Digital Manufacturing Technology
https://ojs.wiserpub.com/index.php/DMT/

UNIVERSAL WISER PUBLISHER

Conference Proceeding

Paper presented at the 1st International Conference on Modern Technologies in Mechanical & Material Engineering [MTME 2023]

Designing of Tooling Solution for Workpiece Handling in Highly Automated Manufacturing System

Muhammad Umair Naseer[1*], Muhammad Waqas Afridi[2], Hamza Mohsin[2], Tauheed Shehbaz[2], Fahd Nawaz Khan[2]

[1]Skolkovo Institute of Science and Technology, Moscow, Russia
[2]Faculty of Materials and Chemical Engineering, Department of Materials Science, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi 23640, Pakistan
E-mail: umairnaseer21@gmail.com

Received: 25 May 2023; **Revised:** 10 July 2023; **Accepted:** 18 July 2023

Abstract: A flexible manufacturing system (FMS) is an integral part of a smart factory of Industry 4.0 in which every machine is interconnected and works autonomously. Robots are in the process of replacing humans in every industrial sector. As the cyber-physical system (CPS) and artificial intelligence (AI) are advancing, the manufacturing industry is getting more dependent on computers than human brains. This modernization has boosted production with high quality and accuracy and shifted from classic production to smart manufacturing systems. However, workpiece handling for such an automated production system is a challenge and needs to be addressed with the best possible solution. Conventional clamping systems are designed for manual work and are not suitable for highly automated production lines. Researchers and engineers are trying to find the most economical solution for loading/unloading and transportation of workpieces from a warehouse to a machine shop for machining operations and back to the warehouse without human involvement. This work aims to propose an advanced multi-shape tooling solution for highly automated manufacturing systems. The currently obtained result shows that it could function well with automated guided vehicles (AGVs) and modern conveyor belts. The proposed solution is following requirements to be automation-friendly, and universal for different part geometry and production operations. We used a bottom-up approach in this work, starting with studying different case scenarios and their limitations and finishing with the general solution.

***Keywords*:** AI, CPS, Industry 4.0, material handling, smart factory, FMS

Nomenclature

AGVs	Auto guided vehicles
AI	Artificial intelligence
CNC	Computer numerical control
FEA	Finite element analysis
FMS	Flexible manufacturing system
IoT	Internet of Things

DOI: https://doi.org/10.37256/dmt.3220233091

1. Introduction

The smart factory is a new concept for manufacturing companies as a part of Industry 4.0. It represents the leap forward from traditional automation to a fully connected and flexible system. It works by employing technology such as AI, robots, analytic big data, and the IoT with the ability of self-learning and control. The main characteristics of a smart factory are enlisted in Figure 1 [1].

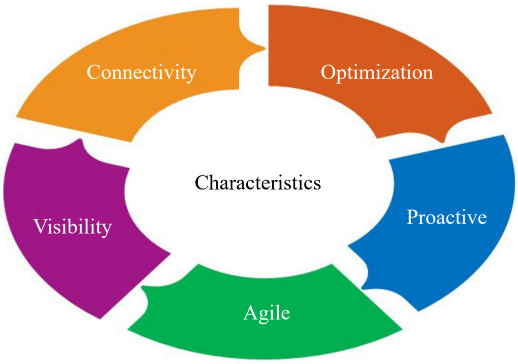


Figure 1. Characteristics of smart factory

The biggest problem to implement this concept in the production company is the optimization of the FMS and agility of transportation. Conventional tools cannot be used to attain a high level of automation, such as conveyor belts cannot be used for logistics and fundamental fixtures cannot be used without human involvement [2]. Therefore, this work aims to design a set of tools that can be attached to different fixtures and clamping systems to make them usable in a highly automated manufacturing system.

Some requirements need to be fulfilled by the tooling solution [3].

a. The design of the tooling set should be simple and transportable through AGVs.
b. It can be loaded and unloaded through robotic grippers.
c. It should hold the workpiece during CNC machining operations such as the drilling and milling process.
d. It should accumulate multi-shape workpieces having a size of 150 mm × 150 mm base area.
e. The tool should be strong enough to bear the weight of the clamping system and workpiece with the cutting force applied during a machining operation.

