarding the environment protection imposes a new perspective on the use of stainless steels, such as protective coatings, corrosion-resistant semi-finished and/or finished products, pharmaceutical or medical applications. According to their chemical composition or crystal structure, stainless steels can be grouped [1] as follows:

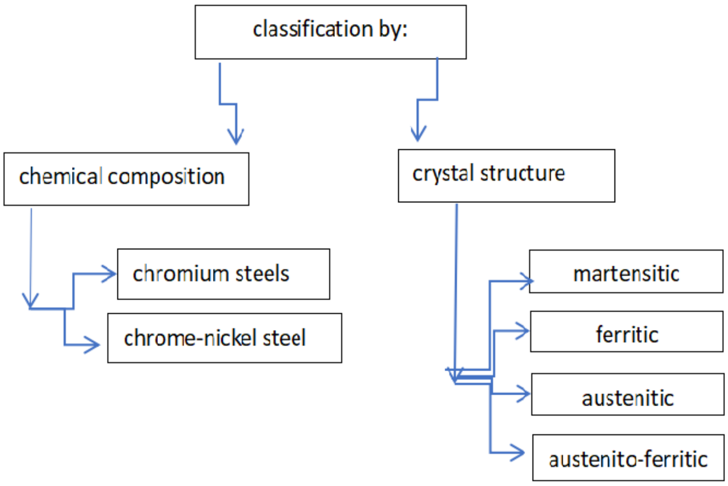

Fig. 2. Classification of stainless steels [2,3]

The properties of stainless steels vary with Cr, Ni and carbon content. The average base composition of stainless steels is: 18% Cr and 9% Ni. The carbon content is less than 1.2%, for those steels that show properties of resistance to aggressive environments, resistant to corrosion. The corrosion resistance is based on the formation of a passive film on the surface, the stability of which increases with the chromium content and can be further increased by alloying with molybdenum. The passivity is ensured by the thin film of hydrate metal oxide, in which an enrichment of chromium is produced compared to the base metal.
The formed film is able to maintain a state of equilibrium with the working environment, and becomes difficult or not at all penetrable for other environments. Once the steady state is reached the corrosion will be of negligible magnitude.
The following types of steel with maximum corrosion resistance are distinguished:
- 18-10 type steels with 0.02 - 0.15 % C;
- steels with improved corrosion resistance by adding molybdenum and copper;
- steels resistant to hot oxidation by adding silicon;
- steels whose wear is improved by adding sulphur, selenium, copper, etc.

The more homogeneous the crystalline structure of stainless steels, the more favorable their properties.
An important role in achieving the homogeneous crystalline structure belongs to the applied heat treatment process.
Thus, stainless steels can undergo structural changes under the action of:
• a thermal treatment (imposed by the manufacturing process);
• cold plastic deformation (austenitic steels);
• a thermomechanical treatment at high temperature (subject to mechanical stress at high temperature).

3. Corrosion resistance of austenitic stainless steels

Destruction by corrosion is a very complex phenomenon, in many cases it causes a change in their properties, which leads to a sudden decrease in mechanical strength. Depending on the steel nature, the aggressive environment, as well as the working conditions, the corrosion rate may remain constant, increase or decrease over time. A metal or an even "stainless" alloy can be very resistant under certain conditions, but can become unstable under others, corroding heavily.
This explains the large number and variety of methods for testing and measuring corrosion resistance, taking into account the changes caused by corrosion in the physical and chemical properties of metals and alloys. The plastic deformation of stainless steels produces important changes in their structure and properties, which influence corrosion resistance [4]. This, in some conditions, can lead to the breaking of the passive film (mechanical depassivation), which can cause the appearance of local or even generalized corrosion. To remedy this phenomenon, a chemical repassivation can be resorted to, using appropriate technologies. The passive film stability, which protects stainless steels against corrosion, is conditioned by a large number of factors: physical-chemical, metallurgical, mechanical, geometric and microbiological. Breaks that can occur in this protective film can lead to various forms of localized corrosion, such as stress corrosion cracking or to the formation of peaks. More significant depassivation can cause cavitation or even the appearance of generalized corrosion. In the case of austenitic stainless steels, the presence of chromium (over 12-13%) ensures the formation of the protective passive film. At the same time, the presence of carbon can also be a factor that contributes to the passive film destabilization, since this element tends, when hot, to form chromium carbides with good stability and chromium is thus no longer available to participate in the passivation of the material (its concentration falls below the allowed limit of 12-13%). Under the action of a superficially applied mechanical deformation, two independent phenomena can occur: a mechanical depassivation and a change in the microstructure. The mechanical depassivation is due to the breaking of the passive film caused by the appearance of important stresses during the manufacturing process of the part, and generalized corrosion may occur. To remedy this phenomenon, a chemical repassivation is often resorted to after alloy deformation, using appropriate treatments and baths. 8 types of hydraulic oil with relatively similar properties and

contents were tested. 5 of these, from the same range (RENOLIN) [5] intended for the technological flow for the processing of steel, alloy and metal parts have recorded close performances. For the 5 types of hydraulic oil, the tests were repeated by increasing the number of operation hours for the same operating conditions (same type of machined part in size and shape and the same material) with each of these oils.

