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Development of an Innovative Assembly Fixture for Machining Synchronization of Multi Fuse Parts on Vertical Machining Center and Productivity Enhancement

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Manufacturing fuse bodies for defence applications demand precision and efficiency, posing challenges due to the complexity of machining operations. This study proposes a novel fixture design to address these challenges on vertical machining center. The study highlights the practical utility of tailored fixture designs in defence manufacturing, offering a replicable framework for productivity enhancement. Two fixture types were modelled using SolidWorks, with the Type-B fixture selected for its superior production capabilities. The study focuses on a specialized Type-B fixture design for fuse body machining, supported by rigorous analysis and testing, distinguishes it and underscores its potential impact on defence manufacturing processes. ANSYS software, stress, strain, and deformation analysis guided the design and simulation process. The novel Type-B fixture reduced entire manufacturing time to 5.41 minutes per part, 33.76% quicker than conventional methods, resulting in a 34.02% increase in production rate (77 parts/shift). This research concludes critical efficiency concerns in defence manufacturing, offering a practical solution to improve productivity while maintaining quality standards. This research highlights the fixture's potential towards significant improvements in productivity and operational efficiency. The detailed comparison of performance of existing manufacturing process with the process using Type-B fixture is presented in this study.

Keywords: ANSYS, Fuse body, Novel Type-B fixture, Productivity improvement, Vertical machining center

Introduction

Manufacturing serves as the foundation for a wide range of industrial applications. Machining processes are responsible to fulfil the demand of manufacturing sectors. Fuse body is the most important part of explosive devices used in defence applications for the purpose of detonation.[1] For instance, Duric *et al*.[2] highlighted an explosive has the sensitive fiery element in which mechanical action or an electrical impulse causes the detonator to explode, fires the primer (However, machining of fuse body is difficult for manufacturing industries as it involves number of precise operations which require special machines. A machine vice or conventional fixture is generally used for holding a single fuse body on Vertical Machining Center (VMC). Although, more machining time is spent on manufacturing of single fuse body which further affect the rate of production. Furthermore, due to the high precision demands of the fuse body, meeting high production needs is challenging.

Precision can be increased by accurate locating, stable supporting, and proper clamping of the work-piece. Fixtures are used to locate, hold, and support a work-piece during machining, which reduces work-piece and tooling deflections brought on by clamping and cutting forces. The work-piece deformation that causes machining errors is reduced by a sound fixture layout.[3] The work-piece must always be completely constrained in order to achieve accuracy and quality during the machining operation. In terms of part precision and dimensional accuracy, the work-piece's location and fixture configuration are essential to product quality. Therefore, machining fixtures have required for improving the machine productivity, accuracy of product and reduces the worker effort by reducing the idle time.[4] It is observed that development of fixture for different work-pieces is a tedious and time-consuming process.[5] Researcher

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reported the various studies for establishment of fixture set up. The design, development and use of fixture in machining of various metals and some of its modelling techniques for improving the machining performance are discussed in the subsection.

Literature Survey

The development of hydraulic fixtures for VMC has significantly impacted machining operations, leading to improvements in productivity and product quality across various industries. Patil *et al*.[3] introduced a hydraulic fixture for VMC, emphasizing the importance of clamping force calculation to ensure optimal stability and reduced loading times. This approach, supported by mathematical and analytical methods, offers a practical solution for maintaining precise positioning against cutting forces, thereby improving operator efficiency. Similarly, Patel & Acharya[4] demonstrated the effectiveness of an 8-cylinder hydraulic fixture in enhancing dimensional accuracy and reducing wear in boring yoke machining, showcasing the practical benefits of controlled clamping forces. Vasundra *et al*.[5] utilized advanced techniques such as FEA, ANN, and RSM to design machining fixtures, enabling accurate prediction of work-piece deformation and computation time. Their findings underscore the superiority of ANN in producing optimal results compared to traditional FEA methods. Moreover, Maniar & Vakharia[6] innovatively employed computer-aided mass balancing methods in rotary fixture design, resulting in safer and more efficient machining processes. This approach not only ensures fixture stability but also yields significant cost savings in industrial applications. Viramgama & Makwana[7] devised a fixture geometry method for valve body machining, offering stability for complex components and enhancing machining accuracy on CNC machines. Lokhande & Tembhurkar[8] utilized computer-aided fixture design and ANSYS analysis to develop an angular drilling fixture, ensuring safe operation through analysis of cutting forces and attachment optimization on VMCs. Amaral *et al*.[9] integrated solid modelling, FEA, and ANSYS to enhance fixture design integrity, highlighting the importance of precise work-piece displacement analysis in machining operations. Liu & Stron[10] focused on minimizing clamping forces in machining fixtures, validating their configurations for nonlinear systems to ensure operational viability. Baraiya *et al*.[11] introduced an innovative fixture for simultaneous finishing of aluminium alloy work-piece surfaces, significantly improving surface roughness and machining efficiency. Wan & Zhang[12] addressed machining vibration issues through optimized fixture layout, significantly improving dynamic machinability and suppressing high-order vibration modes. Matejic *et al*.[13] developed a novel mounting frame modular fixture, enhancing accessibility, flexibility, and stiffness while improving reliability, accuracy, and productivity in machining processes. Dhulia & Maniar[14] introduced an automatic clamping fixture using hydraulic cylinders, reducing non-productive time, operator fatigue, and improving clamping quality. Swami & Kondhalkar[15] developed a suitable fixture for VMC for holding engine cylinder blocks, showcasing the practical benefits of computer-aided fixture design and FEA analysis in enhancing accuracy and stability. Jegan *et al*.[16] addressed machining vibration issues by modifying a hydraulic fixture for housing hydraulic lift, resulting in improved product quality and reduced vibration during machining processes. Attila *et al*.[17] presented a fixture planning and design system for gearbox housing machining, emphasizing the importance of accuracy and stability in achieving optimal machining efficiency. Overall, these discussions highlight the diverse approaches and innovations in fixture design and application, underscoring their crucial role in optimizing machining processes across various industrial sectors.

