STRUCTURAL AND FABRICATION PROCESS OPTIMIZATION FOR A ROBOT EFFECTOR

ANASTASIU Alexandru-Ioan[1]

[1]Facultatea de Inginerie Industrială și Robotică, Specializarea: Robotică, Anul de studii: II, e-mail: alexandru.anastasiu@stud.fiir.upb.ro

- Conducător ştiinţific: **Prof. Dr. Ing. Gheorghe-Gabriel JIGA**
- Coordonator științific**: Ing. Alexandru Andrei ANCUȚA**

REZUMAT: This paper aims to provide research into structural and fabrication methods for a robot effector, specialized for palletizing operations. The goal was to achieve a high-reliability, low-cost gripper, in order to be able transport cylindrical parts. The analysis performed was both of a structural type (by comparing different parameters, such as infill percentage and construction shape) and from a cost perspective. Material choice was also considered, between different types of FDM, and one SLA variant.

CUVINTE CHEIE: Structural analysis, Finite Element Analysis, Structural optimization

1. Introducere

The field of robotics has been rapidly advancing in recent years, experiencing exponential growth. In various settings, particularly those involving repetitive and demanding tasks, industrial robots are taking over the roles traditionally performed by humans. These machines are particularly valuable when human limitations hinder the optimal functioning of technological processes.

When delivered in their factory configuration, robots lack practical utility beyond serving as mere demonstrations. To be effectively incorporated into a technological environment, robots need to be equipped with a component known as an effector. This effector determines the specific functionalities and capabilities of the robot. The type of effector required varies depending on the application, such as manipulation (moving parts between multiple points), palletizing (specifically keeping the part parallel to the ground plane), arc welding, and so on.

The objective of this article is to provide a comprehensive analysis of the structural aspects related to an effector necessary for the palletizing process. In addition to considering orientation requirements, this analysis encompasses various physical and structural constraints. The purpose is to ensure that the reference load can be efficiently manipulated within the workspace, utilizing the maximum speeds permitted by the load-bearing structure. Safety considerations for both the environment and the operators in the vicinity are also taken into account.

2. Stadiul actual

A means of achieving low-cost, fast fabrication is via FDM (fused-deposition-modeling). FDM (Fused Deposition Modeling) Fabrication:

FDM is a widely used additive manufacturing technology that creates three-dimensional objects by extruding thermoplastic materials layer by layer. It has gained popularity due to its affordability, versatility, and ease of use. FDM technology supports a wide range of thermoplastic materials, including ABS, PLA, PETG, nylon, and more. Manufacturers have developed specialized filaments with improved properties, such as enhanced strength, flexibility, heat resistance, and chemical resistance. This expanding material selection allows for diverse applications and end-use parts. A base characteristic of FDM is that most parts generated are hollow, with a parameter named “infill” determining both the percentage and shape of material used for rigidization and support of the outer shell.

Robot palletizing refers to the automated process of using robots to stack or arrange items, products, or packages onto pallets in a systematic and organized manner. It is a common application of robotics in industries such as manufacturing, warehousing, logistics, and distribution centers. The process typically involves a robot equipped with an end-effector, such as a gripper or vacuum system, that can grasp and lift objects. The robot is programmed to precisely pick up items from a conveyor belt, production line, or storage area, and place them onto pallets following a predefined pattern or configuration. Overall, robot palletizing plays a significant role in streamlining warehouse operations, optimizing logistics, improving product handling, and enhancing overall productivity in industries that involve the movement and storage of goods.

In order to analyze the structural behavior of the end-effector, a process called FEM is employed: FEM stands for Finite Element Method. It is a numerical technique used for solving engineering and mathematical problems by dividing them into smaller, simpler parts called finite elements. FEM is widely used in various fields, including structural analysis, heat transfer analysis, fluid dynamics, electromagnetics, and many others.

The steps involved in using FEM typically include:

- Discretization: The domain is divided into a finite number of elements, and the nodes and connectivity between elements are established.
- Formulation: Mathematical equations are developed to describe the behavior of each element based on the governing physical laws and properties.
- Assembly: The individual element equations are combined to create a system of equations that represents the entire problem.
- Solution: The system of equations is solved numerically using iterative or direct methods to obtain the solution.
- Post-processing: The results obtained from the solution are analyzed, visualized, and interpreted to gain insights into the problem being studied.

