Design and Deployment of Fixture on Assembly Line to Improve Productivity

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Abstract. In this research, fixture was designed and implemented on assembly line to improve ergonomics along with reducing the required time and manpower. It reduced the required manpower in half and subsequently led improvement the productivity. Providing ease in operation, fixture significantly reduced fatigue to the workers. The aim of this paper was to design and development of fixture for engine door assembly. The problem with assembly was analysed and fixture is proposed to tackle the key issues. To eliminate traditional trial and error approach, the fixture was designed using CAFD along with FEA validation. The proposed fixture manufactured and deployed in current assembly line. It improves total profitability and quality of process by achieving significant reduction of 40% in assembly time. Prior to fixture, time needed for assembly was 24 minutes. After the fixture, this assembly time reduces to 14.4 minutes i.e. 40% reduction is observed.

1. Introduction

The current manufacturing scenario is in great demand of variety of parts with high quality [1]. This also need to be manufactured within short span of time. Such requirement can be achieved by making use of jigs and fixtures while manufacturing.

Fixture design is essential in the setup planning stage. Appropriate fixture design improves the product quality with respect of accuracy, surface finish and precision of the machined parts. In manufacturing industry, 10-20% of total cost can be associated with fixturing [2]. Thus, before manufacturing validation of fixture design becomes necessary. According to the study done by Y. Rong et al [3], generally, 10 years of manufacturing experience is essential to build well designed fixtures. The task of designing fixture also becomes important since approximately 40% rejected components are due to improper fixture design [4]. By implementing Computer Aided Fixture Design (CAFD) in manufacturing processes, such errors can be avoided [5].

The fixtures are used to locate and hold any component firmly in desired orientation. This establishment is done using locators, clamps and supporters, which are also the basic components of fixtures. The fixture design must satisfy the criteria of design specifications, industrial safety norms, agronomics and cost economics in order to improve overall profitability as well as safety. The points that are taken into consideration for designing an assembly fixture are as following:
a) Fixture must be strong enough to reduce the deflection due to external forces. The frame of the fixture should have sufficient rigidity to prevent vibrations during the machining or other operation.

b) Clamping mechanism should be easy to incorporate and must require less amount of effort.

c) The movement of the sub assembly should be restricted after clamping and necessary mechanism should be provided along the desired directions to obtain smooth assembly flow. Sharp corners and redundant locators must be avoided.

d) The design must be robust in order to maintain the quality over a long period.

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f) The design of fixture should be as simple as possible to facilitate ease in manufacturing and usage of the fixture.

g) Minimum cost should be incurred in the fabrication of the project.

To meet above requirements and to reduce the error in fixture design, new approach is taken in to account while designing the fixture.

Computer aided fixture design (CAFD) is an effective way to design the fixtures by using computers [6]. It uses Computer Aided Design (CAD) software to improve design process. CAFD have grown a lot since 1980s, and doing efficient work of improving fixture design processes [7]. CAFD technology generates and optimizes CAD model according to the need of manufacturing processes. There are six phases involved in it:

a) Selection of components

b) Structure design

c) Assembly of components

d) Modification

e) Interference checking

f) Assembly sequence planning

Even though, CAFD is better alternative for traditional design, it cannot be considered as complete mistake proofing technique. By implementing Finite Element Analysis (FEA) in CAFD environment, designers can avoid “trial and error” experimentation [8]. The FEA simulates the physical condition before the actual manufacturing, which enables providing more accurate design solutions. The material and geometry can be modified accordingly.

The current paper uses CAFD approach along with FEA validation to design a fixture which aims to reduce the production time with improving the overall process quality.

2. Problem Statement

The work prescribed in this paper, has been done in small manufacturing company. The company was facing issues with engine door assembly. The task was to lift and hold the door and get it fixed with engine. Manual operation was taking more time for assembly with more workman engagement. Hence to improve the overall process, it was decided to build an optimized fixture. The aim of fixture is to reduce the assembly time and improve the quality by reducing fatigue of workmen. The figure 1 shows the actual photos of engine door assembly.
3. Concept Generation

After identifying the issues in current assembly process, brainstorming was carried out to generate effective ideas. As per CAFD, to demonstrate the actual problem with engine door, CAD model of every component with primary design fixture was generated.

