Temperature prediction in the mechanical elements of Industrial Robots

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***Abstract*—One of the important aspects of Industrial Robots design is related to the heat transfer through their mechanical elements. The present paper represents a study for predicting the temperature generated by the electric servomotors in the mechanical elements of a robot. A case study was made on a SCARA industrial robot structure.**

Keywords-Industrial robot; temperature; prediction

I. INTRODUCTION

In the design process of an industrial robot, there are many important factors that need to be taken into consideration. Amongst them, heat transfer needs to be addressed in order to make sure that the temperature levels reached in the mechanical elements of the industrial robot are acceptable. Usually, for predicting the temperature of the mechanical elements, if the heat losses in the servomotors are known, FEA programs for fluid flow and heat transfer can be used in order to simulate the heat transfer in the robot. The main problem with using an FEA package is the time needed to develop a model that will provide useful results, and also the time needed for the FEA program to converge to a solution. In order to overcome these problems, and to avoid the need of an FEA package, a thermal model to predict the temperature depending on the heat losses in the servomotors is proposed. Given that a servomotor geometrical shape is made out of simple shapes, the heat transfer equations for evaluating natural and forced convection coefficients can be used. The method will be using the existing empirical equations for flat surfaces, for both the natural convection [1] and forced convection [2] situations. The industrial robot is made out of two main mechanical systems, the positioning system and the orientation system. In the case of the positioning system, each mechanical element (link) will have one servomotor. For the orientation system, the situation is different, given that all the industrial robots orientation systems have more that one servomotor. The prediction model presented by this paper will deal with the situation of having just one servomotor in an enclosure. The enclosure is considered to be the mechanical element structure with the outer cases mounted on it. The mathematical relations have been written in MATLAB. The theoretical model results were compared with physical measurements made on a rig specially build for this application. The difference between the theoretical predicted numbers and the measurements are shown in the conclusions.

II. THE THERMAL MODEL

With the servomotor being the source of heat, an arrangement like in the below figure has been considered.

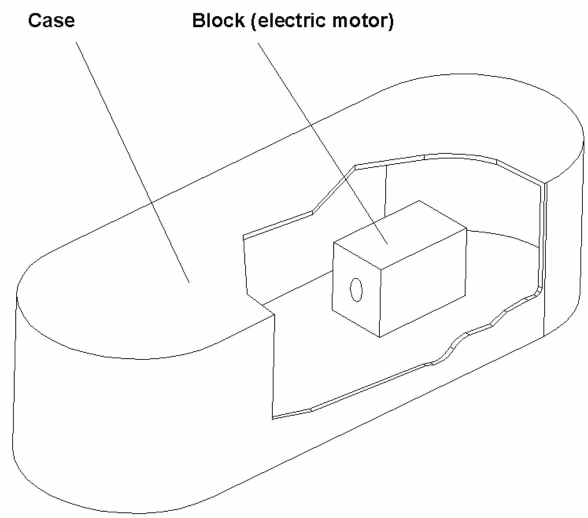

Figure 1. A simplified representation of the mechanical element

The block was considered as an idealized model of the servomotor, due to the very similar shape. The round shape made in the block was used for mounting a resistor inside, to simulate the heat losses in the servomotor. The case was made out of plastic material (Nylon66), with a thickness of 3mm. The base plate of the rig was made out of Al6063T6, 10mm thick. The reason for using aluminum for the base plate was the intention to measure the thermal expansion of it. This was to be used at a later date. The picture shows the rig that was used for natural convection. For the case of forced convection, a fan type EBM-8314H was used. The case shape was chosen as close as possible to the orientation system of an SCARA industrial robot, for which a case study was made. The shown shape is applicable for all the mechanical elements of a SCARA robot, as shown in the figure below, with the description of the rotary (R_1, R_2, R_3) and linear (T_1) degrees of freedom.

