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Considerations regarding the Use of Infrared Thermography in the Maintenance of Hydraulic Drive Installations

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Abstract: *Infrared thermography, as a non-contact investigation technique, has proven its usefulness in preventive maintenance and in monitoring mechanical, electrical systems or production processes. Engines, pumps, couplings, hydraulic installations, rotating equipment, servomechanisms, furnaces, tanks, but also other equipment can be found in all industrial activities. Examples of the use of infrared thermography are known only at the level of hydraulic components, not hydraulic drive installations / systems. For this reason, the authors present several points of view regarding the use of this technique on a specific case of a hydraulic drive installation.* ***The installation*** *contains a high-pressure* ***pumping station,*** *consisting of a double electric pump, low-pressure equipment for flow distribution / pressure regulation, three oscillating hydraulic pressure amplifiers of the mini booster type and two* ***double-acting hydraulic cylinders****. The following are presented: the composition, technical characteristics and operation of the hydraulic drive installation; diagnostic method, through infrared thermography, of the installation in operation.*

Keywords: *Infrared thermography, hydraulic drive system, high-pressure pumping station, mini booster*

1. Introduction

The high-precision results obtained by infrared thermography lead to a reduction in the time required to detect defects and to an efficient assessment of the condition of technical equipment during operation, without the need to stop them or perform more complicated operations, such as dismantling and transporting them to a testing/diagnostic center. The infrared thermography method is currently used in multiple technical applications [1] in: the industrial field, the most targeted being energy, electrical engineering, electronics and microelectronics; the machine-building, oil, metallurgical/steel, processing industries; the construction field; the field of technological processes, such as the field of welding; the field of medicine.
If one or more problems occur in the installations/systems in these fields, production interruption is very likely, and downtime is very costly. High temperatures, as seen in thermograms obtained by scanning with a thermal imaging camera, can indicate an electrical problem, wear in a component, insufficient lubrication, or other problems that can lead to expensive repairs or even production interruptions.
Many of these types of problems are not visible to the free eye and are not noticed until the equipment physically fails. Trying to find these problems through visual inspections is a time-consuming process that cannot identify the cause of the problems.
With the help of thermal imaging, thermal anomalies that endanger the safety and reliability of technical equipment can be quickly and accurately indicated [2]. Tens or even hundreds of points can be inspected with thermal imaging, which can be analyzed in a complete report of the thermal stresses hidden in this equipment.

2. Diagnosing of hydraulic drive installations by infrared thermography

Practice has shown that the correct operation of a hydraulic system under pressure is done in a well-defined temperature range. Maintaining this temperature range ensures the operation of hydraulic drive systems within parameters, without energy losses, because the properties of the hydraulic oil do not alter in terms of viscosity, density and compressibility. Therefore, the use of infrared thermography as a method of predictive maintenance of these systems is justified. However, in the field of hydraulic drive systems / installations of fixed or mobile machines /

equipment, some applications of infrared thermography are known only at the level of components, and not of the system as a whole.

A first example is the thermographic scan of a Brueninghaus (Germany) axial piston pump with inclined block, figure 1, mounted on the functional test stand in figure 2. The thermograms obtained, figure 3 and figure 4, indicate that the pump does not show wear, since the temperature difference between the left end, where the bearings are mounted, and the right end, with the distribution plate and connections, is less than 10ºC [3]. The thermogram in figure 4 indicates that the pump operates within the manufacturer's catalog parameters. It can serve as a "standard thermogram" for determining the degree of wear of all similar pumps in operation, under similar conditions, on hydraulically driven machines / equipment.

Fig. 1. Brueninghaus pump

Fig. 2. Stand for testing pump

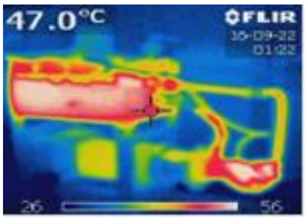

Fig. 3. Stand thermogram

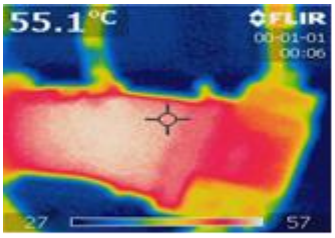

Fig. 4. Pump thermogram

Another example is the thermographic scanning of the hydraulic cylinders driving the bucket of a front-end loader, figure 5. The thermograms obtained, figure 6, indicate an equal load for the two hydraulic cylinders driving the bucket under load.

