SINHAGAD TECHNICAL EDUCATION SOCIETIY'S

SMT.KASHIBAI NAVALE COLLEGE OF ENGINEERING

PUNE-411041

# CERTIFICATE

This is to certify that, the project report entitled

## "DESIGNING OF A SPECIAL PURPOSE MACHINE FOR CONTROLLING THICKNESS OF THRUST WASHERS"

SUBMITTED BY


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For the partial fulfillment for the award of degree of B.E. (Mechanical Engineering) from University of Pune, is a record of their own work carried out under my supervision and guidance during the session 2010-2011.

Prof. A. P. Pandhare
(Guide)

Prof. K. R. Borole
(Head, Dept. of Mechanical Engineering)

# Acknowledgement

We are glad to present this project report carried out by us as a part of our academic activity.

We are deeply indebted to our project guide Prof. Amar Pandhare, for his valuable suggestions, scholarly guidance, constructive criticism and constant encouragement at every step of our project.

The entire project was conceptualized and designed at "Kirloskar Oil Engines Ltd." Pune under the guidance of Mr. Ram Deshpande (Head of Manufacturing Engineering) and Mr. Amol Jagtap (Sr.Engineer). We also thank other staff of KOEL for design directions, providing valuable information and technical literature supporting this project.

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Finally, special thanks to our families, colleagues and friends who stood by us throughout this work and for their unconditional support which has led to the successful completion of our project.

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# Abstract

Thrust washers are very critical element in the most of the I.C engines. They undergo large amount of thrust load. In order that the functioning of the thrust washers is full proof it is necessary to maintain all the effective parameters of these thrust washers into their permissible tolerable limits. The most critical of which is the thickness of these thrust washers. Maintaining uniform thickness within the permissible limit is of a great challenge and a difficult task. This can be achieved by using a typical type SPM which controls thickness and related parameters of these thrust washers as per the user's requirement.

The SPM designed here is a universal machine which meets the user's demand. It makes use of a broaching operation. Now a days the focus of engineer's is to optimize the performance of engines and other parts of machine. So, there is a need to manufacture the washers into very precise and correct dimensions. This develops a need of a futuristic machine called as SPM in order to meet the requirements in the current industries which will be a great challenge and have a wider scope in the current scenario of the manufacturing industries. Modelling software like CATIA V5, AutoCAD helped to analyze the real time working of the machine.

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# 1. Introduction

## 1.1 Background

Kirloskar Oil Engines manufactures plane shaft bearings, journal bearings in their bearing division. Kirloskar bearings are leaders in Indian bearing industry today. They are manufacturing half bearings, bushes and thrust washers and hold utmost position in India for more than past two decades.

They manufacture bearings in totally backward integrated plants where virgin metals are converted into alloys from which bearing raw material (bimetallic strip) is made and is converted into finished components in the machine shop.

There are slapping bearings, bushes, thrust washers in all automobile industry and engine manufacturers in India wants to take out maximum possible power from compact engines. So, the critical dimensions of the bearings must be manufactured with very close tolerances.

Kirloskar bearings are continuously updating their manufacturing capabilities. To address these issues while discussing with the top management of the Company, the bearing department head, the designers and including the participation of the workers we understood this phenomenon and selected challenging project which will be helpful to the Kirloskar bearings in future and ultimately to us. Project selected by us is "Design of a Special Purpose Machine for controlling thickness of Thrust Washers".

## 1.2 Problem Statement

Title: Design of a Special Purpose Machine for controlling thickness of Thrust Washers.

### 1.2.1 Thrust Washers specifications –

- Types-

Fig 1.1
(a) Half Washer

Fig 1.2
(b) Full Washer

- Dimensions-

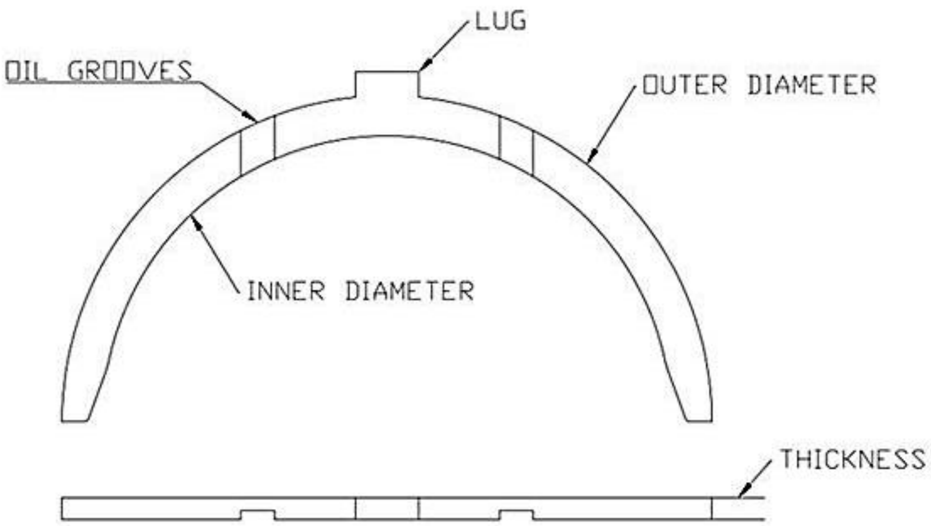



Fig 1.3: Schematic of thrust washers showing dimensions.

- Outer Diameter-

It is outer diameter of thrust washer.

Range-

Minimum = ϕ 40 mm.

Maximum = ϕ 120 mm.

- Thickness-

It is thickness of the washer. If washer thickness is more it fouls with crank shaft and creates problem for rotation and if it is less it increases the axial play and engine performance detoriates. After continous usage of the engine at the time of repowering washer with different higher thicknesses are used to take care of wear of thrust area of crank shaft. With usage of such oversize thrust washers more life from crank shaft is extracted.

Range-

Minimum = 1.5 mm

Maximum = 4 mm.

- Lug-

As half bearings have nick for ease of assembly in washer lug is provided. Lug also positions the washer and prevent it from rotation and falling. The lug may be at any position.

- Broaching allowance-

Max. 0.12 mm.

- Thrust Washer Material-

a) Aluminium based (Al-Sn) b) Copper based (Cu-Pb)

### 1.2.2 Output specifications

- Wall thickness Tolerance- 30 microns.

- Flatness-

  This is a dimension which measures straightness/flatness of the thrust washer (thrust washer is not having any bend).

  Required- 0.05 mm

- Surface Finish-

  Surface finish, by definition, is the allowable deviation from a perfectly flat surface that is made by some manufacturing process. Whenever any process is used to manufacture a part, there will be some roughness on the surface.

  Required- 0.4 Ra.

- Cycle time - 3 seconds.

- Setting Time - 20 min.

- Production rate - 8,000 washers per shift.

## 1.3 Organization Background

It is India's largest Engineering and Construction Conglomerate with sales exceeding $3.5 billion. The Kirloskar Group today export products to over 70 countries. The Kirloskar group of companies was one of the earliest industrial groups which made a mark in the engineering industry in India.

The Kirloskar Group:

- Kirloskar Brothers Limited,
- Kirloskar Oil Engines,
- Kirloskar Ferrous Industries,
- Kirloskar Pneumatic Company,
- Kirloskar Ebara Pumps Ltd,
- Kirloskar Construction And Engineers Ltd,
- SPP Pumps (UK),
- The Kolhapur Steels Ltd.

The group produces:

- Engines and Auto components,
- Pumps,
- Compressors,
- Lathes,
- Electrical equipments like Motors, Transformers and Generators.

- Kirloskar Oil Engine Limited (KOEL):

It is a highly respected brand in energy generation and auto component market. The organization engaged in manufacturing:

- Diesel Engines,
- Power generators,
- Auto components such as Engine Bearings, Bushes, Thrust Washers and Flanges.

KOEL started in 1957 and today it is <u>the largest Engine bearing manufacturing industry in India</u> with production rate 60 million nos. With high end technology supported by equally skilled dedicated team, the company enjoys leading position in automobile sector in its class.

Fig1.4: Automobile Product Basket

# 2. Literature Survey

## 2.1 Types of Bearings That KOEL Manufactures

### 2.1.1 Half bearing:

Fig 2.1: Half Bearing

These are half circular in shape as bearings are fitted in between housing and shaft. For ease of fitment these bearings are manufactured into two half's and fitted as a pair into the engine.

### 2.1.2 Bushes or Bush Bearings:

Fig 2.2: Bush Bearing

These are round in shape. Different types of bushes used in engines are small end bush, cam bush, rocker arm bush.

### 2.1.3 Thrust washer:

Fig 2.3: Thrust Washer

These are flat plates semicircular or circular in shape.

### 2.1.4 Flange bearings:

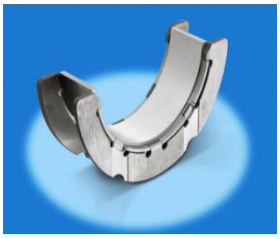


Fig 2.4: Flange bearing

These are half bearings with thrust as an integral part of it.

## 2.2 Positioning of Different Bearings In I.C Engines

The positioning of different bearings in the engine is as shown in figure below:

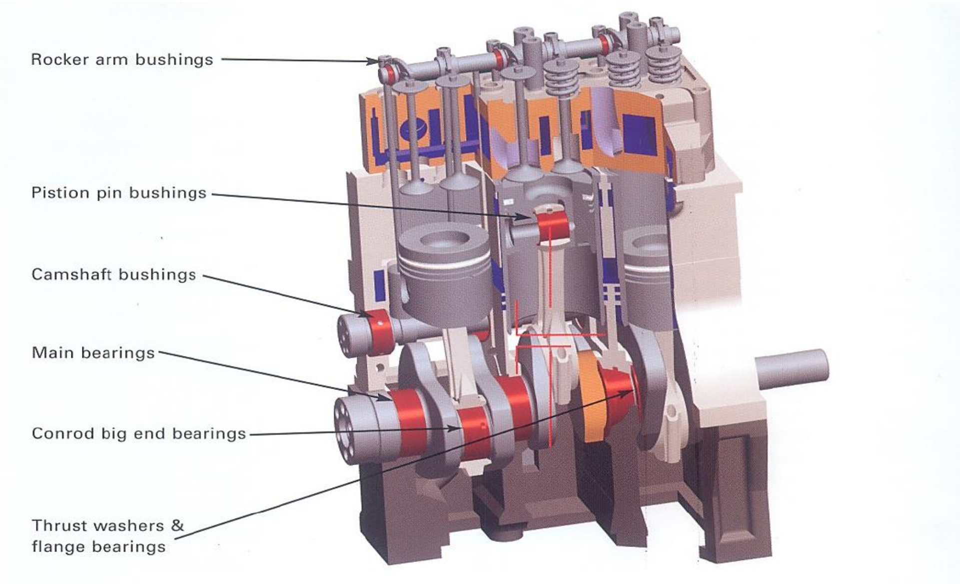



Fig 2.5: Position of Different Bearings in I.C Engines

## 2.3 Bimetallic Bearings

Cold rolled steel strips used in the manufacture of Bearings, Bushings and Thrust Washers confirms to SAE 1008, SAE 1010 and SAE 1020 standards. A bearing requires taking various loads in respective areas and also needs to be very strong and sturdy. As assembled, these bearings experience tangential and radial hoop stresses. In operation, the bearings experience higher pressures, cavitations zones, dirt embedment, oil churning effects, higher temperatures, wear, exposure to combustion gasses, acid attack and much more depending on the application. To address this requirement these bearings are manufactured in combination of bearing alloy with steel back. Such bearings are also called as bimetallic bearings. The bearing material needs to support high loads at high temperature and at high speed. These bearings are designed to address all these properties, these bearings safeguards very costly parts like crankshaft and crank case at the time of repowering of the engine comparatively low cost bearings are changed.

## 2.4 Material Families of Bearings

In KOEL, the two types of bearing materials are used which are as follows:

### 2.4.1 Aluminium based materials:

These materials contain Copper, Nickel individually or together, for strength to the matrix, Tin as a soft phase and Silicon as a constant shaft polishing media. The Tin metal gets uniformly distributed along the grain boundaries of Aluminium-Copper-nickel matrix. Silicon particles are uniformly distributed in the matrix as islands. The cast bearing lining material is cladded with pure Aluminium foil, rolled down and is roll bonded onto the steel back.

The forms of bearings in this family are half bearings, wrapped bush, thrust washer and flanges. These alloys are suitable for medium loaded engines and have excellent resistance to corrosion. Aluminium-tin-nickel alloy half bearings can be overlay plated.

### 2.4.2 Copper based materials:

Mostly, these materials are Copper, Tin and Lead alloys. The Lead metal gets distributed uniformly along the grain boundaries of sintered Copper-Tin i.e. bronze matrix on to the steel backing.

The forms of bearings in this family are half bearing, wrepped bush, thrust washer and flanges. These alloys are having superior hard phase properties like load carrying capacity, wear resistance and cavitation erosion resistance which are nessary for higher-powered engines. If required, the soft phase properties like conformability, embeddebility and compatibility are achieved by overlay plating. The corrosion resistance and improvement in fatique strength are also achieved by the overlay plating.

## 2.5 Thrust Washer

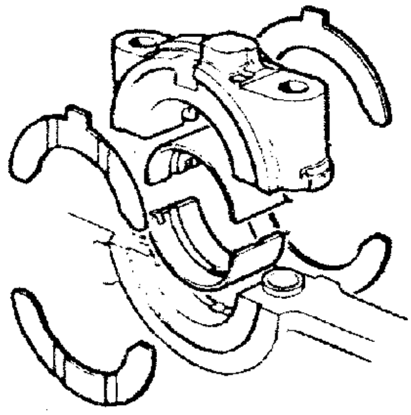


Fig 2.6: Thrust Washer

The crankshaft is subjected to end-thrust, which is an axial load in addition to that experienced by the big-end journals and bearings. This axial load is transferred from the crankshaft to the main bearing housing. This thrust may be generated intermittently or continuously due to several factors which includes:

- Intermittent disengagement of the clutch causes the flywheel to push against the crankcase.
- Continuous torque conversion in some automatic transmissions causes the flywheel to pull away from the crankcase.
- Either acceleration or deceleration of the helical valve-timing gear train during operation pushes or pulls the crankshaft axially one way or the other.
- The helical-gear primary drive on front-wheel-drive cars with integral engine and transmission creates an almost continuous load on the thrust washers.

The crankshaft is subjected to bending loads under certain operating conditions. This imposes strains on the cylinder block and crankcase disturbing the axial alignment. Under this situation, only the crankcase half of the thrust washer controls axial movement effectively. Thrust washers are provided on each side of only one main-bearing housing bore, which takes total axial crankshaft thrust in both directions. Since the thrust washers and the crankshaft web have a parallel-ring face contact, no wedge-shaped oil film can develop to separate these rubbing pairs, so very marginal lubrication takes place under continuous axial loading. This explains the working of the thrust washers.

## 2.6 Current production process of thrust washers

Currently the production process starts from the formation of bimetallic strips for bearing materials till the complete manufacturing of Bearing.

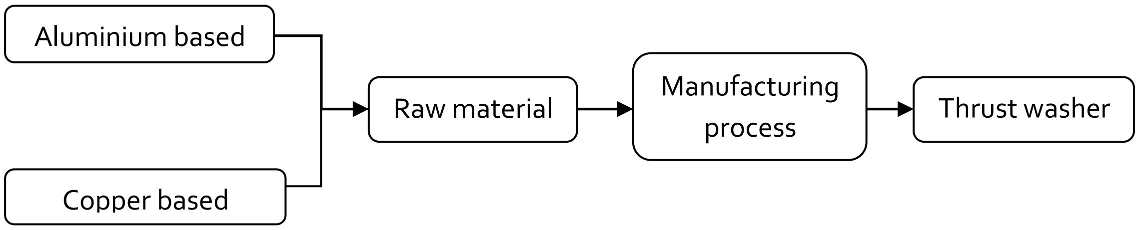



Fig 2.7: Generic Production Flow Process

### 2.6.1 Process of Manufacturing Bi-Metallic Strip for Copper Based Engine Bearings:

The following processes are used for manufacturing bi-metal strips for copper based engine bearings:

A. Sintering process for copper based bi-metal strips
B. Casting process for copper based bi-metal strips

Both processes are capable to produce the wide range of Copper based bearing materials.

Cast materials are stronger than sintered of the same composition due to possible voids and pores characteristic for sintered alloys. In addition to this the Grain structure of cast bearing alloys consists of copper dendrites oriented perpendicular to the bearing surface and therefore capable to resist progressing Fatigue cracks. Here, at KOEL the bimetallic strip is manufactured by sintering process.

➢ Sintering process for copper based bi-metal strips:

The powder for sintering copper alloy is prepared by atomization of a melt of the alloy.

The sintering process includes the following stages:

- Uncoiling steel strip.
- Straightening the steel strip.
- Washing the strip by a hot alkaline solution and mechanical cleaning by rotating steel wire cylindrical brushes.
- Sanding the strip surface by an abrasive rotating endless belt.
- Spreading the powder of the copper alloy over the steel surface:

  The necessary powder alloy thickness is pre-calculated. The calculation takes into account two factors: the ratio between the densities of the powder and the sintered alloy and elongation of the strip as a result of Rolling.

- Sintering the powder:

  The process is performed in a long (about 33ft/10m) sleeve-type continuous sintering furnace.

Fig 2.8: Sinter Line

Fig 2.9: Sinter Furnace

The sintering temperature is within the range 824-880°C (1515-1615°F) depending on the alloy composition. The atmosphere in the furnace is reducing, it consists of a mixture of Hydrogen ($H_2$) and Nitrogen ($N_2$), which may be prepared in Ammonia cracker by the process of dissociation of gaseous anhydrous Ammonia ($NH_3$) according to the reaction:$2NH_3 = N_2 + 3H_2$. During the sintering process atmospheric hydrogen converts the oxides of copper (and other metals) on the surface of each powder particle into the metallic state. ($CuO + H_2 = Cu + H_2O$)The particles then physically join (weld) to each other and to the steel strip due to the mutual diffusion of their atoms.

- Compaction:

After sintering stage density of the alloy is higher than in the powder state but it is still 20-30% lower than in fully compact state. The pores between the joined particles are closed in the compaction stage when the strip passes a Rolling mill.

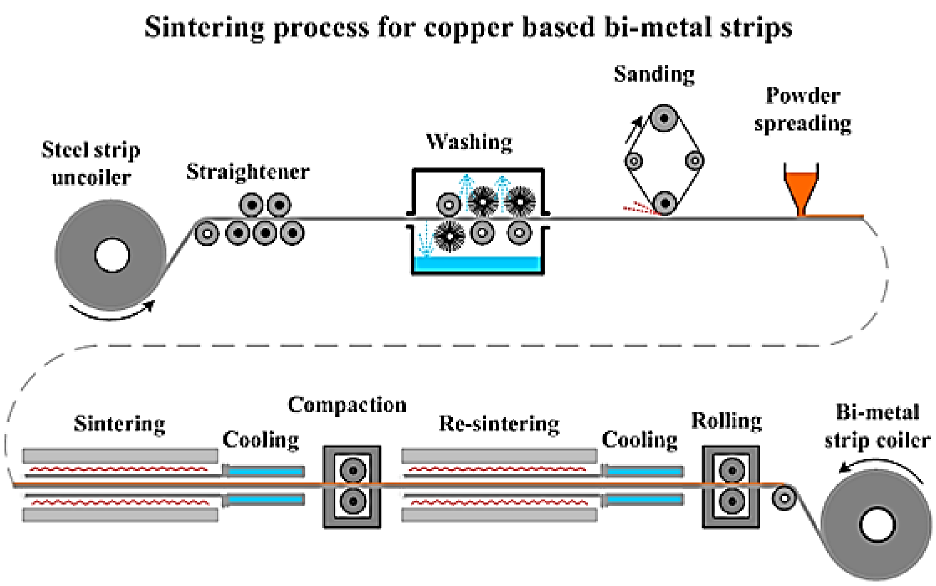



Fig 2.10: Sintering Process for Copper Based Bimetallic Strips

- Re-sintering:

This stage is performed in order to set physical joining (welding) between the surfaces of the pores mechanically closed in the compaction stage. Re-sintering is conducted in a sintering furnace similar to that of the sintering stage. Parameters of the process are also similar to those of the sintering. As a result of re-sintering sound (no porosity), sinter structure of the copper alloy forms. The second phase (lead, bismuth) is homogeneously distributed throughout the copper based matrix in form of small particles located between the copper grains.