2. Workpiece classifications

There are 11 basic types of mathematical geometric shapes depending on sides and angles. Mostly, the workpieces are based on these shapes or a combination of them. Based on industrial research, some of the workpieces have been selected to demonstrate the functioning of the tooling system [4, 5]. Some of them have been enlisted in Figure 2.

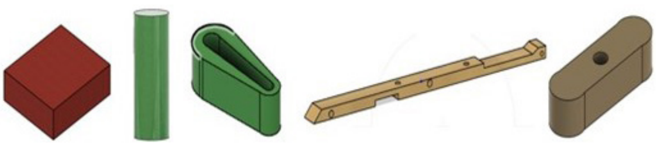
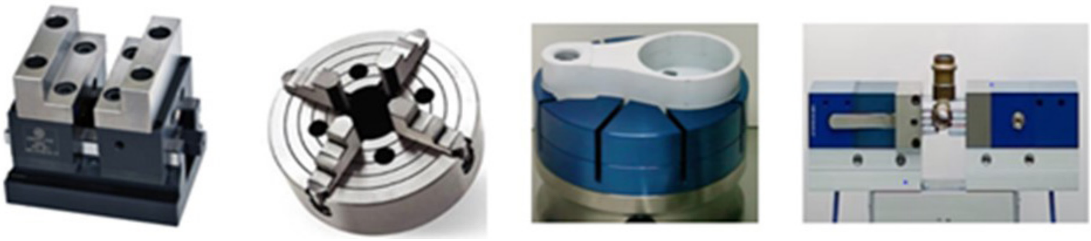


Figure 2. List of considered workpieces

3. Conceptual design of the tooling system

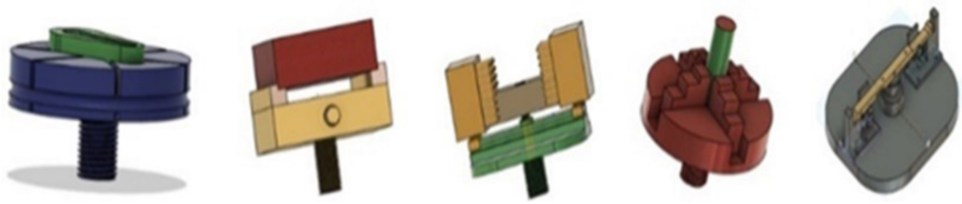
Based on the shortlisted workpieces, some clamping systems were selected. These conventional clamping systems shown in Figure 3, can hold multi-shape bodies for different machining operations which include milling and drilling operations.



(a) (b) (c) (d)

Figure 3. Conventional clamping systems: (a) vise clamping system; (b) chuck clamping system; (c) in-mold clamping system; (d) matrix clamping system

In Figure 4, 3D models of these clamping systems are demonstrated. All the models are designed in Fusion 360 software.



(a) (b) (c) (d) (e)

Figure 4. 3D Models of fixtures: (a) in-mold clamping system; (b) vise clamping system; (c) matrix clamping system; (d) chuck clamping system; (e) modular clamping system

According to the considered requirements, we designed an adapter that can be transported through AGVs, loaded and unloaded through a robotic gripper, and hold a clamping system during the machining operation.

Figure 5 shows the workflow of the tooling solution. All the fixtures can be attached to the same adapter, and it can be fixed in the base, which is placed in the machining cell. In this way, multi-shape workpieces can be machined under the same platform through an automated process.

