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THERMOGRAPHIC INVESTIGATION OF THE HYDRAULIC DRIVE SYSTEMS

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***Abstract:** The authors develop a new non-contact diagnostics of hydraulic drive functional plants. It is based on infrared thermography of rotary and linear volumetric machines, as well as two-phases hydraulic equipment: a "no wear" phase, performed at plants commissioning tests, where these components are news or recently repaired, respectively "with possible wears" phase, performed during the periodical technical revisions. By comparing the two sets of thermograms, "standard" and "reals", of the same hydraulic drive plants, we can detect in early the components with wears in incipient or advanced form and we can take precautions to avoid the accidental interruption of the plant operation.*

***Keywords:** Thermographic investigation, hydraulic drive systems*

1. Introduction

Thermographic investigation of the industrial machinery and equipments is a component of the maintenance work, that provides the necessary informations on defects and early wears. These informations allows to be taken timely correction necessary measures to reduce the risk of damages.The infrared thermography is a non-destructive control technique, typically used to detect and locate mechanical and electrical defects, which is manifested by overheating components of the machine or its plants.
It is known that the infrared thermography is a latest technology, in the field of the modern diagnostic methods in industry, delivering high precision results, which lead to reduce the faults detection time and performing assessment of the equipments state in operating time, without it may be necessary to stop them, or to perform more complicated operations, such as them dismantling and transporting to a diagnostic center.The method is currently used in multiple technical applications in: the industrial field, the most important branches being energy, electrotechnics, electronics and microelectronics, machine building industry, petroleum industry or metallurgical / steel industry, manufacturing; construction field; the field of technological processes, such as the welding process; the field of medicine and others.
Hydraulic drive systems are characterized by the combined action of the thermal conduction, by the internal energy accumulation and mixing motion, the convection being the most important heat exchange mechanism between the solid surfaces and hydraulic oil, between there is direct contact and relative motion.As a result of the time operation of hydraulic drives plants, some components wear out more or less,having on thermal images, respectivelly on "thermograms", which shows "thermal maps", zones with different "overheating", compared to "standard thermograms", depending on the wear degree.In present, have not developed non-contact diagnostic methods based on infrared thermography at the level of the hydraulic drive system as a whole. However, there are known examples of the use of infrared thermography for diagnosis at the level of a hydraulic component, such as a cylinder, a pump or a hydraulic motor.
The system proposed by the authors represents an extension of the infrared thermography diagnosis from the hydraulic component to the level of the hydraulic drive plant.

2. Examples of hydraulic cylinders diagnosis by infrared thermography

An example of the practical application of infrared thermography for the diagnosis of hydraulic cylinders for terrain equipments is the one made by **SIMCO** in Spain on a Caterpillar charger 993 K

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CAT, Z9K series (Fig. 1) provided with six hydraulic cylinders acting the bucket drive: two for lifting, two for lower tilting and two for upper tilting(Fig. 2).

Fig. 1. Caterpillar charger

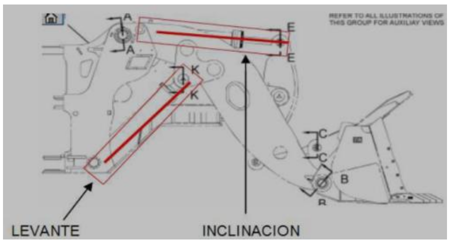


Fig. 2. Hydraulic cylinders for lifting and tiltingof the machine bucket

The machine task book provides 8000 operating hours under normal conditions for the hydraulic drive plant of the bucket. After a normal operating time, the machine beneficiary finds that the bucket lifting is slower and, therefore, is addresses to **SIMCO** for diagnosis.
Prior to thermography diagnosis, check the functional parameters of the bucket machine driving cylinders (table 1 and table 2).

