FINDING THE ACTUAL CAUSES OF HYDRAULIC CYLINDER FAULT

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ABSTRACT
Hydraulic cylinder malfunctions are very common causes for the failure of the operation of the hydraulic system. Most common causes are in cylinder's seal failure, whereby the error by replacing the seals can be relatively quickly eliminated. In the case of frequent occurrence of the same failure, the problem should be more carefully addressed.

The focus of the paper is searching for the actual cause of the frequently repeated failure of the closing cylinder on the plastic blow-moulding machine. The solution of the problem presented was the use of a combined approach: analysis of wear particles in the oil, and measurement of the accuracy of the motion of the cylinder's piston rod.

Keywords: blow-moulding machine**,** hydraulic cylinder, seals failure, causes

1. INTRODUCTION
On the blow-moulding machine for production of plastic canisters with volume up to 5 L, a fault on the closing part of the machine occurred periodically. Opening and closing of the tools is carried out by means of a hydraulic cylinder with dimension of 125/80 (Figure 1).

Figure 1. Closing unit together with tool (left) and closing cylinder (right)

Based on the detailed inspection of the entire machine, especially the hydraulic components and the machine control system it was found out, that the cause of the fault could be in the hydraulic cylinder, because after replacing the hydraulic cylinder with the new one, the machine was working properly. But after a certain time, the same error occurred again. A repetitive errors lead to a longer standstill of the machine, due to the purchase and installation of the new cylinder, causing a huge loss of production downtime.

After dismantling, disassembly and detailed inspection of the cylinder, the consequences of wear on the inner surface of the cylinder were observed - the damaged surface of piston rod, cylinder (scratches), and damaged seals – Figure 2.

Figure 2. Damages on the piston rod and the seal

2. COMMON CAUSES OF HYDRAULIC CYLINEDR DAMAGES

The causes that can lead to the cylinder damage and its seals are numerous and are very different. A proper equipment inspection, a preventative maintenance procedure, a proper cylinder design and installation… can all decrease the chances of these common cylinder failures. The most common causes of faults in hydraulic cylinders and seals are as follows.

Seal installation - Improper installation is a major cause of hydraulic seal failure. The important things to watch during seal installation are: cleanliness, protecting the seal from nicks and cuts, and proper lubrication. Other problem areas are over tightening of the seal gland where there is an adjustable gland follower or folding over a seal lip during installation. Installing the seal upside down is a common occurrence, too. The solution to these problems is common sense and taking reasonable care during assembly.

Side loading of cylinder - Side loading is the most common cause of wear and cylinder failure. A common result of side loading is cylinder misalignment, which creates an unusual force on the piston rod. A side load of enough magnitude can result in tube scoring, piston rod and rod bearing wear, and even seal failure.

Contaminated Fluid - Contaminated fluid can cause premature rod seal failure. Abrasive particles in the fluid can damage the seal and the piston rod surface; airborne contamination can be drawn into a cylinder by a faulty wiper seal. Contamination occurs in numerous ways, the most common is drawn in from oil or from the pump.

Proper Fluid Conditioning - Check for and remove any dirt or foreign materials in the hydraulic fluid. Be careful not to introduce aerated fluid which can cause sound level issues. Verify the filtration system is operating properly. Finally, inspect filter elements for clogs and replace as necessary.
Rough or scored rod - It is crucial to ensure the cylinder rod is in good condition. Rough places on the rod damage the seals and reduce their normal life resulting in the necessity for

frequent replacement. Be sure to inspect the rod finish as well. Worn seals are caused by too smooth of a finish, while leakage past the seal is caused by too rough of a finish.

Chemical causes - Chemical breakdown of the seal material is most often the result of incorrect material selection in the first place, or a change of hydraulic system fluid. Misapplication or use of non-compatible materials can lead to chemical attack by oil additives, hydrolysis and oxidation reduction of seal elements. Chemical breakdown can result in loss of seal lip interface, softening of seal durometer, excessive swelling or shrinkage. Discoloration of hydraulic seals can also be an indicator of chemical attack.

Impact of heat - Heat degradation is to be suspected when the failed seal exhibits a hard, brittle appearance and/or shows a breaking away of parts of the seal lip or body. Heat degradation results in loss of sealing lip effectiveness through excessive compression set and/or loss of seal material. Causes of this condition may be use of incorrect seal material, high dynamic friction, excessive lip loading, no heel clearance and proximity to outside heat source.