3.1. CAD modelling

As per the requirement of the company the assembly procedure needs to be more efficient in order to reduce takt time, increase production rate and reduce the assembly time. The current assembly procedure was carefully examined in order to understand the critical areas for fixture design consideration, thus to design an easy to operate fixture. The dimensions of the component were studied. It was observed that in manual assembly operation, a total manpower of 2 technicians was required to lift, place and assemble the door sub-assembly onto the vehicle. A CAD model of the fixture was created to generate concepts for the fixture is shown in figure 2.
A concept design sketch is created to plan the fixture layout, utilities and assess the usability of the fixture. A main column supports the sliding holder. The fixture can be placed in the holder. Rail bearing is used for smooth translational motion. It was necessary to hold the engine door firmly at one location. To tackle this issue a hand winch is incorporated to one end. The whole fixture is mounted on four wheels to give ease in transportation of the engine door assembly from the sub assembly station to the main assembly line. The figure 3 shows the concept sketch of fixture including engine door with holder and main frame. A handle was also proposed in the manufacturing stage for the operator’s ease.

3.2. Hand Winch Mechanism

Hand winch consists of a set of inter meshed toothed sprockets with an attached ratchet mechanism. The hand winch working is based on the gear reduction mechanism. It has a handle with adjustable length of lever arm connected to the driver gear. The smaller driven gear is meshed with the driving gear. This combination offers a reduction in speed while enhancing the torque. Thus, with relatively less effort, the operator can lift the desired assembly. The rotary motion of the handle is converted into the vertical translational motion of the mobile platform by winding a steel core rope around the winch hub.

![Figure 3. (a) Hand Winch Mechanism, (b) Rachet Mechanism](image)

A ratchet mechanism is provided to allow continuous linear or rotary motion in only one direction while preventing motion in the reverse direction. The ratchet is given bidirectional control by attaching a spring-loaded control lever. Here the hand winch mechanism is used for lifting and lowering of the engine door subassembly for correct alignment for engine door bolting onto the main frame.

3.3. Material Selection

Considering the loading conditions, availability and cost, Structural Steel A36 was selected as a fixture material. The properties are shown in table 1.

| Properties          | A36 Steel |
|---------------------|-----------|
| Young’s modulus     | 200 GPa   |
| Poisson’s ratio     | 0.3       |
| Yield strength      | 250 MPa   |
| Ultimate tensile strength | 460 MPa   |
The weights are shown in table 2. For static structural analysis, boundary conditions are decided by weight of each component. Total weight of primary components comes out to be 25.1 Kgs.

**Table 2. Weights of Components**

| Components          | Weight (Kg) |
|---------------------|-------------|
| Engine Door         | 18.4        |
| FRP Part            | 4.5         |
| Other Accessories   | 2.2         |
| **Total Weight**    | **25.1**    |

4. Analysis of fixture model

After completion of CAD model along with the material selection it is necessary to simulate the results before manufacturing the components. Finite Element Analysis of holding bracket and main frame is carried out to test the strength criterion against the actual loading condition. The analysis is done with ANSYS 18.1 software.

4.1. Analysis of Holding Bracket

4.1.1. Initial Design.

For initial design, the material of 5 mm thickness has taken into consideration. The STEP file of model is imported in ANSYS 18.1 Workbench. Figure 4 shows the geometry of holding bracket in ANSYS environment.

![Figure 4. (a) Geometry of Holding Bracket, (b) Meshing of Holding Bracket](image)

The holding fixture is meshed with Solid 186 Tetrahedral elements forming a total of 48644 nodes and 28432 elements. The following figure shows the meshed model of the bracket.

The total weight of engine assembly is supported by two arms of holder bracket. According to table 2, total weight of engine assembly (m) is 25.1 kg. Total load on holding bracket \( P_t \) calculated as:

\[ P_t = m \times g \]

\[ P_t = 25.1 \times 9.81 \]

\[ P_t = 246.231 \text{ N} \]
Thus, a load \( P_a \) acting on a single arm of the holding bracket is calculated as,

\[
P_a = \frac{P_t}{2}
\]

\[
P_a = \frac{246.231}{2}
\]

\[
P_a = 123.115 \text{ N}
\]

Thus, a load of 123.115 N is applied on each arm of the holding bracket. The boundary conditions are shown in figure 5.

![Figure 5. Boundary Conditions](image)

The maximum value of equivalent (Von Mises) stresses comes out to be 115.97 MPa whereas maximum total deformation comes out to be 1.86 mm. The contour diagrams for stresses and deformation are shown in figure 6.

