EVALUATION OF TEMPERATURE OF THE AXIAL PISTON HYDRAULIC MOTOR BY INFRARED THERMOGRAPHY

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Abstract: *When a hydraulic system has problems, it is common practice to first look at the pump or hydraulic motor. Obviously, when preliminary troubleshooting, the analysis focuses on the hydraulic motor, a series of steps can pinpoint the specific problem and lead to the cure. The monitoring condition of a hydraulic system can bring benefits, other than just reliability and improved safety.*

This paper aims to present a modern diagnosis method of specific malfunctions of the hydrostatic drive systems and the use of the equipment with an axial piston hydraulic motor. The diagnostic technique described is using the infrared thermography and can be considered a predictive maintenance.

Different operation modes of the axial piston hydraulic motor are simulated by changing the pressure in the hydraulic drive test system. Specific thermograms are obtained for each operation mode.

Keywords*: Maintenance, predictive maintenance, infrared thermography, axial piston hydraulic motor, hydraulic drive systems*

1. Introduction

Maintenance was an area that was often thought to not need much attention. However, with the greater focus on safety, environment, energy efficiency and profitability, maintenance has now become an area where there is renewed attention [1, 2, 3].

Hydraulic systems are becoming more complex in design and in function and the reliability of these systems must be supported by efficient maintenance regimes [4, 5]. There are three such regimes: breakdown maintenance (most expensive), time-based maintenance, and condition-based maintenance (least expensive). Choosing a maintenance regime depends on the hydraulic system - if the systems do not require high reliability or if economics or safety are not the issue, the breakdown maintenance approach may be sufficient. However, for maximum reliability and safety, the condition-based maintenance approach should be implemented. In general, most hydraulic systems do require high reliability and thus, the latter approach regarding the monitoring condition is most desirable [6, 7, 8].

The energy conservation involves the optimum use of resources and represents an imperative when it comes to the application of measures in order to develop an economy based on healthy growth. For this reason, it is necessary to obtain some accurate information on the energy performances of the equipment, installations or machinery. The information is obtained by drawing energy balances or developing an analysis based on data resulting from the inspection of selected aims. The evaluation of all energy losses susceptible to reduce the efficiency of a system requires a good vision on the thermal distribution of its components. This is achieved by thermography technique, which allows monitoring the temperature distribution on the equipment's surface, by a method of measuring the infrared radiation [9].

Thermography (or thermovision) is a technique of measuring the thermal field of a physical object, which uses the infrared radiation, for recording and visualization of temperature distribution on the surfaces. Thermography is a non-destructive method that does not require direct contact with the analyzed surface and is particularly useful in malfunctions, diagnosing within industrial systems, because it is not necessary to interrupt the technological flow [10, 11, 12]. The industrial equipment presents energy losses, which depend on configuration, quality and sealing installation [13, 14, 15].

2. Theory of Thermography

2.1 Electromagnetic Spectrum

The electromagnetic spectrum is divided arbitrarily into a number of wavelength regions, called bands, distinguished by the methods used to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of the electromagnetic spectrum. They are all governed by the same laws and the only differences are those due to differences in wavelength [16].

Thermovision or infrared visualization (IV) is a technique whereby a camera detects and displays a radiation intensity map on an electromagnetic spectrum field. The term "thermovision" defines the image obtained by the thermal camera and is used especially in military or civil surveillance applications, while thermography also involves temperature measurement, in industrial or scientific applications. It is known that any object, with temperature above 0 Kelvin, emits electromagnetic radiation. Substances considered cold and very cold: liquid nitrogen, ice and snow, emit infrared as well. The intensity of this radiation varies depending on the temperature of the object and its ability to emit energy.

The infrared occupies a wide portion of the electromagnetic spectrum, from 0.8 μm (micrometers) to 200 μm, but only a small part is usable by IV measurement and visualization equipment. For thermovision, only the domain raging between 0.75 μm and 15 μm presents interest. Basically, according to the manufacturer, 3 (or 2) sub-domains are recognized, Figure 1:

- SW – Short waves or near infrared: 0,8÷1,5μm;
- MW – Mid-waves: 2÷5μm;
- LW – Long waves: 7÷15μm.

