Study of Fixturing Accessibilities in Computer-Aided Fixture Design

By

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Abstract

Fixtures form an important factor in traditional and modern flexible manufacturing systems, since fixture design directly affects manufacturing quality and productivity. Hence, it is necessary to evaluate quality of fixture design.

The fixturing accessibility refers to machining feature accessibility and loading /unloading accessibility. The development of Computer Aided Fixture Design (CAFD) has simplified this task. Fixture design activities include setup planning, fixture planning and fixture configuration design. Fixture design verification comes next. Fixturing accessibility using Computer Aided Fixture Design is part of the verification process and has not received much attention till date.

Machining feature accessibility analysis involves the evaluation of possible interference between fixture components and the cutting tool, which moves with pre-programmed tool path, while the loading and unloading accessibility relates to the ease with which the operator attaches/detaches the workpiece from the surrounding manufacturing environment.

This research has three main focuses. The first focus is to evaluate machining feature accessibility, by integrating fixture designs in SolidWorks and the NC programming in Esprit. The main goals are evaluation of fixture design for any kind of interference between tool/workpiece/fixtures and enable Esprit to indicate interference, if any. The next step is to modify the fixture design accordingly and thus, finally obtain an interference free fixture design by reiteration.

The second and third focuses deal with analysis of loading and unloading accessibility. A simulation based approach is applied to evaluate loading/unloading paths for different workpiece-fixture setups and checking interference in a dynamic mode. Then the third focus is to develop analysis method and criteria of comparisons of fixturing accessibility in different fixture designs.

Thus, this research establishes methods of analysis for accessibilities in fixture design. Also, the guidelines for good fixture design will prove to be of great use to both, the beginners as well as the experienced fixture designers in this field.

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Table of contents:

List of tables:

List of Figures:

Appendix – A

Chapter 1: Introduction to Fixturing Accessibilities in Computer Aided Fixture Design

This chapter gives an overview of Computer Aided Fixture Design (CAFD), fixturing accessibility and the scope and limitations of the thesis.

1.1 Introduction to Computer Aided Fixture Design and Fixturing Accessibility:

Fixtures are important in both, the traditional manufacturing and modern flexible manufacturing systems (FMS), which directly affect the machining quality, productivity and cost of products. The time spent on designing and fabricating fixtures significantly contributes to the production cycle in improving current products and developing new products. Therefore, great attention has been paid to the study of fixturing in manufacturing. The manual fixture design requires the consideration of a number of factors like primary requirements of the design, demand to be met, use of automated and semi-automated clamping devices, safe operation etc. The application of these fundamental principles to an individual fixture design depends primarily on the designer's experience. Collection and representation of this knowledge from the designer's experience is a crucial part in Computer Aided Fixture Design (CAFD). [17]

CAFD consists of three major aspects: setup planning, fixture planning and fixture configuration design. As part of manufacturing tooling, fixture design and verification activities make a significant contribution to the production time and cost in the daily production. Quality can be assessed in terms of different aspects of a design. Not all of those aspects have received the same kind of attention in previous studies. Thus, the main goal has been to focus on those aspects which have not been looked into, to a very great extent earlier and thus, set a platform for further evaluations. The main aspects that have been focused on are machining feature accessibility and loading/unloading accessibility, which is a very important technical problem involved in fixture design. The quality of the component can be affected to a great extent by the accessibility of the system. The objective of accessibility analysis is to help fixture planning to select the right kind of fixture design for manufacturing purposes. An improper fixture design affects the quality of the component to a great extent thereby, affecting the tolerances and accuracy. This research focuses on three different methodologies to work towards a foolproof fixture design.

1.2 Objectives and Methods:

The main focus is to verify the fixturing accessibility as a performance of fixture design with CAFD using simulation-based methods. Here, three different methods have been adopted as follows:

1. Integration of Computer Aided Design and Manufacturing systems, to analyze Machining Feature Accessibility.

2. Simulation of Loading and Unloading paths for a workpiece using SolidWorks Animator and interference check using COSMOS Motion 2007.

3. Establishing a set of rules to differentiate between the given fixture setups on the basis of certain individual characteristics of each of them. This will enable us to perform a comparative study among a given number of fixture designs to set them aside from the others on the basis of their quality characteristics.

1.3 Contributions and Limitations:

The existing research in the field of Computer Aided Fixture Design Verification focuses mainly upon analysis of Point and Surface Accessibility methods. Thus, machining feature accessibility and loading and unloading accessibility have not received much attention, except for a few methods that have been put forth. Thus, this research makes an attempt to establish a procedure for analysis of machining feature accessibility and loading and unloading accessibility. Further, general guidelines for a good fixture design have been set to aid the designer in process of designing fixtures. The limitation of method to study machining feature accessibility is that it may be used for an off-line simulation which needs to be programmed into seamless integration systems. Also, the limitation of method established for loading and unloading accessibility is that path optimization has not been paid much attention to, thus, enabling space for further explorations in the same. Finally, how to use the detection results to modify fixture design is still a challenge and relies upon the designer's knowledge and experience.

Chapter 2: Background Research and Literature Review

This chapter gives an overview of the literature review in the field of Computer Aided Fixture Design. The various methods to automate the fixture design process as well as to analyze types of accessibilities have been stated briefly.

2.1: Review of Computer Aided Fixture Design (CAFD):

Fixture design is an important design activity for which automation is critical for the integration of computer aided design (CAD) and manufacturing (CAM). This integration activity is crucial for Computer Aided Fixture Design. Fixture design activities in manufacturing systems include three major aspects: setup planning, fixture planning and fixture configuration design. This is followed by fixture design verification activities, as seen in fig. 1 shown below. [10]

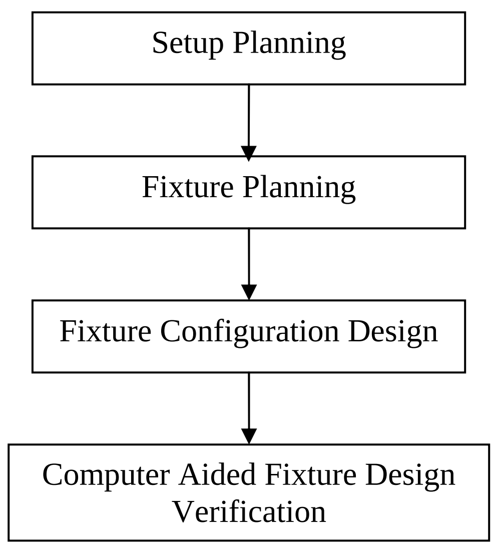


Figure 2.1: Four stages of fixture design

The various published articles in the Computer Aided Fixture Design and its different aspects have been studied in this section. Some of the important research articles are listed below:

Attempt were put forth earlier to automate the fixture design process, by adopting interactive and semi-automatic methodologies to aid in the generation of fixture design for a given part design [13],[14]. These also include the work on clamping aspects of fixture design.[4] Further, an expert system approach was also adopted to perform fixture design which made use of a heuristic rule base system to generate a list of fixturing recommendations.[15] Other Computer Aided Fixture Design works include attempts to automate set-up planning and fixture design.[19] Recent approaches include the modular element database creation method, the IDEF-0 (integration definition) model method of fixture design activities using the prototype software called TAMIL the automatic selection of preliminary locating and clamping positions and many others.[3]

2.2: Machining Feature Accessibility Analysis:

Machining feature accessibility refers to the ease with which a particular feature on the workpiece surface can be accessed for machining purposes. A fixture design can be said to be the one, which does not pose problems to the machining of features on the workpiece surface. A fixture design should always be such that, it gives the operator enough room to carry out the machining of intended features, with minimum of interference. The following gives a detailed explanation about all possible interferences that may take place in the workpiece fixture setup. Generally, there are four types of interferences that may take place in fixture design [8]. They are:

Type A is the interference between the fixture components and the swept volume generated

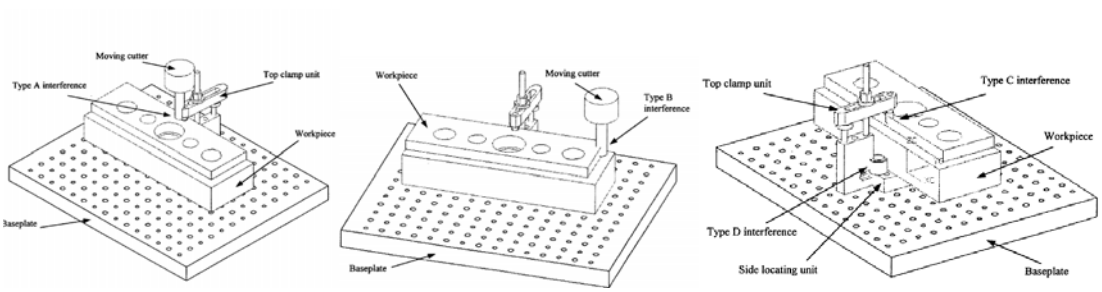


Figure 2.2: Interference types A , B, C and D in fixture design

by the cutting tool. Type B is the interference between the workpiece and the moving cutter during the machining process. Type C is the interference between fixture components and the workpiece. Type D is the interference between the fixture components. In the figure below, it can be seen that interference may exist between the side locating unit and the clamping unit, since the distance between them is insufficient. Out of the above four stated types, only types A, C and D are considered since, type B does not deal with fixture components at all. Since there may be many fixture components in a fixture design, the interference checking may take a long time if the standard functions in a commercial CAD package are used where the manipulation of solid models are heavily involved. Interference checking is an important topic in the fields of CAD/CAM, robotics and computer simulation or animation.

Following gives a brief explanation of the different methods that have been put forth for analyzing this accessibility:

The Cutter Swept Volume Approach was put forth to describe development of a system to produce a tool-collision-free fixture design using a machining interference detection sub module based on a cutter swept volume approach [11]. A Fast Interference Checking Algorithm for Automated Fixture Design Verification was an interference check method dealing with a fast interference checking algorithm for automated fixture design validation [8]. It was based on the study of geometric characteristics of the modular fixture components and the machine tool. In this method, the fixture component was simplified into a 2D contour model with height information. The tool-path model was represented by a moving dot for 3-axis operations or a moving line segment for 5-axis operations. This can be seen form the figures given below:

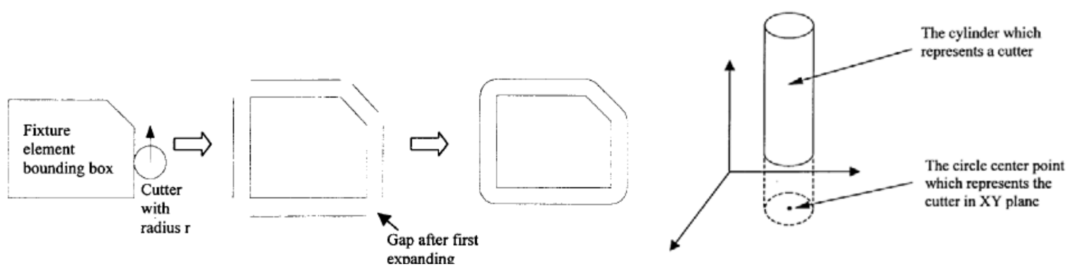


Figure 2.3: Representation of fixture models and cutting tools in 2D

Application of this method reduced the complexity involved in computations for fixture interference checking.

The above stated methods need extensive algorithms which can be very time-consuming. Also, integration of CAD and CAM systems still remain to be a bottleneck and have not received much attention in the past few years.

2.3: Fixturing Surface Accessibility Analysis:

Point accessibility refers to the ease with which a point on the surface of the workpiece is approached in fixture design (i.e. how easy it is to place the fixture component (locator/clamp) in contact with the fixturing candidate point. Surface accessibility is the extent of ease with which, the fixture components can be placed in contact with the fixturing candidate surface.

The accessible cylinder method dealt with the analysis of the point and surface accessibility [9]. It made use of an accessible cylinder method, for which various parameters like locator bounding height, locator bounding radius, accessible height and accessible radius were defined. The definitions for these parameters may imply that their corresponding values may be anywhere up to infinity. In order to eliminate this infinity problem, satisfactory factors were introduced. Thus, the accessibility and detachability of a point were defined on the basis of a comparison between their ratios with the satisfactory factors.

The next method for analyzing point accessibility is the Self Individual Accessibility and Neighbor Related Accessibility method [12]. The point accessibility was divided into two parts: the point self individual accessibility (SIA) and the point neighbor related accessibility (NRA). The SIA primarily corresponds to an isolated accessibility of fixturing point, whereas the NRA reflects the extended accessibility of the fixturing point. This method defined the point accessibility in terms of three attribute tags, which were defined on the basis of the position status, obstruction status and contact area respectively. The accessibility value for each of these tags was evaluated and hence, the point accessibility, as a whole, was a combined evaluation of the attribute tags. The surface accessibility was then calculated as the average of point accessibilities over a number of different locations.

The Non-Obstructive Angle Method put forth was also a surface accessibility analysis method [5]. The method defined two access angles, serving as rating factors and can be decided on the basis of the relative ease of accessibility of each surface and the workpiece geometry. The concept of access angles is shown in the figure below:

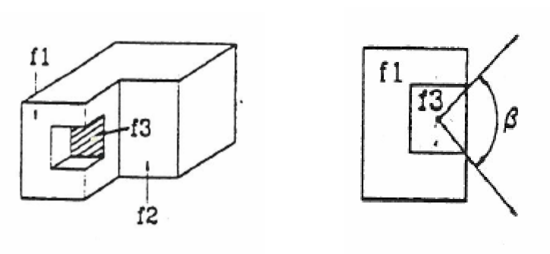


Figure 2.4: Measurement of access angles to check loading and unloading accessibility

The same can be extended to workpiece loading an unloading by constructing an access cone in the 3-D space from the clamp and locator layout.

2.4 Loading and Unloading Accessibility Analysis:

Loading and unloading accessibility is the ease with which the workpiece can be loaded into a fixture setup and unloaded from the fixture when the fixture has been designed has been constructed. It should be noted that loading and unloading accessibility is different from fixturing surface accessibility because the former refers to the ease with the fixture elements can be placed in contact with the fixturing surface.[17]

The Jacobian Matrix Method modeled fixture - workpiece relationship in 3D space using Jacobian matrix and performed kinetic analysis for a deterministic positioning of the fixture and accessibility and detachability analysis.[1] The method derived conditions for strongly accessible/detachable and a weakly accessible/detachable fixture workpart combinations. The condition for weakly accessible/detachable workpart fixture combination is given by:

$$G\Delta q \geq 0$$

Thus, any value of Δq which satisfies this equation causes the workpart to be detached from atleast one fixture element. But, it should be noted that the other fixture elements might still remain in contact with the surface of workpiece.

The condition for a strongly accessible/detachable condition is given by:

$$G\Delta q > 0$$

Thus, any value of Δq that satisfies this inequality causes the workpiece to be detached from all the fixture elements at the same time and so can be said to be a strongly accessible/detachable workpart fixture combination.

Thus, the integration of CAD and CAM systems continues to be a bottleneck in the current production systems. Though many methods have been put forth for evaluating surface accessibility, not much work has gone into evaluating loading and unloading accessibility. Thus, these two fields remain unexplored even today.

2.5: Summary and Limitations:

Thus, the methods explained above give a brief idea of the research that has been carried out in this field so far. But, it can be seen that not much work has gone into analyzing the machining feature accessibility or the loading and unloading accessibility. Machining feature accessibility and loading and unloading accessibility are two important aspects of a fixture design. Thus, it is important to focus on their analysis methods. This is exactly what has been carried out as part of this research, as will be seen in the successive sections.

Chapter 3: Machining Feature Accessibility Analysis for Computer Aided Fixture Design

This chapter deals with the integration of fixture design in CAD and CNC programming in CAM systems, the procedure for the same and the technical challenges involved in the integration. In the successive sections, examples of fixture designs with simulations have been included to aid the understanding of this process.

3.1: Problem Definition

Machining feature accessibility is the ease with which a feature on the surface of the workpiece can be reached for the purpose of its machining. A fixture design should be such that it should allow easy access to the workpiece surfaces for the purpose of any machining features on it. Thus, we can differentiate between a good and poor quality fixture design on the basis of any interference between the tool/fixture components/ workpiece. The problem can be defined as to establish this differentiation between a good and poor fixture design from the machining feature accessibility point of view by focusing on interference in fixture design. This is explained clearly in the succeeding sections.

3.2: Integration of CAD/CAM to verify fixture design:

As stated in the literature review, not much work has gone into analyzing the accessibility of manufacturing systems. Till date, there have been two methods for checking interference in fixture design. Also, generation of algorithms, as stated in the second method takes a considerable amount of time since it involves extensive calculations. Thus, by adopting an approach of integration of Computer Aided Design and Manufacturing Systems, the extensive calculations will be avoided. The literature review conducted earlier also indicates that fixture design has been a major bottleneck in the integration of CAD and CAM activities. After a fixture has been designed, its testing for manufacturing processes is equally important to know the errors in fixture design. Also, the current process as sown below, is such that the fixture design activities and the CNC programming activities take place simultaneously. This is not the ideal method, since, it is less flexible. Thus, the integration method put forth makes possible the betterment of this existing process, which is shown below.

Thus, integration of CAD and CAM will enable the designer to essentially carry out a virtual test of manufacturing process too, on the fixture design. Thus, the designer will be in a better position to modify the fixture design accordingly. Thus, the integration activities work on the principle of Virtual Enterprise (VE) oriented manufacturing environment.

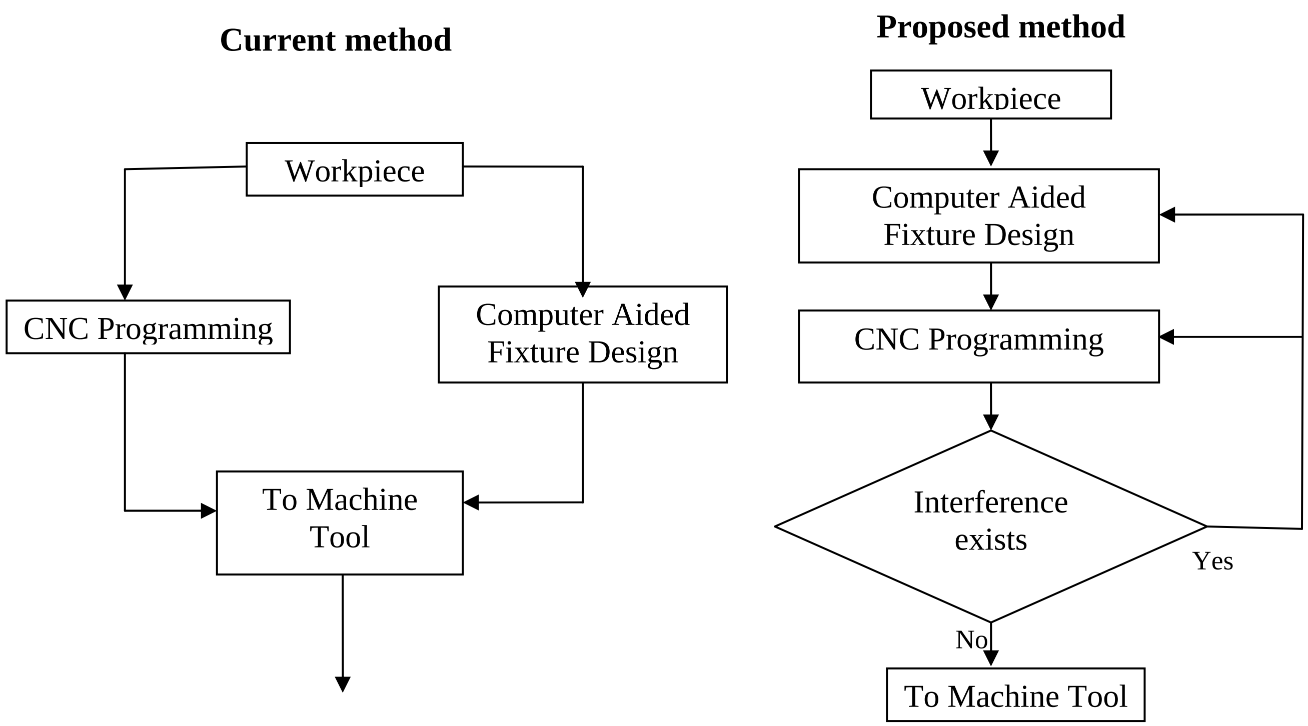


Figure 3.1: Comparison of the existing method with the proposed method

3.2.1: Procedure:

The method, as the name suggests, uses the integration of Computer Aided Design and Computer Aided manufacturing Systems in order to analyze the machining feature accessibility. The CAD software which was used for research is SolidWorks and CAM software is Esprit. Esprit enables users to simulate tool paths in manufacturing processes. Esprit makes use of the concept of virtual reality, where all the manufacturing operations can be simulated, so that we can come to know of interferences or other drawbacks in the fixture design, once it goes into the manufacturing line. The following steps are involved in the integration of SolidWorks and Esprit:

The main objectives in establishing the procedure of integration were to enable the analysis of fixture design qualitatively. This qualitative analysis refers to analysis of a fixture design from the interferences point of view. In a workpiece-fixture setup, as we know, interference might take place between the fixture components themselves, or between the workpiece and fixture components or between the tool and fixture components. The main goals here have been to be able to detect any such kind of interference by integrating SolidWorks and Esprit.

Following is the procedure established for the same:

1. Design the fixture setup for the workpiece in SolidWorks and import the solid models of workpiece-fixture setup SolidWorks into Esprit. Then, the workpiece-fixture assembly origin is defined in space.

2. The next step is to define the features to be machined. Features form the basis of machining operations. After the machining features have been defined, the next step is to set up the type of machine to be employed. This can be done through 'Machine Setup' in case of milling and turning machines. The next step is to set up the mode of machining through the Machining menu.

3.. The next step is to define cutting operations and cutting tools. Then the cutting operations are defined. The definition of cutting operations includes specifying the speed, feed, depth of cut and other such parameters. This can be done through the technology pages.

4. The next step is then to simulate the cutting operations. This can be done by using the simulation toolbar in Esprit. This is an important step since; in this stage the workpiece and the fixture components are defined. The fixture elements can be defined in either of the two groups, fixtures in general or clamps, depending upon the type of fixture element. This step is very important since it forms an important role in the detection of interference. In the simulation window, the type of interference can be specified. Type if interferences may be of different kinds. The user may check interference between the tool and workpiece, or the tool, tool holder and fixture setup and so on.

5. After the simulation is run, the tool path will be indicated in a color pre-selected, generally red. Also, if any interference takes place in the assembly, it will be indicated by a red blinking light.

6. After the indication of interference, the next step is to take the assembly back to SolidWorks and make the necessary modifications in the fixture design, in order to avoid the

interference. In order to export the esprit file back into SolidWorks, it may be saved as a .igs file in esprit and then may be opened in SolidWorks. If making changes in the fixture design is not possible, changes may be made in the CNC program, which ever is possible.

7. After the modifications have been made, the procedure for interference check is again repeated in Esprit and the process continues till we obtain an interference free fixture design. Thus, the same workpart-fixture model goes back and forth in SolidWorks and Esprit and thus, we can say that this process is an integration of the two softwares to serve our purpose of interference check. It must however be noted that the manual transfer of files is an important part of this process.

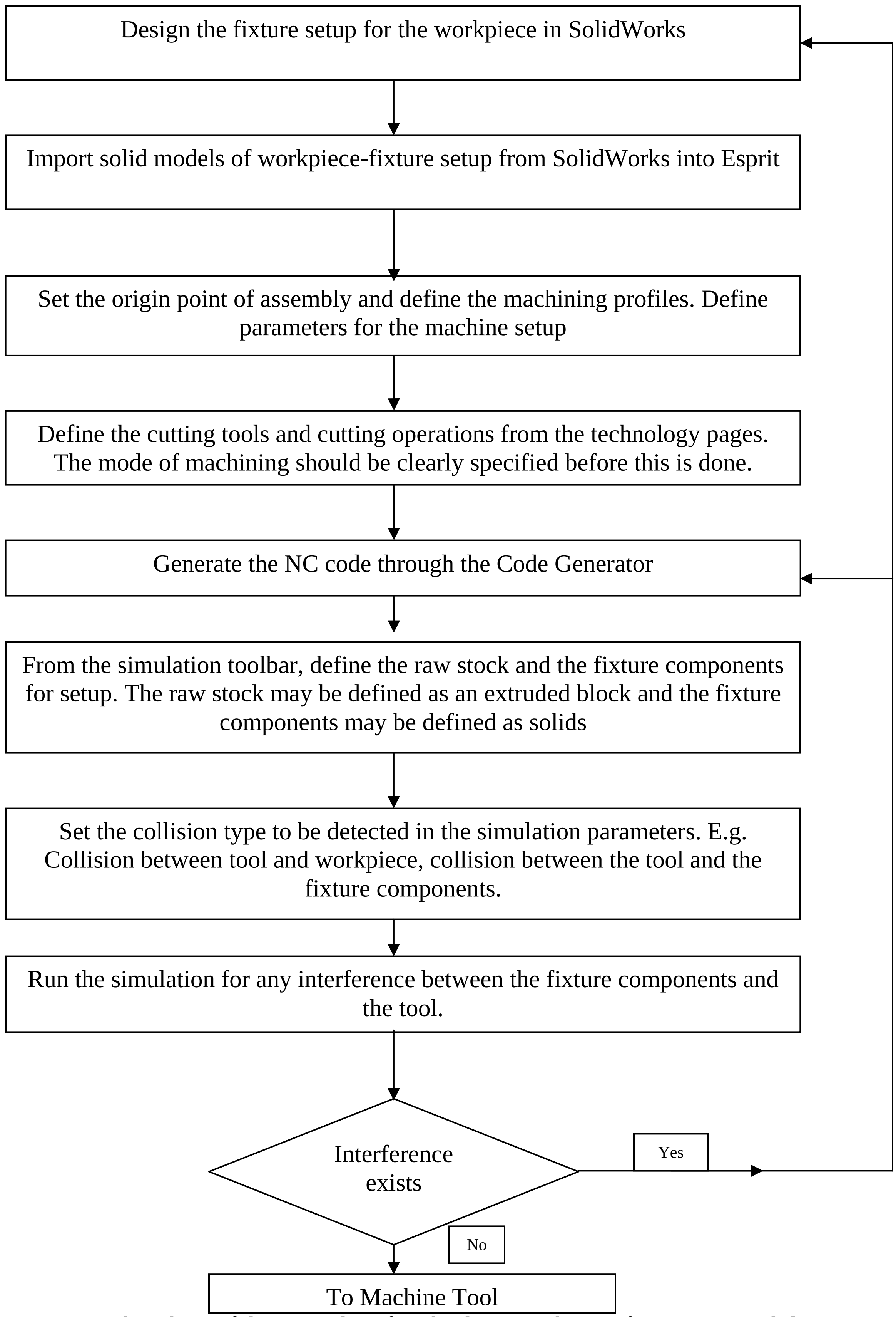


Figure 3.2: Flowchart of the procedure for checking machining feature accessibility

3.3: Computer Aided Manufacturing Simulations to verify fixture design :

Esprit is a Computer Aided Manufacturing software. It allows the operator to use advanced technologies to give him full control over the NC programming. Esprit makes it easy to machine solid, surface and wireframe part geometry. Esprit allows the user to simulate all kind of machining operations and thus, prepare NC codes to further take it into manufacturing. Following gives an example of a simulation carried out in Esprit in order to enable the interference check. The image shown below shows the image of the workpiece to be machined with its machined surfaces.

