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Design and Fabrication of Multi-functional Fixture with Experimental Case Studies

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Abstract

A general practice in manufacturing industry, especially in machine shops, is to design and develop a dedicated jig or fixture for a single operation. The scope of dedicated fixturing has become challenging due to the need of improvisation of adjustability as well as to incorporate a range of production operations. Usually, few machining operations are performed on conventional fixtures i.e. vices for the rectangular work parts, and additional attachments are used to incorporate cylindrical work which increase the workholding time, the cost as well as the limitation of variability of dimensions. Furthermore, if the size of the work is small (slender or thin sheets) then it imposes the difficulty in fixturing. To perform several manufacturing operations (machining, joining, and welding etc.) on prismatic as well as cylindrical parts, each operation needs to have a dedicated fixture which may not be useable for a new part or the part with varying dimensions. These fixturing issues are addressed through the use of modular kits or custom CNC machined. There are many simple applications, especially in case of light duty manufacturing operations like riveting, adhesive bonding, and inspection of machined features etc. In simple applications the use of modular kits and specialized fixtures are not the preferred choice with respect to economic reasons. Therefore, a multi-purpose fixture has been designed and presented in this study. The fixture design is verified through the fabrication of its parts and their assembly. The applicability and repeatability of the multi-functional fixture is validated through different experimental case studies including the inspection of hole quality, examination of microstructure through mini-microscope, drilling, and milling operations.

Keywords
Multi-functional fixture, drilling, welding, milling, quality inspection, degree of freedom

1. Introductions

Modern industry is progressing towards automation to achieve high level of productivity. Jigs and fixtures have been important elements in manufacturing owing to have large list of needs and benefits. A well-designed jig and/or fixture augment the manufacturing processes in several aspects such as increase in production, process cost reduction, interchangeability, reduction in inspection (as quality control is expensive), declining the rate of accidents (as safety measures are improvised), easy machining of complex parts, and automation of machine tool etc. In addition to other cost components the overall manufacturing cost also includes the cost of designing and development of fixtures. Inspection and quality control related expenses adds up further in the cost calculations.

Fixtures are one of the integral parts in almost every type of conventional machining processes and some other manufacturing processes. The main purpose in machining is to securely hold and clamp the job and withstand the mechanical forces and vibrations produced during the machining operations. The researchers (Rashid and Mihai Nicolescu, 2006) developed fixture to control the vibrations caused under heavy mechanical forces of milling. Facilitation and reduction in time for loading and unloading the work parts is also required to be incorporated while

fixture designing. Provision of an appropriate support to the work piece is another element of consideration in fixtures. Increase in productivity, repeatability in operation, accurate position, interchangeability (Chikwendu Okpala, 2015), low variability in geometrical errors, and reducing the need of highly skilled labor are the salient rationales of designing and developing fixtures (Said et al., 2023). It is a common practice in machine shops to design and develop custom-made fixtures to do s specific job such as specific fixtures for welding, drilling, and milling (Wang et al., 2010). For instance, a dedicated fixture is designed for the welding of thin sheets (Ahmed and Saha, 2018) and a different fixtures is designed to have butt welding of thick steel plates (Lu et al., 2023).
Fixture requirements for friction stir welding has been researched by several researchers. For instance in a study (Kamble et al., 2017) the researchers designed and fabricated a welding fixture to accommodate substrates of different sizes and thicknesses. Friction stir welding requires specialized fixtures to hold and clamp two work parts to be welded. Depending on the workpiece geometry, the fixture design has to be changed and a new fixture is required to accommodate a new geometrical workpieces. Each specification of the friction stir welding requires a dedicated design (Vijaya Ramnath et al., 2018). Drill jig for a brake lining components is designed by the research shown in (Rajesh et al., 2021). A case based reasoning method for the fabrication of welding fixture is also presented in (Wang and Rong, 2008).

The universal modular jigs and fixtures design system (UMJFS) is an efficient approach to design modular fixtures having the capability to accommodate variety of work parts types and operations (Kakish et al., 2000). Computer aided platforms are used to design such modular fixtures that requires the use of intelligent algorithms in order to address the decision making and design functions required especially in manufacturing and machining processes of complicate parts (Parvaz and Nategh, 2018). An example use of flexible fixture has been presented in (Li et al., 2016) to support a thin wall frame type large structure. However. such modular fixtures are relatively expensive and for simple to do operations the selection of such an expensive fixtures is not justifiable. Many of the manufacturing operations doesn’t undergo mechanical forces such as welding and adhesive bonding. So the consideration of heavy mechanical forces in the design of fixturing is not always mandatory. For example, in another research (Jha and B, 2018) it is explained that the welding fixtures are under static load and there is no need of consideration for mechanical forces.

2. Need analysis

Flexibility is required in production tooling design due to cost effectiveness. A general practice in manufacturing industry, especially in machine shops, is to design and develop a dedicated jig or fixture for a single operation. The scope of dedicated fixturing has become challenging due to the need of improvisation of adjustability as well as to incorporate a range of production operations. Few machining operations are performed on conventional fixtures i.e. vices for the rectangular work and the attachments are used to incorporate cylindrical work which increase the cost as well as the risk of variability of dimensions. Furthermore, if the size of the work is small (slender or thin sheets) then it imposes the difficulty in fixturing. To perform several manufacturing operations (machining, joining, and welding etc.) on prismatic as well as cylindrical parts, each operation needs to have a dedicated fixture which may not be useable for a new part or the part with varying dimensions. In this way the work holding devices may not be rated as viable. Especially if there is an absence of heavy mechanical forces in manufacturing processes then the fixture is not mandatory to have high strength. Some simple machining operations performed on relatively ductile materials the mechanical forces are not that much high compared with machining of complicated features in hard-to-cut materials. This imposes a need of design and development of a certain multi-purpose fixture that incorporate a number of operations with the shape adjustability of workpiece especially in case of basic level machining operations on soft materials and/or other manufacturing processes where there are no mechanical forces such as welding, bonding, and basic level quality inspections etc. However, it is not be taken as an easy job to have a fixture with such a capability to be used in several manufacturing operations. Modular fixtures, as another alternate, are being used to overcome this difficulty but the modular fixtures are somewhat expensive.