Fig. 5. Front loader with the 2 hydraulic cylinders driving the bucket

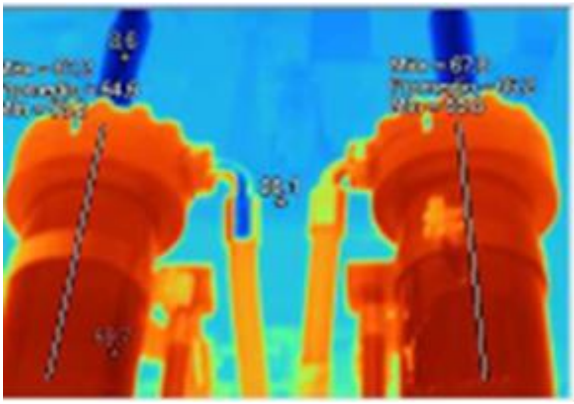

Fig. 6. Thermograms of the front loader bucket drive hydraulic cylinders

A procedure for applying infrared thermography to a real hydraulic drive installation is proposed, which consists of presenting: *the structure, technical characteristics, operating mode and main causes of installation failures; the method of predictive maintenance* of the hydraulic drive installation using infrared thermography.

2.1 Hydraulic cylinder drive system with high loads in one or both directions of travel

The installation with the hydraulic diagram in figure 7 allows the actuation, successively or simultaneously, of two double-acting hydraulic cylinders, of which the first experiences a maximum resistant load, on the advance stroke (+L) and retraction (-L) of the piston, equivalent to a pressure force of 1000 bar, and the second experiences the same resistant load only on the advance stroke (+L) of the piston. This installation is part of a range of six products in the field of high pressure generation for hydraulic drives and was developed by the authors within a research project, carried out in partnership with a private company and a higher education institute [5].

The structure of the hydraulic diagram in figure 7 is as follows: **1**= 60 l hydraulic oil tank; **2**= double low-pressure electric pump 2x8 cm3/rot, 200 bar, 1500 rot/min, 9kW; **3**= filling and venting filter; **4**= return filter; **5.1,5.2=** hydraulic blocks with four devices each, respectively: pressure regulating valve 0...200 bar; pressure gauge 250 bar; pressure filter; hydraulic directional control valve 4/3, Dn6, with electric control (electromagnets **EA** and **EB**). The blocks have four connections each: **P** (pump discharge), **T** (tank), **A** (cylinder piston chamber consumer) **B** (cylinder rod chamber consumer); **6.1, 6.2, 6.3**= **HC7** mini boosters with: amplification ratio i=5; primary connections **IN** (inlet), **R** (return); secondary connections **H1, H3** to the cylinder, **H2, H4** to *2000 bar* pressure gauges. A mini booster, figures 8 and 9, contains: two one-way valves, **SS1** and **SS2**; one unlockable one-way valve, **SSD**; a oscillating piston pumping unit, **UPO**, consisting of a two-piston assembly (**LP+HP**) and a hydraulically actuated spool valve (**BV1**), figure 9; **HC1**= double-acting hydraulic cylinder, with a maximum load of 1000 bar on both piston strokes; **HC2**= double-acting hydraulic cylinder, with a maximum load of 1000 bar only on the piston forward stroke.

