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# Design and Analysis of Jigs and Fixtures for Manufacturing Process

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**Abstract.** This final year paper report is about the design and analysis of jigs and fixtures for manufacturing process. For this project, it is focus on the perspective of the job handling to produce the part. Currently, they implement the manual handling to assembly each component. Improvement that is trying to do is by replace the manual handling for the process by designing the semi auto jig for this process. The objectives of this project are to investigate the collected data and analyse the design of jig and fixture to ease work handling. The methodology of research procedures covered on this project consists of collect data, brainstorming and interprets data, design concept, and documentation. The design of jig and fixtures is using Unigraphics NX7.5 software. The data that can be studied include the analysis of Finite Element Analysis (FEA) using CATIA software, the analysis of design ergonomic, the time study analysis and cost analysis. At the end of this project, this research will be able to give understanding about jig and fixture, design by using Unigraphics NX7.5 software and finally able to do the analysis for the selected part of product by using FEA and other relevant analysis

## 1. Introduction

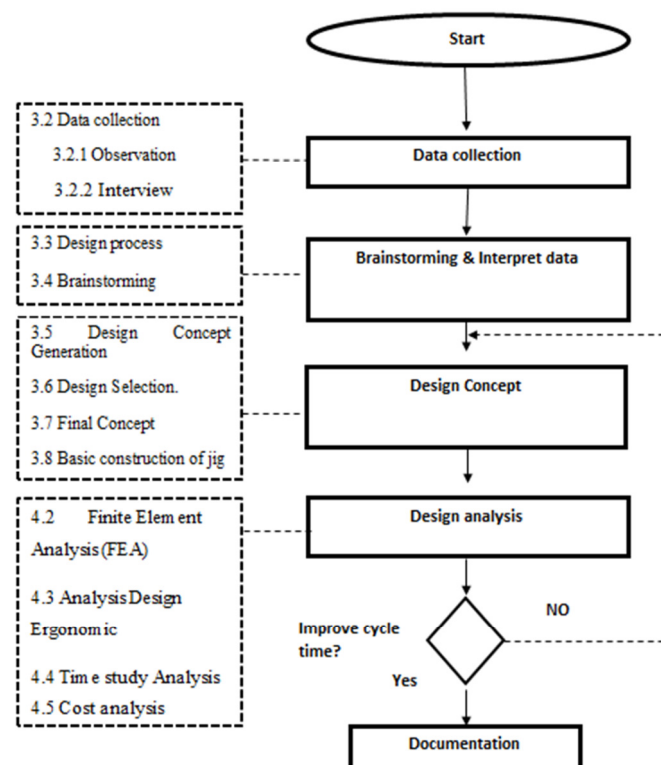
Over the past century, manufacturing sectors play an important role to the economic development of a country. Jigs and Fixtures are devices that used to facilitate production work in industry especially that involve in machine. The perfect jigs and fixtures can work repeatability and interchangeability to produce the same parts in production. In manufacturing industry, jigs and fixtures are most important device that can assist the workers in their production process become easier. Jig and fixture is important tool using in industry. Tool that are carries the main forces will form the final shape of the workpiece. [1]. The difference between jig and fixture is in the way of the tool is guided with the workpart [2]. . Fixture are essential element in production operation as it always important in industry such as automated manufacturing, inspection, and assembly operation [3]. One of the principles that can be follow for designing the jig and fixture for this project is as states by Nee et al. [4] The general factors to be considered when designing jig and fixture are shape, material and state of workpart, pre-machined surface tolerance, type of operations and the machine tools used, workpiece handling, ergonomics and safety considerations. However, the other studies are different from Taufik et. al. [5] . The design parameter such as maximum deformation, maximum shear stress, number of contact faces, and maximum holding force were presented. It is found that the gripping ability is the important factor that affected to the clamping and holding the workpart perfectly during machining operation. Besides



