An Advanced Treatise on Jigs and Fixture Design

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Abstract

Jigs and fixtures are special production tools which make the standard machine tool, more versatile to work as specialized machine tools. Even with the advancement of manufacturing industries, there is a continued use of jigs and fixture either in some form or other, either independently or combination with other systems.

Various areas related to design of fixtures are already well described by various authors but there is a need of basic approach to design these jigs and fixtures. This paper gives a brief introduction to the general and classic principles of jigs and fixtures design. These principles are still very applicable and form the basis of good of jigs and fixtures design, despite the rapid advancement of machine tools and manufacturing technology, principle of location, clamping, automation in fixtures design and this will continue to evolve in the future. An ideal fixture should not only provide the machining repeatability and high productivity, it should also offer a solution which reduces work piece distortion due to clamping and machining force.

Key words: Jigs and fixtures design importance of location and clamping, manufacturing considerations and need of automation of jigs and fixtures.

1 Introduction

A jig is a device which holds and locates the work piece in its position and guides the cutting tool during machining operation, and fixture is a device for locating, holding and supporting a work piece during a manufacturing operation. Fixtures are essential elements of production processes as they are required in most of the automated manufacturing, inspection, and assembly operations.

Fixtures must correctly locate a work piece in a given orientation with respect to a cutting tool or measuring device, or with respect to another component, as for instance in assembly or welding. Such location must be invariant in the sense that the devices must clamp and secure the work piece in that location for the particular processing operation. There are many standard work holding devices such as jaw chucks, machine vises, drill chucks, collets, etc. which are widely used in workshops and are usually kept in stock for general applications.

Fixtures are normally designed for a definite operation to process a specific work piece and are designed and manufactured individually. Jigs are similar to fixtures, but they not only locate and hold the part but also guide the cutting tools in drilling and boring operations. These work holding devices are collectively known as jigs and fixtures.

1.1 Elements of Fixtures

Generally, all fixtures consist of the following elements:

1.1.1 Locators: A locator is usually a fixed component of a fixture. It is used to establish and maintain the position of a part in the fixture by constraining the movement of the part. For work pieces of greater variability in shapes and surface conditions, a locator can also be adjustable.

1.1.2 Clamps: A clamp is a force-actuating mechanism of a fixture. The forces exerted by the clamps hold a part securely in the fixture against all other external forces acting on to the component.

1.1.3 Supports: A support is a fixed or adjustable element of a fixture. When severe part displacement/ deflection is expected under the action of imposed clamping and processing forces, supports are added and placed below the work piece so as to prevent or constrain deformation. Supports in excess of what is required for the determination of the location of the part should be compatible with the locators and clamps.

1.1.4 jig Body : jig body, or tool body, is the major structural element of a jig. It maintains the spatial relationship between the other elements mentioned above, ***viz.,*** locators, clamps, supports, and the machine tool on which the part is to be processed.

The use of fixtures has benefits such as it eliminates individual marking positioning and frequent checking before machining operation starts, thereby resulting in considerable saving in set-up time. In addition, the usage of work holding devices saves operator labor through simplifying locating and clamping tasks and makes possible the replacement of skilled workforce with semi-skilled labour, hence effecting substantial saving in labour cost which also translates into enhanced production rate.

2 General Requirements of a Fixture

In order to maintain the work piece stability during a machining process, an operational fixture has to satisfy several requirements to fully perform its functions as a work holding device. The following constraints must be observed while designing a viable fixture

2.1 Deterministic location The work piece is constrained by a locators so that it is presentable for the machining operation. Locating errors due to locators and locating surfaces of the work piece should be minimized so as to accurately position the work piece within the machine coordinate frame.

2.2 Contained deflection Work piece deformation is unavoidable due to its elastic/plastic nature, and the external forces impacted by the clamping actuation and machining operations. Deformation has to be limited to an acceptable magnitude in order to achieve the tolerance specifications.

2.3 Geometric constraint Geometric constraint guarantees that all fixturing elements have an access to the datum surface. They also assure that the fixture components do not interfere with cutting tools during a machining operation. In addition to these requirements, a fixture design should have desirable characteristics such as quick loading and unloading, minimum number of components, accessibility, design for multiple cutting operations, portability, low cost, etc.