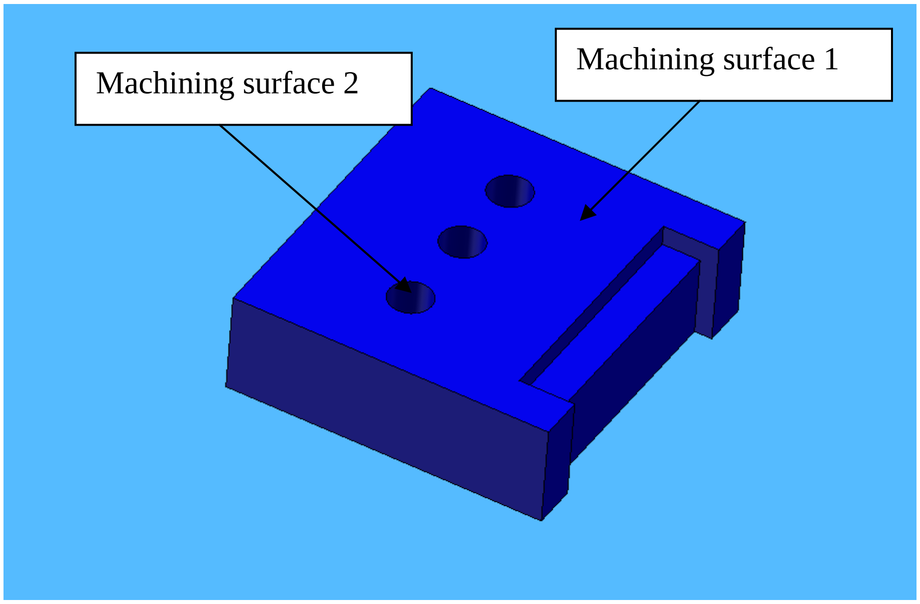


Figure 3.3: Workpiece to be machined in Esprit

The machining surfaces on the workpiece include milling the top surface and drilling the three holes. Following gives the fixture setup for machining the same:

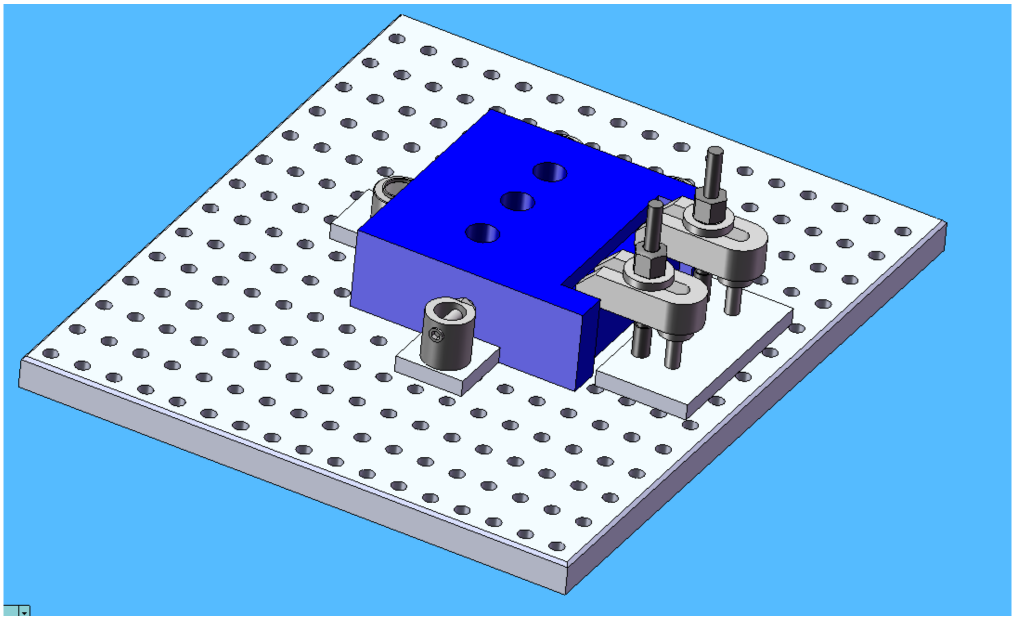


Figure 3.4: Original fixture design

This is the original fixture design and as can be seen, there are high chances of the tool interfering with the strap clamps. The fixture setup uses two mechanical strap clamps and a side clamp in order to keep the workpiece against the locating surfaces. It should be noted that bottom locators have not been used, even though drilling operation is to be performed. This is because the holes to be drilled are not through holes. The fixturing makes use of the normal 3-2-1 principle.

The next important task was to check if there exists an interference between the tool and the fixture components. In order to check the interference, the method described above was followed. The following shows the workpiece-fixture setup with the toolpath ready to be simulated:

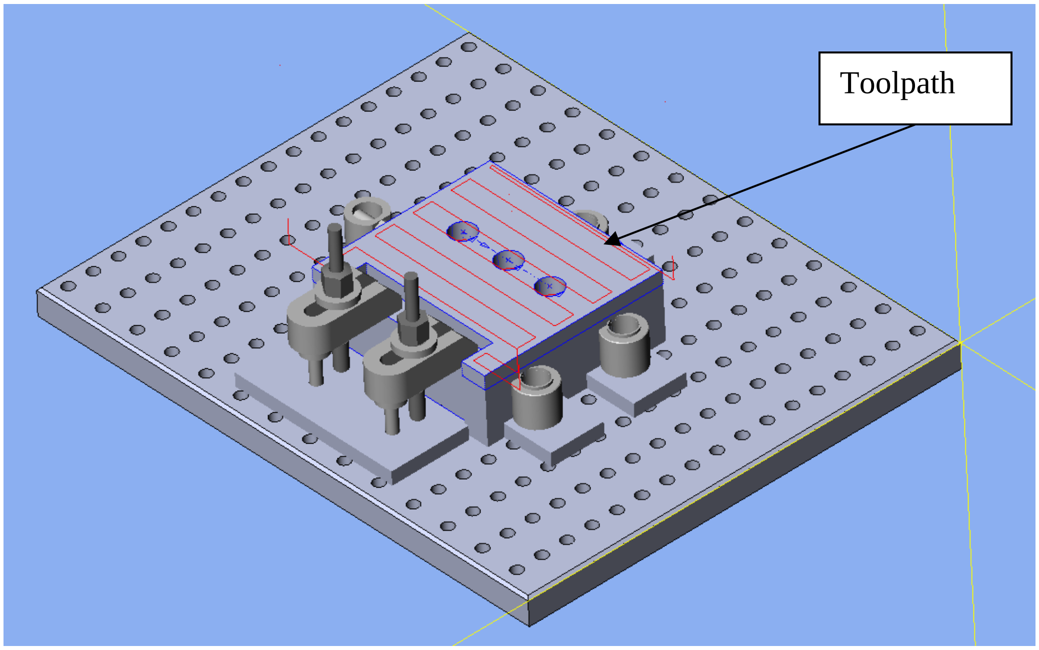


Figure 3.5: Toolpath for machining the workpiece using original fixture design

Following images show the sample pages for defining tools and operations respectively. The parameters can be varied to be able to obtain the required toolpath.

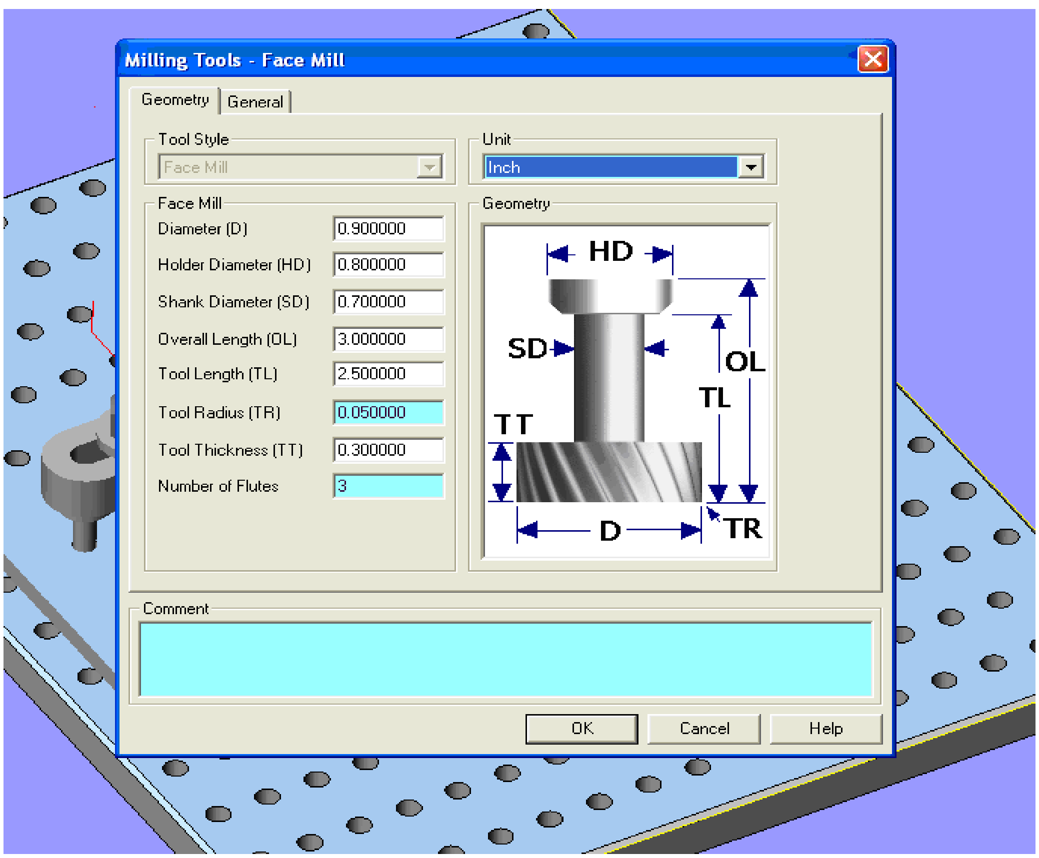


Figure 3.6: Definition of milling tools in Esprit

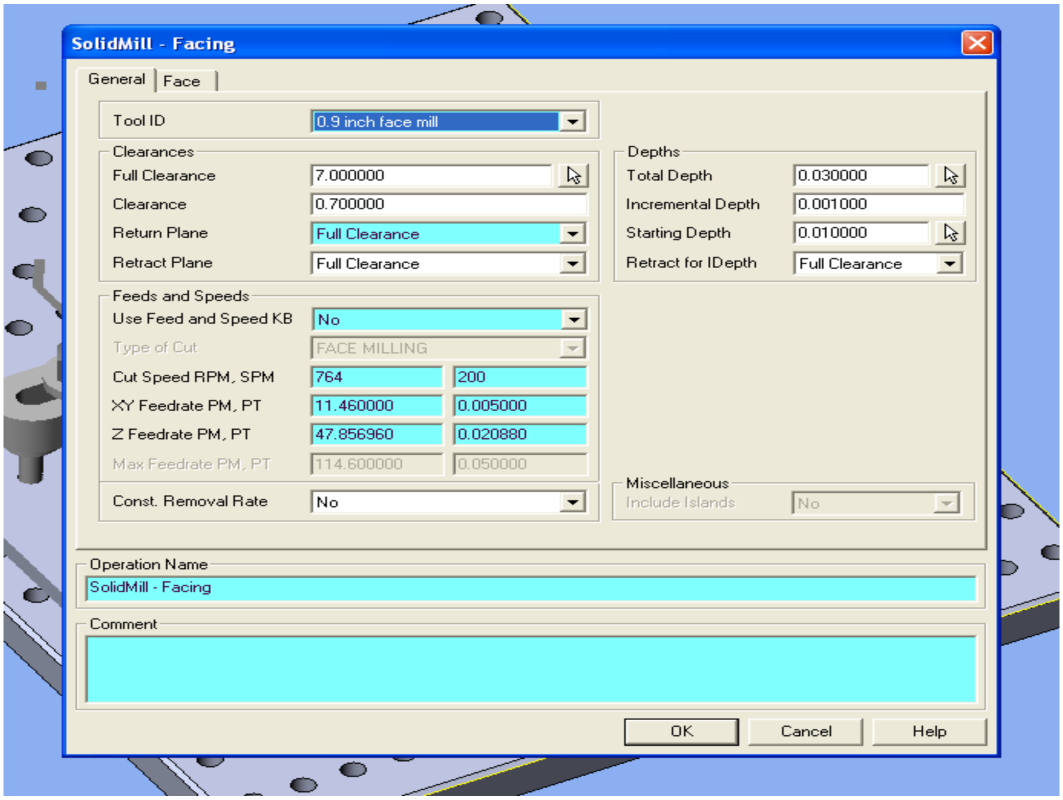
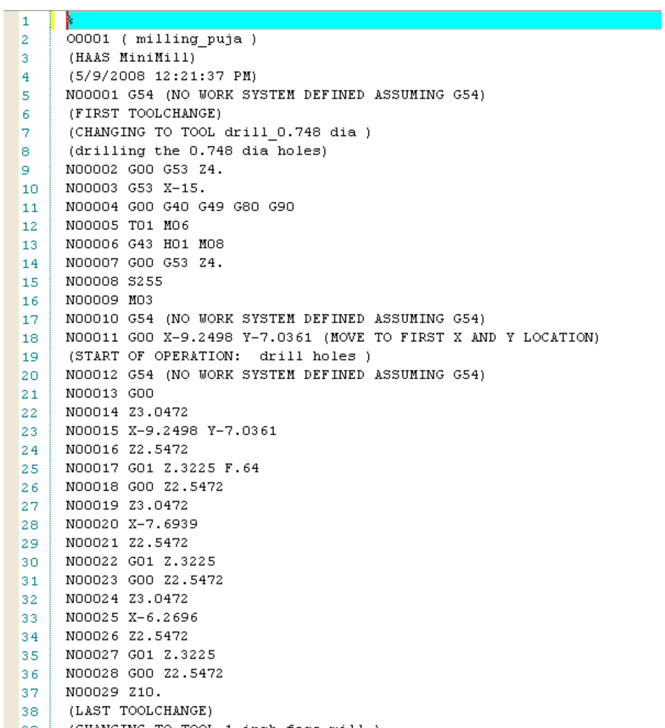


Figure 3.7: Definition of milling operations in Esprit

The next stage was to generate the NC code through the Code Generator.Following gives the NC code for manufacturing this component.



```
%
O0001 ( milling_puja )
(HAAS MiniMill)
(5/9/2008 12:21:37 PM)
N00001 G54 (NO WORK SYSTEM DEFINED ASSUMING G54)
(FIRST TOOLCHANGE)
(CHANGING TO TOOL drill_0.748 dia )
(drilling the 0.748 dia holes)
N00002 G00 G53 Z4.
N00003 G53 X-15.
N00004 G00 G40 G49 G80 G90
N00005 T01 M06
N00006 G43 H01 M08
N00007 G00 G53 Z4.
N00008 S255
N00009 M03
N00010 G54 (NO WORK SYSTEM DEFINED ASSUMING G54)
N00011 G00 X-9.2498 Y-7.0361 (MOVE TO FIRST X AND Y LOCATION)
(START OF OPERATION:  drill holes )
N00012 G54 (NO WORK SYSTEM DEFINED ASSUMING G54)
N00013 G00
N00014 Z3.0472
N00015 X-9.2498 Y-7.0361
N00016 Z2.5472
N00017 G01 Z.3225 F.64
N00018 G00 Z2.5472
N00019 Z3.0472
N00020 X-7.6939
N00021 Z2.5472
N00022 G01 Z.3225
N00023 G00 Z2.5472
N00024 Z3.0472
N00025 X-6.2696
N00026 Z2.5472
N00027 G01 Z.3225
N00028 G00 Z2.5472
N00029 Z10.
(LAST TOOLCHANGE)
(CHANGING TO TOOL 1 inch face mill )
```

Figure 3.8: NC code generation in Esprit

After NC code generation, the simulation was carried out to check interference. Following image shows the interference taking place between the tool and the strap clamps. The interference is indicated by a red blinking color as shown in the image below:

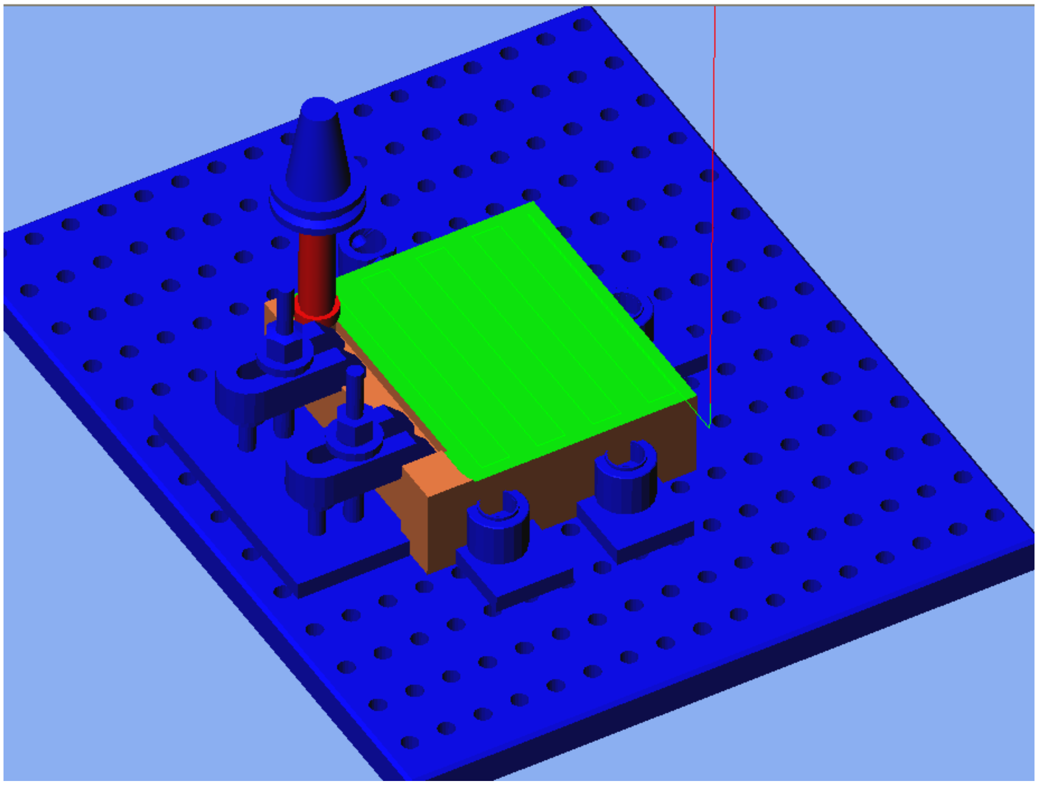


Figure 3.9: Interference between tool and fixture components for original design

Once, the interference was seen, the same workpiece-fixture model was taken back to SolidWorks and was modified to give a fixture design given below:

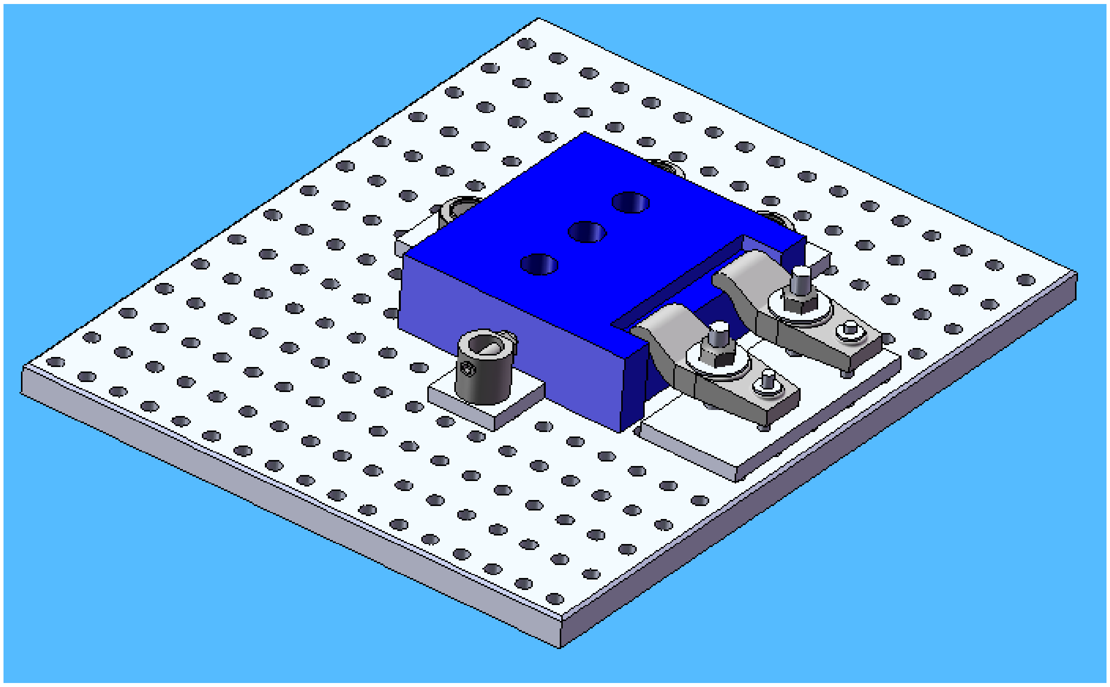


Figure 3.10: Modified fixture design to avoid interference

The same procedure was again followed to check interference for this setup. It had exactly the same toolpath as the earlier original design and it was found that there was no interference. Following image shows the modified workpiece-fixture setup in Esprit.

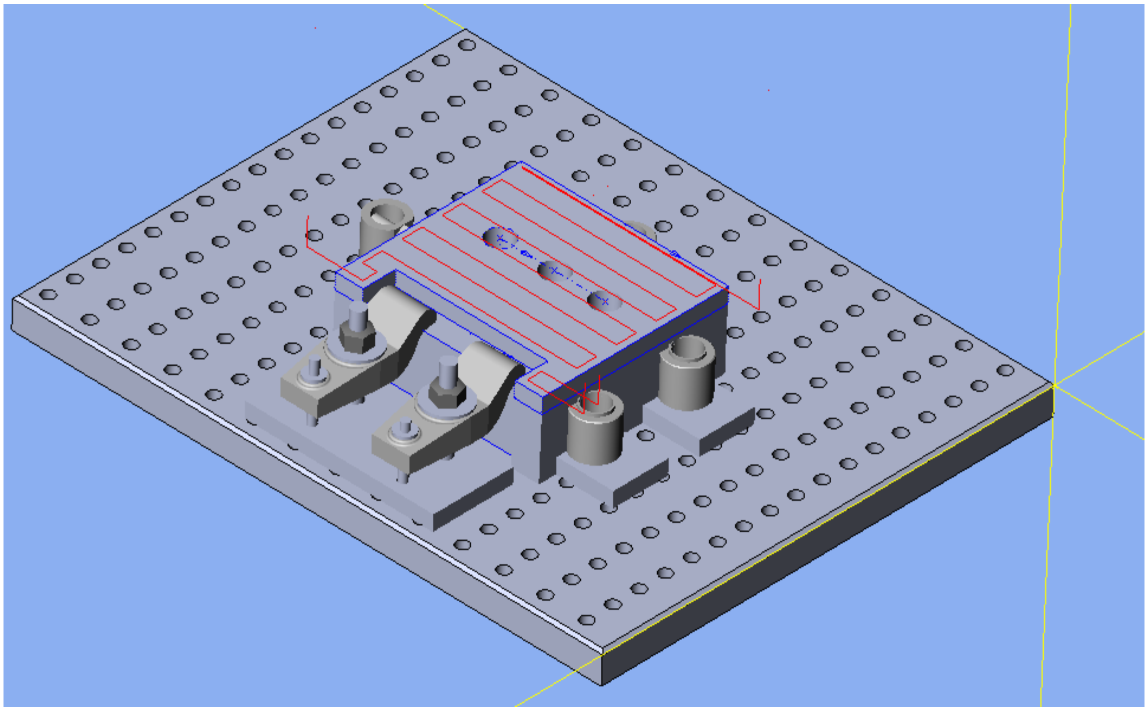


Figure 3.11: Toolpath for machining the workpiece using the modified fixture design

This was because; the original design uses mechanical strap clamps as against the modified one which makes use of gooseneck clamps. Hence, the chances of interference are reduced to a great extent.

Thus, fixture design in SolidWorks and CNC programming in Esprit can be partially integrated in order to verify fixture design.

3.4: Summary

Thus, SolidWorks and Esprit were successfully integrated to evaluate the quality of fixture design. In this method, the evaluation of quality is done in terms of any kind of interference taking place in the manufacturing systems. No interference between the difference components of the manufacturing environment, i.e. the fixture elements, the workpiece, tool indicates that the fixture design is good (except for the optimum interference between workpiece and tool during cutting operation.). Thus, this is a good and reliable way and has special importance in the study of complicated cases where interference cannot be seen visually.

Automating the methodology of integration of CAD and CAM softwares however, is a technical challenge. The current research focuses on the manual method of integration of both, since the user has to switch back and forth from SolidWorks and Esprit during the process, for verification of fixture design. But, automating the process as the next step, might require considerable amount of time and research in the field. Another limitation of the method is that it does not consider the optimized setup for machining a particular surface on the workpiece. Also, for the optimized setup, a criterion as to what type of cutting tools, geometry of workpiece, cutting conditions, offset parameters need to be established for a particular machining operation. Thus, the criterion will reinforce the method of interference check by the use of Esprit.

Chapter 4: Simulation based Loading and Unloading Accessibility Analysis

This chapter deals with the procedure for loading and unloading analysis. Loading and unloading analysis for any component can be carried out in terms of the feasibility and time. Unloading and loading can be said to be feasible for a particular component if and only if, there exists atleast one path in which the workpiece can be loaded and unloaded in and out of the fixture setup without interference. If there exists not even a single path , we say that loading and unloading is not feasible and hence, accessibility is poor. The second criterion uses time as a measure of loading and unloading analysis. The higher the time to load and unload the workpiece, the worse the fixture design is and vice-versa. The following gives an explanation of the various steps involved in the analysis of loading and unloading a workpiece from a fixture setup.

4.1: Problem Definition

Loading and unloading accessibility is the ease with which the operator can load and unload the wokpiece into the fixture setup. The main goal has been to establish a procedure for analyzing the loading and unloading accessibility. One of the important stages in the procedure for analysis is simulating the loading and unloading conditions using SolidWorks animator. The main intention in simulating the loading and unloading paths is to make sure that the fixture-workpiece setup under consideration is as close as possible, to the real life conditions. But, one of the drawbacks with Animator is that it does not allow the user to check any interference in the dynamic mode. Thus, in case of fixture-workpiece setups that come across interferences, such interferences cannot be detected by using SolidWorks Animator, except for the static interference. Hence, COSMOS Motion 2007 can be used to simulate the mechanism partly, and show the interference. Thus, the above two aspects make use of virtual reality to a great extent. But, the simulations cannot provide any basis for differentiating between different fixture designs from quality point of view. Hence, the next step has been to establish a platform to enable the comparison between different fixture setups and establish a ranking method to clearly distinguish between them as poor, good, better and the best designs. A number of case studies have thus been studied and a major task has been to formulate some guidelines that help work towards a good fixture design.

The following better explains the concept of loading and unloading:

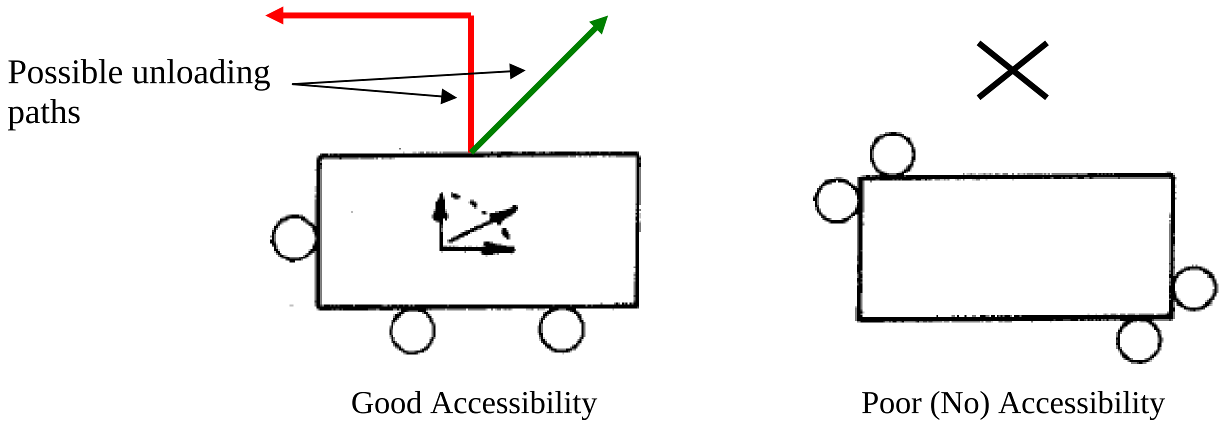


Figure 4.1: Examples illustrating good accessibility and poor accessibility

The first example shows that the workpiece can be loaded and unloaded in atleast one way without interfering with the fixture components. On the other hand, the second example shows that the workpiece locating and clamping is such that the loading and unloading is not possible without interference**.**

4.2: Procedure for Accessibility Analysis:

A simulation based approach has been used to analyze the loading and unloading accessibility. The procedure for analysis established here, again makes use of concept of virtual reality. The simulations for loading and unloading paths and interference check for fixture design using COSMOS Motion 2007 both form a very important part of the analysis procedure and hence, the approach has been called a simulation-based one. The main task here has been to establish the entire procedure for analysis of loading and unloading accessibility.