Although wavelengths are given in μm (micrometers), other wavelength units are often used in this spectral region, e.g. nanometers (nm) and Ångström (Å) – 10000 = 1000 nm = 1 μm.

2.2 Equations of the Thermography Camera

When visualizing an object, the camera receives radiation, not only from the object itself, but also collects the radiation reflected in the surroundings of the object's surface. Both radiation are attenuated to some extent by the measurement atmosphere. In addition, a third radiation which must be considered, is the radiation from the atmosphere. This description is a real one, describing the measuring conditions.

What can be neglected, however, is sunlight and spreading in the atmosphere of uncontrolled radiation from intense radiation sources, outside the field of vision. Such disturbances are difficult to be quantified, but, however, in most cases, they are fortunately small enough to be neglected. If they are not neglectable, the measurement configuration is uncertain, even for a trained operator.

The operator is responsible for modifying situations where measurements can be disturbed: for example, by changing the direction of visualization, protection, etc., Figure 2.

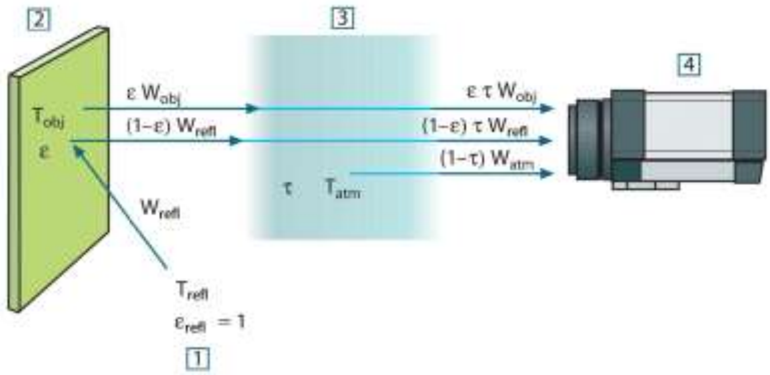


Fig. 2. Schematic representation of the method of thermography:
1-environment; 2-object; 3-atmosphere; 4-camera [16]

In order to obtain a formula for calculating the temperature of the object using the thermography calibrated camera, it is assumed that a power radiation W of a black object with a source temperature T_{source}, is received at a short distance. The camera will generate an output signal U_{source}, proportionately with the input power (linear power of the camera). Thus, the following equation can be generated:

$$U_{source} = CW\left(T_{source}\right) \tag{1}$$

or simplified:

$$U_{source} = CW_{source} \tag{2}$$

where: C – the constant.

If the radiation source is considered, for a grey object with an emissivity of ε, then the radiation received will therefore be the εW_{source}. Under these conditions, it can be defined:

1 – emissivity of the object = $\varepsilon\tau W_{obj}$,

where ε is the emissivity of the object, and τ atmospheric transmittance. The object's temperature will be T_{obj}.

2 – reflected emissivity of the external sources = $(1-\varepsilon)\tau W_{refl}$,

where $(1-\varepsilon)$ is the reflection coefficient of the object. The temperature of the external sources considered is T_{refl}. It is assumed that the temperature T_{refl} is the same for all surfaces emitting from the environment. This, of course, is for the case of the simplified hypothesis. It is also assumed that the emissivity of the environment is equal to 1. This is implied by the perspective of Kirchhoff's law.

3 – atmospheric radiation = $(1-\tau)\tau W_{atm}$,

where $(1-\tau)$ is the atmospheric emissivity. The atmospheric temperature is considered T_{atm}.
Total radiation can be written as:

$$W_{tot} = \varepsilon\tau W_{obj} + \left(1-\varepsilon\right)\tau W_{refl} + \left(1-\tau\right)W_{atm} \tag{3}$$

By multiplying each term with the constant C in the equation (1) and replacing the CW product, the corresponding output signal U, shall be obtained:

$$U_{tot} = \varepsilon\tau U_{obj} + \left(1-\varepsilon\right)\tau U_{refl} + \left(1-\tau\right)U_{atm} \tag{4}$$

Solving equation 3 for U_{obj}, we obtain:

$$U_{obj} = \frac{1}{\varepsilon\tau}U_{tot} - \frac{\left(1-\varepsilon\right)}{\varepsilon}U_{refl} - \frac{\left(1-\tau\right)}{\varepsilon\tau}U_{atm} \tag{5}$$

The formula resulting from the equation (5) is the measuring formula used in the FLIR System Series Thermographers [16].

