Design of a force control gripper using Matlab Simulink

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Abstract— **The working body usually called the gripper in manipulators is an essential component of industrial automation systems. They are designed to hold and manipulate objects with precision, speed, and reliability. Robotic applications and the creation of functional organs are both widespread. The working body may be incorporated into the robot's overall design or added to its fundamental framework. The design is determined by the robot's function, the object it must grasp, the task it must complete, and its working environment. Force control is an essential feature of robotic grippers that allows them to handle delicate or fragile objects without causing damage. This paper outlines the many decisions that are made when designing and selecting the robot's gripper. Aspects of the process and environment are covered first. Power, joint adaptability, load capacity, and connections are all included. Following is a section that offers an overview of the various working bodies and their constructive directions. The sensors and elements of the control system are also featured.**

Keywords—robot gripper, force control, CAD model, Simulink model.

I. INTRODUCTION

Robots perform a wide range of tasks with varying sizes and payloads. Some robots are made to perform particular, specialized tasks, like manipulating parts or performing welding, cutting, sharpening, or sanding operations. These robots employ particular tools as a working body. In these applications, the tool, orientation, and tool management are the main design considerations to ensure efficient work of the robot. Other robots are made for multipurpose use and component manipulation. When building the working body, these robots need more engineering details. The tasks and environment of the robot must always be taken into consideration when choosing or building a suitable robot or working organ.

The development of robotic grippers has a long history that spans several decades. The earliest robotic grippers were basic mechanical devices that were often limited in their capabilities. Over time, advancements in technology led to the development of more advanced robotic grippers, including pneumatic, hydraulic, and electric grippers. Such advancements in grasping can be seen in [1] where a robotic end effector is capable of performing in-hand manipulation tasks. Govindan and Thondiyath proposed a new type of robotic gripper that can manipulate objects with both shape-conformity and within-hand manipulation in [2]. Their work consists of two finger gripper that can adjust their contact forces independently. These systems are developed for underwater operations with sensory haptic feedback as can be seen in [3]. Robotic grippers have a wide range of use in the medical field. One such example is [4] where a design is presented of an endoscopic grasper for manipulating large body organs. Several studies have been conducted on the design and implementation of robotic grippers with force control. These studies have focused on various aspects of the gripper, including the design of the gripper fingers, the selection of the force sensor, and the development of the control system This can be seen in [5] where force control is used to control robotic instruments for minimally invasive surgery. Another implementation of force control in the medical field can be seen in [6] where a teleoperated endoscopic grasper is designed for minimally invasive surgery. Force control can be achieved by different means. The authors of [7] outline the design of the grasper and the mechanism for controlling its force using the shape memory alloy. Further advancements in robotic gripper design can be seen in [8] where the authors describe the design and manufacturing process of the grasper, which uses compliant materials and embedded sensors to achieve greater dexterity and sensitivity in manipulating objects.

Within this paper the following was obtained: a simulation of the model, calculation of the length of each part of the gripper links. Definition of the mechanical construction of the gripper as well as information of the compatibility and functionality of the structure. Kinematic analysis of the mechanism, the magnitude of the forces, speeds and accelerations which occur in the links and the required torque to drive the mechanism.

II. DESIGN OF THE GRIPPER IN MATLAB SIMULINK

When the gripper grasps an object, the material of the object is just as important as the force with which he grasps it. Catching a plastic ball is different from doing so with a metal ball. If a plastic ball with more strength than required is grasped, the material itself deforms, and the part may become permanently deformed and rendered useless. Because of these factors, the objective is to create a gripper that will clamp and grip parts with a controlled amount of force. The gripper is designed and simulated using Matlab Simulink

The fundamental components of working bodies in manipulators are grippers. The construction of a gripper must take into account geometric movement as well as the kinematics of the gripper [9]. There are countless variations of gripper

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constructions. However, there are a number of straightforward kinematic designs that are frequently used as grippers such as grippers with parallel axis grippers with rotational movement [11], grippers with multiple claws, gripper with joints [10,11]

Two models have been designed in Matlab/Simulink of the gripper where the second model is an advancement on the first. The calculation of the length of each part of the gripper links, the definition of the mechanical construction of the gripper as well as information of the compatibility and functionality of the structure can be obtained from the model. Also, the kinematic analysis of the mechanism, the magnitude of the forces, speeds and accelerations which occur in the links and the required torque to drive the mechanism can be evaluated.