Table 1. Presentation of the 8 types of hydraulic oils tested

FLUID CODE	Hydraulic oils/Industrial lubricants
HYDROTHERM 46 M	Fire-resistant hydraulic fluid from the HFC group
RENOLIN AR-SERIES	General lubricating oils based on mineral oils, lubricating oils according to DIN 51501: L-AN
RENOLIN B 46 CP	AW high-quality hydraulic oil for highly stressed hydraulic circuits
RENOLIN B HP PLUS-SERIES	High-quality AW/EP hydraulic fluids and hydraulic oils based on special base oils of the latest generation in combination with new additive technology
RENOLIN MR3 VG10	HLPD special hydraulic and lubricating fluids, according to DIN 51502, with outstanding corrosion protection and strong cleaning and dirt-carrying capacity, Excellent oxidation stability based on high-quality hydrated base oils; ISO 6743-4: HM with DD performance
RENOLIN CLP PLUS-SERIES	Specially approved, long-term gear oils with very high aging stability and excellent detergent characteristics (DD) – self-cleaning oils
RENOLIN MR 310/520/1030	Multi-application oils for bearings, transmissions and hydraulic systems with excellent viscosity-temperature behavior for low temperature applications, detergent / dispersant
RENOLIN ZAF D HT-SERIES	Universal zinc and ash free hydraulic fluids and industrial gear oils with very high aging stability and excellent wear protection, detergent / dispersant

With all these aspects in mind, RENOLIN MR3 VG10 hydraulic oil was chosen after the test period was completed. The analysis of hydraulic oil samples was carried out after the manufacture of the same type of part (in number of 190 pcs) and the number of hours of operation (3-4 part/h, 6h/day, 10 days of tests, approximately 60 hours of operation) of the EMCO/MCX-600 machine tool.

Fig. 3. Counter for the operating hours number

Fig. 4. Hydraulic oil samples analyzed

This type of hydraulic oil identified and tested confirmed the characteristics given by the technical data sheet [6] and the guide for understanding the DIN 51502 codes on the designation of lubricants, namely:
- excellent oxidation stability;
- HLPD according to DIN 51502 [7];
- protection against corrosion;

- strong cleaning capacity;
- meets and exceeds the requirements according to DIN 51524-2 HLPD;
- ISO 6743-4 HM[1] with DD performance [8]

RENOLIN-MR-3-VG-10 is a hydraulic lubricating fluid that:
- contains: detergent, dispersant, refined oils and additives
- has the following physico-chemical properties:
  - density (15 ^oC) = 0.84 g/cm^3;
  - kinematic viscosity at (40 ^oC) = 10 mm^2/s and at (100 ^oC) = 2.7 mm^2/s;
  - ignition temperature 160 ^oC;
  - insoluble in water;
  - characteristic smell;
  - translucent yellow;
- does not present risks for human health (operator) through handling and exposure with appropriate equipment.

The lubrication capacity of the selected fluid is based on the ability to form a resistant film, a fact that determines the performance of the process carried out with a reduced energy consumption, determined in principle by the reduction in a significant proportion of the frictional forces. Different additives or surface-active chemical compounds in the composition of hydraulic oil are substances with low surface tension with a double hydrolytic function (they change the surface tension of the fluid in which they are introduced in small concentrations) and adhere to the metal surface with which the fluid comes into contact, forming a capillary-active film. These agents in different concentrations, in relation to the HLB (hydrophilic-lipophilic balance) value, can provide the lubricant film with a high breaking resistance by acting as an extreme pressure (EP) agent.

In contact with the cylinder surface, it adheres due to adhesive forces, forming physical adsorption or even chemosorption films resistant to very high surface tensions. This phenomenon is also due to the fact that the active substances form pseudo-stable compounds on the metal surface that compose a continuous fine film that covers the surface in contact, substantially reducing friction, thus ensuring smooth sliding.

Due to the physico-chemical affinity determined by the surfactants, the additive fluid achieves important effects, namely:
- improves the sliding coefficient (good resistance to high pressures);
- causes a lubrication of the sliding surfaces that reduces the internal friction force (releases potential centers preventing the formation of micro agglomerations with various impurities).

Through all these cumulative effects, hydraulic fluids contribute to the reduction of frictional resistance and implicitly to the reduction of energy consumption in the processes used. Therefore, an effective lubricated system must provide a balance between lubrication and cooling. Theory has shown that at a lower coefficient of friction lower rolling forces are required. Implicitly, in this situation wear phenomena are reduced and the amount of heat generated by the friction that occurs at the working contact on the technological flow is reduced. In such conditions, it is allowed to increase the speed and as a consequence energy and material consumptions are reduced, especially of the cylinders whose wear is slower. Friction and lubrication are influenced by a number of parameters such as fluid properties, temperature, sliding speed, contact pressure. From the point of lubricant view, parameters that affect friction and lubrication, respectively parameters depending on which the performance of a lubricant and the coefficient of friction vary, are: viscosity, thickness of the lubricant film, pressure stability, temperature stability, additives used in a special regime of work (pressure and temperature). The oil film thickness is directly proportional to the viscosity. Research has shown that an increase in the degree of long-term wear of hydraulic oils can lead to an amount of carbonic residues of 0.9 - 2 mg/L. Carbon residues could be limited by choosing an improved waste oil filtration system. Their presence leads to a strongly favourable environment for the oil oxidation process to take place. During the heat treatment, the residual products formed react with the gaseous products, and cause the formation of areas with carbon concentrations on the surface of cylinders of the drive systems. The knowledge and control of the phenomena that occur due to the poor quality of the hydraulic fluids used, correlated with the other

