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PREDICTIVE MAINTENANCE USING INFRARED THERMOGRAPHIC CAMERA IN AGRICULTURAL MACHINES

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Abstract. *This paper describes a work on predictive maintenance using thermographic analysis to inspect agricultural machinery. Predictive maintenance is one of the most widely used methods to avoid downtime since it can predict possible machine failures efficiently and at low cost through data collection and periodic inspections, preventing the machine from being stopped for several days for one unscheduled repair. The thermographic analysis method is a process in which, from a thermographic camera, photographs are generated that are generated by infrared radiation. These images are handled through software, which then sets the temperature of the machine compartments. The analyzed compartments are strategically selected based on the parts of the machine that have the possibility to present a heating from the beginning of failures that generate heat: friction, short circuit, etc. Therefore, it is evaluated whether the temperature measured in the compartments corresponds to the temperature range predetermined by the manufacturer. The agricultural machines evaluated in this paper were two tractors and two sugarcane harvesters of the same manufacturer, and each of them presented a fault of different origin, being identified by the thermographic analysis. The problems encountered were faults in the hydraulic system, electrical system and power transmission system. The high temperature was only a indicative of a failure and, in each of the cases studied, the origin of the elevated temperature had different causes.*

Keywords: *thermographic camera, predictive maintenance, agricultural machinery.*

1. INTRODUCTION

According to Souza (2008), predictive maintenance is based on data collection by monitoring or inspecting equipment. Frequency, responsibility and gathering method vary according to equipment type, lifespan and importance. This method is important in agricultural segment because activities in countryside depend largely on climatic conditions and must be extremely well planned. This way, a sudden failure of machine during operation might compromise and entire harvesting or seeding operation, leading to production and logistic problems due to the consequential losses of machine breakdown.

Da Costa et al. (2015) reports that predictive maintenance is one of the cheapest methods, because it prevents complete failure of parts and disassembly of equipment, increasing availability and overall productivity. Besides that, this method permits perform a check-up on several compartment of machine like, covering electrical components, fluids and regions of mechanical friction.

Among the different predictive strategies, such as oil analysis, vibration measurement and thermographic evaluation, the later deserves special attention. Bezerra (2007) states that thermography is a non-destructive technique which allows estimation of temperature or verification of irregular temperature distribution patterns through infrared radiation, providing information related to operational condition of a component, equipment or process, with a fast, efficient and cheap result. In addition, it can be said that this method is safe because there is no need for contact during the evaluation (Brique, 2016; Caramalho,2012).

Cendeira et al. (2011) emphasizes the use of thermography in situations where there is a temperature variation indicating some atypical condition in any system. In view of this advantages, the use of thermocamera in the predictive maintenance of agricultural machines becomes an attractive option, because it can be run in field quickly. However, as a limitation, the photographs must be taken after the machine has been operated because, outside the actual working conditions, the compartment temperatures can vary significantly.

Another limitation is the strong influence of the climate, making it impossible to thermographic analysis in certain periods (night period or rainy days for example), making it difficult to schedule the of predictive maintenance. In this paper, thermographic analysis capabilities were assessed in association with a local tractor dealership. Use of this predictive strategy is under evaluation by this enterprise to be applied or not in after sale services. Results will base the decision-making process and define when general machine maintenance will be required.

2. METHODOLOGY

Thermal analyses were carried out for different types of agricultural machinery in varied components. The components that was selected was a strategy points where can have a focus in irregular heat generation like gears, hydraulic bombs, electric components as show at Fig. 1. A thermographic camera Flir One Pro-3a (Fig. 2) was attached to the technician's cellphone during field inspections, while digital image was generated with FLIR Tools® software in computers of central office.