The goal of this paper is to design a gripper with force control up to 70 [N] and a grasping range of around 80 [mm]. The gripper will be mainly designed for spherical objects and the form of grasping will be with the tip of the claws. The Simulink model is shown in Figure1 while Figure 2 depicts the design of the gripper.

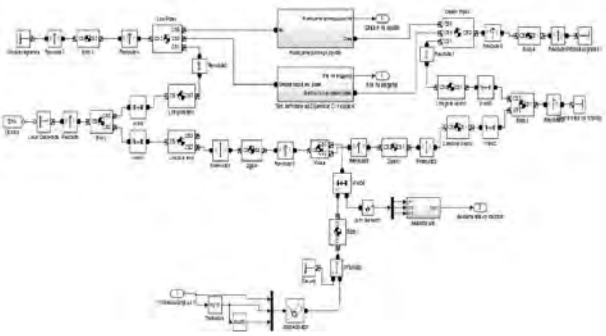

Figure 1. Simulink model of gripper

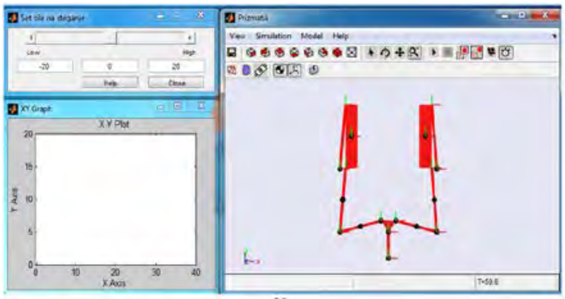

Figure 2 Simulink depiction of gripper

Within the Simulink model there is no real body that will be grasped by the gripper, in that regard a simulated body is introduced that has a certain elasticity k and damping b. If the deformation of the body is measured, and its stiffness is known, then the force with which that body is grasped by the catcher can be determined.

To regulate the grasping force, a PID regulator has been installed. For predetermined grasping force values, this regulator includes an automatic adjustment of the best coefficients for the predetermined mechanism and using Simulink the ideal coefficients can determine by using the Tune option in the block for the PID controller

Reference forces are set as inputs to the PID controller and the outcomes are tracked, including gripping speed, required traction force, forces acting on the claws, working space dimensions, required clamping time, etc.

III. SIMULATION RESULTS FROM THE MATLAB SIMULINK MODEL

The elastic body that is used has a diameter of D=50.8 [mm] and a stiffness of 500 [mN/mm]. The obtained results are shown on the following figures. Figure 3 shows the starting position of the gripper while Figure 4 shows the end position for a given force of 5 [N].

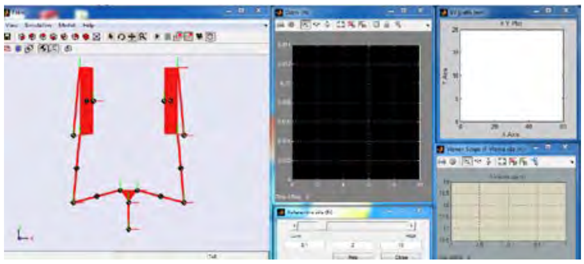

Figure 3. Gripper starting position

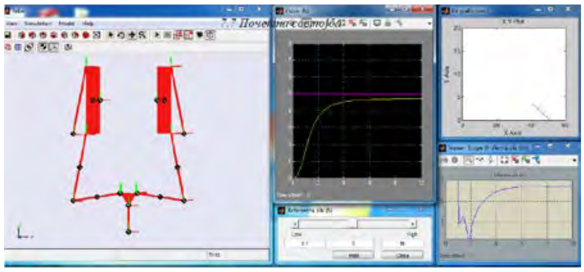

Figure 4 gripper response to clamping force 5 [N]

The Matlab model has been improved by placing the first and second link at a 90^0 angle. The resulting model can be seen on Figure 5.

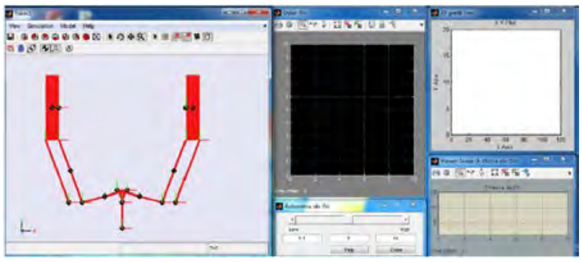

Figure 5 Improved grasper model

For this model several referent force values have been imputed and the results have been observed.