- Rolling:

  This stage is performed in order to strengthen (strain hardening) both the steel back and the sintered cooper alloy.

- Recoiling the bi-metal strip.

### 2.6.2 Process of Manufacturing Bi-Metallic Strip for Aluminium Based Engine Bearings:

The Process includes the following stages:

- Annealing cast strips of Aluminium bearing alloys:

  Most methods of Continuous casting of Aluminium based bearing alloys result in internal stresses therefore the castings should be annealed prior to cladding.

- Cladding Aluminium bearing alloy with pure Aluminium:

  Two pure Aluminium layers may be clad from both sides of the casting: the bonding layer and the protection layer preventing tin “sweating” on the Aluminium surface during the final annealing of the bi-metal strip

- Roll bonding Aluminium and steel strips:

  Prior to bonding with steel clad Aluminium strip is degreased, mechanically cleaned and brushed by rotating circular brushes (either nylon or steel) in a cleaning line where the Aluminium strip passes through a solvent degreaser (similar to the line for cleaning pure Aluminium strip).

The drum with the coil of clean strip of Aluminium bearing alloy is then installed on the bonding line.

Coil of a steel strip is installed on the uncoiler of the bonding line. The steel strip is uncoiled straightened, cleaned by circular rotating brushes in the washing unit using a hot alkaline solution and then grinded by rotating abrasive belts.

In parallel the Aluminium alloy strip is uncoiled and brushed by steel wire rotating circular brushes (only the surface, which is to be bonded to the steel strip is brushed).

Two strips enter rolling mill where they adhere to each other as a result of Solid State Welding (SSW). The pressure necessary for achievement of bonding is obtained at relatively high thickness reduction for on-pass rolling operation. Four-high rolling mills are used for bonding Aluminium alloy with steel strip.

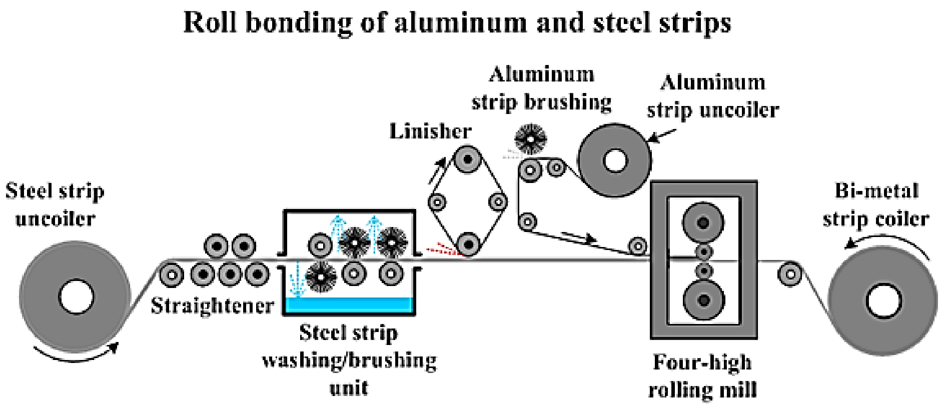



Fig 2.11: Roll bonding of aluminium and steel strips

- Annealing bi-metal strips:

  Aluminium bearing alloy on the bonded bi-metal strips has internal stresses and the stress on the boundary between the Aluminium and steel strip. The stresses may lead to the bearings failure therefore stress relief operation of the bonded strips is necessary.

### 2.6.3 Limitations of the Process:

The major limitation of the process above mentioned is that the thickness achieved cannot be controlled accurately because of the low efficiency of the rolling mill. Also surface finish achieved is inadequate. It requires large amount of rework.

## 2.7 Generic Process Flow For The Manufacturing Of Thrust Washer

The various operations are carried out on the manufactured bimetallic strip in order to produce the washer of the required specifications.

The sequence of the operations carried out is as follows:

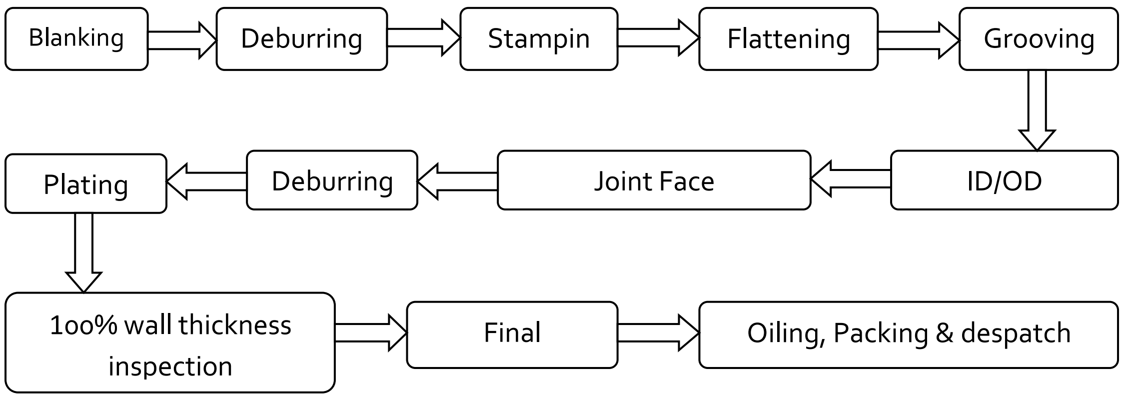



Fig 2.12: Process Flow of operations for manufacturing of Thrust Washers

These processes are described as follows:

- Blanking :

  After uncoiling, the bimetallic strip is continuously fed to the press machine, where the bimetallic strip is cut in the shape of thrust washer by hydraulically operated punch. Also because of blanking, the flatness of the washer is affected.
- Deburring :

  In this process, thrust washers are manually fed in centrifuge. The Centrifuge contains pebbles and some solution which is continuously rotating. The washers are kept in centrifuge for around 30 minutes. The burr is removed because of continuous friction developed between the pebbles and thrust washers for prolonged time.

- Stamping:

  In this process, the details regarding the thrust washer are inscribed onto the washer. It usually contains the Manufacturer's logo and name, the washer specification and product code etc. It is important parameter which designates product's respective identity.

- Flattening:

  Flatness is an important parameter of thrust washer and is required to maintain critically. The flatness of the washer is affected in the blanking process. Hence the flatness is maintained in this process. The washers are passed through the number of rollers which are closely placed causing uniform pressure on washers resulting in flattening of the washers.

- Grooving:

  The grooves are cut on the thrust washers for the oil channels needed for lubrication. The grooves are cut by the milling process. The washer works best when they are lubricated as they take unwanted axial thrust. Usually the energy transfer takes place by friction hence in order to minimize the losses and improve the efficiency; the grooves are cut on the thrust washers.

- ID & OD chamfering:

  The process takes care of the chamfering at inner and outer diameter of the washers. For easy fit and easy installation, the chamfering is provided. Also removal of any sharp edges which can cause any harm is avoided.

- Joint face chamfering :

  The joint face chamfering is done with the help of grinder.

- Deburring:

  The washers are again deburred to remove any burrs produced due to processing of washers.

- Plating :

  It is done on the copper-lead thrust washers for maintaining its softness as the copper-lead becomes very hard after cold operations which is undesirable property as a bearing. It is not necessary operation and may not be taken in operation.

- 100% wall-thickness inspection:

  If washer thickness is more it fouls with crank shaft and creates problem for rotation and if it is less it increases the axial play and engine performance deteriorates. After continuous usage of the engine at the time of repowering washer with different higher thicknesses are used to take care of wear of thrust area of crank shaft. With usage of such oversize thrust washers more life from crank shaft is extracted.

  As the thickness is important parameter in thrust washers, 100% wall-thickness inspection is done. Each and every washer is tested for the wall-thickness with the help of NO-GO gauge. The washers are allowed to fall under gravity in NO-GO gauge. If the washer fails to pass through the gauge, it is discarded as scrap.

- Final inspection:

  The manufactured washers are sent to the inspection where the washer is inspected visually for any defects.

- Oiling and Packing:

  After the final inspection, which means the washers manufactured are ready for the use. The oiling of washers is done in order to protect it against rusting. The washers are the packed accordingly for its transportation.

### 2.7.1 Limitations of The Process:

- The surface finish achieved does not satisfy the application need.
- Its difficult to acquire permissible tolerance regarding the thickness.
- Its difficult to maintain uniform flatness.

## 2.8 Solution

As the current manufacturing has some major limitation, the rejection rate was unaffordably high. In order to overcome those limitations, re-work is needed to be done, increasing the cost overall.

It was impossible to alter all the manufacturing process from bimetallic strip formation to washer formation, only a part of it has to be changed to overcome the limitations. Major thought has been given on this problem and considering various different solutions, the optimum and economical one has been selected.

The solution selected is to put a machine in the existing process itself which will carry out surface cutting operation to maintain washer's thickness and also satisfying the other parameters such as surface finish and flatness.

As it is concluded to introduce a certain machine which will overcome these limitations, our project scope is to design this machine!!!

## 2.9 Various Manufacturing Processes Available

As our task is to design a machine which will fulfill the requirements, we started this by considering the various operations which could perform the task best.

### 2.9.1 Milling:

Fig 2.13: Milling Operation

Milling is the complex shaping of metal or other materials by removing material to form the final shape. It is generally done on a milling machine, a power-driven machine that in its basic form consists of a milling cutter that rotates about the spindle axis (like a drill), and a worktable that can move in multiple directions.. The spindle usually moves in the z axis. It is possible to raise the table. Milling machines may be operated manually or under computer numerical control (CNC), and can perform a vast number of complex operations, such as slot cutting, planing, drilling and threading, routing, etc. Two common types of mills are the horizontal mill and vertical mill.

In order to keep both the bit and the material cool, a high temperature coolant is used. In most cases the coolant is sprayed from a hose directly onto the bit and material. This coolant can either be machine or user controlled, depending on the machine.

Materials that can be milled range from Aluminium to stainless steel and most everything in between. Each material requires a different speed on the milling tool and varies in the amount of material that can be removed in one pass of the tool. Harder materials are usually milled at slower speeds with small amounts of material removed. Softer materials vary, but usually are milled with a high bit speed.

The use of a milling machine adds costs that are factored into the manufacturing process. Each time the machine is used coolant is also used, which must be periodically added in order to prevent breaking bits. A milling bit must also be changed as needed in order to prevent damage to the material. Time is the biggest factor for costs. Complex parts can require hours to complete, while very simple parts take only minutes. This in turn varies the production time as well, as each part will require different amounts of time.

Table 1: Summary of Milling Operation

| | |
|---|---|
| **Materials:** | Metals, Alloy Steel, Carbon Steel, Cast Iron, Stainless Steel, Aluminium, Copper, Magnesium, Zinc. |
| **Surface finish:** | Ra 0.8–3.18μm. |
| **Tolerance:** | ± 0.0254 mm. |
| **Advantages:** | All materials compatible,<br>Very good tolerances,<br>Short lead times. |
| **Disadvantages:** | Limited shape complexity,<br>Part may require several operations and machines,<br>High equipment cost,<br>Significant tool wear. |
| **Applications:** | Machine components, engine components. |

### 2.9.2 Grinding Operation

1. 

Fig 2.14: Grinding Operation

Surface grinding is used to produce a smooth finish on flat surfaces. It is a widely used abrasive machining process in which a spinning wheel covered in rough particles (grinding wheel) cuts chips of metallic or non-metallic substance from a workpiece, making a face of it flat or smooth.

Grinding uses an abrasive process to remove material from the workpiece. A grinding machine is a machine tool used for producing very fine finishes, making very light cuts, or high precision forms using abrasive wheel as the cutting device. This wheel can be made up of various sizes and types of stones, diamonds or inorganic materials.

Grinders have increased in size and complexity with advances in time and technology. Grinders need to be very rigid machines to produce the required finish.

In the past grinders were used for finishing operations only because of limitations of tooling. Modern grinding wheel materials and the use of industrial diamonds or other man-made coatings (cubic boron nitride) on wheel forms have allowed grinders to achieve excellent results in production environments instead of being relegated to the back of the shop.

Modern technology has advanced grinding operations to include CNC controls, high material removal rates with high precision, lending itself well to aerospace applications and high volume production runs of precision components.

Generally a finishing operation achieves the surface finish of up to0.025μm and extremely close tolerance.

Table 2: Summary of Surface Grinding Operation

| | |
|---|---|
| **Materials:** | Aluminium, Stainless steel, Brass, Some plastics, Cast iron and minor steel. |
| **Surface finish:** | Up to 0.025μm. |
| **Tolerance:** | ± 5 to 8μm. |
| **Advantages:** | Very fine finish,<br>Extremely close tolerances,<br>High volume production runs. |
| **Disadvantages:** | Very High equipment cost,<br>Significant tool wear,<br>Clogging of wheel due to soft materials,<br>Coolant is required. |
| **Applications:** | For finishing operations. |

### 2.9.3 Surface Broaching

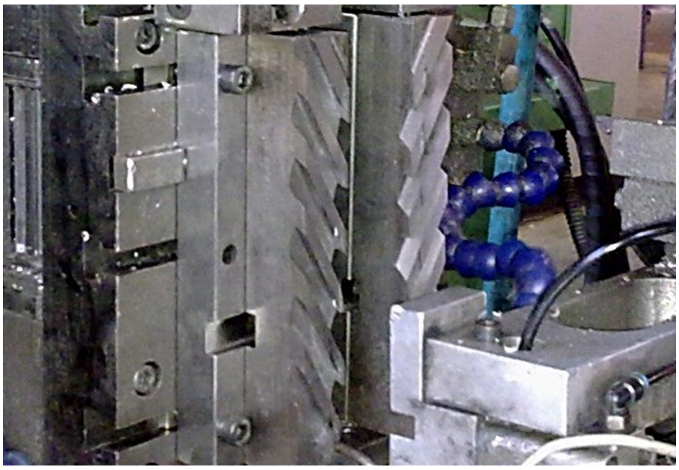


Fig 2.15: Surface Broaching Operation

Broaching is a machining process that uses a toothed tool, called a broach, to remove material. There are two main types of broaching: linear and rotary. In linear broaching, which is the more common process, the broach is run linearly against a surface of the workpiece to affect the cut. Linear broaches are used in a broaching machine, which is also sometimes shortened to broach. In rotary broaching, the broach is rotated and pressed into the workpiece to cut an axis symmetric shape. A rotary broach is used in a lathe or screw machine. In both processes the cut is performed in one pass of the broach, which makes it very efficient.

Broaches are shaped similar to a saw, except the teeth height increases over the length of the tool. Moreover, the broach contains three distinct sections: one for roughing, another for semi-finishing, and the final one for finishing. Broaching is an unusual machining process because it has the feed built into the tool. The profile of the machined surface is always the inverse of the profile of the broach. The rise per tooth (RPT), also known as the step or feed per tooth, determines the amount of material removed and the size of the chip. The broach can be moved relative to the workpiece or vice-versa. Because all of the features are built into the broach no complex motion or skilled labor is required to use it.A broach is effectively a collection of single-point cutting tools arrayed in sequence, cutting one after the other.

Most of the time is consumed by the return stroke, broach handling, and workpiece loading and unloading. Broaching works best on softer materials, such as brass, bronze, copper alloys, aluminium, graphite, hard rubbers, wood, composites, and plastic. However, it still has a good machinability rating on mild steels and free machining steels. When broaching, the machinability rating is closely related to the hardness of the material. Tolerances are usually ±0.05 mm, but in precise applications a tolerance of ±0.01 mm can be held. Surface finishes are usually between0.4 to 1.6µm.

Table 3: Summary of Surface Broaching Operation

| | |
|---|---|
| **Materials:** | Bronze, Copper alloys, Aluminium, Mild steels and free machining steels, Graphite, Hard rubbers, Wood, Composites, Plastics. |
| **Surface finish:** | Ra 0.4 to 1.6µm. |
| **Tolerance:** | ±0.01mm. |
| **Advantages:** | High Material Removal Rate<br>Good surface finish<br>Used for high-quantity production runs<br>no skilled labour is required<br>Versatility & economical<br>Low cycle time.<br>Automation is easy |
| **Disadvantages:** | Tool cost is high<br>Cutter design is complex<br>Limited workpiece complexity<br>Time is consumed in return stroke |
| **Applications:** | Used for key ways,<br>Internal guide slots<br>Finishing operations,etc. |

## 2.10 Selection of best Cutting Process

Considering and keenly studying all the above manufaturing process discussed, we tabulated and compared the process to suit us as per our requirement.

Table 4: Selection of Cutting operation

| Parameters considered | Broaching | Grinding | Milling |
|---|---|---|---|
| Surface finish | ●● | ●●● | ● |
| Tolerance attained | ●●● | ●●● | ●● |
| Cost of production | ●●● | ● | ●● |
| Mass production | ●●● | ●● | ● |
| Ease in automation | ●●● | ●● | ● |
| Time required for machining | ●●● | ● | ●● |
| Al. & Cu. machining | ●●● | ● | ●● |

●●● Maximum Suitable.

●● Medium suitable.

● Minimum suitable.

The points are given according to our requirements and are relative to each other.

According to above table broaching was selected.

# 3. DESIGN CONCEPTS

After finalizing the broaching operation, our next approach was to consider the various design concepts suitable to carry out the cutting operation. We considered many possibilities including our own creations, fewer of them are discussed below.

## Various Possible Design Concepts Considered

## 3.1 Vertical Broaching

At first, we considered the orientation of the broaching operation vertical. As the vertical configuration uses less floor space (floor space is not the constraint though). In this configuration, the cutting stroke would be vertical. The washer will be held vertically fixed in the fixture and the broaching operation will be done in vertical stroke of the broach cutter.

The vertical broaching machine is already in use in the company for the purpose of joint face broaching of half bearings. Thus, the basic idea at first was to create a machine with vertical broaching configuration. Also all the necessary data required regarding vertical broach was available.

We decided to use existing equipment in the company with slight changes to take trials for vertical broaching and to study its feasibility.

The equipment consisted of the following parts:

- Magnets to hold washer vertically
- Pneumatically operated support
- Support for washer at its base

Procedure:

For taking the trials we first clamped the half thrust washer into the magnetic clamping device as shown in the figure below, the upper part of the washer was given support with the help of pneumatically operated mechanism. Also, provision was made to support the washer at the lower part i.e., the base. Vacuum type of support was one of our choices but due to less force generated by it, this type of support was discarded. We made used of cutter tool which is used for the joint face broaching which was easily available in the company. Our idea was to make a simple vertical clamping device which can be used for the broaching of the thrust washer with help of vertical push type broaching machine.

Fig 3.1: Clamping mechanism developed for the trial

Observations of the conducted trial are given below:

- The washer bends due to improper clamping.
- The washer fails in the region of the grooves because of abrupt change in c/s results to stress concentration.
- There are unwanted vibrations during broaching which reduces its tolerance.
- The flatness gets affected due to internal stresses generated during broaching which are released when magnet gets demagnetized.

Fig 3.2: Trial result of the Vertical Broaching mechanism

As the thickness of the washer is very small, the area on which the washer is supported is insufficient compared to the acting cutting forces. The fixture is unable to provide the firm grip on the washer. As a result of this, we totally eliminated the concept of vertical broaching.