For the present study, the Ansys software was utilized.

3. Initial process:

In developing an end-effector for the application, the first step was to develop a 3D model: this was done following two approaches: two different versions of the effector have been suggested, each with implications for the generation of the robot's workspace. The first variant is eccentric, enabling the complete accessibility of the workspace by positioning the load along a guiding radius that runs parallel to the robot's workspace. Nonetheless, this eccentric variant has a drawback as it introduces additional loads that result in bending and shearing forces at the contact points between the chucks, screws, and mounting flanges.

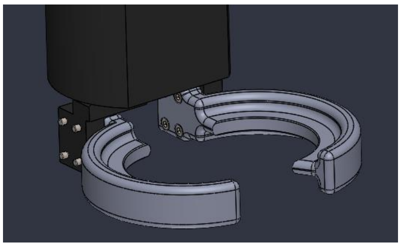


Fig. 1. Chucks in an eccentric configuration

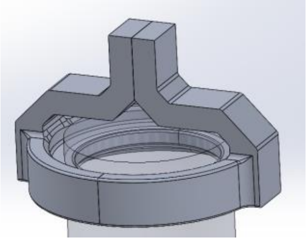
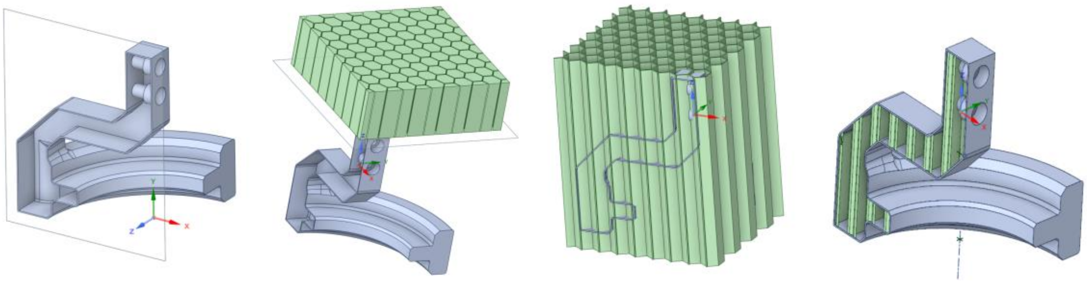


Fig. 2. Chucks in a concentric construction

An initial analysis was performed, after which the concentric variant was chosen to continue the study. Initially, an infill parameter of 100% was chosen, in order to eliminate pertaining to it. The concentric variant performed best under loads applied.

4. Generation of geometry

The geometry, with different infill configurations, was difficult to obtain from the CAD software. A workaround was devised, utilizing the Space Claim CAD software: by first generating a cube above the model, creating the desired infill, then projecting said infill downwards, it was possible to generate two bodies: the outer shell of the chucks and the inner infill. Between the two bodies, a frictionless contact was generated.



Figs. 3-6. The shape generation process

5. Material choice

Material choice is extremely important, both when designing the real product, and when performing the analysis. Material properties were obtained both from the manufacturer datasheets, and from literature. Of great importance are parameters such as Young's Modulus, the Shear Modulus, and S-N Curve, necessary for fatigue analysis. Three different plastics were considered: ABS, PLA and HIPS.

6. Configuration of the FEA model

The model must first be configured, in order to allow the analysis to be performed. Firstly, contacts have been defined. These can be broken down in 3 types: between the chucks, between the chucks and the object being palletized and between the outer shell and infill.