Modeling validates the relationship between input and output factors in metal removal processes as a means of fitting things together.[18–20] Modelling and upgrading fixtures can help to control the machining process's production time, as highlighted in the study by Deshpande *et al*.[21] From the literature, it is observed that the researchers have developed different types of fixtures for reducing non-productive time and increasing industrial productivity. Although, the development of desired fixture is the complex job, researchers recommended various modelling techniques such as FEM, ANSYS, CATIA V5, CAFD for system development.

According to literature and industrial survey, it is noticed that no fixture is available for holding multiple fuse bodies at a time during machining on VMC. Although existing literature covers various fixture designs and their impact on machining processes, there remains a significant gap in understanding the specific efficiency and productivity enhancements offered by innovative fixtures.

Therefore, in the present work an attempt has been made to design and develop multi-fuse bodies holding fixture for performing VMC operations. CATIA and ANSYS software are used for modelling and simulation purposes respectively. Based on the design and simulation results, multi-fuse bodies holding fixture is recommended. The novel fixture is manufactured and installed on VMC machine for productivity improvement. Moreover, this research addresses this gap by evaluating the Type-B fixture, which introduces novel design features and demonstrates measurable improvements in total cycle time and production rates. The study’s contribution is twofold: it provides empirical evidence of the Type-B fixture's effectiveness and offers insights into its potential applications, setting a benchmark for future advancements in fixture design.

Materials and Methods

Existing Machining of Fuse Body with Conventional Fixture

A fuse is a device that initiates an explosive function in a munition, most commonly causing it to detonate or release its contents, when its activation conditions are met. Machining of fuse body is difficult as it involves various operations such as facing, turning, drilling, boring, taping, grooving, interpolation, milling, finishing etc. The views of fuse body are presented in Fig. 1. Primary operations are carried out on CNC machine and semi-finished fuse body then transferred to VMC for performing secondary and product critical operations. A conventional type machine vice or fixture is generally used for holding a single semi-finished work part on VMC as shown in Fig. 2. The total time reserved for machining a single fuse body is about 8.20 minutes which include repetitive loading and unloading of part. Although, more time is spent on manufacturing of single fuse body which further affect the rate of production. Moreover, due to high precision requirements of fuse body, it is difficult to meet high demands of the production. Therefore, machining of multi-fuse bodies at a time is identified as the need of manufacturer.

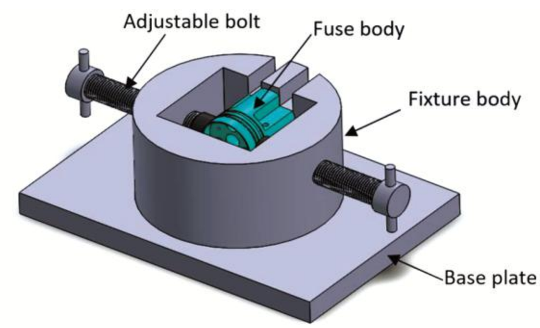


Fig. 2 — Conventional fixture holding a fuse part

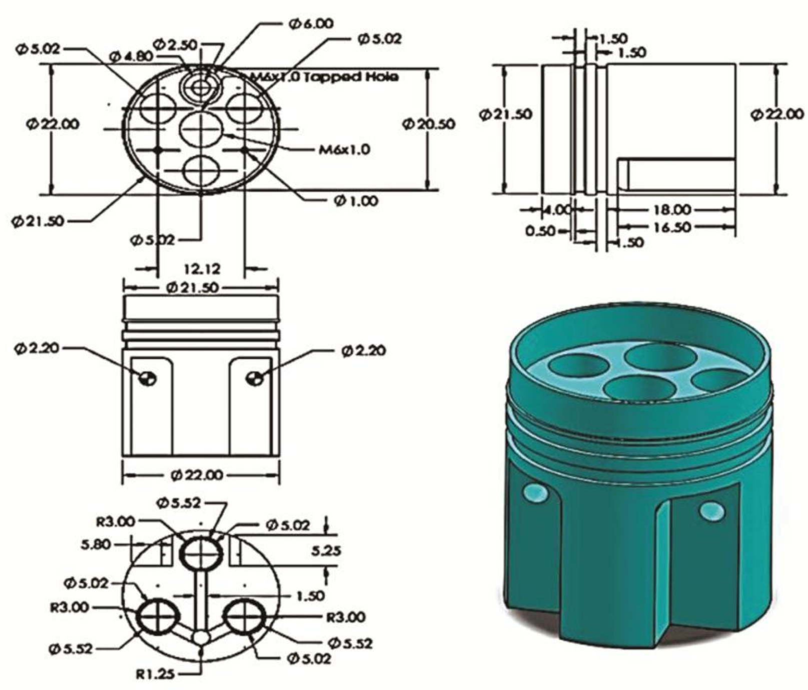
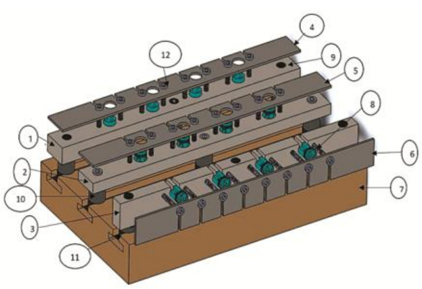