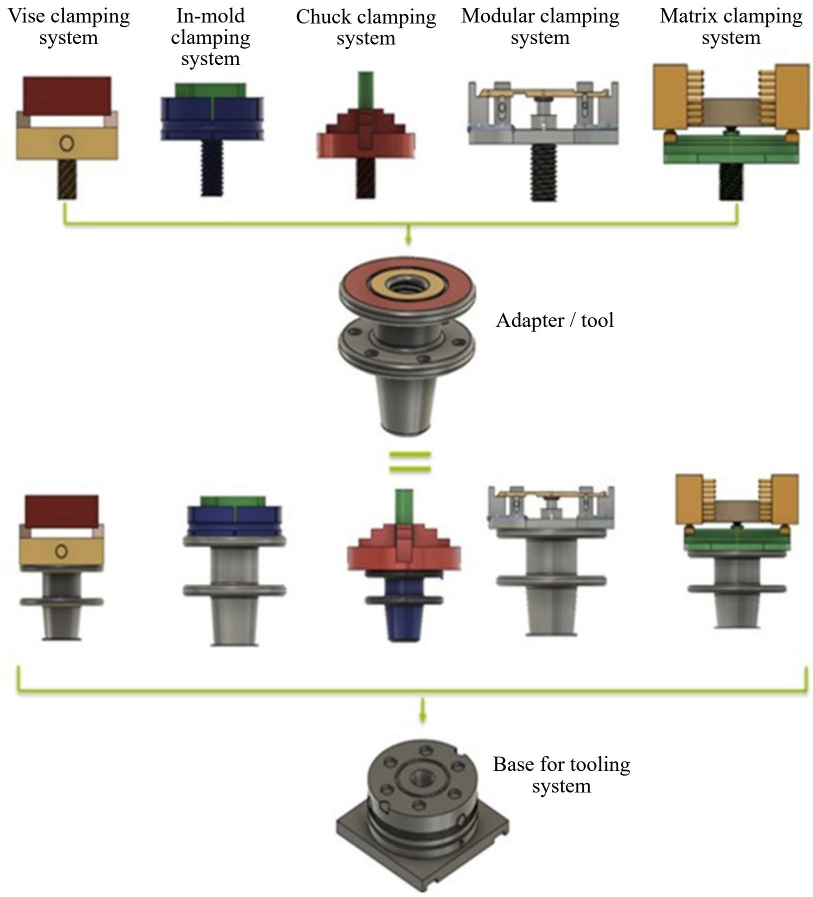


Figure 5. Workflow of tooling solution

4. Material selection

The material of this adapter should be lightweight with high strength to bear maximum fatigue cycles. Therefore, steel is the most suitable material for the adapter. Many tools such as HSK-A63 are made of steel .

Contemporarily, there are different kinds of steels available in the market depending on the heat treatment process and alloying elements, they have been graded. The alloyed stainless graded steel 304 and 430 are good options for manufacturing the tools. A comparison of the mechanical properties of mentioned steel is shown in Table 1.

Table 1. Mechanical properties of AISI 304 and AISI 430

Material	Young's modulus (GPa)	Poisson's ratio	Ultimate tensile strength (MPa)	Yield tensile strength (MPa)	Density (kg/m^3)
AISI 304	190	0.265	720	215	7930
AISI 430	200	0.28	500	260	7750

5. Analytical calculations of stress and deformation

An adapter is divided into three main sections according to stress distribution areas. The scheme of the adapter is shown in Figure 6.

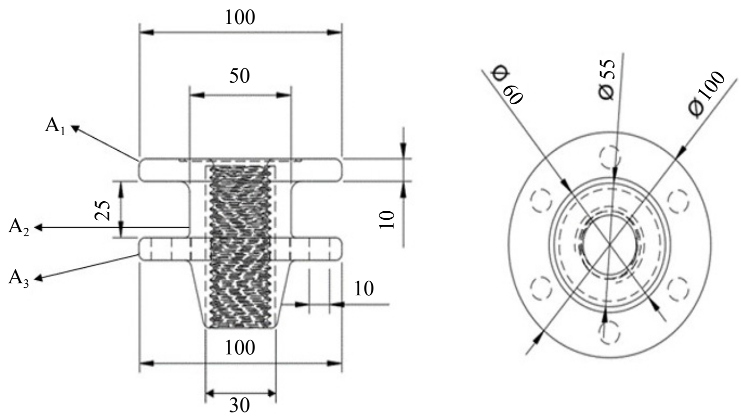


Figure 6. Isometric view with dimensions

The total cross sections area is described in Equation (1).