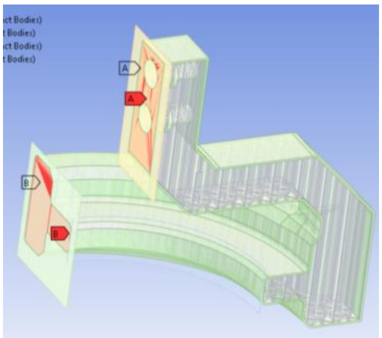


Fig. 7: Chuck contact

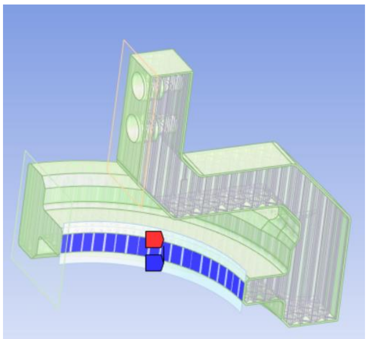


Fig. 8: Chuck and object contact

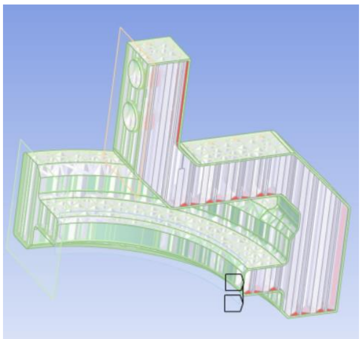


Fig. 9: Outer shell and infill contact

7. Identifying areas of interest

Discretization can be broken down into two types: generalized and fine-grained. Generalized discretization utilizes large spatial shapes, lowering computation time, but also reducing accuracy. An initial, gross discretization is done. Iterating further, in areas that present high loads additional reference systems are created. In spherical areas, radiating out of these reference systems, the discretization was refined, in order to achieve parity with a real behavior.

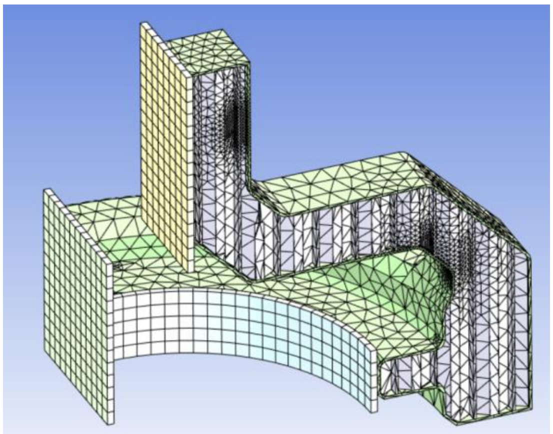


Fig. 10: Discretization

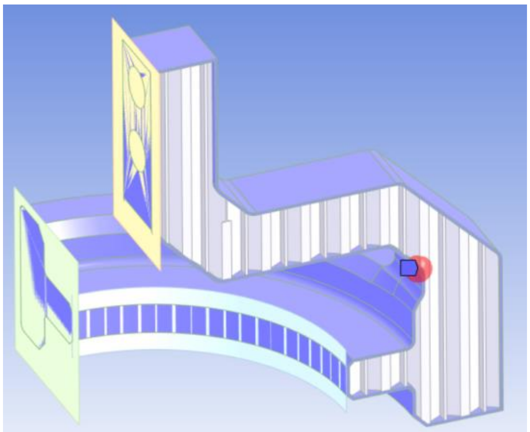
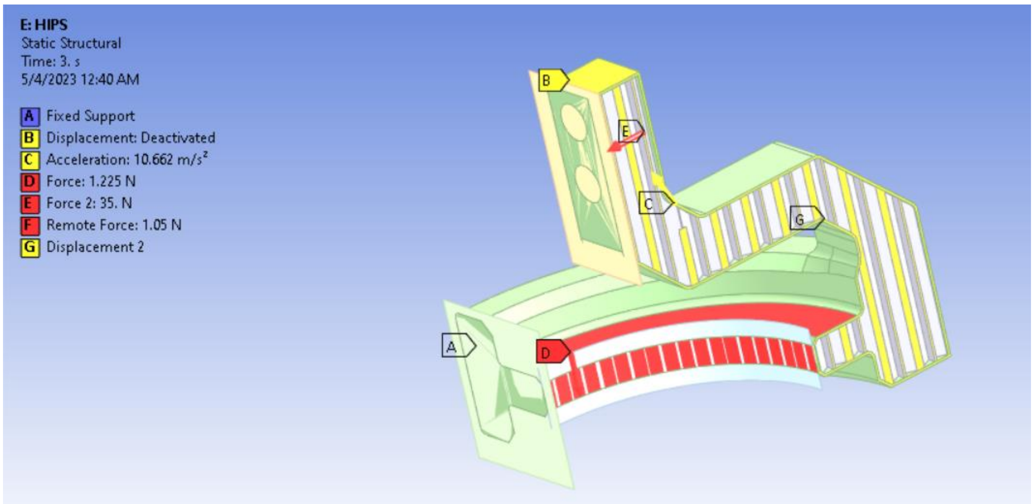