3. Design and Fabrication

3.1 Basic Manufacturing Processes

While designing a fixture, the designer must have a familiarization with the fundamental concepts of manufacturing processes especially machining and joining processes. Essential knowledge is therefore shortly presented before taking a direct to designing details. In material removal manufacturing processes a diversity of part geometries can be fabricated. An appropriate work holding device is essential to resist the applied/generated mechanical forces or to provide nominal clamping and identical positioning for a number of parts. Every material subtractive and/or addition process i.e. milling, drilling, conventional welding, friction stir welding, adhesive bonding and inspection have different workholding requirements to be incorporated in design of workholding device. While designing the fixture, following criteria requirements are addressed:

- Work dimensions/ complexity (Design Specifications)
- Orientation of work within fixture
- Locating and Clamping Surfaces
- Usability and Safety

3.1.1 Milling Operation

In this machining operation, the work is fed past a rotating cylindrical tool with multiple cutting edges. Milling operation is of two types: peripheral or plain milling and face milling. Since both of the types are depended on the orientation of the cutting via tool. Figure 1 shows the two types of commonly used parts (cylindrical and rectangular) used in milling operations. To machine such parts appropriate locating is required at different surfaces such as locating at the face surfaces A and B (along XZ axis) and locating at the peripheral milling on surface B and D (along YZ axis) respectively. All degrees of freedom should be restricted with enough clamping force and locating provision form all sides except on one side used for part loading and unloading.

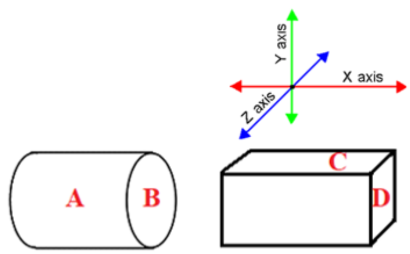


Figure 1. Commonly used parts in milling operation

While designing fixture, the design must permit as many surfaces as possible to be machined. Tool should be changed to suit the part when needed. Moving the part to accommodate one cutter for several operations may not be accurate and efficient as compared to changing the tools. Locator must be designed to resist the forces and thrust, only clamping forces should not be used. Sufficient space must be available to load and unload the part. The fixture must prevent the twisting and spring while operation and proper space must be available for chip removal as well as coolant.

3.1.2 Drilling Operation

It is a machining operation that is used to produce holes. The fixturing requirements for drill operation are that it shall correctly locate the work with respect to the tool. It must securely clamp and rigidly secure the work during operation. There must be arrangement to clamp the fixture with worktable to minimize the vibrations during operation. The work is required to be restricted from all degrees of freedom except on one side used for part loading and unloading.

3.1.3 Welding Operation

It is a joining process, usually metals or thermoplastics are melted and then allowing them to cool causing fusion. The process requires fixturing to hold the part in correct and convenient position to weld. Another requirement is to reduce distortion and provide alignment between both work parts. There must be proper distance to provide space to filler material. The most important requirement imposed on fixturing is to provide ease and maximum accessibility to point of weld. For electrical welding, electrical conductivity is critical for arc stability which requires a good conductive material of all parts of the fixture used to hold work parts.

3.1.4 Friction Stir Welding

It is a solid-state welding process in which material is welded without melting. It is very much similar to the face milling and performed on vertical milling machine. In this process, two rectangular sheets are joined together, and work is fed past a rotating tool that generates enough heat energy to join the surfaces. For friction stir welding, an extra important requirement along with the milling operation requirements is to avoid deflection and minimize the bending action. Therefore, this factor must be considered while designing the fixture.

3.1.5 Bonding Operation

It is used to fasten two surfaces together by producing a smooth bond through glues, epoxies and other polymeric agents. The process requires proper alignment of the surfaces for correct application of bonding. As there are no mechanical forces are required, so no hard clamping is required. While designing the fixture suitable for bonding operation, there is no restriction on the material of the fixture parts and their mechanical strength. However, the fixture should have the ability to accommodate varying sizes of the work parts to be joined together.

3.1.6 Inspection Operation

Controlling the process to manufacture accurate parts and assemblies, inspection fixture plays an important role during quality check. The process may require proper alignment or not. For many inspection purposes, the clamping of the parts is required which may vary into height with respect to other part clamped. The use of mini-microscope is progressively gaining the popularity to inspect and perform feature size measurements. The use of multi-functional fixture can also be practiced in different inspections especially the inspections through mini-microscopes.

3.2 Computer Aided Design and Fabrication

The requirements of different manufacturing operations, as listed above, were considered in the designing of the multi-functional fixture design developed in this study. The fixture consists of numerous parts and for the designing of each part of the fixture, following major points of considerations were emphasized: geometry of each part, size of the workpiece to accommodate, degree of freedom, and ease of clamping and unclamping. SOLIDWORKS 2018 computer aided design software was used for designing the fixture and its parts.

3.2.1 Individual Parts and Sub-assemblies

The fixture designs consists of several individual parts, sub-assemblies of individual parts, and the overall assembly of the fixture. Table 1 shows the names of each individual parts, their symbols, and quantity of each individual parts and each sub-assembly. Further design details pertaining to each part are discussed one by one.