## 3.2 Lotus mechanism

(Note: The name given is our creation and it's a hypothetical)

After the failure of vertical broaching machine concept, we thought of a mechanism which will support the washer at various points with the help of pebbles following a defined path to hold various sizes of washers. It was basically derived from the idea of a lathe chuck holding a job. This concept is briefly described below:

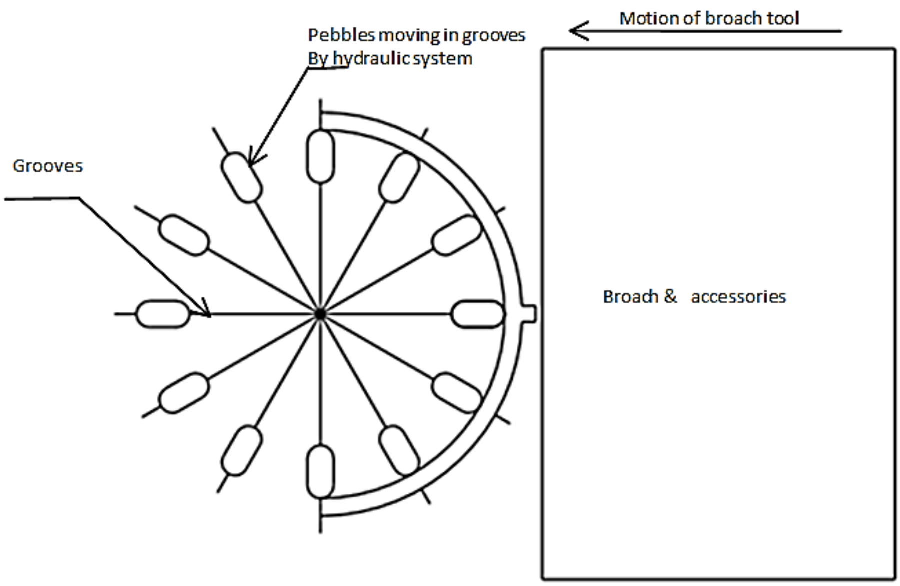



Fig 3.3: Lotus Clamping Mechanism

In this concept broach clamp is stationary and the broach tool moves. This mechanism has pebbles which move in grooves. These grooves are throughout the length of table and thus can hold any size of washers. According to this mechanism, washer will be supported only by few pebbles thus strength of pebbles required was high. To take care of these broaching forces, hydraulic systems were used. The advantage of this mechanism was that it distributed equal forces at all points of the washer. For avoiding the lifting of the washer there were two possible methods:

- Using magnet :

  The magnet will be placed on table to hold the washer in correct position. Due to magnets, internal stresses would get developed while cutting later their release would result in unwanted deformation which will hamper the flatness of the washer.

- Using cylinder :

  A cylinder was to be made use of, to hold the washer in its position. This cylinder will apply downward force on the washer while taking the first cut. This is more reliable method hence we decided to go forward with this mechanism.

Drawbacks:

- In this mechanism, input and output of the washer was complicated and hence it was discarded.
- Manufacturing was complicated and it was difficult to predict its feasibility.

## 3.3 Continuous broaching Mechanism

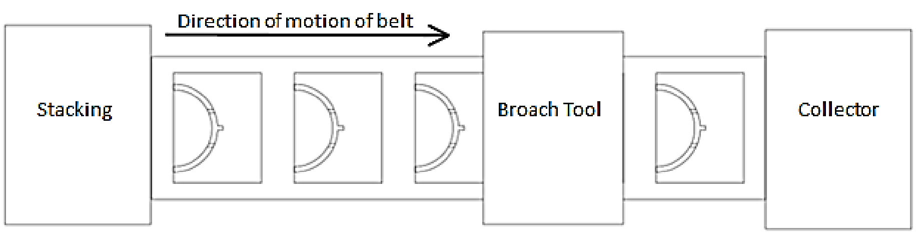



Fig 3.4: Continuous Broaching mechanism

As the requirement is of high production rate we had to meet, we thought of the process having less cycle time and we came up with the continuous broaching machine.

The mechanism consists of following components-

Stacking Assembly-

The mechanism uses a manual stacking assembly which consists of three movable arms. The arms will accommodate the washers of different sizes by moving the arms. It can also accommodate around 60 to 80 washers at a time. Also it has provision to remove only one washer at a time.

Conveyor-

It is continuously moving. It has a square shaped slot for accommodating washer. While moving, conveyor takes single washer at a time.

Broach cutter and accessories-

It consists of subassembly involving broach tool, and a mechanism to vary the height of broach tool to correctly accommodate the washers having different thickness. The broach tool is stationary and rigidly fixed together with height varying mechanism.

Collector-

It is box used to collect the processed washers.

Working-

The main component in this mechanism is the continuously moving conveyor belt and the stationary broach.

The idea was to place the washers onto the conveyor having rectangular slots to hold the washers at its place. The washers are fed continuously to the stationary broach cutter which will remove the material and the processed washers will be collected at the output block further. In this way the broaching operation will be carried out continuously and thus the rate of demand of high production rate can be achieved.

Drawbacks:

- Cutting forces needs to be taken by conveyor belt
- Need of highly rigid conveyor system which was nearly impossible
- Sagging of Conveyor may happen under load
- Difficult to hold washer while broaching
- Cannot control the cutting parameters critically
- Jerking of conveyor while broaching process

**The points taken out from this mechanism which are modified further and used-**

1. Instead of conveyor belt reciprocating slider mechanism is used.
2. Same concept of Stacking assembly is used with little modification
3. The concept of varying broach height is used with little modification.

## 3.4 Reciprocating slider Mechanism

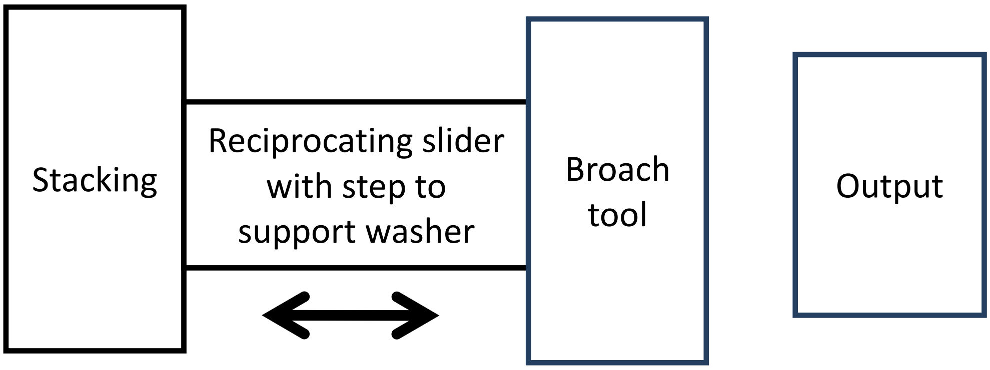



Fig 3.5: Reciprocating Slider Mechanism

It works on the same principles of above mechanisms. Only instead of versatile belt it has a solid, rigid slider. The slider contains a step of about 1mm which supports the washer. The actual operation delivers the load on this step, thus decreasing the possibility of failure. The stacking and cutting operations are simple.

Stacking Assembly-

The mechanism uses a manual stacking assembly which consists of three movable arms. The arms will accommodate the washers of different sizes by moving the arms. It can also accommodate around 60 to 80 washers at a time. Also it has provision to remove only one washer at a time.

Broach cutter and accessories-

It consists of sub assembly involving broach tool, and a mechanism to vary the height of broach tool to correctly accommodate the washers having different thickness. The broach tool is stationary and rigidly fixed together with height varying mechanism.

Working:

In this, the slider reciprocates taking in the washer from stacking assembly on its step. This slider with washer passes under the broach cutter which gives the washer its required thickness. This washer is taken out from the step at the end of forward stroke. The slider reciprocates doing work only in forward stroke and no work is done during return stroke. The speed of slider is very high and it reciprocates with high speed, the speed of return stroke being more than that of forward stroke. As in above concept, the broach cutter is stationary.

Advantages:

- As all the parts are rigid, design is reliable.
- Life cycle of this design is more as it does not require frequent changing of belt.
- Stacking is simple and easy.
- Removal of washer after broaching is simple.
- It can be easily automated.
- Less attention is required.

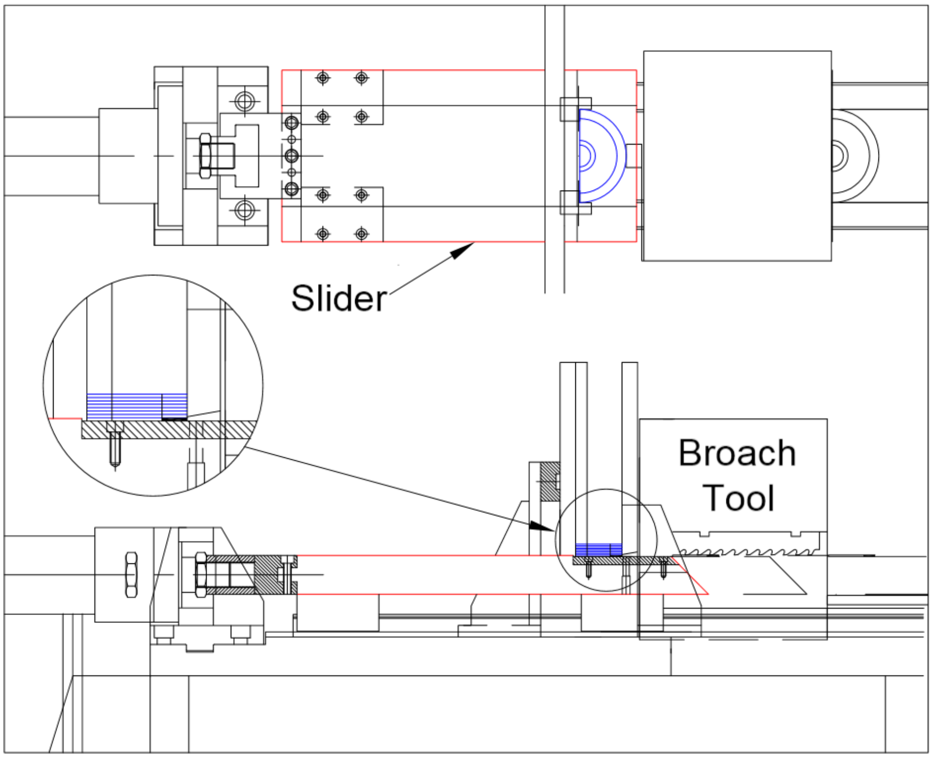



Fig 3.6 Illustrating Reciprocating Slider Mechanism

## 3.5 Selection of Design Concept

We considered many concepts including few of them described in earlier topics for the creation of the final concept. We noticed many difficulties while looking for solution and tried to overcome those difficulties in further concepts. Also we considered the different helpful elements in the various designs and were able to combine them in the final design to give best results.

The "Reciprocating Slider Mechanism" was the finest concept we had come across. The concept was remarkably simple in operation compared to other concepts also overcoming almost all the drawbacks previously had. The developed mechanism had least moving parts- only the reciprocating slider- and was easy for automation. Overall concept was feasible and would be able to work satisfactory for long term.

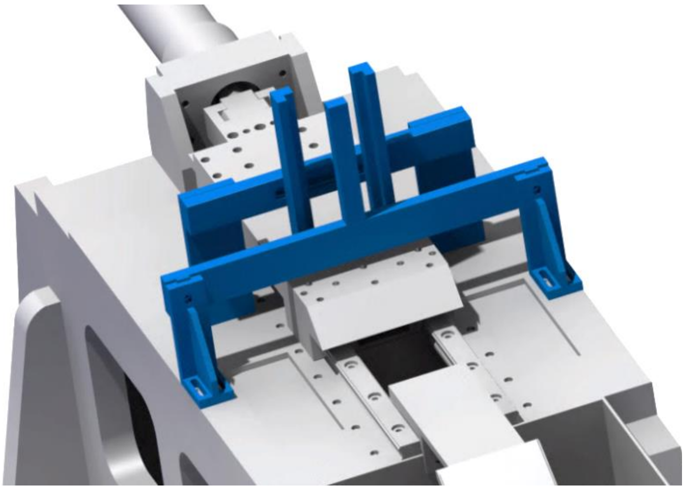
The derived concept was able to provide all the arrangement for the accommodation of all types of washer and all types of materials. The other arrangements such as tool change in case the tool life is over or the tool has damaged could be made. The tool height could be able to change which is required for cutting of washers having different thickness requirements.

Thus the present concept showed remarkable calibre required to be universal machine which would be able to serve for all different types of Thrust Washers that KOEL manufactures!

Considering the major concerns and with the help of company's expertise we finalised the "Reciprocating Slider Mechanism" as principle design concept for our machine.

# 4. Preliminary Design

## 4.1 Stacking Assembly



| Material | Mild steel |
|---|---|
| Modulus of Elasticity in ($Kg/mm^2$) | 20000 |
| Density ($Kg/m^3$) | 7850 |
| Weight of assembly (Kg) | 25.12 |

Fig 4.1: Stacking Assembly

Stacking assembly consists of two parts, front side stacking and back side stacking.

Front side stacking assembly consists of three parts, and has two relative motions. It is explained as follows:-

- Stacking frame support (front) (Qty. 2 nos.):

  These supports have slots on the face which is adjacent to base frame. It facilitates the forward and backward motion of the front stacking assembly to accommodate washers of different sizes. The moment is as illustrated in the fig above. It allows the assembly to move longitudinally varying the distance between both the front and back side of stacking assembly.It is L-shaped.

  It has one more slot on the vertical face which facilitates the movement of front frame to move up and down. This allows only one washer to pass under it for further processing.

- Stacking frame (Qty. 1 nos.):

  It consists of T –shaped frame which is used for supporting washers from front side. It has moves up and down.

Back side stacking assembly consists of five parts, and has one relative motion. It is explained as follows:-

- Stacking frame support (back) (Qty. 2 nos.):

  These are supports which are rigidly fixed to the base with the help of Allen bolts and there is no relative motion between them. It is an L-shaped block with stiffener for support. Two of them hold together a bridge which in turn supports the stacking guides.

- Bridge (Qty. 1 nos.):

  It has a slot grooved by milling on it along its length. This bridge allows the motion of guides along its length. This facilitates various sizes of washers.

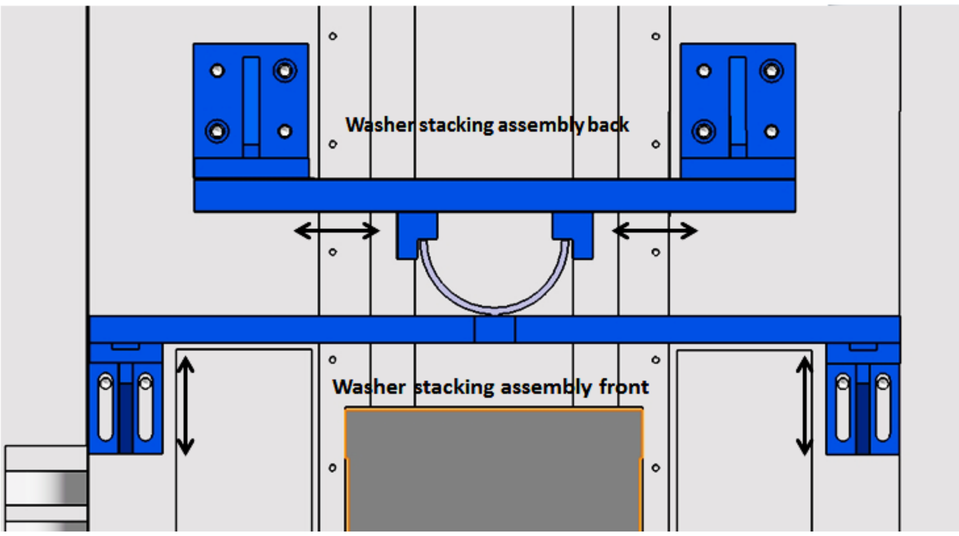
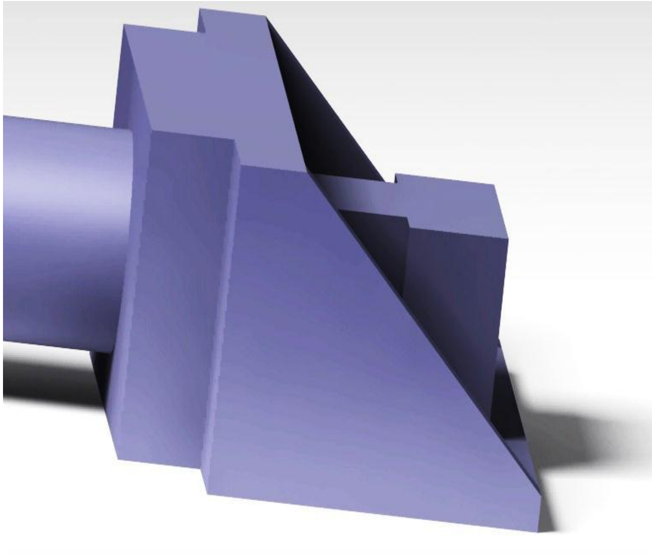



Fig 4.2: Working of Stacking Assembly

- Guide for Washer (Qty. 2 nos.):

  There are two guides, one on left side and other on right side. They move independent of each other in slot provided on the bridge. These guides are L-shaped and have considerable length. The distance between them can be varied to accommodate different washer sizes and shapes. They can also accommodate circular washers in correspondence to the stacking frame. The maximum size which it can accommodate is dia.165mm. While placing a circular washer, the guides would be arranged such that they make an angle of 60 degrees with respect to each other.

## 4.2 Cylinder Support Bracket



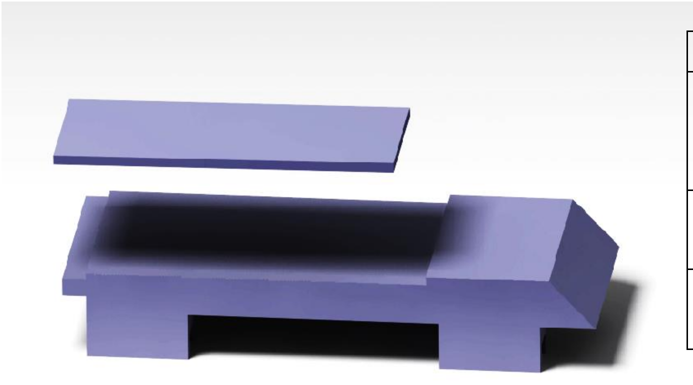
| | |
|---|---|
| Material | Mild steel |
| Modulus of Elasticity in $Kg/mm^2$ | 20000 |
| Density $Kg/m^3$ | 7850 |
| Weight of part Kg | 12.56 |

Fig 4.3: Cylinder Support Bracket

Cylinder support bracket is used to support the main cylinder or working cylinder and fixes it on base. It gives rigidity to cylinder, in which the piston moves due to oil pressure. This bracket is one of the most crucial parts in the machine. The forces acting on the piston are transferred to oil which in turn is transferred to cylinder. These forces are transferred to base through this support bracket. Thus the load acting on this bracket is about 5 tonnes at maximum capacity. The load acts generally while cutting stroke while it is negligible during return stroke when no operation takes place. Thus it has cyclic loading and it should sustain fatigue loads. The cylinder weight will act as cantilever load as it is not supported anywhere. Thus the construction of the bracket is as shown in the figure.

It has an L-shaped structure supported with stiffener at both edges. Its bottom face is rigidly fixed to the base with the help of four Allen bolts. On the other end, cylinder is fixed with the help of four Allen bolts. On this face, there is a big hole to accommodate motion of piston through it. The above bracket was made rigid and the stresses on it were calculated manually. The results were satisfying. Thus, we went for ANSYS analysis. The working of machine depends on this part. If there are too much vibrations or deformations of this part, the cylinder will deform too and will cause problems in working. Being one of the major parts, its reports were important.

## 4.3 Slider



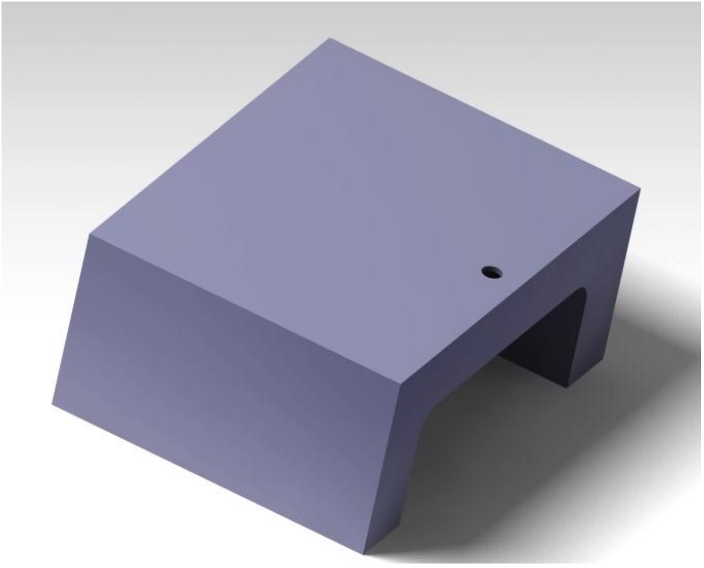
| Material | Mild steel |
|---|---|
| Modulus of Elasticity in (Kg/mm$^2$) | 20000 |
| Density (Kg/m$^3$) | 7850 |
| Weight of part (Kg) | 40.546 |

Fig 4.4: Design of Slider

The slider is the major moving part in the machine. It facilitates broaching of thrust washers. It reciprocates at very high speeds on base frame. It is the part which actually takes the load and transfers it to piston. It is one of the most stressed parts. It has 4 guide blocks attached to it on the lower side. This part takes in washer from stacking assembly and then passes under broach thus broaching the washer. To facilitate this operation step is provide on slider.

