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Development of A SCARA Robot with Extensible Arm

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ABSTRACT
This study aims to develop robotic arm extension for SACARA type robots. Modeling and simulations have been done to understand the stress distribution on a robotic arm with extension to increase the accessibility of the robot. The mesh were generated by using commercially available SolidWorks software and static analysis of this program was utilized to conduct the numerical simulation module. The extension of the robot arm is designed in a modular joint construction so that the access distance can be increased or decreased according to need. The stress and displacement values of the robot arm and the effect of the fasteners when the access distance is increased are analyzed with Finite Element Methods. The necessary improvements were made according to the results obtained.

Keywords - Finite Element Analysis, moduler robot, robot access, SCARA

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I. INTRODUCTION

The industrial companies are consantrated more and more to increase production capacity besides activities such as lowering costs. In the era of technological growth and improvement, there are also high efforts to reduce the human factor and security problems, which direct the planners to use more robots in the manufacturing plants. As a result of these developments, automation of work flow and control demands robotic technology in production.

Durukan, Mahmutoglu and Sakoglu [1], in the first stage of SCARA robot development presented a simple model for forward and inverse kinematic equations of the robot by using Denavit-Hartenberg method. Using the Newton-Euler method, robot dynamic equations are extracted and the accuracy of the results of the dynamic equations is confirmed by using Lagrange approximation. After dynamic model of the system based on the dynamic equations that was extracted, controller of the system was designed and the simulations of the model were made in Matlab environment. The mechanical design of the system has been realized by using the data obtained in the direction of the studies made. Design of user interface is made by using Visual Basic programming language to be able to run on Windows based operating systems. The responses of the SCARA robot under different loading loads were tested with experimental studies.

Nowadays, there are many efforts to design low cost 6-axis robot robots with electronic and structural materials. Some more efforts has been put on the other robots such as 4 – axis SCARA type robots to increase the availability and reduce the cost to manufacture. Researchers also concentrated to improve load caring capacity, workspace without increasing the cost. The followings are some earlier studies, which are conducted before the presents study and has been studied for better understanding of the problem.

Santur [2] has designed a 3-axis cylindrical robot system specified for automatic pizza machine, which can be used for other purposes also. All the designed materials were produced, and one axis was added to the robot arm to make the X-axis rotate bound up with the horizontal axis. Y and Z-axis are driven by servomotors, and X and A by stepper motor via PLC. The position accuracy is achieved in the desired completeness (0,1 mm) so as not to be affected by vibrations during stopping and starting.

The SCARA type of manipulator is designed with the SolidWorks program by Demirci [3]. The static and natural frequency analysis are performed in the same program. Motion analysis has also been done with the Motion plugin of the SolidWorks program. Analyzed parts were manufactured and assembled. Alp [4] designed a robot manipulator with 3-axis and one gripper tip. Manipulator is designed with PIC controlled servo motor driver card which is guided by command from accelerometer to provide human hand sensitivity. Robot arm design was done with SolidWorks program. The design of the motor driver card has been made in computer environment and robot arm elements are manufactured.

Sanlıturk [5] designed Delta robot with visual processing unit. An analytical model of the robot was created and performance characteristics were examined also. Optimization process was performed using this model. By performing stress analysis, it was researched whether the robot would work under specified conditions or not. Inertia and gravitation forces are also exerted to the model. The study was supported by experimental studies what resulted in a system that is able see. Çetinkaya [6] designed a robot arm with 4 degrees of freedom in the computer environment. In the study, the position control in the computer environment is also discussed. Özkarakoç [7] introduced the SCARA robots and structural elements, discussed the technical features, made comparisons of various bearing type, trying to define the best bearing for robotic axis.. They also used SolidWorks in computer environment to design their robot in their study.

Saygılı [8] has developed a complete solid model of robot by designing a SCARA robot type firstly, than solid parts of all the parts were obtained by using SolidWorks program. The resulting motion in the angular positions given by the robot joints is regulated by the Gifmax program, animated by the movement of parts and movement. A forward and inverse kinematic analysis was performed and the robot animation was generated with Matlab program using the data from kinematic analysis.