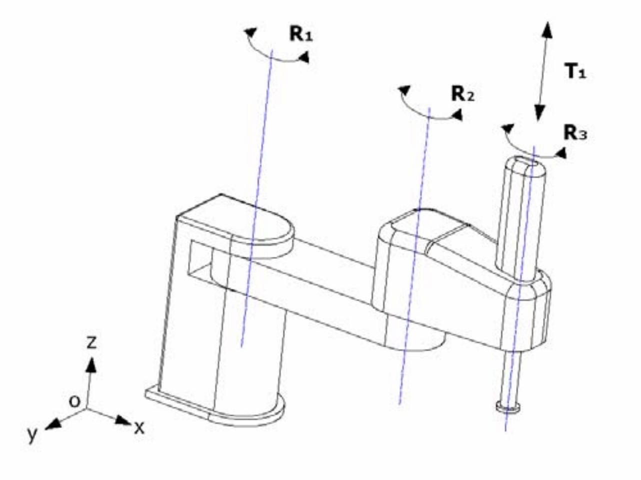

Figure 2. Generic representation of a SCARA industrial robot

The configuration of the robot consists of three degrees of freedom of rotation, in the horizontal XY plane and one degree of freedom of translation, on the vertical Z axis. The mechanical elements giving rotations R_1 and R_2 will be the subject of the present study. The mechanical design of these elements consists usually of a base plate made from a material that will give it enough stiffness and strength (usually aluminum). The servomotor and all the mechanical devices being involved in the motion generation are mounted on this base plate, which is covered by a case. On the figure above we can see a general view of the robot, where only the cases are visible.

For the thermal model, the thermal resistances diagram has been drawn, with the heat source being the aluminum block, which will release heat through convection inside the case to the mass of air contained in it. The mass of air will cede heat through the case to the surrounding environment. The diagram is shown in the below figure.

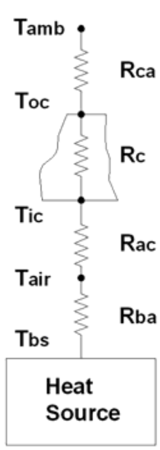

Figure 3. Thermal resistances diagram

In the above figure, we have the following variables:

Rba – thermal resistance in convection between the rectangular block and the inner air filling the whole volume of the robotic arm;
Rac – thermal resistance in convection between the air volume and the inner total surface of the case;
Rc – thermal resistance in conduction of the case;

Regarding the temperatures of all the above mentioned elements, we have:
Tbs – temperature of the outer surface of the rectangular block;
Tair – temperature of the volume of air enclosed in the robotic arm;
Tic – temperature of the inner surface of the robotic arm case;
Toc – temperature of the outer surface of the robotic arm case;
Tamb – temperature of the ambient.

All these thermal resistances are connected in series, so the total thermal resistance will be equal with the sum of them. All the detailed mathematical relations used for predicting the heat transfer through natural convection have been presented in [3]. For the case of forced convection, the detailed mathematical relations can be found in [4]. To process all the predicted temperature levels, the MATLAB application from the below figure was created.

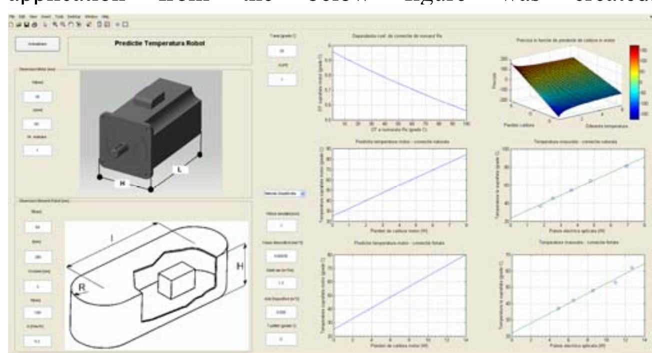

Figure 4. Temperature prediction user interface

The program was called “TemperaturaRobot”, and is presented in [4]. The predicting accuracy of this package is discussed in the conclusions. The geometrical size of the servomotor and case can be varied, as well as the material thermal conductivity, heat losses in the servomotor, type of convection at the surface of the servomotor and ambient temperature. The plots show the temperature variation with the variation of the heat losses and also with the variation of Rayleigh number. The graphs from the right side column show the results of the measurements made on the rig, with changing the heat losses for each point, and read the temperature values after thermal steady state was achieved.

III. CONCLUSIONS

The accuracy of the thermal model was studied for both natural and forced convection. For natural convection, the error was expressed as follows:

$$E(\theta)=1.0633\cdot\theta-1.71. \tag{1}$$

In the above equation, “E” represents the error in degrees Celsius, which depends on the heat loss “θ”. For the case of forced convection, the error was:

$$E(\theta)=0.8721\cdot\theta+3.1807. \quad (2)$$

In both situations, the error is linear, given that the same heat transfer coefficient was considered, with varying only the heat loss. So as the heat loss increase, the error will increase as well. As future work, improving the accuracy of the model by including the radiation heat transfer is proposed. As seen, the predicting error in the case of forced convection is higher, so a deeper research to improve the accuracy of the model by researching the effects of the position of the heat source in an enclosure in reference to the air flow source (fan) would be highly beneficial, not only for industrial robots, but also for machine tools and other similar applications where heat transfer needs to be taken into consideration from the early stages of the design. Also, the whole research process described by the present paper was made only for the case of using electric servomotors, so considering other types would be beneficial as well.

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