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Temperature Effects on Performance of Industrial Robots Made of Composite Materials

Alin Ristea[1, a] and Aurel Oprean[2, b]

[1]Motion Control Products R&D

Thorlabs Ltd. Ely, United Kingdom

[2]Machine Tools and Production Systems

University Politehnica of Bucharest, Bucharest, Romania

[a]alin.ristea@gmail.com, [b]aurel_oprean@yahoo.com

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Abstract. Industrial Robots design is always a challenge in terms of the materials being chosen for manufacturing the mechanical elements of the robots. The present paper is a theoretical study on the effects of temperature to the positioning precision of the robots with mechanical elements having composite materials in their structure. A case study was made on a SCARA industrial robot structure.

Introduction

Composite materials are being used due to the good ratio between their mechanical properties and density. In industrial robotics, the materials used for manufacturing the mechanical structure of the robot needs to have an advantageous ratio between the modulus of elasticity and density. A stiffer material with a lower density will always be preferred. This is directly related to the positioning precision of the robot. A very stiff and very light material will shift the natural frequencies of the mechanical structure further up. With a low density, the mass of the mechanical elements of the robot will be reduced, thus giving the chance of achieving higher velocities and accelerations. So the performances of an industrial robot can be improved by selecting stiffer and lighter materials.

In the design process of an industrial robot, in these days, the tendency is to migrate towards composite materials, given all the reasons mentioned earlier. This process is still in the early stages, given the challenges imposed by the composite materials, as being orthotropic materials and also the challenges of manufacturing precision parts. At the moment, some companies like KUKA already started manufacturing industrial robots that have parts made out composite materials. The purpose of this paper is to highlight some of the problems that composite materials will raise and to include some recommendations that would be useful to be accounted starting from the design process of the industrial robot.

Carbon Fiber Composite

Amongst all existing composite materials, carbon fiber composite materials are recognized to have very good mechanical properties, with a low density. In the table below we can observe a brief comparison [1] in terms of mechanical properties between Aluminum and two different composite materials, a 30% carbon fiber reinforced polyether ether ketone (PEEK) and a carbon fiber composite with a volume ratio of 70% carbon fiber and the rest of 30% resin.

Table 1. Carbon Fiber Composite Properties

Material	Mechanical properties	
	Density (kg/m3)	***Elastic Modulus (GPa)***
Aluminum 6063 – T6	2700	70
PEEK (30%) Carbon Fiber	1441	20
Carbon Fiber (70%) Composite	1600	140

This table highlights the main differences between the actual main material that is used for industrial robots manufacturing, which is aluminum and the mentioned composite materials.

For the carbon fiber composite, the elastic modulus shows was considered in one direction. Composite materials can be manufactured with all the fibers oriented in one direction (0°/90° angle orientation) or with half the fibers oriented in one direction and the second half oriented perpendicular on the first ones (±45° angle orientation). The carbon fiber composite considered was with all the fibers oriented in one direction. This material is superior to the others in terms of elastic modulus and density as well, offering a higher stiffness with a lower density. The mass of a part made out of carbon fiber composite will be lower with about 40% than the mass of the same part made out of aluminum. This is going to reduce the forces acting on the mechanical element by the same amount, thus reducing the loads required to be driven by the robot servomotors. For this reason, the preferred route in designing industrial robots will be to use carbon fiber composite materials, as the manufacturing technologies will advance in order to achieve the manufacturing precision needed. The challenges imposed by carbon fiber parts manufacturing are not the subject of the present paper, which will focus only on the temperature effects to the positioning precision of the robot, given that the composite material stiffness will change with the temperature change, like shown previously [2]. Composite material stiffness will have a variation with temperature, meaning that temperature increase will decrease stiffness.

Case Study Of A Scara Robot

The case study was made for the case of a SCARA (Selective Compliant Assembly Robot Arm) industrial robot. A simplified representation of a SCARA robot is shown in the figure below, with the description of the rotary (R_1, R_2, R_3) and linear (T_1) degrees of freedom.