that as explained by Sawita et. al.[6] which has done a design and finite element analysis of jig and fixtures for the design are very useful for this project methods. In addition, the dimension of design is very important. This statement can be proves by the research from Peshatwar et. al. [7] which has presented a fixture design system of eccentric shaft for ginning machine. Designer should design a fixture according to dimension required by industry to fulfil production target. The important consideration that taken when designing this jig and fixture before making any decision also gathered from the research study by Saari et. el. , product design and development requires that engineers consider trade-offs between product attributes for the cost, weight manufacturability, quality and performance. The optimum design is the usually one that compromise are acceptable, but understanding the impact of design decision on all relevant attributes is difficult. [8]. According to Yugeskumat et. al. [9] on the journal titles an advance method of jig and fixtures planning by using CAD methods, it review methods and techniques for the geometry analysis of fixture feasibility in product development which the synthesis methods including geometrical analysis and fixture assembly planning are surveyed. The decision making for selection of material used is based on the reviewed research from Kharmiza Japar [10], states that a jig and fixture are made from a variety of materials. Some of which can be hardened to resist wear. It is sometimes necessary to use nonferrous metals like phosper bronze to reduce wear of the mating parts or nylon or fibre to prevent damage to the workpiece.

## 2. Methodology

The overview on the overall research methodology and operation steps as shown in Fig.1 are required in achieving the objectives of this project.



**FIGURE 1.** The overall research methodology.

### 3. Data Collection

The product planning is based on the data collected on observation from the current process. The process that needs to do the improvement for the jig and fixture are at insertion of the e-ring as shown in Fig.2.

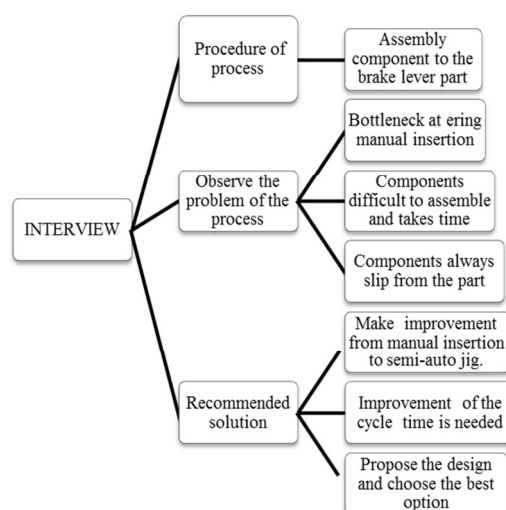


**FIGURE 2.** Manual E-Ring insertion

From the data taken for this operation time, this process took 12.15 seconds to complete the job. So, from the collected data, the target cycle time that needs to improve is 8 seconds,

From observation, this process is highly recommended for improvement because compared to other process in this operation line, this process are difficult with the uses of manual handling tool and operators always take a time for the job done. To do this process, operators need to make sure that the e-ring must insert in their position and grip to the part very well. Currently, operator always faces a problem to insert the e-ring. Sometime the e-ring is loose and missing at the end of the process. This will cause the reject part and need to rework. So, it shows that this process was selected to make an improvement because it has high possibilities to improve the overall time of the process with the new design and more advance of the jig and fixture. With the use of jig and fixture, it not only can improve the cycle time but it also can improve productivity and help to make the operator job become much easier.

The author used qualitative method to collect data through interviews. Based on that method, the researcher was able to analyze the gap of design study. The data collected can be shown in Fig.3.



**FIGURE 3.** Interview data

#### 4. Design Process

The engineering design process is one of the steps required for the development of product. Step in designing a jig and fixture is by evaluation of its functional requirements in order to find the balanced combination of design characteristics at a reasonable cost. At this step, tool design process should be clearly state the problem to be solved and achieve as needed. The design process also included the analysis that involve to the product such as the clamping position, the load distribution, the material selection and more analysis and information from the design.

This process also will explain on how the semi-auto e-ring insertion jig will designed and how the analysis will be performed. CATIA CAD software is used to designing and analyse for FEA. The targeted result for the FEA analysis is to find the value of deformation when the load applied and to estimate the value of maximum allowable strength based on the material yield strength. These values are very important in order to determine if the design of the part is suitable and meet requirement.

#### 5. Brainstorming

Brainstorming is how the rough idea can be drafted to form the design. One of the methods for brainstorming the idea is through the benchmarking of related product for designing. Benchmarking is the study of existing products with functionality similar to that of the product under development or to the sub problems on which need to be focused. Benchmarking can reveal existing concept that have been implemented to solve a particular problem. The designer obtained the related products in order to discover the general concepts on which that can be absorbed for the new product.