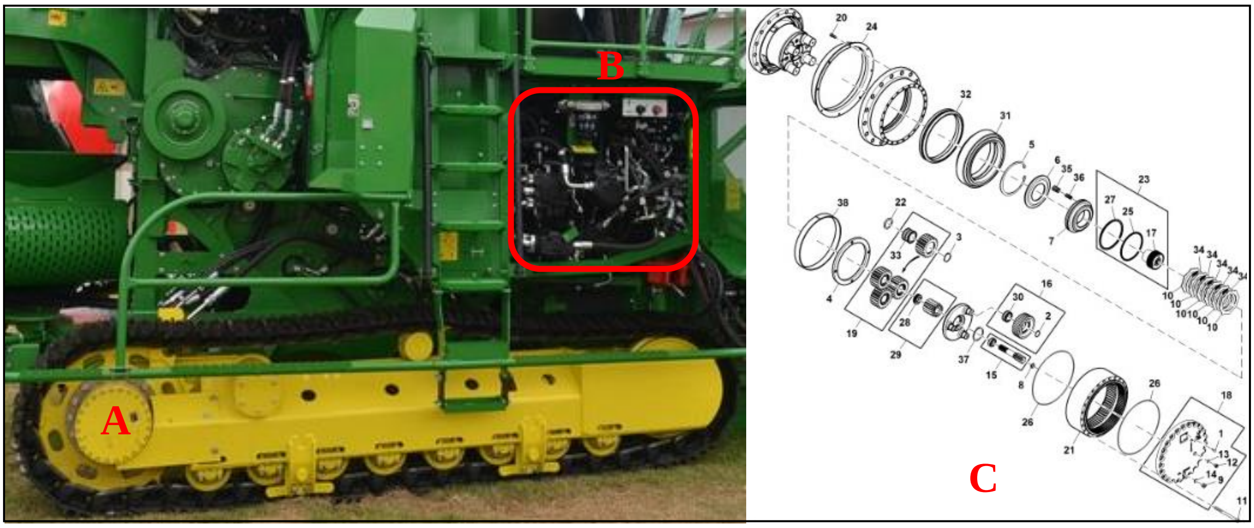

Figure 1. Right side view of a sugar cane harvester. A) Final reduction of the power train. B) Set of hydraulic pumps. C) Schematic drawing of the final reduction of the power train.

Figure 2. Exemple of camera Flir One Pro-3ª coupled into a smartphone.

This camera permits measure temperature at -20ºC to 120º (out of this range the camera loss precision) with 0,1ºC resolution and 3ºC precision approximated. The camera produces a two-dimensional matrix while the software transforms numeric data in an image, as exemplified in Fig. 3. Technician then selects the region of image for which software will delivers average, maximum and minimum temperatures. This information is compared with usual operational parameters and must stay within a range (stipulated by the manufacturer). Any deviations will lead to further detailed inspection. The usual values are determined according to service provider and database information. Two types of sugar cane harvesters (A and B) and two tractors (C and D) was inspected. Points that was analyzed was gears, hydraulic pumps and electrical components.

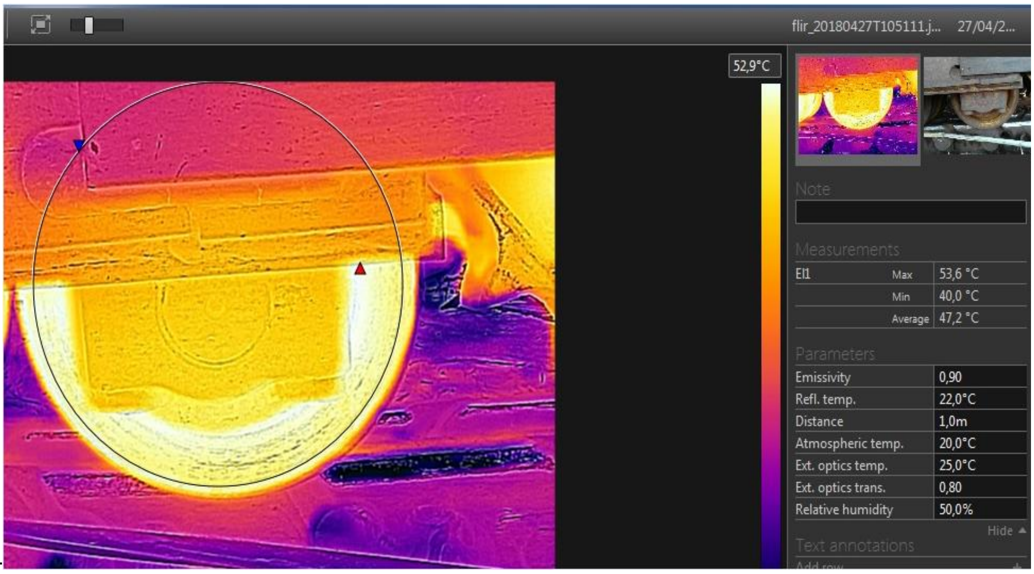

Figure 3. Example of a photograph obtained by thermographic camera and software.

