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Modern Techniques for Remanufacturing Hydraulic Equipment in the Context of Circular Economy and Energy Efficiency

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Abstract. The article presents several current methods of remanufacturing hydraulic components, a trend that is encouraged, on the one hand, by concerns about reducing material consumption in the context of the circular economy - some of these materials being expensive or in short supply. On the other hand, remanufacturing by modern methods can lead to a decrease in energy consumption in the devices concerned, due to obtaining shapes that are difficult to achieve by classical procedures. Among the remanufacturing processes considered there are additive manufacturing, metal coating, reverse engineering, etc.

An important step in the remanufacturing process is testing of components, which certifies the achievement of performances at least equivalent to those of the original products. To this end, the article presents a test bench solution with the help of which tests can be carried out on hydraulic devices such as hydraulic pumps and (linear or rotary) motors, hydraulic directional control valves or other types of valves.

Keywords: Remanufacturing, additive manufacturing, reverse engineering, circular economy, energy efficiency, test bench.

1 Introduction

‘Circular economy’ is a phrase that one can encounter nowadays in most areas of industrial production. Mainly, the circular economy involves the re-introduction into the circuit of use of products or materials obtained from other products that can no longer be used [1]. Therefore, in the first phase, the product is put back into operation (if possible), in a state closer to or further away from its original state; the degree of achievement of the initial parameters of the product makes the difference between repair, rebuilt, remanufacturing, etc.

If, for technical or economic reasons, it is no longer possible to put it back into service, the product enters the recycling circuit, by which parts of it or only materials are reused.

In the process of using the natural resources, from extraction to recycling and reintroduction into the use circuit as a raw material, the products can be new or remanufactured, according to the diagram in Fig. 1 below. This means that, in the context of the circular economy, remanufactured products are products that have the same characteristics and performance as those first manufactured, but at a lower cost, as they include some reused parts.

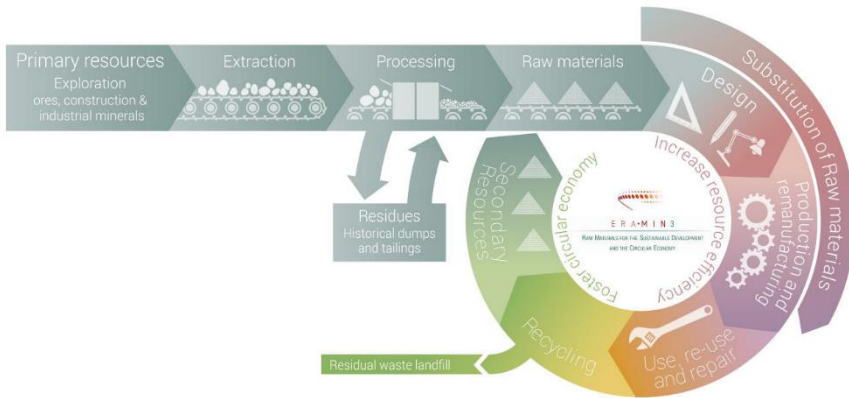


Fig. 1. Manufacturing, remanufacturing, repair and reuse in the context of Circular Economy [2]

Concerns about the circular economy can also be found in the field of Fluid Power. Modern products in the field of pneumatics, but especially hydraulics, include increasingly sophisticated materials and components, leading to a high manufacturing price; replacing such a product with a new one will significantly affect the end user's budget and will be included in the price of the products or services offered by the user of Fluid Power equipment.

That is why the remanufacturing of Fluid Power products, in various ways, is of particular importance. In the following, a definition of the terms in the field will be made, related to specific equipment.

2 Defining specific concepts in the field of Fluid Power

Fluid Power equipment, whether they are power generators (pumps, compressors), distribution and control elements (valves, directional control valves, etc.) or execution elements (linear or rotary motors) can, for the most part, be remanufactured or repaired.

Remanufacturing is a process by which a used and worn out product is brought back to the parameters and condition of a new product; this means, e.g., that a hydraulic pump will have the same volumetric efficiency as a new one, and this parameter will be maintained at similar values for both products for the entire estimated life [3].

A **refurbished** product is a product that suffered minor damage, most often aesthetic, and on which no in-depth intervention is made; wear of such a product is reduced. Such a product will not have the same performance as a new one, as no intervention is made on the main components, but will have a satisfactory service life.