According to the above, the causes of the cylinder damage can be very different. The actual cause of the repeated damage can be determined only by the appropriate analysis of the individual cause using the elimination process.

3. RCA APPROACH

An effective procedure for finding the real cause of the fault offers Root cause analysis (RCA). RCA is a systematic process for identifying “root causes” of problems or events and an approach for responding to them.

The chemical influence of the seal decomposition due to simultaneous damage to the piston rod, as well as the thermal causes (e. g. elevated temperature) were eliminated. The causes of incorrect installation of the seal and material used also fall off, because the identical cylinder of the same manufacturer has been replaced for some time without any problems. So we can pay more attention to the other causes.

3.1. Cleanliness of the hydraulic fluid

Due to the extensive damages on hydraulic cylinder (see Figure 2): visible metal parts of wear, damaged seal... it is absolutely essential to check the condition of the hydraulic fluid, not only the cleanliness level of hydraulic fluid, but also the other parameters, for example, water content, hard particles... - a complete laboratory analysis of basic properties.

Especially because the fact, that high quality hydraulic components are used, e. g. a pilot operated directional control valve with integrated electronics, which requires the use of an appropriate cleanliness level of hydraulic fluid (a component of the servo hydraulics!). Otherwise, there will be irregularities in the operation of the machine resulting from the wear of hydraulic components and / even causes of sudden failure of a certain function.

In accordance with valve manufacturer recommendations (data sheet!), the use of hydraulic mineral oil of HLP 46 quality, is recommended. Regarding the recommended oil cleanliness level, the manufacturer prescribes the following requirements:

Maximal permissible fluid contamination class, according to ISO 4406 (c)	Valve pilot stage	class 17/15/12
	Main valve stage	class 20/18/15

Considering the fact, that both the pilot valve stage and the main valve stage are supplied from the same source, the cleanliness of the oil should be handled according to a higher requirement, that is, for the pilot valve: 17/15/12! The oil cleanliness level in the hydraulic system is always determined with regard to the most sensitive component built into the system! In the case of the use of such components, a high-pressure filter is also present.

In order to determine the actual state of the hydraulic fluid, a sample of the oil from the hydraulic reservoir (a Minimess measuring port or a dynamic oil sampling attachment cannot be observed on the aggregate) was taken and sent for detailed analysis to the appropriate, certified laboratory (OLMA d. o. o., Ljubljana).

Sample	1
Appearance of oil - visually	clear oil
Flash point ASTM D 92 (°C)	258
Viscosity /40 °C ASTM D 445 (mm^2/s)	44.24
Viscosity /40 °C ASTM D 445 (mm^2/s)	6.83
Viscosity index ASTM D 2270	109
Neutralisation number ASTM D 974 (mg KOH/g)	0.57
Cleanliness level ISO 4406 NAS 1638	21/19/15 11
Water content ASTM D 4377 (ppm)	316.0
Additive elements ASTM D 6481 Phosphorus (P) (wt. %) Zinc (Zn) (wt. %)	 0.065 0.0463

Figure 3. A section of the laboratory report of general parameters

The following conclusions and recommendations are based on the results of the laboratory analysis of the oil sample. The oil contains water. The content is still in the permissible range, and due to the non-homogeneous distribution in the oil, the content in other places in the system is also significantly higher (it should be noted that the sample was taken from the upper part of the reservoir).

The cleanliness level of the oil is too low for this hydraulic system, which contains the components of the servo systems. On the basis of experience, it can be assumed that the cleanliness level in case of in-line sampling it would be better for one to two levels, but the but there would still be no change in opinion on the lack of fluid cleanliness.

3.2. Additional laboratory analysis

The number and size of particles in oil are very useful parameters in contamination monitoring process of hydraulic fluids and represents the state of the art in the field of Condition Monitoring of hydraulic fluid. They enable determination of cleanliness level and comparison with hydraulic equipment producer specifications. The most convenient way for cleanliness level determination is use of automatic particle counters. Particularly when the cleanliness level is outside of recommendations, we usually want to find material and source of particles.

A general analysis of hydraulic fluids, including cleanliness level measurement, gives no answer about material and source of contaminants. One method that gives an answer about material of particles in oil is X-ray fluorescence spectrometry (XRF). XRF-method enables determination of concentration of different chemical elements; indirectly it gives an opportunity to make inferences about their source.

