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STUDY OF STATE OF STRESSES USING PHOTOELASTCITY IN CASE OF AN INDUSTRIAL ROBOT SCARA

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Abstract: *The aim of this paper consist of numerical and experimental determining of stresses for a simple structure of the industrial robot type SCARA, with one degree of freedom. The numerical study is realized using finite element method (Ansys 12.1) and the experimental study by photoelasticity method.*

Key words: *study, stresses, numerical, photoelasticity by reflection, robot.*

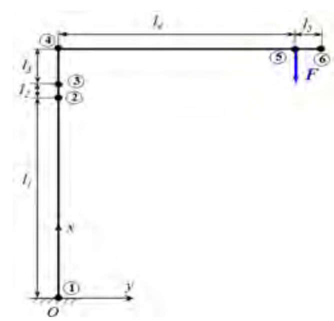
1. Introduction

Study in this paper aims to determine the state of stresses for a simple structure of robot type SCARA.

As seen in figure 1, the mechanical structure of the robot is constituted by two elements (the base of the robot and arm), having square tubular section and the connection between base robot and arm is realized through a ring part (which can be compared with a rotation joint). This robot is provided with a base mounting plate.

In Figure 1a is presented the supported and loading of the robot in a simplified scheme, and in Figure 1b has represented the CAD modeling with corresponding section of each element. Are known:

$l_1 = 209.5\,mm$; $l_2 = 7\,mm$; $l_3 = 40\,mm$;
$l_4 = 207.5\,mm$; $l_5 = 12.5\,mm$; $B = H = 90\,mm$;
$b = h = 80\,mm$; $D = 84\,mm$; $d = 30\,mm$.



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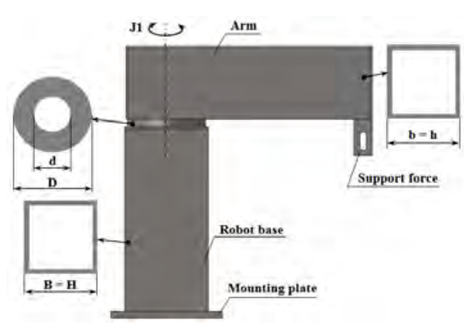

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Fig. 1. *a) The simplified scheme of the robot; b) CAD modeling*

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2. Numerical study of the stresses

Based on CAD model of the industrial robot is performed a numerical study using finite element method (FEM) with aim to determine the stresses in a chosen point.

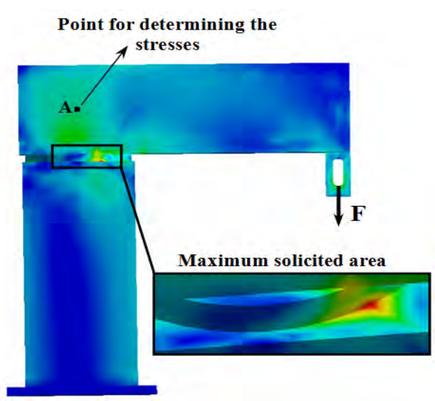
The robot is considered fixed in base mounting plate, and to the free end of the arm are applied, successively, the forces F that will subject the robot to bending.

For numerical modeling of the robot's structure, has used the following mechanical properties of the constituted material (epoxy resin) [3]: Young's modulus $E = 3.1 \cdot 10^3\ MPa;$ tensile strength $\sigma_r = 130\ N/mm^2$; Poisson's ratio $\upsilon = 0.3$.

After the introduction of the initial constrains and solving the equations from mathematic model implemented in Ansys, are obtained the values of stresses in measurement point A, and stress distribution on entire structure of the studied robot.

In Figure 2a is presented the stress distribution, respectively the maximum solicited area when the structure is loaded with force $F = 93.8817\ N$.

In Figure 2b is given the variation of numerical stresses in point A according to applied forces, and this variation has a linear path.



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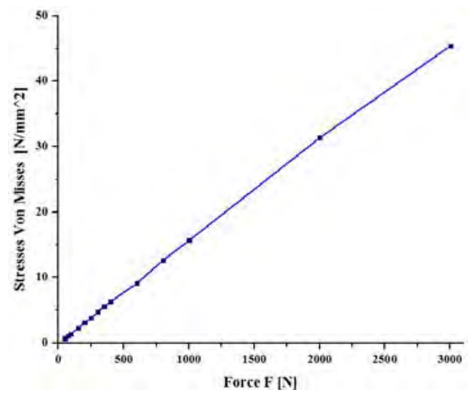

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Fig. 2. *a) Distribution of stresses and maximum solicited area for* $F = 93.8817\ N$ *; b) Stresses variations versus applied forces*

3. Photoelasticity by reflection. General considerations

Photoelasticity is used in large scale and can be applied easily in any field of study, where state of stresses and distribution mode is required (thus are identified the maximum values of stresses) in parts or parts assembly and mechanical structures, regardless of section's complexity, subjected to static and dynamic studies [2].