A **rebuilt** product is a product that has undergone an inspection of all components that are defective, worn, or likely to malfunction or wear out; these components are checked and those with defects or wear above the permissible limits are replaced. In the case of a hydraulic pump, the distribution plate will be replaced, but the pistons will be retained, for example. In this case, the service life after rebuilding will be shorter than that of a remanufactured product and, most likely, than that of a refurbished product.

Finally, the **repair** of a product consists of the punctual replacement of a defective component and the removal of the cause that led to its failure, without interfering with other components, regardless of their degree of wear.

It is clear from the above that **remanufacturing** is the most complex process, by which a product with the same characteristics and performance as a new product is obtained, and which is covered by the same operational warranty. For this purpose, the components are replaced or reconditioned by processes that provide a quality at least equal to that of the original ones. For hydraulic equipment, which often works in difficult conditions, in which any failure of the machines has serious repercussions, remanufacturing is the preferred solution.

In the remanufacturing process, depending on the existing possibilities, classic or modern methods are used:

- Classic machining
- Metal coating
- Additive manufacturing

Obtaining shapes and sizes, if the original documentation is not available, can be done by **reverse engineering**.

When reverse engineering an equipment a commonly way for one to follow is to start by accurately measuring the dimensions of key components in the equipment in question. Nowadays, engineers often use 3D scanning technologies to make these kinds of measurements as they can gain accurate readings of the specifications of a product and automatically transfer this information in their databases. The information that has been gathered and recorded is then used for subsequent analysis and redesigning by creating computer-aided design (CAD) drawings. In the case of hydraulic repair, after completing the steps of measuring the dimensions and redesigning, the parts - being made of metal – go through either computer numerical control (CNC) machining or classic (manual) machining.

As techniques have evolved from manual measurements to using the possibilities that lie within 3D scanning and CAD programming, reverse engineering has become a much easier and faster process. In many cases, it is not even necessary to deconstruct manually the components and equipment whose design needs to be replicated, thus avoiding the risk for some parts to be lost or misplaced. Moreover, using 3D scanning and CAD programs for reverse engineering purposes is most suitable for parts with

complex geometry; it shortens significantly the time required before such parts can enter the machining or production process.

Remanufacturing by **metal coating** [4, 5]. Hard coatings based on binary transition metal carbide have been extensively studied in recent decades, being considered ideal protective coatings for a variety of applications due to their high hardness and strength, good thermal conductivity, thermal and chemical stability, low friction and excellent wear, erosion and corrosion resistance. They have a mixture of covalent, ionic and metallic bonds that define their properties. Improving the performance of carbide coatings has been achieved so far by adding various elements in the composition of traditional binary coatings (TiC, ZrC, WC, MoC, VC, TaC, CrC). Various strong or weak metals that form carbides, as well as non-metals (Si, B, S), were chosen as alloying elements and the resulting coating properties received much attention due to their high hardness, chemical stability even at high temperatures (1100 – 1200°C), ductile mechanical behaviour, wear and oxidation resistance, low coefficient of friction, as well as good electrical and thermal conductivity. This method is used on components such as axial piston pump distribution plates, hydraulic cylinders, pump pistons, etc.

One of the most promising techniques in hydraulics is that of **additive manufacturing (3D printing)**.

This manufacturing technique is essentially different from the classical one, in which a metal block is processed by removing material; in additive manufacturing, shapes are obtained by adding layers, according to a "map" generated by the CAD drawing of execution for the machine. The mechanical and pressure resistance of the parts is obtained through an appropriate number of layers.

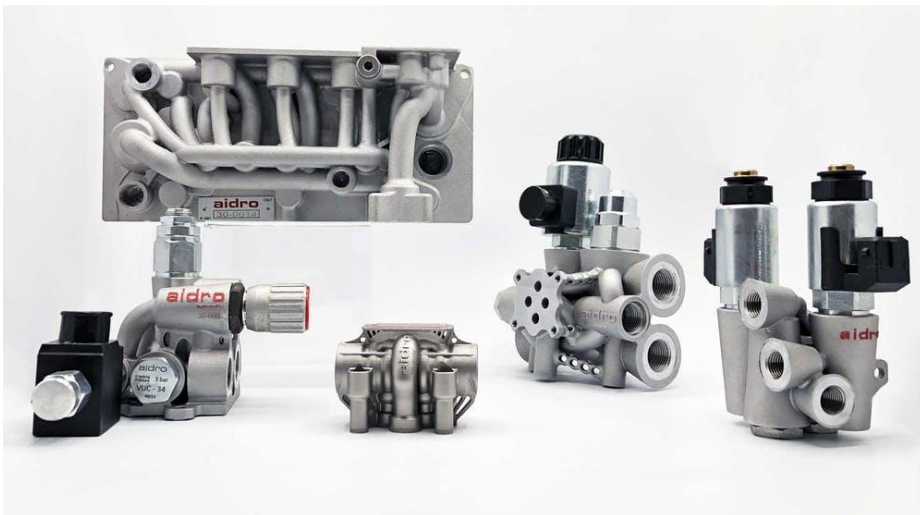


Fig. 2. Hydraulic components produced through metal 3D printing [6]