2.2 Fixture Design Fundamentals

Fixture design consists of a number of distinct activities: fixture planning, fixture layout design, fixture element design, tool body design, etc. They are listed in Figure 4 in their natural sequence, although they may be developed in parallel and not necessarily as a series of isolated activities in actual execution.

2.3 Fixture Design

Fixture planning is to conceptualise a basic fixture configuration through analyzing all the available information regarding the material and geometry of the work piece, operations required, processing equipment for the operations, and the operator. The following outputs are included in the fixture plan:

- Fixture type and complexity
- Number of work pieces per fixture
- Orientation of work piece within fixture
- Locating datum faces
- Clamping surfaces and Support surfaces, if any

The following design criteria must be observed during the procedure of fixture design:

- Design specifications
- Factory standards
- Ease of use and safety
- Economy

A typical Fixture of Base plate component for milling operation is as shown in fig 1. Strap clamps are provided to hold the workpiece firmly engaged with the locating elements during operation. The clamping system should be strong enough to withstand forces developed during operation. At the same time, the clamping force should not dent or damage the workpiece. Speed of operation, operator fatigue and strategic positioning are other important considerations for contriving a clamping system. Cylindrical Locators are used to restrict the degrees of freedom (DOF) of the workpiece, these locators should be strong enough against the cutting forces to keep the workpiece in place.

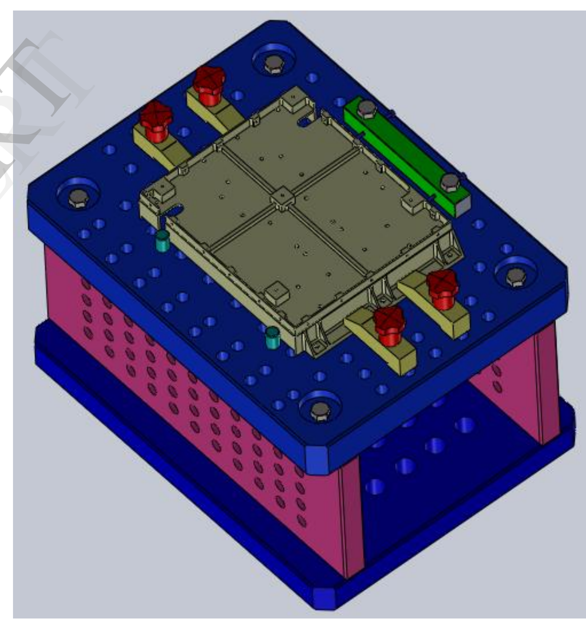

Fig.1 Fixture of Base plate component for milling operation

3.1 Fixture Design Procedure

In the design of a fixture, a definite sequence of design stages is involved. They can be grouped into three broad stages of design development.

Stage one deals with information gathering and analysis, which includes study of the component which includes the shape of the component, size of

the component, geometrical shape required, locating faces and clamping faces.
Stage two involves product analysis such as the study of design specifications, process planning, examining the processing equipments and considering operators safety and ease of use. In this stage all critical dimensions and feasible datum areas are examined in detail and layout of fixture is done.
Stage three involves design of fixture elements such as structure of the fixture body frame, locators, clamping and tool guiding arrangement.
Stage four deals with final design, assembly of the fixture elements, evaluation of the design, incorporating the design changes if any required and completion of design. Stages involved in the design aspects is as shown below.