#### 6. Design Selection

Design selection is the process to choose the concept that has been evaluated according to the requirement and the criteria needed.[11,12] When comparing the relative strengths and weakness of the concept, select the best concept that can be used for further investigation. Generally, concept selection is the process of narrowing the alternative concept that has been considered.[13,14] In order to choose the final concept for the jig, the screening method was choosing.[15] This method can help designer to make a decision for the best design. For the beginning, the design of jig comprises of three designs which it have the different concept design.

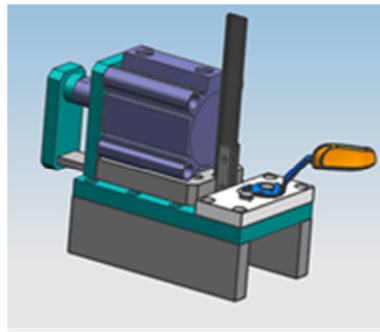
**Table 1.** Concept screening matrix

Selection criteria	Concepts		
	First Concept (Datum)	Second Concept	Third Concept
Ease of handling	0	-	+
Ease of use	0	+	+
Durability	0	+	+
Ease of manufacture	0	-	-
Portability	0	+	+
Cleaning ease	0	0	0
Maintenance ease	0	+	+
Production time	0	-	+
Sum +’s	0	5	6
Sum 0’s	8	1	1
Sum -’s	0	3	1
Net score	0	2	5
Rank	3	2	1
Continue?	No	Yes	Yes

From the Table I shown above, the result shows the best option can be selected by choosing the high rank. The third concept was the first rank which is the most acceptable for this requirement.

Concept scoring always uses to select the final concept selection which use the rating score to rate the design. For this design, the concept scoring need to be skipped because the best design was selected from the design screening which it is shows that the Third Design as the dominant among others. So that, the Third Design will be proceed for further research.

## 7. Final Concept

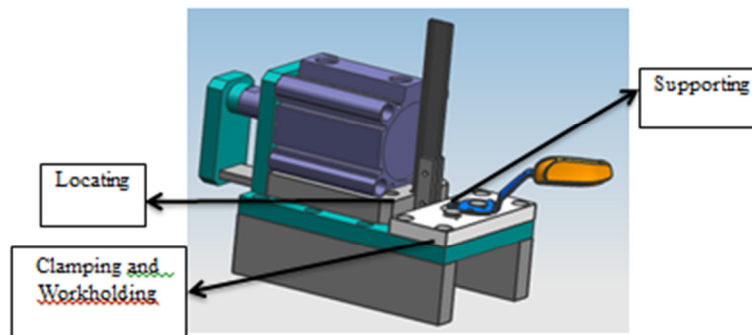


**FIGURE 4.** Final concept

The final concept of design as shown in Fig.4 are selected based on the decision that has been made during concept selection which is here the third concept is the best option. This final concept design which is the semi-auto insertion jig are much more better than second design which is the assembly part for this design also are more simple.

## 8. Basic Design Principle for Jig and Fixture

Basic principle while designing of jig and fixture is supporting, locating and clamping and workholding. From the final design of semi-auto insertion this principle can be shown in Fig.5.



**FIGURE 5.** Classification for Basic Principle.

The supporting of the part should be rigid. From this semi-auto insertion jig, make sure the design for supporting is sufficiently stiff to secure the accuracy while inserting the e-ring to main lever part. Locating of the part must be “fool proofing” which means that main lever part must lead into jig and fixture in a proper position at the same time not interfere with loading and unloading the workpiece. The foolproofing device that is used for this parts is pins which clears can correctly position parts and prevent incorrectly parts from entering this jig. This semi-auto insertion jig using screw clamps. Clamping screw is suitable for this jig because it can be used for light clamping. The basic screw clamp uses the torque to hold a part into places by direct pressure on another part. The holding power for this jig is using the bolts and nuts. The bolts and nuts are easy to use and every part can assemble to each other's.

## 9. Economical

When designing the jig and fixture it is important to make sure the product is simple in construction, give high accuracy and rigid. For this project, the economic in terms of the cost analysis of the product will calculated to satisfy this condition.