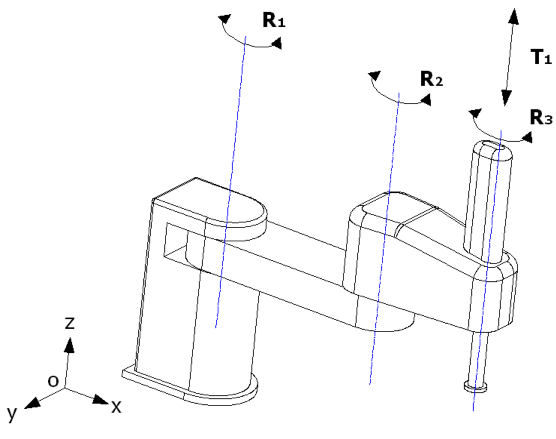

Figure 1. Generic representation of a SCARA industrial robot

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 base plate, the study is made on a sample of dimensions 400 x 100 x 20 mm. A simple shape was kept in order to perform an FEA analysis, which was performed in Ansys. The study shows the variation of the mechanical element deflection with temperature, given that the stiffness of the carbon fiber composite material will change with any temperature change. Data [2] about the material elasticity modulus shows the following modulus/temperature dependence, for the 0°/90° oriented fiber (unidirectional fiber):

$$Y=(9.94E-0.1)+(5.11E-04)X-(1.05E-05)X^2. \tag{1}$$

In the above equation, “Y” represents the material elastic modulus (in GPa) and “X” is the ambient temperature (in °C). The equation is applicable for an ambient temperature from 20°C onwards. For the case of ±45° oriented fiber (bidirectional fiber), the dependence is described by the following relation:

$$Y=1.105+0.005X. \tag{2}$$

The Ansys simulation was performed for both material types. The simulation results are shown in the figure below.

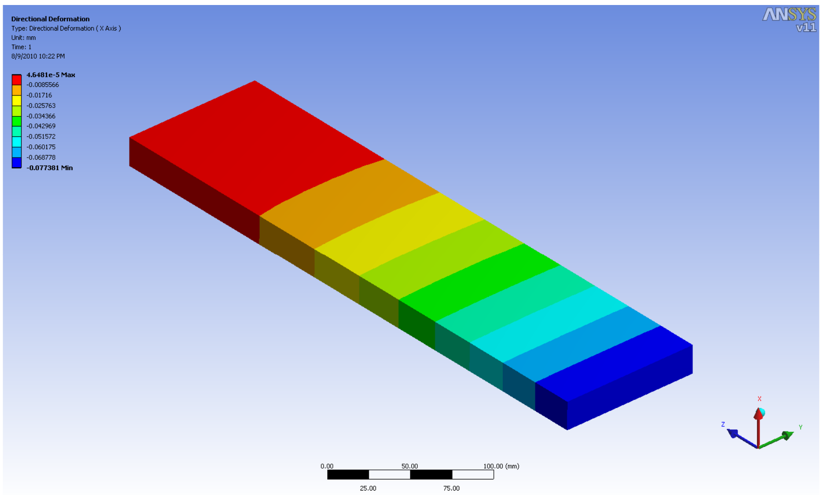

Figure 2. Ansys simulation showing deflection

The mechanical element has been constrained at one end, shown with red color. At the other end a force of 50N has been applied, representing the equivalent of a load of up to a maximum of 5kg that can be carried by the robot. Two simulations were made for each one of the material types, given the different orientation of the carbon fiber. For the unidirectional fiber, a variation of temperature in the range [3] of 20°C to 45°C shows a variation of the beam deflection of 1%. In the case of the bidirectional carbon fiber composite material, on the same temperature range, a variation of up to 14% of beam deflection was shown by the simulation. All these results have been obtained by using isotropic material properties. For improving the accuracy of the simulation, orthotropic material properties could be used.

The figures shown above have been obtained only for the deflection of one beam. Given the design of the SCARA robot, it is obvious that the deflection variations will affect the robot precision on a 2:1 scale, as the robot has two of the mentioned beams in the horizontal plane, performing rotations R_1 and R_2. That means that the positioning error fed into the coordinate transformations matrix will be double, assuming that the two mechanical elements of the robot, consisting of these beams, will be identical.

Conclusions

An FEA static structural type simulation was performed in Ansys to check the composite material thermal behavior effects to a SCARA Industrial Robot positioning precision. A simple beam of material has been used to check the deflection given by a force equivalent to 5kg of load on the robot, The deflection value was determined for the material stiffness at 20°C and at 45°C. Two types of carbon fiber composite materials have been considered, depending on the fiber orientation. For the unidirectional material, a deflection variation of 1% was obtained, while for the bidirectional material, the deflection variation was more significant, with a value of 14%. The present paper recommends including the actual analysis as a standard step in designing industrial robots that have in their mechanical structure composite materials. This will ensure that any thermal variation effect to the robot precision will be included in its target specification, leading to a more accurate prediction of what the precision values are. As a future work, it is recommended to use orthotropic material properties for the simulation, thus getting the most accurate results that a FEA analysis can give.

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