Table 1. Part names, symbols, and the quantity of each individual part and sub-assembly

Part Name	Symbol	Quantity
V-Type Locator	VL	4
Side Pillar	SP	4
Screw Locating Pin	SLP	2
Sliding Slots Plate for locators assembly	SSP	2
Locator Sliding Rod	LSR	2
Locator Sliding Base	LSB	2
Locator Assembly Sliding Rod	LASR	4
Washers	-	4
Nuts	-	10
Base Plate	BP	1
Assembly	**Symbol**	**Quantity**
V-locator Sliding Assembly	LSA (VL + SLP + LSR + LSB)	2
Side Pillar Sliding Assembly	SPSA (VL + LSB + LASR)	2
Collective Fixture Assembly	CFA (LSAs +SPSAs+BP)	1

3.2.2 Design of V-Locators (VL)

V-locators are designed to locate and accommodate the cylindrical as well as rectangular parts. The base of the fixture is designed to have more thickness as compared to the other elements due to stability as well as the weight bearing application. V-type locator (VL) is designed to locate the cylindrical and rectangular workpiece. There are two v-type locators used in the design, i.e. moveable V-type locator and fixed V-type locator. Moveable v-type locator (VL) will help to locate the workpiece with respect to other and screw clamp is designed for holding purposes. The fixed locator will support, and the moveable locator will adjust the size and position of the workpiece according to the operation requirements. The hole at the bottom of the locator is to slide the locator on the rod to adjust the position accordingly. The base plate on which the workpiece is clamped within fixed and moveable locator. The CAD model and the actual machined and fabricated locators are shown in Figure 2. The measurement details of V-locator are mentioned in Table 2.

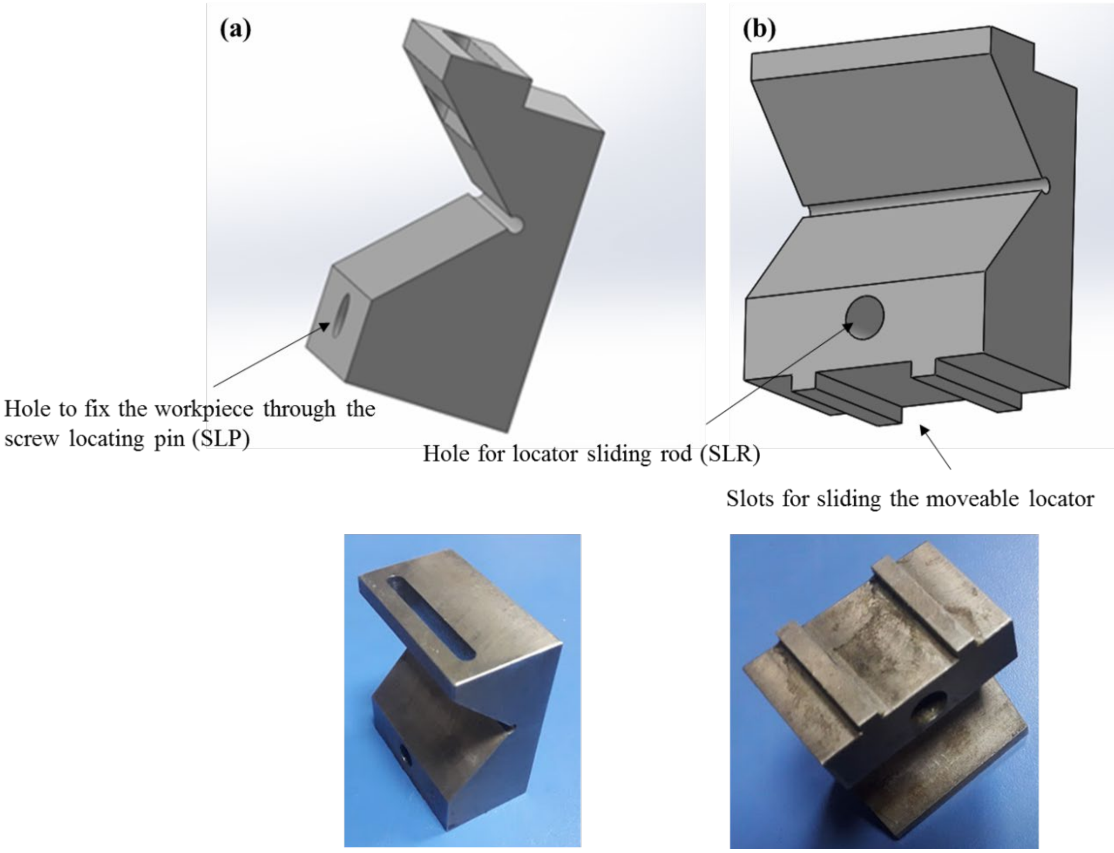


Figure 2. CAD of V-Type Locators (two orientations of the locator) and the actual fabricated locators.

Table 2. Design measurements of V-type locators

V-locator details		
Dimension Name	**Symbol**	**Measurement**
Width	W_{VL}	60mm
Height	H_{VL}	30mm
Length	L_{VL}	50mm
V-Height	VH_{VL}	15mm
Hole Diameter	HD_{VL}	8mm
Slot Width	SW_{VL}	5mm
Material	M_{VL}	Cast Iron

3.2.3 Design of Locator Sliding Base (LSB)

The fixed v-locator and the movable v-locator generates a sub-assembly. A base plate (named as Locator Sliding Base; LSB) was designed to complete this sub-assembly. The base for the locator assembly is designed to slide the assembly of moveable and fixed VL as shown in Figure 3. The LSB slides over the rod (termed as Locator Sliding Rod; LSR) passed from the bottom of the base to adjust the position of a part with respect to the other similar or dissimilar part. The whole clamped assembly of locators and workpiece slide on the base of fixture including the feature of adjustability of different alignment options. Locator sliding base is designed to slide the complete assemble on the assembly sliding rod to adjust it according to requirement. The detailed design measurements of LSB are shown in Table 3.