## 10. Design for safety

When designing jig and fixture, make sure that the product is safe and convenient in use. Some factor of safety that must be followed is:

1. Sharp corner on the body of jig or fixture should be avoided. In this project, while designing the semi-auto insertion jig, every design part are using chamfers in every single corners to make sure that no sharp corner that can harm operator while using the jig.

2. Bolt and nut should be inside the body and not protrude the surface. The surface of this semi-auto insertion are designed well as all the bolt is put inside of the jig which is make the work surface clear and can avoid any injury and obstacle while doing the job.

## 11. Results and Discussions

### 11.1. Finite Element Analysis (FEA)

CATIA uses the displacement formulation of the finite element method to calculate component Von Mises stress, principal stress, tension and compression, and displacement under internal and external loads. The main parameter on this analysis is the material and the force on the jig. The material selections for each part are steel because the actual materials to produce the part are made from a composition of steel. The static force represents the force applied by the operator to part while insert the e-ring. All these parameters had been analyzed by searching for the limit force of the part and the relevant size and further it has been designed in CATIA to simulate the load on the jig. Table 2 shows the force reacted on the jig.

**TABLE 2.** Comparison of Several Studies with Task similar to Those Being Investigated ( in Newtons) [16]

		Mean	Std Dev	5 <sup>th</sup> Percentile	20 <sup>th</sup> of 10 <sup>th</sup> Percentile (Kodak)	Normalized Peak Force at ACGIH Action Limit
Schoorlemmer and Kanis (1992) <sup>1</sup>						
Thumb Push (free posture)	Male	86.9	43.0	16.0	6.3	39.1
	Female	68.5	36.1	8.9	4.4	30.8
Thumb Push (90° elbow flexion)	Male	81.3	26.7	37.2	9.4	36.6
	Female	64.1	32.4	10.6	4.5	28.8
Astin (1999) <sup>1</sup>						
Index-Finger Push (forward)	Male	52.6	18.0	22.9	5.9	23.7
	Female	39.3	14.9	14.7	4.0	17.7
Index-Finger Press (down)	Male	50.9	18.4	20.6	5.4	22.9
	Female	35.2	14.9	10.6	3.2	15.8
Hertzberg (1973)						
Thumb Push	Male	77.4	16.7	49.9	11.2	34.8
Index Push	Male	56.8	12.7	35.8	8.1	25.6
Dickson (1972) <sup>2</sup>						
Index Push (Dominant)	Male	45.1			9.0 <sup>3</sup>	20.3
Index Push (Non-dominant)	Male	43.1			8.6 <sup>3</sup>	19.4
Army (MIL-STD-1472D) <sup>4</sup>						
Grip Push (up)	Male			98.0	19.6 <sup>5</sup>	n/a <sup>6</sup>

<sup>1</sup> Participants were seated

<sup>2</sup> Only 50<sup>th</sup> percentile male were reported

<sup>3</sup> Values represent 20% of the mean

<sup>4</sup> Only 5<sup>th</sup> percentile male were reported

<sup>5</sup> Values represent 20% of the 5<sup>th</sup> percentile

<sup>6</sup> Mean was not provided, cannot be calculated

To decide the force distribution values are getting from Table II which is the limit force for the thumbs is 36.6 N. So that, the distributed load for part on the jig assumed as 40 Newton. The factor of

safety that has been choose is 2 which is it is used for well-known material under reasonably constant environmental condition and also subjected to loads and stresses that can be determined readily.

For OCTREE tetrahedron mesh, the meshing size is 14 mm and for the absolute sag is 1.4 mm. This parameter is used to all jig and fixture design when doing the nanalysis because different meshing parameter will influence the result when computing.