$$
\begin{aligned}
A_1 &= \frac{\pi d^2}{4} = \frac{\pi}{4}((100\ \text{mm}^2) - (30\ \text{mm}^2)) = 7143.5\ \text{mm}^2 \\
A_2 &= \frac{\pi d^2}{4} = \frac{\pi}{4}((50\ \text{mm}^2) - (30\ \text{mm}^2)) = 1256\ \text{mm}^2 \\
A_3 &= \frac{\pi d^2}{4} = \frac{\pi}{4}((100\ \text{mm}^2) - (30\ \text{mm}^2) - 6(10\ \text{mm}^2)) = 6672.5\ \text{mm}^2 \\
A_T &= A_1 + A_2 + A_3 = 15072\ \text{mm}^2 \qquad (1)
\end{aligned}
$$

where A_1 is cross-sectional area of section-1 in mm^2, A_2 is cross-sectional area of section-2 in mm^2, A_3 is cross-sectional area of section-3 in mm^2.

Total deformation:

Total deformation is the sum of deformation in each section. The value described by Equation (2).

$$
\begin{aligned}
\delta &= \frac{FL}{AE} \\
\delta &= \frac{F}{A}\left(\frac{L_1}{A_1} + \frac{L_2}{A_2} + \frac{L_3}{A_3}\right) \\
\delta &= \frac{1200\ \text{N}}{2 \times 10^5}\left(\frac{10\ \text{mm}}{7143.5\ \text{mm}^2} + \frac{25\ \text{mm}}{1256\ \text{mm}^2} + \frac{10\ \text{mm}}{6672.5\ \text{mm}^2}\right) \qquad (2)
\end{aligned}
$$

where δ is deformation in mm, F is the force applied in Newton, L is the thickness of the section in mm, E is Young's modulus of the section.

Total stress distribution:

Similarly, total stress is calculated by summarizing stress from each section in Equation (3).

$$
\begin{aligned}
\sigma &= \frac{F}{A} \\
\sigma &= F\left(\frac{1}{A_1} + \frac{1}{A_2} + \frac{1}{A_3}\right) \\
\sigma &= 1200\ \text{N}\left(\frac{1}{7143.5\ \text{mm}^2} + \frac{1}{1256\ \text{mm}^2} + \frac{1}{6672.5\ \text{mm}^2}\right) \\
\sigma_T &= 1.38\ \text{MPa} \qquad (3)
\end{aligned}
$$

6. Establishing the finite element model

Material considered for FEA:

We considered steel as a material for the tool. The mechanical properties of steel are mentioned below in Table 2.

Table 2. The mechanical properties of steel

Properties	Steel
Young's modulus	2.0E+05 MPa
Poisson's ratio	0.3
Density	7850 kg/m^3
Yield strength	250 MPa
Tensile ultimate strength	400 MPa

FEA:

There are two kinds of static structural analysis:

a. linear structural analysis;

b. non-linear structural analysis.

In linear structural analysis, the applied force and displacement have linear relations. We considered linear analysis because the applied force lies in the elastic region [6, 7]. Static structural analysis has been carried out in ANSYS Workbench 18.2. This software can be used for fluid flow, heat, and mass transfer. Furthermore, stress-life fatigue analysis has been done with the same software.

Meshing:

Meshing is an important part of FEA. The whole body is divided into a finite number of elements and software solves the problem according to given constraints and boundary conditions for each element [8]. After accumulating the result of all elements, we can predict the behavior of the body. It is better to have a greater number of elements to have a more accurate result. Similarly, our tool has been divided into 70,514 nodes and 41,451 elements for the analysis, as shown in Figure 7.

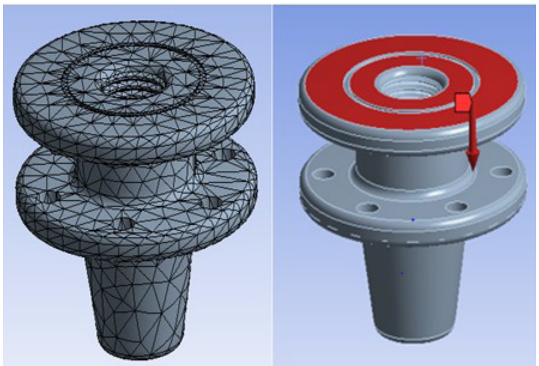


Figure 7. Isometric view with dimensions

7. Results

Total deformation:

In ANSYS, we have two types of deformations:

a. total deformation;

b. directional deformation.

