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THERMAL YIELDS IN THE MECHANICAL ELEMENTS OF CLEAN ROOM INDUSTRIAL ROBOTS

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Abstract
Industrial robots are being widely used in clean room environments for a wide range of applications like semiconductors manufacturing industry, medical devices and other applications. There can be different types of clean room environments depending on the size of the particles allowed in the clean room ambient. A common particularity for all the clean room industrial robots is that all of them are being sealed, in order to avoid particles contamination from the moving parts of the mechanisms of the robot to the ambient environment of the clean room.

Keywords: Thermal expansion – Industrial robot – Heat losses

1.Introduction
Industrial robots are used in most of the industrial applications where an automated manufacturing cycle is preferred due to its long term financial benefits. The present study is looking to highlight some differences between the industrial robots used generally and the ones that can also be used in clean room applications. In a clean room environment, the particle sizes from the air will need to be limited depending on the standard required by the manufacturing process or by the laboratory conditions. Clean room robots are largely used in laboratory environments and also for painting applications, a particularity being that all of them will need to have all the moving parts encapsulated, to avoid contamination of the clean room ambient with particles coming from the moving parts. Sealing the motors of the industrial robot in enclosures will mean that the overall temperature inside the robot body will increase. The next chapters in this study will show a simple theoretical model which will reveal how the temperature in a positioning system of a clean room industrial robot will increase and what effects can this have to the positioning system precision of the robot.

2.Positioning system
Common industrial robot architecture is the vertical articulated arm robot. A cinematic diagram of the positioning system of such a industrial robot is presented in figure 1.

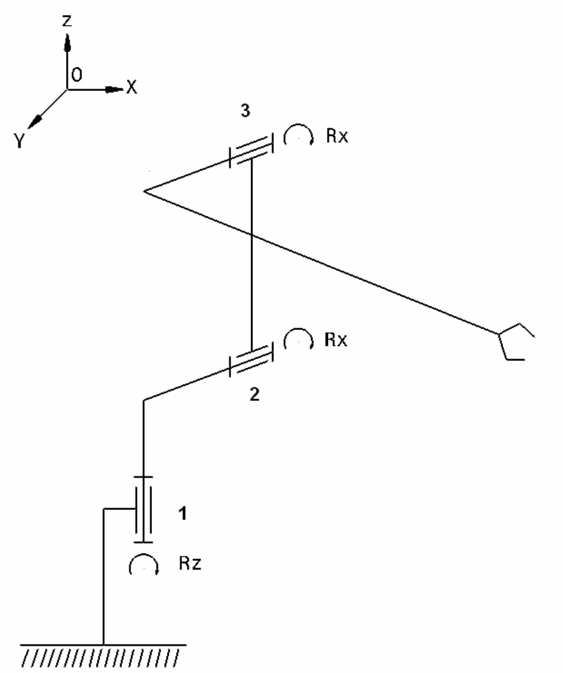

Fig. 1 - Typical Articulated Arm Positioning System

[1] - MSc. Dipl. Eng.

This system has three degrees of freedom, one rotation on Z axis and other two rotations on X axis. We will analyze the heat transfer from the motor through element between joints 2 and 3.

3.Simplified thermal model and expansion of the mechanical element

The simplified thermal model will assume that the heat in the motor from the joint number 2 is a volumetric heat. Also the motor will be considered to be a volume of a simple shape. The general equation governing the heat transfer at steady state is:

$$\Delta T = R_{th} \cdot q \qquad (1)$$

In equation (1), DT is the difference in temperature in ºC, R_{th} is the thermal resistance in ºC/Watt and q is the heat in Watts.
The general heat transfer schematic for an axis of a industrial robot for general applications is shown in figure 2.

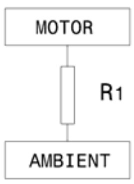

Fig. 2 - Heat Transfer diagram for a robot for general applications

In figure 2, R1 is the thermal resistance of the heat transfer between the motor and the ambient temperature. The heat transfer equation in this situation can be written as follows:

$$\Delta T = R_1 \cdot q \qquad (2)$$

R_1 is a convection thermal resistance of the motor to the ambient. The motor is not enclosed in a case, allowing a direct convection heat transfer between the motor and the ambient of the environment where the industrial robot is working. In this manner, the motor will be always exposed to that ambient temperature, which will provide a better cooling for it, thus avoiding also for a amount of the heat to be transferred into the mechanical elements of the robot.
For a clear understanding of the particularity of the robots called "industrial robots for general applications" we can see an example in figure 3.
The motors used for the positioning system are not encapsulated and directly exposed to the ambient air.
The picture is showing and FANUC M-420i robot used in a handling application.