Flowchart:

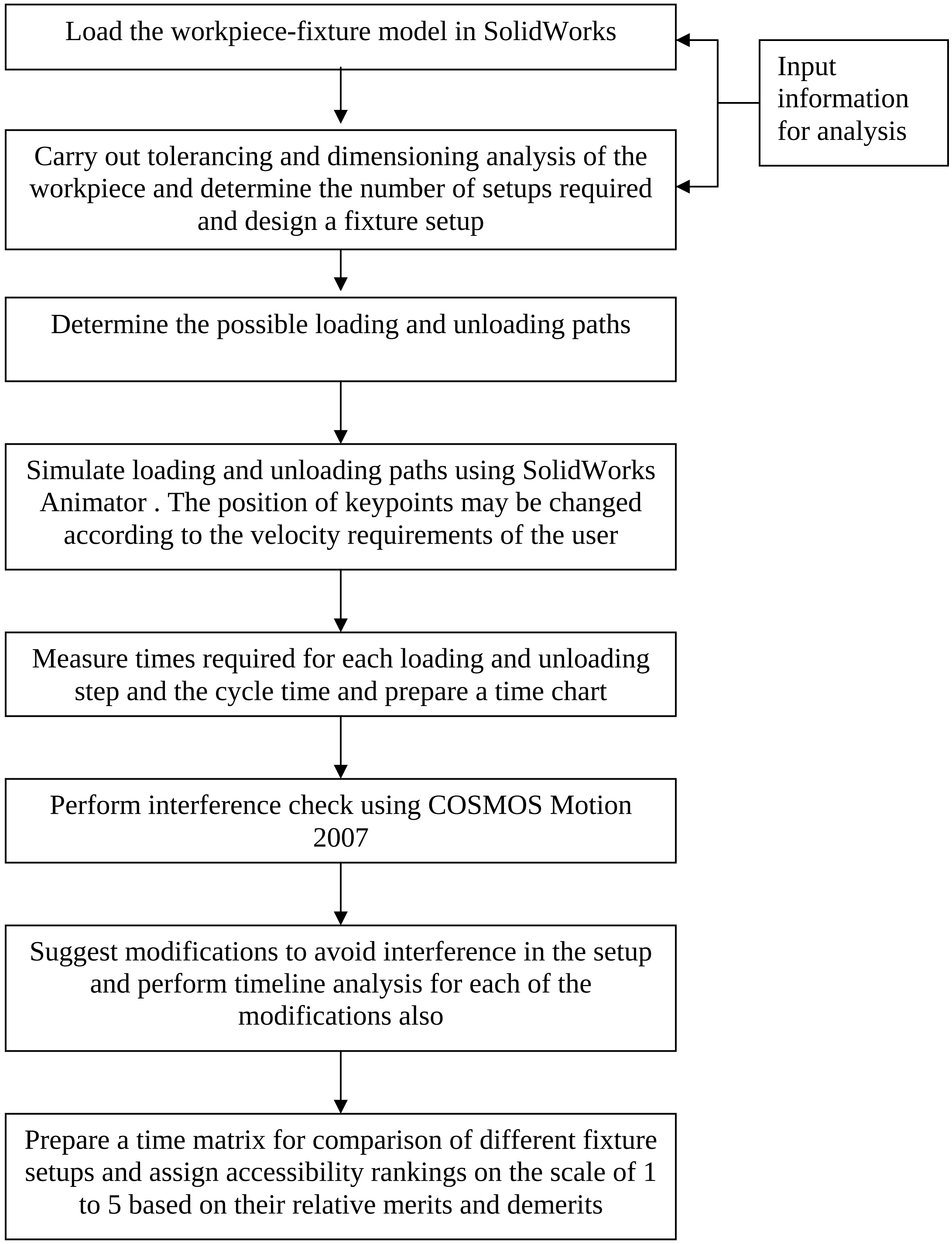


Figure 4.2: Flowchart for procedure for loading and unloading analysis

Following are the steps in the analysis:

1. The solid models of workpiece are loaded in SolidWorks or imported from any other application if required. Identify the machining surfaces and the tolerance requirements. In this stage, various dimensional and geometrical tolerances are assigned to the workpiece. This can be done after a clear understanding of the manufacturing processes to be performed and the machining surfaces. This is followed by the determination of number of setups to create the surfaces. The next step is to design a fixture setup specific to the machining operation. Identifying the accessibility problem is the next step. Before that is done, it is important to determine, whether the workpiece loading and unloading is feasible or not.

The above steps are for the purpose of input information for further analysis. The actual process starts from step 2.

2. Next step is to simulate the loading and unloading paths for the original fixture design. This is done using SolidWorks Animator. A point to be noted is that, the shortest path cannot always be chosen for the simulation. This may be because; there might be certain manufacturing environment obstructions that might not allow the operator to use the optimum path. Thus, simulations here, have been carried out for any path at random. But, the same method of simulation can be used to simulate a number of other loading and unloading paths also. Next, the time required for each loading and unloading step is measured and the information is put in form of a chart. This is called a timeline analysis. This includes the cycle time for loading and unloading. For eg, for unloading, the instant from operation of clamps, to the instant when the workpiece reaches the final position is measured for unloading purpose. A time matrix is the one which contains many such timeline analyses for different setups for comparison purpose.

A sample of time measurement can be shown as follows:

Unloading process	
Step	Time in seconds
1. Operation of clamps	x secs
2. Movement in X direction: step 1: step 2:	y1 seconds y2 second
3. Movement in Z-direction	z seconds
Total time:	(x + y1 + y2) seconds

Table 4.1: Sample time chart for analysis

A drawback with SolidWorks Animator is that it cannot indicate interference taking place in the dynamic mode. Thus, COSMOS Motion has been used further to show any kind of interference that might be taking place during the simulation. Interference detection enables the user to understand properly the errors in fixture design.

3. Thus, the next step would be to suggest modifications, in order to avoid interference again. Again, separate timeline analysis is carried out for each of them.

4. The next step is to put the collected data in a matrix form for comparison purposes. Thus, we can differentiate between the different fixture designs on the basis of time required for loading and unloading. Accordingly, the accessibility rankings can be given on the scale of 1 to 5 based on the comparison of their relative merits and demerits.

4.3: Simulations for analyzing loading and unloading accessibility:

SolidWorks Animator and COSMOS Motion 2007 are softwares used for simulation and analyses purposes. Here, they have been used to illustrate a virtual reality concept. This means that loading and unloading path during simulations can be shown in order to understand the behavior of these paths in the actual production line. Next, the interference check can be performed for the setup. Following sections provide procedures for the same:

4.3.1: Simulation of loading and unloading paths in SolidWorks Animator:

As mentioned in the previous section, SolidWorks Animator has been used to simulate the unloading and unloading paths for various workpiece-fixture setups. In real life situations, while loading or unloading a workpiece from a fixture setup, there can be a number of paths for loading or unloading the workpiece from the fixture setup. But, this research does not focus on optimizing the path. The main objective here, as stated earlier, has been to establish a procedure for simulating the loading and unloading accessibility. Thus, while simulating the loading and unloading paths, any random path has been chosen to study the different factors which can affect its accessibility.

The following gives the procedure for simulating loading and unloading paths for a particular fixture-workpiece setup.

Flowchart:

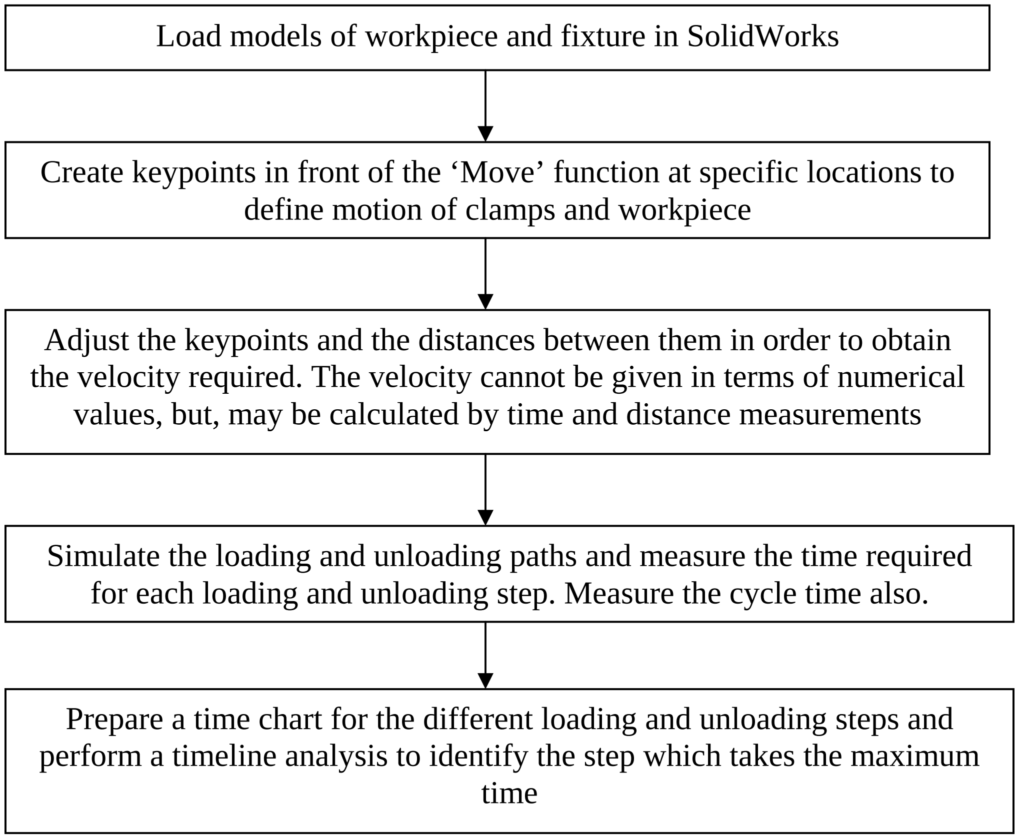


Figure 4.3: Flowchart for simulating loading and unloading paths in SolidWorks Animator

1. Load the workpiece-fixture setup in SolidWorks.

2. The next step is creation of keypoints for simulations. Keypoints are created in order to define the exact loading and unloading paths. These keypoints are so defined, that they represent the path that the workpiece will take while being loaded or unloaded. There is a lot of flexibility in the use of keypoints. They can be moved around in order to control the velocity at which the loading and unloading takes place. It also allows for simulating simultaneous motions of components, if required by the user. It should be noted that these keypoints should always be defined in front of the 'Move' function next to the feature manager tree.

3. After the keypoints have been created, the next step is to simulate the paths. This can be done with the help of the Simulation toolbar. Thus, simulation of loading and unloading paths aids the understanding of the user, as to any possibilities of interference that the workpiece could come across during loading and unloading. Thus, a number of such paths

may be defined in SolidWorks Animator for a particular fixture workpiece setup and each of these paths can then be analyzed for interferences, seen visually only.

4. The next step is to perform a timeline analysis of the original design. The time for each loading and unloading step is measured with a stop watch and then put in a table chart form. This helps to understand which of the unloading or loading step takes the maximum amount of time. An important point to be noted in the simulations of loading and unloading paths is that SolidWorks Animator may be used to see interferences visually only. The software does not have the ability to indicate to the user the exact interference areas. Hence, COSMOS Motion has been made use of in the next step of analysis. The following section provides in-detail information about the same.

4.3.2: COSMOS motion and simulations for interference check of fixture designs:

Flowchart:

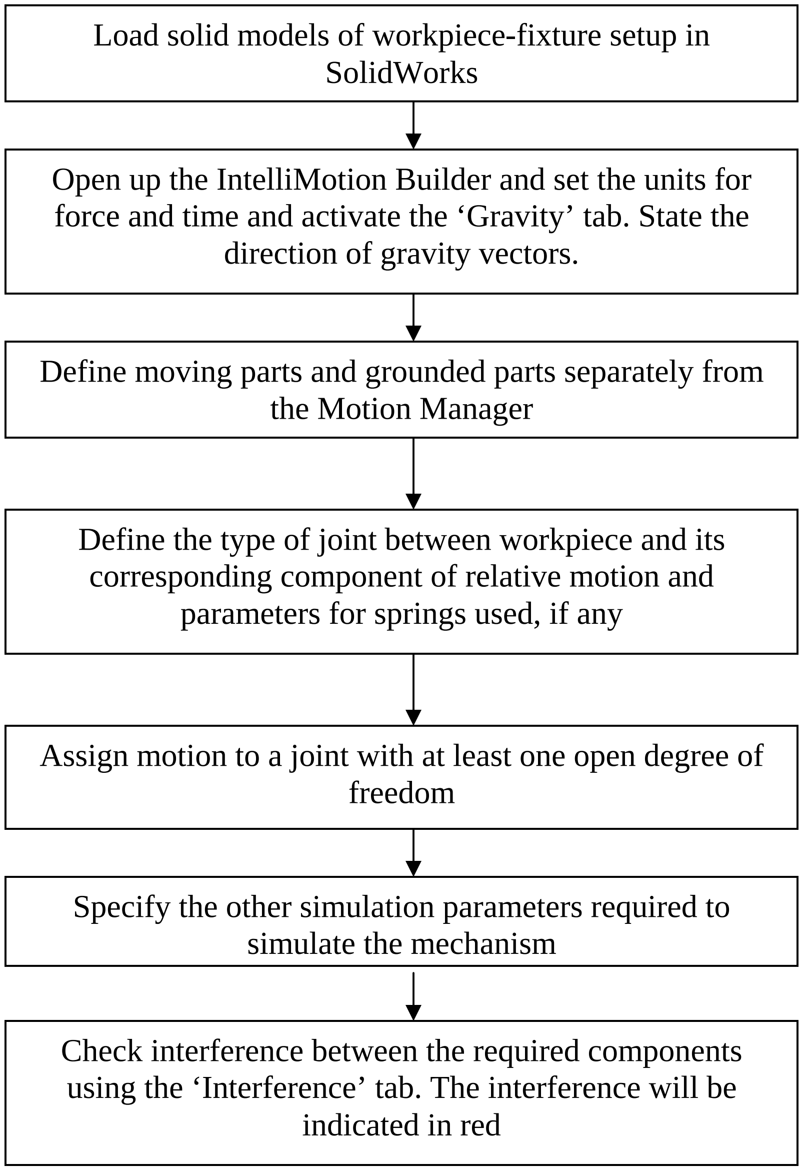


Figure 4.4: Flowchart of procedure for interference check in COSMOS Motion 2007

Simulating loading and unloading paths is one part, and checking interference in the process is another. The former can very well be done using SolidWorks Animator but, interference check cannot be performed by Animator, when there is dynamic interference. Hence, for this purpose, COSMOS Motion 2007 was used to check interference.

COSMOS Motion 2007 is a design software for mechanical system simulation. Embedded in SolidWorks, it enables engineers to model 3D mechanical systems as virtual prototypes. The following gives procedure for interference check in COSMOS Motion 2007:

1. The solid models of workpiece-fixture setup are first loaded into SolidWorks.

2. The next step is to start the IntelliMotion Builder. The builder is a tool to build and simulate any kind of mechanisms, as per the user's requirements. The Units tab should be activated. Under the units tab, the units for force and time are entered. Generally, time in seconds and force in Newton is taken as default.

3. After the units have been set, the next step is to hit the 'Gravity' tab. Under this tab, the 'Gravity On' feature should be marked. The value of acceleration due to gravity is generally taken to be 9.8 m/s^2 by default, unless the user wants to use any other value. Next, the direction vectors for gravity are set.

4. Next step is to define the moving parts and the grounded parts separately. The moving parts list includes all the parts that will undergo motion during simulation. The grounded parts list includes all those which will remain fixed during the simulation of mechanism. Typically, for the kind of simulations this research is focusing on, the workpiece is the only defined moving part and all the remaining parts, including baseplate, fixture components are included under grounded parts.

5. The next step is to define the type of joints. These typically refer to the type of motion the workpiece would have with respect to the grounded parts. Different kinds of joints may be selected, like translational, cylindrical, revolute, planar, universal and many others. Springs may also be defined under the 'Springs' tab, if the mechanism contains any.

6. Under the 'Motions' tab, the use may assign motion to any open degree of freedom. For this, the specific joint should be selected from the tree , the degree of motion where the motion will take place should be selected and then the motion function should be specified.

7. The next step is to simulate the mechanism after setting up the appropriate simulation parameters. This is followed by interference check. Under the 'Interference' tab, all the parts to be tested for interference should be selected. If interference is found to take place, it will be indicated in red at the end of simulation.

After simulation, the user may go back to make changes in the mechanism, if required and iterations of the simulation may be run, until an interference free fixture design is obtained.

Chapter 5: Case Studies for Loading and Unloading Analysis

This chapter deals with the study of two case studies. The procedure for analysis set in the previous section has been applied to the case studies. Also, simulations in SolidWorks Animator and interference check in COSMOS Motion 2007 have been carried out for each of them. They also explains the formation of a time matrix and a method to decide accessibility rankings when a number of fixture designs are being compared.

5.1: Case study 1- A Pump Component:

The first example is that of a pump component. This workpiece has been analyzed for the accessibility-detachability point of view. The machining features for this part are the central hole, the end surfaces on both the sides and the small holes seen in a circular pattern on these surfaces. The machining operations for this component is milling for machining the surfaces and drilling for both, the smaller and large holes.

Following gives an in-detailed analysis of the existing component with respect to it tolerances, loading/unloading simulations and interference, followed by suggestions to improve the fixture design from loading/unloading point of view and its validation.

The analysis has been carried out assuming that the component will mate with other components for use in an assembly of a pump. Thus, it has been further assumed that the hollow section inside the part will be in contact with some kind of fluid always. Thus, the analysis includes the tolerancing and dimensioning of the part, the steps to simulations, the interference check and then, the suggested interference free fixture design.

The following image shows the workpiece to be machined:

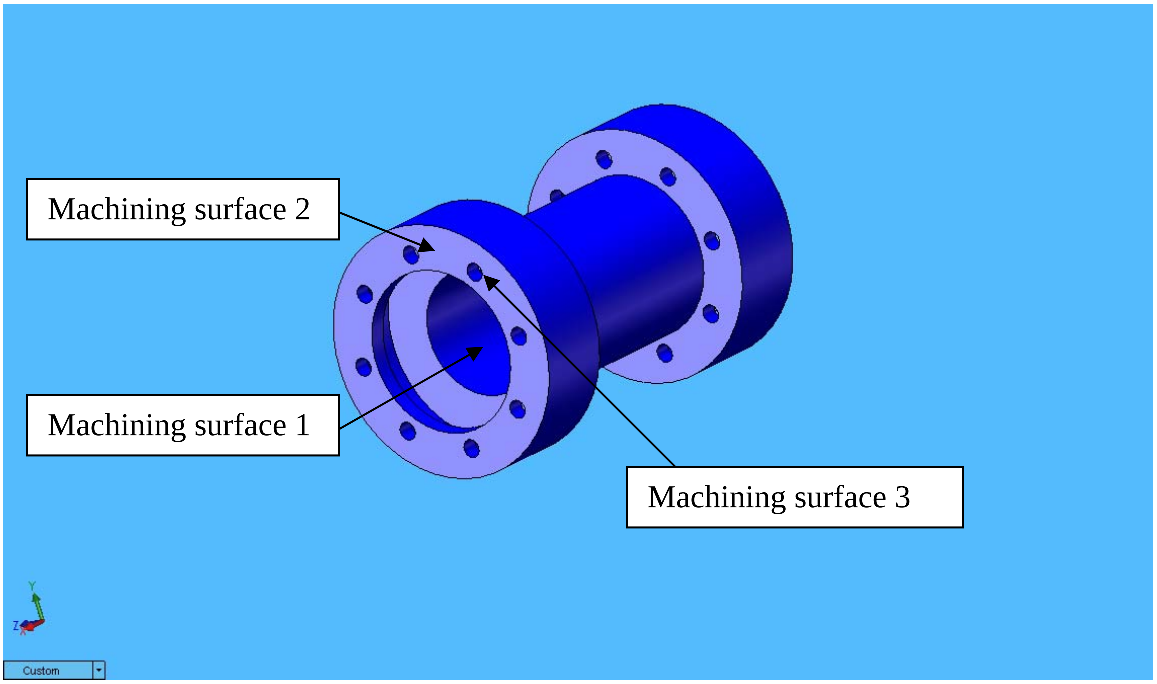


Figure 5.1: The workpiece

The machining surfaces of the workpiece are as shown above. They are:

1. Machining surface 1: The central hole to be drilled. Drilling operation will be used to produce this surface. The diameter of central hole is 35 mm. The analysis of its machining features has been done assuming that it is a cast component.

2. Machining surface 2: The vertical surfaces on the front and rear end of workpiece. End milling can be used to produce these surfaces. The machining of surface at the rear end is more important since it forms the datum for the next set of machining features. Tolerancing of the workpiece has been explained in the next section.

3. Machining surface 3: The smaller holes to be drilled in a circular pattern. Holes have to be drilled in this fashion on both ends of the workpiece. These holes should be through holes so that, they can be used for bolting the workpiece at the time of assembling the workpiece with the other components.

5.1.1 Tolerancing and dimensioning:

The following gives a brief description of the tolerancing and dimensioning to aid the analysis of the part for fixturing purposes:

There are two datums that have been assumed for this purpose.

The first datum surface is the surface A, i.e. the vertical surface at the rear end of the part. The second datum is axis of the central hole B. All the dimensional and geometrical tolerances have been given in reference to these two datums. The only dimensional tolerance that has been given is for the central hole, which measures 35 mm. A bilateral tolerance of 0.01 mm has been assumed for the same. The geometrical tolerances assumed are listed as follows:

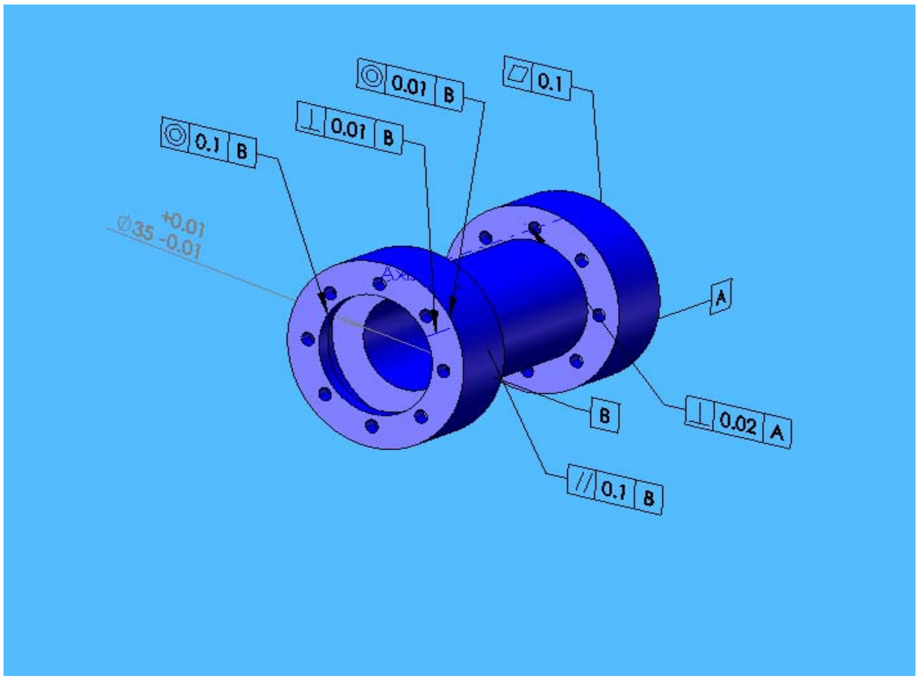


Figure5.2: Dimensional and geometrical tolerances for the workpiece

1. Flatness: The vertical surface of the rear end of the workpiece should be flat since, that surface mates with the primary locating surface of the baseplate. Thus, it has been assigned a flatness value of 0.1 mm. No datum specification is necessary here, unlike the usual methods of assigning geometrical tolerances.

2. Perpendicularity: The front vertical surface has been assigned a perpendicularity geometrical tolerance of 0.01mm with respect to the axis B. This tolerance is very important to make sure that two vertical surfaces of the workpiece remain emerge parallel to each other as a result of the machining operation.

3. Concentricity: The outer hole on the front end of the workpiece has been assigned a concentricity tolerance of 0.1mm with respect to the axis B. This tolerance is to make sure that the all the circular portions of the workpiece remain concentric with axis B, and hence, concentric with each other.

4. Concentricity: The concentricity of central hole with the axis B has been defined with a tolerance of 0.01mm. This tolerance value is greater than the one assigned to the previous concentricity value, because, this is the prime machining feature. It is the central hole of the workpiece that will actually come into contact with any fluid or any other mating assembly component. Hence, it is important to keep its tolerance value higher than the others. It is important that the concentricity of the holes be maintained, because, any disruptions in this feature may cause errors in the machining of the successive features including drilling of the smaller holes on the front end of the workpiece.

5. Parallelism: The axis of small holes in the circular pattern has been assigned to be parallel with the axis B. This will ensure that the drilling of smaller holes take place such that its axis remains parallel with the axis B. Thus, this will keep the smaller drilled holes parallel to the central as well as the other holes of the workpiece, thus, maintaining a consistency.

6. Perpendicularity: The axis of patterned hole is defined perpendicular to the datum surface A with a tolerance value of 0.02mm. This tolerance will ensure the correct positioning of the hole while it is being drilled. Both, the parallelism tolerance defined in (5) and perpendicularity tolerance defined in (6) will make sure, that the correct position of the hole is located for drilling operation to take place.

5.1.2 Process Plan:

Fixtures, as mentioned earlier are important in manufacturing operations, since, they hold the workpiece in place against cutting forces against all the cutting forces. Not to mention, this is a similar case and hence would need an appropriately designed fixture. A total of two setups will be required for machining of the complete component. The first setup will be to machine the vertical surface and drilling holes in circular pattern. Next setup will be drilling of the central hole, the milling of vertical surface and drilling of smaller holes in circular fashion.

5.1.3 Original Fixture Design:

Based on the geometric tolerances and dimensional tolerances given, the fixturing of workpiece was decided. The fixture components consist of three hydraulic clamps and V-blocks. The rear end of workpiece is used as the primary locating surface. Thus, three degrees of freedom will e taken care of, i.e. translational motion in X-direction and rotation about Z and Y axes. Next, the V-blocks take care of two degrees of freedom, i.e. translational motion about Y and X axes. Next, hydraulic clamping system has been made use of. The hydraulic clamps have an advantage over the mechanically operated retracting clamps, since, in case of the former, manual operation of clamps is not required. This shortens the cycle time for loading and unloading the workpiece, which includes the time required for loosening and tightening the clamps also.

Based on the analysis above, following is the fixture design for the given workpiece:

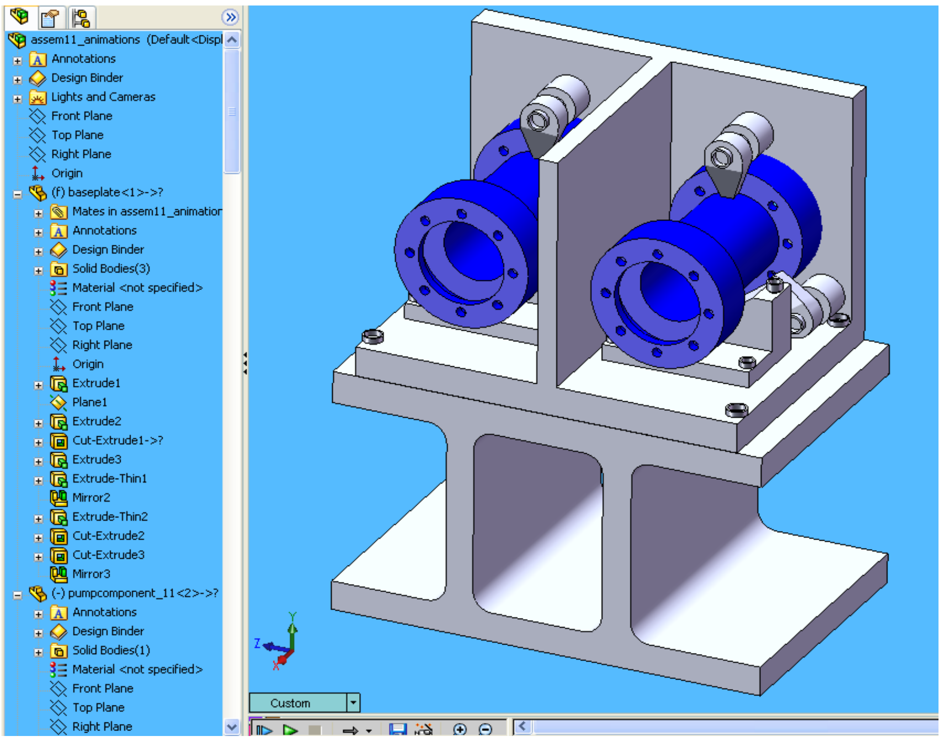


Figure 5.3: Fixture setup for machining surfaces 1, 2 and 3 in the first setup

Apart from the tolerances, we consider one important dimension in the assembly. The dimension of the V-block side surface to the end of baseplate have been shown in the image below. This dimension in the original assembly measures 40.42mm. This dimension specifically is very important from among all the other dimensions in the assembly, because, it defines the loading/unloading problem more clearly and explicitly, as will be seen in the successive sections. The figure below shows three dimensions, dx, dy and dz, out of which the dimension v is of interest to us. It has been marked in red in the image given below.