Total deformation is an accumulation of all directions (x, y, z-axis). But in directional deformation, the effect of stress on a particular axis can be evaluated [9, 10].

In our case, total deformation is considered and according to FEA result its value is 0.0012493 mm. The result of the simulation is shown in Figure 8.

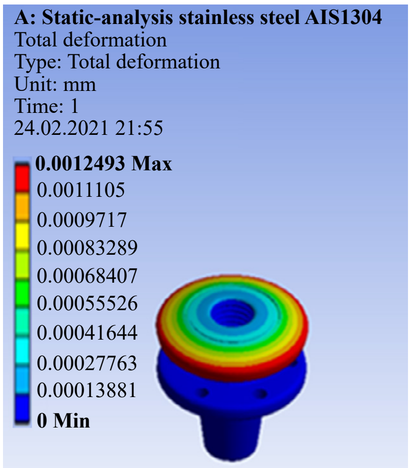


Figure 8. Total deformation

Von Mises stress distribution:

Through ANSYS von Mises stress value can be calculated to know the stability of the structure. The theoretical calculation can be done by using Equation (4) .

$$\sigma_v = \sqrt{\frac{[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]}{2}} \tag{4}$$

where σ_v is von Mises stress, σ_1, σ_2, σ_3 are principal stresses and σ_y is the yielding strength of the material. If $\sigma_v \geq \sigma_y$, then the structure collapse.

The von Mises stress distribution value is 4.4312 MPa, which is less than the yield stress of the material. So, it can be concluded that the structure can sustain the given value of the load applied. Results are shown in Figure 9.

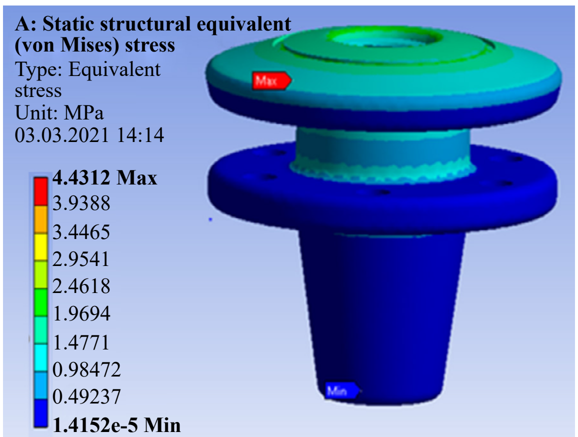


Figure 9. Von Mises stress distribution

Fatigue analysis:

When the applied load on the structure is less than the yield stress then fatigue analysis is done to evaluate the long-term effect on the structure.

In this case, the minimum life cycle for a tooling system is 10^6. It means that the tool can bear an infinite life cycle with this amount of load. The simulation result is shown in Figure 10.

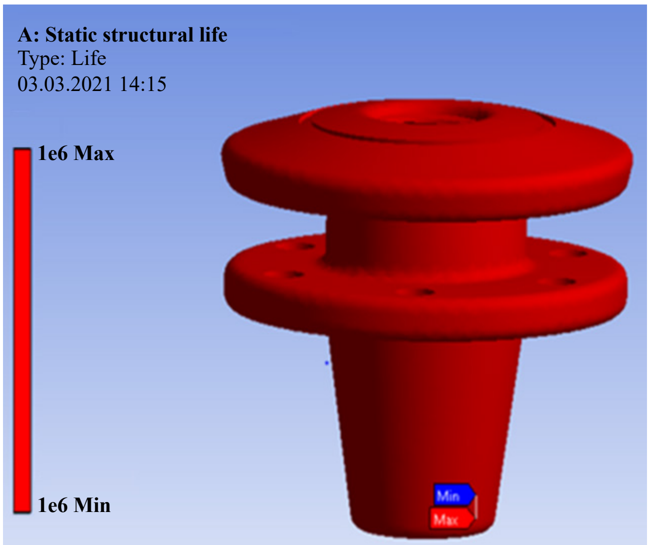


Figure 10. Fatigue analysis result

8. Conclusions

The adapter design can successfully attach to different fixtures to accommodate different geometrical shapes of workpieces.

