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RELIABILITY AND FAILURE ANALYSIS OF HYDRAULIC DRIVE SYSTEMS OF MOBILE MACHINERY

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Abstract. *The paper presents the analysis of the hydraulic system of the S1202 excavator from the perspective of operation and reliability. The main hydrostatic circuits of the machine are investigated, highlighting the role of 4/3 directional control valves, volumetric pumps, and actuators (hydraulic cylinders and motors) in performing the working functions. Based on the functional schemes, the system is modeled as a series-type structure, in which the failure of any component leads to the unavailability of the entire system. Additionally, aspects related to the defectology of hydrostatic systems are analyzed, as well as their influence on the reliability and maintenance of mobile machinery. The study also considers the application of reliability indicators, such as failure rate and mean time between failures, for evaluating system performance. These parameters allow a quantitative assessment of component behavior and support decision-making processes related to maintenance planning, system optimization, and the overall improvement of hydraulic equipment efficiency. The results highlight the importance of understanding failure modes in order to improve the design and operation of hydraulic systems, with a direct impact on increasing reliability and reducing maintenance costs. The obtained results emphasize the influence of hydraulic system reliability on the operational performance of the analyzed excavator.*

Keywords*: excavator, hydraulic system, reliability, hydrostatic installations, hydraulic control valve, defectology, maintenance*

INTRODUCTION

Hydraulic drive systems represent fundamental components in the operation of modern mobile machinery, being widely used in construction, agriculture, extractive industry, and transportation. They are preferred due to their ability to generate high forces, ensure precise motion control, and operate efficiently under various working conditions. However, the high complexity of these systems, as well as the intense operational loads, favor the occurrence of failures and negatively influence reliability over time. Failures lead to reduced performance, increased downtime, and higher maintenance costs.
In this context, reliability evaluation and failure mode analysis are essential for improving the performance of hydraulic systems.

MATERIAL AND METHODS

Considering the diversity of mobile machinery using hydrostatic installations, this paper briefly presents the main types of excavators equipped with such systems:

- longitudinal digging excavators
- bucket-chain excavators
- bucket-wheel excavators
- transverse digging excavators
- radial digging excavators

The analyzed equipment is the S 1202 hydraulic excavator, intended for industrial construction and irrigation platform development. It uses hydraulic cylinders for linear motion (displacement) of the working equipment and hydraulic rotary motors for rotational movements. The system is controlled through manually operated hydraulic distributors.

The operation of complex technical systems is analyzed according to the principles of reliability theory (LEWIS, 1987; BIROLINI, 2017). The analysis consists of:

1. defining the system operation and identifying possible causes leading to failures;
2. identifying components and their functions;
3. developing the logical model of the system (HENLEY & KUMAMOTO, 1981).

Failure analysis evaluates the impact of each component on the overall system operation.

RESULTS AND DISCUSSIONS

From the perspective of hydraulic actuation, the operation of the S 1202 hydraulic excavator is based on the principles of hydrostatic transmissions, as described in the specialized literature (HERBERT E. MERRITT, 1967; BALASOIU VICTOR, 2007).

The operation of the hydraulic system (Figure 1) is characterized as follows:

• the power unit is supplied by two axial piston volumetric pumps with fixed flow rate, operating at a pressure of approximately 280 bar;

• the execution elements are hydraulic cylinders for actuating the working equipment and hydraulic motors for rotation mechanisms;

• the control of these elements is performed according to the schemes presented in Figures 2 and 3, corresponding to hydraulic motors numbered 5, 6, 7, and 8.