To carry out the photographs you must leave the machine working for at least 3 hours in your workplace. The climate can influence the temperature of the machine because the agricultural machines work outdoors. Therefore, the manufacturer suggests performing the thermographic analysis during the afternoon, with the ambient temperature is between 20 and 30 ºC. There is no correction factor for other conditions, so it is not possible to perform the analysis on rainy days or at night, for example. The thermography system requires some calibration and the result may depend on other factors such as the absorption and reflection of infrared radiation (Potdar and Zehnder, 2003).

According to the manufacturer of agricultural machinery (which provides the ideal temperature base of each compartment to refer the thermographic analyzes), a single photograph of the compartment is sufficient, since the resolution of the photo has no significant influence on the determination of the temperature via infrared, it is sufficient since the picture is correctly positioned. The frame is also determined by the manufacturer John Deere.

If more than one photograph is taken, there is a tendency to distort the actual value of the temperature that the machine compartment operates, because this temperature does not stabilize. Therefore, it is only possible to record photographs with the machine stopped, and they must be obtained quickly because the temperature drops gradually. Therefore, a method of making the photographs for each type of agricultural machine was standardized. A maximum deadline and an order in which photographs are to be performed based on the temperature drop of each compartment was stipulated. For larger machines, it is even necessary to perform the acquisition in two or more steps.

In this way, the photograph is only taken again to the same compartment in case it is not in the correct frame, or has been made after the maximum time after the machine has stopped. In this case, the machine must be re-operated for at least 30 minutes (general value for any compartment of any machine) so that the compartment returns to its working temperature.

The possibility of averaging between photos of the same compartment as well as being unnecessary, makes the method unfeasible due to the excessive time it takes to reheat the machine. The standard deviation of the average between photos arrives, in the overwhelming majority of cases already tested, is less than 1/6 of the total value of the temperature that the compartment can present without inferring in an excessive temperature in the respective compartment.

The maximum acceptable temperature variation varies for the enclosure type. The temperature should not exceed 25°C from the ideal temperature for fluids compartments (eg hydraulic system pumps) and mechanical friction (eg transmission system gears). For electrical components, the tolerance is 15ºC above the ideal compartment temperature. All these tolerances were stipulated by the machine manufacturer (John Deere, 2018).

3. RESULTS AND DISCUSSION

3.1 Sugar cane harvesters

Thermographic analysis performed on parts of the sugar cane harvester A revealed abnormalities in temperature range of roller 7, roller 8 and final direct reduction (Fig. 4) of treadmill where the operation temperature was 131% higher above to the ideal. Two possible causes were suggested. First one was lack of lubrication in the system, since it would lead to more severe contact and thus increase friction, consequently leading to higher temperature. Another hypothesis is that lubricating oil used in the system was out of date or contaminated, since it would also lead to poor lubrication and more severe contact. Table 1 indicates the ideal operating temperatures of each agricultural machinery and the out-of-range temperatures found through the thermographic analysis.

Figure 4. Thermographic analysis in final right reduction of roller conveyor from sugar cane harvester where the average temperature was 46,2°C.

In sugar cane harvester B, increased temperature was found in all hydraulic system which is composed by pumps, linear and rotary actuators, valves, hoses and pipes. Figure 5 shows the image of the analyzed pump, whose fluid outlet pressure is around 420 bar. A higher than expected temperature was tracked presenting 142 % above to the ideal, indicating that this part was overproducing heat, and this heat was being transported to the rest of the system through the hydraulic oil. A subsequent inspection identified that this rise in temperature was due to excessive pressure. This pressure in turn, originated by the exaggerated amount of hydraulic oil.

