



STIFFNESS STUDY OF AN INDUSTRIAL ROBOT

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Abstract. For an industrial robot, stiffness is an important parameter because, over certain loading limits can affect its working accuracy. The purpose of this paper consist in stiffness study in static domain (which define the displacements) for two structure of industrial robots realized by epoxy resin, using digital image correlation method, and also, study of stresses by reflection fotoelasticity.

Key words: stiffness, structure, robot displacement, stress, experimental.

1. INTRODUCTION

Notation:

δ - displacement [mm]; σ - normal stress [N/mm²]; F - force [N]; N - axial effort [N/mm²]; E , G - longitudinal module of elasticity (Young's modulus), respectively transversal (Poisson's modulus) [N/mm²]; $l_{2,3}$ - length of element 2, respectively 3 [mm]; A - cross section area [mm²]; I_z , I_p - axial inertial momentum, respectively polar inertial momentum [mm⁴]; W_z - axial strength modulus [mm³]; p , m - subscript used for prototype structure (3D), respectively model structure (2D).

The stiffness is the propriety of solid bodies to not deform under the action of loads [4].

Generally, stiffness is the features of mechanical parts or structures, like hydraulic presses, machine tools, industrial robots etc. The stiffness is important because it can affect the good function of machines; for example, in the case of industrial robots, a low stiffness reduces the working accuracy.

After character request, the stiffness can be at bending, at tensile or compressive, torsion and shear [4].

At axial solicitations, stiffness is defined by expression EA , at bending EI_z , at torsion GI_p and at shear GA .

To perform stiffness study, has chosen an industrial robot structure type SCARA¹, with

one degree of freedom. It has opted for this structure, because the solicitation is reduced, due to its construction, making it possible to easily apply the investigative methods and understanding the behavior of structure.

Experimentally has determined:

- displacements in three points for two structures of SCARA robot: robot 3D (prototype) and 2D (plane model);
- stresses on the base element of the plane model.

Then, analytically has calculated the displacements and stresses of 3D structure, by experimental values obtained for plane model.

The paper presents these results and opening the possibilities of studies to others configurations of industrial robots.

2. LAWS OF SIMILARITY
DISPLECEMENTS AND STRESSES

For this study has realized the C.A.D. structures of the models (3D and 2D). In figure 1 is presented the SCARA structures, composed by two elements (base and arm), with different dimensional cross sections, which means that, the stiffness modulus is different for each structural element.

In figure 1 are known: $B_p=H_p=B_m= 90$ mm; $b_p=h_p=b_m= 80$ mm; $t_p= 2.5$ mm; $D_p= 84$ mm; $d_p= 30$ mm; $t_m= 6$ mm, $l_2=165$ mm; $l_3=255$ mm.

¹ The acronym represents *Selective Compliant Articulated Robot Arm*.