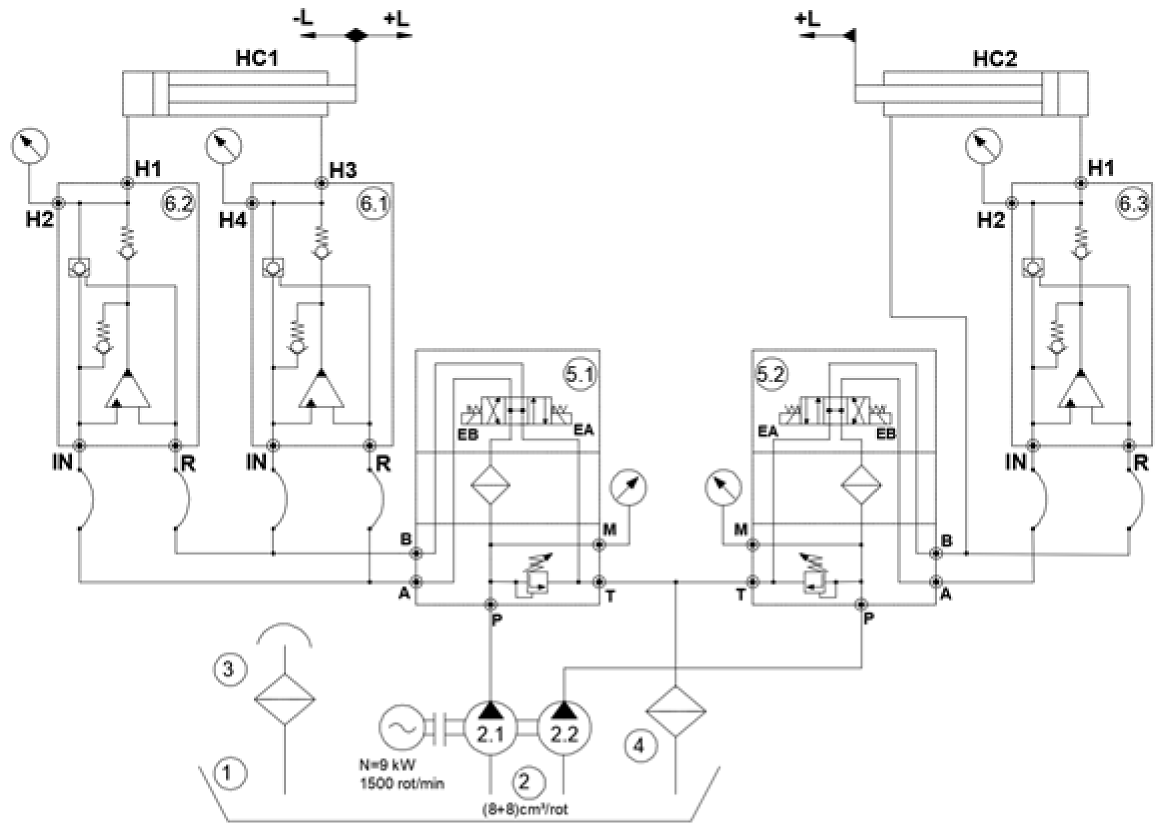

Fig. 7. Hydraulic scheme of the drive system

The **technical characteristics of** the drive system in fig.7...fig.10 are the following:

- **electric motor power** = *9 kW*; **electric motor rotational speed** = *1500 rpm*; **electric motor supply voltage** = 380V; double pump **flow rate** = *2x10.5 l/min*;
- **number** of mini boosters = *3 pcs.;* mini booster *amplification factor = 5*; mini booster **primary pressure** = *0...200* bar; mini booster **secondary pressure** = *0...1000 bar*; **maximum primary** mini booster **flow rate** = *2x10.5 l/min*; **maximum flow rate** (at maximum pressure) secondary mini booster = *2x1.2 l/min*;
- **number** of driven hydraulic cylinders = *3 pcs*.; driven cylinder **load** = **±L**, for **HC1** and **+L**, for **HC2**; **dimensions**: Ø piston = 38.1x 10-3 m, Ø rod = 25x10-3 m, stroke length = 257x10-3 m;
- **number** of hydraulic dimensional control valves 4/3 = *2 pcs*.; **number** of pressure filters = *2 pcs*.; number of pressure valves = *2 pcs*.;
- **number** of pressure gauges 200 bar = *2 pcs.*; **number** of pressure gauges 2000 bar = 2 pcs.;
- **number** of hoses = 6 pcs.

