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RELIABILITY CENTERED MAINTENANCE OF MANUFACTURING EQUIPMENT USING INFRARED TERMOGRAPHY

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***Abstract:**. Preventive and predictive maintenance tasks became easier than current methods, by using infrared thermography. IRT shortens testing procedures, emphasizing trouble spots in sophisticated manufacturing equipments Experimental researches conducted by the authors on the thermal behavior of machine tools and industrial robots were used to detect the main thermal sources and temperature values on the equipments. Thermal images captured at different moments, were processed with the additional soft of IR camera and the main temperature values were detected. Analyzing the processed thermograms and their time evolution, were detected the sections and the parts with higher temperatures, which needed for further monitoring and actions for preventive maintenance*

***Key words:** maintenance, manufacturing equipment, infrared thermography, robot.*

1. INTRODUCTION

The effective maintenance programs are indispensable in today's industrial equipments in which unexpected production interruptions are intolerable. Increased productivity demands, sophisticated production process and just-in-time delivery require using every resources available to prevent disrupting production schedule. The importance of the maintenance function and therefore of maintenance policies has grown throughout the years. The development of mechanization and automation has increased the capital involved in production equipments and has reduced the number of production personnel. On the other hand, the fraction employees in the maintenance activities has grown, as well as the fraction on maintenance spending on the total operational costs. In very big factories the operations and the maintenance departments are the larges and each comprises about 30% of total manpower [1]. Maintenance spending next to energy costs are now the larges part of the operational budget.

2. MAINTENANCE PROCEDURES AT INDUSTRIAL EQUIPMENTS

Proper maintenance programs of machines and industrial equipment are important for keeping machine status with less spending. The costs of maintenance programs have to be balanced against the consequences of unscheduled downtime. Good maintenance programs are considered when is well known what to measure, and if the results are accurately interpreted.

Maintenance procedures generally follow three common philosophies.

- *Corrective maintenance* or run until breaks practice, may proceed only if the costs of repairs and the penalties of unexpected production downtime are acceptable [1].
- *Time based maintenance* or fixed schedule maintenance, means that machines are inspected at fixed intervals and then are done necessary replacements of certain parts and adjustments. This practice has the potential drawback of over or under maintaining the equipment. All components do not wear the same way and some equipment will get unneeded attention, or even be replaced, regardless of their condition. On the other hand, the inspection interval may be too long to prevent failure of fast-wearing components.
- *Condition based maintenance* is a two step process: first a performance base of all equipment must be established, and then maintenance is carried out based on how various components are performing. This preventive maintenance, or on condition monitoring programs, ranges from using a single meter, for a single temperature, vibration or pressure reading, to detailed multivariable analysis. The key of condition based maintenance is to detect shifts in performance [2]. Data are taken on the equipment when it is performing to specifications, then periodically the same parameters are checked. Unexpected shifts mean something bad is happening within the equipment. Using a good monitoring program based on adequate parameter checking a time of failure can be predicted, and so the equipment may be shut down and fixed off-line. Very important are the data and the programs that allow diagnosing, and showing what goes wrong in the equipment as well as give a prognosis of what is the remaining life of various components. Preventive maintenance is more than trying to prevent failures; it is keeping the performances of the equipment up to specifications. An overview on maintenance policies and activities is presented in Fig. 1.

3. RELIABILITY-CENTERED MAINTENANCE

The realization of a good maintenance planning is a complicated task, because of many causes of equipment failure and their various properties. Some are depending on the age of machines, other are depending on running

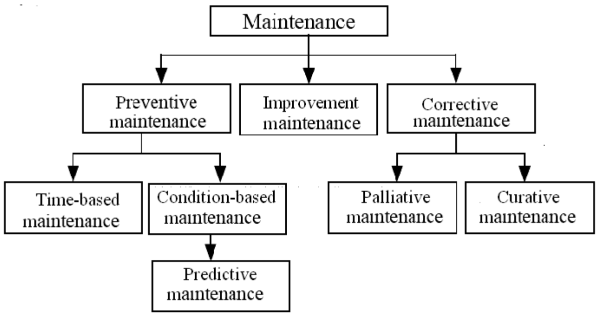

Fig. 1. Classification of maintenance activities.

condition and some may be considered stochastic. It is difficult whether to adopt time-based maintenance or condition-based maintenance (Fig. 1). The maintenance cost activities may be considered as helpful criterion.