Table 1: Lifting / down bucket times

Measuredparameter	**Manufacturer's standard**	**M1**	**M2**
Bucket lifting time (s)	9,4	11	11
Bucket down time (s)	3,7	4	4,1
Pump pressure (psi)	2900	2850	2850

Table 2: Higher / Lowerbucket tilting times

Measured parameter	**Manufacturer's standard**	**M1**	**M2**
Higher tilting time bucket (s)	2,4	3	3
Lower tilting time. bucket (s)	2,1	3	3
Working temperature (^{o}C)	65	64	66

It was noticed that the machine was not working properly due to the internal pressure loss at the lifting cylinders, which worked slowly. It was decided making thermal images to all the drive bucket hydraulic cylinders, after the machine commissioning, the drive bucket and the hydraulic oil temperature raising to 75 ºC.

a. Right lifting cylinder

Temp.	Max	Average	Min
[^{o}C]	80,6	78,1	67,2

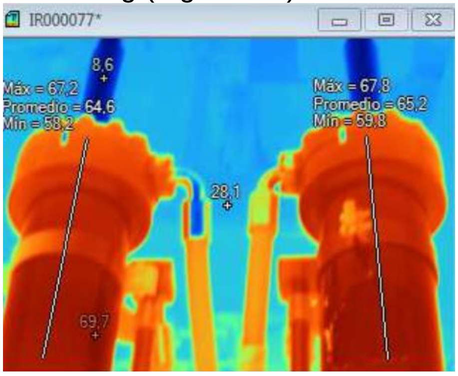
b. Left lifting cylinder

Temp	Max	Δ	Average	Δ	Min	Δ
[^{o}C]	74,2	6,4	71,6	6,5	66,9	0,3

Fig. 3. Thermal images of bucket lifting cylinders

The thermal images of the bucket lifting cylinders (Figure 3) were analyzed and the maximum, minimum and average operating temperatures were compared, measured on two equal lines (one

on each cylinder) parallel to the axes of the cylinders, with the same number of measuring points, identically positioned. It is noted that the maximum, average and minimum temperatures of the right cylinder (Fig. 3a) are higher by 6.4 °C; 6.5 ° C and 0.3 ° C respectively than those of the left cylinder (Figure 3.b), so the lifting cylinders are not work at the same load. The explanation is the damage of the left cylinder piston seal, due to internal pressure loss occurs, respectively oil leaks from the active chamber in the passive chamber of the cylinder.
Further, the thermal images of the left / right cylinder pairs for the higher tilting (Figure 4.a) and for the lower tilting (Figure 4.b) of the bucket were analyzed.



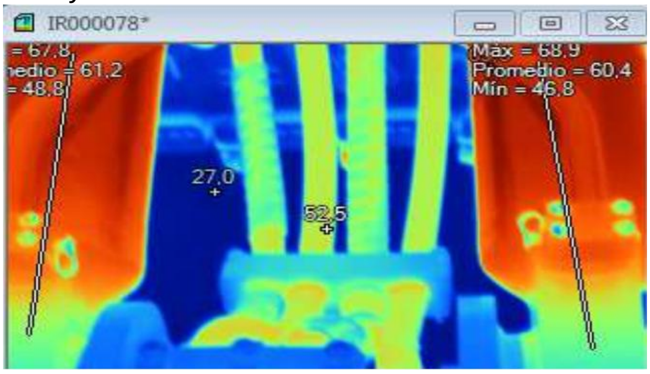
a. Higher tilting left / right cylinders