The tensions used in the equation (5) are defined as*: U_{obj} – calculated output voltage of the thermovision camera for the black object's temperature, T_{obj}; U_{tot}* – the measured voltage of the thermovision camera for particular cases; U_{refl} – the theoretical output voltage of the thermovision camera for the black object's temperature, T_{refl}, according to the calibration; U_{atm} – theoretical output voltage of the thermovision camera for the black object's temperature, T_{atm}, according to the calibration.

3. Experimental equipment

The experiments were carried out on a hydrostatic plant (test bench) in a laboratory in the Department of Manufacturing Engineering, Faculty of Engineering, "Dunărea de Jos" University of Galați, Romania. Figure 3 shows the equipment needed to determine the recorded values.

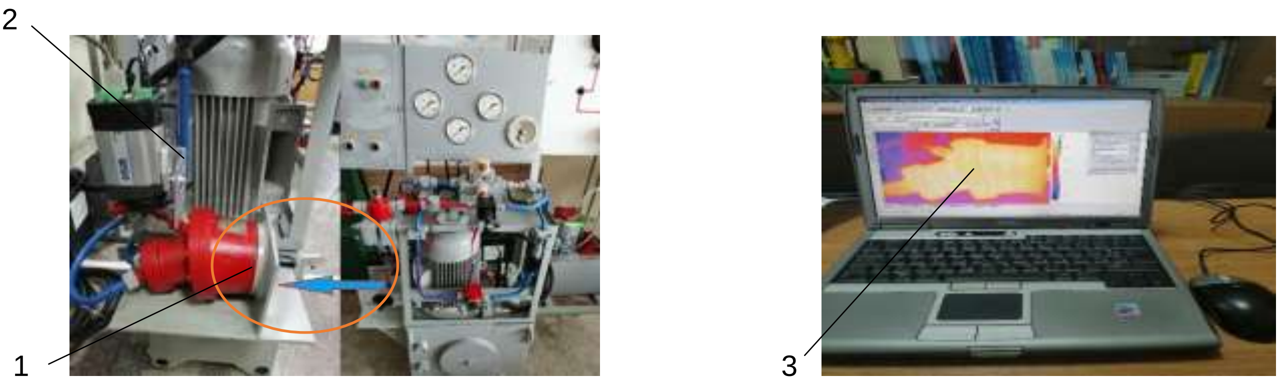
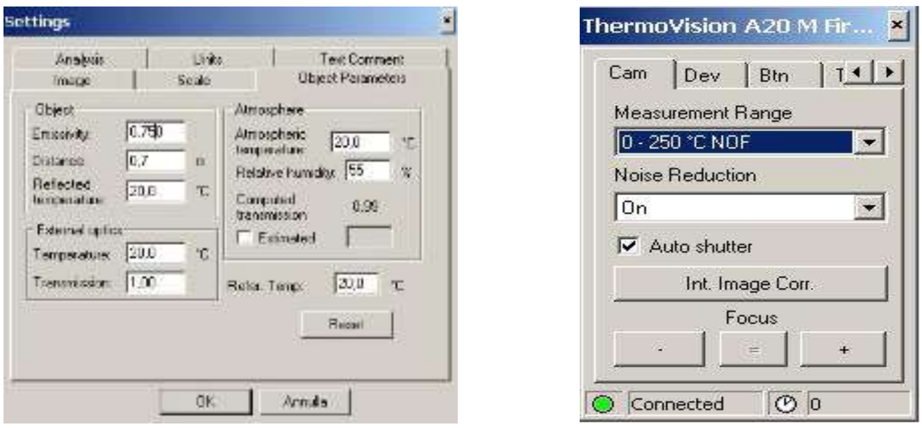


Fig. 3. Hydrostatic plant with camera thermography: axial piston hydraulic motor (1); FLIR ThermoVision A20M infrared thermal camera (2); ThermaCAM Researcher Professional specialized software for acquisition and processing of thermograms (3)