Fig. 1 — Details of fuse body

Proposed Fixtures for VMC Operations

The proposed type-A fixture facilitates with 3 stages, each of which mounted with 4 semi-finished work-parts (fuse bodies). The fixture model is created with SolidWorks software as shown in Fig. 3. Hence, execution of 12 multi-fuse bodies holding fixture is expected for VMC operations. The purpose of type-A fixture is to lower the machining time and improve production rate compared to single fuse body fixture. Based on the accessibility of bed space and manufacturers requirement, various fixture models are generated by Solid Works. It is also perceived that the more number of bodies can be locating using total bed length of 500 mm. Hence, after conducting the trials, the novel fixture (type-B) is projected for allocation of 24 work-parts in 3 stages (8 bodies per plate at a time) for VMC operation which would significantly increase the production rate. Therefore, existing set up is preferred to replace with type-B fixture. Generated view of Type-B fixture for holding multi-fuse bodies is shown in Fig. 4.

Permitting bed or pallet size of 500 × 300 × 75 mm, main parts are considered and arranged for making a novel Type-B fixture. Assembly with 2D and 3D views of multi fuse bodies holding fixture (Type-B) is presented in Fig. 5. Patent for Type-B fixture is filed on dated 31.05.2023 with application No.202321037535 and published on 11.08.2023. Design details of Type-B fixture is discussed in the subsequent section.



Part no	Part name	Qty
1	Lower plate-1	01
2	Lower plate-2	01
3	Lower plate-3	01
4	Upper plate-1	01
5	Upper plate-2	01
6	Upper plate-3	01
7	Pallet	01
8	Fuse body	12
9	Allen bolt for T-Nut	09
10	Dowel	09
11	T-Nut	09
12	Allen bolt	24

Fig. 3 — Type-A fixture for holding 12 fuse bodies

System Design of Type-B Fixture

Design and development of multi-bodies holding fixture is a specialized task which requires careful planning, engineering expertise, and consideration of the specific application and requirements. Additionally, safety considerations are paramount in any fixture design to protect operators and prevent damage to the components being held. Therefore, component design of Type-B fixture for holding fuse bodies is assessed here.

Details of Fuse Body: Material section is pure aluminium; Diameter = 22 mm and height = 27 mm. The cutting force is required to cut the raw aluminium bar for making the fuse body. Subsequently, fuse body is machined with VMC operations. Therefore, highest cutting force is considered 140 N for designing the fixture and crushing stress value of aluminium is 112 N/mm^2.[22] Kalaikathir A, *Design data: data book of engineers* Based on the machining requirement of fuse part following components are considered for the designing of fixture.

Design of Lower Plate Fixture: Load subjected on lower plate during operations is considered on the basis of load carrying on bolt (which is used to fit the lower plate with foundation bed) and it is given by

$$F = F_i + C\,F_e \qquad \ldots (1)$$

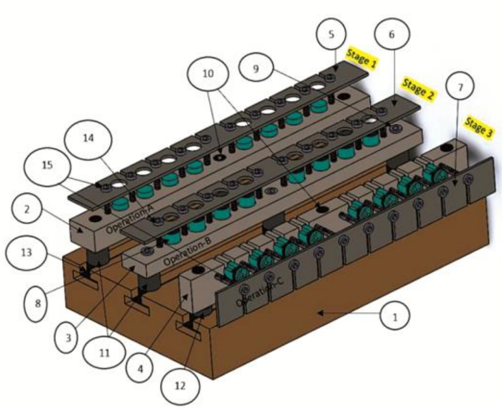
'where,' F - Total force (N)

F_i - Initial force (N)

F_e - External force (N)

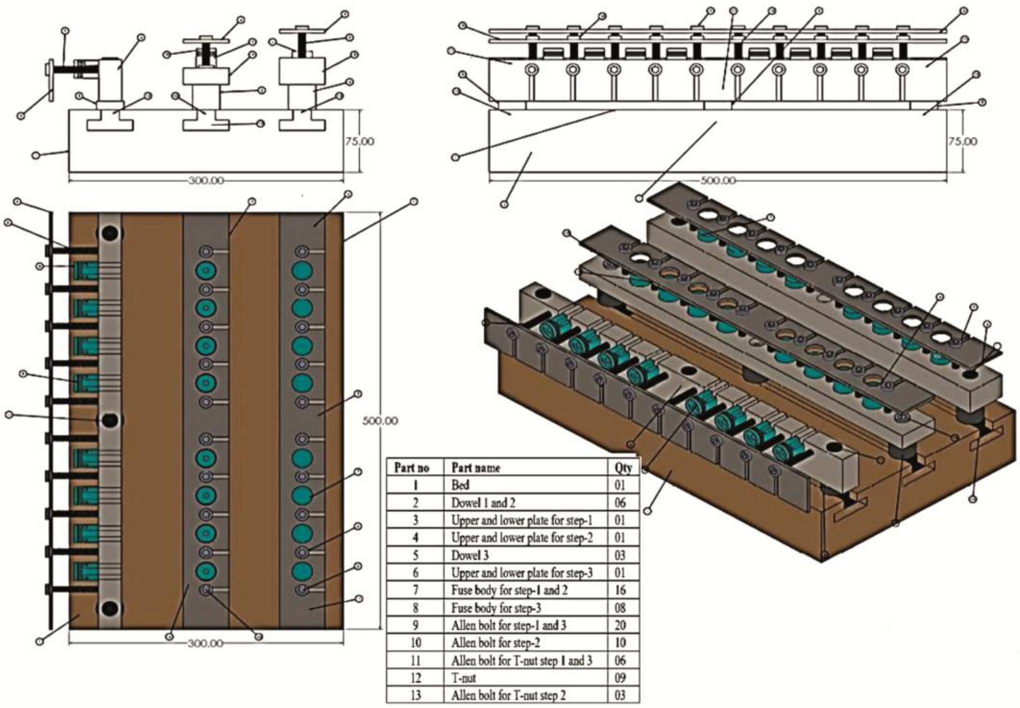
C- Constant, Value of C = 0, as joint is without gasket