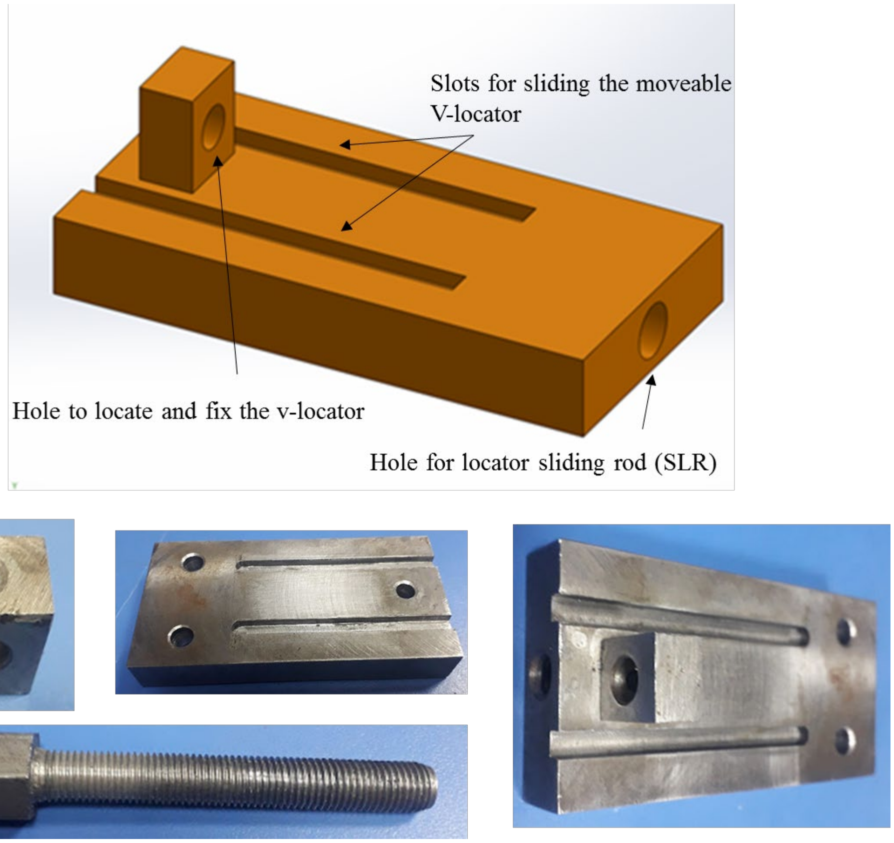


Figure 3. CAD of Locator Sliding Base (LSB) and the actual LSB along with its components.

Table 3. Design measurements of locator sliding base plate.

Locator Sliding Base (LSB) details		
Dimension Name	**Symbol**	**Measurement**
Width of Base Plate	W_{LSB}	50mm
Length of Base Plate	L_{LSB}	100mm
Thickness of Base Plate	T_{LSB}	15mm
Height of Rectangular Support	HR_{LSB}	18mm
Width of Rectangular Support	WR_{LSB}	15mm
Thickness of Rectangular Support	TR_{LSB}	10mm
Hole Diameter of Rectangular Support	DR_{LSB}	8mm
Hole Diameter of Base Plate	DB_{LSB}	10mm
Slotting Depth	SD_{LSB}	3mm
Material	M_{LSB}	Mild Steel

3.2.4 Design of V-Locators Assembly Sliding Rod (LASR)

A screw rod was required in order to locate and position the v-locator assembly. This rod moves along the horizontal direction to adjust the horizontal position of the v-locator assembly as well as it moves vertically through the slots of the sliding pillars (SPs) to adjust the height of the v-locator assembly. The CAD model and the actual fabricated rod are shown in Figure 4. Adjusting screw is designed to position the locators with respect to each other on locator-base and the design measurements of the part are shown in Table 4.

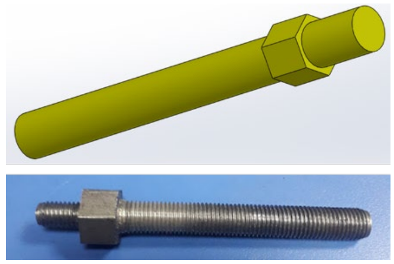


Figure 4.V-locators assembly sliding rod (the CAD model and the fabricated rod)

Table 4: Design details of locator assembly sliding rod (LASR)

Locator assembly sliding rod (LASR) details		
Dimension Name	**Symbol**	**Measurement**
Bolt Thickness	BT_{ASR}	10mm
Screw Length	SL_{ASR}	100mm
Threaded Length	TL_{ASR}	25mm
Major Sliding Rod Length	RL_{ASR}	75mm
Threads		M10 x 15
		M10 x 75
Material	M_{ASR}	Mild Steel

3.2.5 Design of V-locators Sliding Assemblies (LSAs)

Since there are two v-type locators, the one is fixed and the other is moveable. The fixed locator is equipped with locating screw added on the top of the fixed locater in order to locate the workpiece inside the locator. The screwed locating pins (SLP) on VLs help to adjust different diameter or width of workpiece and the rod on which the VL slides, help to clamp the workpiece. Both of these fixed and moveable locaters are assembled together on the locator sliding base (LSB) with the help of locator slider rod. This assembly is called V-locators sliding assembly as shown in Figure 5.

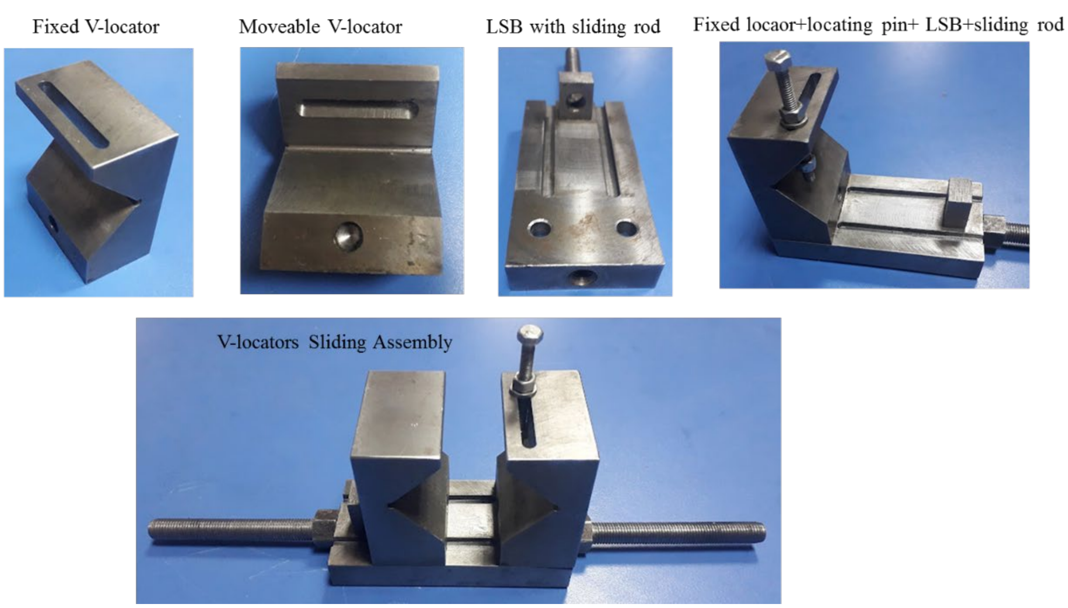


Figure 5. Individual parts and the v-locator sliding assembly (one assembly out of two identical assemblies)