Reliability-Centered Maintenance (RCM) is a systematic method for selecting the appropriate and applicable maintenance activity types [3]. The main steps of RCM activities are presented as follows:

a – target equipment, components or products are clearly defined, and necessary data are collected

b – the possible failures and there effect on target equipment, components or products are systematically analyzed.

c – predictive or corrective maintenance operations are established. Selection of operations as based of effectiveness calculation for operations required to achieving maintenance quality such as reliability or cost.

The presented steps need to be repeated to realize effective maintenance planning. Steps *a* and *b* of the RCM are generally very tedious and time consuming. Their contents are basically the same as Failure Mode and Effect Analysis (FMEA). Effective and practical approach to FMEA is only based on computer –aided technology [3].

4. PREDICTIVE TESTING AND INSPECTION TECHNOLOGIES

To perform maintenance job properly, there are needed the right tools to detect the problems and the abilities to use them on the equipment. A wide variety of methods are used to assess the condition of equipment to determine the most effective time to schedule maintenance activities. Monitoring the equipment means measuring some parameters, which could have something to do with its performances. The data acquired permits an assessment of equipment performance degradation from the as designed or required condition. What to measure and when can be scheduled depending on the monitored machine, available approaches and additional costs [4, 5].

The approaches covered by predictive testing and inspection include:

- Vibration Monitoring and Analysis is an important way to determine the condition of rotating equipment and structural stability in a system. Using vibration analysis in time domain and frequency domain the faulty component can be detected.
- Thermals Monitoring. These tests can show hot components or areas on the equipment.
- Infrared Thermography is attractive for identifying hot spots in running equipment, such as machine tools or industrial robots.
- Noise and Ultrasonic Detection pick-up sounds of motors, machinery, gas, air and hydraulics. Spectral analysis of sounds could be an effective monitoring solution.
- Lubricants and Wear Particle Analysis is a good way to detect if a malfunction is in progress.
- Electrical Condition Monitoring using current flow tests could indicate overloaded wires or bad electrical contacts.

The importance of maintenance activities is also reflected by the number of specific standards, mainly from the group 60706 (ASRO 2007).

Infrared thermography (IRT) is the application of infrared detection instruments to pick-up thermograms (pictures of temperature differences). IRT is a non-contact technique and it is adequate for identifying hot spots in electrical, mechanical and structural facilities. IRT techniques are identified as either quantitative (absolute) thermography or qualitative (comparative) thermography.

Comparative thermography provide relative differences, hot and cold spots and deviations from normal or expected temperature ranges. The thermographer obtains highly accurate temperature differences ΔT between like components, such as vee-belt transmissions, ball bearings, three-phase circuits [6]. Any uneven heating could quickly be identified with the IRT imaging system, and could indicate some malfunction.

5. INFRARED CAMERAS MAIN FEATURES

Infrared cameras characteristics can be grouped in many categories. For industrial equipment measurement the most important features might be considered:

- *Temperature Range*: from -10 up to +450° C (with filter from -20 up to 1500° C);
- *Measurement accuracy:* 2% or 2°C;
- *Price.* If the characteristics typical for the IT sector (interface, software, image storage, system status indication, etc.) are convergent, the price is related to the main features and cameras quality. Examples:

– MobIR M2, price: 3290 EUR, temperature range: -20 °C ÷ +250 °C, accuracy ±2°C or 2%);

– FLIR Systems InfraCAM SD, price: 5500 EUR, Temperature Range: -20 ... 360°C, accuracy 0.1ºC.

6. IRT INPECTION OF INDUSTRIAL ROBOTS FOR PREVENTIVE MAINTENANCE

Qualitative or comparative thermography is an effective method in evaluating the machine or component condition, by comparing their approximate temperatures to identical units, reference values or baselines.

Experimental researches regarding preventive maintenance using IRT were initiated after the installation and putting into operation of an industrial robot KUKA IR 663 (Fig. 2) in the technology laboratory of the Materials Technology and Welding Department from “Politehnica” University Bucharest [7].

Fig. 2. KUKA IR663 robot.

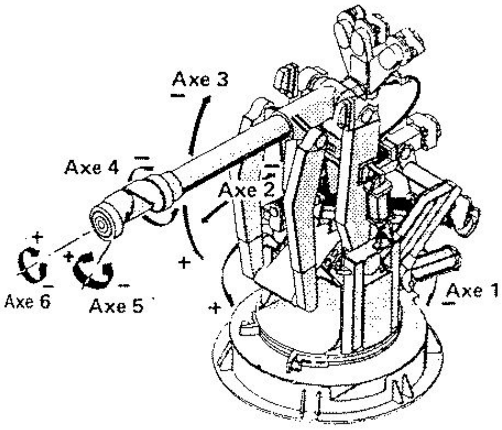

Fig. 3. Axis of the KUKA robot.