Infrared ThermoVision A20M from Flir Systems has been connected to a portable computer terminal, allowing it to be ordered from both the computer and an integrated keyboard (IK), in the forms of buttons placed accessible at the top of the camera. The most important features of the thermographic camera have been set: measuring range: 20 ÷ 900 °C; image frequency: 50 Hz; image resolution: 160x120 pixels; thermal sensitivity <0.1 °C; Digital Video Interface: FireWire;
- Spectrum wavelength: 7.5 ÷ 13 μm. In order to obtain a true infrared image, it is also necessary to consider the parameters describing the physical properties of the material to be processed (emissivity, reflected temperature), environmental temperature, relative humidity, distance from the lens of the camera to the hydraulic motor, Figure 4a and 4b.



a. b.

Fig. 4. ThermoVision A20M ThermoVision Camera: the properties of the hydraulic motor material (a); choice of the temperature measurement range (b)

4. Specialized software ThermaCAM Researcher Professional

ThermaCAM Researcher Professional is the ThermoVision A20M ThermoVision thermo-imaging software - capable of measuring and capturing images of objects that emit infrared radiation. Due to the fact that radiation is a function which depends on the surface temperature of an object, the software allows the camera to make it possible to record the temperature in real time, but it can also be used for the acquisition and processing of thermograms that include the temperature range, recorded at the axial piston hydraulic motor, the images obtained showing the thermal state at a certain moment during the functioning process [17]. Using the ThermaCAM Professional software, the recordings of the thermography camera are captured and can be expressed numerically or graphically in the form of images, profiles, histograms etc. For the numerical analysis of the temperature and statistical information in the images, obtained either on the basis of the absolute measurements (the result is a real temperature) or the relative ones (the result is a difference in temperature), markers (evolution lines) were used on the image in infrared, which highlights the areas where the radiation of the object is equal. Markers can be punctual - temperature is measured in one place on the image, zonal - temperature, maximum, minimum, average and standard deviation, in a perimeter chosen in the image or linear - measuring the minimum temperature, maximum temperature, average and standard deviation, along a straight line within the image.

5. Results and discussions

In implementing the best predictive maintenance practices, a particular impact on the operation of industrial equipment, in general and hydraulic, in particular, is the way in which the operating temperature of the components of the installations is controlled. Thus, in experimental research it was measured, with the aid of an infrared thermal imaging camera FLIR ThermoVision A20M, the temperature recorded at the rotary hydraulic piston engine with axial pistons for two working pressure values: 20 bar and 50 bar. The registration with FLIR ThermoVision A20M was performed for 10 seconds after 15, 25, 35, 45 and 50 minutes of operation of the plant. The operating parameters of the rotary hydraulic engine with axial pistons are presented in Table 1.

Table 1: The parameters of the axial piston hydraulic motor

The parameters of the axial piston hydraulic motor	Value
p_n (nominal pressure) [daN/cm^2]	150
Q_n (nominal flow) [l/min]	17
n (rotation speed) [rpm]	1450

Test 1 - On the basis of the operating values of the pump n = 1275 rpm and p = 20 bar, images of the temperature variation with the infrared camera FLIR are presented in Figures 5, 7, 9, 11. In the present study, it was chosen to draw the evolution lines (L01, L02, ..., L05), Figures (6, 8, 10, 12), present graphs to plot from the recorded values opting for the maximum temperature.

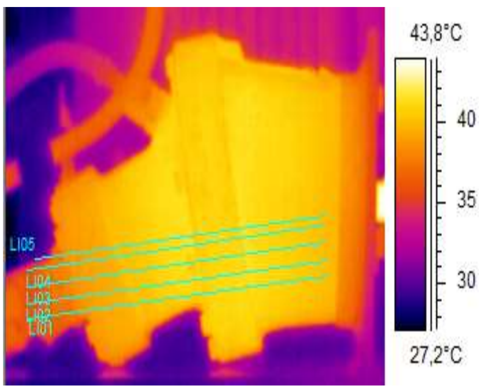


Fig. 5. FLIR camera frame-image after 15 min.