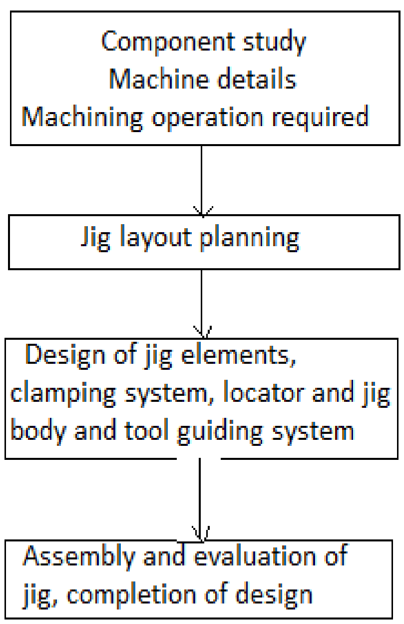

Fig. 2 various aspects of jigs and fixtures planning

3.1.1 Locating Principles

One of the principal purposes of a machining fixture is to locate the work piece surfaces for performing a machining operation. This is usually done with respect to a nurnber of factors to be considered such as the reference datum, supporting surfaces, features that are likely to obstruct the tool movement or access direction, etc. In general, the following surfaces should be distinguished:

- **Active surfaces** These are surfaces to be machined, ***i.e.*** surfaces which are subjected to the action of cutting tools.
- **Supporting and locating surfaces** These are surfaces by means of which the work piece is to be located with respect to set-to-size cutting tools.
- **Clamping surfaces** Clamping surfaces are subjected to the clamping forces for obtaining invariant location. Clamping surfaces are usually not finish-machined surfaces as clamping marks could damage the finish.
- **Datum surfaces** Datum surfaces are reference surfaces where the dimensions are to be maintained and measured.
- **Free surfaces** Free surfaces are surfaces not involved in the set-up for the particular machining operation.

3.1.2 Restrictions on the Degrees of Freedom of a Work piece

A work piece, just like any free solid body, has six degrees of freedom (some researchers have referred this to the twelve degrees of freedom by considering the **+/-** movements in each category)

- Three rectilinear displacements along the mutually orthogonal co-ordinate axes
- Three angular displacements with respect to the same axes.

During a set-up, it is necessary to restrict certain degrees of freedom so as to locate and orient the active surfaces with respect to the cutting tools. Since supporting or restricting surfaces may vary from the true geometrical shape, especially on rough-machined surfaces or cast blanks, it is desirable that the work piece be located with respect to the point supports.
Locating using point supports in the form of hemi-spherical rest buttons would considerably reduce the influence of geometrical variations of locating surfaces on the locating accuracy. For prismatic parts, the general principle of 3-2-1 location is most commonly employed. For achieving greatest stability, the first three points of location on the primary surface should be as far apart as possible, or the area enclosed by the three points as large as possible. For cylindrical work pieces, three-point location cannot be obtained because of the non-existence of plane surfaces, V-locators and close-fitting bushes are often used instead. For circular laminae, location can be achieved with the aid of a slot support. When a work piece is required to be located with respect to an inside hole or bore, a plug is used for locating the work piece. Locating from two holes typically uses a full and a diamond plug combination, with the latter inserted in the larger of the two holes.

3.1.3 Clamping Principles

In every machining operation, clamping of work pieces is an essential requirement. A clamp can be defined as a device for providing an invariant location with respect to an external loading system. Hence, when a cutting force is producing a load or moment on the work piece, it is necessary that a sufficient clamping force must be exerted to withstand such actions. The creation and retention of locking effect against external loads are the principal objectives of any locking devices. The generalized requirements of locking elements can be summarized as:

- To provide a suitable locking for achieving the stability of location,
- To produce sufficient frictional effects for the above purpose but without causing any undesirable effects to the work piece such as distortion or surface damage.

It is also essential that the idle time involving loading, locking, unlocking and unloading of work pieces should be minimized as much as possible to reduce the overall set-up and non-machining time. Certain additional requirements are therefore to be fulfilled with respect to clamping devices:

- The clamping devices must be easy to manipulate manually or otherwise,
- These devices must be quick-acting so as to reduce time for setting the clamping and simultaneous locating,
- They must be low-cost so that their application in small lot sizes is economical.

3.1.4 Basic Principles of Clamping Force

It is necessary in all clamping devices that the clamping forces hold the work piece in its located position and should not cause any positional displacement or excessive distortion under the action of the clamping forces. Clamping forces should be directed towards supporting and locating elements on overhanging or thin sections of the work piece. In addition, the force should be
transmitted to the rigid sections of the body frame of the fixture. Cylindrical work pieces located in V-blocks can be clamped using another V block, making a 4-point clamping, or clamped in a 3-jaw chuck, in a 3-point clamping configuration. The latter is usually more common, especially in turning operations.