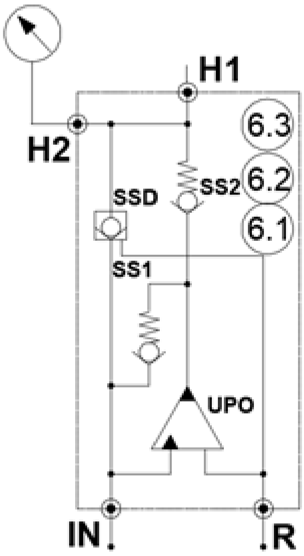

Fig. 8. Simplified mini booster hydraulic scheme

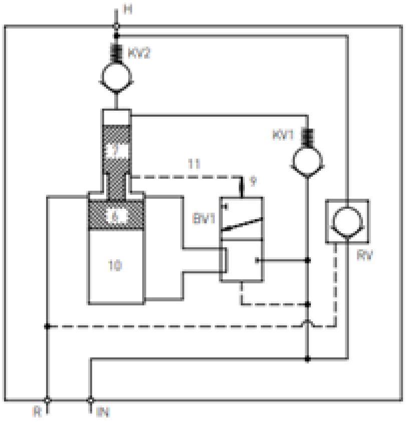

Fig. 9. Developed mini booster hydraulic scheme [4]

Fig. 10. High-pressure pumping station in the hydraulic scheme fig.7

The operating mode of the hydraulic drive system is presented in table 1. It has two phases: for low pressures on the secondary of the mini booster (0...40 bar in the primary), when the hydraulic cylinders move in idle (without load) being supplied directly by the low-pressure electric pump (the flow bypasses the **UPO** mini booster, according to fig. 8); **for high pressures** on the secondary of the mini booster (40...200 bar in the primary), when the hydraulic cylinders move in load being supplied by the **UPO** mini booster (the **LP+HP** pistons pulsate with 10...20 Hz under the hydraulic control of the **BV1** distribution spool, according to fig. 9).

Table 1: Operation of the hydraulic drive system

Controls / Adjustments / Hydraulic circuits	
Name of control/ adjustment / circuit	**Execution control/ adjustment / circuit**
HC1 cylinder piston advance	
Actuation *of* hydraulic directional control valve block 5.1	Electromagnet status: **EA +**; **EB -**
Pressure adjustment - phase I	Pressure valve adjustment ***0...40 bar***
Feeding circuit *of oil from chamber of HC1 cylinder piston*	pump-**tank** (2.1)-P (5.1)- pres. filter - directional control valve.-A (5.1)-IN(6.2)-SS1-SS2-SSD-H1 (6.2)- **piston chamber**
Exhaust circuit *of oil from chamber of HC1 cylinder rod*	**rod chamber** H3 (6.1)-SSD-IN(6.1)-B (5.1)-directional control valve T (5.1)-(4)-**tank**
Pressure adjustment - phase II	Pressure valve adjustment ***40...200 bar***
Feeding circuit *of oil from chamber of HC1 cylinder piston*	**pump-tank** (2.1)-P (5.1)- pres. filter directional control valve..-A (5.1)-IN(6.2)-UPO (6.2)-SS2-H1 (6.2)- **piston chamber**
Exhaust circuit *of oil from chamber of HC1 cylinder rod*	**rod chamber** -H3 (6.1)-SSD-IN(6.1)-B (5.1)-directional control valve -T (5.1)-(4)-**tank**
HC1 cylinder piston stationary	
Unactuated *of* hydraulic directional control valve block 5.1	Electromagnet status: **EA +; EB -**
Hydraulic *circuit of pump 2.1*	**pump-tank** (2.1)-pressure valve block 5.1-4-**tanck**