Slider assembly consists of two parts slider and slider plate. This plate is fixed to the slider by bolts. The size of this plate is changed as the thickness of washer changes. It more for thick washers and less for thin ones it is changed with washers. All the forces of cutting are transferred to this plate and thus this plate is made of M.S.

## 4.4 Cutter Support Frame



| Material | Mild steel |
|---|---|
| Modulus of Elasticity in (Kg/mm$^2$) | 20000 |
| Density (Kg/m$^3$) | 7850 |
| Weight of part (Kg) | 62.56 |

Fig 4.5: Design of Cutter Support Frame

It is one of the most important parts in the machine as it should take all the forces on the cutter and transfer them to base. In this machine the broach cutter is stationary hence even slight displacement will change surface finish and tolerance of the washer. It should also facilitate easy changing of tool this block contains two cylinders mounted on it. Washer input cylinder and washer output cylinder, thus it should also take these loads. It should also facilitate easy up and down motion of broach cutter in corresponds to taper blocks. This motion should be precise. It is the most complicated part in the machine. It is also prone to impact loads and fatigue loads. It is fitted to the base frame through two rectangular blocks.

It is a c shaped block. It has a groove inside it on its lower side of upper face in which the upper taper block moves and transfers load through it. This block is bulky. It has provisions to put hinge supports on one side so that it can be hinged and lifted by cutter changing cylinder to change the tool. This part has provisions to fit two cylinders on it as mentioned above. This block is fitted to base by another support this support applies pressure on one side of the block while the other side is hinged and bolted. This pressure is applied with the help of another plate which is bolted to a pillar which is fixed to the base. This mechanism is like c clamp and thus is called c clamp mechanism. There is no direct hole through the part. All the sides in this have same thickness. The major force on it is the force from cutter. Its maximum value is 5tonnes. Being the most important part and prone to failure the analysis is important. Thus the ANSYS analysis of this part is done and the reports are given below.

## 4.5 Cutter Assembly

Cutter assembly is used to hold the broach cutter and it is fixed on to the upper block with the help of suitable bolt arrangement. It is an assembly of nine parts. Following are the different parts used in this assembly.

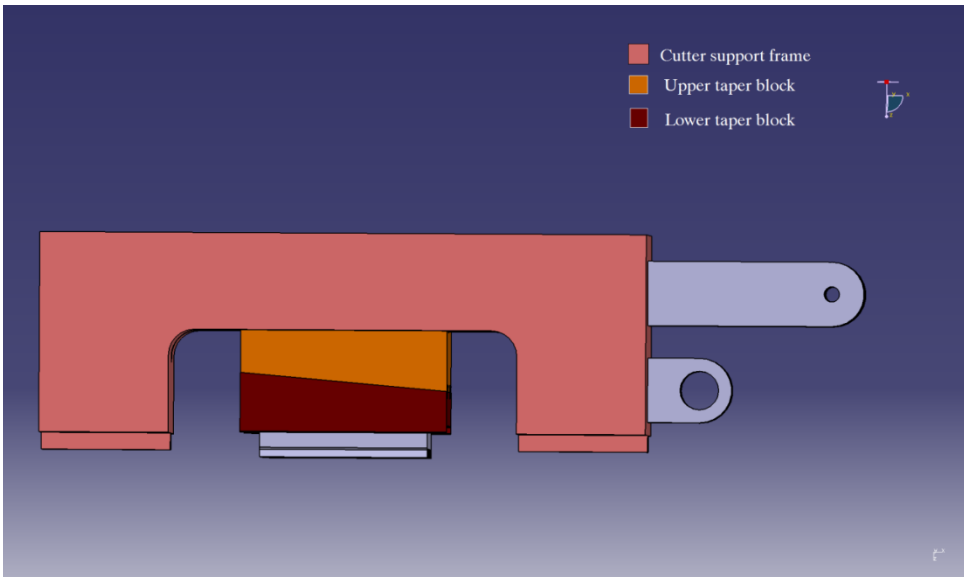



Fig 4.6: Cutter Assembly

- Upper taper block:

  It is mounted in between the cutter support frame and lower taper block with the help of slot and bolts. This is a wedged shaped block. It has a side screw type slot drilled through it to permit the upward –downward motion of the cutter tool in case of varying thickness of the thrust washer, this is done with the help of a typical screw which on rotation converts to the linear motion of the taper blocks resulting into the adjustment of the tool as per the thickness of the washer. The broach tool goes down by 0.3mm for one rotation of this screw. This value is taken into account in order to compensate for the tolerance required. It is made up of M.S.

- Lower taper block:

  It is mounted in between the upper taper block and the broach tool with the help of rails having arrangement for bolts in order to mount the tool. It is also a wedged shaped block. The design of this lower block is very critical because it has to cater for the force which will be coming onto the broach tool during cutting process. It is made up of M.S.

- Cutter support frame:

  It is the main part of the cutter assembly. It is the topmost part having a slot along it to accommodate the upper taper block. The taper block is then bolted to it with the help of Allen bolts. This frame needs to be very sturdy because it takes the load coming from the cutting of the washers. Also it supports the auxiliary input cylinder, the cutter opening bracket and the support blocks. The cutter support frame is rigidly fixed to the base assembly with the help of Allen bolts.

- Broach cutter:

  It is the most important part in machine. It is mounted on to the lower taper block with the help of special arrangement having slots to accommodate the cutter and fix it with the help of special alien bolts. The cutter tool is manufactured by the company and needs special care while designing and manufacturing. Broach cutter is many times designed and manufactured by experts. It is made up of HSS.

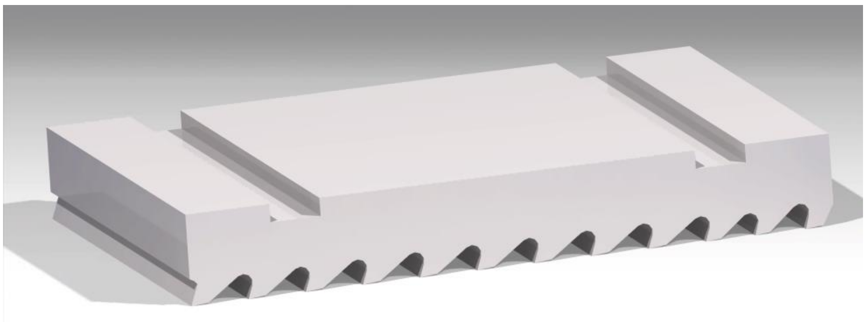


Fig 4.7: Broach Cutter

- Cylinder 2 (Input cylinder):

After taking into account the expert comments from the designers there was a possibility that the thrust washer might be getting uplifted at the washer edge which will come in contact with the cutter. This is one of the critical observations in our design. We started analyzing for the solution to this problem. We came up with the several ideas.

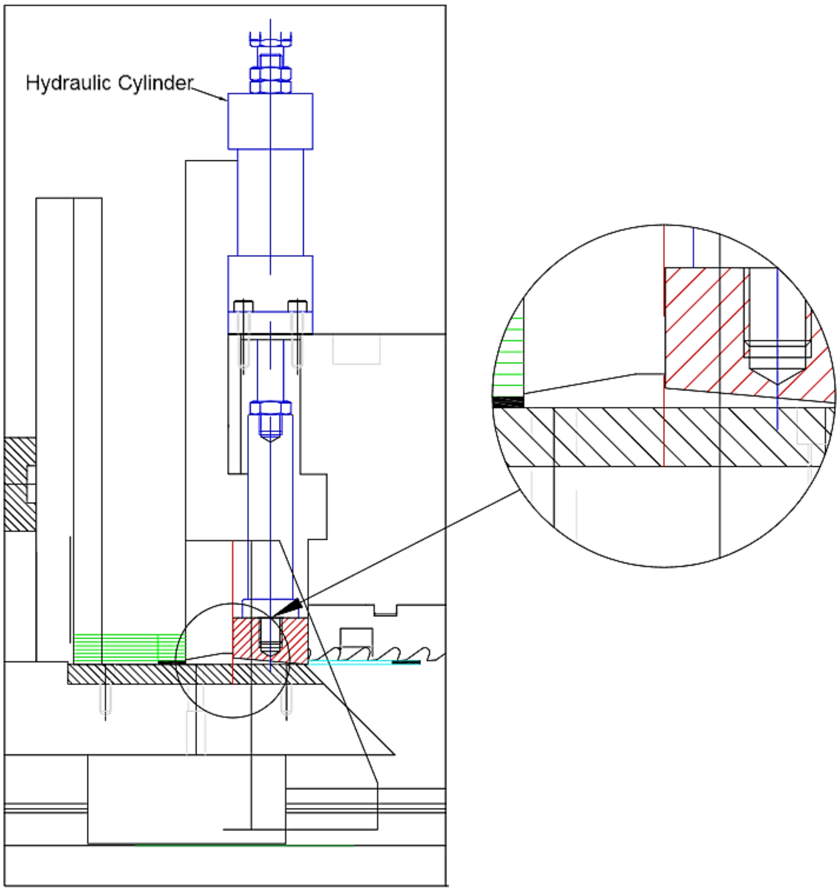



Fig 4.8: Working Mechanism of Cylinder 2

Firstly, we thought of using a spring operated cylinder which will be applying uniform pressure on to the washers. This cylinder is located onto the cutter support frame, at the start of cutter tooth. The idea behind this was to pre tension the spring and apply almost enough force to avoid the lifting of the washer. This was one of the effective methods. But the problem behind using this type of operation is that every time the tension of this spring was required to be adjusted which increased manual labour. Also, maintaining uniform pressure was difficult and there was chance of spring deformation which required frequent changing of spring.

Secondly, the idea was to use a pneumatically operated cylinder which required pneumatic circuit which was designed by experts. This was the simplest of all. A continuously applied force was acting on the washers with the help of piston cylinder arrangement this was the feasible type of operation and long lasting.

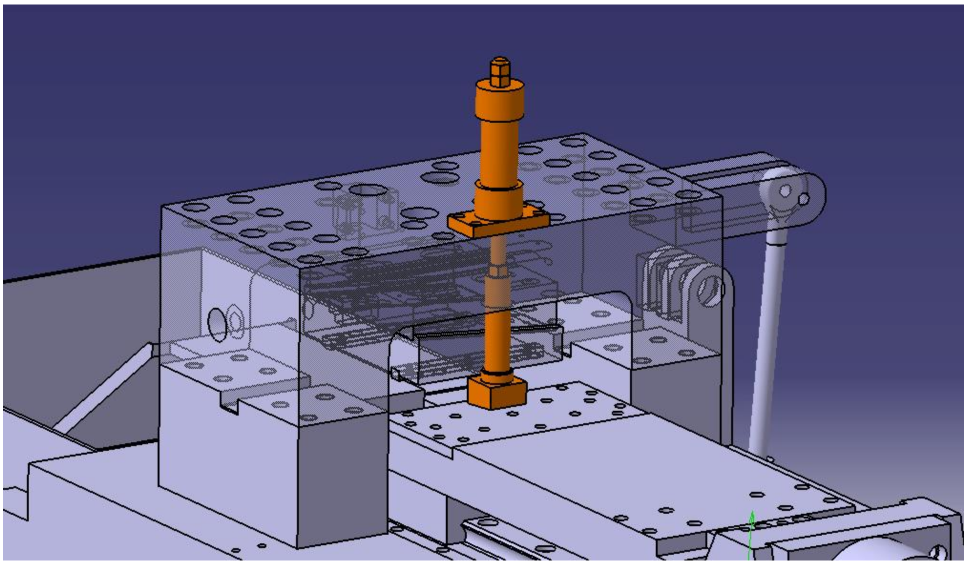


Fig 4.9: Cylinder 2

This cylinder rests on the support frame and is fixed to it with the help of Allen bolts. Even though small in size, this cylinder is of great significance. Its basic function is to avoid the lifting of the washers due to the couple that acts on them when they come in contact with the broach cutter. It applies a downward force on the washers while they enter the cutting section. It is hydraulically operated and its height can be varied according to the thickness of the washer.

- Cylinder 3(Output):

This cylinder is fixed to the support frame, towards the output side of the machine. Its function is to grip the washer after it has been broached and deliver it to the washer output box. Its motion is adjusted in such a way that it keeps moving up and down after certain time intervals with the help of limit switches and is so matched that when the slider plate reaches its forward limit, the cylinder travels its downward limit.

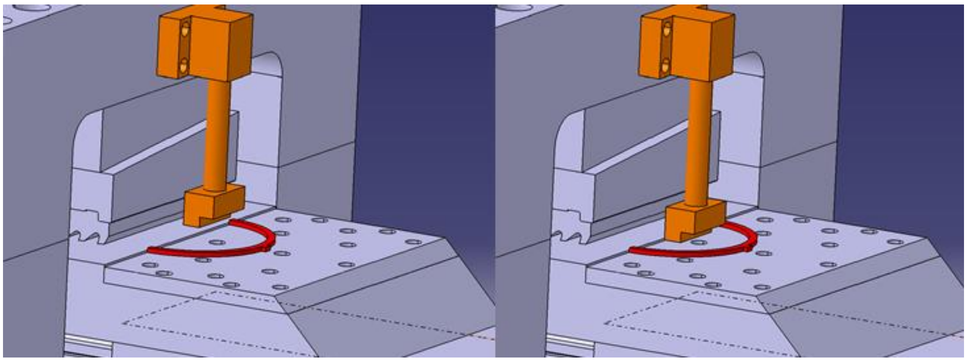


Fig 4.10: Output Auxiliary Cylinder

- Cutter opening bracket:

This bracket basically mounts a cylinder on it so as to facilitate the opening of the cutter assembly when need of changing the broach tool arises. So, this bracket plays an important role of holding the cylinder. Hence, to take up the load of the whole assembly during lifting, the bracket needs to be sturdy and enough rigid.

- Support block:

It is fixed onto the cutter support frame. It acts as a hinge during the changing of broach tool. They are two in number.

## 4.6 Base Assembly

Base is the foundation element of any machine. Base assembly is the building block of our machine on to which almost all the parts are mounted accordingly. It consists of several parts as listed below:

- Base frame:

  It is the load carrying structure of machine transmitting all the forces to the foundation. Base frame needs to be sturdy in order to sustain all the loads. It is made of cast iron. It is a rigid structure on which the base of the cutter assembly, the support for guides, the support for the cutter opening cylinder and the cylinder support bracket are mounted. Also on the upper face, provision is made for effective burr removal. Considerable weight reduction is achieved with the help of pockets provided at the side faces.

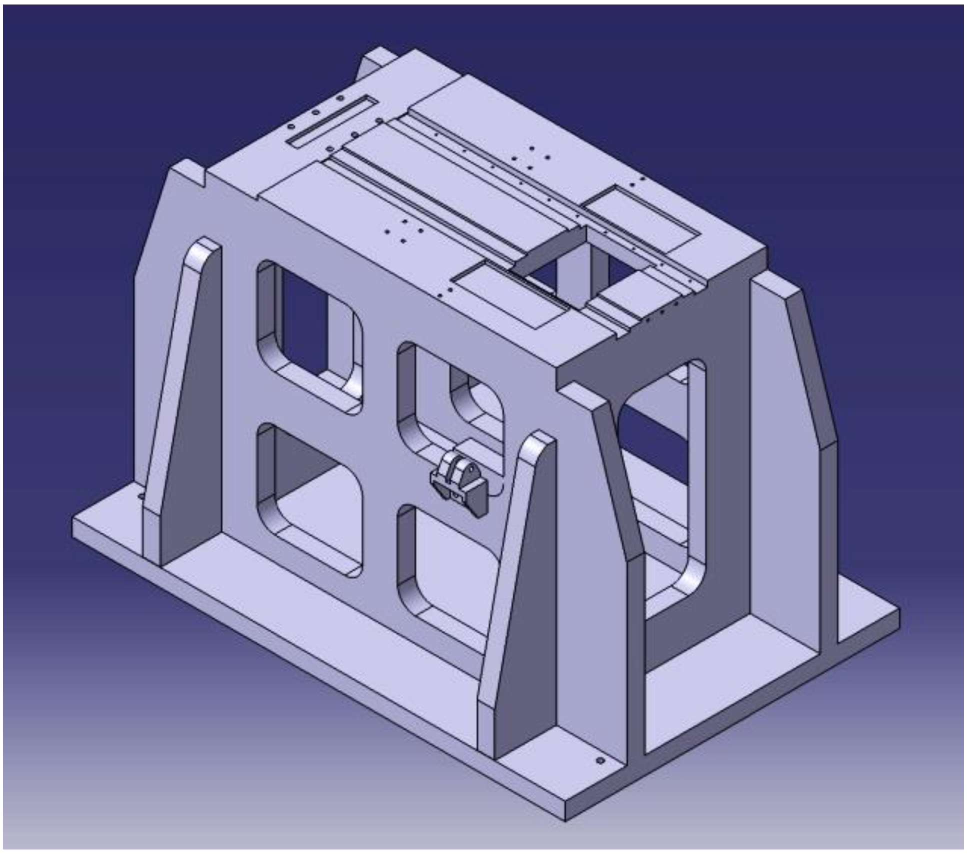


Fig 4.11: Base Frame

- Cutter assembly base:

It is welded to the base frame. The whole cutter assembly is mounted on the cutter base with the help of suitable bolts. It is rectangular in shape and made of M.S.

- LM Guide-ways:

This assembly forms the link between the base frame and the slider assembly. They are mounted on the base frame with the help of Allen bolts. There are two LM guide-ways used and the configuration of 4 blocks, 2 being on each guide is selected for this particular case. The guides allow the reciprocating motion of the slider, for broaching operation of thrust washer.

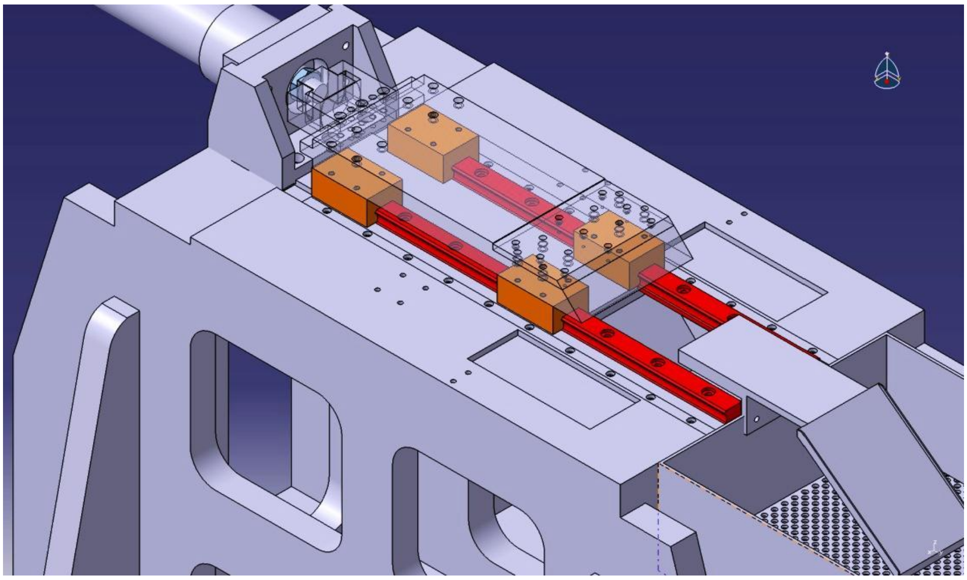


Fig 4.12: Linear Motion Guide-ways

- Scrap guide:

During broaching operation, the material is removed in the form of burr which needs to be removed from the cutting zone. It is important to remove this burr from the machine before the next stroke so as to perform the operation without the damage of thrust washer, broach tool and the guide-ways. There is opening on the upper face of the base frame from where the burrs are allowed to fall into scrap bin through the scrap guide.