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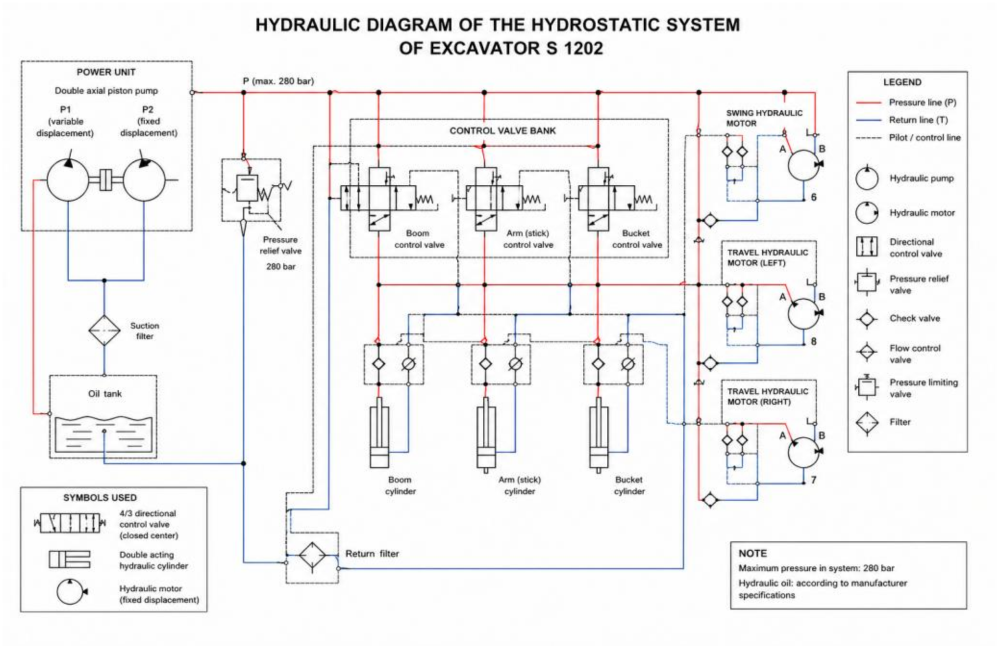

Figure 1. Hydraulic diagram of the hydrostatic system of the S 1202 excavator
(source: own elaboration based on ESPOSITO, 2009; LEWIS, 1987; MERRITT, 1967)