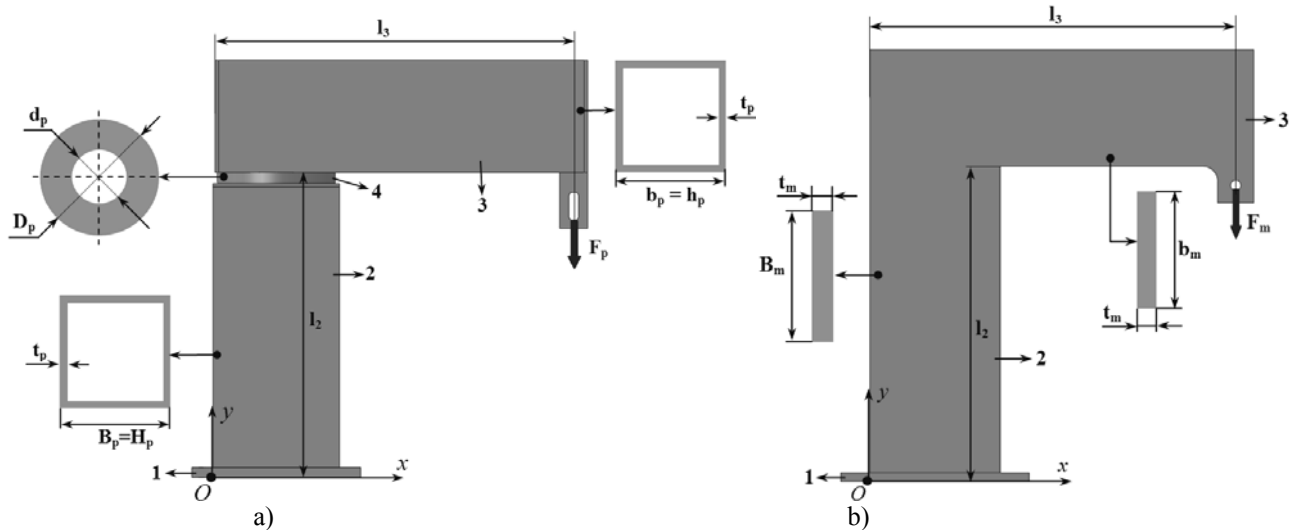


Fig. 1. The C.A.D. structures of the SCARA robot a) prototype (3D); b) model (2D), where: 1 – fixing plate; 2 – base modulus; 3 – robot’s arm; 4 – rotation joint

For this type of robot, using Castigliano’s theorem [1], the displacements by direction of applied force (y axis) F_p (F_m), can be determined with relation:

$$\delta = F \left(\frac{k_2}{EI_{z2}} + \frac{k_3}{EI_{z3}} \right) \quad (1)$$

where, k_1, k_2 are constants and have the expressions:

$$k_2 = l_2^2 \cdot l_3 ; \quad k_3 = \frac{l_2^3}{3} \quad (2)$$

Having in view the relation (1) and using the similarity principle between models (3D and 2D), written in displacements [3], has obtained the expression:

$$\delta_p = \delta_m \cdot \frac{F_p}{F_m} \cdot \frac{\left(\frac{k_2}{E_p I_{z2p}} + \frac{k_3}{E_p I_{z3p}} \right)}{\left(\frac{k_2}{E_m I_{z2m}} + \frac{k_3}{E_m I_{z3m}} \right)} \quad (3)$$

Applying the same reasoning used in case of displacements, the normal stresses can be calculated using the expression:

$$\sigma_p = \sigma_m \cdot \frac{\left(\frac{N_{2p}}{A_{2p}} + \frac{F_p \cdot l_3}{W_{z2p}} \right)}{\left(\frac{N_{2m}}{A_{2m}} + \frac{F_m \cdot l_3}{W_{z2m}} \right)} \quad (4)$$

Relations (3) and (4) allow determining the displacements in every point of prototype structure, respectively, of normal stresses

from element 2 of the robot, in function of experimental values of displacements and stresses of model structure (2D).

3. EXPERIMENTAL AND NUMERICAL STUDY OF DISPLACEMENTS AND STRESSES

For both structures, the displacements has determined in points noted with $P_i, i = 1 \div 3$, being subjected with different forces $F_i, i = 1 \div 8$.

The experimental study of displacements has performed by digital image correlation method (Dantec Dynamics Q-400), and the experimental set-up (for 2D structure) is presented in figure 2. To determine the stresses in element 2 of the plane structure has used the reflection fotoelasticity method (LF/Z-2 Vishay) [2], and the experimental set-up is presented in figure 3.

By numerical analysis (Ansys 12) has verified and validated the experimental dates.

Thus, in figure 4 has represented graphically the variation of displacements (δ) versus applied force in points P1, P2 and P3 taken in consideration for 2D structure, displacements determinate experimentally (digital image correlation) and numerical (finite elements method – Ansys 12).

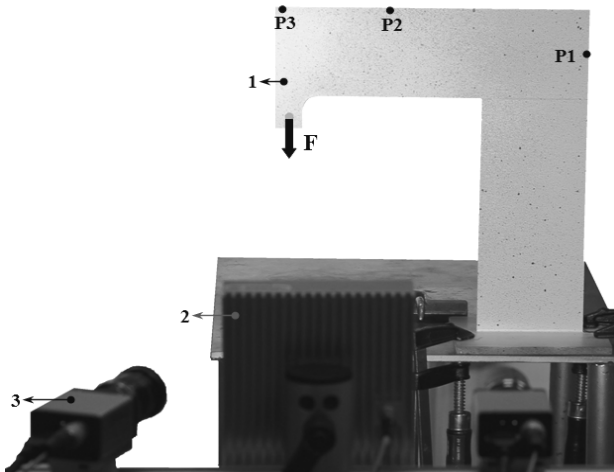


Fig. 2. Experimental set-up for determine the displacements (δ) for 2D structure with DIC, where: 1 – SCARA robot (2D); 2 – light source (green light); 3 – video cameras CCD