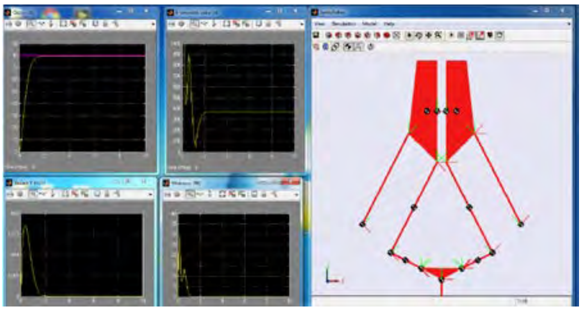

Figure 6 Reference force value of 10 [N]

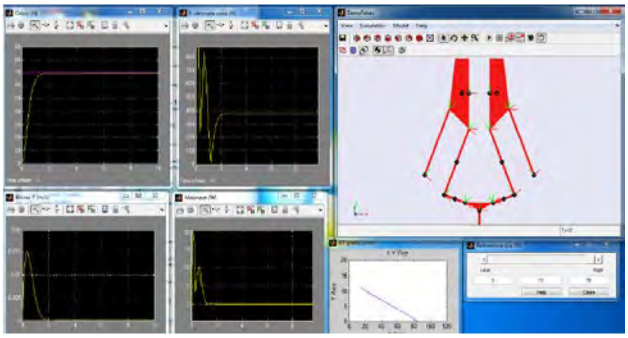

Figure 7 Reference force value of 70 [N]

Figures 6 and 7 demonstrate the grasping results of the gripper for two reference force values of 10N and 70N respectably. It can be seen that due to the PID control the grasper achieves the desired force value in around 1s, moving with a speed of 0.016m/s in both cases

When the results from the first and second models are compared, it becomes clear that the second model produced better results because the accepted body diameter is larger, at 80mm, as opposed to the first model's 50mm. The different forces that both models experience, such as the pulling and clamping forces in the claws are negligible. The following are the Simulink results that are required for the calculation and dimensioning of the gripper parts:

For a clamping force of 70 [N]

- Required maximum traction force F = 800 [N]
- Linear velocity V_{lin} = 6 [mm/s\
- Traction power required P = 6 [W]
- Maximum diameter that can be caught d_{max}=80 [mm]
- Required linear distance l_{max} = 16 [mm]

IV. DIMENSIONING OF THE GRIPPER

Having achieved the required results from the simulation the dimensions of the threaded spindle need to be calculated.
The first step is calculating the diameter based on spindle core pressure

$$d \approx 1.3\sqrt{\frac{F}{\sigma_{max}}} = 1.3\sqrt{\frac{F}{\frac{R_e}{s}}} \qquad (1)$$

Where for construction steel C.0545 Re=285[N/mm^2] and the safety factor s is taken as 3.5 giving the diameter of the spindle d>4.1 [mm]

The next step is to calculate using the bending moment. The force F=800 [N] acts at 10 [mm] from the core of the output shaft giving a bending moment M=8000 [N/mm]

$$d \approx \sqrt[3]{\frac{32M}{\pi\sigma_{max}}} = \sqrt[3]{\frac{32 * 8000}{\pi * 96.43}} = 4.4\ [mm] \qquad (2)$$

Using ISO 2904:1977 the first larger diameter from 4.4 is d=6.2 [mm] which corresponds to a trapezoidal spindle of Tr=8x1.5.