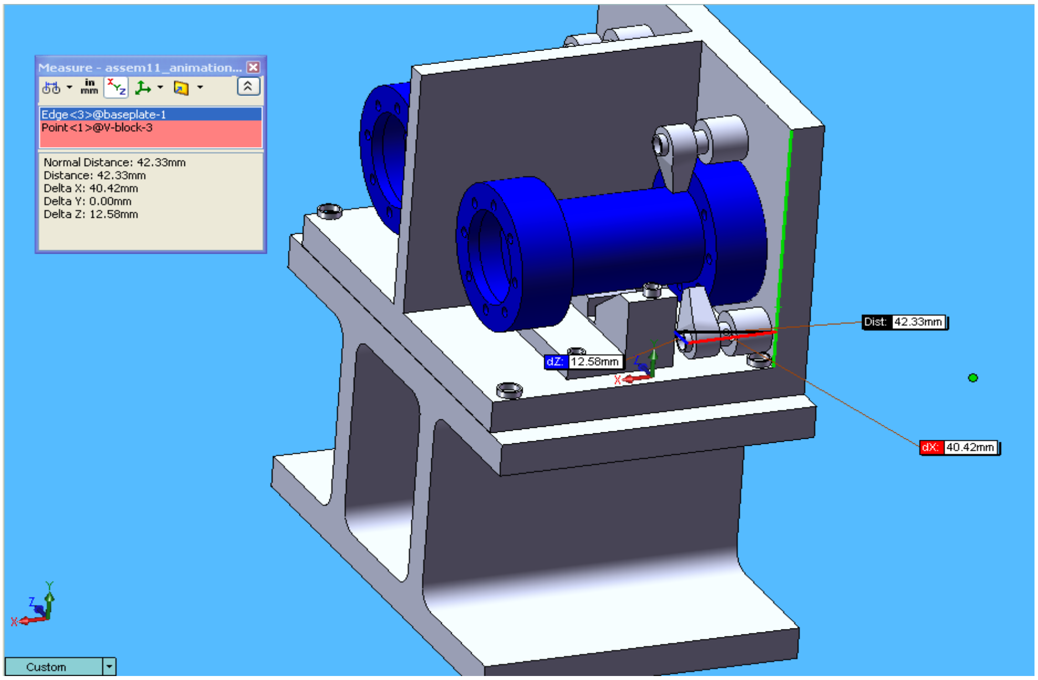


Figure5. 4: Distance 'dx' between V-block and workpiece

The designed fixture poses an accessibility problem. While loading and unloading, the workpiece is bound to interfere with the clamps, during its motion in the positive Y direction. Thus, accessibility analysis becomes a necessity here. Applying the first criterion, it is found that the loading and unloading accessibility analysis is not feasible, since, the workpiece cannot be loaded and unloaded in at least one way from its initial position to the final position without interference. The recommendations are made accordingly.

5.1.4 Workpiece loading and unloading simulations:

The very first step in analysis of workpiece loading and unloading is to check if loading/unloading the workpiece is feasible in the first place, or not. Thus, this refers back to the criteria, which states that the workpiece is accessible if it can be loaded from its initial to final position, in atleast one way, such that it does not interfere with any other elements in the manufacturing environment. The same applied to the detachability also. Thus, this criteria serves as a basic screening criteria to understand whether a workpiece is accessible at all, or not, before we go on to analyzing it for the same.

Applying this criterion to the pump component, we can say that the workpiece can be loaded/unloaded in atleast one way, such that it does not interfere with other components in its environment. As seem from image 1, the assembly of workpiece and fixture components, the workpiece has been located using the vertical surface of the baseplate as the primary locating surface. Next, the V-block is the secondary locating surface. The geometry of workpiece is such that, it has protrusions at both ends, which can possibly make loading/unloading a problem, especially, if there is not enough distance between the V-block and the front vertical surface of baseplate. But, there surely exists atleast one way of loading and unloading this workpiece. This can be done by moving it by some distance in the X-direction such that, it almost touches the surface of V-block, and then moving it in the Y-direction by a distance. This is subject to condition that enough distance be maintained between the V-lock and vertical surface of baseplate, as mentioned earlier.

Simulation of loading/unloading paths in SolidWorks Animator:

Loading and unloading simulations were carried out using SolidWorks Animator, as a primary step towards loading/unloading analysis. The main purpose in simulating the loading/unloading processes were, to enable the measurement of time required for the same, check the interference in the successive steps and be able to comment on the various loading/unloading approaches based on path taken, time taken and interference between fixture components and the workpiece.

The steps followed for simulating the loading and unloading paths were as follows:

1. Turn on the SolidWorks Animator module from the Add-ins standard function of SolidWorks.

2. Open the workpiece-fixture assembly setup, and make sure that the SolidWorks animator icons appear on the screen. Also, when in the Animator mode, the user can see animation tabs, next to the main solid model, thus, indicating that the SolidWorks Animator has been activated.

3. Position the V-block at a distance of 60mm or lesser from the vertical surface of the baseplate. This is done intentionally, to show clearly the loading/unloading problem. Make sure that cylindrical surface of the workpiece mates with the V-block. This can be done by specifying mate conditions between the two components.

4. Generate keypoints on the timeline to simulate the clamps.

Create keypoints for simulating the clamps. Keypoints are created in front of the ‘Move’ function for all the components that have to be simulated.

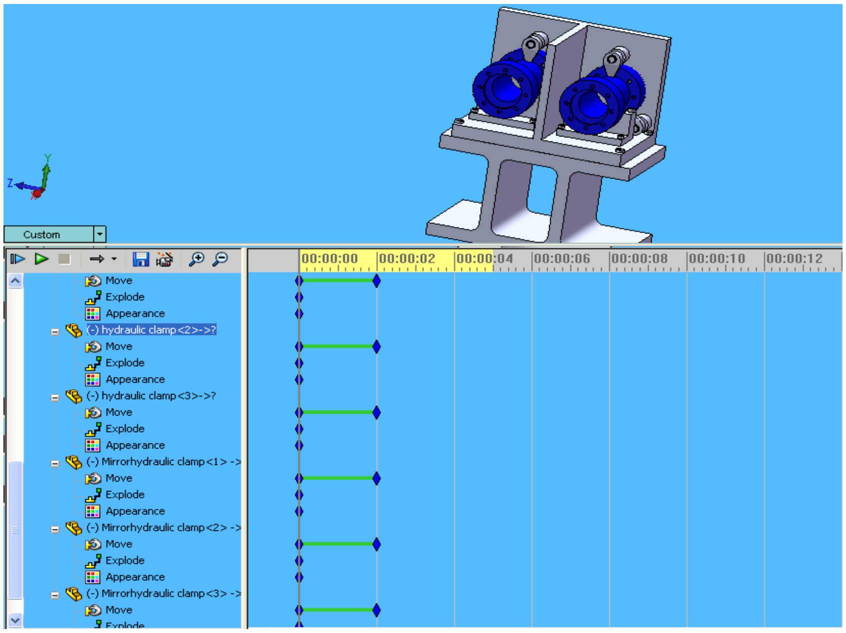


Figure 5.5: Formation of keypoints for simultaneous motion of clamps

Once the keypoints have been created, each of the keypoints are selected turn-by-turn to specify the position of the component as that particular keypoint. The image shown above is for unloading the workpiece from the fixture setup. For unloading purpose, the complete cycle time will include the rotation of clamps, to make way for the workpiece, followed by the movement of the workpiece in the specified direction. Thus, the image above, shows the procedure for rotation of the clamps. Each of the keypoints specified on the clamps indicates its position at that particular instant of time. The first keypoint on the timeline indicated zero time position and the second keypoint indicates position of the clamp after it has been turned, to allow the workpiece to come out of the fixture setup.

Once, the simulation of clamps has been done, the next step is to simulate the workpiece along the same timeline, in relation to the clamps. Again, the procedure consists of creating keypoints along the 'Move' function for each of the components. An important assumption here, is that the loading and unloading of both the workpieces takes place simultaneously. Thus, the time required for loading and unloading both of them will be exactly the same. Thus, while creating keypoints, care should be taken to see that the keypoints for both workpieces are created at correspondingly the same locations on both timelines, to get simultaneous motion of the two. The following image gives a better explanation of creation of keypoints for simultaneous motion.

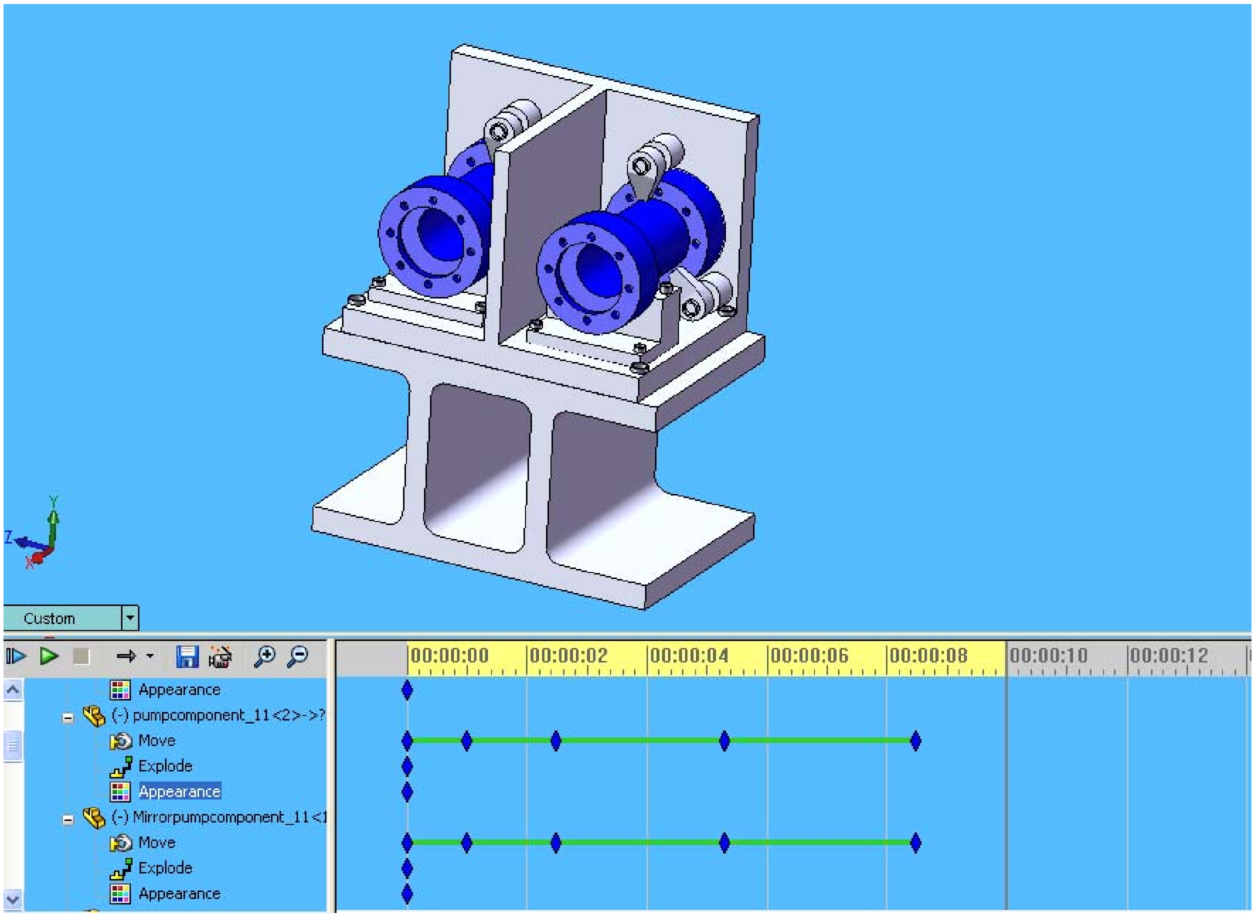


Figure 5.6: Creation of keypoints for simultaneous motion of two workpieces

As seen above, five keypoints have been created to completely define motion of the workpiece. The green color connecting lines indicate that two keypoints have been linked together by defining a motion between them. It should be noted, however, that in this example, no connecting link has been defined above, between the first two keypoints. This means that there is no motion of workpiece between the first and second keypoint. When the workpiece is being unloaded, the first step, as mentioned earlier is to rotate the clamps. Once, the clamps are rotated enough for the workpiece to come out, only then, can the motion of workpiece start. Thus, the first two keypoints define the time for which the workpiece remains stationary, before it actually starts moving after the rotation of clamps. These keypoints can be dragged anywhere along the timeline to adjust the speed of motion of the components.

During unloading, the path defined here is motion in the X direction along the V-block followed by motion in the Z-direction. This case shows loading and unloading for the original assembly, in which case, the distance between the V-block face and vertical face of the baseplate is not enough to let out the workpiece without interference. Thus, interference can be visually seen when simulations are carried out. But, as stated earlier, the major drawback of SolidWorks Animator is that it cannot detect interference between components while in dynamic motion with each other. Static interference can be checked though.

Thus, after the keypoints have been defined and motion at respective keypoints specified, the next step is to simulate the motion. The keypoints can be adjusted in order to achieve the motion required by the user. If it is required to increase the velocity of motion, the distance between the keypoints may be reduced to get the required kind of effect.

Similar procedure is followed for simulation of loading motion into the fixture setup.

For simulating the loading motion, we need to start with the final position of the workpiece, which lies outside the fixture setup. The loading of two workpieces is also going to be a simultaneous motion and hence, keypoints are made at the same corresponding locations for both of them. In this case, however, the cycle time would consist of motion of the workpiece in the Z-direction first, followed by rotation of clamps, to allow the workpiece to move in without interference, followed by motion of the workpiece again, to move in the X-direction and mate with the vertical surface of the baseplate acting as the primary locating surface.

Thus, the initial position of the workpiece is first decided and a keypoint is created corresponding to that position. This will now act as a staring point for loading the workpiece into the fixture setup. Next step is to create keypoints along the path that we want the workpiece to follow. The creation of keypoints is followed by assigning them their corresponding positions and motions. Care should be taken here, because, when loading the workpiece into the fixture setup, the clamps should rotate and close only after the workpiece has completely moved in and has mated with the front end surface of baseplate. If the clamps close before the workpiece moves incompletely (the X-direction movement), then, there is a high possibility of interference taking place during simulations.

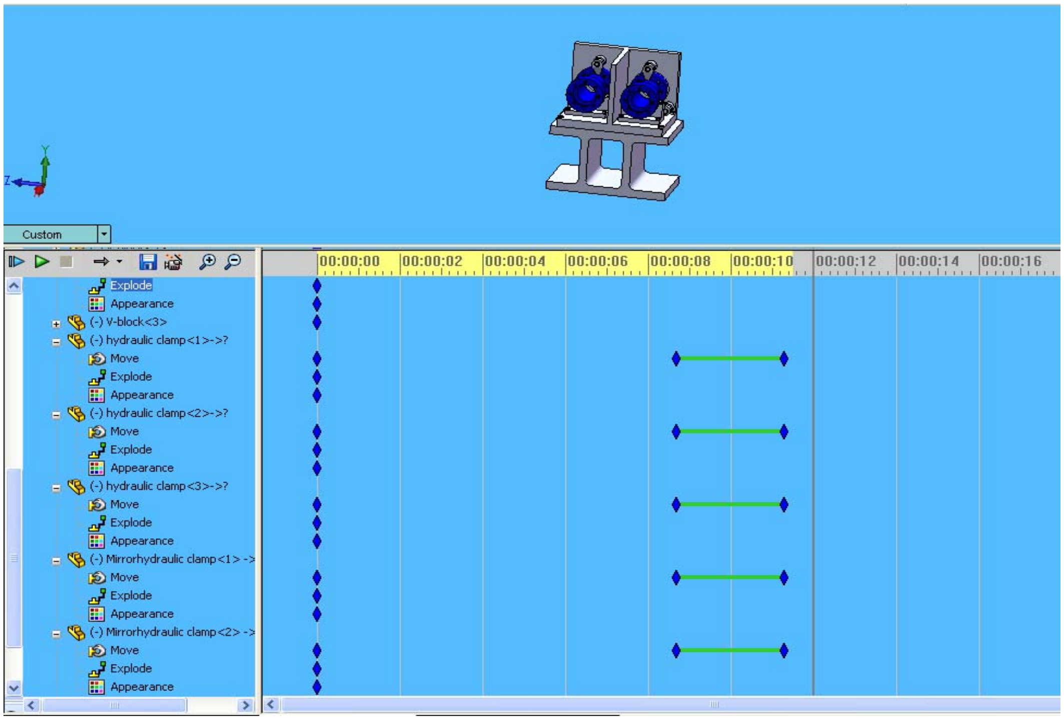


Figure5.7: Adjustment of keypoints for simulation of clamps

The image shows keypoints created for simulating the clamps. The clamps should operate only towards the loading process and hence, the clamps have been shown further away on the timeline. As mentioned earlier, there is no connecting line between the first and second keypoint. This indicates that the clamp remains stationary for that period of time and is activated only when the workpiece reaches the right position with respect to the clamps.

5.1.5 Time measurements:

Unloading process	
Step	Time in seconds
1. Operation of clamps	3 secs
2. Motion in X-direction	2 seconds
3. Movement in Y direction: step 1: step 2:	4 seconds 1 second
4. Movement in Z-direction	3 seconds
Total time:	13 seconds

Table5.1: Time measurements for unloading process

Loading process	
Step	Time in seconds
1. Movement in Z-direction	3 secs
2. Movement in Y direction: step 1: step 2:	1 second 4 seconds
3. Motion in X-direction	2 seconds
4. Operation of clamps	3 seconds
Total time:	13 seconds

Table 5. 2: Time measurements for loading process

From the time steps, it is seen that, on an average, eight minutes are taken up in the second and third stages of both the processes. Thus, in the successive sections, more attention has been paid to minimizing the time taken up in these stages particularly and a few alternatives have been suggested, so as to eliminate them completely, too.

The original assembly has certain problem areas because the distance between the V-block and front end surface of the baseplate is not enough to let the workpiece be removed or put in without interference. As seen earlier, this distance is 40.42mm. Thus, for loading and unloading, the workpiece interferes with the clamps, especially the top clamp. The probability of interference with the remaining two clamps is comparatively lesser, as compared to the one above.

Hence, it is required to make modifications in the fixture design to avoid the interference. For this purpose, the first modification which has been put forth is changing the distance dx in the assembly. With trial and error method, it has been found out that for any distance lesser than 60mm, the interference will still, take place. Thus, the modified assembly now had this distance equal to 60.62mm. thus, it is seen that, since the difference between the required and modified distance is not much, the workpiece will be separated from the V-block by a very minute distance (0.62mm only). Changing this distance in real practice will be very feasible. No changed can be made in the component geometry, since, we keep that as a standard. Thus, this modification can certainly be made to make the fixture design interference free. Also, it can be further said, that the distance can be increased even more, depending upon the user.

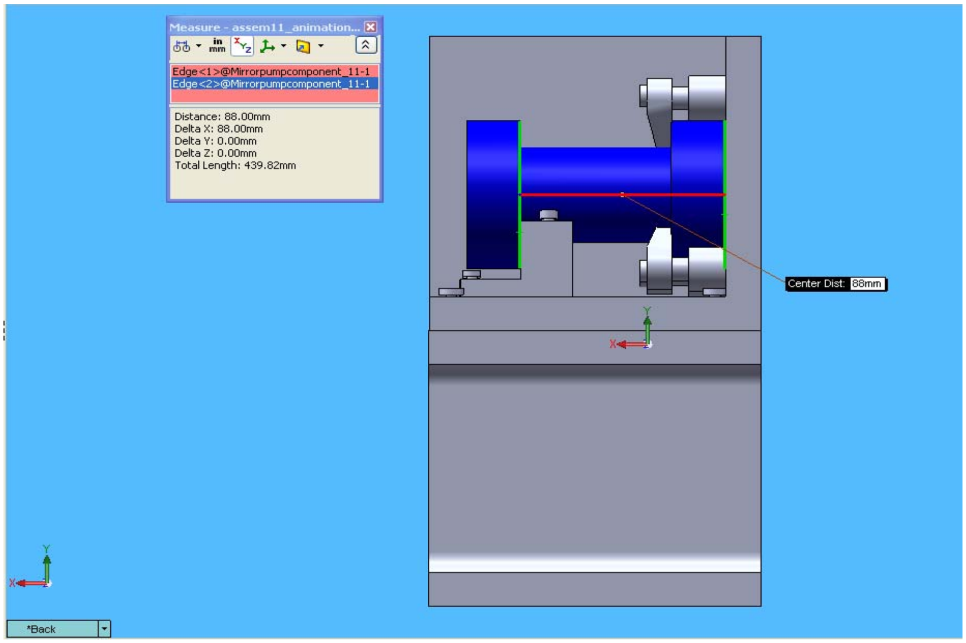


Figure5.8: Maximum possible distance between V-block and workpiece

The image above shows the maximum distance through which the V-block can be moved in order to avoid interference. Increasing the distance any further will cause the V-block to interfere with the workpiece.

5.1.6 Interference detection using COSMOS Motion 2007:

So far, the simulations for loading and unloading have been carried out. But, as mentioned earlier, SolidWorks Animator has a drawback since, it cannot indicate interference in the system, in the dynamic mode. Any kind of static interference only, can be seen. To overcome this drawback, the fixture wokpiece assembly was further taken into COSMOS Motion 2007 and a separate interference analysis was carried out. The following gives the procedure for the same:

1. State units for the Force (external force if any,) and the time. There are no external forces acting in this case and hence, we can safely neglect that. Time has been stated in terms of seconds.

2. Enable the option ‘Gravity On’. State the value for acceleration \(9.81 m/s^2 in this case). Also, specify the direction vectors. The vectors will indicate what direction the motion will take place in.

3. The next step is to specify the moving and grounded components in the assembly. This depends upon which parts have to undergo motion during the simulation. In this case, the

pump components have been specified as moving components and all the others, including the base plate, the hydraulic clamps, the pallet changers and V-block have been stated as grounded components.

4. Next step is to define the joints in the assembly. These joints indicate the relative motion between the surfaces of two components. Here, two translational joints have been defined. Both have been defined for translational motion of the pump component with respect to the V-block. The motion may be defined with respect to any other component also, as long as it lies in the grounded category of parts.

Each translational joint is defined by certain set of properties like the definition of the joint, motion, frictional properties and finite element analysis. An important feature is that the motion properties also allow the user to define the motion that may be a constant or harmonic one, or in form of a step function, or given by a spline or in form of a mathematical expression. The type of function used for this simulation is of the constant type with velocity of 10 mm/sec.

5. An additional tab named ‘Springs’ is also seen if in case, any motion is to be defined in terms of the spring motion. This feature hasn’t been made use of in this case, since, there is no motion controlled by springs.

6. Next step is to define the type of motion. This motion refers to the joints that have been defined in the earlier stage. Also, in addition to this, the user can state the ‘motion on’ parameter with a user defined velocity and displacement.

7. The following step is simulating the mechanism. The simulation parameters make use of the time duration of the simulation and the number of frames. Greater the number of frames, better is the accuracy. The option ‘Animate during simulation is enabled’. If required, the user may also make use of mass properties that might be stored for a particular component, for simulation purposes. After the ‘Simulate’ function is hit, the simulated mechanism is seen in a minute or two. After it ends, the results can be deleted and a new simulation can be started again.

8. An animation file (.avi) can then be created out of the simulation.

9. The last step is to check interference between the moving and fixed components of the assembly. In this case, the distance between the V-block and surface of the baseplate is such that, the pump component cannot be loaded or unloaded without interference. To check the interference, select the components among which the interference check is to be carried out.

Interferences if any, are shown in red in the assembly. The red marks indicate that the components clash with each other at those points when the loading/unloading process is taking place.

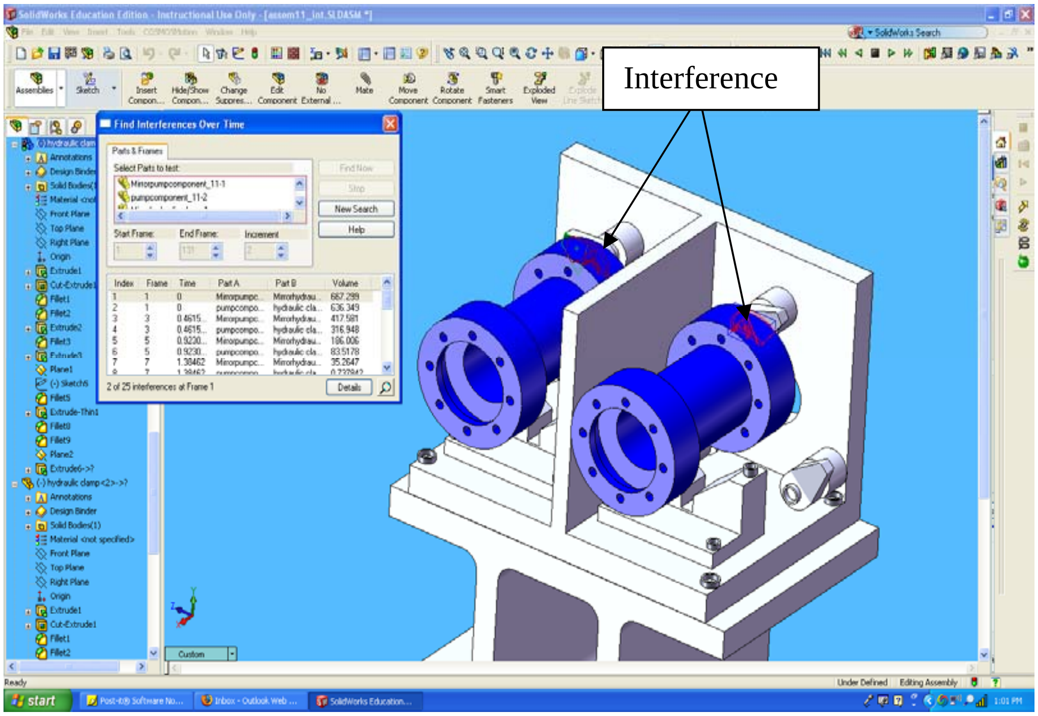


Figure5.9: Indication of interference indicated in red.

Thus, as is seen above, interference takes place at the clamps, hence have been shown in red color. It should be noted that indications of interference are shown on the fixture components only, not on the workpiece. This is because, the workpiece actually clashes with the fixture components a number of times in the process, but, cannot be shown at each of the points on the workpiece. Hence, interference is indicated on the fixture components only.