HC1 cylinder piston withdrawal	
***Actuation** of hydraulic directional control valve block 5.1*	Electromagnet status: **EA -**; **EB +**
Pressure adjustment - phase I	Pressure valve adjustment 0...40 bar
***Feeding circuit** of oil from chamber of HC1 cylinder rod*	**pump-tank** (2.1)-P (5.1)- pres. filter-directional control valve B (5.1)-IN(6.1)-SS1-SS2-SSD-H3 (6.1)-**piston chamber**
***Exhaust circuit** of oil from chamber of HC1 cylinder piston*	**piston chamber**-H1 (6.2)-SSD-IN(6.2)-A (5.1)-directional control valve T (5.1)-(4)-**tank**
Pressure adjustment - phase II	Pressure valve adjustment ***40...200 bar***
***Feeding circuit** of oil from chamber of HC1 cylinder rod*	**pump-tank** (2.1)-P (5.1)- pres. filter-directional control valve-B (5.1)-IN(6.1)-SS1-SS2-SSD-H3 (6.1)-**rod chamber**
***Exhaust circuit** of oil from chamber of HC1 cylinder piston*	**piston chamber**-H1 (6.2)-SSD-IN(6.2)-A (5.1)-directional control valve-T (5.1)-(4)-**tank**
HC2 cylinder piston advance	
***Actuation** of hydraulic directional control valve block 5.2*	Electromagnet status: **EA +**; **EB -**
Pressure adjustment - phase I	Pressure valve adjustment ***0...40 bar***
***Feeding circuit** of oil from chamber of HC2 cylinder piston*	**pump -tank** (2.2)-P (5.2)-filter pres.-directional control valve -A (5.2)-IN(6.3)-SS1-SS2-SSD-H1(6.3) – **piston chamber**
***Exhaust circuit** of oil from chamber of HC2 cylinder rod*	**rod chamber**-B (5.2)- directional control valve-T (5.2)-(4)-**tank**
Pressure adjustment - phase II	Pressure valve adjustment ***40...200 bar***
***Feeding circuit** of oil from chamber of HC2 cylinder piston*	**pump-tank** (2.2)-P (5.2) pres. filter-directional control valve -A (5.2)-IN(6.3)-UPO-SS2-H1(6.3) - **piston chamber**
***Exhaust circuit** of oil from chamber of HC2 cylinder rod*	**rod chamber**-B (5.2)- directional control valve T (5.2)-(4)-**tank**
HC2 cylinder piston stationary	
***Unactuated** of* hydraulic directional control valve block 5.2	Electromagnet status: **EA -; EB -**
***Hydraulic** circuit of pump 2.2*	**pump-tank** (2.2)-pressure valve (5.2)- 4)-**tank**
HC2 cylinder piston withdrawal	
***Actuation** of hydraulic directional control valve block 5.2*	Electromagnet status: **EA -**; **EB +**
***Feeding circuit** of oil from chamber of HC2 cylinder rod*	**pump-tank** (2.2)-P (bloc 6)-) pres. filter-directional control valve -B (5.2) – **rod chamber**
***Exhaust circuit** of oil from chamber of HC2 cylinder piston*	**piston chamber**-H1(6.3)-SSD-IN (6.3)-A (5.2) - directional control valve-T (5.2)-(4)-tank.

The main causes of malfunctions of this hydraulic drive installation are:

- **vibrations, self-vibrations and shocks** caused by the pulsations of the electric pump **2**, pressure valves and hydraulic directional control valve 4/3 on blocks **5.1** and **5.2,** oscillating piston units (**UPO**) of mini boosters **6.1, 6.2, 6.3** together with nonlinearities in the dynamic regime;
- **temperature and quality of the oil** used as a working fluid;
- **selection of sealing elements** in terms of appropriate shape, material quality and its compatibility with the working fluid;
- **the quantity and size of impurities in the system** which, in addition to normal wear, cause blockages of moving parts (pistons, spools, valves), which disable the hydraulic devices to which they belong (especially the mini boosters **6.1, 6.2, 6.3,** the pressure valves and the 4/3 hydraulic directional control valves on the blocks **5.1, 5.2**) or even the entire drive system;
- **too high a temperature**, above 80°C, can cause: failures in the seals; alterations in the properties of the working fluid (especially viscosity); destruction of the lubricant film and, implicitly, of some mechanical-hydraulic components of the system. The presence of high temperatures in the hydraulic system is caused by the following factors: **the amount of hydraulic oil** in the tank **1** is below the minimum mandatory level; the **appearance of a cavity** and the production of air

bubbles in the oil; **increased drainage** of volumetric machines and hydraulic equipment which leads to an increase in the amount of fluid passing from high pressure to reservoir pressure, with heat production.