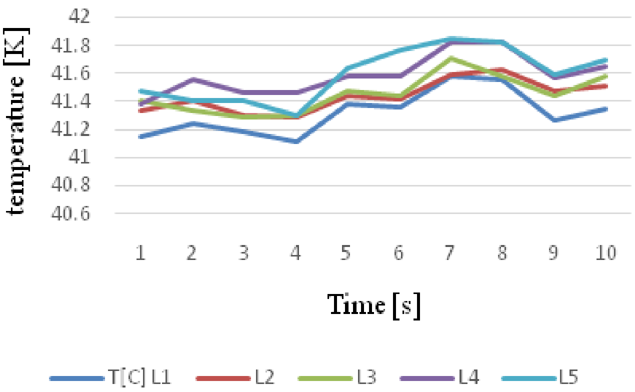


Fig. 6. Temperature variation for p = 20 bar after 15 min.

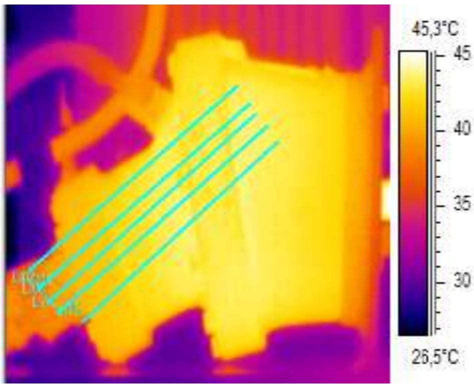


Fig. 7. FLIR camera frame-image after 25 min.

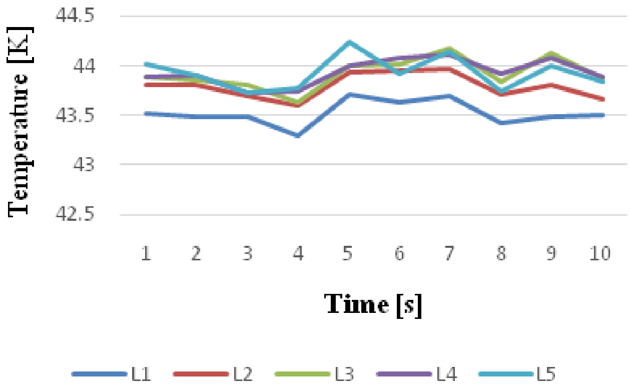


Fig. 8. Temperature variation for *p* = 20 bar after 25 min.

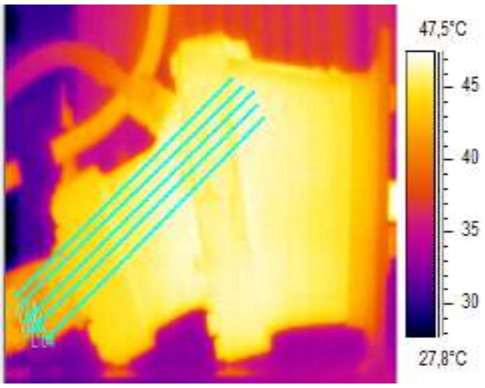


Fig. 9. FLIR camera frame-image after 35 min.

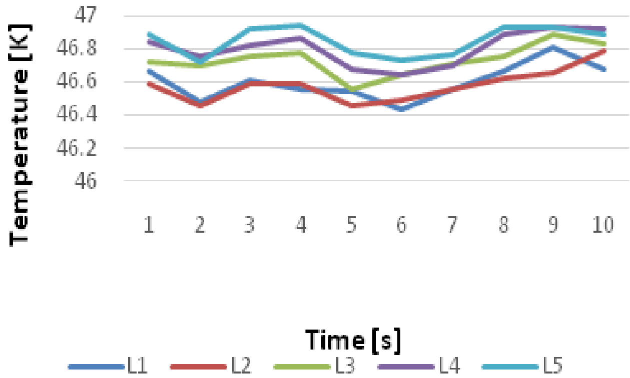


Fig. 10. Temperature variation for *p* = 20 bar after 35 min.