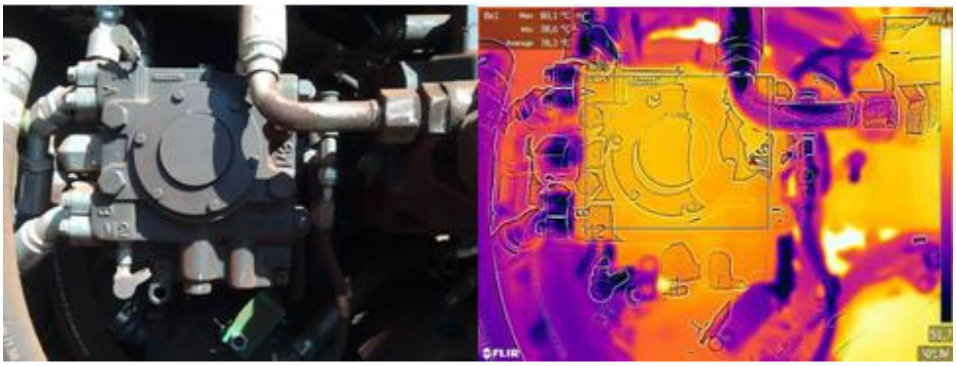

Figure 5. Thermography of one of the hydraulic pumps of the cane harvester B operating with average temperature of 48,4°C.

3.2 Tractors

In the inspection of the tractor C through thermography, a temperature above the required temperature was found in one of its light switches, as seen in Fig. 6 (A). In Fig. 6 (B) the ideal temperature is seen after correction of the failure, with is a temperature of 267% above the ideal temperature. For safety reasons, this fault was urgently repaired, because with the heat dissipation by the electric current, the light switch was at high risk of generating a fire.

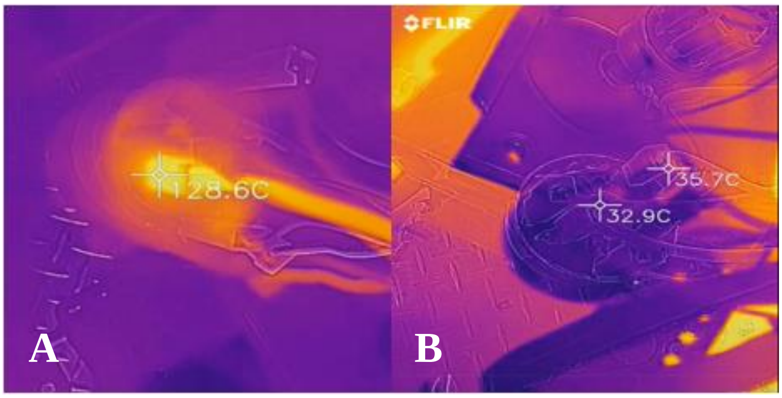

Figure 6- A) Damaged light switch. B) Light switch after repair.

In the tractor D, through thermographic analysis a temperature increase in the hydraulic pump was detected. Fig. 7 shows a thermography performed on the hydraulic pump operating at a temperature above the ideal with average of 68,2 ºC, while in Fig. 8 shows a hydraulic pump operating under normal conditions with a average temperature of 41,9 ºC.

Figure 7- Thermography of a hydraulic pump operating at an above ideal temperature.

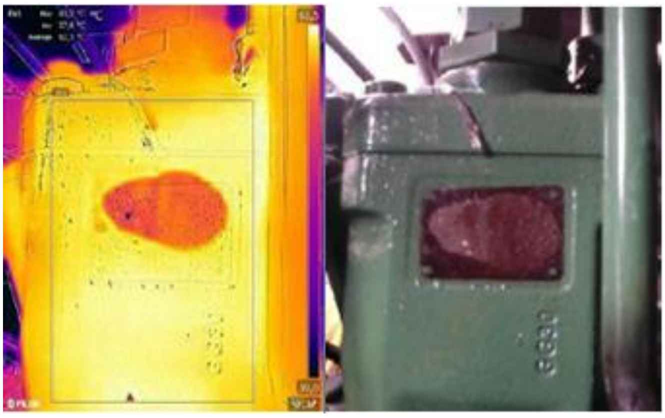

Figure 8 – Thermography of a hydraulic pump operating at an ideal temperature.