Toker [9] has made a mechanical design of an industrial robot with six degrees of freedom, and also the rigid models of the robot's mounting parts with corresponding CNC manufacturing codes of these parts. The robot which model has been produced as a project in a university environment was manufactured.

Kayman [10] mechanically designed a three-axis SCARA- robot type, produced technical drawings of the assembly parts, and supplied the manufacturing codes required for serial production. Kinematic analysis equations have also been been derived. This study aimed to be used in Robotics lessons by providing detailed information to have a reference compilation feature for industrial robots.

The purpose of this work is to develop type of SCARA robot for mass-production plants where very high speed and best repeatability is needed, an extensible robot system that can be easily adapted to different arm lengths. Robot arm design and simulation are done in SolidWorks 3-D Computer Aided Design (CAD) software. Static simulation study of the designed robot arm will be made and the boundary conditions and the stress and displacement values under load will be examined. A simplified and improved design will be achieved by evaluating the obtained simulation results.

1.1. Design of SCARA robot arm

In order to complete the robot arm model the SCARA robotic arm body, bearing and motion transfer elements used for industrial robot design are examined, and robot arm-forming parts are drawn in 3-D in the commercial program. The necessary changes and analyzes have been made to obtain an original and improved design. Fig. 1 shows the basic elements of the SCARA robot arm. The body and arm parts shown here are designed in accordance to the casting method to be manufactured by aluminum casting processes and paying attention to the edges of manufacturing dies.

Fig. 1. shows axis structure of the 4-axis SCARA robot arm. Along these axes, motion can be reached with 4 AC servo motors. The J1 axis allows movement of the top and front joints along the main axis. J2 axis is for forward arm movement in order to position SCARA robot arm.

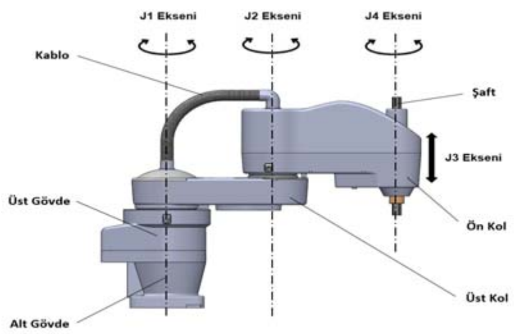

Figure 1. SCARA robot arm and main parts

The J3 axis moves up and down to form the Z-axis. J4 supplies rotational movement of Z-axis. The upper arm and fore arm lengths of the SCARA robot determine the robot arm access. [10, 11, 12] SCARA robots have the best reproducibility performance of all robot types. Errors in the XY position were caused by having two motors in J1 and J2. Other types of robots have two motors in J1 and J2 to supply XY positioning. The more motors are responsible for bigger number of different errors. Forcing the excellent reproducibility tolerances to be in value of a few microns is important for precise assemble lines. Bold and screw works, placing the connectors on the circuit boards are sample application of SCARA type robots which are employed in the assemble and manufacturing lines [13, 14, 15]

1.2. The simulation of design of SCARA robot arm

The models of the SCARA robots with extensible arm to be used in the studies are shown in Fig 2. Stress and displacement analyzes were applied to these models, respectively. The reference model in the world is treated as a model with 300 mm access (300 mm only upper arm access distance - Robot arm access distance 650 mm) according to general acceptance. The distance between these centers is 300 mm.

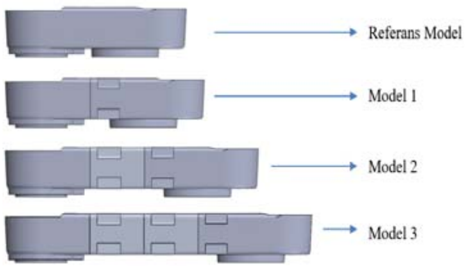

Figure 2. SCARA robots with extensible arm whics are are simulated in the present study

Since the distance between centers of 300 mm for the upper arm is not enough to obtain Model 1, the reference model is extended by 50 mm and the distance between the axes is made 350 mm. The extended model is divided into two parts and designed to be mounted with 4 bolts. (Fig.3)

According to the requirements, the intermediate part is designed so that extra access parts can be added to the upper arm and the access distance would be increased by 150 mm (Fig. 4). Up to two parts can be added in total. In this way, the robot arm access distance can be increased to 850 mm or 1000 mm in total.