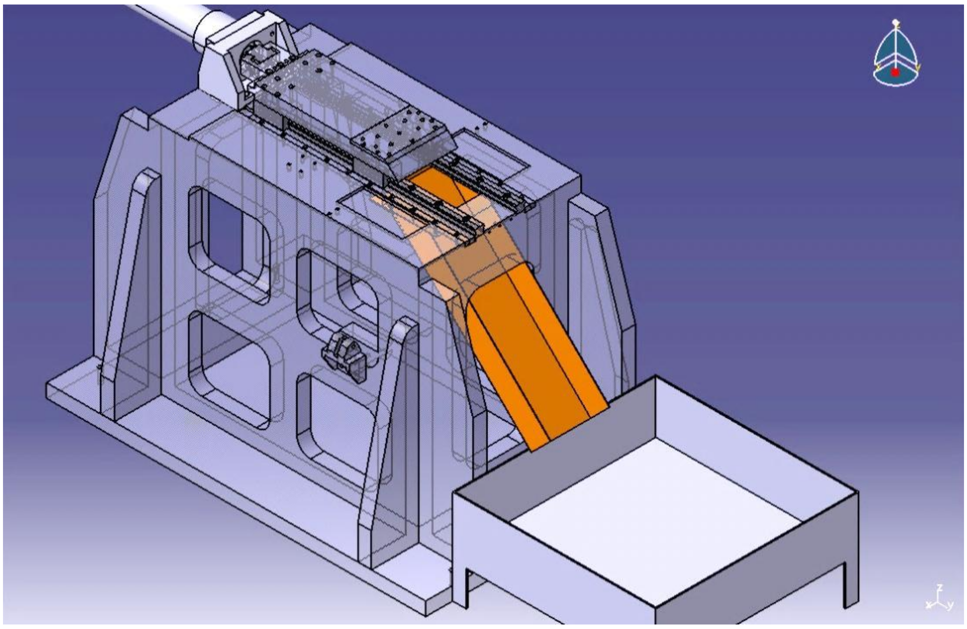


Fig 4.13: Scrap Guide

- Main cylinder:

  It is the main hydraulic cylinder which provides the force required to carry out the broaching operation. It is attached to the bracket support with the help of bolts. It is operated by hydraulic pump which imposes the load on the piston forcing it to move.

- Scrap bin:

  It is open box type component of the machine in which the removed material is collected. The material removed in the form of burr while broaching operation is allowed to fall in the Scrap bin through the scrap guide.

- Washer output guide plate:

  It is a guide plate attached to the base frame in such a way that it receives the washers from the slider after the cutting operation is done and delivers this washer to the washer output box.

- Washer output box:

  It is output box of the machine where washers are collected after the broaching operation is done.

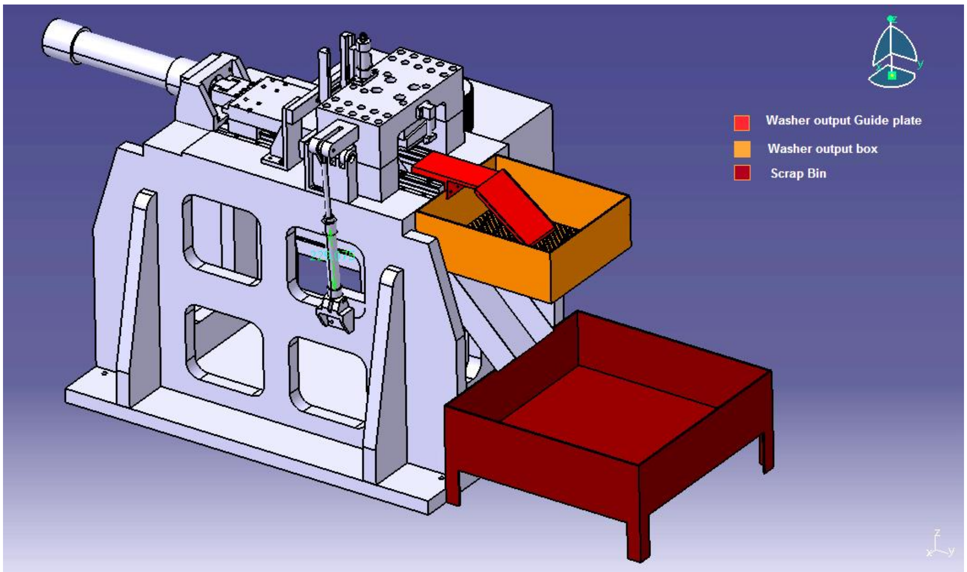



Fig 4.14: Post-processing Collector

- Cutter assembly support:

  It is welded to the base frame rigidly. The cutter support frame is rotated about the support provided by this component when the cutter assembly is opened for tool change or for other purposes. Further, it acts as a support for the broach tool assembly making it sturdier. It is made up of M.S.

## 4.7 Guide and Slider Assembly

- Slider: It is as explained in the section4.3.
- Slider plate: It is as explained in section4.3.
- Slider-Piston connector:

  This component is used to connect the slider with the piston of the main hydraulic cylinder through the T-connector. It is connected to the slider by using bolts. Due to its subjection to alternate compressive and tensile stresses due to reciprocating motion, this component needs to be capable of sustaining such loads. For this purpose the component is made having sufficient thickness to achieve the same. It is made of M.S.

- T-connector:

This component acts as link between piston of main hydraulic cylinder and the slider. It is connected to the piston with the help of nut of M30. Due to its subjection to alternate compressive and tensile stresses due to reciprocating motion, this component needs to be capable of sustaining such loads. For this purpose the component is made having sufficient thickness to achieve the same. It is made of M.S.

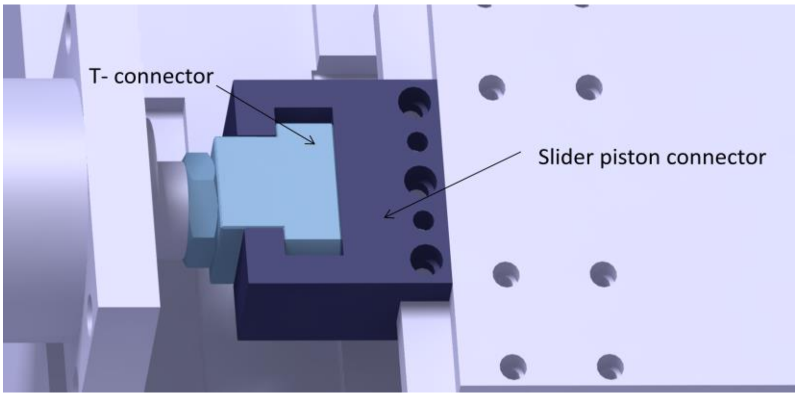



Fig 4.15: Linkage between Piston and Slider

## 4.8 Main Assembly of the Machine (Preliminary Design)

All the components and sub-assemblies mentioned above are assembled together in the Main assembly of the machine.

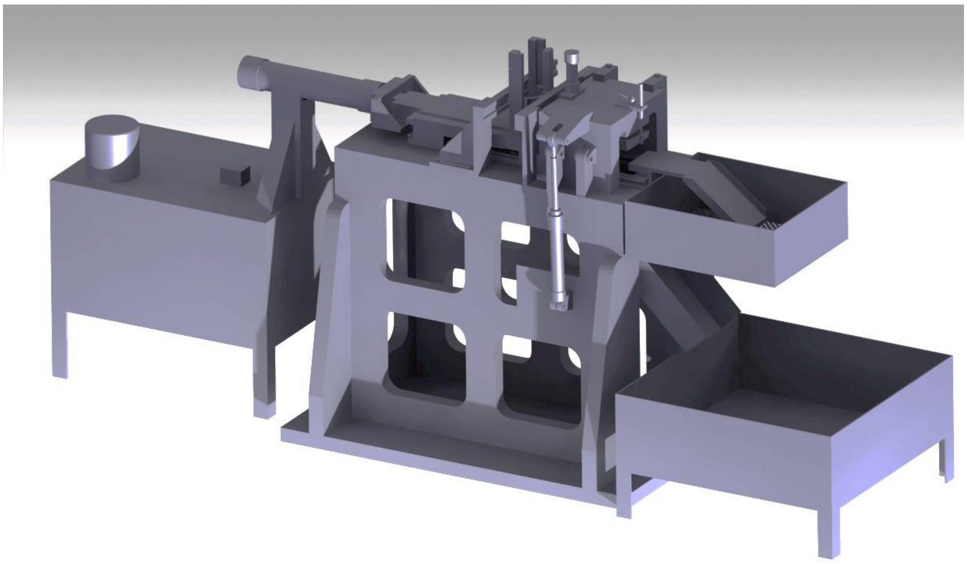


Fig 4.16: Main Assembly of the Machine

## 4.9 Some Special Features of the Machine

❖ **Changing Height of Broach Tool:**

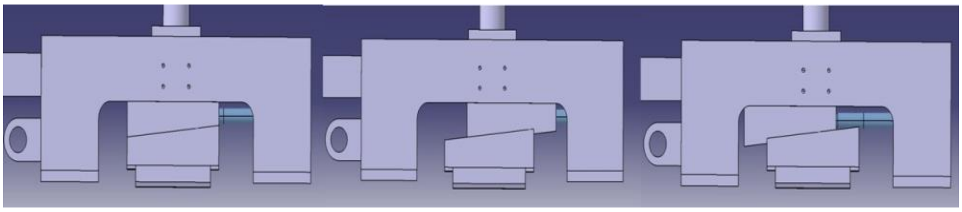


Fig 4.17: Mechanism for Height Changing of Tool

Working:

Above figure illustrates the upward – downward motion of the broach cutter. This is required because the washers are of varying thickness and in order to broach these washers this arrangement is needed. It consists of a special screw fitted on to the upward block and the cutter support frame. For one rotation of screw the linear motion of the broach cutter is 0.3 mm. This value is taken because of requirement of 0.3mm tolerance. The maximum movement of the tool provided is ±2mm.

❖ **Broach Tool Changing Cylinder:**

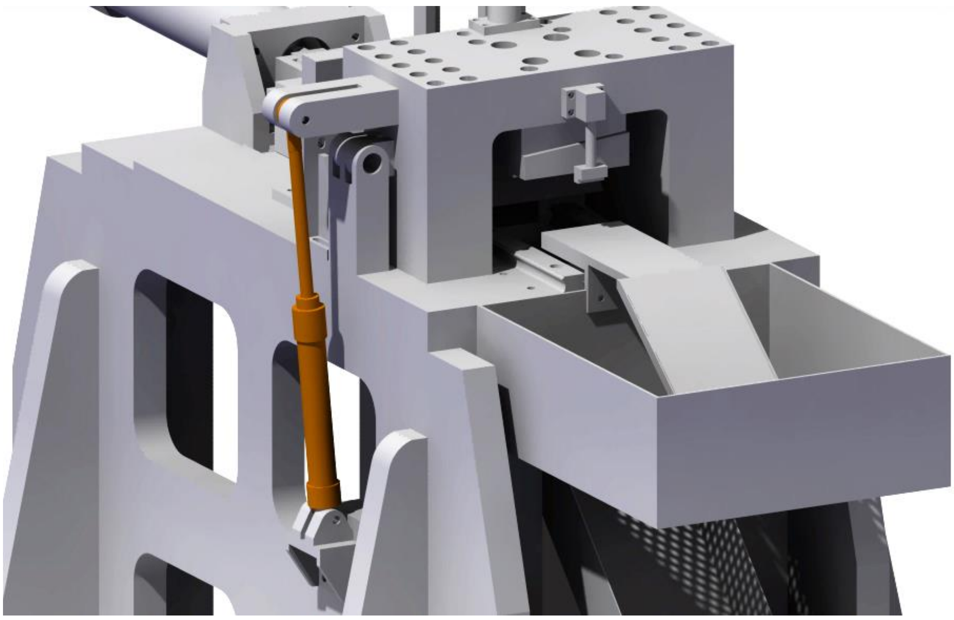


Fig 4.18: Broach Tool Changing Cylinder

The figure below illustrates the cutter opening assembly. When after certain time interval of continuous broaching operation of the cutter, it gets worn out and does not function effectively. Thus there is need of changing this worn out broach tool. For this purpose the above illustrated mechanism is mounted. It consists of a piston- cylinder arrangement one end of which is mounted on to the cutter support fame and the other is mounted on to the base frame with help of suitable nut-bolt type arrangement. The cutter opening bracket opens with help of hinge which is formed in the support block and the cutter assembly support and is connected to each other with help of suitable nut-bolts. This cylinder is operated only when the cutter needs to be changed.

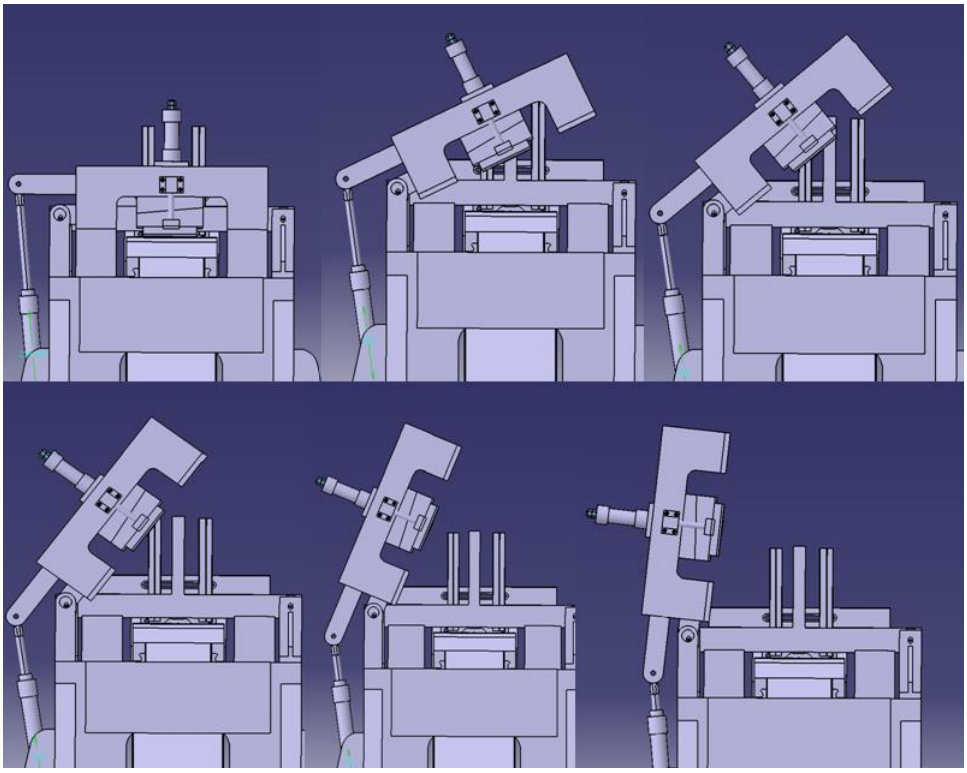


Fig 4.19: Working of Tool Changing Mechanism

## 4.10 Comments on Nagar Visit

We visited Kirloskar plant at Ahmednagar on 11/10/2010 and took expert comments from the professionals working there. There we analysed for the changes in the current design which was developed by us.

The following were some of the check list given to us.

- Possibility of Lifting of the thrust washer (During forward stroke).
- Achieving Input Washer flatness (Quality Flattener).
- Strengths & deformations of machine parts.
- Burr removal issue.
- Type of Cutting (Dry or with Coolant). Also provision for Coolant.
- Possibility of displacing 2 washers at same time (During forward stroke).

# 5. Design Calculations

## 5.1 Broach Tool

- Tool nomenclature:

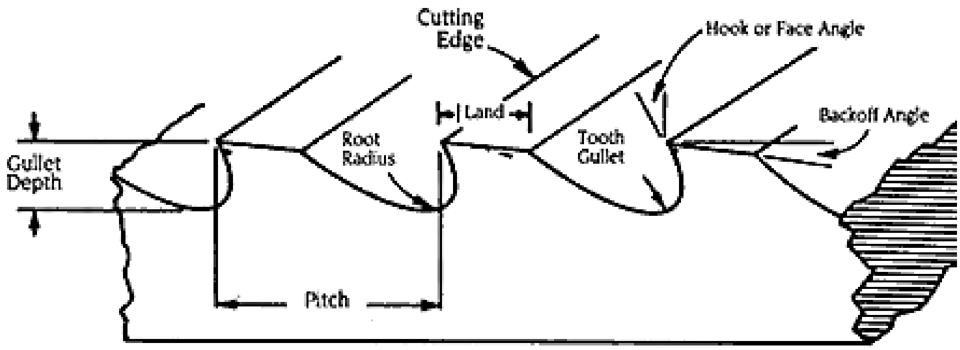



Fig 5.1: Surface Broach Tool

- Length:

  The length of a broach tool, or string of tools, is determined by the amount of material to be removed, and limited by the machine stroke.

- Cutting teeth:

  Broach teeth are usually divided into three separate sections along the length of the tool: the roughing teeth, semi-finishing teeth and finishing teeth. The first roughing tooth is proportionately the smallest tooth on the tool. The subsequent teeth progressively increase in size up to and including the first finishing tooth. The difference in height between each tooth, or the tooth rise, is usually greater along the roughing section and less along the semi-finishing section. All finishing teeth are the same size. The face is ground with a hook or face angle that is determined by the workpiece material. For instance, soft steel workpieces usually require greater hook angles; hard or brittle steel pieces require smaller hook angles.

- Tooth land:

The land supports the cutting edge against stresses. A slight clearance or back-off angle is ground onto the lands to reduce friction. On roughing and semi-finishing teeth, the entire land is relieved with a back-off angle. On finishing teeth, part of the land immediately behind the cutting edge is often left straight, so that repeated sharpening (by grinding the face of the tooth) will not alter the tooth size.

- Tooth pitch:

The distance between teeth, or pitch, is determined by the length of cut and influenced by type of workpiece material. A relatively large pitch may be required for roughing teeth to accommodate a greater chip load. Tooth pitch may be smaller on semi-finishing teeth to reduce the overall length of the broach tool. Pitch is calculated so that, preferably, two or more teeth cut simultaneously. This prevents the tool from drifting or chattering.

$$\text{Pitch, p}=\sqrt[3]{length\ of\ cut \times rise\ per\ tooth \times gullet\ area}$$

- Tooth gullet:

The depth of the tooth gullet is related to the tooth rise, pitch and workpiece material. The tooth root radius is usually designed so that chips curl tightly within themselves, occupying as little space as possible.

- Chip load:

As each tooth enters the workpiece, it cuts a fixed thickness of material. The fixed chip length and thickness produced by broaching create a chip load that is determined by the design of the broach tool and the predetermined feed-rate.

- Chip breakers:

Notches, called chip breakers, are used on broach tools to eliminate chip packing and to facilitate chip removal. The chip breakers are ground into the roughing and semi-finishing teeth of the broach, parallel to the tool axis.

Chip breakers on alternate teeth are staggered so that one set of chip breakers is followed by a cutting edge. The finishing teeth complete the job. Chip breakers are vital on round broaching tools: without the chip breakers, the tools would machine ring-shaped chips that would wedge into the tooth gullets and eventually cause the tool to break.

- Shear angle:

Broach designers may place broach teeth at a shear angle to improve surface finish and reduce tool chatter. When two adjacent surfaces are cut simultaneously, the shear angle is an important factor in moving chips away from the intersecting corner to prevent crowding of chips in the intersection of the cutting teeth.

It ranges between 5 degrees to 20 degrees

- Side relief:

When broaching slots, the tool becomes enclosed by the slot during cutting and must carry the chips produced through the entire length of the work piece. Sides of the broach teeth will rub the sides of the slot and cause rapid tool wear unless clearance is provided. Grinding a single relief angle on both sides of each tooth does this. Thus, only a small portion of the tooth near the cutting edge, called the side land, is allowed to rub against the slot. The same approach is used for one-sided corner cuts and spline broaches.

## 5.2 Variation of Cutting Force with Angle

### 5.2.1 Broaching Force Calculations:

A. Force calculation as per Production Technology HMT (by TMH publications) (abbreviation used TMH)

For surface broach

$P = Kst \times l \times f \times z \times k$

Where,

P= Broaching Force (kgf)

Z= number of teeth cutting at a time.