The theoretical stress value is 1.38 MPa which is less than 4.4312 MPa. The main reason for this difference is internal threads which acted as a stress raiser and intensified the stress value around the threaded portion. Still, the maximum value of von Mises stress is less than the yield stress. So, there will be no plastic deformation.

The design of the tooling system is functional according to requirements and easy to handle.

In future work, we can upgrade the design of the hold by considering the complex shape and bigger size workpiece samples. Further, detailed design can be considered as a future task.

Acknowledgments

Muhammad Umair Naseer thanks Ivan Sergeichev (Assistant Professor in CDMM Department, SKOLTECH) and Ighor Uzhinsky (Professor in CDMM Department, SKOLTECH) for their input in simulation results and consistent feedback.

Conflict of interest

There is no conflict of interest for this study.

References

[1] Cheng K, Niu ZC, Wang RC, Rakowski R, Bateman R. Smart cutting tools and smart machining: development approaches, and their implementation and application perspectives. *Chinese Journal of Mechanical Engineering*. 2017; 30: 1162-1176. https://doi.org/10.1007/s10033-017-0183-4

[2] Parmar PN, Mehta NC, Trivedi MV. Investigation on automation of lathe machine. *International Journal of Emerging Technology and Advanced Engineering*. 2014; 4(5): 524-529. https://www.researchgate.net/profile/Nirajkumar-Mehta/publication/280313628

[3] Choi YC, Xirouchakis P. A production planning in highly automated manufacturing system considering multiple process plans with different energy requirements. *The International Journal of Advanced Manufacturing Technology*. 2014; 70: 853-867. https://doi.org/10.1007/s00170-013-5306-1

[4] Kibira D, Morris KC, Kumaraguru S. Methods and tools for performance assurance of smart manufacturing systems. *Journal of Research of the National Institute of Standards and Technology*. 2016; 121: 282. https://doi.org/10.6028%2Fjres.121.013

[5] Azizi A, Yazdi PG, Humairi AA, Alsami M, Rashdi BA, Al Zakwani Z, Al Sheikaili S. Design and fabrication of intelligent material handling system in modern manufacturing with industry 4.0 approaches. *International Robotics & Automation Journal*. 2018; 4(3): 186-195. https://doi.org/10.15406/iratj.2018.04.00121

[6] Zunic E, Besirevic A, Skrobo R, Hasic H, Hodzic K, Djedovic A. Design of optimization system for warehouse order picking in real environment. In: *2017 XXVI International Conference on Information, Communication and Automation Technologies (ICAT)*. Sarajevo, Bosnia and Herzegovina: IEEE; 2017. p.1-6. https://doi.org/10.1109/ICAT.2017.8171630

[7] Lingaiah K. *Machine design databook*. New York: McGraw-Hill Education; 2003. https://www.accessengineeringlibrary.com/content/book/9780071367073

[8] Lee CK, Lv Y, Ng KKH, Ho W, Choy KL. Design and application of Internet of things-based warehouse management system for smart logistics. *International Journal of Production Research*. 2018; 56(8): 2753-2768. https://doi.org/10.1080/00207543.2017.1394592

[9] Lokesh A, Reddy B. Design and analysis of fixture for component cradle in HMC-800. *International Research Journal of Engineering and Technology*. 2017; 4(10): 1994-1998. https://www.irjet.net/archives/V4/i10/IRJET-V4I10361.pdf

[10] RadhaMadhavi C, Ramu B, Srinivasulu K. Design of machining fixture for turbine rotor blade. *International Journal of Research in Engineering and Technology*. 2014; 3(3): 1-14. https://doi.org/10.15623/ijret.2014.0303001