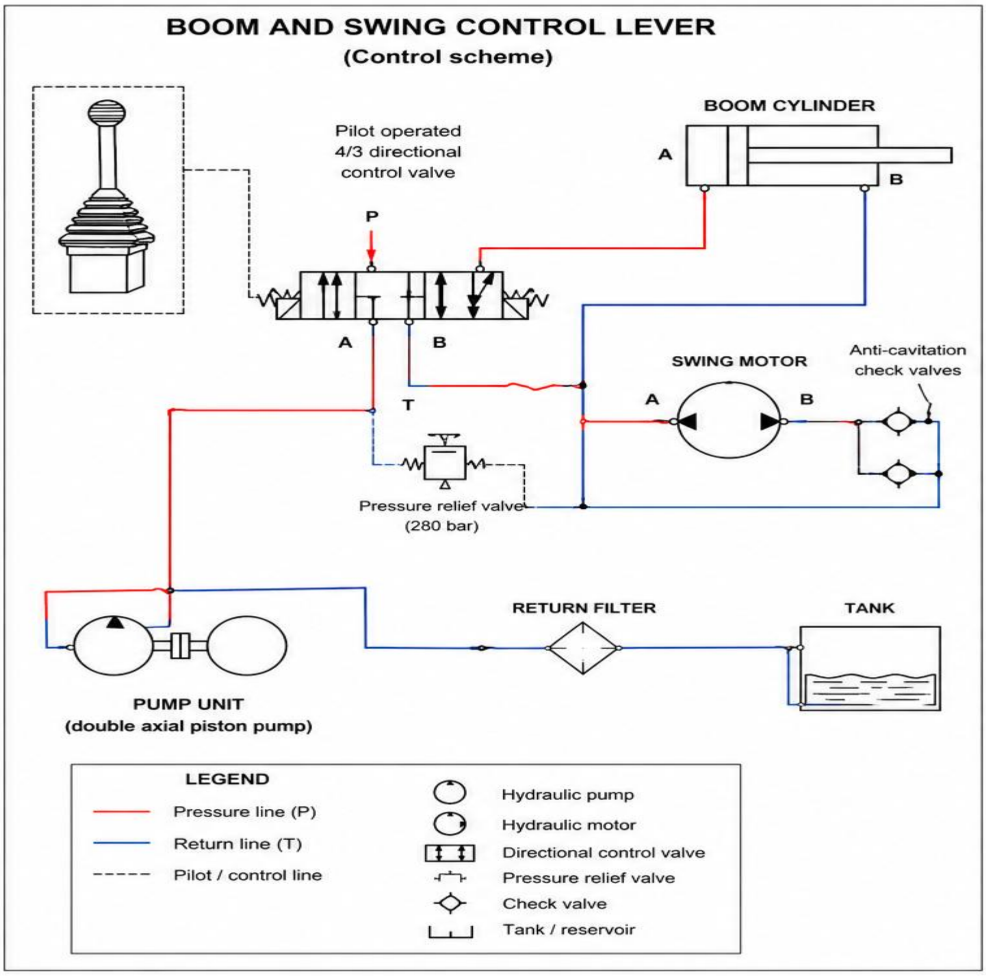

Figure 2. Control scheme of the hydraulic system (boom and rotation) of the S 1202 excavator (source: own elaboration based on ESPOSITO, 2009; LEWIS, 1987; MERRITT, 1967)

Figure 2 shows the scheme for actuating the stick cylinder and the rotary hydraulic motor.

In the neutral position, the flow is blocked, and the actuators maintain their position.

In active positions, the oil is directed to the cylinder chambers and to the rotary hydraulic motor, producing translation (extension of the boom/bucket) and rotation of the superstructure.

The circuit includes safety valves and anti-cavitation valves, which protect the system and stabilize its operation.

The motor circuit is equipped with check valves and anti-cavitation valves, ensuring operational stability and protection against depressions in the circuit. A pressure relief valve is included in the system, limiting the pressure to approximately 280 bar and protecting the installation against overloads. The return oil is filtered before re-entering the tank, contributing to maintaining fluid quality and increasing system reliability.