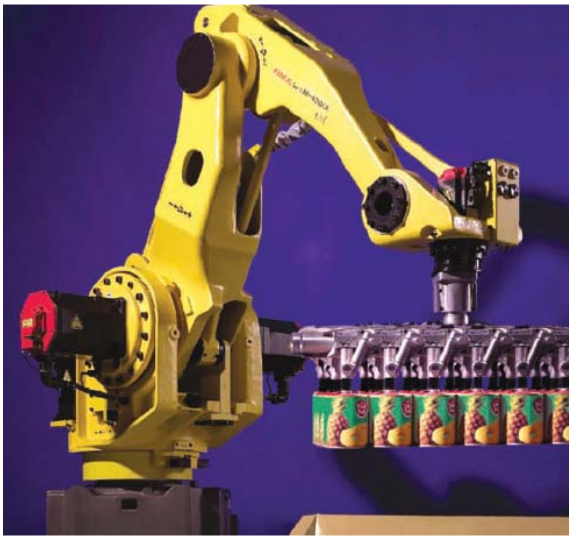

Fig. 3 - FANUC M-420i Robot. This picture is the property of FANUC ROBOTICS[1]

For an industrial robot dedicated to clean room applications, the heat transfer diagram presented previously will change. The motors in the elements of the industrial robot will be enclosed like shown in the example in figure 4.

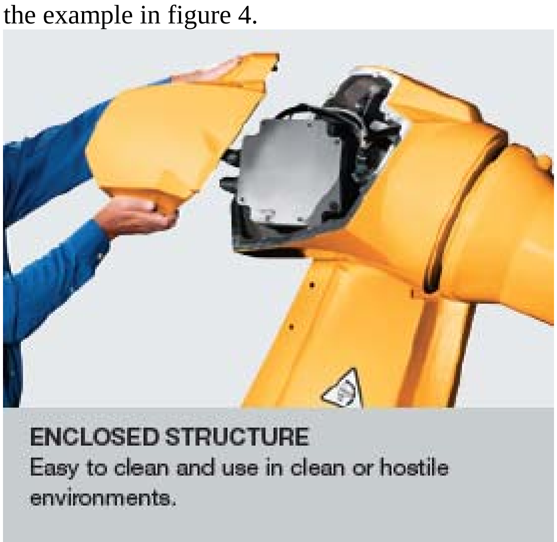

Fig. 4 - STAUBLI TX 200 Robot. This picture is the property of STAUBLI[2]

There will be additional thermal resistances which will increase the difference in temperature between the motor as a heat source and the ambient temperature from the robot environment. This diagram is shown in figure 5. There will be two additional heat transfer thermal resistances; R2 will be the conduction thermal resistance of the casing and R3 the convection thermal resistance of the casing to the ambient air. Thermal resistance R1 is still a convection thermal resistance like in the first case and it will be considered to be the same as the convection between motor and air.

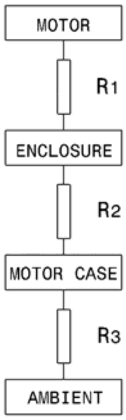

Fig. 5 -Clean room robot motor temperature

Equation (2) becomes:

$$\Delta T = (R_1 + R_2 + R_3) \cdot q \qquad (3)$$

The difference in temperature between the motor and the ambient will depend on the overall thermal resistance of the system, per each element. The thermal resistance of each element of the industrial robot will depend entirely of all the details of the design. A general rule can be established for the overall thermal resistance of each element. The correlation is shown in figure 6.