3.2.6 Design of Side Pillars (SP)

Side pillars (SP) are designed to lift the complete assembly along z-axis to adjust the height with assistance of locking nuts or riser blocks. There are four pillars designed in total to be attached in the fixture. Figure 6 shows the CAD image of the SP and the manufactured SPs (quantity 4). The slot provided in the pillar allows the locator assembly sliding rod (LASR) to slide vertically so that the whole v-locators assembly can be fixed at a desired height. Since there are two sub-assemblies associated with v-locators therefore each of these two sub-assemblies can be positioned at the same height or at different heights depending on the nature of the job and nature of the operation to be performed. Different operations can be performed by adjusting the similar height or different height of the parts clamped in the locators. Side pillars are designed to support the whole assembly with enough strength at some intended height. The design details of SP are shown in Table 5.

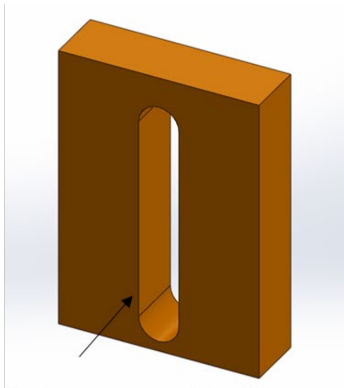


Figure 6: CAD of side pillars to accommodate and position the locator assembly sliding rod (LASR)

Table 5. Design measurements of side pillars

Side pillars (SP) details		
Dimension Name	**Symbol**	**Measurement**
Width	W_{SP}	50mm
Height	H_{SP}	70mm
Thickness	T_{SP}	15mm
Adjustable Height Slot	AHS_{SP}	50mm
Material	M_{SP}	Mild Steel

3.2.7 Design of Sliding Slots Plate for Locator Assemblies

In order to hold, position, and provide orientation to the v-locator assemblies (two assemblies), a plate was designed having two slots on each side. These slots allows the assemblies to move towards and/or away from each other in order to provide the required space for the work part to be clamped inside the v-locators. The design measurements are detailed in Table 6.

Table 6. Design details of sliding slots plate for locators' assemblies

Base Plate		
Dimension Name	**Symbol**	**Measurement**
Length	L_{BP}	200mm
Width	W_{BP}	150mm
Thickness	T_{BP}	15mm
Material	M_{BP}	Mild Steel

3.2.8 Design of Side Pillars Sliding Assemblies (SPSAs)

Similar to LSA (locators sliding assembly) there are two assemblies named as side pillars sliding assemblies (SPSAs). Since there are four side pillars attached to the plate through sliding slots, each pair of the pillars serves to hold one LSA (locator sliding assembly). In this way when two LSAs are mounted through four side pillars, it creates two assemblies named as SPSAs. The two LSAs assembled over the sliding slots plate are show in Figure 7.

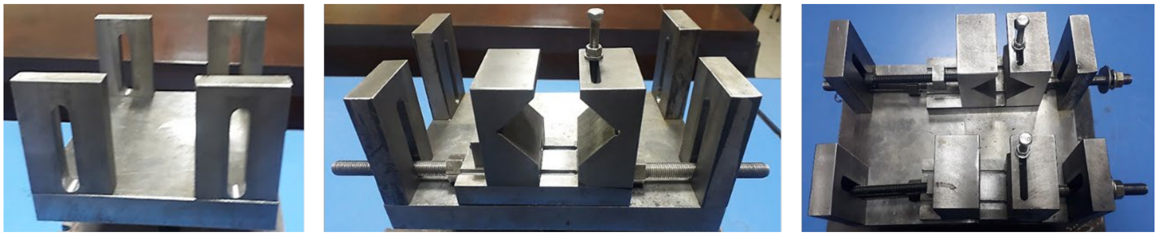


Figure 7. Side pillars sliding assemblies (SPSAs); Side pillars mounted over the plate, one LSA, and two LSAs.

3.2.9 Design of Base Plate

Base plate is designed to hold the SPSAs. It is a rectangular plate containing a solid rod in the middle. Threads are provided at the top of the rod. These threads allows the whole assembly of the fixture to be mounted on the base plate. The other purpose of the threaded rod is to get a provision of 360 degree rotation of the fixture assembly. The actual use of base plate is shown in Figure 8 wherein SPSAs acquires different rotation angles.

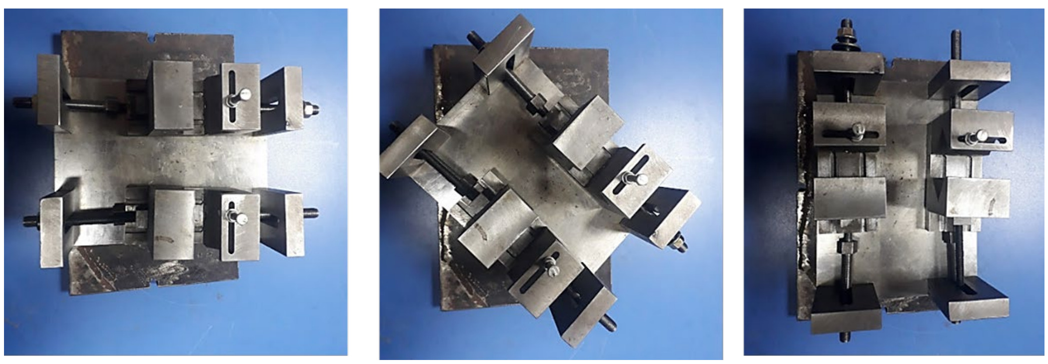


Figure 8. Base plate providing 360 degree of rotation to SPSAs.