Therefore, $F = F_i \qquad \ldots (2)$



Part no	Part name	Qty
1	Pallet	01
2	Lower plate (1)	01
3	Lower plate (2)	01
4	Lower plate (3)	01
5	Upper plate (1)	01
6	Upper plate (2)	01
7	Upper plate (3)	01
8	Fuse bodies	24
9	Allen bolts for lower plate step 2	03
10	Allen bolts for lower plate step 1 and 3	06
11	Dowel for step 1 and 2	06
12	Dowel for step 3	03
13	T-Nuts	09
14	Allen bolts for upper plate step 2	10
15	Allen bolts for upper plate step 1 and 2	20

Fig. 4 — Type-B fixtures for holding 24 fuse bodies



Part no	Part name	Qty
1	Bed	01
2	Dowel 1 and 2	06
3	Upper and lower plate for step-1	01
4	Upper and lower plate for step-2	01
5	Dowel 3	03
6	Upper and lower plate for step-3	01
7	Fuse body for step-1 and 2	16
8	Fuse body for step-3	08
9	Allen bolt for step-1 and 3	20
10	Allen bolt for step-2	10
11	Allen bolt for T-nut step 1 and 3	06
12	T-nut	09
13	Allen bolt for T-nut step 2	03

Fig. 5 — 2D and 3D views of Type-B fixture (Patent publication No.202321037535)

For normal tightening of bolt the value of force is

$$Fi = F = 1420 \times d \quad \ldots (3)$$

where, d is nominal or major diameter of bolt

F = 1420 × 10 = 14200 N

It means that force of 14200 N is being applied on lower plate of fixture. This force is applied during operation and general nature of load is compressive.

Material: SAE 1020 and compressive stress is considered as 400 Mpa.[22]

Considering factor of safety (FS) = 5. Allowable stress (б) = 400/5 = 80 Mpa

$$б = F / A \quad \ldots (4)$$

where, A = Area of plate

W = Width of plate

T = Thickness of plate

80 = 14200 / A

A = 177.5 mm^2

A = W × T (W = 30mm)

T = 5.91 mm

The outer diameter of fuse body is 22.5 mm to fit the fuse in lower plate should be more than diameter of fuse with extra allowances for handling the lower plate. Therefore, the width of lower plate is considered as 50 mm. Length of lower plate is decided on the basis of number of fuses to be fitted in one batch of operation. The length of lower plate is taken as 500 mm, as the size of bed is restricted to take the length of lower plate.

Height of lower plate is taken on the basis of height of fuse as fuse is to be fitted in lower plate with due consideration of extra height required for maintaining the strength. Therefore, height of lower plate is 30 mm.

Design of Locking Plate: Material: SAE 1020; Force acting on locking plate = 14200 N; Yield strength in tension σ_{yt} = 246 MPa and consideration of FS is 2.

Allowable stress (б) = 246 / 2 = 123 MPa

Using Eq. 4, (б) = F/A

123 = 14200/A

A = 115.44 mm^2

A = W × T

W = Width of plate

T = Thickness of plate

T = 3.84 mm

Design of Bolts for T-Nut: To hold the object in fixture, minimum two bolts are considered, using the fundamental equation [Eq. 3] for designing the bolt:

The general equation for designing of bolt is

$$F = \frac{\pi}{4} d^2 \times \sigma_t \quad \ldots (5)$$

Material: SAE1035; The allowable stress 367 MPa and FS = 2

Equating Eq. 3 and 5

$1420 \times d = \frac{\pi}{4} d^2 \times \sigma_t$

$1420 \times d = \frac{\pi}{4} d^2\ 183.5$

d = 9.85 = 10 mm

Design of Locking Bolt: Bolt is used for locking arrangement.

Fi = 1420 d

The general equation for designing of bolt is

$F = \frac{\pi}{4} d^2 \times \sigma_t$

Material: SAE 1035; allowable tensile stress = 367 MPa and FS = 2

Equating Eqs 3 & 5

$1420 \times d = \frac{\pi}{4} d^2 \times \sigma_t$

$1420 \times d = \frac{\pi}{4} d^2\ 183.5$

d = 9.85 = 10 mm

***Selection of T-Square Nut*:** Considering the specification of component as Base length = 50 mm; Base width = 25 mm; Base height = 12.5 mm; Nut area: 20 × 20 mm^2; Major diameter = 10.11 mm; Core diameter = 8.70 mm,[23] here, the dimension of base of T-bolt and connected threaded part is taken on the basis of major diameter of tapped hole.

***Design of Distance Piece*:** The width of lower plate is 50mm, to maintain the gap between bed and lower plate, the distance piece is used. Considering the width of lower plate, 30mm outer diameter of distance piece is used.