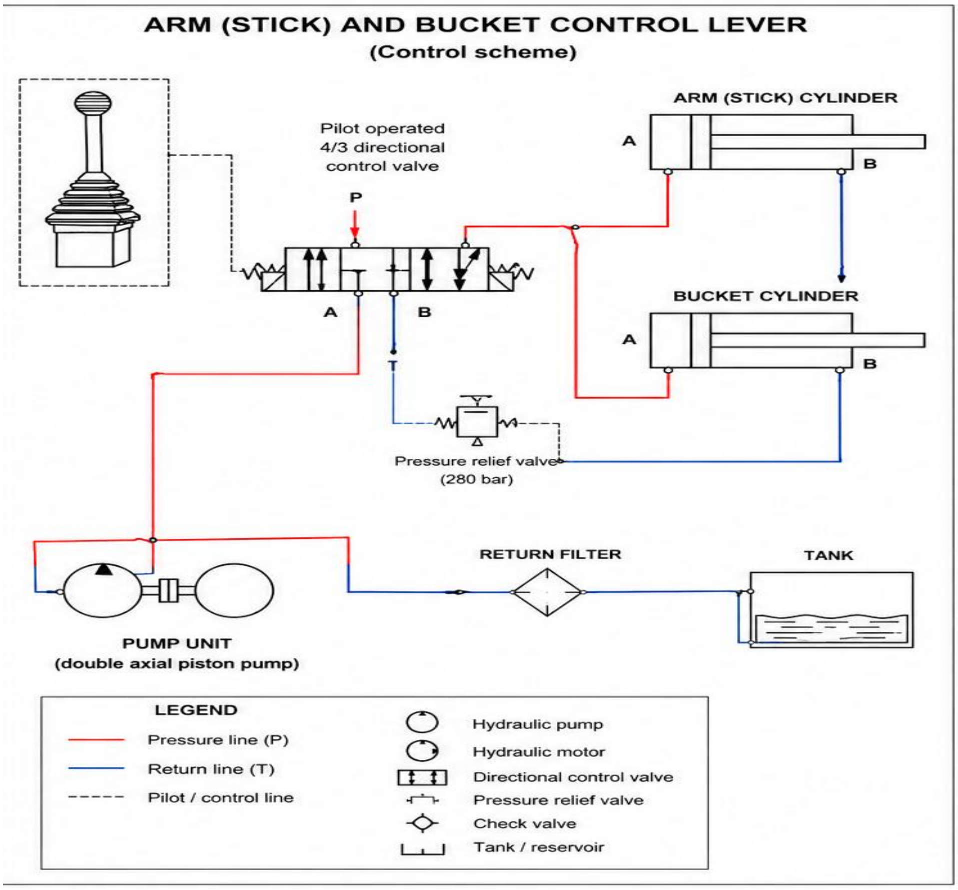

Figure 3. Hydraulic control scheme of the boom and bucket cylinders of the S 1202 excavator (source: own elaboration based on ESPOSITO, 2009; LEWIS, 1987; MERRITT, 1967)

Figure 3 presents the operation of the hydraulic system for actuating the oscillating boom and the bucket of the S 1202 excavator.

Similarly, the system is supplied by a hydraulic pump delivering pressurized oil to a 4/3 hydraulic distributor. This is manually operated and allows the control of two hydraulic cylinders: the boom cylinder and the bucket cylinder.

Depending on the distributor position, the fluid is directed to the active chambers of the cylinders, generating extension and retraction movements. Thus, the boom performs lifting and lowering motions, while the bucket performs opening and closing operations.

The circuit includes a safety valve that limits maximum operating pressure and protects system components against overloads. Check valves are also used to control flow direction and maintain load position under certain operating conditions.

The oil discharged from the cylinders is directed through the return line, filtered, and stored in the tank, from where it is recirculated.