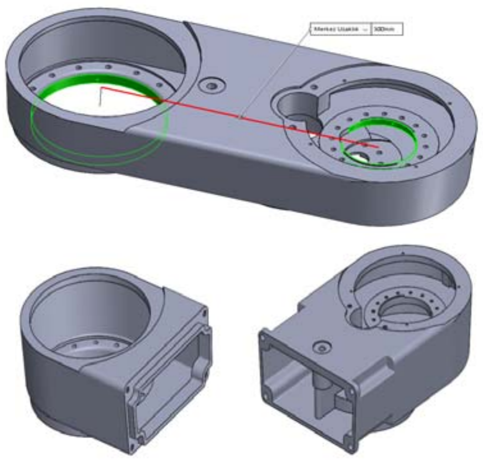

Figure 3. Standard SCARA robot arm and modified model

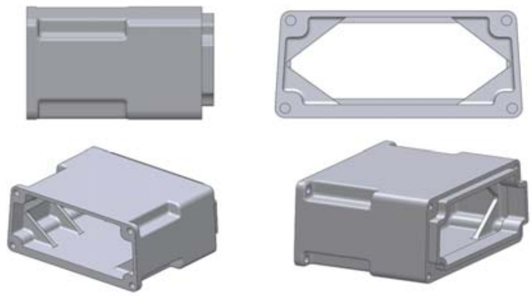

Figure 4. Arm extension designed with a length of 150 mm

II. SIMULATION FOR EXTENSIBLE ARM

First application of the robot arm that simulation process has been done for is transferring the solid model of robot arm designed in CAD environment before. The design of the part is created in 3D in the computer environment, then the initial, boundary and loading conditions of the part are defined. The numerical model was created by setting the parameters necessary to form the mesh (mesh) of the model and then solving the simulation. The results obtained are examined and necessary arrangements are made to obtain optimum design and that resulted in final design. Finite Element Analysis was performed using SolidWorks 2016 commercial software for structural analysis of the robot arm. The information about the robot arm insertion geometry is given in Table 1. The same boundary conditions were also used for all of the models.

Figure 5. Boundary conditions for basic robot arm

Table 1. Types robotic arm models

No.	Distance Between Top Arm Centers	Total Access
Reference Model	300	650
Model 1	350	700
Model 2	500	850
Model 3	650	1000

Table 2. Material parameters

No.	Parameters	Values	Unit
1	Elastic Module - E	69000	MPa
2	Poisson's rate - ν	0.33	
3	Yield resistance	125	MPa

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Table3 shows in which environment our model is solved and which parameters are used.

Table 3. FEA simulation conditions

No.	Parameters	
1	Software	SolidWORKS
2	OS	Windows 10
3	Platform	PC
4	Element type	Curved
5	Number of nodes	52447
6	Number of elements	28313

Table 4. FEA Simulation Parameters

No.	Parameters	
1	Study Type	Static Structural
2	Mesh type	Solid Mesh
3	Used Mesh	Curve Based
4	Jakoben points	4 points
5	Max. Element	25 mm
6	Min. Element	5 mm
7	Mesh quality	High
8	Total node	52447
9	Total staff	28313
10	Maximum Aspect	14.284
11	Percent of elements with Aspect Ratio	70.7
12	Percent of elements with Aspect Ratio	0.537

III. SIMULATION RESULTS

Fig. 7 shows that in the reference model, the largest von Mises strain occurs at the bottom of the part. Stress values below 0.5 MPa are shown in gray.

With the Reference Model, the von Mises stress and displacement in Model-1 have been increased about 2 times. Although the lengths are the same, this increase in the analysis values is due to the fact that the reference model consists of single part and the Model 1 is consist of two parts which are connected by a bolt connection. The increases in both the stress and displacement values of Model 2 and Model 3 are due to the fact that these models have been extended with inserts.