5.1.7 Improvements in fixture design:

The current design faces a problem for loading and unloading. Hence, the next step is to make modifications in the current design so as to eliminate all the problems that the current design has been facing. The most important problem with this fixture design is that of interference between the clamps and workpiece when the distance between the V-block and front end face of the baseplate as shown in the figure above, is not enough to let the workpiece pass through. Hence, as will be seen in the following section, interference takes place between the workpiece and fixture components. It is necessary to avoid this interference in order to make it a good quality fixture design. Following modifications have been suggested for the same:

5.1.7.1 Modification 1:

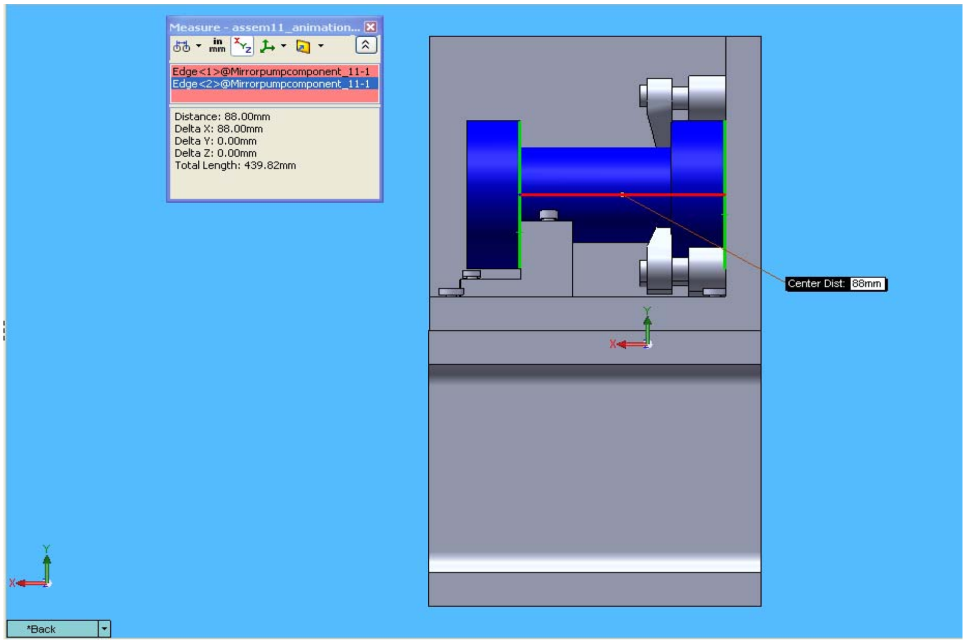


Figure 5.10: Modification 1-Repositioning of V-block

Reposition the V-block. Change the distance between the V-block and front face of the baseplate. It has been found that, for any distance of *dx* lesser than 60mm, the interference takes place. Thus, we can always change the distance of the V-block from baseplate. This is feasible, since, it does not require us to make any modifications in either fixture components or the workpiece. Further, making any kind of changes in the geometry of the workpiece is not feasible. So, that alternative is ruled out immediately.

But, a disadvantage of this alternative is that the time required for loading and unloading in this case is the greatest in this case. It takes a total of 14 seconds, where the total time refers to cycle time, when the distance between V-block and the front vertical face is 60.62 mm. This is because, since the clearance between the workpiece and V-block is very small, the velocity of workpiece should be lesser when it moves out of/into the fixture setup.

Also, the next solution to this problem could have been increasing the distance of V-block from the vertical face to a distance much greater than 60mm, because, the greater this distance can be, the easier loading and unloading will be. But, it is seen, that increasing this distance further causes a stability problem, since, the V-block position becomes such that its center of gravity does not align with that of the workpiece. Hence, increasing the distance might not be the best solution in the end.

Following gives the time split-up for the loading and unloading processes.

5.1.7.1.1 Time Measurements:

Unloading process	
Step	Time in seconds
1. Operation of clamps	3 secs
2. Motion in X-direction	1 second
3. Movement in Y direction: step 1: step 2:	3 seconds 1 second
4. Movement in Z-direction	3 seconds
Total time:	11 seconds

Table 5. 3: Time measurements for unloading process

Loading process	
Step	Time in seconds
1. Movement in Z-direction	3 secs
2. Movement in Y direction: step 1: step 2:	1 second 3 seconds
3. Motion in X-direction	1 second
4. Operation of clamps	3 seconds
Total time:	11 seconds

Table 5.4: Time measurements for loading process

Thus, with this alternative, it can be seen that the time taken for steps two and three are still considerable. This is because, the distance maintained is such that the clearance is very small. Hence, the workpiece motion takes place at a very small velocity, thus, keeping time factor higher. Even though it takes two seconds lesser than the original design, it is not the best design alternative.

5.1.7.2 Modification 2:

Change the position of clamps. The current design has 3 hydraulically operated clamps, spaced at 120 degree each. The clamps are so placed that one clamp is at the top and other two at 120 degrees to it on its either side. The interference problem is traced back to this clamp on the top. Thus, the modified design now consists of three clamps again, but, the position of clamps has changed. Changing the geometry of workpiece is not possible in actual practice. Thus, we can change the arrangement of fixture components to improve the design. For this purpose, the modified design consists of two clamps positioned on the top and one at the bottom. Thus, the two clamps are so positioned, that the workpiece will be able to pass through the space in between them without any interference. Also, it is seen that time required for loading and unloading this workpiece is 10 seconds, which is lesser than the time required in modification one. Thus, we can say, that this design is better than the first one.

The following image shows the modified design with the three clamps in position. One drawback of this modification is that, the V-block might require some geometry modification, to accommodate the change. This is because; the height of workpiece from horizontal surface will increase, if the clamps be repositioned. Thus, the height of V-block needs to be modified accordingly to match the height of workpiece.

This solution is better than the first alternative because in this case, the position of V-block has not been changed at all. Hence, there would be no stability problem as in the earlier case. Hence, this is a more feasible option than the one suggested prior to this one.

Following gives the time split up for the loading and unloading processes:

5.1.7.2.1 Time Measurements:

Unloading process	
Step	Time in seconds
1. Operation of clamps	3 secs
3. Movement in Y direction:	4 seconds
4. Movement in Z-direction	3 seconds
Total time:	10 seconds

Table 5.5: Time measurements for unloading process

Loading process	
Step	Time in seconds
1. Movement in Z-direction	3 secs
2. Movement in Y direction:	4 seconds
3. Operation of clamps	3 seconds
Total time:	10 seconds

Table 5.6: Time measurements for loading process

Thus, the analysis of time measurements here, shows that, time which was earlier taken up by the motion of workpiece in X directions is totally eliminated, since the position of clamps has been changed. Thus, the time required here is lesser than the ones stated previously.

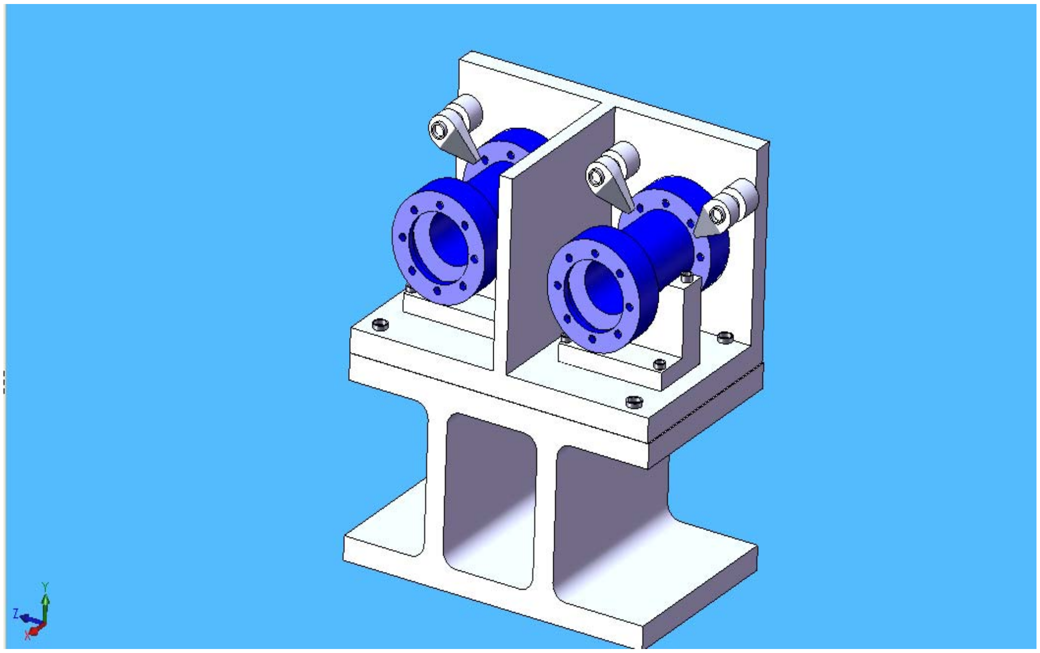


Figure 5.11: Modification 2-Change position of clamps

5.1.7.3 Modification 3:

No clamp repositioning, but V-block geometry is modified. Modifications of V-block geometry can also eliminate the problem of interference. If the width of V-block be reduced such that, it makes more room for the workpiece to be loaded and unloaded. Reducing the width of V-block increases distance of V-block from the front face of the baseplate and hence, can prove to be a feasible design modification.

The following image gives a clear picture of the design modification.

Reducing the width of V-block gives greater space between the vertical face of baseplate and the V-block face. Thus, loading and unloading becomes easier since, there is greater scope to remove the workpiece without any interference with surrounding components. An advantage of this design modification is that, lesser time will be required for loading and unloading, since, there will be comparatively looser tolerances in this case, than in the above two cases. Thus, the workpiece can be removed with greater velocity and with lesser possibility of interference with its fixturing environment.

Simulations show that the time required for loading and unloading for this modification is 9 seconds.

5.1.7.3.1 Time Measurements:

Following gives the time split-up for the same:

Unloading process	
Step	Time in seconds
1. Operation of clamps	3 secs
2. Motion in X-direction	2 second
3. Movement in Y direction: step 1: step 2:	2 seconds 1 second
4. Movement in Z-direction	3 seconds
Total time:	11 seconds

Table 5.7: Time measurements for unloading process

Loading process	
Step	Time in seconds
1. Movement in Z-direction	3 secs
2. Movement in Y direction: step 1: step 2:	1 second 2 seconds
3. Motion in X-direction	2 second
4. Operation of clamps	3 seconds
Total time:	11 seconds

Table 5.8: Time measurements for loading process

The image below shows that when the V-block is modified, there is no change of distance required.

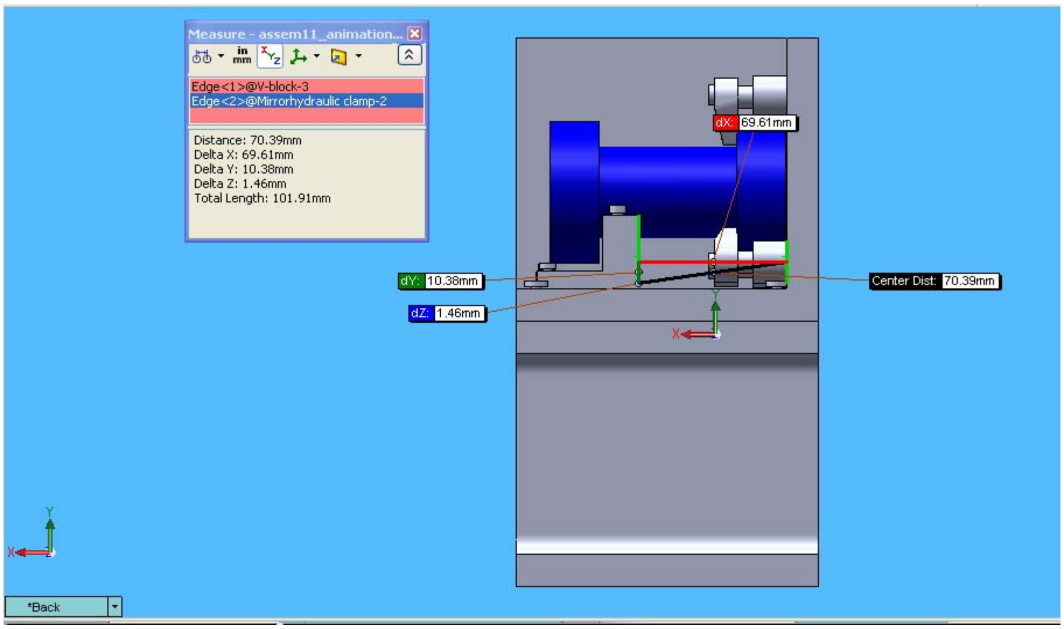


Figure 5.12: Modification 3- Change the geometry of V-block

On the other hand, without making any changes in dx, loading and unloading process becomes easier, thus, leaving more space for workpiece to travel in and out without any constraints. The distance dx here, measures 69.61mm which is far more than the condition of minimum distance put forth in the section earlier. This, as visible from the simulations, is because, since, the tightness of clearances reduces; the process can take place at a much faster rate, thus reducing the time to a great extent. But, a drawback at the same time, is that the V-block position exceeds past the center of gravity of the workpiece. This might affect the stability of the workpiece. Stability of workpiece is equally important in manufacturing systems, to be able to help the workpiece firmly and steadily against the cutting forces. Thus, from the stability point of view, this would not be a very feasible option.

Thus, it is seen that time can certainly be one of the factors to analyze the given workpiece fixture setup for loading and unloading. If the time required is lesser, we can say that loading and unloading accessibility is better and vice-versa. Here, one of the intentions have been also to enable a comparison between the ‘good’ and ‘better’ fixture designs, and not only the

Step	Original design	Repositioning of V-block	Change in position of clamps	Modification of V-block geometry
UNLOADING PROCESS				
Operation of clamps	3 secs	3 secs	3 secs	3 secs
Motion in X-direction	2 secs	1 secs	**step eliminated**	2 secs
Motion in Y-direction	step 1: 4 secs step 2: 1 sec	step 1: 3 secs step 2: 1 sec	4 secs	step 1: 2 sec step 2: 1 secs
Motion in negative Z-direction	3 secs	3 sec	3 secs	3 secs
Total time	**13 secs**	**11 secs**	**10 secs**	**11 secs**
LOADING PROCESS				
Motion in positive Z-direction	3 secs	3 secs	3 secs	3 secs
Motion in negative Y direction	step 1: 1 sec step 2: 4 secs	step 1: 1 sec step 2:	4 secs	step 1: 1 sec step 2: 2 secs
Motion in negative X direction	2 secs	1 secs	**step eliminated**	2 secs
Operation of clamps	3 secs	3 sec	3 secs	3 secs
Total time	**13 secs**	**11 secs**	**10 secs**	**11 secs**

Table 5.9: Time matrix for Case Study1

‘bad’ and ‘good’ ones. Thus, the next step was to validate the modified fixture designs.

Hence, simulations were again carried out, with the modified fixture design. Similar procedures like the ones described above were followed. Similarly, the interference was also carried out for the modified fixture designs. It was found that after the modifications were made, there is no interference. Thus, with a number of alternative solutions, an interference free fixture design can be obtained. After careful analysis of each of the alternatives stated above, we find that alternative no. 2 is the best possible solution. This is because, the time for loading/unloading is minimum and in addition to this, the stability of workpiece is also maintained since the V-block position passes through the center of gravity of workpiece.

5.1.8 Comparison of results:

The following matrix provides a comparison of results and factors that affect the loading and unloading for this particular fixture workpiece setup.

Rankings: Best: 5, Better: 3 and 4, Good: 2, Bad: 1

Factors affecting loading/unloading	Time Unloading	 Loading	Accessibility Rankings	Remarks
1. Position of clamps a. Original position	13 secs	13 seconds	1	Interference takes place
b. Changed position	10 secs	10 secs	5	1. Motion of workpiece in X-direction completely eliminated. 2. Path optimized as compared to all others
2. Width of V-block a. Width >25mm	13 secs	13 secs	1	Even though stability of workpiece is good, time required is considerably greater
b. Width changed to 17mm	11 secs	11 secs	3	Stability of workpiece affected, even though time is reduced
3. Distance '*dx*' a. '*dx*'<60mm (40.42mm)	13 secs	13 secs	1	Time required for loading and unloading higher due to tighter clearances
b. '*dx*'>60 mm	11 secs	11 secs	2	Stability problem because V-block position does not pass through center of gravity of workpiece
4. Operation of clamps a. Manually operated	more than 13 secs	more than 13 secs	1	Time required considerably higher
b. Hydraulic/ pneumatic operated clamps	10-13 secs	10-13 secs	2-5	Ranking will be affected by first three listed factors accordingly

Table 5.10: Accessibility rankings of fixture designs based on comparisons

5.2: Case Study 2- An Automotive Clutch Housing

The next example of analysis is the automotive clutch housing. The objectives of analysis are to evaluate its fixture design from quality point of view, simulate loading and unloading processes, detect interference, if any and lastly, suggest modifications to obtain an interference free fixture design. The following image shows the clutch housing and its machining surfaces.

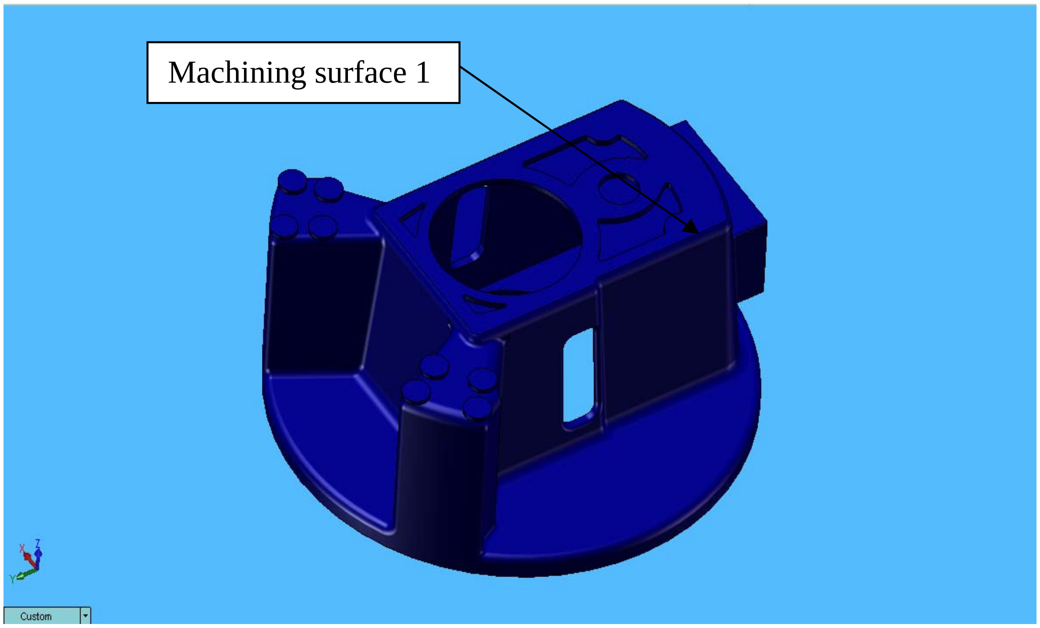


Figure 5.13: Machining surface 1 on the workpiece

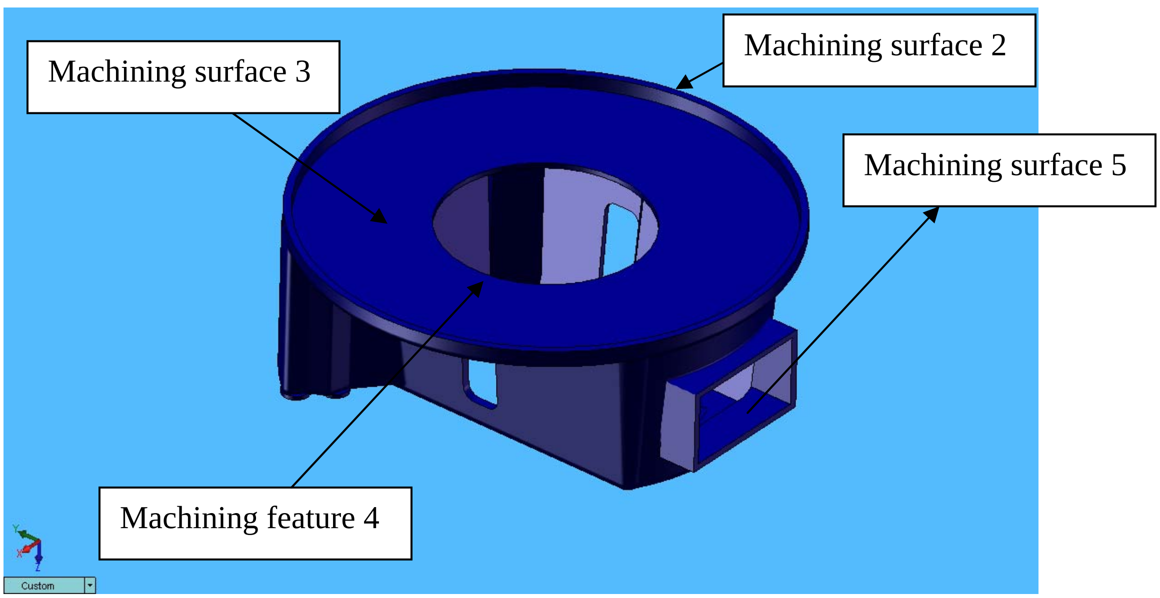


Figure 5.14: Machining surfaces 2, 3 , 4 and 5 on the workpiece

Following are the surfaces to be machined on the clutch housing:

The component is basically manufactured as a cast component. After casting has been done, the following surfaces are machined to give it the required tolerances.

1. Machining surface 1: This surface is the flat face on the top, as can be seen. The three slots in the surface are still part of casting. The face milling operation is used and no machining takes place for the slots in surface.

2. Machining surface 2: This surface has been considered as datum surface, while machining of surface one. Hence, machining of this surface is very important.

3. Machining surface 3: This surface is the one on the underneath of the component as shown in the image. This surface does not act as datums for any of the fixturing setups, but, machining of the surface will be important, if the user wished to use it as one of the manufacturing datums.

4. Machining feature 4: The machining feature here is drilling the central hole. This hole has already been cast, when the component has been initially manufactured. But, casting a hole of bigger dimension is not usually recommended. Hence, the hole is cast to a dimension lesser than the required one and then, the boring or drilling operation may take place to bring it to the required dimensions. The machining of this hole will be important while assembling the workpiece with its counterparts.

5. Machining surface 5: This surface contacts with the secondary locator directly, and hence, should be machined.

5.2.1 Tolerancing and dimensioning:

The following section gives an in-depth analysis of geometrical and dimensional tolerances:

The only dimensional tolerance that has been given on the workpiece is for diameter of hole on surface one. It has been assumed that this hole has to mate with other parts during assembly, and hence, needs dimensional tolerancing. Its diameter is 51.67mm and the required tolerance has been assumed to be +/- 0.01 mm.

The geometrical tolerances are as listed below:

1. Datum A: As seen, datum A forms the manufacturing datum for machining surface one. Datum A is the outer ring of surface on the rear end of component which runs parallel to the top surface. This datum has been selected so as to act as the bottom locating surface while designing a fixture setup for the same.

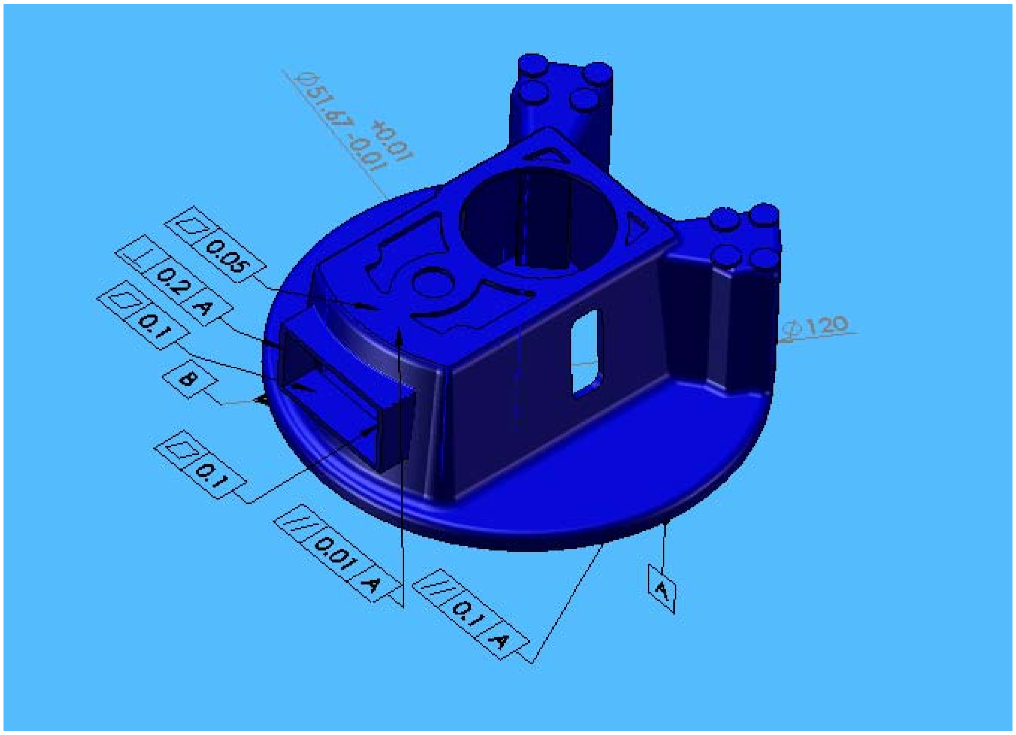


Figure 5.15: Tolerances and dimensions for the clutch housing

2. Datum B: The diameter of datum surface A forms the datum B. In this case, the axis has not been chosen as datum. The reason for selection of a diameter as a datum, instead of an axis is that there are a number of circular features that have the same axis. Selection of axis as datum does not specify which diameter the axis corresponds to. Hence, the outer most circular profile has been chose, which measures 120mm in diameter. Thus, the datum B corresponds to this diameter, rather than its axis.

3. Flatness: A flatness tolerance of 0.1mm has been assigned to the top surface, assuming it to be an important machining feature.

4. Parallelism: A geometrical tolerance of parallelism has been assigned to the machining surface one. This surface should be parallel to the datum surface A.

5. Flatness: The rectangular protrusion on the front end of workpiece has been assigned a flatness tolerance of 0.1mm. This tolerance, too, is important because it acts as a secondary locating surface for fixturing purposes. Hence, it should have the required accuracy.

6. Perpendicularity: A perpendicularity tolerance of 0.2mm has been assigned to the front face of the rectangular protrusion (stated in the previous geometrical tolerance). This feature should have the required perpendicularity to mate with the secondary locating component appropriately.

7. Concentricity: A concentric geometric tolerance has been assigned to the central hole on the rear end, which measures 51.67mm in diameter. This hole should be concentric with the diameter that forms datum B, i.e. the outermost circular profile of 120mm in diameter. This is assuming that the hole has to mate with other components during assembly and hence, has been considered as an important feature in tolerancing.

8. Parallelism: A geometric tolerance of parallelism has been assigned to the surface on the rear end of the workpiece. This surface is separated from the datum A by a few millimeters. It should remain parallel to datum surface A for fixturing purposes.

9. Flatness: The inner surface which contacts with the secondary locator has been assigned a flatness tolerance of 0.1mm. Since the surface comes in direct contact with the inner surface, it should have high locating accuracy.

5.2.2 Process plan:

The clutch housing, unlike the pump component is unsymmetrical and hence, needs greater and in-depth analysis. For complete machining of the workpiece, three setups will be required. The first one will be for machining the surface two, since that has been considered as of the design and manufacturing datums, and the machining of surface three and feature four. The next setup will be for machining surface one, i.e. for the top surface. The third setup will be for machining surface. This analysis deals in greater details with machining setup for machining feature one. Before designing the fixture, it is necessary to carry out the tolerancing.

5.2.3 Original Fixture Design:

Based on the tolerancing analysis, the fixture design below given below has been suggested.