F= rise/ tooth (mm)

l= width of contact of each tooth (mm)

k=Blunt broach factor

Kst = Sp. Cutting force (kgf/mm2)

Substituting respective values;

$$P = 1175 \times 83 \times 3 \times 0.05 \times 1.3$$

$$P = 18994.46 \text{ N}$$

The cutting force calculated as per TMH book is 18994.46 N

B. Force calculations as per book Production Technology R.K.Jain(abbreviation used R.K.Jain)

For surface broach

$$P = \frac{w \times Ss \times \cos(\lambda - \alpha) \times f}{\sin(\varphi) * \cos(\varphi + \lambda - \alpha)}$$

Where,

P= Broaching Force(kgf)

w=width of cut

λ =friction angle= tan-1μ

α=radial rake

f=cut per tooth

Ss=ultimate shear stress of the work material

Instantaneous broaching load

$$= \text{cutting force per tooth} \times \text{ no. of teeth in contact}$$

Therefore,

$$P = \frac{(82.9\times0.05\times143\times\cos(50.19-(-5)))\times3}{\left(\sin(10)\times\cos\left(10+50.19-(-5)\right)\right)}$$

P = 13931.12 N

The cutting force calculated as per **R.K.Jain** is 13931.12 N

C. Force calculation as per Production Technology CMTI(abbreviation used CMTI)

$P = Ksc \times w \times f \times z \times 9.81$

$Ksc = 450 + 3 \times \sigma - 11 \times \alpha - 2500 \times f$

$Ksc = 450 + 3 \times 7.48 - 11 \times (-5) - 2500 \times 0.05$

$Ksc = 402.43$

$P = 402.43 \times 82.9 \times 0.05 \times 3 \times 9.81$

P= 49090.89 N

The cutting force calculated as per **CMTI** is 13931.12 N

## Variation of Forces w.r.t Rake Angle:

Table 5: Force calculation of broach tool

| Material | | Copper | | | | | |
|---|---|---|---|---|---|---|---|
| **Input** | | Values | | | | | |
| Rise per tooth | f | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Ratio of gullet area to chip cs | | 5 | 5 | 5 | 5 | 5 | 5 |
| Width of cut | w | 82.9 | 82.9 | 82.9 | 82.9 | 82.9 | 82.9 |
| Shear angle | ϕ | 10 | 10 | 10 | 10 | 10 | 10 |
| Friction angle | λ | 50.19 | 50.19 | 50.19 | 50.19 | 50.19 | 50.19 |
| Radial rake | α | -5 | 0 | 5 | 10 | 15 | 20 |
| cut per tooth | | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| ultimate shear stress | S8 | 143 | 143 | 143 | 143 | 143 | 143 |
| No. of cutting tooth | z | 3 | 3 | 3 | 3 | 3 | 3 |
| Sp. Cutting force CMTI | Ksc | 402.43 | 347.43 | 292.43 | 237.43 | 182.43 | 127.43 |
| Sp. Cutting force TMH | Kst | 1175 | 1175 | 1175 | 1175 | 1175 | 1175 |
| Blunt broach factor | k | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Ultimate Tensile Strength | uts | 220 | 220 | 220 | 220 | 220 | 220 |
| Tensile strngth | σ | 7.48 | 7.48 | 7.48 | 7.48 | 7.48 | 7.48 |
| Coefficient of friction | μ | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |

| **Output** | **Load Values in Newton** | | | | | |
|---|---|---|---|---|---|---|
| R.k.Jain | 13931.12 | 13187.75 | 12641.40 | 12217.21 | 11873.64 | 11585.70 |
| TMH | 18994.46 | 18994.46 | 18994.46 | 18994.46 | 18994.46 | 18994.46 |
| CMTI | 49090.89 | 42381.59 | 35672.28 | 28962.98 | 22253.68 | 15544.37 |
| Machine tool design | 17533.35 | 17533.35 | 17533.35 | 17533.35 | 17533.35 | 17533.35 |

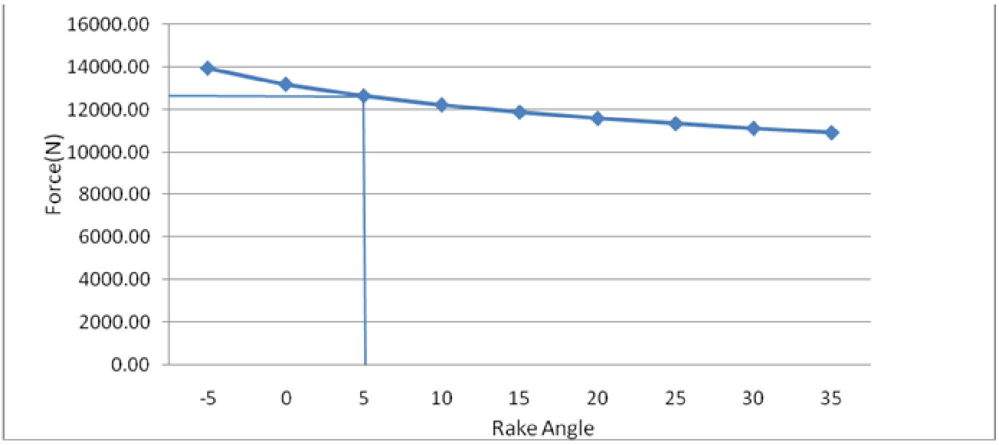



Fig 5.2: Graph showing variation of force with Rake angle according to R.K.Jain calculations.

D. Calculations done as per rake angle=5deg as per the previous data and expert comments.

Table 6: Force calculation of cutter as per rake angle 5 deg

| **Input** | Notation | Value | Unit | |
|---|---|---|---|---|
| | | | | |
| **Copper** | | | | |
| Rise per tooth | F | 0.12 | mm | |
| Ratio of gullet area to chip cs | | 5 | | |
| Width of cut | W | 82.9 | mm | |
| Shear angle | ϕ | 10 | degrees | |
| Friction angle | Λ | 50.19 | degrees | |
| Radial rake | A | 5 | degrees | |
| cut per tooth | | 0.05 | mm | |
| ultimate shear stress | S8 | 143 | MPa | |
| No. of cutting tooth | Z | 3 | | |
| Sp. Cutting force CMTI | Ksc | 117.43 | $kgf/mm^2$ | |
| Sp. Cutting force TMH | Kst | 1175 | MPa | |
| Blunt broach factor | K | 1.3 | | |
| Ultimate Tensile Strength | Uts | 220 | MPa | |
| Tensile strngth | Sigma | 7.48 | kgf/mm2 | |
| Coefficient of friction | M | 1.2 | | |
| | | | | |
| **Output** | **N** | **kN** | **kgf** | **Tonnage** |
| R.k.Jain | 30339.36 | 30.34 | 3092.70 | 3.09 |
| TMH | 45586.71 | 45.59 | 4646.96 | 4.65 |
| CMTI | 34378.80 | 34.38 | 3504.46 | 3.50 |
| Machine tool design | 42080.04 | 42.08 | 4289.50 | 4.29 |

E. Broach Design :

As the standard broaching tool was not available, we had to consider various combinations of the helix angle, the number of cutting teeth, pitch and there relations. So the results obtained are plotted below. And after comparing them, the configuration was chosen eclectically.

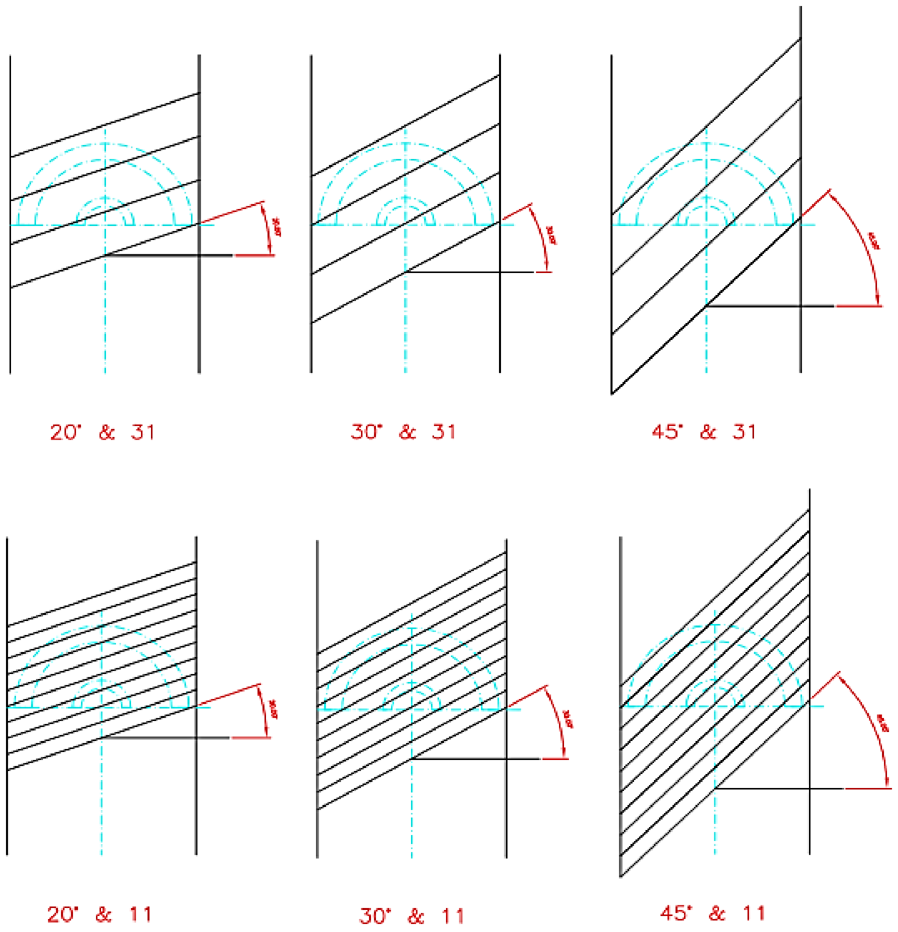



Fig 5.3 Selection of Helix Angle

The above diagram shows variation of helix angle for constant value of pitch. We observed that 20 degrees helix angle is suitable because it allows optimum number of cutting teeth to be engaged, also as the helix angle increases the thrust force increases.

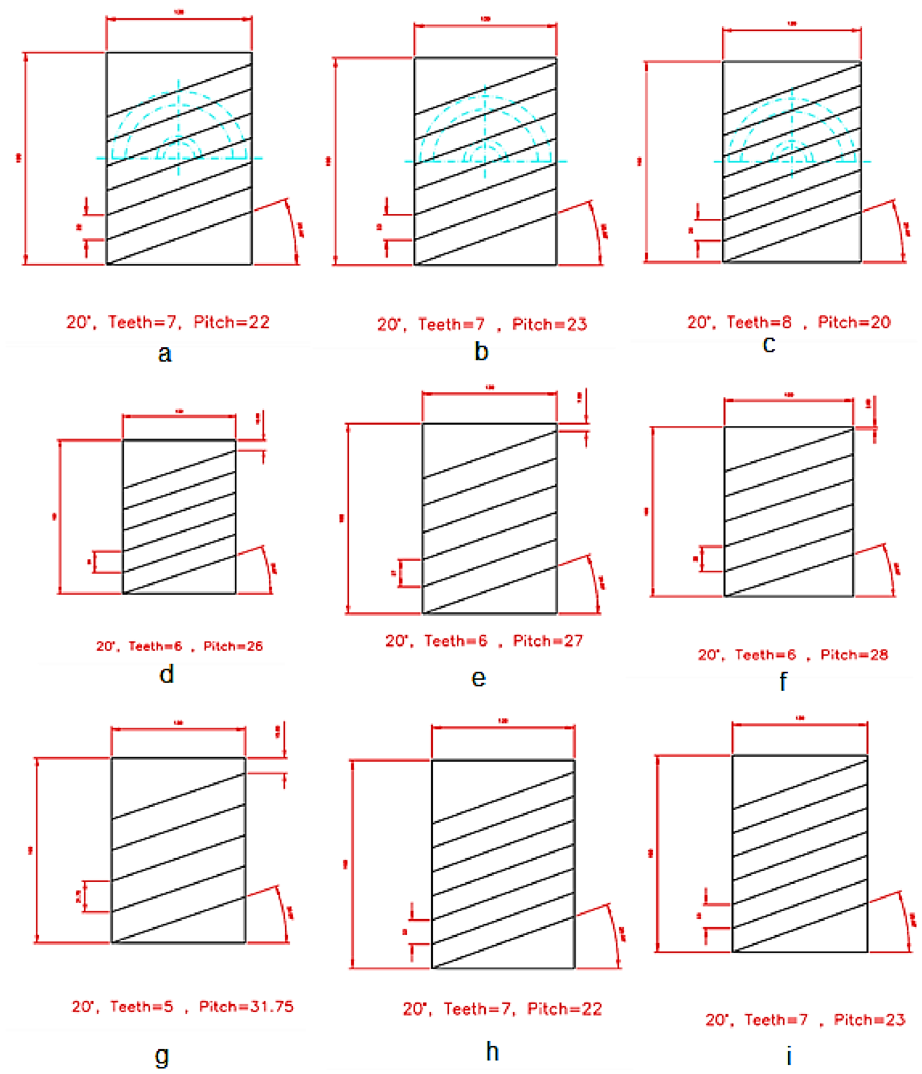



Fig 5.4 Selection of Pitch

The second diagram shows the variation of teeth with respect to pitch for constant value of helix angle 20 deg.

During the process we observed:

- At constant pitch, as angle increases no. of teeth coming in contact increases.
- At constant Angle, as Pitch increases no. of teeth coming in contact increases.

Table 7: Selection of Rise Per Tooth

| Tooth No. | Total 0.12 | Feed/Tooth |
|---|---|---|
| 1 | 0–1 | 0.02 |
| 2 | 1–2 | 0.02 |
| 3 | 2–3 | 0.02 |
| 4 | 3–4 | 0.02 |
| 5 | 4–5 | 0.02 |
| 6 | 6–7 | 0.02 |
| 7 | 7–8 | 0.00 |

a

| Tooth No. | Total 0.12 | Feed/Tooth |
|---|---|---|
| 1 | 0–1 | 0.03 |
| 2 | 1–2 | 0.02 |
| 3 | 2–3 | 0.02 |
| 4 | 3–4 | 0.02 |
| 5 | 4–5 | 0.02 |
| 6 | 6–7 | 0.01 |
| 7 | 7–8 | 0.00 |

b

| Tooth No. | Total 0.12 | Feed/Tooth |
|---|---|---|
| 1 | 0–1 | 0.03 |
| 2 | 1–2 | 0.02 |
| 3 | 2–3 | 0.02 |
| 4 | 3–4 | 0.02 |
| 5 | 4–5 | 0.02 |
| 6 | 6–7 | 0.01 |

c

| Tooth No. | Total 0.12 | Feed/Tooth |
|---|---|---|
| 1 | 0–1 | 0.03 |
| 2 | 1–2 | 0.03 |
| 3 | 2–3 | 0.02 |
| 4 | 3–4 | 0.02 |
| 5 | 4–5 | 0.02 |
| 6 | 6–7 | 0.00 |

d

For the selection of number of teeth and rise per tooth considering both parameters, we considered different configurations. From the above table we selected (c) which found to be satisfying the conditions best. Optimum pitch 26mm has been selected from fig 5.4.

The specifications of Cutter selected is-

Helix angle- 200
Pitch- 26 mm
Length-190 mm
Number of teeth- 6

## 5.3 Cylinder calculation

1. Broaching Cylinder(1) Selection:

   Now according to broach tool calculations force required for cutting is 5 tonnes (including factor of safety). Thus we take capacity of cylinder as 5 tonnes. Taking pressure as 100 bar we calculated the bore diameter and rod diameter. Stroke length required is 300mm thus taking stroke as 300. In the table below we have summarized the above results.

| TW Broaching Cylinder Selection | | |
|---|---|---|
| Operating Cylinder Pressure | 100 | Bar |
| Bore diameter. | 80 | mm |
| Rod Diameter. | 36 | mm |
| Stroke length | 300 | mm |
| Piston Area | 5024.00 | mm2 |
| Force in Forward Stroke | 50240 | N |
| Calculated Load | 5121.30 | Kg |
| | **5.12** | **Tonne** |

Table 8

2. Cylinder 2 (to resist the uplift of TW)

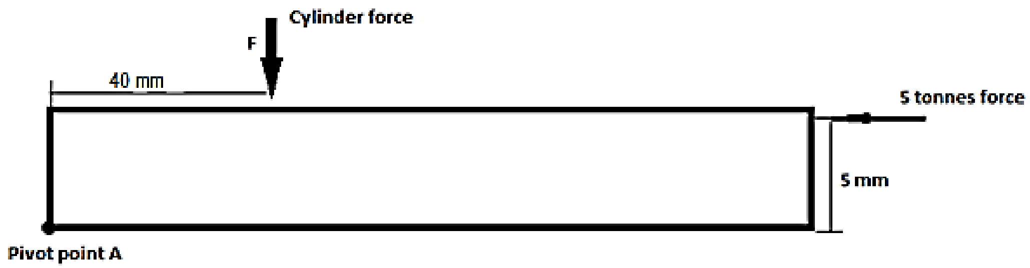



Fig 5.5 FBD of Cylinder 2

**Force calculation**

5 tonnes force of broach acts in horizontal direction at a distance of 5mm.

We have to find how much amount of force that acts in vertical direction at a distance of 40 mm.

By moment equation about point A we get,

$5 \times 5 - 40 \times F = 0$

On solving we get,

F = 0.625 tons

Thus we select the cylinder of capacity 1 tons to resist the uplift of thrust washer considering F.S.

3. Cylinder 3 (Output cylinder)

It has negligible load on it as it only stops the washer from returning with the return stroke.

4. Cylinder 4 (broach changing)

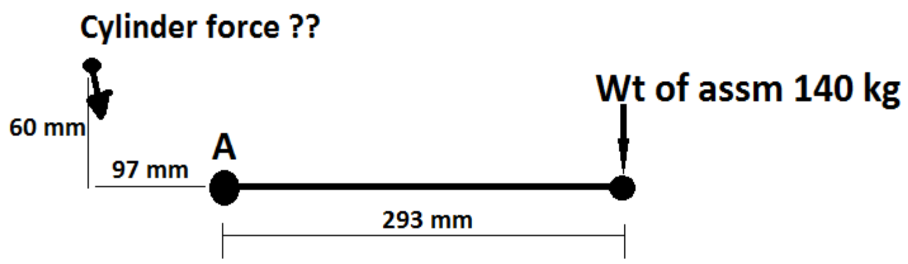



Fig 5.6: FBD of Cylinder 4

**Force calculations:**

Total wt. of assembly is 140 kg

The force required is calculated by taking moment about A

The moment equation is as follows:

$293 \times 140 + 60 \times x \times (\cos 85) - 97 \times x \times \sin 85 = 0$

On solving,

$x$= 448.788 kg

Hence we take cylinder of capacity 1 tonnes

## 5.4 Rail

### Calculating Applied Load

The load applied to the LM guide varies with the external force exerted thereon, such as the location of the centre of gravity of an object being moved, the location of the thrust developed, inertia due to acceleration and deceleration during starting and stopping, and the machine resistance.

To select the correct type of LM Guide, the magnitude of applied loads must be determined in consideration of the above conditions.