### 11.2. Analysis result

Static case analysis are deformation analysis, Von Mises stress analysis, translation displacement analysis, and principle stress. In this result that we gain from the analysis, several factors we should understand to make sure our product will be okay without failure. Other than that we also identify the modulus young, yield strength and density in this result that effect to product. This data are very important to identify the failure factor at the product before we could send to factory to produce it. The condition of each product is 40N acted downward. This analysis will show the areas that have high stress when the structure deformed. The material that is selected for all the part is steel. The steel material properties are shown in Table 3:

**TABLE 3.** Material Properties of Steel

Material properties	Value
Young modulus	$2 \times 10^{11} \text{ (N/m}^2\text{)}$
Poisson ratio	0.266
Density	$7860 \text{ kg/m}^3$
Thermal expansion	$1.17 \times 10^{-5} \text{ Kdeg}$
Yield strength	$1.25 \times 10^8 \text{ (N/m}^2\text{)}$

This value  $1.25 \times 10^8 \text{ N/}$  of allowable stress is useful to identified either the part will deform if the load is applied. If the value of stress is higher than the value of allowable stress, the part considered as plastically deforms. So, from the data analysis using the FEA, if the von misses stress value is not exceed the allowable stress, yielding will not occur. Von misses stresses are used to predict the yielding of material under any loading condition which is if the maximum value of distortion energy per unit volume in material is smaller than distortion energy per unit volume required causes yield strength, the design part is safe.

### 11.3. Von Misses Stress

Base plate. The von misses maximum value for this part is  $2.73 \times 10^6 \text{ N/m}^2$ . This value is lower than the allowable stress value  $1.25 \times 10^8 \text{ N/}$ . Thus, the base plate will undergo plastic deformation because the base plate can handle the maximum stress given by the load given by the push of main lever using finger force. It is elastic deformation which is after the load applied, the structure will a bit deformed but after the load is removed the base plate will back to its original shape.

E-Bit .The von misses maximum value for this part is is  $8.7 \times 10^4 \text{ N/m}^2$ . This value is lower than the allowable stress value  $1.25 \times 10^8 \text{ N/}$ . Thus, the e-bit will undergo elastic deformation at the end of the tool. It can handle the stress given by the pneumatic cylinder but it is elastic deformation which after the load is applied, the structure will slightly deformed. But after remove the load, the e-bit will back to its original shape structure.

Connector .The von misses maximum value for this part is is  $1.5 \times 10^4 \text{ N/m}^2$ . This value is lower than the allowable stress value  $1.25 \times 10^8 \text{ N/}$ . Thus, the connector will undergo elastic deformation. Same as the e-bit, the force applied also given by the pneumatic cylinder. The connector also can handle the stress given by the pneumatic cylinder but it is elastic deformation which after the load is



applied, the structure will slightly deformed. But after remove the load, the e-bit will back to its original shape structure.

Base plate support (B-P Support).The von misses maximum value for this part is is  $1.0 \times 10^5$  N/m<sup>2</sup>. This value is lower than the allowable stress value  $1.25 \times 10^8$ N/. Thus, the base plate support will undergo elastic deformation. The base plate support can handle the stress given by the load from upward because the this plate is act as the support to all part. But it is elastic deformation which after the load is applied, the structure will slightly deform. But after remove the load, it will back to its original shape structure.

LR jig .The von misses maximum value for this part is  $2.26 \times 10^5$  N/m<sup>2</sup>. This value is lower than the allowable stress value  $1.25 \times 10^8$ N/. Thus, the LR jig will undergo elastic deformation. The applied load to this LR jig is given by the force from the finger to put the main lever on this plate which is this LR jig will support the main lever while the e-ring inserted to the part. It can handle the stress given by the load from upward but it is elastic deformation which after the load is applied, the structure will slightly deform. But after remove the load, it will back to its original shape structure.

#### 11.4. Displacement Analysis

Displacement analysis can be describe as the better approximation of displacement function is the one that yields a lower potential energy. In structural analysis, the approximation are represented by consideration that displacement are small and can be neglected in equilibrium equation, the load are conservative, independent on displacement and the support of the structure remain unchanged during loading. The materials behave nonlinear or linear material model cannot be used if stress exceeded some value because the load may change their orientations according to displacements and support may change during loading.

Base Plate. From the analysis the translational displacement is  $7.97 \times 10^{-5}$ . As the value is very small, the displacement of the structure is considered as negligible because the maximum displacement of this part is 0.05mm in order to maintain the insertion of e-ring to the main lever. This can avoid from dislocation of e-ring to the main lever.