![Figure 6. (a) Total Deformation, (b) Von Misses Stress](image)

4.1.2. Design Modification.

The values of induced stresses and deformation of the structure are observed to be greater than the pre-decided values. Thus, the design of the bracket is modified by analysing the areas of maximum stresses and deformation. Necessary changes are incorporated, and the new design is again imported to ANSYS for analysis.

The thickness of the plate used for the bracket is increased from 5 mm to 7 mm. A rib stiffener is provided at the back to reduce the deformation. The CAD model of the optimized design is imported to ANSYS and is meshed. The meshing forms 32650 solid tetrahedral elements with 52472 nodes. The maximum aspect ratio of meshing comes out to be 33.943. The same boundary conditions have applied for modified design. The modified holding bracket reduces the maximum stress value to 26.709 MPa and maximum deformation value reduces to 0.5540 mm which ensures the strength of bracket.
4.2 Analysis of Main frame

On the basis of weight data, similar static structural analysis has been carried out for the main frame. The CAD geometry is imported and meshed with ANSYS software. The solid tetrahedral mesh forms total 26188 elements with 51744 nodes. Maximum aspect ratio comes out to be 30.027. Similar boundary conditions are applied to solve the model for equivalent stresses and total deformation. The equivalent stress induced is 2.9633 MPa and the maximum deformation value is 0.1198 mm.
5. Development of Fixture

The analysis results conclude that the values of induced stresses and deformation are within appropriated limits and the fixture design is seemed safe.

The fixture design is approved for manufacturing. The material required for complete fabrication of the fixture is calculated. Market survey is done to obtain an estimate of manufacturing. An estimate quotation for fixture is generated based on received quotations. The required amount is sanctioned and the parts procurement and fabrication work on fixture is started. The fixture is taken for manufacturing. The cost estimate report is created. The cost for fixture comes around INR 16500. In which hand winch mechanism costs around INR 3200, raw material costs around INR 2500 and rail bearing costs around INR 5800. The completed fixture is shown in figure 9.

![Manufactured Fixture](image)

**Figure 9.** Manufactured Fixture

![Rail bearing, holding bracket and hand winch mechanism views](image)

**Figure 10.** Rail bearing, holding bracket and hand winch mechanism views

6. Results

The completed fixture is deployed at the assembly line for testing and implementation. Assembly time data is recorded and compared with times recorded before implementation of fixture. Prior to
fixture, time needed for assembly was 24 minutes. After the fixture, this assembly time reduces to 14.4 minutes i.e. 40% reduction is observed. The time comparison of each step is shown below graph,

![Figure 11. Assembly Time Comparison](image)

The fixture used in actual assembly process is shown in figure 12.

![Figure 12. Fixture deployed in assembly](image)

7. Conclusion
The paper highlighted the importance of CAFD technology in manufacturing sector. The FEA validated fixture is successfully implemented for engine door assembly which improves the overall quality of process.
The assembly time is drastically reduced by 40% to all the produced components with the help of this fixture. This also leads to effective utilization of worker’s time with improvement in total profitability of company.

8. References
[1] Hoffman E. G., Jig and Fixture Design (5th Edition), Delmar Cengage Learning, 2008
[2] Bi ZM, Zhang WJ., Flexible fixture design and automation: review, issues and future direction. International Journal of Production Research, 2001
[3] Rong Yiming (Kevin), Huang Samuel. Advanced computer-aided fixture design. Boston (MA), Elsevier Academic Press, 2005
[4] Nixon F., Managing to achieve quality, McGraw Hill: Maidenhead, 1971
[5] Wang H., Rong Y., Li H., Shaun P., Computer aided fixture design: Recent research and trends, Elsevier, 2010
[6] Price, S., A study of case-based reasoning applied to welding computer aided fixture design [M.S. thesis], Worcester Polytechnic Institute, 2009
[7] Peng, G., Chen, G., Wu, C., Xin, H., and Jiang, Y., Applying RBR and CBR to develop a VR based integrated system for machining fixture design, Expert Systems with Applications, vol. 38, no. 1, pp. 26–38, 2011
[8] Amaral, N., Rencis, J. & Rong, Y., Development of a finite element analysis tool for fixture design integrity verification and optimization, International Journal of Advanced Manufacturing Technology, 2005