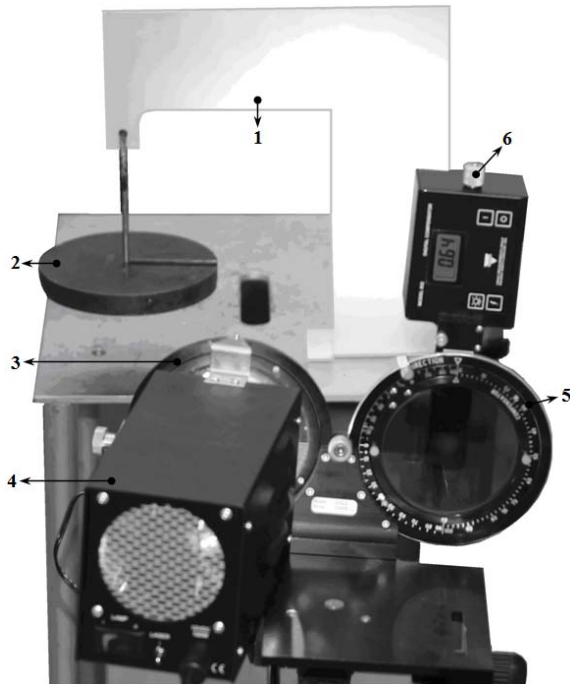


Fig. 3. Experimental set-up to determine the stresses using reflection fotoelasticity, where: 1 – SCARA Robot (2D); 2 – support with weights of mass m ; 3 – polarizer filter; 4 – white light source; 5 – analyzer filter; 6 – digital compensator (Vishay)

Applying the similitude relation (3) starting from 2D model and also the experimental (DIC) and numerical (FEM) investigations on 3D model, has build the variation paths of displacements corresponding to points taken into study.

From state of stresses point of view (about characterization of normal stresses σ), has

taken into study the interior fiber of base module (see figure 1 the element 2). How is known, in this area the bending momentum is constant, so results that the normal stresses are constant to.

Thus, in figure 6 has build the variation diagram of normal stresses from interior fiber of base module, stresses which has been determinate by experimental using fotoelasticity by reflection method, and numerical by finite element method (Ansys 12).

Based on similarity relation (4), and starting form 2D model, and also on numerical modeling on 3D model, has realized the variation diagram of normal stresses (σ) due to applied forces, from interior fiber area of base modulus.

5. CONCLUSION AND RESEARCH DIRECTIONS

The main idea of this study is to determine the displacements and stresses for SCARA robot prototype structure, depending on experimental values of SCARA plane model using the similarity relations.

For this study, was built SCARA robot - model plane (2D) and prototype (3D) by epoxy resin, with sections shown in figure 1.

Based on the studies of two structures, can be concluded:

- were determined: *displacements* (δ) in horizontal plane for point P1 and in vertical plane for points P2 and P3 using CDI, FEM and by analytical relations; *normal stresses* (σ) in element 2 of 2D structure using reflection fotoelasticity, FEM and similarity relations.
- has obtained a various distribution of displacements (this is due to different section of the structures, 3D model having a greater rigidity than 2D model) and a similar distribution of normal stresses (σ).
- diagrams from figures 4, 5, 6, 7 give a good agreement of the experimental and numerical results, for 2D and/or 3D structure, in three considered points, which validates the proposed similarity relations (relations 3, 4);

- the use of similarity law offers the following advantages:
 - material needed to build a model structure (epoxy resin) is cheaper than metallic materials;
 - study of state of stresses and displacements can be achieved through various optical experimental methods (digital image correlation, fotoelasticity by reflection or transperence) or mechanical methods (displacement transducers, digital or/and analog comparators), avoiding destruction of prototype structure;

- based on model structure, is possible to optimize the structure of early prototype design phase;
- transition from the prototype to model structure can be achieved using similarity relations (for example, relations 3 and 4), obtaining the values of stresses and displacements of prototype structure.