E-Bit .The translational displacement is  $1.61 \times 10^{-5}$ . As the value is very small, the displacement of the structure is considered as negligible. E-Bit are very important part which is it is used to carry the e-ring and insert to the main lever. So, the maximum displacement that is allowable for this part is about 0.01mm because it is important to make sure the insertion of e-ring is accurately to the main lever. If the displacement value is higher after the load is applied, this will cause failure for the insertion of e-ring due to the high deflection of the ebit from its original size.

Connector. From the analysis, the translational displacement is  $2.85 \times 10^{-7}$ . As the value is very small, the displacement of the structure is considered as negligible. This part is also important which is it is useful to carry the E-Bit that act as a tool to insert the e-ring. The small displacement value can avoid the dislocation of e-ring to be inserted to the main lever.

B-P Support.The translational displacement is  $2.85 \times 10^{-5}$ . As the value is very small, the displacement of the structure is considered as negligible. B-P support is the part that used to support all the part that assembled under it. So the value of displacement is very important to make sure that this part can support all the applied load that exerted . so, this small value of displacement shows that the part are excellently support the other part without a lot of changes.

LR Jig. The translational displacement is  $8.62 \times 10^{-6}$ . As the value is very small, the displacement of the structure is considered as negligible. This part is also important as the place to support the main lever during the e-ring insertion. Because of the load applied is not too much, so the displacement value is not too high. This can help to maintain the main lever in its position which is the insertion of e-ring are easier and successfully inserted.

The finite element analysis is very important in manufacturing engineering. With some help by technology, it could determine the product result by using CATIA software. This software can help to try an error the product until biggest improve can do at the product. Furthermore, this could reduce the percentage to get failure.

## 12. Conclusions

This semi-auto insertion jig has added a lot of changes to the job handling in process operation. It help to ease the handling for the job by eliminate the manual insertion to semi-auto. The conclusion from the result data are as follows:

- i. The FEA analysis shows that the von misses stresses and translational displacement for each part of material structure is stable which the results are not exceeds the required maximum value for each condition when 40N loads was applied.
- ii. For ergonomic analysis, the risk factors identified before implement this jig can be eliminate. It shows that the risk of injury can be avoided.
- iii. From the time study, when eliminate the manual handling, the cycle time can be improved from 12.15 seconds to 8 seconds which is this will result the time to produce the required quantity of part are shorted to 34.16%.
- iv. Lastly, the cost analysis shows that the cost of production can reduce and productivity is increase which is the parts per hour can be increased to 51.88%, the cost of labor expenses reduced to 34.16%, and the cost per part can be reduced to 14.29%.

The objective of the study are achieves at the end of this project which is the data analysis are completely collected, the design the jig and fixture to ease work handling is successfully developed and finally all the analysis result is successfully done.

## References

- [1] Krsulja M *et al* 2009 *J. Adv. Eng.* **6** 6.
- [2] Hoffman E G, "Jig and Fixture Design." 2004.
- [3] Soo W H, "Development of Modular Jig and Fixture for Catia." 2007.
- [4] Nee A Y C *et al* 1987 *Robot Comput. Integr. Manuf.* **3** 195.
- [5] Taufik R S *et al* 2012 *Malikussaleh Industrial Engineering Journal* **1** 19.
- [6] Sawita D D *et al* 2014 *International Journal of Research in Advent Technology* **2** 1.
- [7] Peshatwar S V *et al* 2013 *Int. J. Eng. Res. Appl.* **3** 1591.
- [8] Saari S M *et al* 2008 *International Journal of Research in Advance Technology* **6** 10.
- [9] Hong S W, "Development of Modular Jigs and Fixture for Catia." 2007
- [10] Kharmizan J, "Design Jigs and Fixture for Surface Grinding Long Part." 2007
- [11] Fatima S B A *et al* 2018 *AIP Conference Proceedings* **2030** 020070.
- [12] Azri N M *et al* 2018 *AIP Conference Proceedings* **2030** 020069.
- [13] Zaidi N A *et al* 2017 *AIP Conference Proceedings* **1885** 020005.
- [14] Zain F *et al* 2017 *AIP Conference Proceedings* **1885** 020023.
- [15] Zhafri Z M *et al* 2018 *AIP Conference Proceedings* **2030** 020071.
- [16] Nussbaum M A *et al*, "Strength Capabilities and Subjective Limits for Repetitive Manual Insertion." 2001.