By proactively monitoring temperature increases, mainly caused by high internal losses of drive system components, which lead to premature wear, **the most important failures can be determined in advance.**

2.2 Predictive maintenance method for hydraulic drive installations using infrared thermography

Hydraulic drive systems are characterized by the combined action of thermal conduction, internal energy accumulation and mixing motion, *convection being the most important heat exchange mechanism between solid surfaces and hydraulic oil*, between which there is direct contact and relative motion.

As a result of the operation of hydraulic drive installations over time, some components wear out, more or less, having on the thermal images, respectively on the *"thermograms",* which present the "*thermal maps*", areas with different *"overheating*", compared to the "*standard thermograms*", depending on the *degree of wear*.

Figure 11 shows the block scheme of the predictive maintenance method [6] for the analyzed drive installation. It involves the use of a **CT** thermographic camera, with which all components (grouped into five classes) of the new hydraulic drive system, called the **standard system**, **IAH (e),** and all components of the same system, called the **technically revised system**, **IAH (r),** are thermographically scanned **during commissioning tests,** namely:

class 1: oil tank **1** with temperature thermostat system; filling and venting filter **3**, return filter **4**;
class 2: electric pump **2** (double pump **2.1**, **2.2** and electric drive motor);
class 3: pipes, hoses, fittings between the tank-double pump - hydraulic blocks, hydraulic directional control valves -mini boosters-hydraulic cylinders;
class 4: hydraulic equipment on blocks **5.1** and **5.2** (2 pressure filters, 2 pressure regulating valves, 2 4/3 hydraulic directional control valves) and mini boosters **6.1, 6.2, 6.3**;
class 5: linear hydraulic motors (hydraulic cylinders **HC1**, **HC2**).

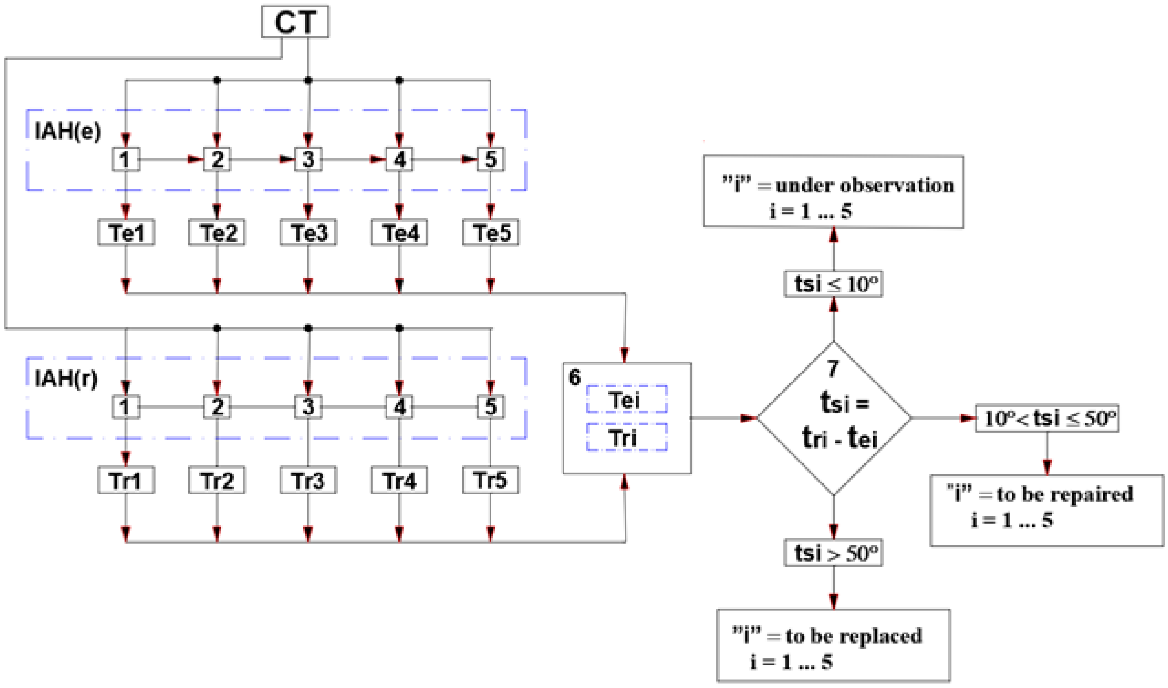

Fig. 11. Block scheme of the predictive maintenance method using infrared thermography [5]