When the length of the simulated model is increased, the amount of stress and displacement also increases. Although these increases are expected, the maximums and the minimum value of the deformation are important in terms of design safety. In other words for a safe design, it is necessary to always design structures so that there is no plastic deformation and the maximum deformation is kept within the elastic limit. When the stress values are examined in the simulations, it can be said that the stresses that occur in the designed models are located within the elastic limit, which is, the design is safe.

The use of the Finite Elements Method in the design phase has provided many advantages in terms of design simplification and investigation of the effect of different geometries. However, in addition to the advantages provided by the Finite Element Method, it also brings certain disadvantages. In the simulation process, some simplifications and idealizations are made for the mechanical properties of the materials and boundary conditions. These simplifications and idealizations cause a difference between simulation and real life.

The conclusions reached as a result of Finite Element Modelling are related to the model we have created. For this reason, in order to obtain correct results in the study, the model closest to the truth should be created from every view point. The difficult part of the simulation is to form correctly. Interpretation of the result obtained from the simulation process is as important as preparation of a good structural model. Three-dimensional Finite Element Analysis gives more realistic results than two-dimensional models. For this reason, 3-D model was preferred in this study.

In Finite Elements Analysis, accuracy of the analysis results is directly proportional to the number of elements used. The increase in the number of elements will increase the number of equations to be solved and make the solution process will longer. For this reason, the optimal number of elements required for an acceptable solution must be predetermined. The results of the studies on the finite elements should be supported by experimental studies. Experimental studies can only be used to assess how well the results achieved in the analyzes comply with the actual values.

When the displacement graph from the reference model in Fig. 6 is examined, the displacement towards the end where the load is applied increases from the point where the part is connected to the shell and reaches to 0.0459mm which is the maximum value, The changes of the variable values at the beginning of the graph shown by the continuous line are due to the model geometry there. The graphic shown with a dotted line is the graph of the slope.

When Model 3 from Fig. 9 is analyzed, there is increase in the stress in different reference points at 250, 400 and 550 mm displacement. The highest stress is 33.3 MPa in point at 400 mm. The reason for this increase in stress in these points is the connection between middle parts and upper arm there. After 550 mm stress is lowering and coming close to zero at 850 mm. Parts with stress lower than 1 MPa are showed with grey.

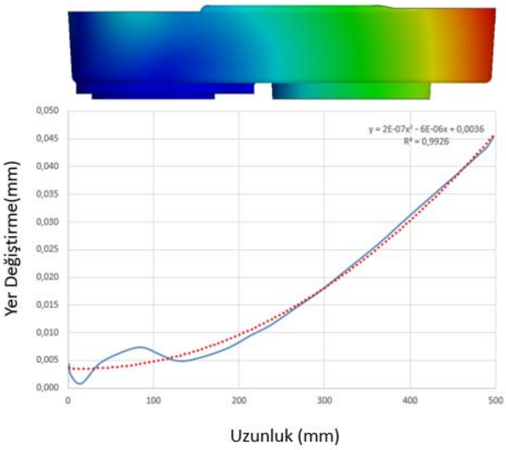

Figure 6. Relocation graph of Model 1

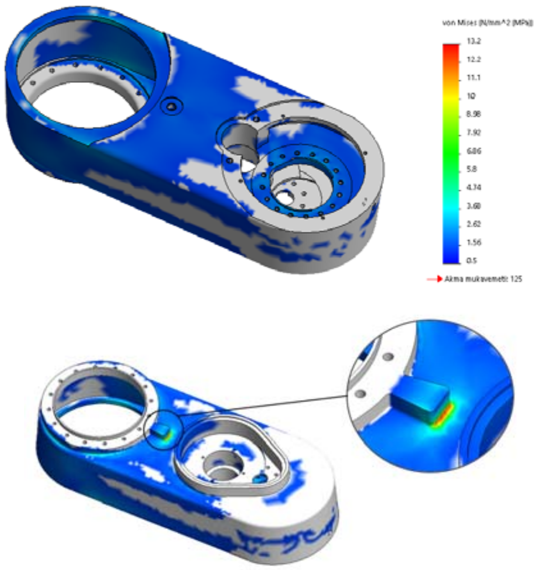

Figure 7. von Mises stress distribution obtained from the simulation of the reference model