Aidro Hydraulics & 3D Printing has achieved remarkable results (see Fig. 2 above) in recent years using this manufacturing technique [6, 7]. The main advantages are the following:

- One can achieve more complex structures than those achieved by classic machining; this makes it possible to connect several devices on shorter routes, which results in reduction of energy losses along the routes (pressure drops);
- One can achieve routes that, by their shape, reduce the pressure drops;
- The amount of material used is significantly reduced; at the same time, the amount of energy required to achieve the product decreases;
- Especially in the case of mobile hydraulics, reducing the weight of the components is beneficial for the energy consumption of the machines; this is even more important in the case of motor vehicles that use electric batteries to ensure the movement and operation of working systems.

Regardless of the technique used for remanufacturing, the quality of such a product is certified at the end by testing on specialized test benches; most companies that perform remanufacturing services have complex benches for testing, and some of them also offer such equipment to other companies interested (e.g., MH Hydraulics – Netherlands).

3 Model of a test bench

Hydraulics and Pneumatics Research Institute offers, in addition to repair or remanufacturing services, specialized benches for the final testing of equipment. Depending on the type of devices to be repaired, the benches can be simple or more complex.

In the following, a complex bench will be presented, which allows the testing of several types of hydraulic devices: pumps, linear (cylinders) and rotary motors, directional control valves, etc. [8]. As the bench has been built at the request of a technical higher education entity, it can also be used in the educational process, in order to impart with students specific knowledge in the field of hydrostatic drives. Due to the high values for pressure and flow rate that one can achieve, one can use the bench for testing industrial equipment, as well.

3.1 Structure and characteristics of the equipment

The structure of the bench has been designed to meet the two purposes, educational and lucrative. Thus, a complex structure has been created, which would provide information about several types of devices: pumps, motors, directional control valves. For this purpose, the bench has been designed in a modular structure, consisting of four parts:

1. SAH / SBS – bench basic structure
2. SAH / MHL – subassembly for linear hydraulic motors
3. SAH / MHR – subassembly for rotary hydraulic machines
4. SAH / BAE – equipped auxiliary tank

One can see the four subassemblies in Fig. 3 below. On the basic structure of the test bench, (SBS) one can identify six subassemblies in the same figure: *1.0* – Main electric pump; *2.0* – Devices block A; *3.0* – Pressure and flow rate measuring subassembly; *4.0* – Filtering and control electric pump; *5.0* – Devices block B; *6.0* – Oil tank.

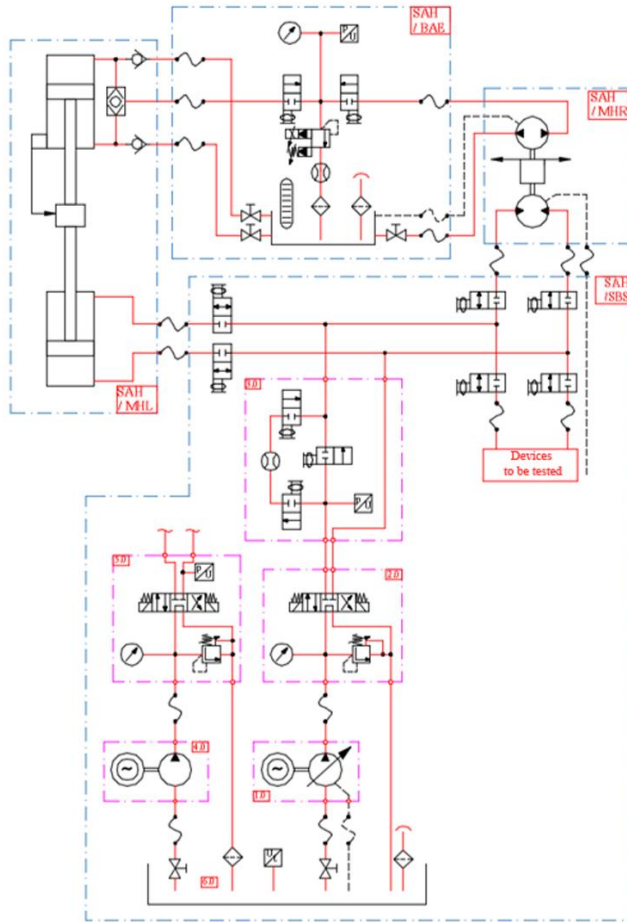


Fig. 3. Hydraulic schematic diagram of the test bench

In this structure, the test bench has the following main features:

- Main electric pump: made with axial piston pump, with variable flow, maximum cylinder capacity of $70 \text{ cm}^3 / \text{rev}$, maximum pressure of 320 bar, electric drive motor power: 45 kW.
- Filtering and control electric pump: gear pump, displacement volume of $6 \text{ cm}^3 / \text{rev}$, maximum pressure of 250 bar, electric drive motor power: 4 kW.

3.2 Physical and virtual bench control panel

The control of the bench for hydraulic component testing applications is done from a bench control panel, which manages the operation of the four subassemblies by means of a programmable logic controller (PLC). The controls for starting the pumps and selecting the solenoid valves are made by pressing physical buttons located on the panel

console. Also with the help of physical buttons, up / down type, one can adjust the flow and pressure rate in the system. The transducers located in the system are connected to the analog inputs of the PLC, and parameters values read are transmitted via the Modbus TCP / IP protocol over the LAN.

For remote operation and monitoring of the bench (in teaching activity) a computer application has been developed that can run on any computer connected to the LAN. The application has a built-in Web server, which allows access from mobile devices to view parameters and make settings for values of flow and pressure rates.

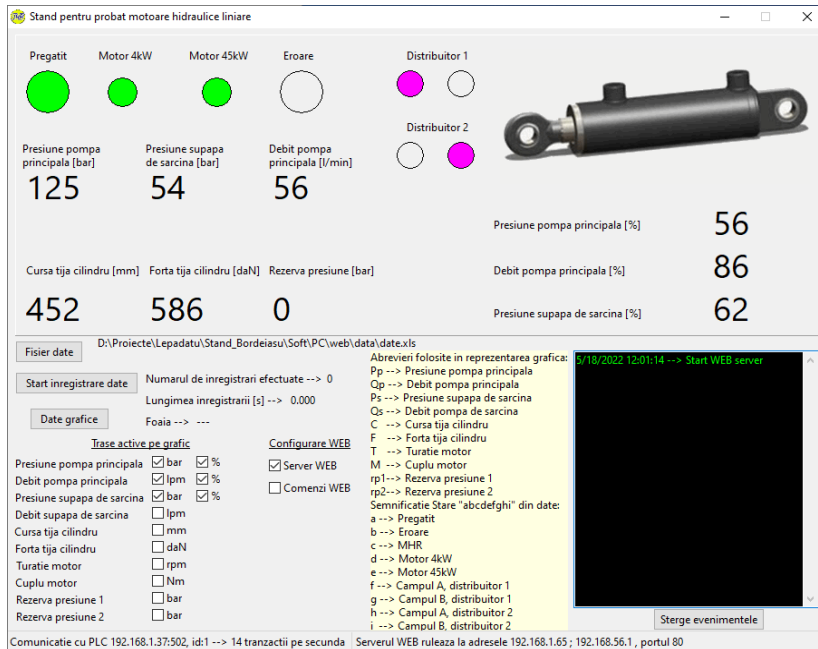


Fig. 4. The main panel of the PC application for control and data acquisition

4 Conclusions

The article presents some basic notions regarding the processes by which industrial equipment, in general, and hydraulic equipment, in particular, are restored to a working condition close to or similar to that from the initial production. The production of component parts or subassemblies can be done by classical methods - the ones initially used in manufacturing - or by modern methods, such as 3D printing.

Any process of restoring the initial parameters has to be certified by laboratory tests; this implies the existence of appropriate means of testing, such as a test bench. In the second part of the article, such an equipment is presented, which allows tests to be performed on most hydraulic components. In a simplified version of operation, addressed to students in higher technical education, the bench can be monitored and controlled remotely with the help of a computer application installed on a mobile device.

The wide range of hydraulic parameters (pressure, flow) and total installed power enable as destinations both teaching use and testing services for equipment in industrial and mobile applications.

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