After the first thermographic scan, a database is generated with **five sets of standard thermograms** $T_{e1}...T_{e5}$, and after **the second thermographic scan**, another database is generated with five sets of **inspection thermograms** $T_{r1}...T_{r5}$. Both databases are stored in a

module **6**, from where they are taken over by a programmable controller **7**, which, based on specialized software, compares the thermograms, calculates the overheating ($t_{si} = t_{ri} - t_{ei}$) of each component of the technically inspected installation, which it then enters into one of the three files, respectively "***under observation***", "***to be repaired***", "***to be replaced***".
The "***under observation"*** file contains all the components of the installation where overheating, respectively the difference between the temperature of the standard component and the temperature of the technically inspected component, is incipient, respectively $t_s \leq 10^oC$. These components ***will be thermally scanned first, at the next planned technical inspection***.
The ***"to be repaired***" file contains all the components of the installation with overheating in the range $10^oC < ts \leq 50^oC$. These components have advanced overheating, are worn out and no longer perform the functional parameters, but ***can still be repaired***.
The ***"to be replaced"*** file contains all the components of the installation with overheating in the **range** $t_s > 50^oC$. These components have serious overheating, very high wear, no longer perform the functional parameters and, as a rule, can no longer be repaired.
The use of this predictive maintenance method requires that the **two thermographic scans** of the components of the hydraulic drive installation, **new** and **technically revised**, be carried out under **the same conditions of: ambient temperature**, in which the installation operates; **temperature of the working fluid**, respectively the hydraulic oil, which circulates through the installation; **nominal loads of 50%...100%,** respectively resistant forces and speeds, for the two hydraulic cylinders.
If, during the periodic inspection tests of the hydraulic drive installation, the nominal loads are achieved in a percentage lower than 50% of the nominal values, then a correction must be applied to the temperature values, calculated as overheating of the components.

3. Conclusions

The proposed investigation method, based on infrared thermography, supports the corrective, predictive and preventive maintenance of hydraulic drive installations, characterized by a high degree of complexity and a large number of components. The non-contact and early detection of worn components within a hydraulic drive installation, in operation, reduces the costs of its maintenance system.
As a rule, to detect a component, which shows faults or wear, in a hydraulic drive installation, all components are dismantled from the installation and tested individually, on specialized stands.
The proposed method has the advantage of removing this impediment, by locating the faults and non-contact detection of worn components; only these will be dismantled from the installation, for testing on the stand before and after repair or for replacement.

Acknowledgments

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References

[1] https://www.virtual.identicom4.ro/wp-content/uploads/2020/09/Termografia_in_industrie.pdf.pdf.
[2] Alexandru, Costel. "Thermal imaging of mechanical equipment / Termoviziune echipamente mecanice". ALC Electrical Testing, 2017. https://www.termoviziune-termografie.ro/echipamente-mecanice.
[3 Marinescu, Alexandru-Daniel, Carmen-Anca Safta and Teodor Costinel Popescu. "Advantages, errors and limitations of infrared thermography used in the maintenance of hydraulic drive systems." Paper presented at International-multidisciplinary conference "Professor Dorin Pavel - the founder of Romanian hydropower", Sebeș, Romania, June 2-3, 2017.
[4] KVT_miniBOOSTER_DE_07-2018_web-catalog.pdf.
[5] "Digital mechatronic systems for generating 1000 bar pressure using hydraulic pressure amplifiers / Sisteme mecatronice digitale de generare a presiunii de 1000 bar, utilizand amplificatoare hidraulice de presiune." Financial agreement no. 272/24.06.2020. https://smgp.ihp.ro/.
[6] Popescu Teodor Costinel, Alexandru Daniel Marinescu, and Alina Iolanda Popescu. "Metodă și sistem de diagnosticare a instalațiilor funcționale de acționare hidraulică, utilizând termografia în infraroșu / Method and system for diagnosing functional hydraulic drive installations using infrared thermography". Patent No. RO133206(B1)-30.07.2024, OSIM.