To perform the experimental study of the proposed robot's structure, is used the photoelasticity by reflection method. This method differs from photoelasticity by transparent method in that, on surface of the real part is bonded a thin layer of active material – epoxy resin – with an adhesive containing reflective particles. Then, when the part is loaded, the surface with the layer of epoxy resin is lighting with polarized light from a polariscop by reflection [4].

In Figure 3 is schematic represented the polariscop by reflection and his constitutive elements, and also is shown the path of polarized light from light

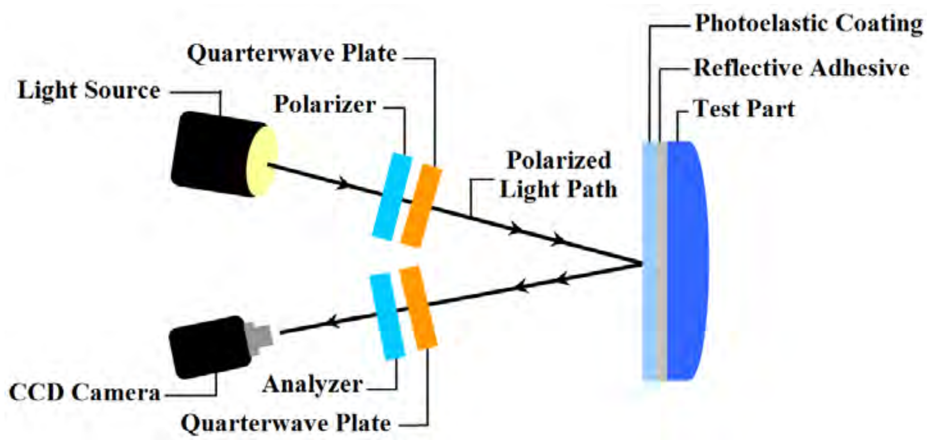


Fig.3. *Simplified polariscope for photoelasticity by reflection*

source to part and to observer.

Thus, are obtained, experimentally, information regarding to distribution stresses, respectively can be easily and quick identified the maximum solicited areas, given by isochromatic fringes. Using an optical transducer (digital compensator) attached by polariscop, can be accurate determined the isochromatic fringe order. Also, the information can be saved by recording or by photos using a CCD camera [4].

In this paper, to obtain the reflective surface has opted to use a chrome plate spray paint (type: ABRO Premium chrome spray paint), which shows no chemical reaction with part's surface made from epoxy resin. This method of obtaining of reflective surface represents a new approach in the photoelasticity by reflection method.

Which means that, to perform the experimental tests, can be used parts made of epoxy resin, thus, avoiding the destruction of real parts, and the obtained results aren't negatively influenced by the chrome paint.

3.1. Experimental study of stresses for the robot's structure SCARA

Based on CAD modeling, the robot's structure has been build from epoxy resin parts, and the surfaces which are bonded to the inside structure, is applied chrome spray paint to obtain the reflective effect.

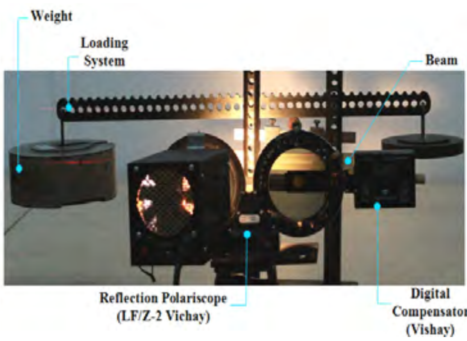
3.2. Photoelastic calibration

To obtain the values of stresses given by isochromatic fringe order formed after applied force, it is necessary to be known the strain-optic sensitivity of the used material, known as characteristic of the material σ_o. For this purpose, is performed the calibration.

Thus, from resin boards of which where made the parts necessary to build the structure of the studied robot, has realized samples in the form of beams, and on a surface is applied chrome spray paint.

Having in view that the parts of the robot have variable thicknesses, has realized three samples with following dimensions:

- beam 1: $h_1 = 6.97\,mm; b_1 = 25.23\,mm;$
- beam 2: $h_2 = 4.67\,mm; b_2 = 25.18\,mm;$
- beam 3: $h_3 = 2.6\,mm; b_3 = 25.84\,mm$, each beam with length $l = 260\ mm$.



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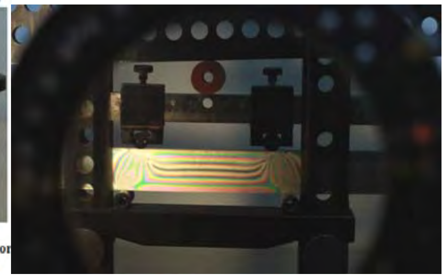

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Fig. 4. *a) The experimental set-up for calibration; b) Obtained fringes for beam with* $b = 2.6\,mm$

The average value for characteristic of material for calibration beams Table1

Beam 1				Beam 2				Beam 3			
F [N]	k_c	σ_o	σ_{o_med}	F [N]	k_c	σ_o	σ_{o_med}	F [N]	k_c	σ_o	σ_{o_med}
130.613	0.71	1.306	1.2845	163.2662	1.28	1.3569	1.5912	163.2662	1	2.9624	2.8636
293.879	1.91	1.092		260.5729	1.84	1.5065		260.5729	1.6	2.955	
494.37	2.4	1.462		494.37	3.1	1.6965		354.6142	2.25	2.8597	
848.331	4.71	1.278		848.331	5	1.805		494.3702	3.35	2.6776	

To realize the calibrations, the beams are subjected to pure bending.