Material: SAE 1015; Yield strength in tension σ_{yt} = 246 MPa; FS = 4; Allowable stress (б) = 246 / 4 = 61.5 MPa.[23]

Using Eq. 4, б = F/A

61.5 = 14200/A

A = 230 mm^2

A = $\pi/4\ d^2$

d = 17.14 mm

Based on the design consideration, availability of space and requirement of manufacturer, component design of Type-B fixture is analysed for holding multi fuse bodies. The fixture parts details with specification is finalized and presented in Table 1.

Results and Discussion

Simulation software is used to simulate computer models of parts. ANSYS is one of the best mechanical FEA software is used to predict how a product would perform under certain conditions without creating test products. The most popular pre/post-processing program for FEA is called ANSYS, and it provides solid modelling, meshing, setup for analyses, and post-processing. It is observed that ANSYS is an appropriate program for doing analysis based on the features of different software. Therefore, ANSYS simulation-based software is proposed to perform stress analysis on the type-B fixture. The IGES file must first be loaded into ANSYS workbench in order to do the analysis of the type-B fixture. Since all of the forces acting on the type-B fixture remain constant with time, the static analysis module has been used as shown in Fig. 6. The engineering data must then be entered into the ANSYS program in order to provide material properties with default settings. Here, AISI-SAE standard: Structural steel is used for manufacturing of the Type-B fixture. The

Table 1— Type-B fixture parts details

Part no	Part name	Material	Dimension (mm)	Qty
1	Pallet or bed	CI	500 × 300 × 75	01
2	Lower plate (1)	MS	500 × 50 × 32	01
3	Lower plate (2)	MS	500 × 50 × 25	01
4	Lower plate (3)	MS	500 × 50 × 25	01
5	Upper plate (1)	MS	500 × 50 × 04	01
6	Upper plate (2)	MS	500 × 50 × 04	01
7	Upper plate (3)	MS	500 × 50 × 04	01
8	Fuse bodies	MS	22 × 27	24
9	Allen bolts for lower plate step-2	MS	10 × 44	03
10	Allen bolts for lower plate step-1 and 3	MS	10 × 70	06
11	Dowel for step 1 and 2	MS	30 × 30	06
12	Dowel for step 3	MS	30 × 10	03
13	T-Nuts	MS	20 × 25	09
14	Allen bolts for upper plate step-2	MS	8 × 46	10
15	Allen bolts for upper plate step-1 and 2	MS	8 × 70	20

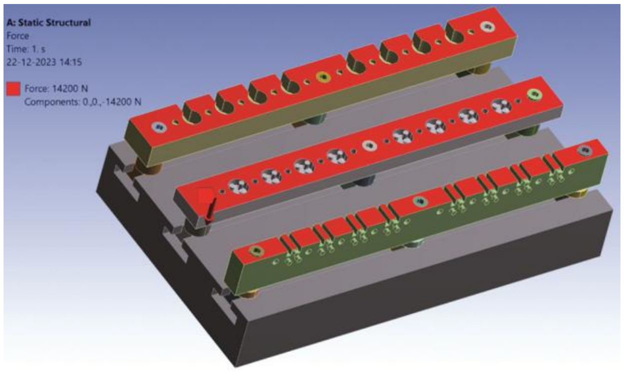


Fig. 6 — Static analysis module of fixture

material properties are fed into the software to determine the appropriate material strength. Poisson's ratio is equal to 0.3 and Young's modulus is 210 GPa. These specifics are provided to the system using engineering data window. After setting the geometry and meshing, the different boundary conditions are applied. During simulation, a three-dimensional tetrahedral mesh was used due to the complex geometry of the model. The mesh was refined in regions with high stress gradients, resulting in a fine mesh with an average element size of 0.5 mm in these areas. A mesh convergence study was performed to ensure that further refinement did not significantly change the results, thus validating the mesh density used. The model was fixed at the base to simulate a clamped condition. A uniform pressure of 2000 N was applied on the top surface of the model. Thermal boundary conditions included a fixed temperature of 100°C applied to the external surfaces, with convective heat transfer assumed for the ambient environment.

In the present study stress, strain, deformation and strain energy analysis were performed using ANSYS software. The simulation analysis is executed for a design load of 14200 N. The solver finds displacement and elastic stresses at each of the nodes and approximates the values to find stress and displacement at each point in the body. The developed images using same loads with stress, strain, deformation and strain energy values are presented from Fig. 7 (a–d).

The distribution of stress over the full assembly of fixture with upper and lower plates is shown in Fig. 7a, with colours closest to red denoting higher stress and colours closest to blue denoting lower stress. The image makes it evident that the lower plate, on which the fuse body is resting, is under minimum stress, indicated by light green colour. The maximum stress at a load of 14200 N is 44.111 MPa. It is attributed that the safe design is demonstrated.

The strain distribution on a fixture body with upper and lower plates is shown in Fig. 7b. The colours closest to red indicate higher strain, while the colours closest to blue indicate lower strain. The image clearly shows that the lower plate, on which the fuse body rests, is under the least amount of strain, as indicated by the pale green colour. At a load of 14200 N, the maximum stress is 2.7635 e^{-4}, hence safe design is credited with being suggested.

The impact of load on deformation is shown in Fig. 7c. The minimum deformation is observed on the fixture body. However, the maximum deformation is observed at the center of middle lower plate. Maximum deformation may cause slight inward bend of plate where the fuse body is fitted. Therefore, high factor of safety is considered during analytical design. Deformation value at higher stage is observed as 0.0159 mm which claimed that the safe design has been demonstrated.