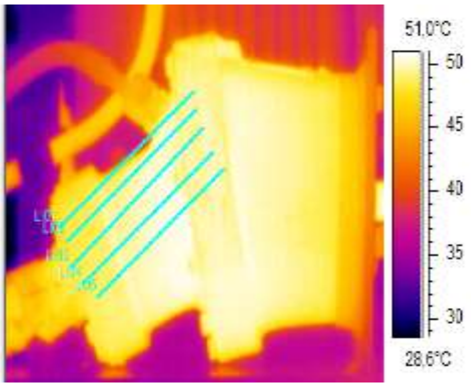


Fig. 11. FLIR camera frame-image after 50 min.

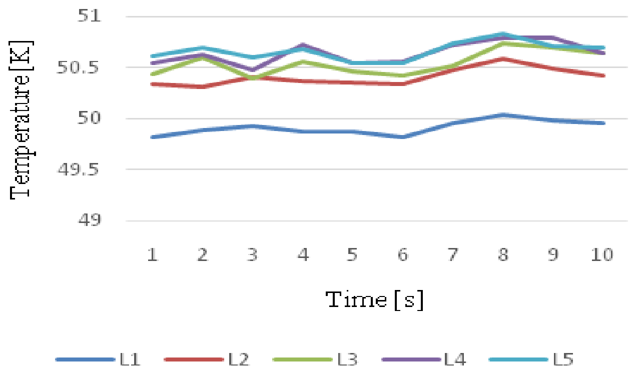


Fig. 12. Temperature variation for *p* = 20 bar after 50 min.

Test 2 - Figure 13 shows the hottest area of the axial piston hydraulic motor. The camera was fixed on this zone to see the variation of the temperature for p=50 bar and n=1700 rpm.

On the basis of the operating values of the pump n = 1700 rpm and p = 50 bar, images of the temperature variation with the infrared camera FLIR are presented in Figures 14, 16, 18, 20.

Figures 15, 17, 19, 21 present graphs to plot from the recorded values opting for the maximum temperature.

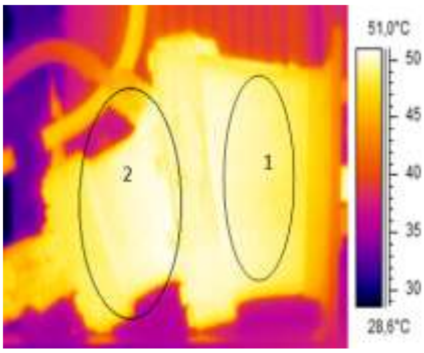


Fig. 13. The hottest area of the axial piston hydraulic motor

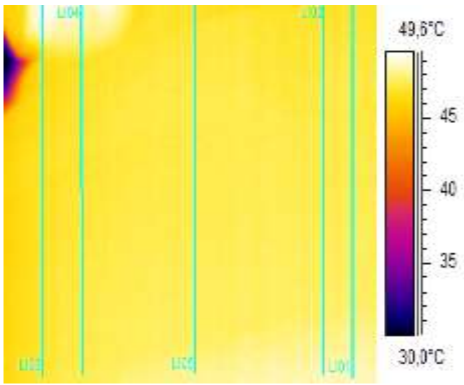


Fig. 14. FLIR camera frame-image after 10 min.

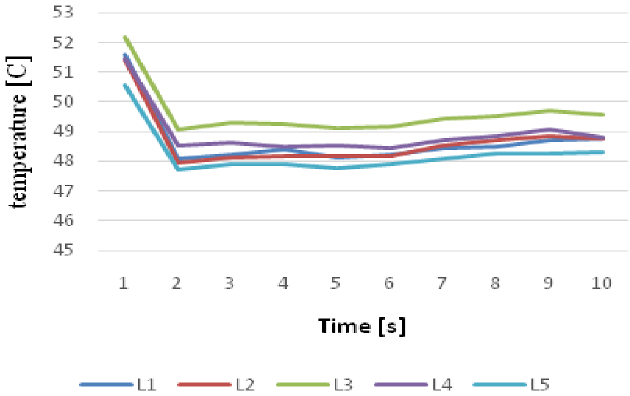


Fig. 15. Temperature variation for *p* = 50 bar after 10 min.