The Operating Condition in our case is as follows –

(The image taken from: THK LM Systems – General Catalog – THK CO., LTD, TOKYO, JAPAN)

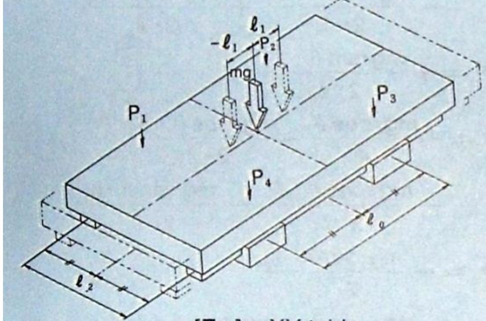
| Operating conditions | Equation for calculating applied load |
|---|---|
| Move on the LM rail.<br>Install in a horizontal position.<br><br>[Ex.] XY table<br>Sliding fork | $P_1 \sim P_4\ (\max) = \frac{mg}{4} + \frac{mg \cdot \ell_1}{2 \cdot \ell_0}$<br>$P_1 \sim P_4\ (\min) = \frac{mg}{4} - \frac{mg \cdot \ell_1}{2 \cdot \ell_0}$ |

Fig 5.7: Location of Various Forces acting on LM rail

M = Mass (kg) = 650 kg

g = Gravitational acceleration = $9.81 m/s^2$

P = Applied load

$l_0$ = length between blocks on same guide = 580 mm

$l_1$ = 290 mm

$P_1 \sim P_4\,(\max) = \frac{mg}{4} + \frac{mg \cdot l_1}{2l_0}$

$= \frac{650 \times 9.81}{4} + \frac{650 \times 9.81 \times 290}{2 \times 580}$

$= 3188.25$ N

$P_1 \sim P_4\,(\min) = \frac{mg}{4} - \frac{mg \cdot l_1}{2l_0}$

$= \frac{650 \times 9.81}{4} - \frac{650 \times 9.81 \times 290}{2 \times 580} = 0$ N

**Calculating Equivalent Load**

The LM guide can bear loads and moments in 4 directions, including a radial load ($P_R$), reverse-radial load ($P_L$), and lateral load ($P_T$), simultaneously

(The image taken from: THK LM Systems – General Catalog – THK CO., LTD, TOKYO, JAPAN)

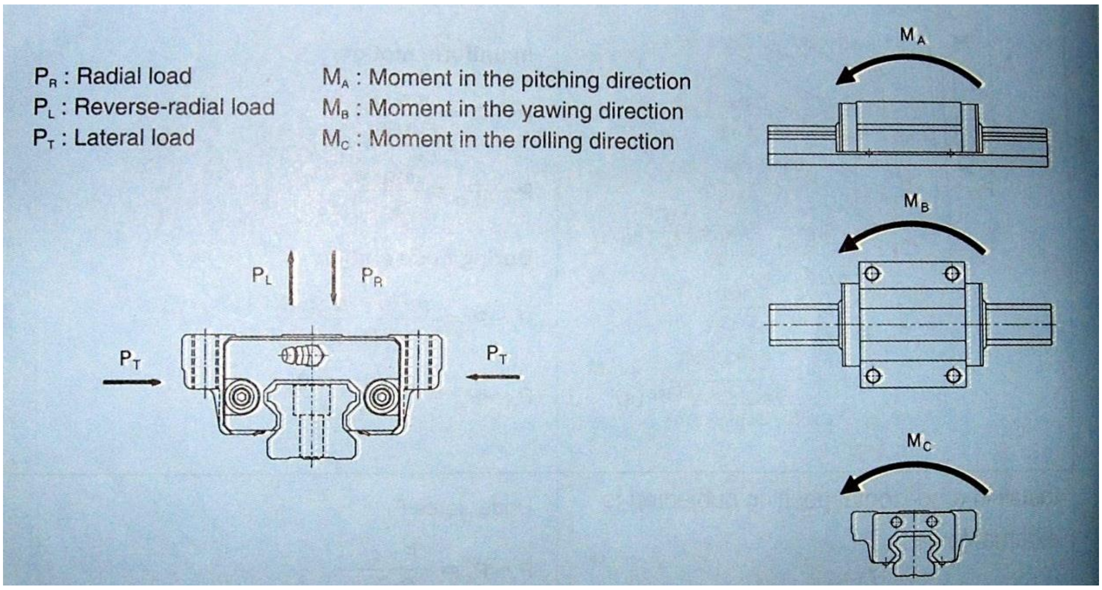



Fig 5.8: Direction of Load and Moment on LM guide

When more than one load (e.g., radial and lateral loads) is exerted on the LM guide simultaneously, the service life and static safety factors should be calculated using equivalent load values obtained by converting all loads involved into radial, lateral, and other loads involved.

This can be calculated by using following equation-

$P_E$ (equivalent load) = $P_R + P_T$

Where,

$P_R$ : Radial load

$P_T$ : Lateral load

Lateral load $= 5000 \times sin20$

$= 1710.1$ N

Longitudinal load $= 5000 \times \cos 20$

$= 4698.46$ N

Radial load $= 650 \times 9.81$

$= 6376.5$ N

$P_E = 6376.5 + 1710.1$

$= 8086.6$ N

Acceleration $\alpha_1 = 1$ m/s^2

Deceleration $\alpha_2 = 1$ m/s^2

L0=370 mm

L1= 150mm

L2= 185mm

L3= 75mm

L4= 54mm

L5= 80mm

M1= 650kg

M2= 40kg

(The image taken from: THK LM Systems – General Catalog – THK CO., LTD, TOKYO, JAPAN)

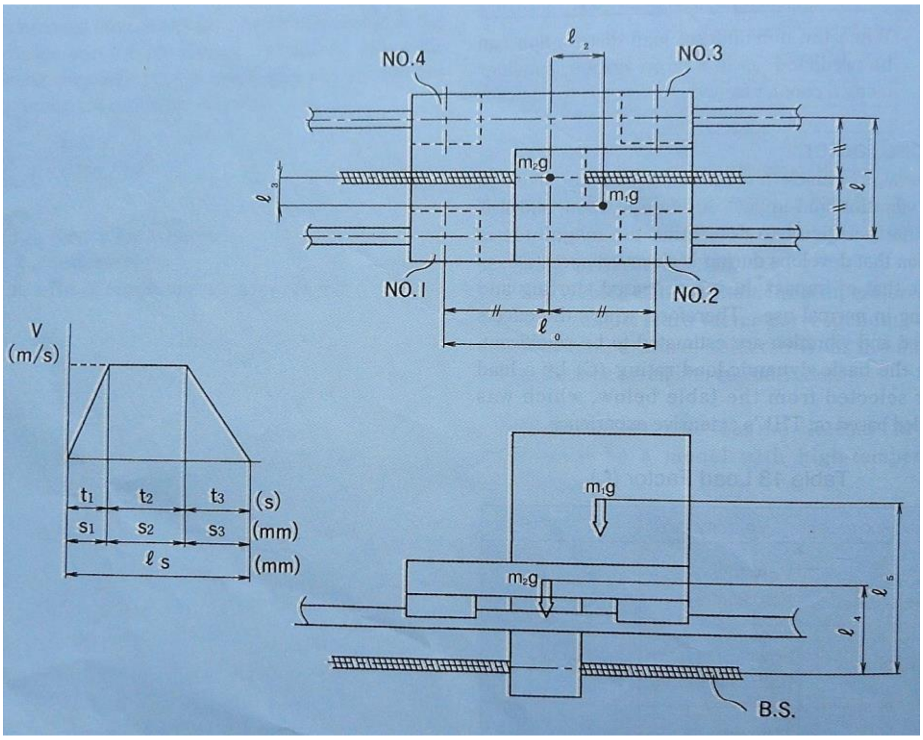



Fig 5.9: Force calculation analysis diagram

Uniform motion

Load applied in radial direction $P_n$

$$P1 = \frac{M1g}{4} - \frac{M1g\times L2}{2\times L0} + \frac{M1g\times L3}{2\times L1} + \frac{M2g}{4}$$

= + 1692.22 N

$$P2 = \frac{M1g}{4} + \frac{M1g\times L2}{2\times L0} + \frac{M1g\times L3}{2\times L1} + \frac{M2g}{4}$$

= +4880.47 N

$$P3 = \frac{M1g}{4} + \frac{M1g\times L2}{2\times L0} - \frac{M1g\times L3}{2\times L1} + \frac{M2g}{4}$$

= +1692.22 N

$$P4 = \frac{M1g}{4} - \frac{M1g\times L2}{2\times L0} - \frac{M1g\times L3}{2\times L1} + \frac{M2g}{4}$$

= -1496.02 N

Load applied in lateral direction $Ptla_n$

$$Ptla_1 = -\frac{M1\times\alpha1\times L3}{2\times L0}$$

= -65.88 N

$$Ptla_2 = +\frac{M1\times\alpha1\times L3}{2\times L0}$$

= +65.88 N

$$Ptla_3 = +\frac{M1\times\alpha1\times L3}{2\times L0}$$

= +65.88 N

$$Ptla_4 = -\frac{M1\times\alpha1\times L3}{2\times L0}$$

= -65.88 N

During deceleration to the left

Load applied in radial direction $Pld_n$

$$Pld_1 = P1 + \frac{M1\times\alpha3\times L5}{2\times L0} + \frac{M2\times\alpha3\times L4}{2L0}$$

= +1765.41 N

During acceleration to the left

Load applied in radial direction $Pla_n$

$$Pla_1 = P1 - \frac{M1\times\alpha1\times L5}{2\times L0} - \frac{M2\times\alpha1\times L4}{2L0}$$

= +1520.93 N

$$Pla_2 = P2 + \frac{M1\times\alpha1\times L5}{2\times L0} + \frac{M2\times\alpha1\times L4}{2L0}$$

= + 4953.66 N

$$Pla_3 = P3 + \frac{M1\times\alpha1\times L5}{2\times L0} + \frac{M2\times\alpha1\times L4}{2L0}$$

= + 1765.41 N

$$Pla_4 = P4 - \frac{M1\times\alpha1\times L5}{2\times L0} - \frac{M2\times\alpha1\times L4}{2L0}$$

= -1569.21 N

$$Pld_2 = P2 - \frac{M1\times\alpha3\times L5}{2\times L0} - \frac{M2\times\alpha3\times L4}{2L0}$$

= +4807.28 N

$$Pld_3 = P3 - \frac{M1\times\alpha3\times L5}{2\times L0} - \frac{M2\times\alpha3\times L4}{2L0}$$

= +1619.68 N

$$Pld_4 = P4 + \frac{M1\times\alpha3\times L5}{2\times L0} + \frac{M2\times\alpha3\times L4}{2L0}$$

= -1422.83 N

Load applied in lateral direction $Ptld_n$

$$Ptld_1 = +\frac{M1\times\alpha3\times L3}{2\times L0}$$

= +65.88 N

$$Ptld_2 = -\frac{M1\times\alpha3\times L3}{2\times L0}$$

= -65.88 N

$$Ptld_3 = -\frac{M1\times\alpha3\times L3}{2\times L0}$$

= -65.88 N

Ptld$_4$= $+\frac{M1\times\alpha3\times L3}{2\times L0}$

= +65.88 N

During acceleration to the right,

Pra$_1$= $P1+\frac{M1\times\alpha1\times L5}{2\times L0}+\frac{M2\times\alpha1\times L4}{2L0}$

= +1765.41 N

Pra$_2$= $P2-\frac{M1\times\alpha1\times L5}{2\times L0}-\frac{M2\times\alpha1\times L4}{2L0}$

= +4807.68 N

Pra$_3$= $P3-\frac{M1\times\alpha1\times L5}{2\times L0}-\frac{M2\times\alpha1\times L4}{2L0}$

= +1619.03 N

Pra$_4$= $P4+\frac{M1\times\alpha1\times L5}{2\times L0}+\frac{M2\times\alpha1\times L4}{2L0}$

= -1422.83 N

Load applied in lateral direction Ptra$_n$

Ptra$_1$= $+\frac{M1\times\alpha1\times L3}{2\times L0}$

= +65.88 N

Ptra$_2$= $-\frac{M1\times\alpha1\times L3}{2\times L0}$

= -65.88 N

Prd$_4$= $P4-\frac{M1\times\alpha3\times L5}{2\times L0}-\frac{M2\times\alpha3\times L4}{2L0}$

= -1569.21 N

Load applied in lateral direction Ptrd$_n$

Ptrd$_1$=$-\frac{M1\times\alpha1\times L3}{2\times L0}$

= -65.88 N

Ptrd$_2$=$+\frac{M1\times\alpha1\times L3}{2\times L0}$

= +65.88 N

Load applied in radial direction Pra$_n$

Ptra$_3$= $-\frac{M1\times\alpha1\times L3}{2\times L0}$

= -65.88 N

Ptra$_4$= $+\frac{M1\times\alpha1\times L3}{2\times L0}$

= +65.88 N

During deceleration to the right

Load applied in radial direction Prd$_n$

Prd$_1$= $P1-\frac{M1\times\alpha3\times L5}{2\times L0}-\frac{M2\times\alpha3\times L4}{2L0}$

= +1619.03 N

Prd$_2$= $P2+\frac{M1\times\alpha3\times L5}{2\times L0}+\frac{M2\times\alpha3\times L4}{2L0}$

= +4953.66 N

Prd$_3$= $P3+\frac{M1\times\alpha3\times L5}{2\times L0}+\frac{M2\times\alpha3\times L4}{2L0}$

= +1765.41 N

Ptrd$_3$= $+\frac{M1\times\alpha1\times L3}{2\times L0}$

= +65.88 N

Ptrd$_4$= $-\frac{M1\times\alpha1\times L3}{2\times L0}$

= -65.88 N

Combined radial and thrust load

In uniform motion

$P_{E1}$ =$P_1$= 1692.22N

$P_{E2}$= $P_2$ = 4880.47N

$P_{E3}$ = $P_3$ = 1765.41N

$P_{E4}$ = $P_4$= -1496.02N

During acceleration to the left

$P_E la_1 = |pla_1|+|ptla_1|$=1586.81N

$P_E la_2 = |pla_2|+|ptla_2|$=5019.54N

$P_E la_3 = |pla_3|+|ptla_3|$=1831.29N

$P_E la_4 = |pla_4|+|ptla_4|$=1635.09N

During acceleration to right

$P_E ra_1 = |Pra_1| + |Ptra_1|$ =1831.29N

$P_E ra_2 = |Pra_2| + |Ptra_2|$ =4873.56N

$P_E ra_3 = |Pra_3| + |Ptra_3|$ =1684.91N

$P_E ra_4 = |Pra_4| + |Ptra_4|$ =1488.71N

During deceleration to the left

$P_E ld_1 = |pld_1|+|ptld_1|$=1831.29N

$P_E ld_2 = |pld_2|+|ptld_2|$=4873.16N

$P_E ld_3 = |pld_3|+|ptld_3|$=1685.56N

$P_E ld_4 = |pld_4|+|ptld_4|$=1488.71N

During deceleration to right

$P_E rd_1 = |Prd_1|+|Ptrd_1|$=1684.91N

$P_E rd_2 = |Prd_2|+|Ptrd_2|$=5019.54N

$P_E rd_3 = |Prd_3|+|Ptrd_3|$=1831.29N

$P_E rd_4 = |Prd_4|+|Ptrd_4|$=1635.09N

Mean load =

$$\sqrt[3]{\frac{1}{2.l_s}\left(P_E {la_1}^3.S_1 + {P_{E1}}^3.S_2 + P_E {ld_1}^3.S_3 + P_E {ra_1}^3.S_1 + {P_{E1}}^3.S_2 + P_E {rd_1}^3.S_3\right)}$$

$Pm_1$= 1699.58 N

$Pm_2$=4890.75 N

$Pm_3$=1764.78

$Pm_4$=1312.27

Static safety factor

Maximum load is exerted on LM guide during second acceleration to the left on second LM guide, and during deceleration to the right on second LM guide. Therefore, the static safety factor ($f_s$) becomes as follows:

$C_0$ = <u>61.1 KN for HSR35</u>

$f_s = \frac{C_0}{P_E la_2} = \frac{61.1\times10^3}{5019.54} = \underline{12.17}$

Calculation of Dynamic Load Factor (C)

Nominal Life, $L_n = (\frac{C}{f_w.P_m})^3 \times 50$

Therefore, C= $(\frac{L_n}{50})^{\frac{1}{3}} \times f_w \times P_m$

Assuming Load factor ($F_w$) = 1.5

C1= 9.27 KN

C2= 26.71 KN

C3= 9.63KN

C4= 7.6 KN

Thus referring to the calculated Dynamic load rating factor and comparing it with the same in THK catalogue, we've selected the LM guide rail <u>HSR35</u>.

## 5.5 Calculations for the cylinder support

Table 9: Calculations for cylinder

| Dimensions | Notations | Units | Values | Formulas |
|---|---|---|---|---|
| Modulus of elasticity | E | Mpa | 200000 | |
| Force | F | N | 49050 | |
| Breadth | b | mm | 20 | |
| Height | d | mm | 110 | |
| length | L | mm | 230 | |
| Moment of inertia for cantilever beam | *I*c | $mm^4$ | 153333.33 | $\frac{L \times b^3}{12}$ |
| Moment of inertia for fixed support beam | *I*s | $mm^4$ | 73333.33 | $\frac{d \times b^3}{12}$ |
| Distance of force from cantilever end | a | mm | 60 | |
| Deflection for cantilever beam | Dc | mm | **0.26** | $\frac{F \times a^2 \times (3d - a)}{(6E \times I_c)}$ |
| Deflection for fixed support beam | Ds | mm | **0.21** | $\frac{F \times L^3}{(192E \times I_s)}$ |

# 6. ANSYS Reports and Modifications

## 6.1 Cylinder Support Bracket

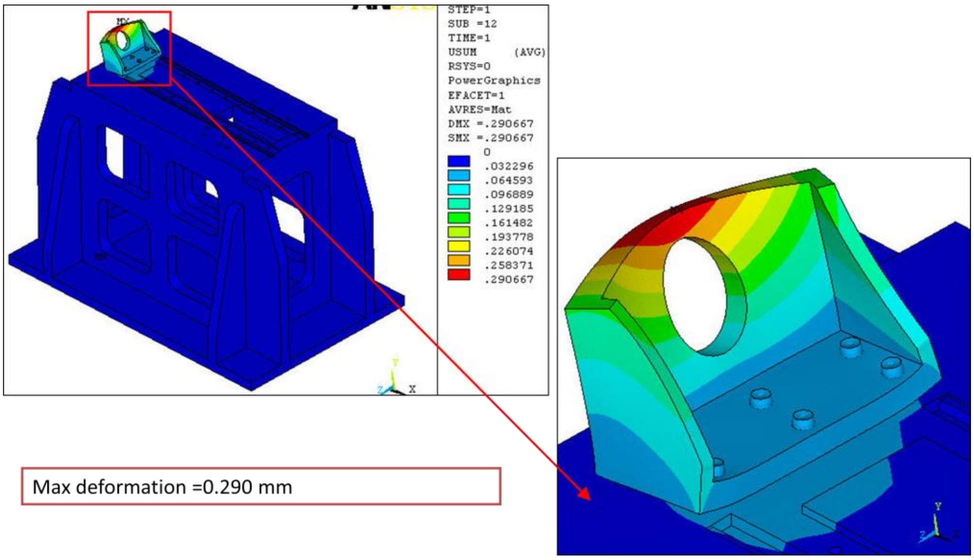
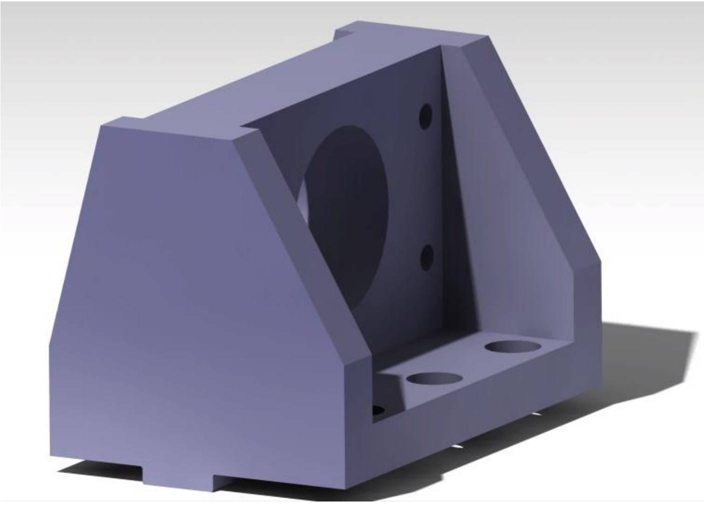



Fig 6.1:Analysis of Cylinder Support Bracket

Conclusion:

- Number of bolts used to clamp bracket to the frame are not sufficient to hold them together during application of load.
- A gap of 0.001 mm to 0.038 mm is expected because of separation of interfaces between bracket and frame. Number of bolts should be increased to avoid this separation.
- Stresses in the frame in the bolt holes for clamping bracket are going beyond yield; this stress will also come down by using more no of bolts for clamping.
- Bracket may strengthened by providing additional ribs to reduce deformation of the bracket.

❖ New Design



| Material | Mild steel |
|---|---|
| Modulus of Elasticity in ($Kg/mm^2$) | 20000 |
| Density ($Kg/m^3$) | 7850 |
| Weight of part (Kg) | 17.793 |

Fig 6.2: New Design Cylinder Support Bracket

The ANSYS report gave us the amount of deflection when different possible magnitude of forces was applied to the bracket at critical sections of this bracket. The basic function of this is to support the cylinder which will slide the slider mechanism and the cylinder is a quick return type mechanism. So, naturally it is subjected to fatigue failure. So changing the preliminary design is must. The ANSYS result matched with calculated result.