The next step is to calculate the needed torque, angular velocity and transmission ratio. The step of the spindle is 1.5mm and for a linear velocity of 6mm/s, the rotation of the spindle is:

n=6/1.5=4 [s^{-1}]

giving the final torque needed as:

$$T = \frac{6}{2\pi * 0.6 * 4} = 0.4\ [Nm] \qquad (3)$$

Finally, the Power of the motor for the gripper can be calculated as

$$P = \frac{P_{out}}{n_{pl} n_{el} n_{ig}} = \frac{10}{0.6 * 0.9 * 0.8} = 23.11\ [W] \qquad (4)$$

For Actuator is proposed Maxon motor BLDC with Hall sensors type EC-MAX 22, which have follows characteristics:

- Power 25 [W],
- Supply voltage 24 [V]
- Nominal current 1.4 [A]
- Nominal speed 10400 RPM or 174 [s^{-1}]
- Max. continuous torque 22.7 [mNm]

The maximum speed of this BLDC motor is 10400 [RMP] and 22.7 [mNm]. In order to satisfy the required speed and torque of the output shaft, like a reducer us proposed with transmission ratio between 40-45. Strain wave gearing harmonic drive which is characterized whit zero backlash, large aspect ratio and compact construction is proposed. A specially made rubber chamber that is exposed to pressure when clamping the object is connected with pressure sensor from where pressure/force can be determined.

V. SOLIDWORKS DESIGN

Once the calculations for the model have been completed, the gripper is designed in a CAD software in order to perform further analysis. This software helps in evaluation of all the shortcomings of the Simulink model. The construction of the parts and the assemblies are designed and the deformations that would occur in certain parts of the structure as well as the stress state are calculated. Using this software all the weak points in the structure itself can be detected.

Figures 8 gives the final design of the gripper for force-controlled grasping.

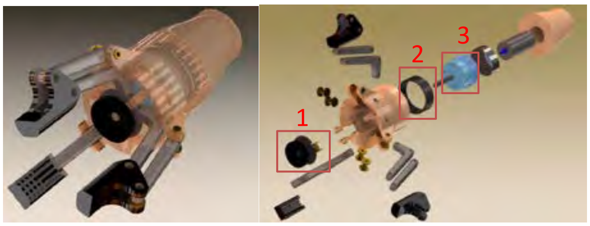

Figure 8 CAD model of the gripper

The specialized chamber for the pressure sensor can be seen on Figure 8 point 1 which allows for the calculation of appropriate force while grasping. Point 2 and 3 show the harmonic drive for the motor which are specifically designed for the chosen one. The dimensions of the levers for the three fingers of the grasper are taken directly from the Simulink model and a FEM analysis is conducted to evaluate their state.

Using final element method (FEM) analysis, the stress and deformation states can be calculated for the gripper. On Figure 9 and Figure 10 the stress and deformation states are given for the gripper finger and the first link.

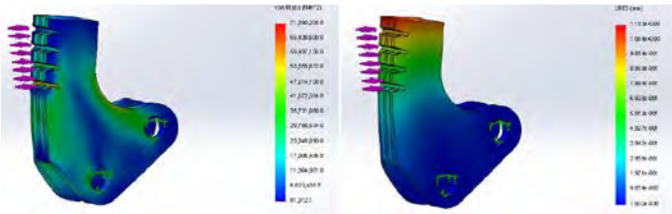

Figure 9 Stress and deformation states of gripper finger

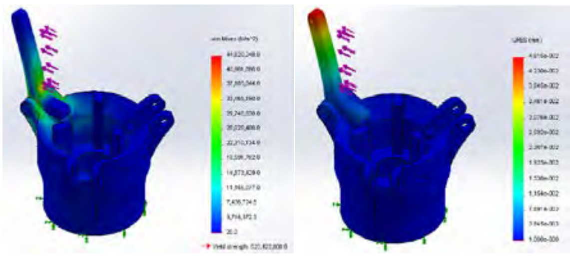

Figure 10 Stress and deformation states of gripper link

The FEM analysis shows the stress and deformation on the gripper fingers and gripper links with an applied force of 100 [N]. The gripper finger shows a nominal stress state of 41 [N/mm] with a maximum deformation of 1.18 [mm], while the gripper links show a nominal stress state of 22 [N/mm] and a maximum deformation of 0.046 [mm].

VI. CONCLUSION

Within this paper a force control gripper which uses a pressure sensor and a harmonic motor drive has been designed and analyzed. A Simulink model has been developed and optimized for a clamping force of 70 [N] regulated by using a PID controller. The simulation results show that the proposed system provides accurate and stable force control with minimal overshoot and settling time. The design parameters acquired from the simulation have been used to calculate the spindle diameter and motor torque required to power the gripper. Using all the parameters a CAD model has been designed which shows a possible variation of the gripper with the positions of all its components. Future work on this topic would include the creation of a physical model of the system and further testing and validation of the simulation results.

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