3.2.10 Miscellaneous Parts

There are further small parts mainly used for securing and locking purpose. These parts are used as per standards and their common availability. It includes the hexagonal nuts (quantity 10), locknut having serrated flange (quantity 4), flat washers of A-type to be used with the threaded rods (quantity 4), and locking washer C-type with internal tooth (quantity 2), and dowel pins (quantity 2).

3.2.11 Collective Assembly of Fixture

After designing individual parts of the multi-functional fixture, each part was manufactured. To facilitate further, all individual parts are arranged in sequence as shown in Figure 9. Moreover, for some selected and the most important parts of the fixtures, further detailed CAD drawing with different views and dimensioning are provided in Table 7. The CAD model of the fixture assembly along with the nomenclature and the actual assembled fixture is shown in Figure 10. The designed multi-purpose fixture has the capability of clamping rectangular as well as cylindrical work pieces. It allows to clamp parts of different diameter and length. It serves the purpose by allowing two work pieces to be aligned (X axis) or adjusted at different position. Diametrically different work pieces can be clamped and aligned with respect to each other, and they can be adjusted at different height (Y axis) with respect to requirement with aid of riser block for better stability.

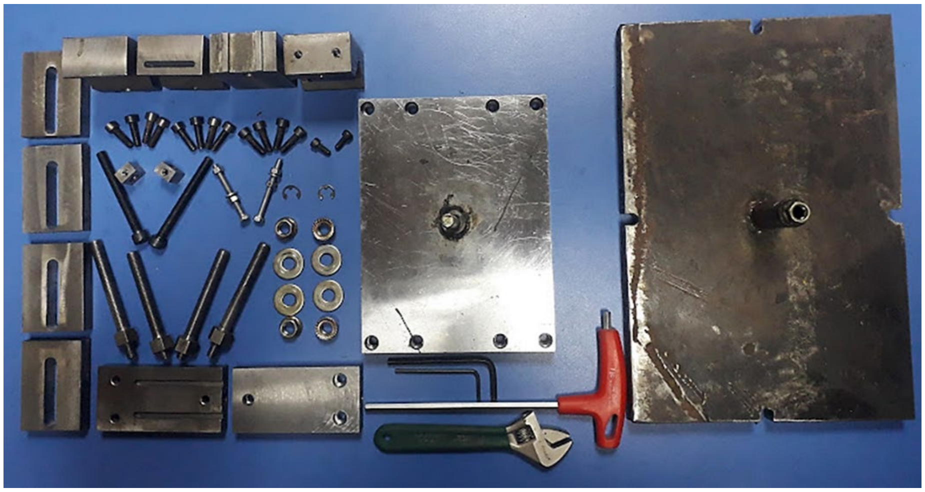
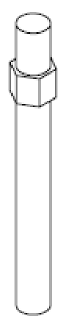
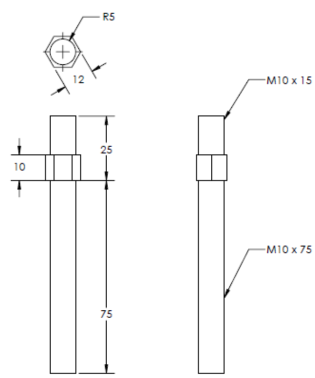
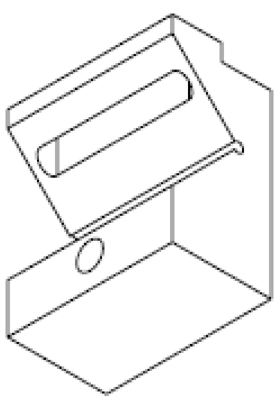
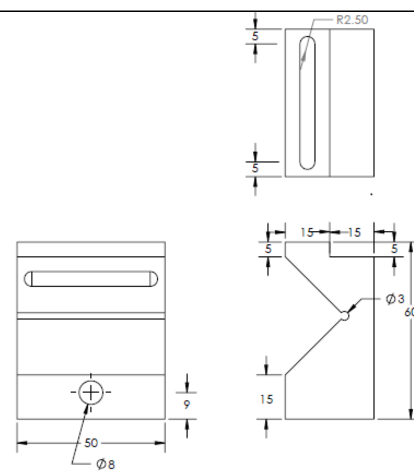
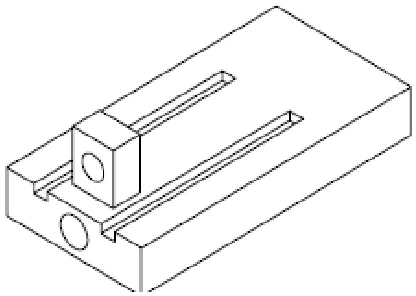
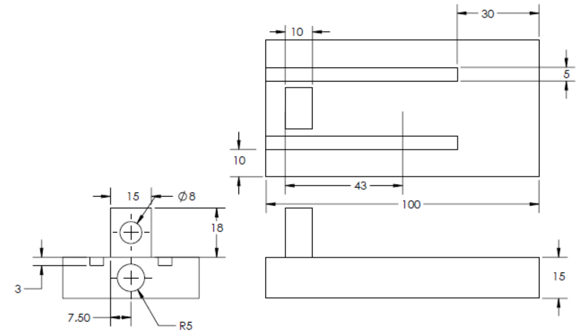
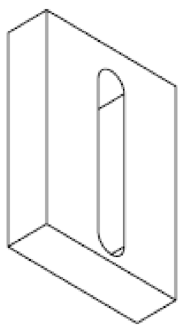
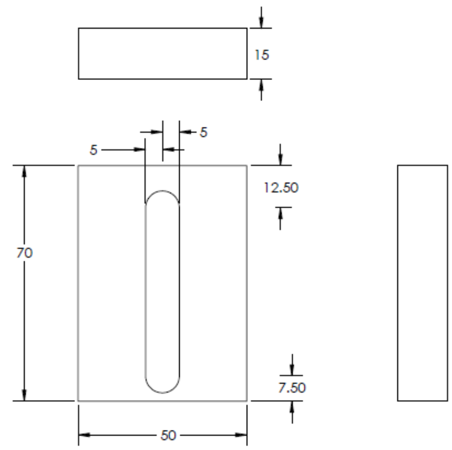


Figure 9. Individual parts of the fixture arranged at one place.