The impact of load on strain energy is shown in Fig. 7d. Strain energy is the energy that a body has stored as a result of deformation. It is also known as resilience. The area under the stress-strain curve towards the point of deformation is referred to as the strain energy. The minimum strain energy is observed on the fixture body. However, the maximum strain energy is observed at the center of middle lower plate. Similar results are observed in case of deformation (Fig. 7c). It means that, strain energy is retained in a structural member as a result of elastic deformation. Hence, deformation takes place after exceeding strain energy of body. At a higher phase, the observed strain energy value is 0.1098 MJ, indicating that the safe design has been confirmed.

Effect of Design Parameters on Fixture Performance

The performance of a fixture is significantly influenced by several design parameters, including stress, strain, deformation, and strain energy. The analysis of these factors is crucial for optimizing fixture design and ensuring its efficiency and durability in manufacturing processes. The following paragraphs elaborate on these influences based on the data presented in Fig. 7(a–d).

The distribution of stress throughout the fixture is shown in Fig. 7(a). It is clear that there are high stress concentrations near the fixture's mounting points, which are essential for load bearing. This shows possible weak points that might need to be reinforced

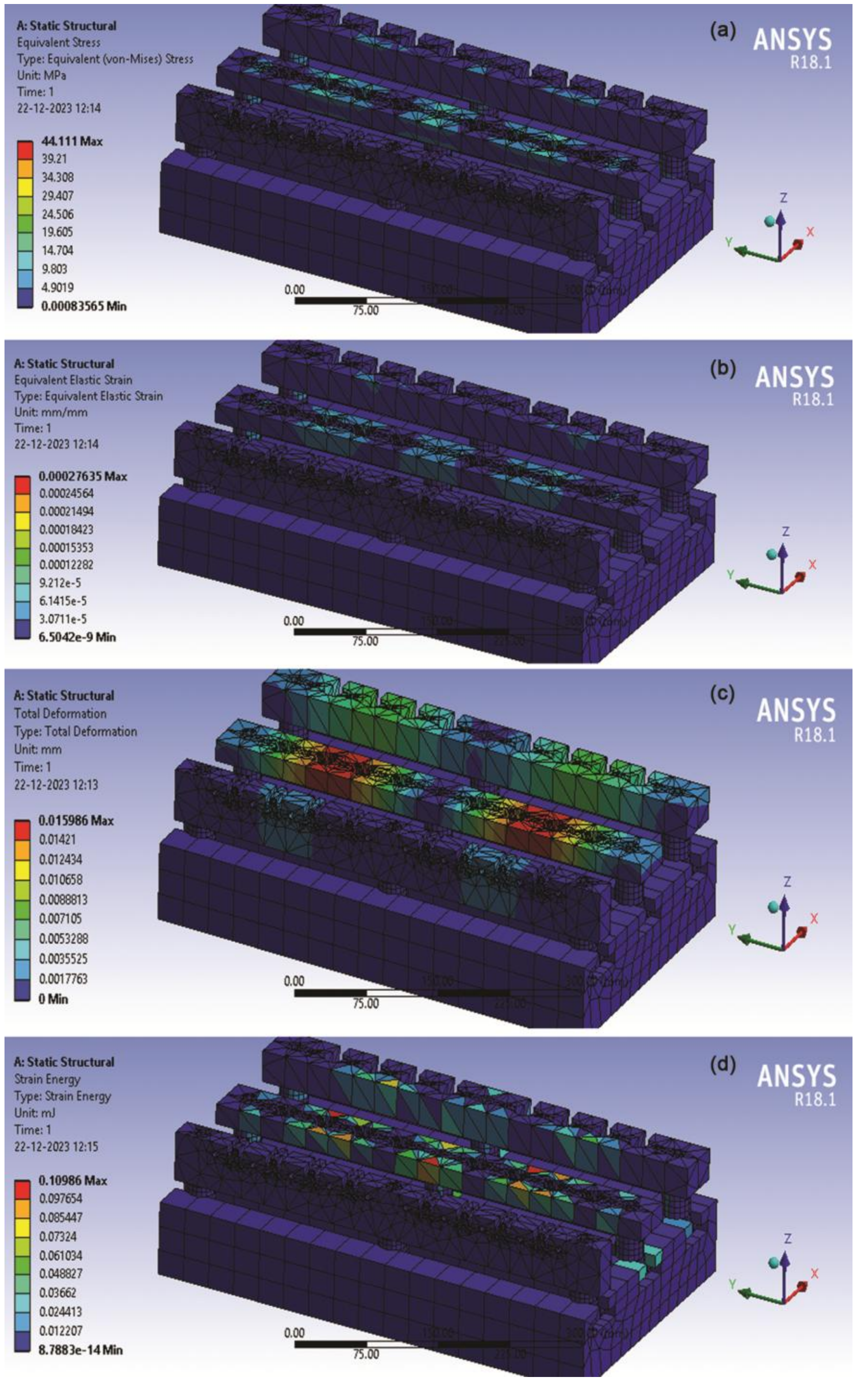


Fig. 7 — Mechanical properties of fixture: (a) stress analysis, (b) strain analysis, (c) total deformation, and (d) total strain energy

or redesigned in order to guarantee that stresses are distributed uniformly. The maximum stress recorded is getting close to the material's yield strength, indicating that the fixture is operating close to its limit and that it would be advantageous to use stronger materials or a different design strategy to reduce these high-stress concentrations.

Results of strain and deformation are shown in Fig. 7 (b–c). A large amount of deformation is seen in the fixture's center, which may affect how precisely it performs its intended function. The strain values show where there is excessive stretching, which could cause permanent deformation or inaccurate alignment of the fixture. This might require using materials with better dimensional stability of the structure to minimize deformation. The distribution of strain energy indicates that these same high-stress areas contain the majority of the strain energy shown in Fig. 7(d). Over time, this focus might become difficult, particularly if the fixture experiences cyclic loading. As a result, utilizing materials with greater fatigue resistance or strengthening these areas could improve the fixture's performance and longevity.