From the temperature differences recorded by the thermographic analyzes, an avarege discrepancy of 25ºC is observed when compared to the hydraulic pump subjected to high temperatures with a hydraulic pump operating under normal conditions. This was due to an oil leak in the tractor's hydraulic system. There was reduction in the amount of oil and contamination of the remaining oil. As a result, the hydraulic pump operated under non-ideal conditions, leading to increased friction and consequently generated an increase in its temperature. In hydraulic systems, hydraulic oil also has a secondary function of lubricating the system.

Table 1: Optimum operating temperature of components and non-optimal temperatures found.

Agricultural machinery compartment	Ideal temperature(°C)	Analised Temperature(°C)		Average Temperature Increase (%)
		Average	Maximum	
A(final right reduction of roller conveyor)	20	46,2	48,4	131
B(hydraulic pump)	20	48,4	52,6	142
C (light switches)	35	128.6	132.4	267
D(Hydraulic pump)	40	68,2	71,3	70,5

4. CONCLUSIONS

After presenting the results of the thermographic analyzes, the sector responsible for the maintenance of the agricultural machinery began an inspection work that verified the failures indicated by the excessive temperature in the compartments of the machines. In the cane harvester A, it was confirmed that the excessive temperature originated from the friction in poorly lubricated gears. The lubricating oil level was below the recommended level due to a leak in a retainer. The worn gear particles contaminated the fluid and consequently the wear and tear tended to get worse. Thanks to predictive maintenance, the problem was solved at an early stage, emphasizing the advantage of the agility of the thermographic analysis that allows quick inspections and in short periods (in relation to a reference of hours worked by the machine).

In the cane harvester B, the excess temperature was confirmed as an indirect effect of excess hydraulic oil. With the excess oil in the hydraulic system, the machine when performing movements, the fluid in the hydraulic cylinders undergoes compression, and there is a greater increase in pressure and temperature than in an ideal condition. This results in greater mechanical stresses and wear on the machine parts (especially the rupturing of hoses and seals), thus reducing its service life. This can be proved through the dissertation of Burma and Khayal, 2014. To avoid this type of problem it is necessary to control the amount of oil injected into the system because both the lack and the excess will tend to creat problems. It was identified that this excess of hydraulic oil originated from a human failure during the oil change: The person in charge was not draining the old oil completely, which was accumulating with the new oil, giving rise to the whole problem.

The high temperature in the tractor light switch C was caused by a short circuit in the wiring. The impedance reduction increases the passage of the electric current abnormally, forcing a dissipation of energy. Most of this energy is dissipated as heat, as can be confirmed by Laska, 2003. This was the most serious case among those studied in this thermographic analysis, since the heat generated is in an external component, and agricultural machinery is often operating in an environment with low humidity and presence of straw (especially during harvesting periods), and consequently there is a high risk of fire in the machine. Therefore, after detecting this failure, the company decided to expand the number of thermographic analysis points in electrical systems of the machines.

The tractor D presented, as well as the cane harvester B, an elevation of the temperature in one of its hydraulic pumps. However, unlike case B where the origin consisted of excess hydraulic oil, in case D a lack of hydraulic oil was diagnosed. Hydraulic oil has the secondary function of lubricating the hydraulic pumps, and their level below the ideal makes it difficult to work the pump. The leakage point found was at a point of low pressure, and in this condition, there is the possibility of particles entering (dust, due to the working condition of an agricultural machine). This particles had a confirmed presence in a fluid analysis done in parallel with the thermographic analysis. Dust in the working environment of the agricultural machine contains silicon (coming from soil) oxides, which are abrasive and wear down the entire hydraulic system.

With bases in these cases, it can be concluded that the application of thermographic analysis in predictive maintenance is a method that besides being low cost, is highly efficient. With a simple inspection, it was possible to find several problems in the equipment that, if not corrected, could in the future generate a large number of faults in several parts. Such failures could generate fires, shutdowns or even accidents with the equipment, the machine and the operator.

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6. RESPONSIBILITY NOTICE

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