KUKA IR 663 is a six axes robot (Fig. 3), with a maximal load of 100/150 kg at the end effector, adapted for the spot welding applications. The robot can work with a supplementary load of 200 kg, as example the welding transformer.

To accomplish comparative thermography, thermal images were picked-up of the operating robot at different moments in order to establish reference values so that the following thermograms may be compared to the initial findings, making possible to accurately detect problems as they develop.

The main thermal sources of the researched robot are the electric or pneumatic motors, the joints and transmission mechanisms of the movement for the driving of the six axis of the robot.

Three driving motors for the axes 4, 5 and 6 (Fig. 4) shown a slightly different heating after one hour of functioning (running). This difference should be considered as normal, taking into account their (different) various loading, which are depending on the programmed working cycle. Comparing many thermal images of these three motors, picked-up at different time moments, it was stated a close relation between motors heating and the programmed cycle of the robot.

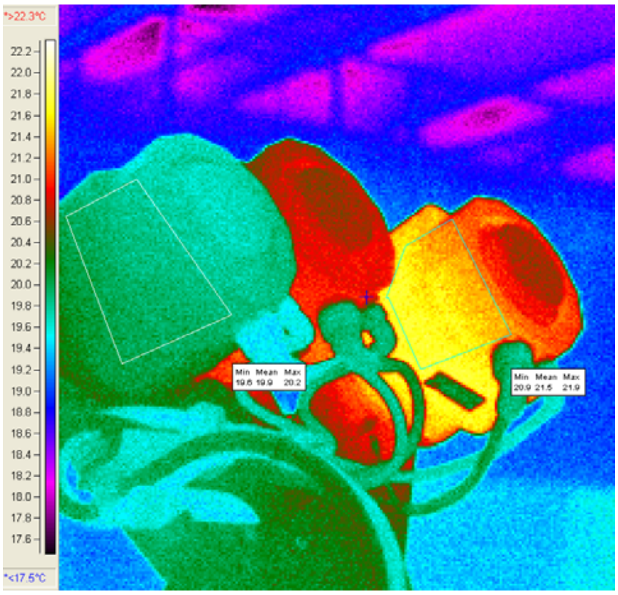

Fig. 4. Driving motors for 4, 5 and 6 axes.

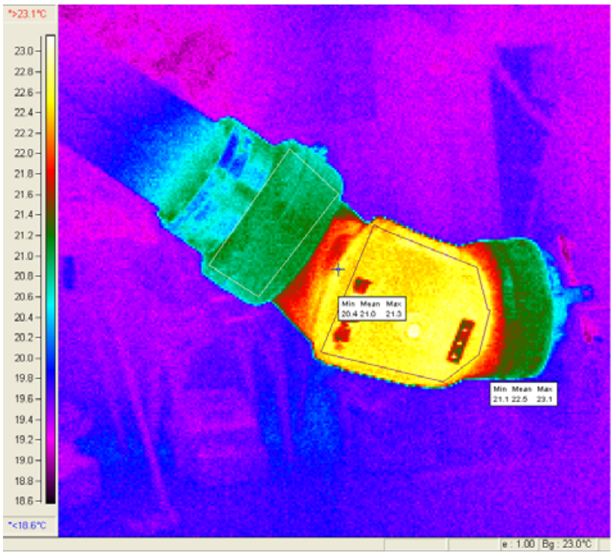

Fig. 5. Bevel gearing housing.

The housing of bevel gearings for the movement transmission to the axes 4, 5 and 6 presents a thermal image (Fig. 5) with a hot spot having a slight temperature difference related to the robot arm.

Temperature values contained in this thermogram show a normal heating of bevel gearing housing, due to the included pre-tensioned bearings and geared mechanisms. This thermogram is also close related with the programmed cycle.

The driving mechanisms for the movement on the axis 2 (Fig. 6) include the electric motor, the screw-nut mechanism and the joints with bearings. On the thermal image it is obvious a significant heating of the driving screw bearing, to a temperature greater than the temperature of the electric motor. Analyzing this thermogram a temperature range between 17 and 41 deg.C was found.

This overheating can be due to the incorrect pre-tension of this bearing or to unsuitable lubrication, as example too old or too viscous lubricant.