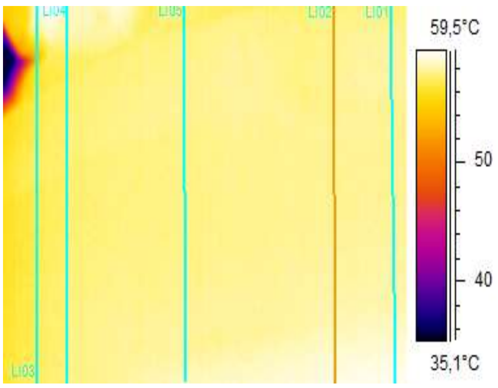


Fig. 16. FLIR camera frame-image after 15 min.

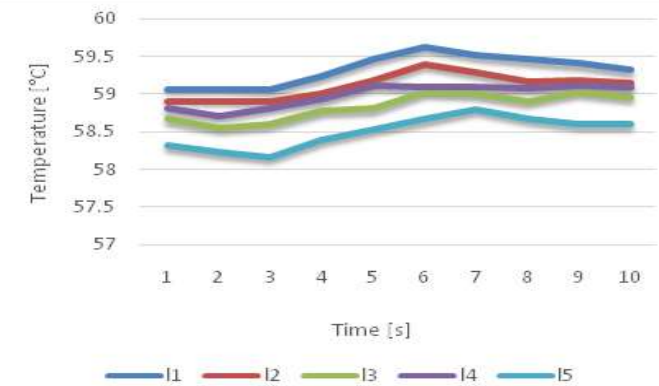


Fig. 17. Temperature variation for *p* = 50 bar after 15 min.

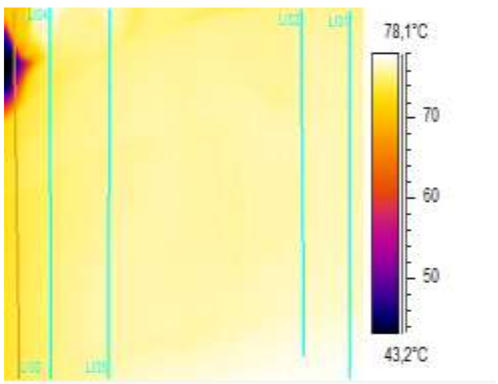


Fig. 18. FLIR camera frame-image after 30 min.

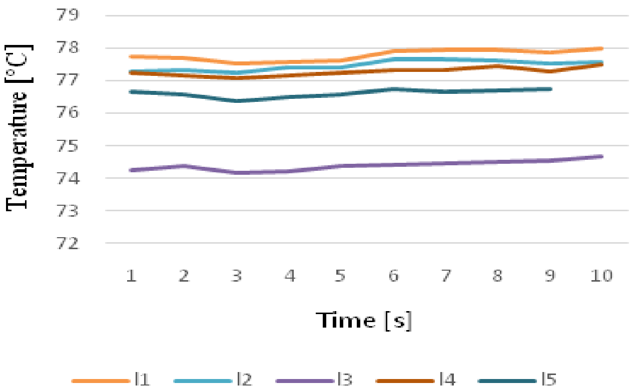


Fig. 19. Temperature variation for *p* = 50 bar after 30 min.

Conclusions

In mechanical and hydraulic drives, overheating is a general problem, which indicates breakdown in near future. Thermal imaging technology serves an important purpose for predictive maintenance of axial piston hydraulic motor and produces heat-based images, where the colors in the image show a relationship between every pixel of the hydraulic equipment image and a reference surface temperature. Following the experimental research presented on the demonstration of the possibility of using infrared thermography to predict the behavior of hydrostatic systems, to evaluate the state of wear and the operation of axial piston hydraulic motor, a series of numerical and graphics was obtained.

Regarding the test performed, the following punctual conclusions are appropriate:

- The first test was performed at p= 20 bar - the thermogram analysis presented in Figure 11 shows that the pump tested in Figure 3 is operating normally. Thus, we see that on the lower side of the pump, corresponding to the piston block (area 2 in Figure 13), the temperature is about 51ºC and on the upper side, where the pistons are located (area 1 in Figure 13), the measured temperature is about 46ºC. The temperature difference recorded at the pump heads is 5°C, which is below the critical value of 10°C.

- For the second test, concerning the hottest portion (1 in Figure 13) of the pump, the temperature rises to 78.1°C at p = 50 bar, after a 30 minutes-operation (Figure 18).

Acknowledgments

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