Table 7. Detailed drawings of some selected parts of the fixture.

Part Name	3D View	Drawing
ASR		
VL		

LSB		
SP		

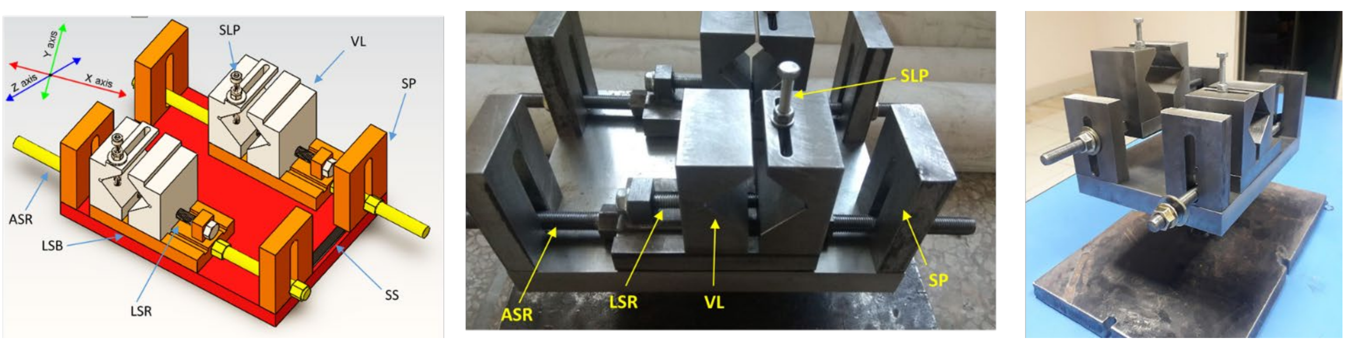


Figure 10. Assembly of fixture; 3D CAD model and actual assembled fixture on base plate.

3.3 Analysis of Degree of Freedom

In the designing of jigs and fixtures the provision of appropriate degree of freedom to the parts plays an important role. Therefore, in order to ensure the appropriateness of degree of freedom of different parts of the designed fixture the analysis is performed. The main emphasis was spared towards the critical parts of the fixture and the degree of freedom of assemblies and sub-assemblies. For instance, the rod on which overall assembly slides (X axis) helps to position both parts of fixture relative to each other. This rod is used for alignment purposes. The side pillars (SP) with the help of riser blocks help to adjust the height of both assemblies with respect to each other to perform different required operations. So, the complete sub-fixture for every individual workpiece can slide on the rod and the height can be adjusted accordingly. The distance between both side pillars can be changed or kept constant which allows to

maintain the proper space for welding, bonding, inspection and machining purposes. Standard screws are selected and designed keeping in view of standardization.
Figure 11 reflects the major three axis (X, Y, and Z with +Ve and –ve directions). Along each direction of the axis the parts are labeled and the total number of degrees of freedom along each +ve and –ve direction of each of the three axis. Further detailed degrees of freedom of different parts of the fixtures and sub-assemblies are provided in Table 8. This analysis of degree of freedom allows to develop the work envelop and ranges of the motion of the parts as well.

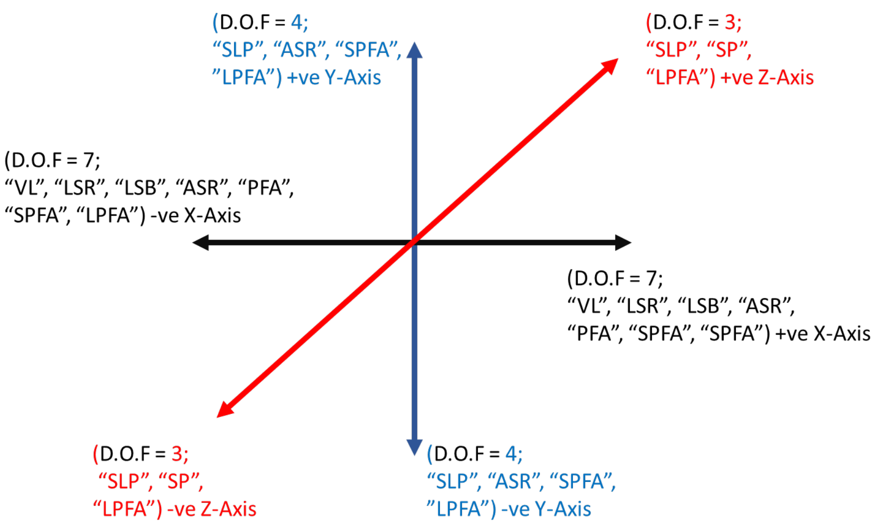


Figure 11. Schematic illustration of degrees of freedom along different axis.

Table 8. Detailed degree of freedom of different parts along different axis.

Part Name	Degrees of Freedom						
	X-Axis		Y-Axis		Z-Axis		D.O.F. No.
	X +ve	X -ve	Y -ve	Y -ve	Z +ve	Z -ve	
VL	✓	✓	-	-	-	-	2
SLP	-	-	✓	✓	✓	✓	4
LSR	✓	✓	-	-	-	-	2
LSB	✓	✓	-	-	-	-	2
LASR	✓	✓	✓	✓	-	-	4
SP	**-**	-	-	-	✓	✓	2
Assembly Name	**X +ve**	**X -ve**	**Y -ve**	**Y -ve**	**Z +ve**	**Z -ve**	**D.O.F. No.**
LSA	✓	✓	-	-	-	-	2
SPSA	✓	✓	✓	✓			4
CFA	✓	✓	✓	✓	✓	✓	6

4. Application Areas and Experimental Case Studies

Since the motive and novelty of the fixture designing was to design a fixture capable of serving more than one manufacturing operations, therefore the designed fixture was manufactured, tested, and validated for several manufacturing operations. First of all, in the context of clamping, different types of the work pieces having different geometries were selected to be clamped in the fixture such as circular shafts, hollow tubes, rectangular plates, and square, triangular, and hexagonal blocks etc. After verifying the appropriate positioning, locating, and clamping of different work parts, the ability of the fixture for manufacturing processes was tested. The manufacturing processes and/or operations on which the fixture was evaluated includes drilling, milling, welding, bonding, and inspection operations. Some of the selected experimental case studies are briefly discussed.