For each beam has performed four measurements, with different forces, obtaining the fringe order k_c and, using the known relations from literature, has determined the average of material characteristic σ_{o_med} .

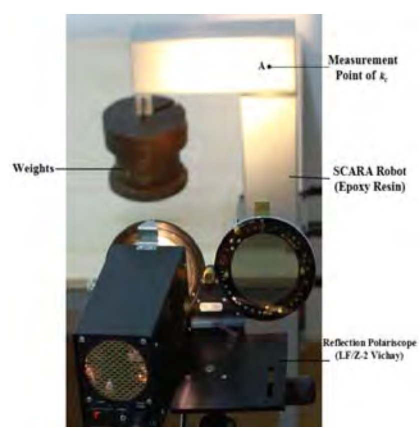
In figure 4a is presented the calibration for the beam with thickness of 2.6 mm, and in figure 4b are given the obtained fringes for $F = 7.57\ N$.

In table 1 are given the obtained results from calibration, which will be used to determine the stresses for the studied robot.

3.3. Experimental study of the robot SCARA

To obtain the experimental values of the stresses, the structure of the robot was successively subjected to bending by three forces F [N].

In Figure 5a is presented the experimental set-up for this study, and in Figure 5b is shown the distribution of fringes. Point A represent the point where was determined the fringe order k_c, corresponding to the chosen point from numerical analysis.



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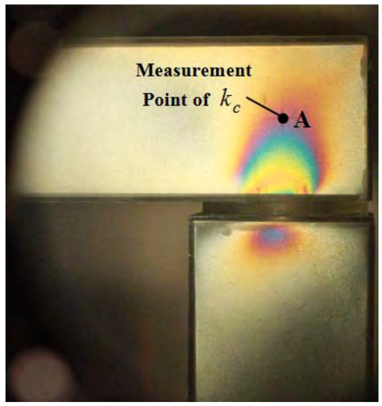

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Fig. 5. *a) Experimental set-up to determine the stresses for SCARA robot; b) Fringe distribution*

4. Conclusions

In this paper has been realized numerical study (by EFM) and experimental (photoelasticity by reflection) of stresses for a robot structure type SCARA.

Based on performed studies can be concluded:

- With EFM has obtained the distribution of the stresses (Von Misses stresses) and values in point A;
- To perform the calibration in case of photoelasticiy by reflection method, is proposed a new method, unique and easy to apply with aim to obtain the reflection effect;
- The relative deviations obtained, indicate that, both experimental and numerical analysis are accurate;
- Comparing the obtained distribution of stresses from performed analysis (see figure 2a and 5b), can be observed that, in both cases the maximum solicited area is the contact area of the ring part with the arm, respectively with the base of the robot;
- The experimental and numerical results of the stresses in point A, and the fringe order determined according to applied force, are given in table 2. Figure 6 represents the variation diagram of stresses (numerical and experimental) versus applied force;
- From this studies have found that, in case of resistance structures of industrial serial robots, the areas with maximum stresses are kinematic joints that are found gears, bearings and other connection mechanical parts between modules in their kinematic chain; in this study, the rotation joint has been simplified by a piece ring.
- Future numerical and experimental studies will be performed regarding the state of stresses for the robot structure SCARA presented in this paper, to obtain results in the maximum solicited area.

The fringe order and stresses obtained experimental and numerical Table 2

Nr. crt.	***m*** *kg*	***P*** *N*	k_c	σ_{FEM} N/mm^2	$\sigma_{exp.}$ N/mm^2	***Relative deviations %***
1	5.07	49.7367	0.22	0.7075	0.6292	11.03
2	7.57	74.2617	0.38	1.0846	1.0881	0.027
3	9.57	93.8817	0.5	1.3877	1.4318	3.08

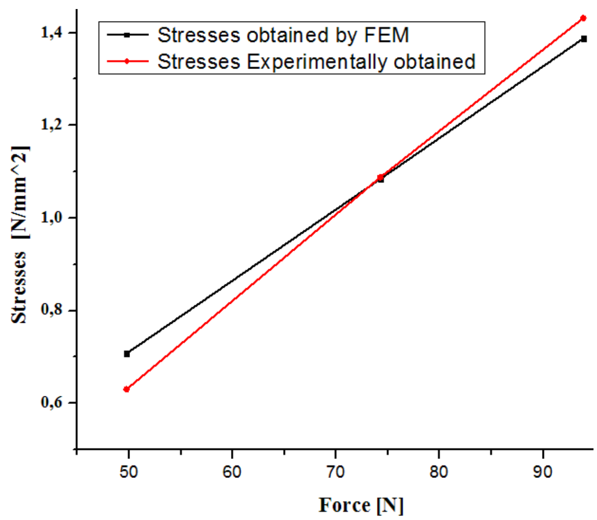

Fig. 6. *Variation diagram of stresses versus applied forces*

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