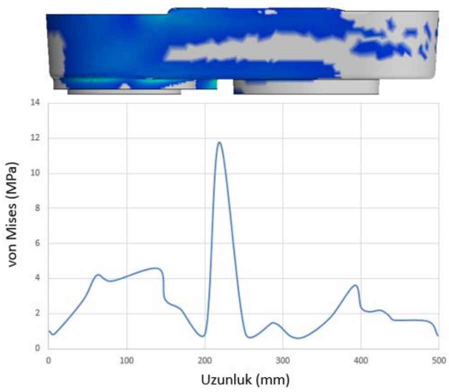

Figure 8. von Mises stress analysis graph of the no-insert reference model

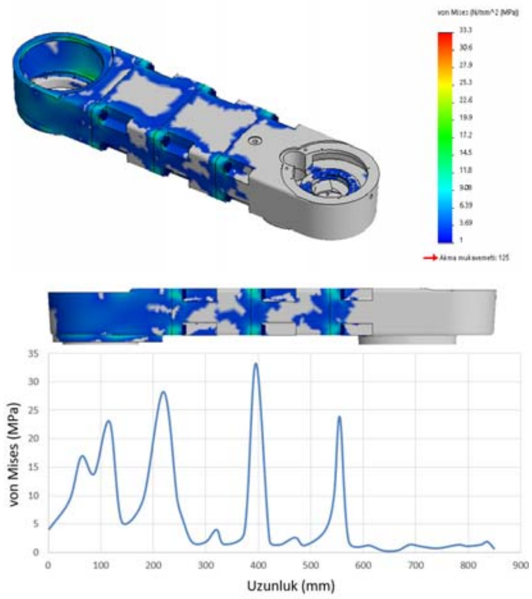

Figure 9. von Mises stress analysis values for Model 3

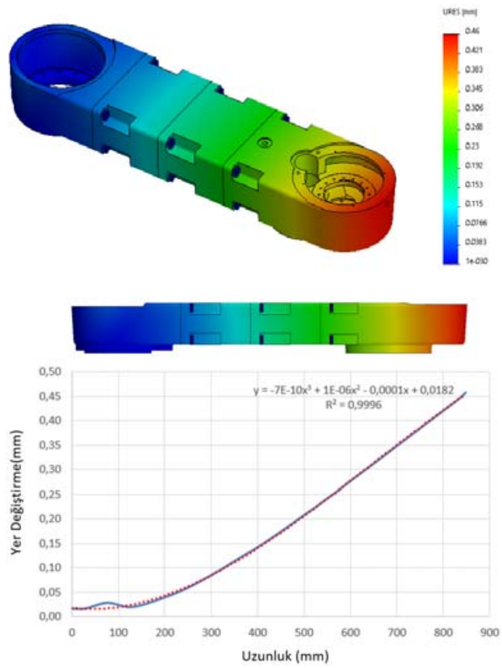

Figure 10. Relocation graph of Model 3

IV. CONLUSIONS

A SCARA type robot with extensible arm having high-speed movement and repeatability has been studied in this study. The extensibility effects to the working precision of the robots while working in assemble lines and the strength at joint axes.

Finite Element Analysis has been conducted to understand how the extensions effect on the stress and strain distribution under constant load at the end of robot arm. For this purpose, all of the robot's geometry is created in 3-D software and then mechanical analysis is performed on several extensions. Results obtained from the simulations has been indicated that extensible SCARA robot arm can be a good solution for increasing robot access. Attentions must be taken in order to prevent stress accumulation at the clamping points. These precautions should be simple and precautions should be taken to increase the bending strength of the joint in the main arm. In general, this work of strengthening the section strength can be carried out with support members and high section moment of inertia profiles, which increase the bending strength.

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