Such research approach will be also applied for an industrial robot type Fanuc (figure 8), with five degrees of freedom. And also, for this industrial robot, the problem is study of stiffness and its effects on working accuracy of the robot [5].

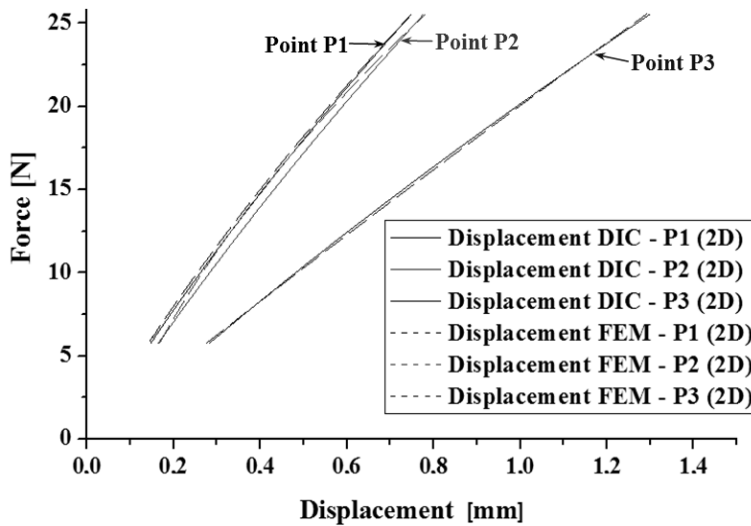


Fig. 4. Displacements (δ) of points P1, P2 and P3 vs. applied force determinate by DIC (Q400) and FEM (Ansys12) for 2D model

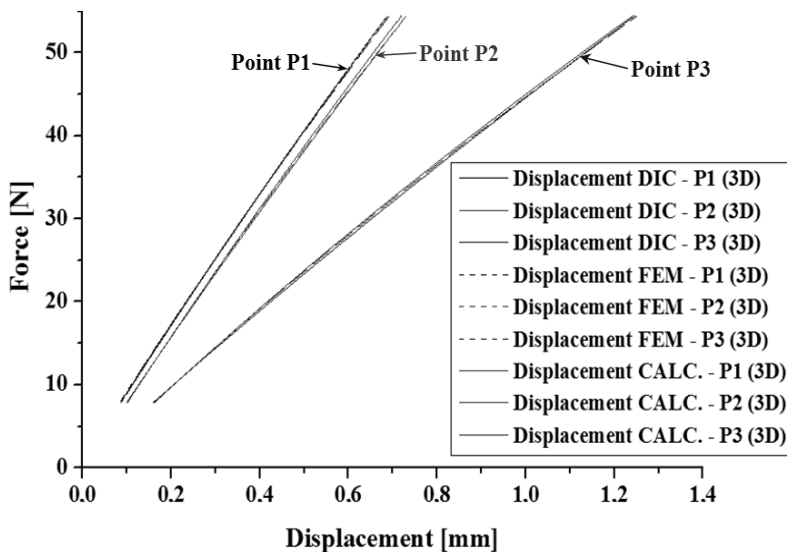


Fig. 5. Displacement (δ) of 3 considered points due to applied force for 3D model (experimental – DIC, numerical – FEM and analytical – similarity relation)

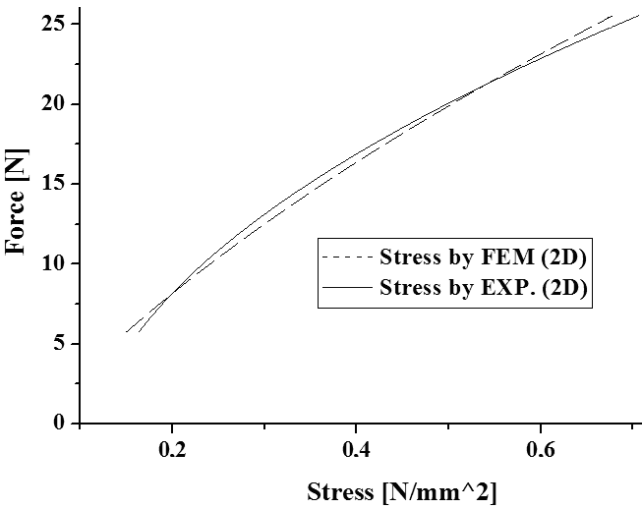


Fig. 6. Variation of normal stresses (σ) vs. applied force to interior fiber area of base modulus of 2D structure (results achieved by numerical modeling – FEM and by DIC)