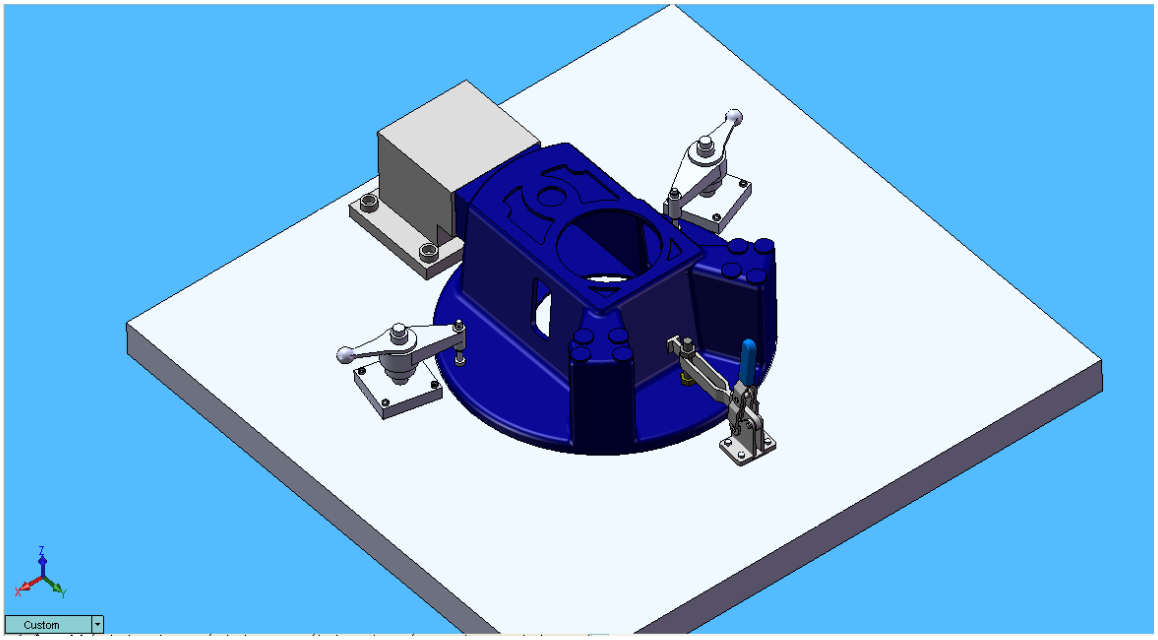


Figure 5.16: Fixture setup for machining surface 1

This fixturing setup is for machining the top surface of the workpiece only. It consists of a base plate, a secondary locator block, two swing clamps and a toggle clamp. For locating purposes, the datum A acts as a primary locating surface. This restricts three degrees of freedom, hence, namely the translational motion about Z-direction and rotational motions about X and Y directions. The fixture block restricts the translational motion in Y-direction. In order to avoid the rotational motion about Z-axis and the translational motion about X-axis, the secondary locating fixture block has an extrusion on its front surface. This fits perfectly into the rectangular hole on the side of workpiece.

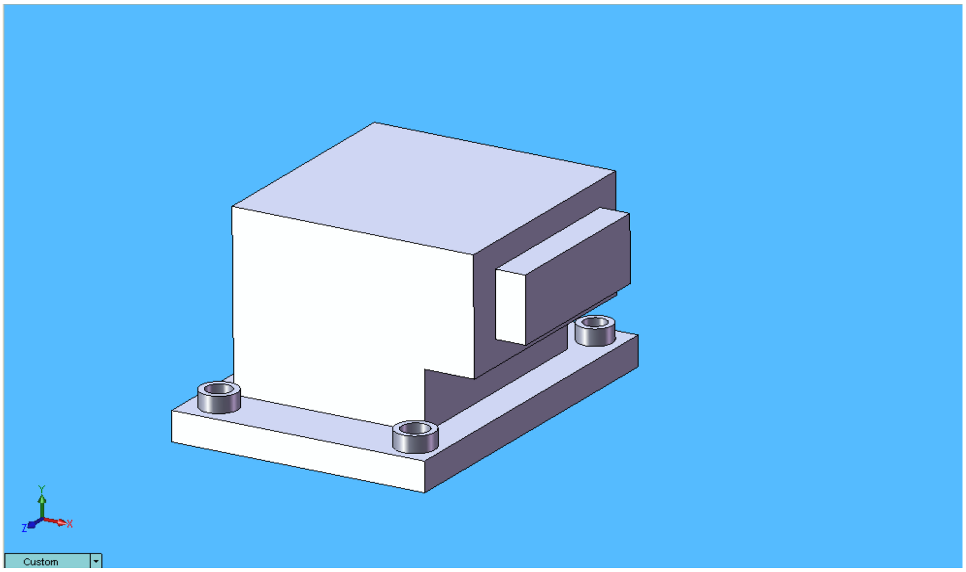


Figure 5.17: Secondary locator used in setup 2

An important assumption made for this case study is that machining takes place on traditional machines; hence, manual handling is more feasible to suit the method of manufacturing. Manual handling refers to operation of clamps for loading and unloading of workpiece. The fixture setup uses swing clamps, which operate in such a way that when the nut bolt arrangement is loosened, the lever can be swung through 180 degrees for loading and unloading the workpiece and through an additional seven deg. in order to tighten/loosen it. Also, a toggle clamp has been to keep the workpiece in position against the locating surfaces. This toggle clamp is different from the standard clamps because, it serves a dual purpose. It provides a force vertically downwards to hold the workpiece against the primary locating surface and at the same time also has an extrusion on its front end that pushes the workpiece against the secondary locator.

The designed fixture has an accessibility problem, because of extrusion on the secondary locator. The workpiece should carefully be moved in or out while loading and unloading to avoid interference with the extruded section. Hence, the workpiece essentially has to move through a minimum distance equivalent to the distance of extrusion. Applying the first criterion, it is found that, there exists atleast one way of loading and unloading the workpiece from its initial to the final position, in or out of the fixture setup.

5.2.4 Workpiece loading and unloading simulations:

The accessibility problem in this case can be defined by the extrusion on secondary locator fixture block. The only possibility of interference during loading and unloading is if the workpiece is moved directly out of the fixture setup without moving it out of the extruded part by a sufficient distance. The first set of simulations illustrates the possibility of interference in fixture setup.

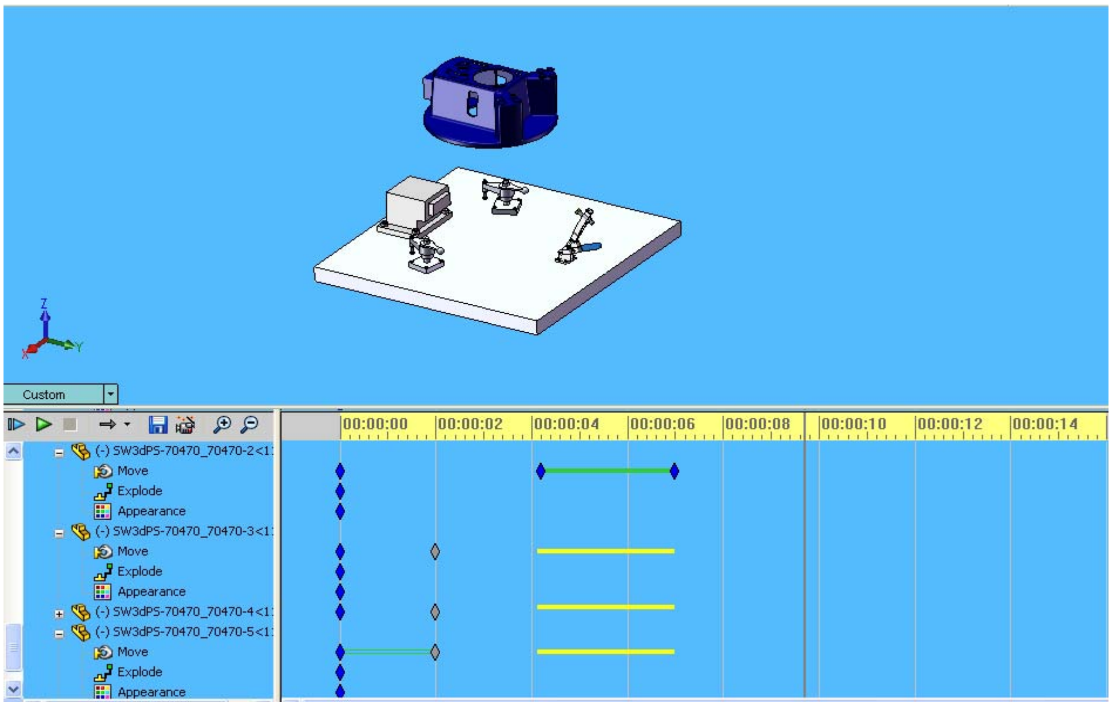


Figure 5.18: Formation of keypoints for dependent motion

For simulations, the following steps were followed:

The unloading process:

1. The cycle time is the time required for loading and unloading the workpiece including the time required to rotate the clamps out of/into their position. Thus, for unloading process, we start with the formation of keypoints for rotation of clamps followed by unloading motion of workpiece. A similar process to the one stated in the previous case study was followed to form keypoints for fixture components. Keypoints were formed in front of the 'Move' function in the feature manager tree. The keypoints are formed as per the order to be followed when operating the clamps. This depends upon what order are the three clamps operated in and accordingly, the time span between them was adjusted. The time span for keypoints was adjusted on the timeframe as shown in the image above. The keypoints were

so adjusted that the clamps operate one after the other. This was done since, it has been assumed that the operation of clamps if manually done.

An important point to be noted in this case study is the formation of keypoints for dependent motion. The toggle clamp was assembled in the main assembly itself, in order to make possible the dependent motion. Dependent motion refers to motion of other components of the toggle clamps when its lever is operated back and forth. This dependent motion is indicated by the grey colored keypoints and yellow lines as shown in the image above. The yellow lines indicate that the respective components have motion dependent on that of a previously defined one.

2. Once the keypoints for clamps were adjusted, the next step was to simulate the path of workpiece. The only interference taking place in this case would be if the workpiece is loaded and unloaded directly, without moving it through the distance equivalent to the extrusion distance. The intension of this simulation is to illustrate the same effect. In order to avoid the interference, the workpiece has to be moved through a minimum distance of 5mm in the Y-direction and then move in the Z-direction for the purpose of unloading and vice-versa for loading process.

The first simulation shows possibility of interference during the loading and unloading processes. For the purpose of simulation, the workpiece should move through any distance lesser than 5 mm to illustrate the interference clearly. This is taken care of when specifying the path of workpiece. The ideal path of motion for loading and unloading would be when the workpiece initially moves in the Y-direction as stated earlier and then in the Z-direction, once the clamps have been rotated and vice-versa for loading process. Thus, it has been assumed here, that the workpiece has not been moved by the minimum distance and hence, interference takes place.

But, the chance of such an interference taking place is not very high. Generally, the operator will move the workpiece through enough distance to load and unload it. This is illustrated in the second simulation. This is an improved case of the initial one, because, the workpiece motion takes place so as to avoid any possible interference.

The loading process:

The keypoints were formed in front of the ‘Move’ function. The timespan between three clamps was adjusted to show that they are being operated one after another. The timespan needs careful manipulation in this case, otherwise, improper manipulation may lead to

interference between clamps and the workpiece during the simulation. Once the clamp keypoints have been formed, the motion of workpiece is simulated. This time, the workpiece motion first takes place by a minimum of 5mm in the Y-direction and then, in the positive Z-direction and then again in positive Y-direction for unloading and vice-versa for loading. Thus, interference is taken care of. But, the workpiece motion is such that its motion is just past the rectangular extrusion in the secondary locator. Thus, this may create a clearance problem. Greater the clearance, lesser will the velocity of motion be and hence, more the time required for loading and unloading. Following shows a clear view of the simulation:
The image below shows the time taken for the workpiece to unload in four different sections. As seen, the first and second section time spans are the longest. Both the time spans are for considerable amount of time since the clearances are very small. This illustrates very clearly, that clearances affect the loading and unloading process of workpiece and hence the time taken for each process.

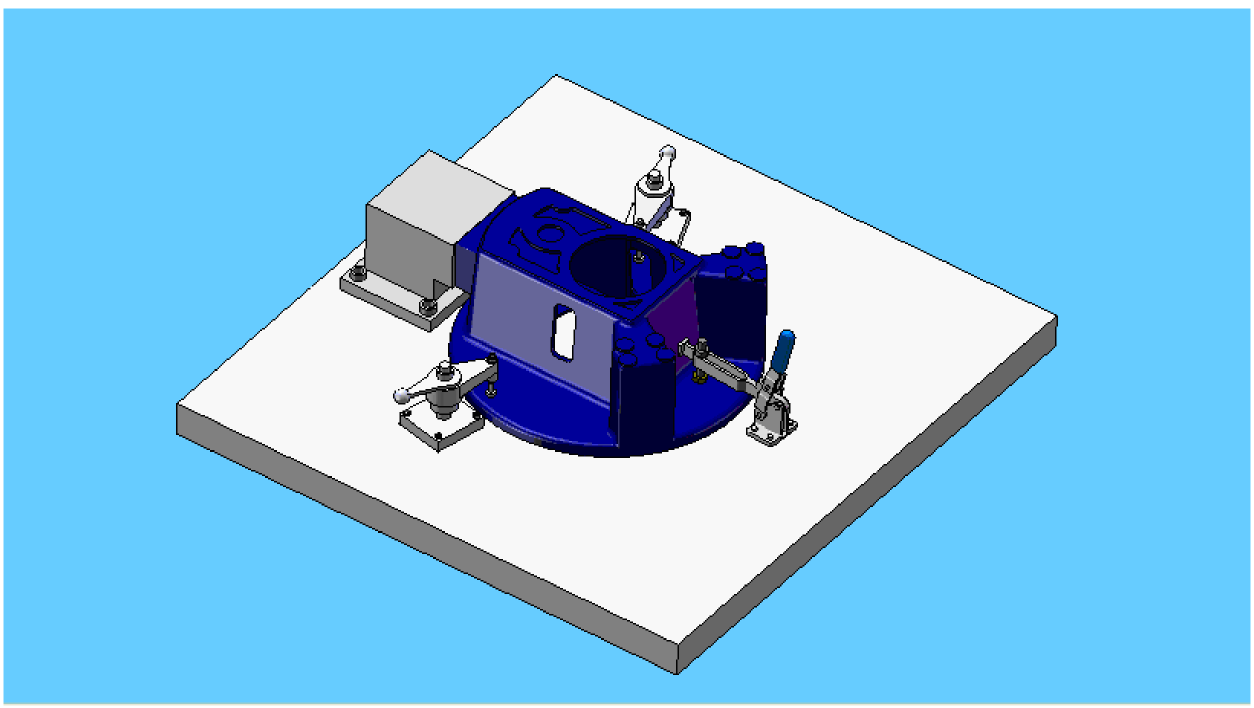


Figure 5.19: Effect of clearances on loading and unloading of the workpiece(1)

Similarly, in case of loading of workpiece, the same observation can be made. Following gives a better illustration for the same.

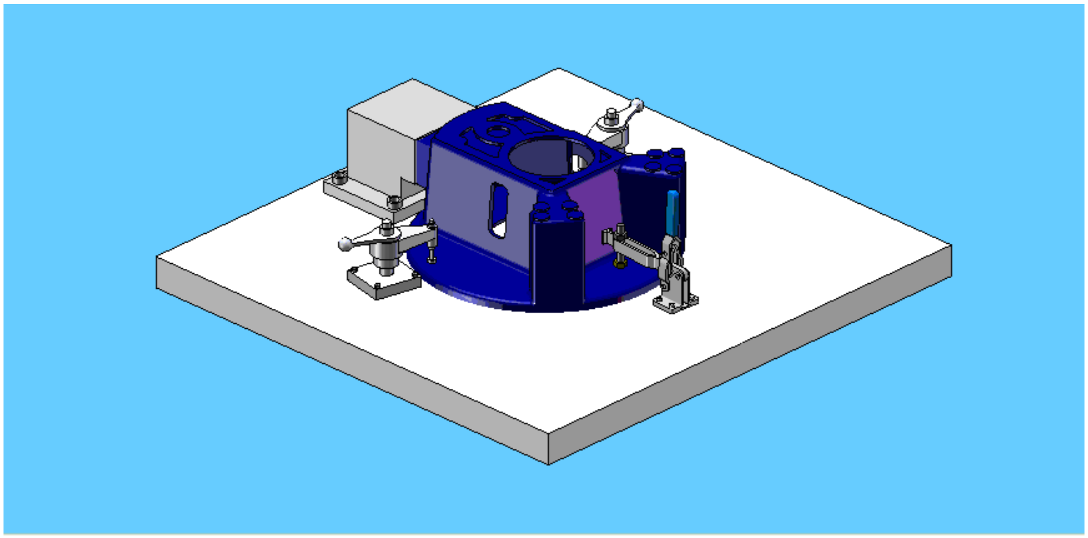


Figure 5.20: Effect of clearances on loading and unloading (2)

In case of the loading process too, it is seen that the time taken by workpiece is maximum in the last two sections, both of which are because the clearances in those sections are very small. The clearances being lesser, loading process should take place at a slower pace, and hence, more the time for loading and unloading process.

It is seen that this although, there's no interference in the second case, the time required for loading and unloading process is 30 seconds. This is a considerable time period and hence, in the following sections, suggestions have been made to bring down the cycle time by improving the fixture setup and hence, making loading and unloading easier and better.

5.2.5 Time Measurements:

Following is the time measurement split up for its loading and unloading simulation:

Unloading process	
Step	**Time in seconds**
1. Operation of clamps	9 secs (+30 secs tolerance)
2.Movement of workpiece in positive Y-direction	7 secs
3.Movement of workpiece in positive Z-direction	step 1: 5 secs step 2: 1 sec
4.Movement of workpiece in positive Y-direction (last stage)	4 secs
Total time	56 secs

Table 5.11: Time measurements for the unloading process

Loading process	
Step	**Time in seconds**
1. Movement of workpiece in negative Y-direction	5 secs
2. Movement of workpiece in negative Z-direction	step 1: 1 secs step 2: 5 secs
3. Movement of workpiece in negative Y-direction	7 seconds
4. Operation of clamps	9 seconds (+30 seconds tolerance)
Total time	57 seconds

Table 5.12: Time measurements for loading process

5.2.6 Interference detection in original design:

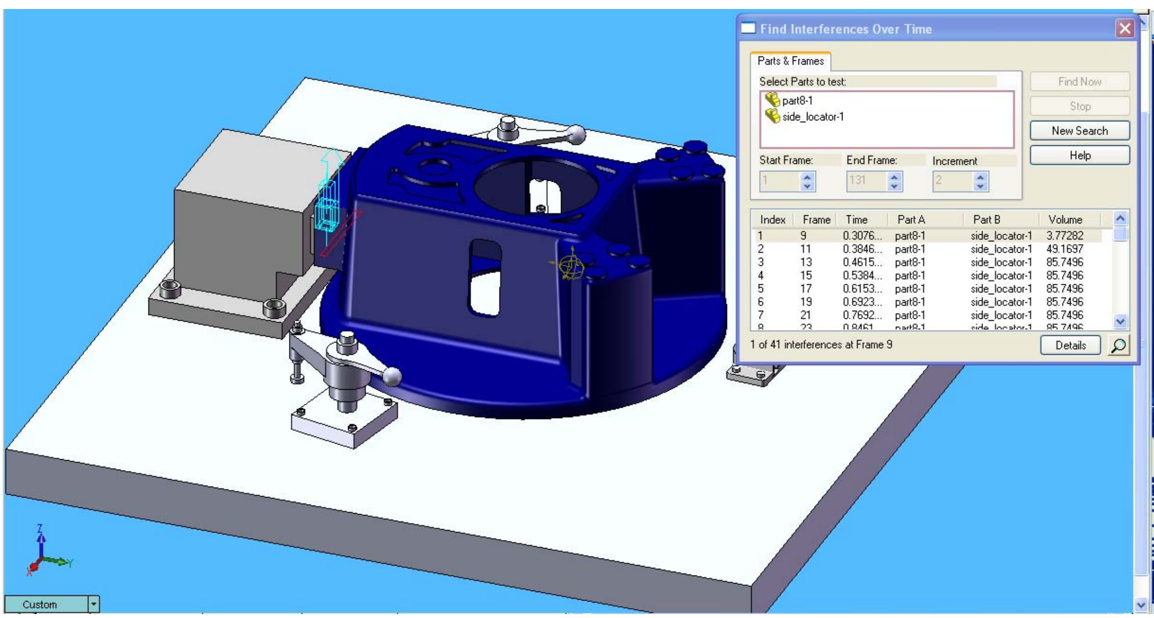


Figure 5.21: Interference between workpiece and locator indicated in red

The following steps were followed to detect interference using COSMOS Motion 2007. As stated earlier, the main drawback of SolidWorks Animator is that it does not allow the user to detect any dynamic interference that takes place in the process of loading and unloading. The only interference that may take place here, is if the workpiece is moved through a distance of lesser then 5mm in the positive Y direction during the process of loading and unloading.

The procedure for interference check can be summarized as follows:

1. Specify the units from the assembly settings. Units used here are N and seconds for force and time respectively. In this case, there is no external force acting on the assembly, so it may be conveniently left aside.

2. Go to the ‘Units’ tab and activate the ‘gravity on’ feature. State the direction vectors in the X, Y or Z direction. In this case, the direction vector is specified in the positive direction, since, the motion of workpiece is required in that direction. Check the value of ‘acceleration due to gravity’ and make sure it is set to 9810mm/s^2. This value is generally assumed by default in COSMOS Motion if the user does not specify.

3. The next tab ‘Parts’ allows the user to specify the components in assembly that will undergo motion and those that will be grounded (fixed). In this case, we specify the workpiece as the only moving part and fixture components including baseplate as fixed components. Selection of these components is made possible by going to the Motion manager tree on the left of the SolidWorks screen. It is indicated by two gears in mesh with each other.

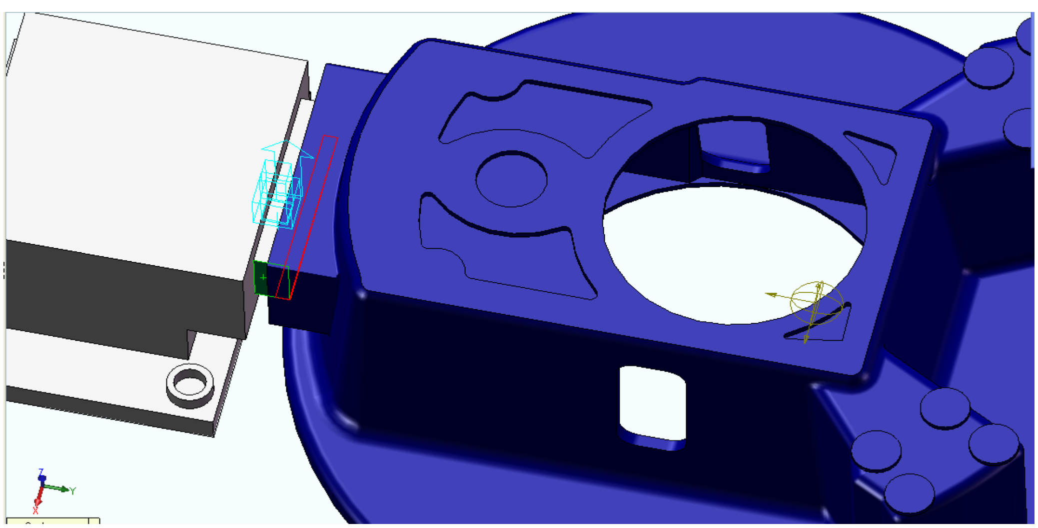


Figure 5.22: Interference check – A closer view

4. The next step is to define the joints. Joints are defined to specify the relative motion among different components of an assembly. In this case, a translational joint between the workpiece and secondary locator block is required. Select the translational joint and then

specify its properties. The properties window mainly includes four different aspects. The first aspect is specifying the two components into consideration, the location and the direction of motion. In order to specify the direction of motion, select one of the vertical edges on either the locator block or workpiece. The next one is defining the type of motion, as to whether it is of a constant nature, or a step function or a harmonic one. The parameters for the same are appropriately defined. Here, we assume that the motion has a constant nature on the positive Z axis and the velocity of motion is 10mm/sec.

5. The next step is to define 'Spring' motion if any, in the assembly. We can safely neglect this factor since no spring motion is involved in this case.

6. Then, under the 'Motion' tab, the Motion on, Motion type, initial displacement and velocities are defined. The motion in this case, is defined on positive Z-axis with initial displacement and velocity equal to zero.

7. Next step is to simulate the mechanism. Under the 'Simulation' tab, the number of frames and time are defined by the user. After specifying these parameters, the 'Simulate' tab is activated. This takes a few minutes to simulate the mechanism. The actual motion is traced out by blue lines, as seen in the image. This indicates the direction of motion and its path taken for the same.

8. After the simulation is done, we create an animation file and then check interferences. To check any interference that may exist in the assembly, we make use of the 'Interferences' tab. In the interference window, the components of consideration for interference check are selected, as they appear simultaneously in the red color box. Any kind of interference present is indicated by red, as seen in the image seen above.

As seen for the screenshot below, the distance between the two faces was assumed to be 3 mm approximately for illustrating the interferences. As said earlier, the interference takes places due to the insufficient distance the workpiece was moved through during the process of loading and unloading. Thus, for any distance lesser than 5mm, interference is bound to take place.

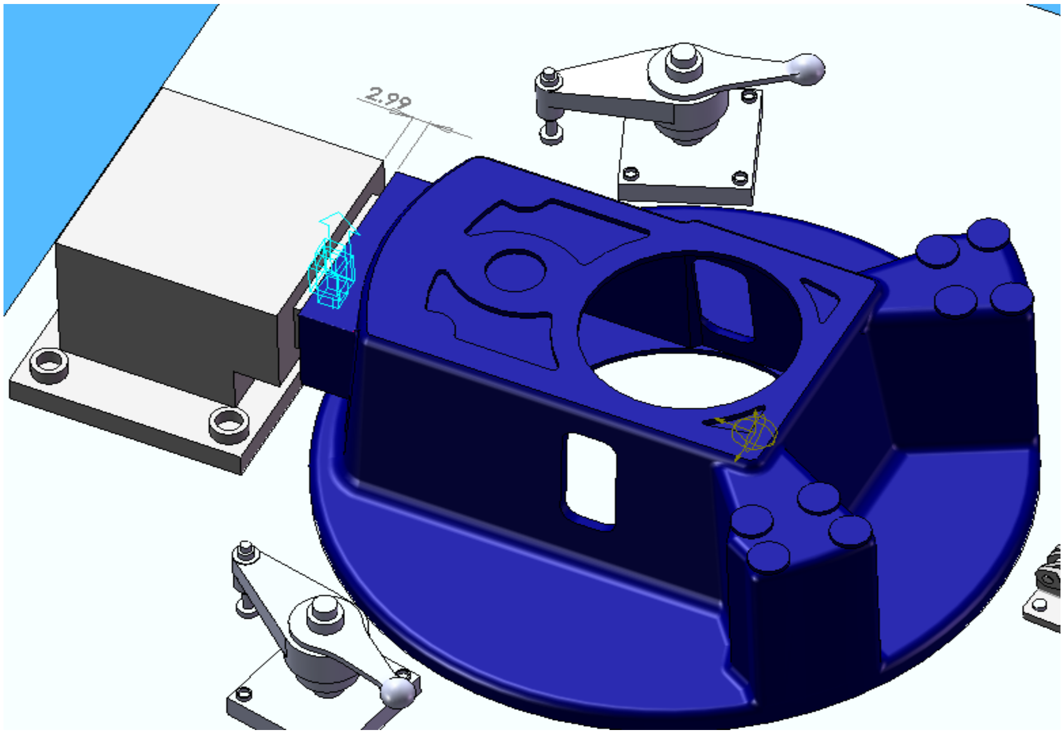


Figure 5. 23: Clearance between locator surface and the workpiece surface

Based on the analysis in the previous sections, it was found that the main problem is loading and unloading this workpiece during machining operations is the extrusion of 5mm. Also, to add to that, when the workpiece has to be moved through an additional distance, the clearances between the fixture components are such that time required for loading and unloading is considerably high. Although, the main assumption is manual operation of clamps, which is bound to add to time, the fixture setup should be redesigned in certain ways, to reduce the cycle time and make loading and unloading better.