Left cylinder

Temp.	Max	Average	Min
[^{o}C]	67.2	64.6	58.2

Right cylinder

Temp	Max	Δ	Ave.	Δ	Min	Δ
[^{o}C]	67.8	0.6	65.2	0.6	59.8	1.6



b. Lower tilting left / right cylinders

Left cylinder

Temp.	Max	Average	Min
[^{o}C]	67.8	61.2	48.8

Right cylinder

Temp	Max	Δ	Ave.	Δ	Min	Δ
[^{o}C]	68.9	1.1	60.4	-0.8	46.8	-2

Fig. 4. Thermal images of bucket tilting cylinders

The thermal images of the higher bucket tilting cylinders (Figure 4.a) were analyzed and the maximum, minimum and average working temperatures measured on two equal lines (one for each cylinder), parallel to the axes of the cylinders, with the same number of measured points, identically positioned. It is found that the maximum, average and minimum temperatures of the right cylinder are greater by 0.6 °C; 0.6 °C and 1.6 °C respectively than those of the left cylinder.
The thermal images of the lower tilting bucket cylinder (Figure 4.b) were analyzed and maximum, minimum and average temperatures were compared, measured on two equal lines (one on each cylinder) parallel to the cylindrical axes, with the same number of measuring points, identically positioned. It is noted that the differences between the maximum, average and minimum right cylinder temperatures relative to the left cylinder are of 1.1 °C; -0.8 °C or -2 °C above those of the left cylinder.
Due to the fact that the temperatures differences (especially average temperatures) between the left / right cylinders for the higher / lower tilting of the bucket are under 1 ° C, it is concluded that the left / right cylinders work at the same load for the higher and lower tilting of the bucket.

The final conclusion *of the thermographic diagnosis of the six actuating cylinders of the Caterpillar charger's bucket is the replacement of the internal sealing system of the lifting left cylinder.*

3. Method and system of thermographic investigation of the hydraulic drive systems

The hydraulic drive systems are characterized by the combined action of the thermal conduction, of the internal energy accumulation and of the mixing motion, convection being the most important heat exchange mechanism between solid surfaces and hydraulic oil, between them being direct contact and relative motion. As a result of the time operation of the hydraulic drives plants, some

components wear out more or less, having on thermal images, respectively on the "thermograms", which shows "thermal maps", different "overheating" zones compared to "standard thermal images", depending on the degree of wear.
The authors proposed method comes to support the corrective, predictive and preventive maintenance of hydraulic drive plants, characterized by a high degree of complexity and a large number of components. Without contact and early detection of the used components, from an on-board hydraulic drive plant, being in operation, reduces the cost of its maintenance system.
As a rule, for the detection of a defective or worn component from a hydraulic drive plant, all the components in a plant are dismantled and individually tested on specialized stands.
A method and an investigation system are proposed which have the advantage of removing of this impediment, by finding without contact of the the unused components and respectively dismantling only them from the plant (Fig. 5).