Thus, it is concluded that safe fixture design is created. However, bending of the lower plate is observed on the part where the work part is fitted but the values of observed deformation are very less so a compelling argument is presented by the design of the type-B fixture which is also confirmed by the safety factor.

Manufacture of Novel Type-B Fixture

In present work, cast iron pallet of size 500 × 300 × 75 mm is placed on VMC. The details of all parts required for making a fixture is tabulated in Table 1 and shown in Fig. 5. The manufacturing of the novel Type-B fixture is carried out in a systematic sequence to ensure precision and efficiency. The following steps are involved in the process as follows:

Step 1: Bandsaw cutting for the development of the lower plate base: The purpose is to obtain the basic shape and dimensions of the lower plate base.

Step 2: Drilling on lower plate base to create holes for fastening and alignment features.

Step 3: End milling for finishing of drilled holes. This operation achieves the desired finish and tolerances on the drilled holes. An end mill is used to enlarge or refine the holes, ensuring they meet the specified tolerances.

Step 4: Slotting is performed to create slots for component alignment and mounting. The fixture is placed on a slotting machine where specific areas are milled to create elongated slots. The complete details for manufacturing of novel fixture are discussed in the subsequent paragraph.

Initially, 8 raw parts are selected for performing basic CNC operations on Lower plate (1) of size 500 × 50 × 32 mm and lower plates (2 and 3) of size 500 × 50 × 25 is produced on bandsaw cutting machine, 8 holes of diameter 22.5 mm are drilled on all lower plates (1–3) for holding of 8 fuse bodies, and 10 holes of 8 mm diameters are drilled on all three plates. Three upper plates of size 500 × 50 × 04 mm are shaped on bandsaw cutting machine, 8 holes of diameter 22 mm are drilled on all upper plates (1–2) for supporting previously placed 8 fuse bodies positioned on lower plates (1–2), 10 holes of 8 mm diameters and 10 slots of size 30 × 6 mm is drilled and slotted respectively on all three upper plates. Upper plates (1–3) are fitted with lower plates (1–3) using 10 anker bolts (size M8). Lower plates (1–3) are fitted with bed using 3 T-bolts of size -M10. Additionally, 16 slots of size 25 × 7 mm are machined on lower plates (3) for easy milling of 8 work parts which are fitted horizontally.

Fixture testing is a systematic process that verifies the fixture work as intended and satisfies manufacturer specifications. Therefore, the necessary clamping, adjustments, calibrations and alignment with good dimensional accuracy are equipped for successful fixture. Once the type-B fixture is fully manufactured and tested, it is delivered to the intended location as shown in Fig. 8.

Installation, Testing and Synchronization of VMC Operations with Type-B Fixture

The manufactured novel Type-B fixture is recommended to install on VMC for machining of 24 work-parts at a time using 3 stages. The issues like alignment, stability and post installation testing of fixture were taken care as discussed.

Alignment Problems: It was challenging to precisely align the Type-B fixture on the VMC during installation. Therefore, proper positioning, alignment jigs and adjustment tools were used and carried out several alignment checks and adjustments to reach the necessary precision.

***Stability of Fixture Mounting*:** After being mounted on the VMC, the fixture developed stability problems

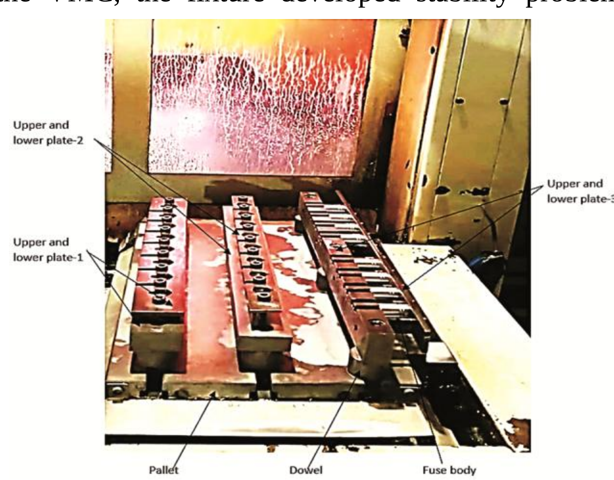


Fig. 8 — Manufactured Type-B fixture holding 24 fuse bodies

that reduced the accuracy of machining operations. Hence, fixture stabilization was achieved by adding locking plate mechanisms on lower plate. Reassessed the mounting procedure to make sure it complied with stability specifications.

Post-Installation Testing: Extensive testing was carried out after installation to make sure all problems were fixed and the fixture and VMC functioned as intended. Based on test results, final adjustments were made to maximize performance and guarantee dependable operation.

Tested assembly of Type-B fixture is installed on VMC as shown in Fig. 9 (a). The fixture is built in 3 stages accomplish with 3 upper and 3 lower plates. Each step of fixture is holding 8 fuse work-parts. The VMC-BMV35 operations (A, B and C) are lined up to finish the fuse body work part in accordance with their order.

Operation A (Stage 1): Drilling, end milling, threading, reamer;

Operation B (Stage 2): Drilling, threading, end milling;

Operation C (Stage 3): End milling, drilling, and chamfer.