After the ANSYS report there were some changes made in the bracket according to given conclusions. One of the major changes was increasing number of bolts used. The original thickness of the bracket was approximately doubled. The bracket shape was changed into T-shape instead of L-shape. Also, there are stiffeners mounted at both ends which are used to increase its rigidity. As it is the critical part of the design, factor of safety taken is too high hence no further analysis is required. Notch is added to its lower face to take care of axial loads and transferring it to the base.

## 6.2 Slider Plate

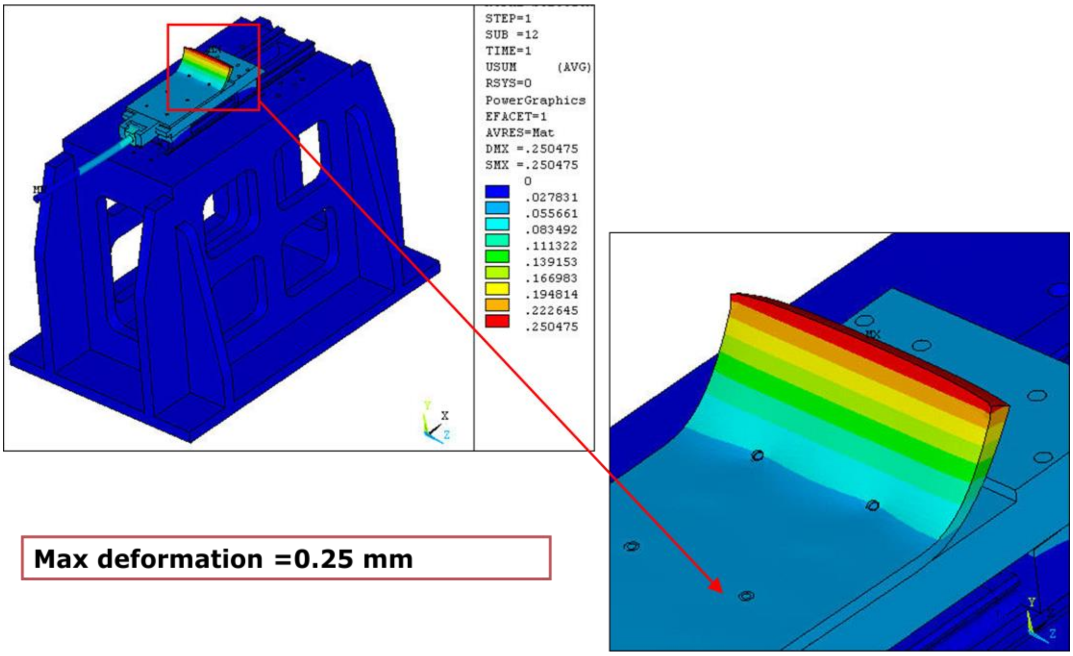
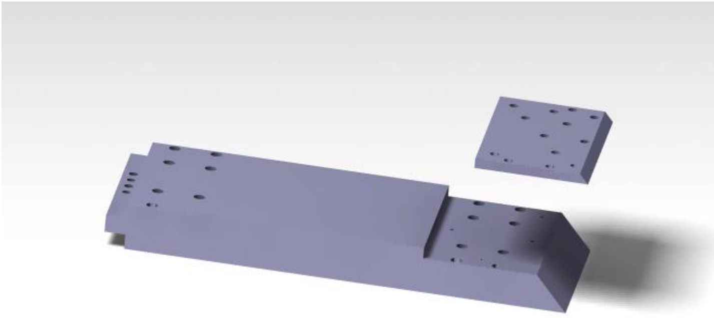



Fig 6.3: Analysis of Slider Plate

Conclusion:

- Numbers of bolts used to clamp top plate to the lower plate are not sufficient to hold them together during application of load.
- A gap of 0.15 mm to 2.5 mm is expected because of separation of interfaces between bracket and frame. Number of bolts should be increased to avoid this separation.
- Stresses in the top plate in the bolt holes are going beyond yield, this stress will also come down by using more no of bolts for clamping.

❖ New Design:



| Material | Mild steel |
|---|---|
| Modulus of Elasticity in ($Kg/mm^2$) | 20000 |
| Density ($Kg/m^3$) | 7850 |
| Weight of part (Kg) | 43.752 |

Fig 6.4: New Design of Slider

In the previous design the above or upper plate was thin thus it could not take forces also its fitting and changing was a problem. Thus we came up with another design in this the step was rigid and its height was 12mm which is more than maximum required. It has the plate which is placed on this step which is responsible for changing thickness and allowing different sizes of washers. Due to this concept all the load was directly transferred to slider. Thus this design was rigid and safe. As the position of plate was changed, changing no of bolts and its size is not important.

The slider plate is the major moving part in the machine. It facilitates broaching of thrust washers. It reciprocates at very high speeds on base frame. It is the part which actually takes the load and transfers it to piston. It is one of the most stressed parts. It has 4 guide blocks attached to it on the lower side. This part takes in washer from stacking assembly and then passes under broach thus broaching the washer. To facilitate this operation step is provide on slider.

## 6.3 Broach Block

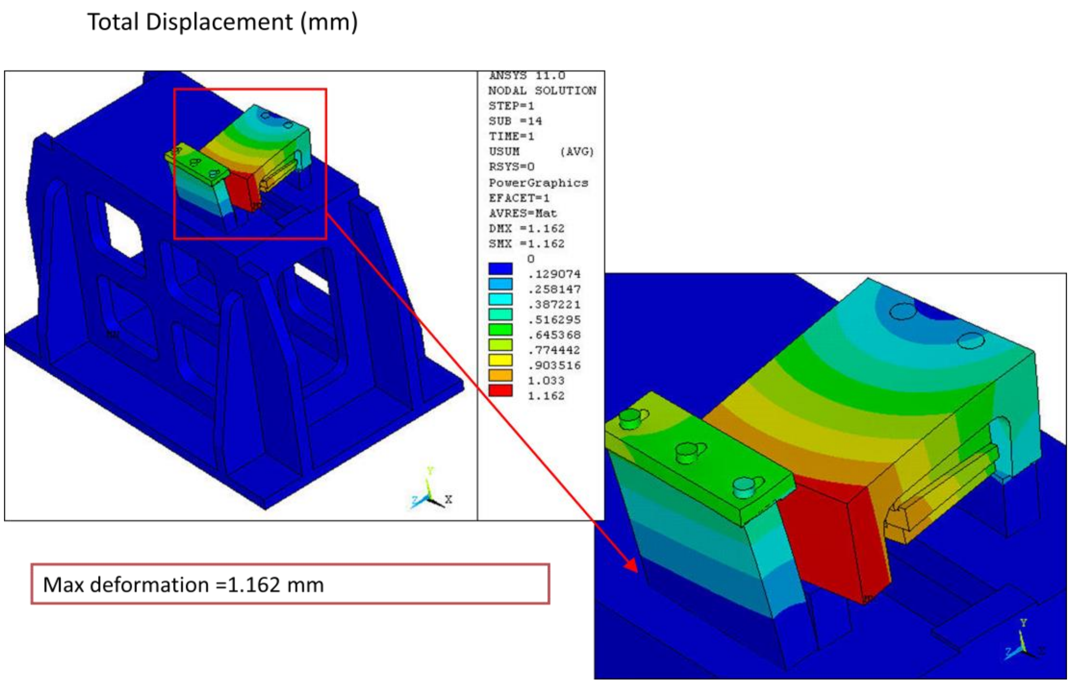
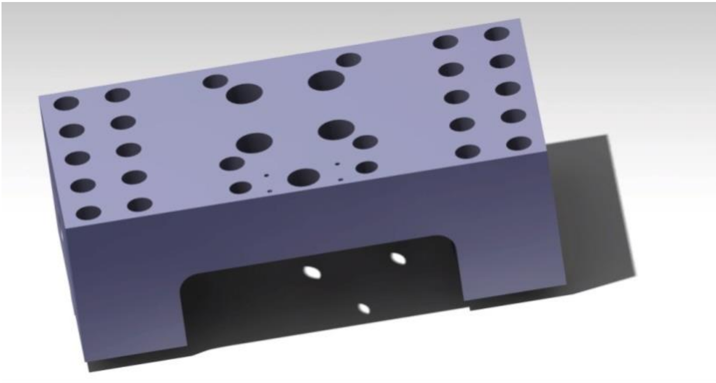



Fig 6.5: Analysis of Broach Block

Conclusions:

- C clamp load and arrangement is insufficient to hold the structure together. It is observed that because of force acting on 'c' ,it is sliding on the surface. 'C' clamping arrangement will not be adequate to hold the structure under the load of 5000kgf . Clamping design needs to be changed.
- Two bolts used to connect 'C' clamp to lower piece are not sufficient.
- Stress produced in bolt holes is beyond yield.
- Contact between the tenons is uneven
- High strength bolts should be used for clamping bolts

❖ New Drawing



| Material | Mild steel |
|---|---|
| Modulus of Elasticity in (Kg/mm$^2$) | 20000 |
| Density (Kg/m$^3$) | 7850 |
| Weight of part (Kg) | 87.41 |

Fig 6.6: New Design of Broach Support Block

Design modifications:

Taking into consideration above results the block was designed again. In this design instead of c clamp type mechanism there are direct holes in two sides of c so that bolts can go through them and hold them giving strength and rigidity. It also contains slot at bottom for easy fitment of block on base. It also has arrangements for fixing and allowing relative motion of upper taper block in it. It itself holds many parts on it can be cleared from the photo below. Also all the parts fitted on it are explained bellow.

## 6.4 Final Assembly

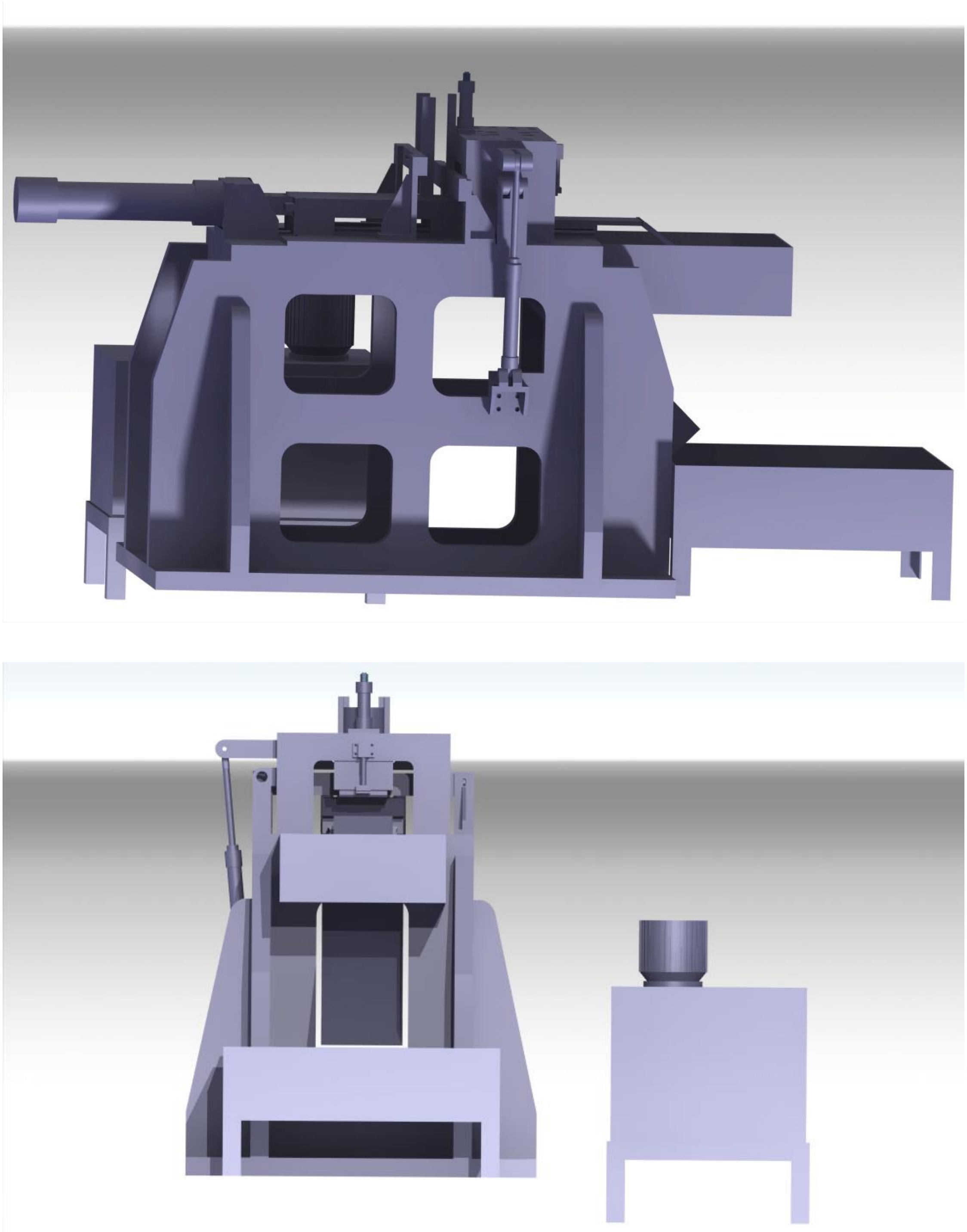


Fig 6.7: Final Assembly

# 7. Time Motion Diagram

After the successful completion of the design process, we evaluated for the real time working of the mechanisms used in our final design concept. We plotted the Time Motion diagram in the excel sheet which will really help and give us the clear idea as to which part will be in action when and for how much time for one complete cycle.

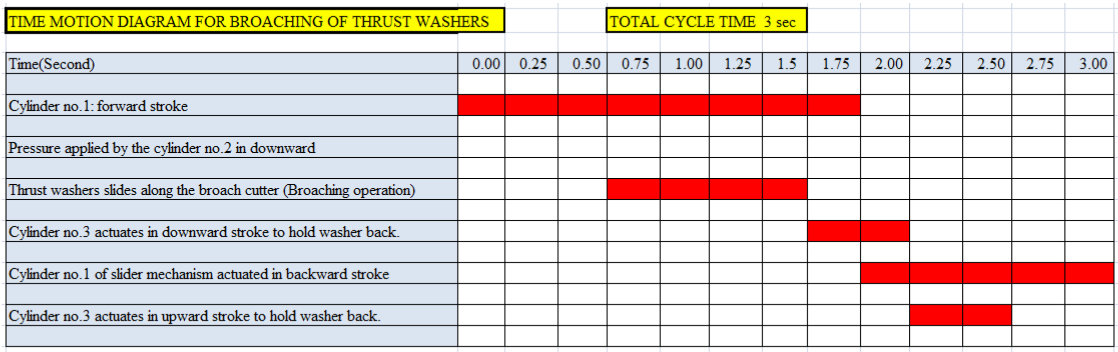



Fig 7.1 Time Motion Diagram

Knowing the length of stroke i.e., 300 mm and referring to the basic kinematics we calculated the time for as to how much time the cylinder no. 1 needs to be in action, it works as a quick return mechanism; the forward stroke is limited to 1.75 sec. Cylinder no2 is continuous operation applying uniform pressure throughout the cycle. Broaching operation starts from 0.75 sec and lasts for 1.5 sec. Thus the washer is effectively broached during this time. The cylinder no. 3 i.e., the output cylinder will start its operation holding back the processed washer and sending it to the Output box, this cylinder will be effective for 0.25 sec, i.e., from 1.75 to 2 sec. Further cylinder no. 1 is operated in backward stroke from 2 to 3 sec. Then cylinder no. 3 starts its backward stroke which lasts for 0.25 sec. And thus the cycle repeats.

# 8. BOM

Table 10- Bill of Material

| Bill of Material | | | |
|---|---|---|---|
| Part Number | Quantity | Type | Total Cost (RS) |
| Base Assembly | 1 | Assembly | |
| Cutter Assembly | 1 | Assembly | |
| Guide And Slider Assembly | 1 | Assembly | |
| Cutter Opening Cylinder | 1 | Standard | 35000 |
| | | | |
| **Bill of Material: Base Assembly** | | | |
| Part Number | Quantity | Type | |
| Base Frame | 1 | Manufactured | 10000 |
| Cutter Assembly Base | 2 | Manufactured | 1000 |
| Rail Support | 2 | Manufactured | 500 |
| Rail Holder | 2 | Manufactured | 500 |
| Rail | 850m | Standard | 30000 |
| Scrap Guide | 1 | Manufactured | 500 |
| Cylinder Support Bracket | 1 | Manufactured | 2000 |
| Main Cylinder | 1 | Standard | 50000 |
| Washer Stacking Assembly Front | 1 | Assembly | |
| Washer Stacking Assembly Back | 1 | Assembly | |
| Washer Output Guide Plate | 1 | Manufactured | 700 |
| Scrap Bin | 1 | Manufactured | 1000 |
| Washer Output Box | 1 | Manufactured | 2000 |
| Cutter Assembly Support | 1 | Manufactured | 400 |
| Hydraulic Circuit | 1 | Standard | 100000 |
| | | | |
| **Bill of Material: Washer Stacking Assembly Front** | | | |
| Part Number | Quantity | Type | |
| Stacking Frame Front | 1 | Manufactured | 1000 |
| Stacking Frame Support Front | 2 | Manufactured | 1000 |

| Bill of Material: Washer Stacking Assembly Back | | | |
|---|---|---|---|
| Part Number | Quantity | Type | |
| Stacking Frame Support Back | 2 | Manufactured | 1500 |
| Stacking Frame Back | 1 | Manufactured | 2000 |
| Guide For Washer Right | 1 | Manufactured | 1000 |
| Guide For Washer Left | 1 | Manufactured | 1000 |
| | | | |
| **Bill of Material: Cutter Assembly** | | | |
| Part Number | Quantity | Type | |
| Taper Block(Upper) | 1 | Manufactured | 4000 |
| Cutter Support Frame | 1 | Manufactured | 8000 |
| Auxiliary Cylinder (Input) | 1 | Standard | 30000 |
| Washer Holding Block(Input) | 1 | Manufactured | 500 |
| Auxiliary Cylinder(Output) | 1 | Standard | 20000 |
| Taper Block(Lower) | 1 | Manufactured | 5000 |
| Taper Block Guide Rail | 2 | Manufactured | 4000 |
| Support Block | 2 | Manufactured | 500 |
| Cutter Opening Bracket | 1 | Manufactured | 1000 |
| Washer Holding Block(Output) | 1 | Manufactured | 700 |
| | | | |
| **Bill of Material: Guide And Slider Assembly** | | | |
| Part Number | Quantity | Type | |
| Slider | 1 | Manufactured | 5000 |
| Slider Step Plate | 1 | Manufactured | 3000 |
| Slider-Piston Connector | 1 | Manufactured | 2000 |
| T-Connector | 1 | Manufactured | 1000 |
| Rail Block | 4 | Standard | 8000 |
| | | | |
| Controls | | | 200000 |
| Nut Bolts | | | 30000 |
| Auxiliaries | | | 20000 |

| | | | |
|---|---|---|---|
| Extra Cutters | | | 100000 |
| Extra Rail Blocks | | | 8000 |
| Slider Step Plates | | | 12000 |
| | | | |
| Total | | | 703800 |
| 20% Extra | | | 140760 |
| Grand Total | | | 844560 |

(Note: The above given costs are subjected to vary.)

# 9. Conclusion

There was requriement of maintaining the thickness of thrust washers in permissible tollerance limit. Thus we studied all the possible processess and the most effective and suitable process was selected i.e. broaching. During desiging it was seen that stacking of Thrust Washer was most important as the thickness of washer is less. Keeping this in mind various stacking concepts were designed and the simplest and best concept was selected. This concept was futher developed. All the sub assemblies were designed so that differnet sizes and shape of washer can be broached.

This designed was shown to top management and workers. Their useful suggestion helped us a lot in our design process. After this analysis was done and necessary changes were made.

This Machine is approved by Top Management and the required amount is sanctioned.The feasibilty of the machine is cheked in CATIA V5, simulations were made to observe its effective working.

At present rework and scrap for aluminium based thrust washers is about 40% and it is about 30% for copper based thrust washers, after including this machine in present process line this will drasticaly reduce. Hence there will be at least 20% cost reduction in manufacturing thrust washers.

This Project will be beneficial for the Company for improving the quality and increasing the productivity of Thrust Washers. We are indeed very much thankful to Management and Staff of Kirloskar Oil Engines Ltd for their immense support and co-operation.

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