[1] *HM: with active substances to increase anti-corrosion protection, resistance to aging as well as to reduce frictional wear in the contact region*

process parameters, allow the establishment of optimal characteristics that lead to the realization of high-performance products from a qualitative point of view [4]. Considering the aspects mentioned above and the recommendations from the specialized literature, we can consider that the selected oil RENOLIN-MR-3-VG-10 use is indicated. The equipment and machine tools used for various manufacturing processes imply a high degree of increase in demands in establishing the hydraulic fluid and the parameters of the manufacturing technological flow. Thus, in the case of the EMCO machine tool, the demand for a very good viscosity stability and chemical inertness was taken into account, characteristics that are met by the selected oil that is part of the range of those recommended for these requirements such as: synthetic fluids from silicon oxide polymers, compounds based on ethers or other synthetic fluids.
It should be noted that at ultra-high pressures of over 30 kbar and not too high temperatures all liquids solidify. In these conditions, it is recommended to use media such as: polyfluoroethylene, silver chloride, etc.

4. Wear and repair of hydraulic equipment used in the manufacture of parts and subassemblies

In order to prevent excessive wear of the EMCO/ MCX-600 type hydraulic equipment used in the technical machining processes, the following aspects are taken into account, namely:
- use according to the conditions specified in the technical book/user manual;
- the use of hydraulic oils and emulsifiable oils according to the specified indications (time, concentration, temperature), for each type of operation performed;
- verification and maintenance according to the maintenance plan developed in accordance with the imposed rules;
- current repairs and specialized capital repairs;
- measures to carry out the repair of the machine safely.

Drawing up the maintenance schedule requires taking into account all the factors that influence the safety of the machine's operation, namely: the load and volume of work, the work pace, the operator, hand carrying out the repair by specialists, corresponding to the machine complexity and the type of repair. The introduction of advanced technologies ensures the repairs quality, the increase of work productivity and the cost price reduction by accurately determining the defects, wear areas and their size on the parts in operation. The actual conditions in which parts work are a function of physical properties (coefficient of thermal expansion, coefficient of linear expansion, temperature coefficient of resistivity), mechanical properties (mechanical strength, toughness, hardness, stress and wear resistance) and the appropriate technological flow. Depending on the condition of the oil film formed, the parts surfaces in friction are completely separated, the external pressure being taken up and transmitted through the moving oil layer. Although the oil layer thickness is very small, the lubricant movement occurs by neglecting the inertia forces and the weight of the fluid, the effect of viscosity being predominant. To reduce friction, fluid friction and the use of quality lubricants are necessary. In this way, boundary friction can be combated, a phenomenon that occurs when the load increases a lot, the relative speed decreases, and the lubricant layer between the surfaces is very thin. The boundary layer avoids erosion wear. Also, the semi-fluid friction that occurs between surfaces with a continuous oil film but of variable thickness, a phenomenon that frequently occurs during overstressed mechanical operations or worn parts and is unavoidable in long-term processes, can also be dimmed. Thus, it is necessary to apply the appropriate technical operation measures such as: greasing the mechanisms, supplying with good quality hydraulic oil, proper adjustment but also observing the operating rules of the used equipment.

5. Conclusions

The quality of the selected and used lubricating fluid refers to good chemical stability, appropriate viscosity, an adequate content of refined oils and additives with anti-corrosive effect, good cleaning ability and oxidation stability. From the analysis of RENOLIN-MR-3-VG-10 type hydraulic oil samples after several cycles of operating hours, it is found that the use of this fluid allows the

formation of resistant films, which eliminate boundary or semi-fluid friction. In high temperature conditions, the addition of detergent, dispersant and additives improves the functionality of the mechano-hydraulic drive system for the performed chipping operation. The hydraulic oil reduces the wear of the EMCO/MCX-600 industrial CNC machine tool by maintaining the parameters (pressure, temperature, viscosity, etc.) within limits that do not affect the physical-chemical properties of the fluid and the adherent film in the hydraulic contact area. The functionality of the hydraulic machine is closely related to the wear uniformity of the main component elements and to the change over time in the structure and physico-chemical properties of the materials. The use of lubrication with a quality hydraulic fluid to form a film of hydraulic oil between the friction surfaces of the cylinder aims to:
- reducing the friction effect;
- preventing and reducing machine wear and temperature;
- increasing the tightness of cylinders;
- anti-corrosion effect on the parts.

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