Initially, 8 raw parts are selected for performing basic CNC operations at that time VMC is inoperative and therefore no part is loaded on fixture as displayed in Fig. 9 (a). Later on, these semi-finished parts are transferred to VMC for completion of operations (A) to (C). Initially, only 8 semi-finished parts are placed on stage 1 of lower plate and forwarded for operation (A) on VMC as shown in Fig. 9 (b). Here, drilling, end milling, threading and reamer operations are performed on parts located on stage 1. These machining of parts is referred as operation (A). After completing operation (A), fixture comes out from VMC, machined 8 parts are then transferred to stage 2 for operation B and stage 1 is occupied with new 8 parts for operation (A) as presented in Fig. 9c. Later on, machined 8 (A) and 8 (B) parts are then transferred to stage 2 and 3 respectively for performing succeeding operations (B) and (C) besides stage 1 is positioned with next 8 parts for operation (A) Fig. 9 (d). Finally, first finished set of 8 work-parts by completion of operation (C) come out from VMC and previous sets of work-parts are then transferred to occupy succeeding stages. All operations (A, B and C) on 24 fuse bodies are completed with proper synchronization of machine tool (VMC-BMV35). It is noticed that the mass production of parts is achieved.

Machining of work parts using arrangement of novel B-Type fixture is shown in Fig. 10. A finished work part is machined in 5.41 minutes including loading and unloading time using Type-B fixture by saving time of 2.79 minutes compared to conventional fixture. Hence, the synchronization of VMC operations with work part using novel fixture is beneficial for boosting manufacturer's productivity.

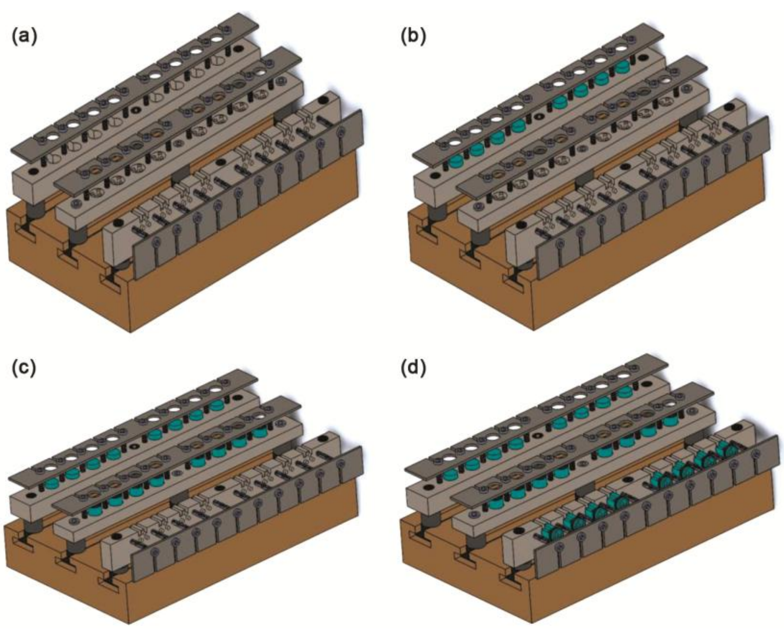


Fig. 9 — Equipped Type-B fixture for VMC operations: (a) Fixture without fuse bodies (b) Fixture with 8 work parts (c) Fixture with 16 work parts, and (d) Fixture with 24 work parts

Table 2 — Comparison of conventional with novel Type-B fixture

S.N.	Parameters	Conventional fixture	Novel fixture	% improvement
1	Work part	Single part	Multi parts synchronisation	—
2	Loading-unloading time/piece	4.62 min	110 sec / 8 fuse parts	—
3	Machining time /piece	3.58 min	3.58 min	—
4	Production/ shift	51 pieces	77pieces	33.76
5	Total cycle time/piece	8.20 min	5.41 min	34.02

Fig. 10 — Machining of work parts using B-Type fixture

Comparison of Results

Earlier fuse part was machined using single part holding conventional type fixture on VMC which require 4.62 minutes of time for loading-unloading. The total time reserved for machining a single fuse body was around 8.20 minutes. According to manufacturer, it requires more machining time with high production cost. In view of production demand, Type-B fixture is mounted on VMC which machined a finished work part in 5.41 minutes, saving 34.02 % in total cycle time over a conventional fixture. It is observed from Table 2, 77 parts are produced per shift which results in 33.76 % enhancement in production rate. Therefore, it is advantageous to increase manufacturer productivity using innovative fixture.

Potential Areas for Further Improvement

The research was conducted using a sample size of 10 runs per fixture. The higher number of runs per fixture will help in capturing all possible variations in performance. Furthermore, the testing setup was restricted to a single material type and machining technique, which has limited the results' generalizability. To overcome these constraints, more extensive trials with a range of operating environments and a better sample size are needed to confirm the findings in the future. Additional refinement of the Type-B fixture design may improve its versatility for various uses. Furthermore, utilizing sophisticated measurement methods and carrying out a comprehensive cost analysis would yield a more thorough assessment of the benefits of the fixture.

Conclusions

The implementation of the novel type-B fixture has significantly advanced the manufacturing process for single fuse bodies. This innovative fixture reduces processing time by 34.02%, allowing a work part to be completed in just 5.41 minutes and increasing the production rate by 33.76%, enabling 77 parts to be produced in a shift. This improvement underscores its role in enhancing manufacturing efficiency by simplifying and accelerating production with minimal effort. While the benefits are clear, including increased productivity and streamlined processes, potential limitations such as scalability across different manufacturing contexts and the need for continuous optimization should be considered. Future research could focus on expanding the fixture's applications and refining its design for broader industry use, marking a crucial step toward more efficient manufacturing practices.

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