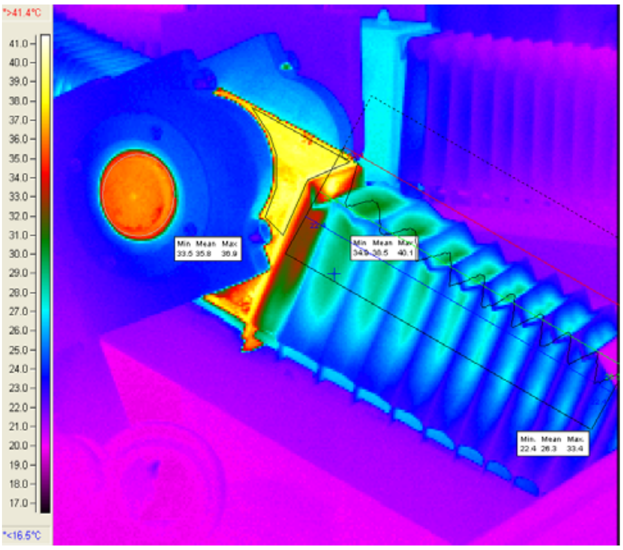

Fig. 6. Driving mechanism for axis 2.

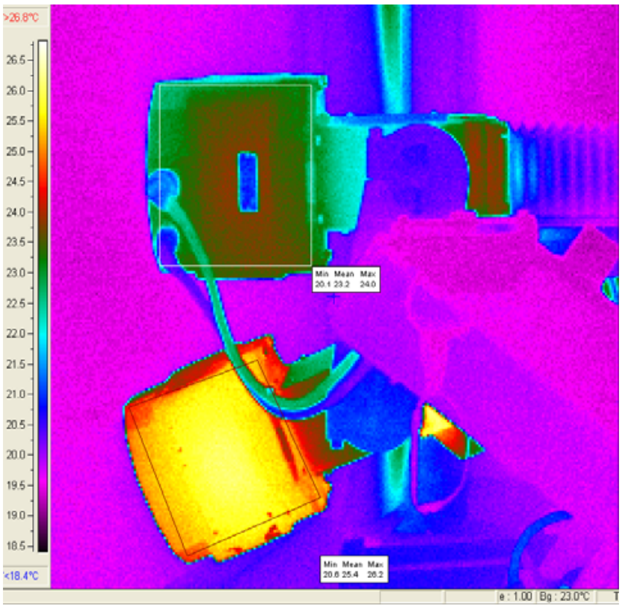

Fig.7. Driving motors for 2 and 3 axes.

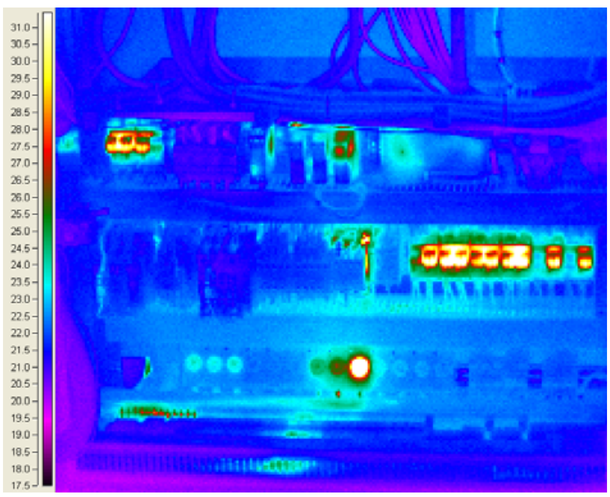

Fig. 8. Electric equipment panel of the KUKA robot.

Thermal image of the driving motors for 2 and 3 axes emphasizes the important heating of the third axis driving motor (Fig. 7). This overheating should be explained through the intensive use of this drive in the programmed cycle.

The electric equipment panel had a thermal image with some heated spots (Fig. 8), representing relays, contactors and electronic devices. Although the temperature range of this thermogram is significant (13 deg. C) the equipment worked properly, and the image can be memorized for further use as reference. Using infrared thermography to monitor the equipments has enhanced our ability to predict the reliability of equipment. It allows us to address safety issues as well as meet our maintenance and repair schedules.

7. CONCLUSIONS

Infrared thermography is an effective tool for preventive maintenance of sophisticated equipments like industrial robots are. Comparative quantitative thermography method can show if something goes wrong. Thermal images picked up from the operating robot KUKA IR 663 are established as reference value for the ongoing preventive maintenance. The readings on certain thermograms made possible to detect some issues on the robot mechanisms.

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