5.2.7 Improvements in fixture design from loading-unloading point of view:

Following are a few suggestions for the same:

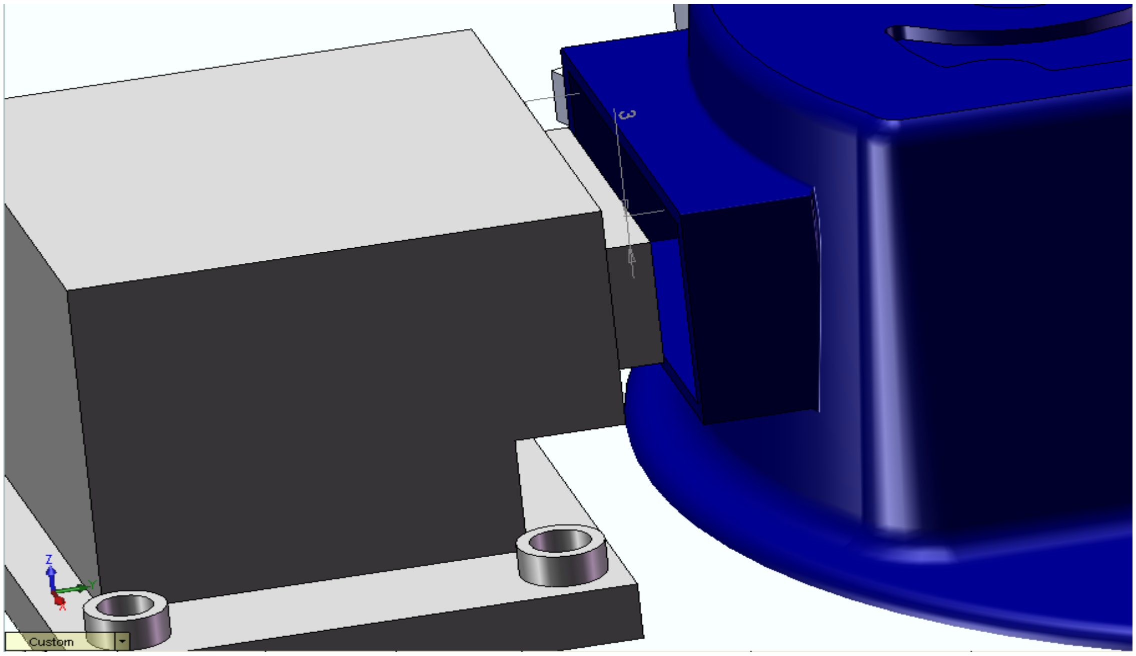


Figure 5.24: Modification 1- Increase clearance between face of extrusion and corresponding face of workpiece

5.2.7.1 Modification 1:

Increase the clearance between the face of extrusion and corresponding face on the workpiece as shown in the image above. This can be done by modifying the geometry of fixture block so as to accommodate the change in clearance. Increasing the clearance will allow the workpiece to be loaded and unloaded faster because of the following reasons:

1. The increased clearance reduces time required for the to move the workpiece through the distance of 5mm in the positive Y-direction, while moving it in and out during loading and unloading process. Increasing the clearance may be feasible only to a certain value, because, if the clearance is increased considerably, it may loosen the contact between the two faces and hence, may result into workpiece movement if the contact breaks for some reason. Hence, it is important that an optimum value of clearance be maintained in order to avoid this problem. At the same time, it shouldn't be too small; otherwise, it will result into more friction between the two faces, thus causing more wear and hence, frequent replacement.

5.2.7.1.1 Time Measurements:

Following is the time measurement split up for its loading and unloading simulation:

Unloading process	
Step	**Time in seconds**
1. Operation of clamps	9 secs (+30 secs tolerance)
2.Movement of workpiece in positive Y-direction	2 secs
3.Movement of workpiece in positive Z-direction	step 1: 3 secs step 2: 1 sec
4.Movement of workpiece in positive Y-direction (last stage)	4 secs
Total time	49 secs

Table 5.13: Time measurements for unloading process

Loading process	
Step	**Time in seconds**
1. Movement of workpiece in negative Y-direction	4 secs
2. Movement of workpiece in negative Z-direction	step 1: 1 secs step 2: 3 secs
3. Movement of workpiece in negative Y-direction	2 seconds
4. Operation of clamps	9 seconds (+30 seconds tolerance)
Total time	57 seconds

Table 5.14: Time measurements for loading process

An analysis of the loading and unloading steps shows that the total time required for the process is 19 seconds(+30 seconds tolerance for manual operation of clamps), out of which, 2 seconds are for the motion of workpiece in positive/negative Y-direction. The timespan here is considerably small as against the case one analysis where clearance was one mm. When the clearance was one mm, the time required for the same step was 7 seconds as against, when the clearance is increased to three mm, the time required is two seconds. Thus, more the clearance, lesser will be the time required for loading and unloading. But, at the same time, more the clearance, lesser will be the contact between the two faces and thus, locating the workpiece might become a problem.

5.2.7.2 Modification 2:

Change the geometry of extrusion on the side locator block, maintaining the same clearance:

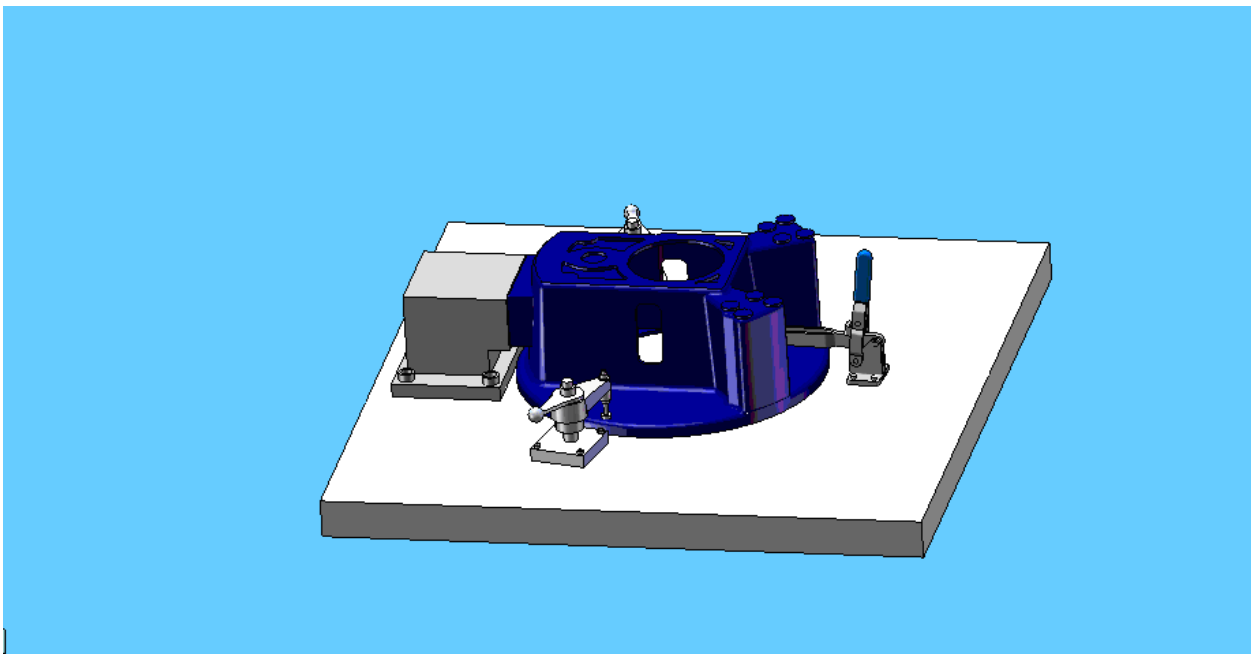


Figure 5.25: Modification 2- Change the geometry of side locator

The current width of extrusion is 5mm. If this distance be increased more than 5mm, then the workpiece will interfere with either the extrusion feature or the toggle clamps while loading or unloading it. The interference with toggle clamps is more possible, since, the workpiece will have to be moved backward/forward by a greater distance during loading and unloading. In order to avoid this, the width of extrusion should be kept to 5mm at the maximum. The suggestion for improvement made here is that the width of extrusion may be reduced to 3mm approximately. The reason behind reducing this distance is to allow easier movement of the rectangular slot (and hence, the workpiece) when moving in and out of the extrusion. If the distance of extrusion is reduced, the distance between the front face of secondary locator and the toggle clamp increases and thus, the workpiece can be removed with relative ease. Relative ease refers to lesser time for loading and unloading.

5.2.7.2.1 Time Measurements:

Following gives a time split-up for loading and unloading processes:

Step one is motion of the workpiece from the end of the toggle clamp to the front face of extrusion in case of loading and vice-versa for unloading. Step two is the distance of extrusion itself, i.e. 5mm in this case. The time required for workpiece to move through step two is always considerably greater than step one, since the clearances are tighter in the latter than the former one. This is illustrated by the images given above.

Unloading process	
Step	**Time in seconds**
1. Operation of clamps	7 secs (+30 secs tolerance)
2.Movement of workpiece in positive Y-direction	step 1: 2 seconds step 2: 1 second
3.Movement of workpiece in positive Z-direction	step 1: 3 seconds step 2: 2 seconds
4.Movement of workpiece in positive Y-direction (last stage)	3 seconds
Total time	48 seconds

Table 5.15: Time measurements for unloading process

Loading process	
Step	**Time in seconds**
1. Movement of workpiece in negative Y-direction	3 sec
2. Movement of workpiece in negative Z-direction	step 1: 2 secs step 2: 3 secs
3. Movement of workpiece in negative Y-direction	step 1:1 seconds step 2: 2 seconds
4. Operation of clamps	9 seconds (+30 seconds tolerance)
Total time	48 seconds

Table 5.16: Time measurements for loading process

5.2.7.3 Modification 3:

Repositioning the toggle clamps and changing the width of extrusion (combined):

5.2.7.3.1 Time Measurements:

Following is the time measurement split up for its loading and unloading simulation:

Unloading process	
Step	**Time in seconds**
1. Operation of clamps	9 secs (+30 secs tolerance)
2.Movement of workpiece in positive Y-direction	step 1: 2 seconds step 2: 1 second
3.Movement of workpiece in positive Z-direction	step 1: 1 seconds step 2: 2 seconds
4.Movement of workpiece in positive Y-direction (last stage)	3 seconds
Total time	48 seconds

Table 5.17: Time measurements for unloading process

Loading process	
Step	**Time in seconds**
1. Movement of workpiece in negative Y-direction	3 sec
2. Movement of workpiece in negative Z-direction	step 1: 2 secs step 2: 1 secs
3. Movement of workpiece in negative Y-direction	step 1:1 seconds step 2: 2 seconds
4. Operation of clamps	9 seconds (+30 seconds tolerance)
Total time	48 seconds

Table 5.18: Time measurements for loading process

Changing the toggle clamp position gives greater space for loading and unloading the workpiece. This is because the clearances between the workpiece and its surrounding fixture components are considerably greater than in the previous cases. This is because of two reasons: mainly because of the change in extrusion width and repositioning of toggle clamp.

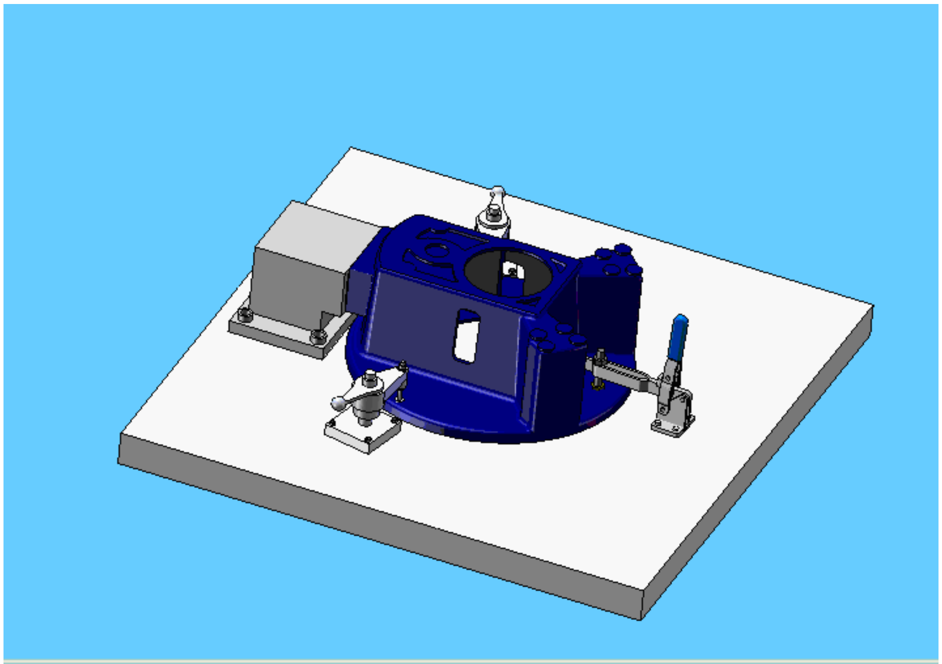


Figure 5.26: Modification 3- Distance changed from 130 mm to 139 mm

The image above gives an illustration of the same. Increased clearances make possible faster and easier loading and unloading. The time required for the same is considerably reduced here as compared to the previous cases.

5.2.7.4 Modification 4:

Change the shape of extruded section. The current design has a rectangular extrusion section and hence, clearance problems reduce the loading and unloading time. Hence, changing the shape of extrusion may be a good way to reduce these clearance related problems. Changing the shape of extrusion from rectangular to oval provides greater scope to load and unload the workpiece faster, because of the clearance at its four ends.

The time measurement for this option is given below:

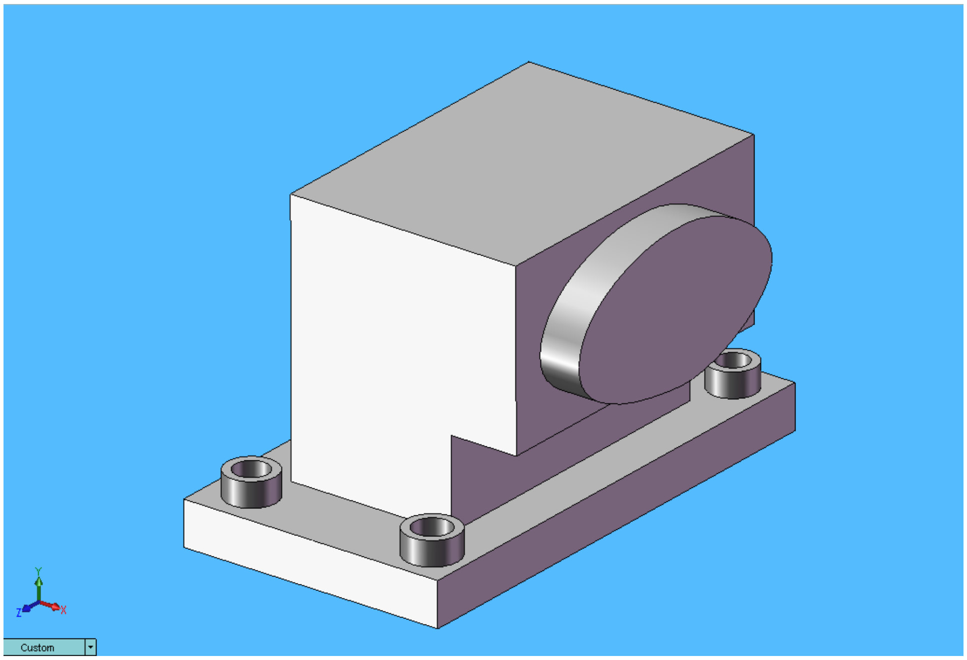


Figure 5.27: Modification 4-Changing the shape of locator extrusion

5.2.7.4.1 Time Measurements:

Unloading process	
Step	**Time in seconds**
1. Operation of clamps	9 secs (+30 secs tolerance)
2.Movement of workpiece in positive Y-direction	6 seconds
3.Movement of workpiece in positive Z-direction	step 1: 4 seconds step 2: 2 seconds
4.Movement of workpiece in positive Y-direction (last stage)	4 seconds
Total time	55 seconds

Table 5.19: Time measurements for unloading process

Loading process	
Step	**Time in seconds**
1. Movement of workpiece in negative Y-direction	4 sec
2. Movement of workpiece in negative Z-direction	step 1: 2 secs step 2: 4 secs
3. Movement of workpiece in negative Y-direction	6 seconds
4. Operation of clamps	9 seconds (+30 seconds tolerance)
Total time	55 seconds

Table 5.20: Time measurements for loading process

Step	Original design	Increase the value of clearance	Change the geometry of side locator block extrusion	Reposition toggle clamps and change width of extrusion	Change shape of extruded section
UNLOADING PROCESS					
Operation of clamps	9 secs (+30 secs)	9 secs(+30 secs)	7 secs(+30 secs)	9 secs(+30 secs)	9 secs(+30 secs)
Movement of workpiece in positiveY-direction	7 secs	2 secs	step 1:2 secs step 2:1 sec	step 1:2 secs step 2: 1 sec	6 sec
Movement of workpiece in positive Z-direction	step1: 5 secs step1 : 1 sec	step 1:3 secs step 1: 1 sec	step1: 3 secs step 2: 2 secs	step :1 secs step 2: 2 secs	step 1: 4 secs step 2: 2 secs
Movement of workpiece in positive Y-direction	4 secs	4 secs	3 secs	3 secs	4 secs
Total time	**56 secs**	**49 secs**	**48 secs**	**48 secs**	**55 secs**
LOADING PROCESS					
Movement of workpiece in negative Y-direction	5 secs	4 secs	3 secs	3 secs	4 secs
Movement of workpiece in negative Z-direction	step 1: 1 sec step 2: 5 secs	step 1: 1 secs step 2: 3 secs	step 1:2 secs step 2: 3 secs	step 1: 2 secs step 2: 1 sec	step 1: 2 secs step 2: 4 secs
Movement of workpiece in negative Y-direction	7 secs	2 secs	step 1:1 sec step 2: 2 sec	step 1:1 secs step 2: 2 secs	6 sec
Operation of clamps	9 secs (+30 secs)	9 secs(+30 secs)	7 secs(+30 secs)	9 secs(+30 secs)	9 secs(+30 secs)
Total time	**57 secs**	**49 secs**	**48 secs**	**48 secs**	**55 secs**

Table 5.21: Time Matrix

Factors affecting loading and unloading	Time required Unloading	Loading	Accessibility	Remarks
1. Distance between toggle clamp and secondary locator a. Distance lesser than or equal to 128.45mm	56 secs	57 secs	1	High interference possibility. Also, tighter clearances increase time required
b. Distance greater than 128.45 mm (135mm)	48 secs	48 secs	5	Interference while loading and unloading eliminated. Modification of toggle clamp required, which is easily possible
2. Width of extruded feature a. width more than 5 mm	56 secs	57 secs	1	Greater width increase time for loading and unloading considerably. More surface contact causes more wear and tear also.
b. Width lesser than 5 mm (3mm)	48 secs	48 secs	4	Possibility of wear and tear reduced. Time period reduces considerably since the workpiece can move faster through the distance between front face of extrusion and toggle clamp. But, stability of the workpiece may be affected in locating
3. Clearance value between lower surface of slot and that of the extruded section a. Clearance value equal to 1 mm or lesser	56 secs	57 secs	1	Clearance related problems cause time to considerably increase. Wear and tear more with increased surface contact.
b. Clearance equal to 3 mm or greater	49 secs	49 secs	3	Clearance related problems minimized. Optimization of clearance becomes necessary, else may affect locating accuracy.
4. Shape of extrusion a. Rectangular extruded feature	56 secs	57 secs	1	Tighter clearances on all four sides and hence, time required increases.
b. Oval shaped extrusion feature	55 secs	55 secs	2	Clearance problems at corners eliminated, thus reducing surface contact and hence, time required.
5. Type of clamps a. Mechanically operated strap clamps	48-57 secs	48-57 secs		Depends upon type of production and feasibility
b. Hydraulic/ Pneumatic operated clamps	Lesser than 48 secs	Lesser than 48 secs	5 (when combined with factor 1.b)	

Table 5.22: Accessibility rankings of fixture designs based on comparisons

Rankings: Best: 5, Better: 3 and 4, Good: 2, Poor: 1

Thus, a comparative study shows that suggestion 4 works the best to reduce loading and unloading time by making the fixture setup easier.

5.3 Summary:

Thus, the fixture design for manufacturing this workpiece was successfully studied and improvements were suggested. Every suggestion has been given equal attention with regards to details of analysis. The operator should, after understanding the manufacturing constraints in the actual environment, make an appropriate decision as to which one will suit the environment the best.

Chapter 6 Guidelines for Loading and Unloading Accessibility for Computer Aided Fixture Design

This chapter deals with the guidelines to be kept in mind in order to design a foolproof fixture design. These rules have been framed on the basis of the results of the case studies carried out in the previous chapter. An attempt has been made to study the case studies in detail, by measuring the time for each of them and certain conclusions have been put forth. The different aspects of fixture design have been given consideration.

6.1: Guidelines for fixture design from loading and unloading point of view

The following figure shows a generalized case of workpiece-fixture setup. A simple workpiece has been chosen for analysis purpose. This may be applied to any other workpieces with a few modifications. Consider a rectangular workpiece with dimensions length (l) x width(w) x height(h). Assume that the workpiece has been supported by a locator on the left hand side of the workpiece. The workpiece has been analyzed differently, if a side locator is used opposite to the locator as well as for a top clamp, instead of a side clamp.

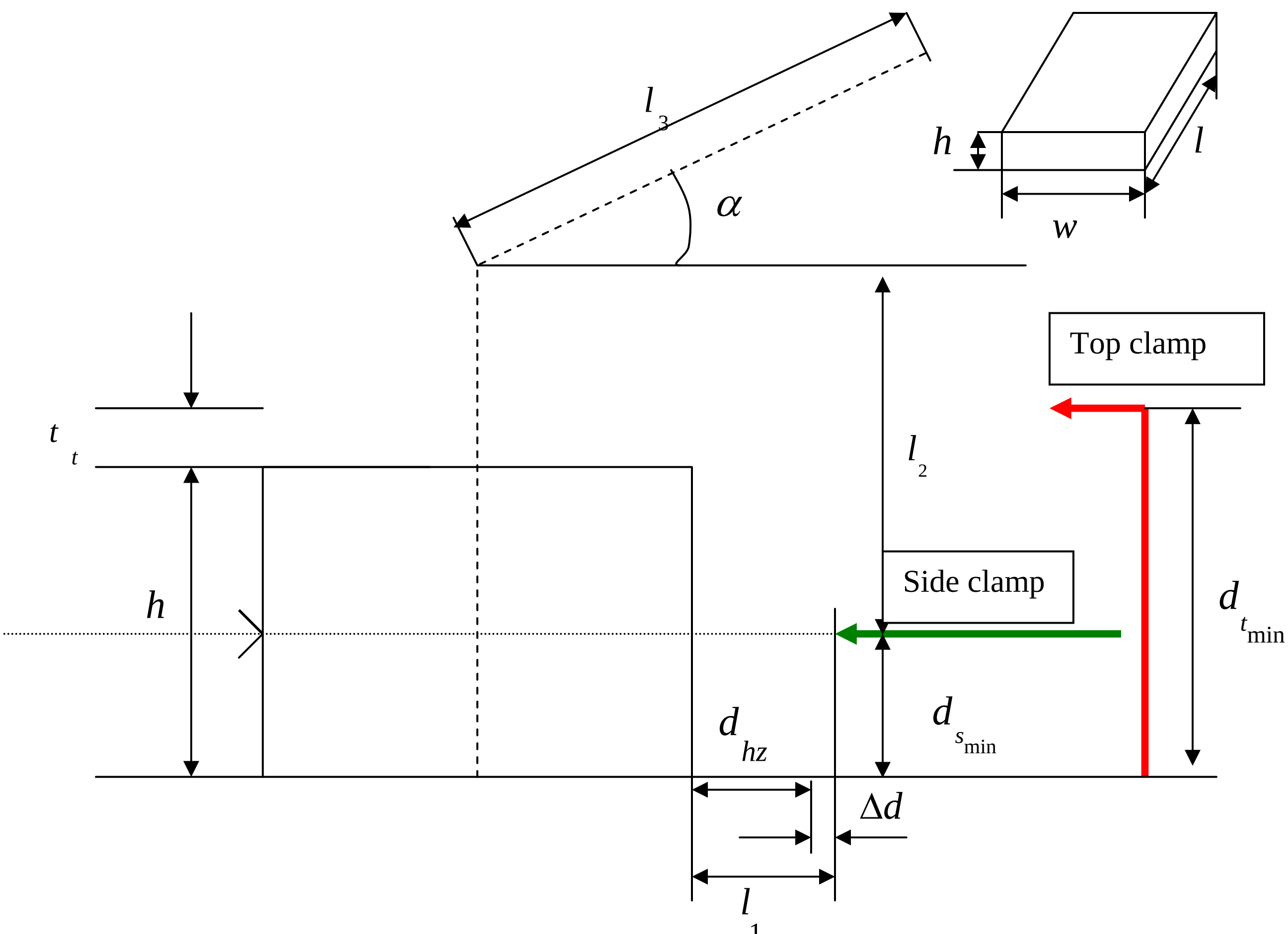


Figure 6.1: Workpiece-fixture model and the terminologies used

Let $d_{s_{\min}}$ be the minimum distance the workpiece has to be moved through when side clamps are used. Let $d_{t_{\min}}$ be the minimum distance the workpiece has been moved through when top clamps are used. The motion of workpiece is divided into three segments. For unloading, the workpiece first moves through the minimum distance to go in or out of the fixture setup. It then moves through an extension path in the vertical direction and then, the path deviates through an angle α to reach the final position. When side clamps will be used, the segment 1 will be $d_{s_{\min}}$, segment 2 will be l_2 and segment 3 will be l_3. When top clamps are used, the segment 1 will be $d_{t_{\min}}$, segment two will be $\left(l_2 + d_{s_{\min}} - d_{t_{\min}}\right)$ and segment three will be l_2 Let the thickness of top clamps be t_t. Let the vertical motion through the minimum distance be M1, the extended path motion is M2, the deviated path M3. An extra term that has been considered for any horizontal motion that the workpiece might have to be moved through a small horizontal distance, in order to be able to load and unload the workpiece easily. In a few cases, this horizontal distance may be zero, depending upon the clearances and the distances between the clamps/locators and the surface of workpiece. Let this distance be d_{hz}. Let Δd be the clearances. This is the average of all the clearances for the fixture setup. Let the horizontal distance motion be M_{hz}

The loading and unloading analysis has been done in terms of time measurement. Thus, the total time for loading and unloading can be put forth as an addition of all the different time measurements. These include time for clamping, time for each of the segments etc. Equations for calculating each of these times have been put forth in the next section. Let be the total time taken for loading and unloading. The total time can be split up into the following:

t_1 - time required to load and unload the workpiece through the minimum distance when side clamps are used.

$t_{t_{\min}}$ - time required to load and unload the workpiece through the minimum distance when top clamps are used.

t_2 - time required to move the workpiece through the extension path 1

t_3 - time required to move the workpiece through the extension path 2

t_{hz} - time required to move the workpiece through any horizontal distance

t_c - time required for clamping/ unclamping

t_v - time taken by the top clamps to move vertically upward/downward

t_r - time taken by the top clamps to rotate in order to reach a final/initial position during unloading/loading process.

6.1.1 Rule 1 - Motion M1:

1. The first criterion in the analysis of loading and unloading is to check if the workpiece is accessible in atleast one way. If there does not exist even a single way, in which the workpiece can be loaded and unloaded without any interference with its environmental components, the workpiece-fixture setup is called inaccessible for loading and unloading. If there exists atleast one way in which the workpiece can be loaded and unloaded without any interference, the workpiece-fixture setup is called accessible for loading and unloading.

2. The minimum time for loading and unloading the workpiece through the minimum distance when side clamps are used, is proportional to the minimum distance, $d_{s_{\min}}$

$$t_1 \propto d_{s_{\min}} \qquad \text{.........(1)}$$

$$t_1 = k_1 \cdot d_{s_{\min}} \qquad \text{..........(2)}$$

Where, k_1 is the proportionality constant and is equal to the reciprocal of the velocity. Thus, the minimum time for loading and unloading the workpiece depends to a great extent upon the minimum distance. The locators and clamps may be so installed, that the minimum distance may be less. But, this distance needs to be optimized; else, the workpiece may lose its stability.

Discussion: In Eq. (2), k1 is the proportionality constant and is equivalent to the reciprocal of speed for minimum distance, V_1. Following shows the time measurements for case study 2. The table 6.1 shows the variation in time required for loading and unloading with variation in the minimum distance. From measurements, average velocity corresponding to = 6.5 mm/sec for this case study. Thus, for velocity more or less constant, it is seen that the time for loading and unloading the workpiece through the minimum distance is directly proportional to the minimum distance. If the right side product is lesser, then, time component t_1 will be lesser and hence, accessibility will be better

The minimum speed during loading and unloading is directly proportional to the clearance between the surface of locator/clamp and the surface of workpiece.

Thus,

$V_1 \propto \Delta d$ ....(3)

Where, V_1 is the velocity of loading and unloading the workpiece through the minimum distance when side clamps have been used.

Thus,

$V_1 = k_2 * \Delta d$ ....(4)

where, k_2 is the proportionality constant. An important assumption here is that Δd is the average of clearances on all sides of the locators and the clamps. Thus, it is seen that speed V_1 increases as the value of average clearance increases, thus reducing the time component t_1.