To monitor contaminants, we must first understand how they get into the system. The first of four major contaminant sources is in the original fabrication process. Even the best-made systems can have some degree of residue in the form of dust, grit, paint chips, or other debris that remains from fabrication. For new or rebuilt systems, a "running-in" period is suggested to completely flush out the contaminants.

A second source of contamination is from air that gets into the system. Typically, hydraulic systems allow a certain amount of air to enter and circulate to compensate for fluctuation in the fluid level due to thermal contraction and expansion. Though necessary, this air can contain microscopic bits of dirt that contaminate the system.

A hydraulic fluid can also be contaminated when new oil is added. Although hydraulic fluids are blended under clean conditions, by the time they reach the system, they would have passed through so many pipes, hoses, and pumps, that it is almost certain that contaminants would have been brought along with them.

Finally, contaminants are generated through the wear that naturally occurs in the system. Even a system running on clean fluid is subject to the natural erosion of its components, and although commonplace, this source of contamination is the most harmful. If the contaminated particles are not quickly collected and removed, they create even more particles at an accelerated rate, exponentially increasing the likelihood of a breakdown.

3.3. Importance of wear metal analysis

Monitoring and controlling problems that lead to active machine wear are critical to an effective oil analysis strategy. For this reason, educated oil analysis users focus their attention on contamination monitoring and control, and on ensuring that the physical and chemical properties of the oil are in good condition. Nevertheless, no matter how effective a proactive lubrication management program might be, at some time or another, a component will start to show signs of wear. This is where wear analysis comes into play. This is especially important in case of hydraulic system and components.

When it comes to wear analysis, there are a number of test methods available, from simple tests (such as assessment of contamination level – quantity of contaminants), to sophisticated tests such as elemental analysis. Each test has its advantages and limitations when detecting and analysing active machine wear. For this reason, it’s important that users of oil analysis become familiar with which test is appropriate for specific situations, enabling the selection of the most appropriate test for routine and exception sample analysis.

Advanced warning of abnormal wear in high value, high mission critical assets, provides important options otherwise unavailable to decision-makers. With advanced warning of failure, a better understanding of the nature of the problem can be obtained, reducing uncertainty about maintenance decisions and enabling the scheduling of maintenance actions. Secondary damage may be avoidable by identifying and removing the worn parts.

To gain an understanding about the failure, the wear particles generated during the wear process should be analysed with intention to forecast wear related failures in e.g. hydraulic system. In Table 1, are as illustration given the some metal elements, which are often found in hydraulic fluids, their possible source and a recommended, allowed concentration.

Table 1. Recommended and still acceptable concentration of wear metals in hydraulic oil

metal	Possible sources	Industrial hydraulic	Servo hydraulic
iron	Hydraulic pump, hydro motor, valves, **piston and rod**, cylinder, roller bearing, pump housing, pipelines, sealing rings	3 to 15 ppm	1 to 7 ppm
chromium	Roller bearing, vanes of (Vickers) vane pumps, **chromate parts e.g. piston rods**,	2 to 8 ppm	1 to 5 ppm
copper	Component of brass and bronze, **parts of pumps** e.g. valve plates, pistons, guiding rings, ball races, oil chillers, bearing rings,	10 to 40 ppm	2 to 10 ppm

In the present case additionally X-ray fluorescent spectrometry (XRF) was carried out. The result of the XRF analysis is a spectrum, with energy on x-axis - regarding the element (material) and its intensity on y-axis. Using a computer programme we can directly compare two spectra of the same fluid - the fresh and already used-up, heavy contaminated the same type of hydraulic oil - Figure 4.

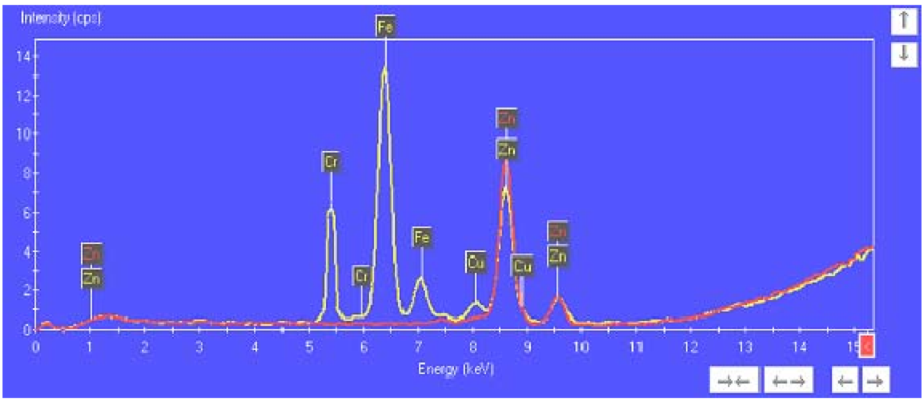

Figure 4. Comparison of fresh (red spectrum, ISO 4406: 22/21/18) and used-up hydraulic oil (yellow spectrum, ISO 4406: >24/24/19