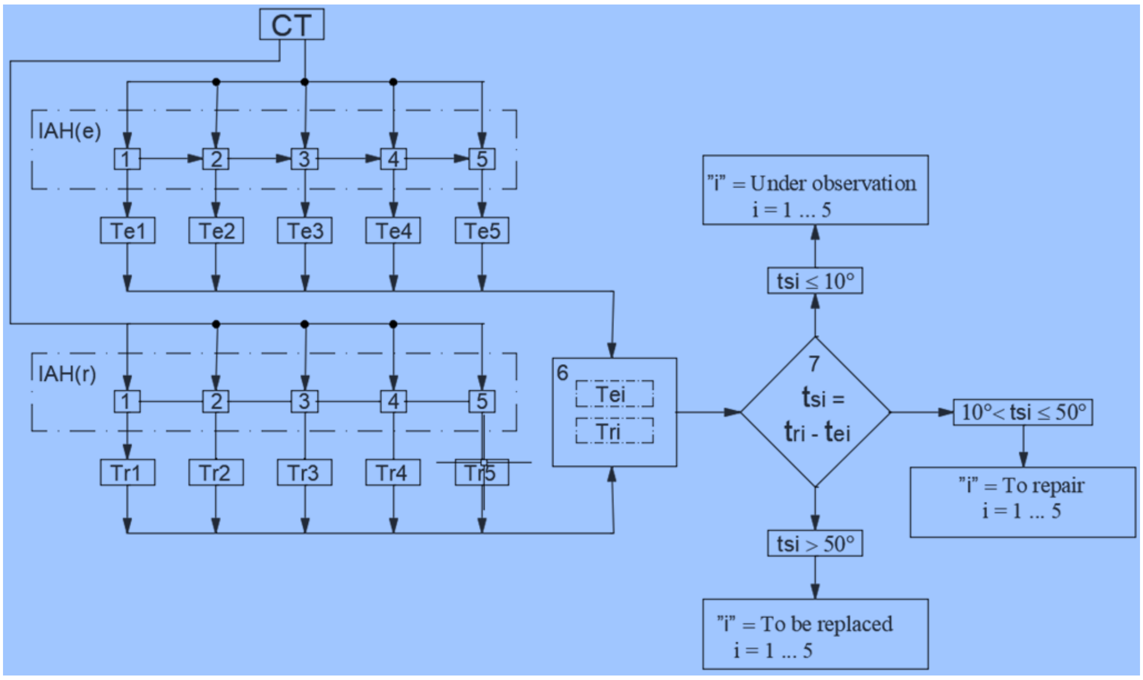


Fig. 5. Method and systemof thermographic investigation of the hydraulic drive systems

The invention also has other advantages in terms of reducing the cost of maintenance of the hydraulic drive systems, serving fixed machinery and equipments, from the manufacturing or mobile flows.The authors proposed method and diagnostic system, presuppose the use of a **CT** thermal imaging camera with which it scaned in thermal images, during the commissioning tests, all the parts of a new hydraulic drive plant , called the standard equipment, **IAH (e),** and all the components of the same installation, called technically revised plant**, IAH (r),** during the periodical technical inspection, namely: oil tank, filters, the hydraulic oil temperature control system **1**; their pumps and their drive motors **2**; pipes, hoses, fittings, hydraulic bindings **3;** valves, hydraulic distributors, throttles, regulators **4**; linear hydraulic motors, rotary hydraulic motors **5**.After the first thermal images scanning, a database of five sets of **Te1** ... **Te5** standard thermal images results, and after the second thermal images scanning, another database with five sets of revision thermal images**Tr1 ... Tr5** results. . The both databases are stored in a module **6**, from where they are taken over by the programmable machine **7**, which, based on a specialized software, compares the thermal images, calculates the overheating of each component of the technically revised plant, then inserts it into one of the three files, namely "**under observation**", "**repaired**", "**to be replaced**".
The "**under observation**" file contains all components of the plant where overheating, ie the difference between the temperature of the standard component and the temperature of the

technically revised component, is incipient (ts ≤ 10°C). These components will be first thermally scanned at the next scheduled technical revision.
The "**repaired**" file contains all the plant components with the overheating in the range of 10°C < ts ≤ 50oC. These components have an advanced overheating, are worn out and no longer achieve functional parameters, but can still be repaired.
The "**to be replaced**" file contains all plant components with the ts > 50 ° C overheating. These components have a serious overheating, very high wear, no longer achieve functional parameters and, as a rule, can not be repaired.
The use of the method and diagnostic system of hydraulic drive plants proposed by the authors, requires that the two thermal images scans of the new and revised hydraulic drive plant components, be carried out under the **same conditions as**:
- **the ambient temperature** in which the plant operates;
- **the temperature of the working fluid** respectively the hydraulic oil flowing through the plant;
- **nominal loads of 50% ... 100%,** ie resistant torques and speeds for rotary hydraulic motors, respectively, resistant forces and speeds for the linear hydraulic motors.
If, during the periodic revision inspection tests of the hydraulic drive plant, the nominal loads can only be achieved in less than 50% of nominal values, a correction must be applied to the temperature values calculated as superheating of the components.

4. Conclusions

-The method and system of investigation proposed by the authors is in support of the corrective, predictive and preventive maintenance of hydraulic drive plants.
-The success of the thermographic investigation of the hydraulic drive systems requires a close collaboration on the maintenance subject of these systems between designer, manufacturer and the beneficiary, namely.
-It is recommended to the components and hydraulic drive designers to determine a set of basic principles for reading, interpreting and comparing of the "real thermal images" with the domain-specific "thermal images".
-It is recommended to manufacturers of pumps, hydraulic motors / hydraulic cylinders, regulating and controlling the flow and pressure equipments to be included in the technical catalogs of the products together with the functional characteristics / parameters and of the "standard thermal images" for which the respective functional parameters are achieved.
-It is recommended to the users of hydraulic drive machines and equipments to make their own bases of "standard thermal images" done on the components of the functionally hydraulic drive plants, during commissioning of the new plants or after capital repairs.

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