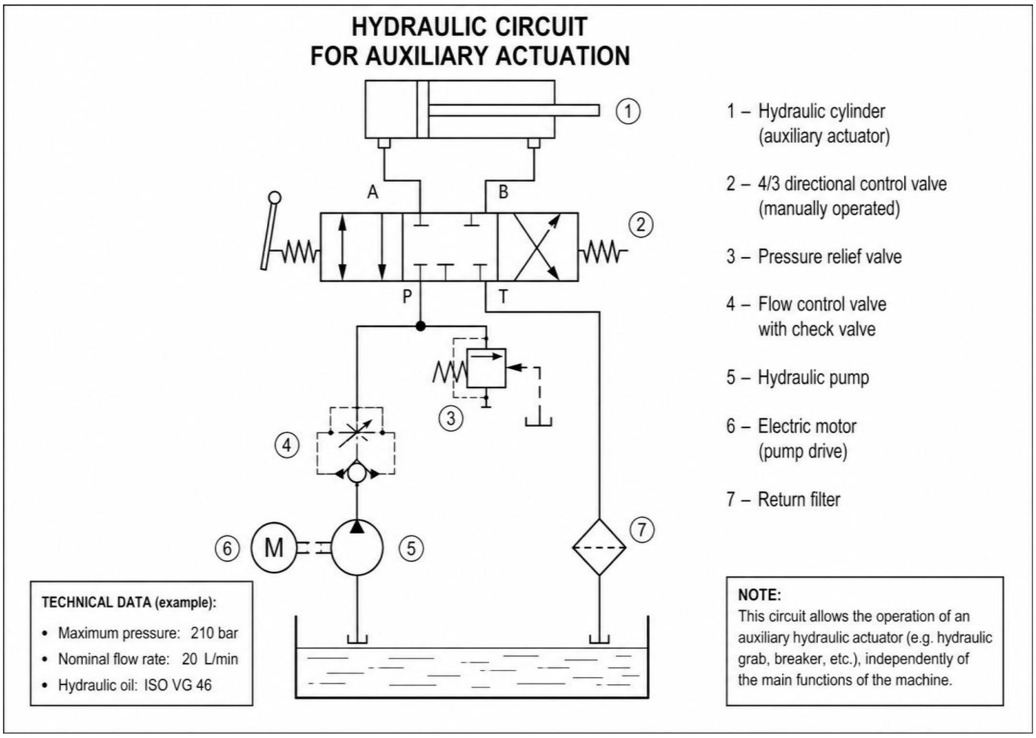

Figure 4. Hydraulic circuit for auxiliary actuation of the S 1202 excavator
(source: own elaboration based on ESPOSITO, 2009; LEWIS, 1987; MERRITT, 1967)

Figure 4 presents the hydraulic circuit for auxiliary actuation of the S 1202 excavator, integrated into the machine's control system.

The numbered components represent:

1 – double-acting differential hydraulic cylinder with single-sided rod
2 – 4/3 hydraulic distributor with manual actuation and spring return
3 – safety valve
4 – throttle valve and check valve
5 – gear pump for auxiliary drives
6 – electric drive motor
7 – oil filter

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1. *Reliability analysis of the system*

From the analysis of the hydraulic scheme, it results that the failure of any component leads to system shutdown. Thus, the S 1202 excavator operates within nominal parameters only when all hydraulic motors function according to design specifications.

Failure of any of the six hydraulic motors results in the loss of an essential function of the machine, as shown in Figure 3.

Common failures include:

Hydraulic cylinder:

- sealing failures (piston seals, rod seals, wiper ring), which are replaced;
- scratches on the rod and cylinder bore, requiring repair (hard chrome plating and polishing for the rod, honing for the cylinder);
- rarely, failures of end-stroke braking bushings or cap-cylinder connections.

Control valves and safety valves:

- spool sticking due to impurities;
- repair by honing and finishing, or replacement if deformations occur.

Hydraulic motors and pumps:

- wear in piston-bore assemblies;
- gear damage;
- spline or keyway defects;
- rare erosion on distribution plates.

Manual control mechanism:

- rare failures in the linkage between spool and control lever.

Although hydraulic motors can be controlled independently, from a reliability perspective they cannot be considered parallel elements. Their importance in overall operation leads to modeling them as a series structure.

2. *Hydraulic system model*

The scheme highlights the main elements of the hydrostatic installation: hydraulic pump, distributors, safety valves, pipelines, and actuators (cylinders and motors), as well as their functional interconnection. Possible failures and their correspondence to system elements are analyzed, and the system is modeled as a series structure. The reliability of the hydraulic system is determined based on this model. Assuming exponential failure distribution with constant failure rate. For a series system, reliability is:

$$R_s(t) = \prod_{i=1}^{n} R_i\,(t)$$

where:

- R_{sys}– system reliability
- R_i– reliability of element i
- n– number of elements

If each element follows an exponential failure law:

$$R_s(t) = e^{-\sum_{i=1}^{n} \lambda_i t}$$

where:

- λ_i – failure rate of element i

For series systems, total reliability is lower than that of each individual component, since failure of any element leads to total system failure.

CONCLUSIONS

The paper analyzed the hydraulic system of the S 1202 excavator from both operational and reliability perspectives.

It was found that the system has a series structure, where failure of any element leads to total system unavailability. Critical components are the control valves and hydraulic actuators.

The defectology analysis highlights the importance of understanding failure modes for increasing reliability and optimizing maintenance.

Applying reliability concepts allows identifying vulnerable points and improving future hydraulic system design.

Overall, the study confirms the importance of reliability analysis in the operation of mobile machinery, both from a technical and economic perspective.

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