Fig. 11: Areas of interest

8. Static loads

Static loads have to be determined in order to simulate the behavior of the model: The “A” surface was considered a fixed support, the plane of contact between the closed chucks of the effector. Surface “B” represents the contact between the chuck and the flange. Surface “D” supports the weight of the load. Surface “E” is the gripping force of the effector, while “F” was considered a remote load, in order to better simulate inertial forces acting upon the chucks.



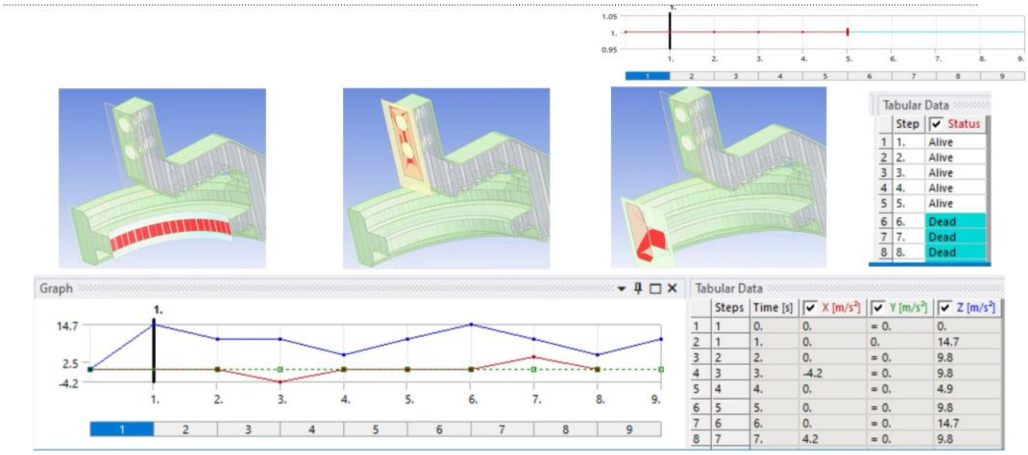
E: HIPS
Static Structural
Time: 3. s
5/4/2023 12:40 AM

A Fixed Support
B Displacement: Deactivated
C Acceleration: 10.662 m/s²
D Force: 1.225 N
E Force 2: 35. N
F Remote Force: 1.05 N
G Displacement 2

Fig. 12: Simulated loads

9. Simulation steps

During the course of a cycle, a number of distinct “steps” can be identified, during which the loads and accelerations change (as contacts become active):



Tabular Data

	Step	☑ Status
1	1.	Alive
2	2.	Alive
3	3.	Alive
4	4.	Alive
5	5.	Alive
6	6.	Dead
7	7.	Dead
8	8.	Dead

Tabular Data

	Steps	Time [s]	☑ X [m/s²]	☑ Y [m/s²]	☑ Z [m/s²]
1	1	0.	0.	= 0.	0.
2	1	1.	0.	0.	14.7
3	2	2.	0.	= 0.	9.8
4	3	3.	-4.2	= 0.	9.8
5	4	4.	0.	= 0.	4.9
6	5	5.	0.	= 0.	9.8
7	6	6.	0.	= 0.	14.7
8	7	7.	4.2	= 0.	9.8

Fig. 13: Contact step control configuration

Accelerations had to be determined experimentally, as the robot datasheet provided no information about them. A measuring apparatus was created utilizing an Arduino Nano 33BLE development board, which was equipped with a 9-axis inertial sensor LSM9DS1. A setup was constructed consisting of a standard AAA battery pack connected through spot welding and supported by a plastic plate. Real-time outcomes were wirelessly transmitted using the Bluetooth Low Energy (BLE) protocol to the central computing unit for subsequent analysis and processing. The device was additionally safeguarded by a soft braid covering to absorb potential impacts, while insulation tape was applied to the plastic plate to enhance grip on the robot's chucks.