3.1.5 Effect of External Forces on the Clamping

Clamping elements can be classified in accordance with their force-deflection characteristics. There are two broad sub-divisions, which are

Type I: clamping elements in which the elastic deformation increases with clamping force, such as screws, levers, cams, etc

Type 11: clamping elements in which the clamping force assumes a constant value independent of the elastic deformation at the contact surfaces such as fixtures operated with hydraulic or pneumatic pressures Within the elastic region, clamping elements based on elastic deformation, ***i.e.*** Type I clamps, would exhibit a linearly increasing clamping force in proportion to the deformation of the clamping element, if the work piece or the locator is assumed to be rigid. If the work piece or locator deforms, it will cause a relaxation of the clamping element and the clamping force will decrease. A limiting case arises when the clamping is lost and the force becomes zero.

In Type I1 clamps, the clamping force remains constant at pre-set values and is independent of work piece and locator deformation. This type of clamping device is therefore more reliable and would not relax over time

3.1.6 Types of Clamps

Clamping elements may be either manually operated or actuated by pneumatic, hydraulic or a combination of other power facilities. They are also classified according to the mechanism by which a mechanical advantage is attained. The two
basic classes include:

- Application of inclined plane theory, *i.e.* wedges, screws, cams, etc.,
- Application of lever principle, *i.e.* levers, toggles, etc.

Manual clamping of work pieces has the following disadvantages:

- Each work piece is clamped with varying force,
- It is difficult to determine the required force for reliable clamping,
- Fatigue of operator due to manual clamping takes place,
- Time required to actuate manual clamping is longer compared to power actuated clamping,
- Comparatively small amount of force is available without large force amplification devices.

Pneumatic and hydraulic clamping devices have eliminated most of the above disadvantages but at much higher cost as well as greater demand for space requirement and maintenance. Justification would be a balance between cost, efficiency, accuracy, operator safety and comfort.

4. Automation in Fixture Design

With the advent of CNC machining technology and the capability of multi-axis machines to perform several operations and reduce the number of set-ups, the jigs and fixture design task has been somewhat simplified in terms of the number of fixtures which would need to be designed. However, there is a need to address the faster response and shorter lead-time required in designing and constructing new fixtures. The rapid development and application of Flexible Manufacturing System (FMS) has added to the requirement for more flexible and cost-effective fixtures. Traditional fixtures (dedicated fixtures) which have been used for many years are not able to meet the requirements of modern manufacturing due to the lack of flexibility and low reusability. The replacement of dedicated fixtures by modular and flexible fixtures is eminent in automated manufacturing systems, due to much smaller batch sizes and shortened time-to-market requirement.

Fixtures are constructed from standard fixturing elements such as base-plates, locators, supports, clamps, etc. These elements can be assembled together without the need of additional machining operations and are designed for reuse after disassembly. The main advantages of using modular fixtures are their flexibility and the reduction of time and cost required for the intended manufacturing operations. Automation in fixture design is largely based on the concept of modular fixtures, especially the grid-hole-based systems, due to the following characteristics:

- Predictable and finite number of locating and supporting positions which allow heuristic or mathematical search for the optimum positions,
- Ease in assembly and disassembly and the potential of automated assembly using robotic devices,
- Relative ease of applying design rules due to the finite number of element combinations.

5 CONCLUSIONS

This paper addresses the jigs and fixture design verification issue. In this paper, the work piece location, clamping stability under dynamic machining and frictional conditions at the interface between jigs and fixture elements and work piece are taken into account. Concluding contributions of this paper in the area of jigs and fixture design are

- jigs and fixture design under machining effect, and its manufacturing considerations
- necessity of clamping ,location, tool guiding and work piece mounting with respect to machine co-ordinate
- various aspects of layout design and planning of jigs and fixtures
- brief on necessity of automation on jigs and fixture design

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