4.1 Inspection Operations

The fixture was used to perform different inspection operations such as quality control measurements and microscopic examination of different workpieces. Since the use of miniature microscope is continuously getting popularity for the evaluation of different microstructures, the hole quality, edge quality of machined parts, bur formation, and features sizes etc. Majority of the mini-microscopes have issues of accurate positioning. Therefore the fixture was used to examine two types of workpieces under the use of mini-microscope. Figure 12 shows the use of fixture wherein rectangular workpiece having through-hole and a shaft and a rectangular long plate. The hole size, and edge quality of the hole were successfully and accurately examined through the fixture. Moreover, the microstructure of the machined face of rectangular plate was also examined with accurate positioning of the work part.

Figure 12. Inspection and measurement operations performed through the fixture.

4.2 Drilling Operation

The fixture was also tested in drilling operations. Drilling was performed on solid shaft as well as the hollow shaft. The clamping forces were enough to hold, and v-type locator was ensuring the locating purpose of the fixture as shown in Figure 13. The experimental case study on drilling machine to drill hole in hollow and solid shaft shown enough utilization of drilling force against clamping force along with ease of removing the chips and maintaining the repeatability of the holes. It clearly indicates that the fixture can be used to perform several drilling and boring operations as well.

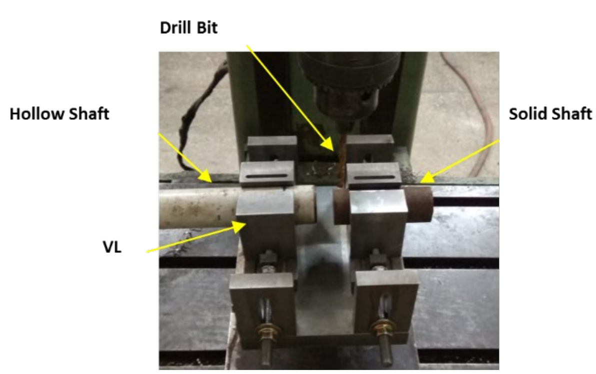


Figure 13. The application of fixture in drilling operation.

4.3 Milling Operations
The fixture was also validated on CNC Milling Center by performing milling operation on rectangular workpiece. The face milling was performed on rectangular workpiece by clamping it and locating it with the locator. Alignment was ensured by adjusting the screw on the desired position as the case is shown in Figure 14.

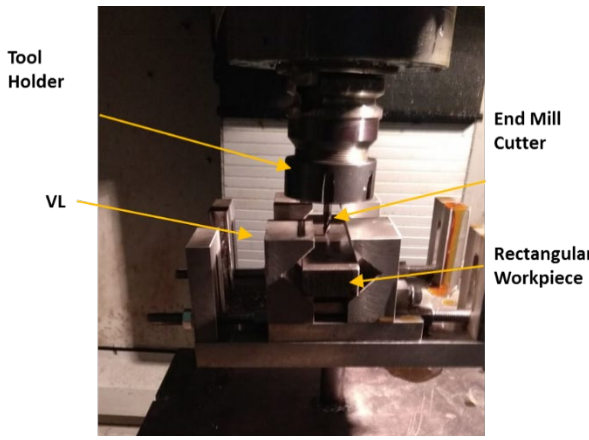


Figure 14. The use of fixture to perform milling operations

4.4 Friction Stir Welding
The fixture was also tested to validate its ability to be used in friction stir welding. In friction stir welding, the applied forces are comparatively low as compared to the milling operation. In the experimental evaluation of the fixture, milling as well as friction stir welding was performed to evaluate the clamping as well as repeatability of the parts position. The arrangement of two parts to be friction stir welded primarily required the accurate position and location in the fixture. The designed multi-functional fixture allowed to locate and position the two parts accurately and in less time. The clamping forces are enough to hold the workpiece to resist the vertical as well as rotational forces of milling and friction stir welding.

4.5 Light Duty Manufacturing Operations
There are several light duty manufacturing operations wherein the only requirement is to position, location and hold the work parts at accurate locations. There are no heavy mechanical forces. Such as adhesive bonding, painting, gluing, spraying, assembly, fastening, nailing, bolting, reviting, and quality inspection operations etc. are some example of light duty manufacturing operations where the mechanical forces are way less than the forces experienced in machining processes. Thus the designed fixture in this research has the potential to be effectively used in variety of light duty manufacturing processes.

5. Conclusion
The aim of this design oriented research is to address the need and use of a multi-purpose fixture. Based on the fixture design, fabrication, analysis of degree of freedom, the application areas of the fixture, and validation through experimental case studies, the following conclusions can be inferred:

1. The fixture can be used to appropriately locate, position, and/or clamp variety of workpiece forms and sizes such as circular and non-circular profiled parts (square, rectangular, triangular, hexagonal, and other polygons).
2. The designed fixture can be manufactured through conventional machining processes and with the use of standards fasteners.
3. The fixture offers all the required degrees of freedom (along all the three Cartesian axis as well as rotation) to locate, position, and clamp the work parts.
4. The fixture can be used for variety of manufacturing, machining, and quality inspection processes such as:
   - Milling operations including side milling, slab milling, and face milling
   - Drilling and boring operations to machine holes in cylindrical as well as non-cylindrical parts

- Welding operations including the friction stir welding of similar profiled parts or dissimilar parts such as welding of rectangular workpieces with cylindrical workpieces.
- Microscopic examinations and other quality inspection operations such as edge quality and hole quality.
- Light duty manufacturing operations such as small assemblies, adhesive bonding, and fastening operations.

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