Following table shows the velocity and time measurements carried out for the case study 2.

Velocity V_1 for minimum distance	clearance Δd	k_2 values
7.62	5.5	1.38
14	7.5	1.86
16.5	9.5	1.89
22	11.5	1.93
24.97	13.5	1.85
27	15.5	1.8
31.25	17.5	1.8
31.25	19.5	1.602
31.25	21.5	1.453
31.25	23.5	1.329

Table 6.1: Variation in k_2 with variations in Velocity and Average clearance

The table gives the variation in k_2 with the variation in the average clearance. It can be seen that as the average clearance goes on increasing, velocity V_1 increases proportionately.

This is because; there is more room for loading and unloading the workpiece through the fixture setup. But, it may however be noted, that if the average clearance value increases beyond a certain point, then, the velocity will remain constant after that point, for any given given value of clearance after that. Thus, correspondingly, we can say that increases as clearance goes on increasing and then, after the peak value again starts reducing as the velocity remains constant. Following shows a graph of the minimum velocity Vs. the average clearance .

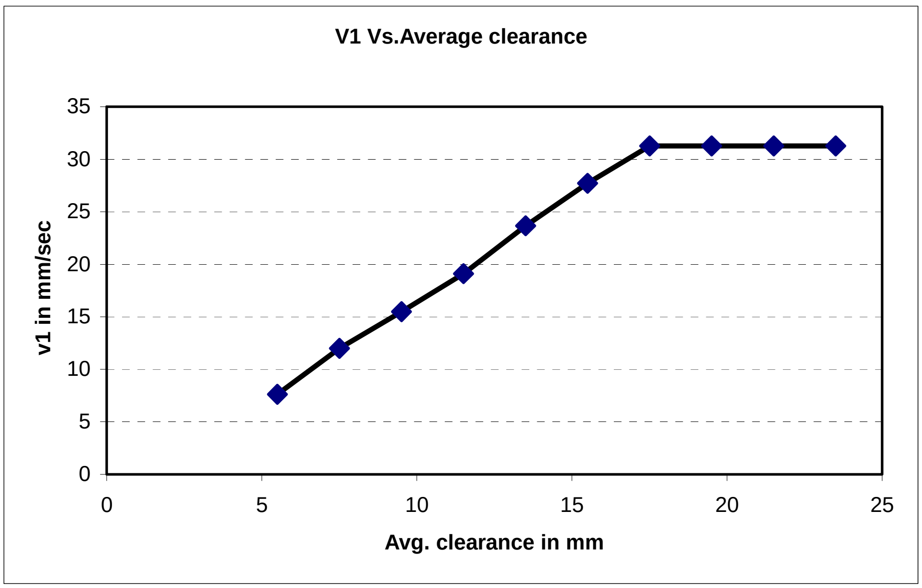


Figure 6.2: Graph of Velocity corresponding to minimum distance Vs. average clearance

Deciding clearances when designing fixture setups:

Two factors need to be taken into consideration when clearances are decided for any fixture setup. They can be stated as follows:

1. The average clearance is proportional to the dimension of workpiece perpendicular to the plane of loading and unloading the workpiece.

Thus,

$$\Delta d \propto w$$

Where, w is the dimension of workpiece in a plane perpendicular to the plane of loading and unloading.

2. Average clearance is directly proportional to the minimum distance the workpiece has to be moved through for loading and unloading in and out of the fixture setup.

Thus,

$$\Delta d \propto d_{s_{\min}} \quad \text{Or} \quad \Delta d \propto d_{t_{\min}} \qquad \ldots\ldots\ldots\ldots(5)$$

If a fixture setup has been designed using side clamps and top clamps both, then calculations may be done for both and the one which gives a greater value of clearance may be selected.

The minimum time to move the workpiece in and out of the fixture setup in the vertical direction when the top clamps are used, is directly proportional to the minimum distance between the upper surface of the clamp and the base surface.

$$t_{t_{\min}} \propto d_{t_{\min}} \qquad \ldots\ldots\ldots\ldots(6)$$

Where, $t_{t_{\min}}$ and $d_{t_{\min}}$ are the minimum time and minimum distance respectively.

Discussion:

The distance should not be given consideration, if side clamps have been used in the setup and loading and unloading of the workpiece over the side clamps is a shorter route compared to the over top clamps. But, it might not be the case always. Sometimes, due to unpredicted manufacturing environment obstruction, it may not be possible to load and unload the workpiece by shortest path over the side clamps. In that case, the top clamps should be given a consideration.

From the figure above,

$$d_{t_{\min}} = h + t_t \qquad \ldots\ldots\ldots\ldots(7)$$

where, t_t is the thickness of clamps. Thus, it is seen that distance $d_{t_{\min}}$ depends upon the height of workpiece h and the thickness of top clamps t_t.

6.1.2 Rule 2:

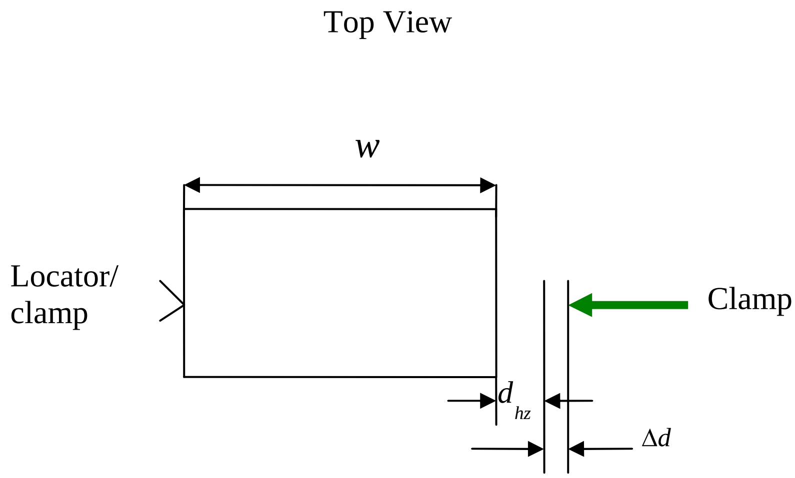


Figure 6.3: 2D model of the workpiece illustrating Rule 2

Time required to load and unload the workpiece is inversely proportional to the distance between clamps and/or locators on the opposite ends.

$$t \propto \frac{1}{(w + d_{hz} + \Delta d)} \qquad \text{............(8)}$$

Where, Δd is the average clearance.

Discussion:

$$t = \frac{k_{opp}}{(w + d_{hz} + \Delta d)} = \frac{k_{opp}}{(w + l_1)} \qquad \text{...........(9)}$$

Where, k_{opp} is the constant of proportionality. The horizontal distance d_{hz} cannot be varied over a wide range. Hence, the only parameter that can be controlled is the average clearance Δd

6.1.3 Motion M2:

Time for extended path l_2 is given by:

$$t_2 = \frac{l_2}{v_2}$$ **…….**for side clamps (10)

$$t_2 = \frac{\left(l_2 + d_{s_{\min}} - d_{t_{\min}}\right)}{v_2}$$ **..……**for top clamps (11)

Where v_2 can be controlled by the operator.

Thus, t_2 depends to some extent upon the overall geometry of the workpiece, when top clamps are used.

6.1.4 Motion M3:

Similarly, time t_3 for extended path l_3 is given by:

$$t_3 = \frac{l_3}{v_3}$$ at the specified path angle α ……….(12)

where v_3 can be controlled by the operator.

Time t_3 thus, depends upon l_3 and the angle of deviated path, α .

6.1.5 Motion M_{hz} :

M_{hz} , as stated earlier, is the motion of the workpiece in the horizontal direction.

We have,

$$l_1 = d_{hz} + \Delta d$$ ..……..(13)

Ideally, during loading and unloading, the workpiece should be moved back and forth through a distance equal to the average of the clearance and the horizontal distance, which can be given as follows:

$$d_1 = \frac{l_1}{2} = \frac{d_{hz} + \Delta d}{2}$$ ………..(14)

where, d_1 is the average distance the workpiece should be moved through the given distance. Hence, time to load and unload the workpiece through the horizontal distance,

t_{hz} is given by:

$$t_{hz} = \frac{d_1}{v_{hz}}$$ ………(15)

Where, the velocity v_{hz} remains constant for the horizontal distance and will have values similar to the velocity for segment of motion M1. This velocity will also be affected by the clearance Δd . If the distance is absent, the ideal distance would be:

$$d_1 = \frac{l_1}{2} = \frac{\Delta d}{2}$$

6.1.6 Calculations of clamping and unclamping time:

Assumption:

Time for clamping = Time for unclamping……………. …………for automatic operation

Time for clamping = Time for unclamping $\pm$ 15 seconds………for manual operation

Let t_c be the total clamping time and t_e be the clamping time for each clamp

For manual operation,

The total clamping time, $t_c = \left(n_1 \cdot t_e\right)$ …………..(16)

Where, n_1 is the number of clamps being manually operated.

For automatic operation,

The total clamping time, $t_c = t_e$

The value of t_e may be calculated such that it is proportional to the clearance of the side clamp from the surface of workpiece. Let this clearance be Δd_e and thus,

$t_e \propto \Delta d_e$

For top clamps, two components need to be taken into consideration when calculating the clamping and unclamping time. The two motions can be split up as motion of the clamp in the vertical direction to tighten or loosen its grip on the workpiece and its rotational movement . Let the component of vertical motion be t_v and the rotational component be t_r

The time for clamping can hence, be given as:

$$t_e = t_v + t_r$$ …………….(17)

t_v can be assumed to be 10 seconds on an average

t_r is the time required for rotation of the clamp and is directly proportional to the angle through which it rotates to take the final/initial position. Thus,

$$t_r \propto \beta \qquad \text{………….(18)}$$

where, β is the angle of rotation. Thus, the constant in this equation will be equal to the reciprocal of the angular velocity. Thus, the time t_r can be calculated.

On an average, it may be assumed that automatically operated clamps take about 30-45 seconds and top clamps may take about 1.5 minutes for operation. A few seconds of tolerance may also be assigned for both cases.

6.1.7 Graphs for illustrations:

1. Distance Vs. Time for loading and unloading:

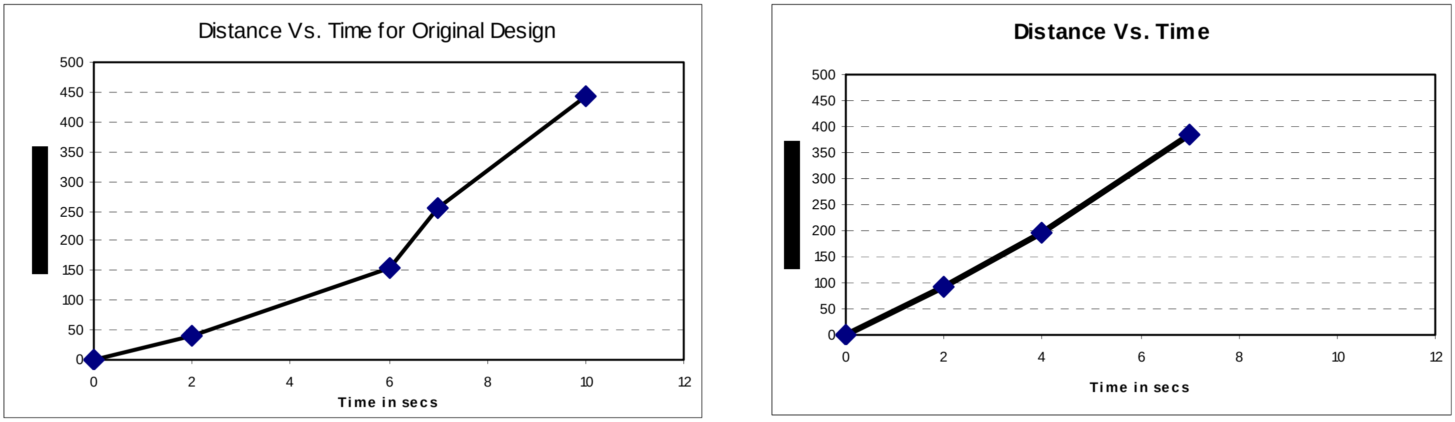


Figure 6.4: Distance Vs. Time Plot comparison between original fixture design and Modification 2

2. Speed and Time for loading and unloading:

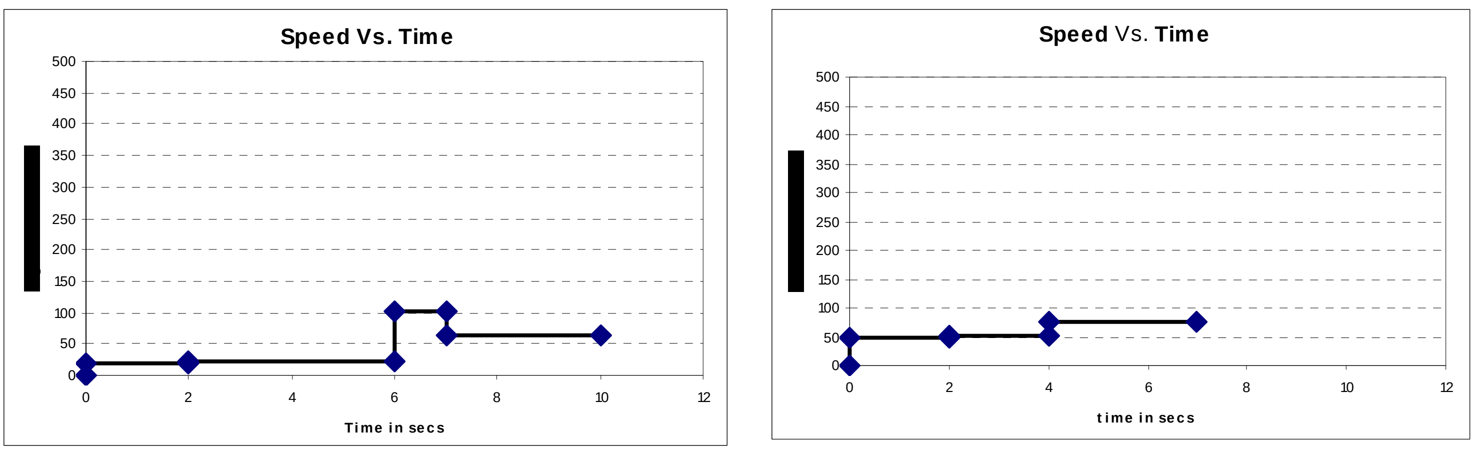


Figure 6.5: Speed Vs. Time Plot comparison between original fixture design and Modification 2

The graphs from set 1 show the distance Vs. Time and the Speed Vs. Time for case study 1 and from set 2 shows that the graphs for distance Vs. time are linear graphs and do not show any discontinuities. On the other hand, the graph of Speed Vs. Time for loading and unloading shows discontinuities. This is because, for a particular time, the speed remains constant and at a few others, the velocity remains constant with increase in time over a particular segment of loading and unloading.

6.1.8 Rule 3:

Time for loading and unloading is directly proportional to the ratio of the total length and inversely proportional to the number of segments. As a general rule, for a particular length, it should be noted that, greater the number of segments used for loading and unloading, the poorer is accessibility.

$$\frac{\Sigma l}{n} = \frac{k_n}{k_l} \qquad \text{……………(19)}$$

k_n and k_l are the proportionality constants for the length and number of segments respectively.

Discussion:

Σl \ n	4	5	6	7	8
443.53	110.88	88.70	73.92	63.36	55.44
463.53	115.88	92.70	77.25	66.21	57.94
483.53	120.88	96.70	80.58	69.07	60.44
503.53	125.88	100.70	83.92	71.93	62.94
523.53	130.88	104.70	87.25	74.79	65.44

Table 6.2: Matrix illustrating Rule 3 for Case study 1

Σl \ n	4	5	6	7	8
525.82	131.45	105.16	87.63	75.11	65.72
545.82	136.45	109.16	90.97	77.97	68.22
565.82	141.45	113.16	94.30	80.83	70.72
585.82	146.45	117.17	97.63	83.68	73.22
605.82	151.45	121.16	100.97	86.54	75.72

Table 6.3: Matrix illustrating Rule 3 for Case study 2

The variation of Σl and n is seen from the matrices given below. It should be noted that the reduction in length and reduction of the number of segments for loading and unloading, both lead to better accessibility.

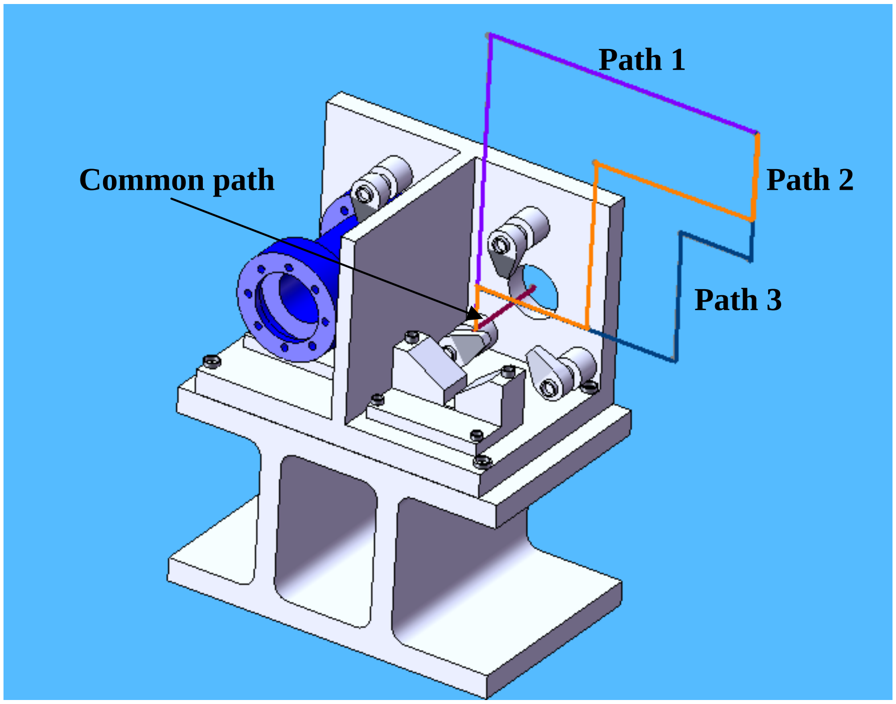


Figure 6.6: Figure illustrating three paths for loading and unloading with the same length and varying number of segments

The above image shows three different paths for loading and unloading the same workpiece. The distance remains the same for all three paths, but, the numbers of segments vary. Path 1 would be better in comparison to paths 2 and 3 since, the number of segments is lesser. Hence, loading and unloading the workpiece through path 1 gives better loading and unloading accessibility as compared to paths 2 and 3.

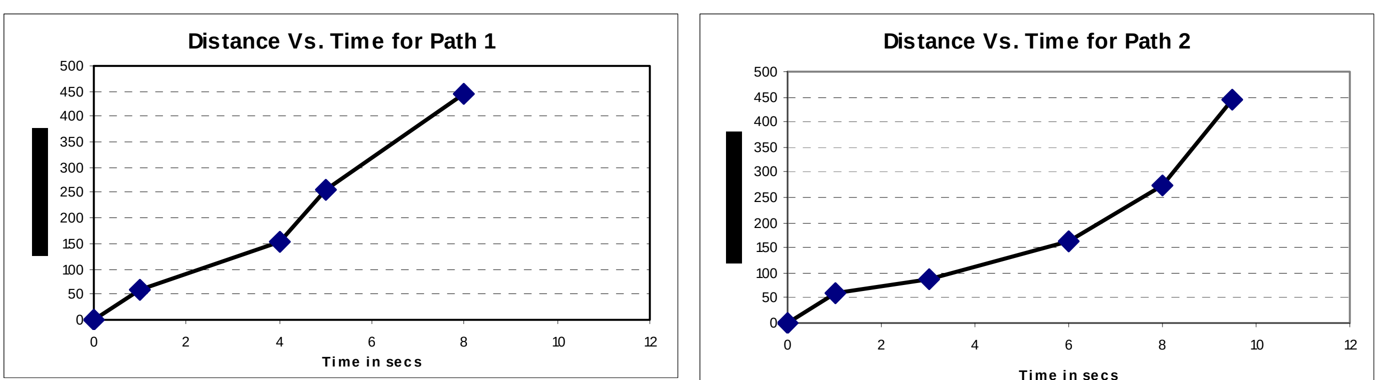


Figure 6.7: Comparison of graphs for time measurements of path 1 and path 2

The graphs above show the time measurements for loading and unloading the workpiece through the path 1 and path 2 respectively. Path 1 is the existing path for this fixture design. It should be noted that the length of path remains the same in each of them and the number of segments for loading and unloading path differ. Thus, greater the number of paths, more is time required and thus, we say poorer is the accessibility .

6.1.9 Analysis of Bridge Fixture Designs:

Minimum time for loading and unloading the workpiece from the bridge fixture components is directly proportional to the ratio of the heights of extrusion geometry to the clearances at the corresponding points of measurement.

Thus,

$$t_1 = k_b \cdot \sum_{k=1}^{k=m} \left(\frac{h_i}{\Delta d_i} \right) \qquad \text{……….(20)}$$

where, k_b is the constant of proportionality. Referring to the figures below:

Real Case

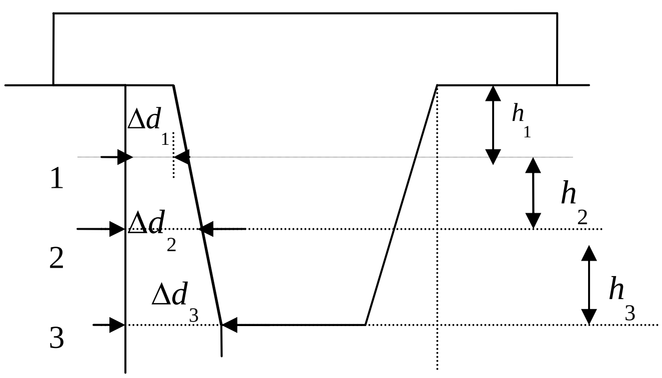


Figure 6.8: Workpiece model similar to case study 7

Model Case

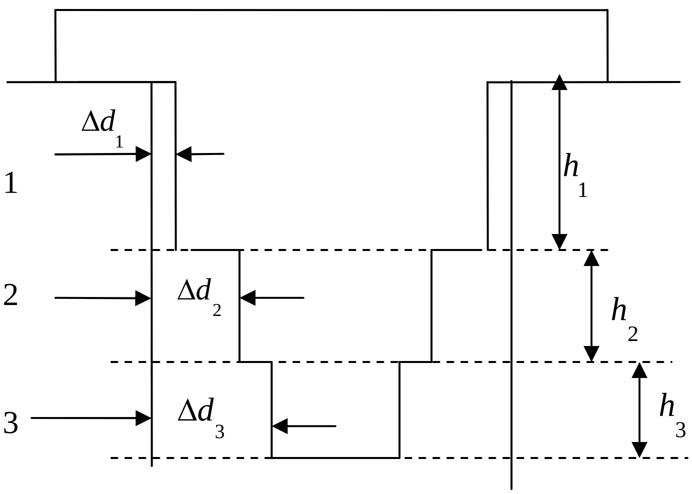


Figure 6.9: Workpiece model with a different geometry

h_i - the height of extrusion geometry at the different locations as shown

Δd_i - value of clearance corresponding to the height h_i

The constant of proportionality should be decided by judgement. Thus, this is a generalized formula and can be applied to any kind of geometry.

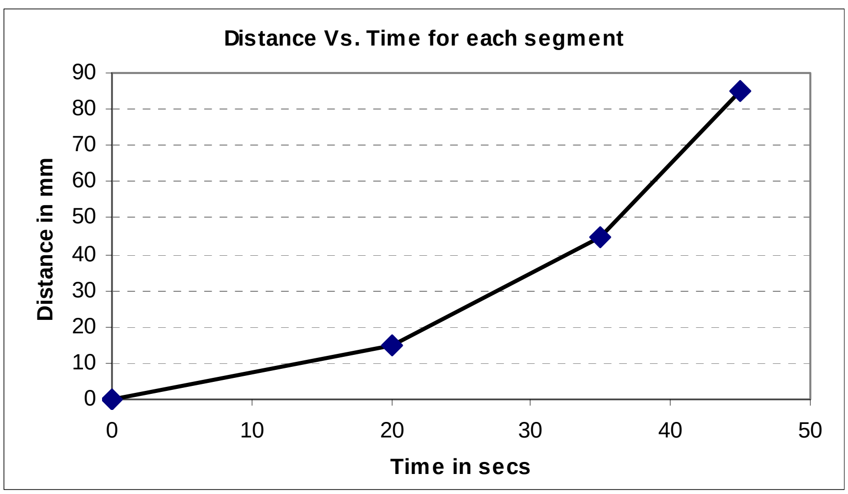


Figure 6.10: Graph illustrating the effect of clearances for bridge fixture designs

The graph above shows that as the clearances at the corresponding locations increase, the time for loading and unloading reduces. Thus, time for loading and unloading depends upon the geometry of the workpiece for bridge fixture designs.

6.2 Summary:

Thus, based on the results of the case studies, certain guidelines were put forth to help design good fixture setups. Fixture design demands that a number of factors be given consideration and hence, the guidelines explain how each of these factors can affect the designing of fixtures. Fixture designs affect loading and unloading to a great extent and hence, needs to be given consideration in the design stage itself in order to avoid the problems that may arise later on.

Chapter 7: Conclusions

7.1: Overview

The current research thus focuses on the fixturing properties rather than the fixture design itself. The fixturing properties deal with verification of fixture design, to make sure that the fixture setup serves the purpose that it has been designed for. Three important aspects have been looked into:

1. An attempt has been made to integrate the Computer Aided Design and Manufacturing Systems. This integration makes use of SolidWorks as the CAD system and Esprit as the CAM system. The integration is done manually and the user has to move back and forth from SolidWorks to Esprit during the process. Integration of CAD and CAM systems has made possible the verification of the quality of fixture design, from the manufacturing processes point of view.
2. The next part of research has attempted to setup a standard procedure for loading and unloading. Loading and unloading affects the quality of a fixture design to a great extent and thus, needs to be given attention. Loading and Unloading paths have been simulated in SolidWorks Animator and the fixture designs have then, been checked for any kind of interference which may exist, during the process.
3. A number of case studies have been studied and a time matrix concept has been put forth for the purpose of comparative study of various fixture designs. On the basis of the case studies considered, the last part of research has concentrated on formulation of guidelines to work towards a good fixture design. These guidelines hold true for any fixture design and thus, have wide applications in the field of manufacturing systems.

Thus, in a nutshell, two different types of accessibilities in fixture design have been studied and recommendations made in the same to obtain the best quality of fixture designs and thereby, take manufacturing systems one step ahead of the existing ones.

7.2: Conclusions

The aspects of this research explained in the previous section, now open doors to a whole lot of new research topics. There are a few things, that have been considered as part of this research, but have not been looked into, in great details. The most important aspect of this research is that, it has established a method of analysis of the two types of accessibilities, which have not received much attention till date. The following explains briefly the scope for future work in this field.

7.3: Future work

The current research focuses on integrating CAD and CAM systems, to enable the verification of the quality of fixture design. But, this research has not focused on the automation of the process. Currently, the user has to follow the procedure of integration manually, to verify the quality of fixture design. The manual integration means that the user has to move the fixture-workpiece solid models to and fro from SolidWorks and Esprit. The process needs to be automated after more research in the field.

This research also puts forth a procedure for analysis of loading and unloading accessibility. This includes the simulations in SolidWorks Animator and the interference check in COSMOS Motion 2007. But, the optimization of loading and unloading path has not been looked into. The analysis has been put forth considering a random path for loading and unloading. Further, the guidelines for a good fixture design have also been down by studying the same loading and unloading paths. If the path of loading and unloading be optimized, it can lead to be better fixture design. Also, this research does not take into consideration any obstructions in the manufacturing environment that may cause obstructions while loading and unloading. Some research has already gone into representation of these obstructions mathematically, but the challenging part is to integrate these mathematical concepts with the simulation work, that has been carried out as a part of this research.

Also, the guidelines put forth for good fixture design do not study clamping in great depth. Using appropriate type of clamps for fixture designs is very important, because the type of clamps greatly affect the loading and unloading time. Thus, future work calls for an in-depth analysis of the fixturing elements like clamps and locators to obtain the best fixture designs.

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