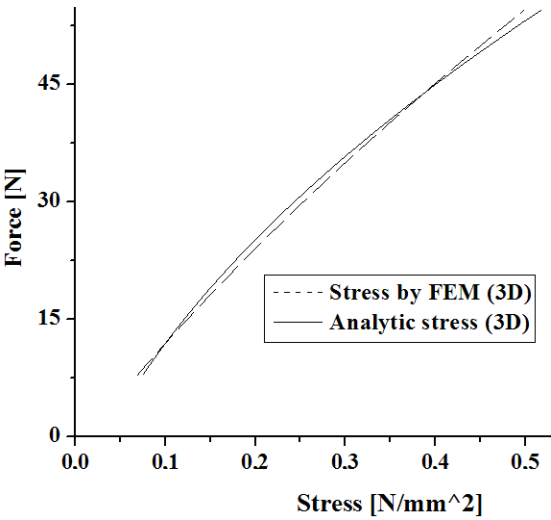


Fig. 7. Variation of normal stresses (σ) vs. applied force to interior fiber area of base modulus of 3D structure (results achieved by numerical modeling – FEM and by applying the similarity relation)

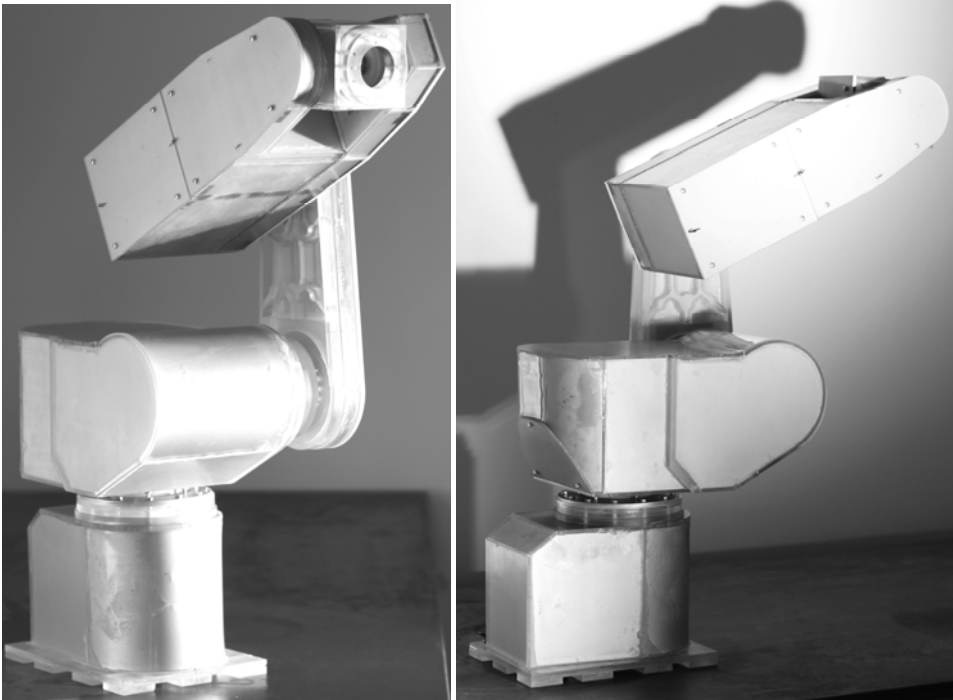


Fig. 8. Industrial robot with 5 degree of freedom (type Fanuc) (prototype realized by epoxy resin)

6. REFERENCES

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Studiul rigidității unui robot industrial

Rezumat. Pentru un robot industrial, rigiditatea este un parametru important deoarece, peste anumite limite de solicitare poate afecta precizia de lucru a acestuia. Scopul acestei lucrări constă în studiul rigidității în regim static (ce definește starea deplasărilor) pentru două structuri de roboți industriali realizați din rășină epoxidică, utilizând metoda corelației digitale a imaginii, precum și studiul tensiunilor prin fotoelasticitate prin reflexie.

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