On both spectra presence of wear particles respectively metal in hydraulic oil is evident. In case of fresh oil the particles of Zinc (Zn) are observable present, in case of used-up oil but beside Zinc as well Iron (Fe), Chromium (Cr) and Copper (Cu). It is known that Zinc is present as an oil additive element, therefore present on both spectra. Comparing their peaks by used-up oil, its intensity is lower, because of consumption this additive in oil.
The presence of all the other elements, as a deviations in intensity the spectra, are only the consequence of the wear processes. This information represents a very useful directive to look for place or component, where are they generated.

4. MEASURING OF CYLINDER MOTION ACCURACY

Due to the presence of excessive wear debris in particular iron and chromium, it was considered that the origin of this combination of damage to the piston rod of the hydraulic cylinder. The cause of the piston rod damage is certainly in the incorrect motion of the piston rod or/and the presence of side forces, which consequently lead to the wear of the piston rod (which is chromed) and the inner cylinder surface (iron). The presence of side forces during the piston motion was verified by measuring the uniformity of motion in two rectangular planes - Figure 5.

Figure 5. Motion accuracy measurement in two directions using precise gauge

On the basis of the measurements, it was found that a larger transverse displacement of the piston rod occurs at the end of the movement, when the tool is already closed and leans on the support point - in this case, on adjustable screw. The movement was inaccessible to 1,125 mm, which already led to the wear of the surface of the piston rod (visible to the naked eye) and probably also the interior of the cylinder (the presence of Fe in the oil).

Why is the increased displacement of the piston rod near the end position? The reason is the incorrect adjustment of the support-screw, which also showed strong signs of wear - Figure 6.

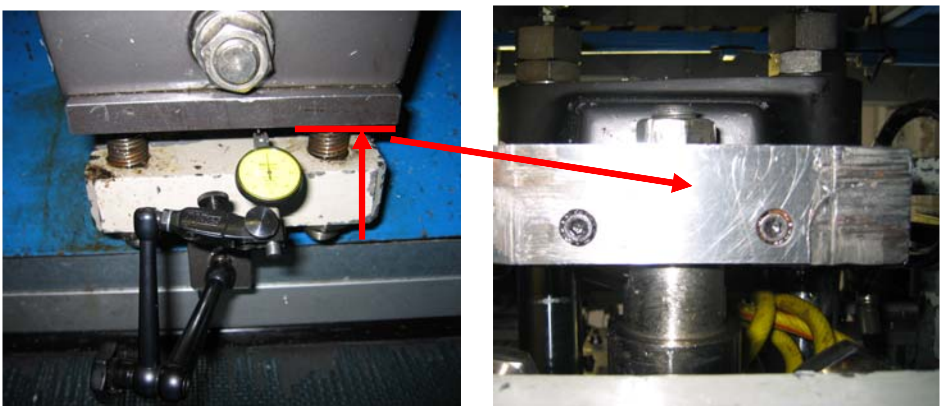

Figure 6. Incorrect adjustment of the support-screw (left) and strong signs of wear (right)

Solving the problem was, in the end, quick, simple and cheap: correct, reinstalling the support screw and re-control with the measurement prevented the worst: further damage of hydraulic cylinder and stopping the machine.

5. CONCLUSION

The presented example illustrates how a detailed analysis of the events and their consequences leading to otherwise repetitive and costly congestion of the machine can ultimately be solved with the minimum costs.

The gradual elimination of possible causes, as well as the use of basic and more detailed analyses, leads to the cause of the error. In our case, a general laboratory analysis of the general hydraulic oil condition, especially the oil cleanliness. On the basis of the results, an analysis of the type of wear particles was additionally carried out. This gave a hint for later locating of failure, based on the measuring the piston rod motion accuracy, throughout the whole stroke, which led to the actual cause - the incorrectly set support-screw.

6. REFERENCES

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