10. Analysis results – Maxmium equivalent von Mises stress

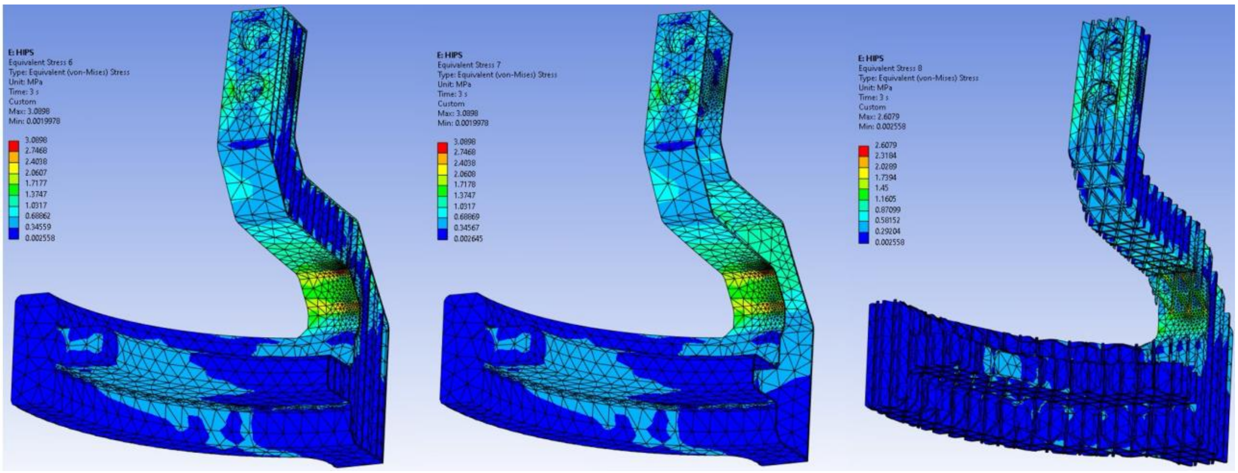


Fig. 14: Maxmium equivalent von Mises stress

Following the analysis, doubled by a fatigue study, it was determined that most infill types yield infinite lifetime for the chucks, proving the viability of the design.

11. Closing thoughts

The FEM and structural optimization analysis of the robot end-effector produced through FDM manufacturing presented intriguing findings. The comprehensive evaluation explored various parameters, leading to insightful observations and potential avenues for further exploration. The results demonstrated promise in terms of enhancing the end-effector's performance, durability, and efficiency. However, additional investigations are warranted to fully comprehend the complex interplay between the design parameters, material characteristics, and printing process. Ultimately, this study serves as a stepping stone for future research and development endeavors in the realm of FDM-produced robot end-effectors, contributing to advancements in robotic systems and their associated applications.

11. References

[1]. Mitsubishi RV-E2 User's Manual,
http://www.roboex.com/Mitsubishi%20Movemaster%20Robot%20Manual/RV-E2/user_manual.pdf
[2]. RV-E2-RV-E3J Specifications Manual,
http://www.roboex.com/Mitsubishi%20Movemaster%20Robot%20Manual/RV-E2/E2%20Specification%20Manual.pdf
[3]. Reddy, J. N. (2017). An Introduction to the Finite Element Method (4th Edition). CRC Press. ISBN: 978-1138031183.
[4]. Chandrupatla, T. R., & Belegundu, A. D. (2012). Introduction to Finite Elements in Engineering (4th Edition). Prentice Hall. ISBN: 978-0132162746.
[5]. Cook, R. D., Malkus, D. S., Plesha, M. E., & Witt, R. J. (2001). Concepts and Applications of Finite Element Analysis (4th Edition). Wiley. ISBN: 978-0471356059.
[6]. Sheng, J., & Zhang, Y. (2018). A Review on Robotic Palletizing. In 2018 IEEE 3rd International Conference on Advanced Robotics and Mechatronics (ICARM) (pp. 379-384). IEEE. doi: 10.1109/ICARM.2018.8610832
[7]. Tien, Y. Y., Huang, T. S., & Lin, T. K. (2013). Development of robotic palletizing system for pick-and-place operations. International Journal of Advanced Manufacturing Technology, 66(9-12), 2065-2072. doi: 10.1007/s00170-012-4690-2