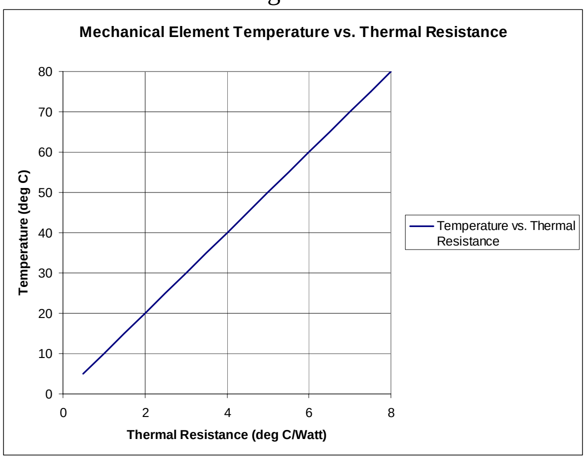

Fig. 6 - Arm element temperature with thermal resistance

The temperature difference between the motor and the outside ambient was estimated for a heat loss of 10 W into the motor. For a different loss in the motor the graph will just shift on the vertical axis; for a higher heat loss the graph will just offset up and for a lower heat loss the graph will shift down on the vertical axis accordingly with equation (1). This graph will give a general guide for the correlation between the thermal resistance and the temperature difference between the motor and the ambient, thus showing also the main difference between a robot element with an encapsulated motor (clean room robot) and one with each element motor exposed to the ambient air. After estimating the temperature into the motor of the industrial robot, the model purpose is to show also the deflection in the robot element due to the thermal expansion. For a general estimation the temperature in the robot element will be considered to be constant. The material for the mechanical element of the industrial robot in this simulation will be Aluminum Alloy 6061[3]. Aluminum based alloys are widely used in robotics mechanical systems. A FEA thermal expansion was made for the main direction orientation of the robotic element. The simulation is shown in figure 7.

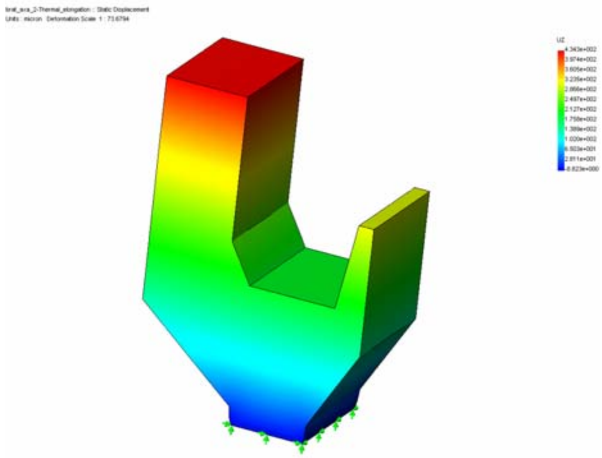

Fig. 7 - Mechanical element thermal expansion across vertical axis

The figure above is showing how the mechanical element length, which is 320 mm, will change accordingly with the temperature applied to it. A correlation between temperature and thermal deflection of the same element is shown in figure 8.

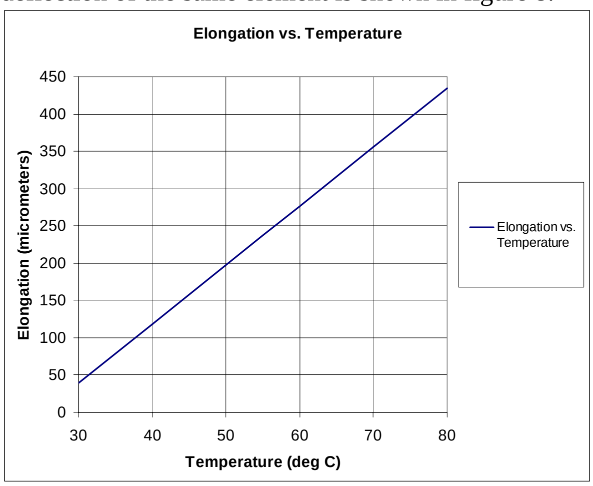

Fig. 8 -Thermal elongation vs. temperature rise

4.Conclusions

The present paper is approaching the problems related to the heat into the industrial robots coming from the electrical motors/actuators. The presented data are a theoretical simple guide through the effects of temperature to an industrial robot positioning precision. The simple theoretical model will offer a guide for identifying the main differences between industrial robots with sealed motors and the ones that have the motors exposed to the ambient air, in terms of positioning precision. The examples presented are just related to a mechanical element of an industrial robot. Proceeding with a combination of mechanical elements and a Hartenberg – Denavit computation for forward kinematics would give a good understanding of the thermal effects to the end effector's positioning precision.

5.Acknowledgment

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6.References

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