Redesign and Finite Element Analysis for Movable Platen of Toggle type Injection Molding Machine

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Major Project Report

Submitted in partial fulfillment of the requirements

For the Degree of

Master of Technology in Mechanical Engineering

(CAD/CAM)

By

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May 2015

Declaration

This is to certify that

1. The thesis comprises of my original work towards the degree of Master of Technology in Mechanical Engineering (CAD/CAM) at Nirma University and has not been submitted elsewhere for a degree.

2. Due acknowledgment has been made in the text to all other material used.

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Undertaking for Originality of the Work

I, Nrupen Patel, Roll. No. 13MMCC21, give undertaking that the Major Project entitled "Redesign and Finite Element Analysis for Movable Platen of Toggle type Injection Molding Machine" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (CAD/CAM) of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that the Major Project Report entitled "**Redesign and Finite Element Analysis for Movable Platen of Toggle type Injection Molding Machine**" submitted by **Mr Nrupen Patel (13MMCC21)**, towards the partial fulfillment of the requirements for the award of Degree of Master of Technology in Mechanical Engineering (CAD/CAM) of Institute of Technology, Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination. The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

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Abstract

The purpose of the project is to redesign and optimize movable platen of 500T toggle type injection molding machine. The one side of platen is connected to toggle clamps and the mold is connected to the other end of movable platen. The movable platen reciprocates over the four tie-bars, which are located at four corners. The detail design of existing movable platen of 500T is studied thoroughly. Finite Element Analysis is carried out for 500T movable platen in Ansys Workbench 14.5 and the stress values are compared with acceptable criteria.

The aim of the project is to redesign the movable platen by changing the tie-bar distance after analyzing the stress and deflection values with the help of Finite Element Analysis, to improve the reliability of the praposed design. The movable platen is the critical component of injection molding machine. Optimization has been carried out to optimize the weight, which ultimately give machine a competitive edge over the market in terms of cost and design.

Keywords : Injection Molding Machine, Finite Element Analysis, Toggle Clamps, Optimization

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Nomenclature

ρ	Density, Kg/mm^3
F	Force, N
P	Pressure, N/mm^2
E	Young's Modulas, MPa
S_{ut}	Ultimate Tensile Strength, N/mm^2
K_a	Surface Finish Factor
K_b	Size Factor
K_c	Loading Factor
K_d	Temperature Factor
K_e	Reliability Factor
S_e	Endurance Limit Stress, N/mm^2
μ	Poisson's Ratio

Chapter 1

Introduction

1.1 Preamble

Plastics are the most versatile of all known material and have established themselves in enviable position. The total consumption of commodity plastic is over 750,000 MT and is estimated to cross 2500,000 MT. That is rise over 4 times by the end of this decade. The per capita consumption of plastics has increased from 0.64 Kg. to 1.06 Kg currently and is expected to 2.16 Kg by the end of decade. This is a good jump. It is much lower as compare 63Kg in W .Europe, 89 Kg in U.S.A. and 58 Kg in Japan in the current year. Most of the commodities plastic are now being manufactured in country and several new capacities are in pipeline to meet growing demand.

Injection molding is one of the most widespread technologies for processing polymer. Many different kinds of products are molded using various types of injection molding. The injection molding process consists of essentially heating the thermoplastic material which comes in powder or granule form so as to make it plastic in a cylinder known as plasticizing barrel and then injecting it into the cavities of mould from which it will take its shape. The process is carried out in machine known as Injection molding machine.

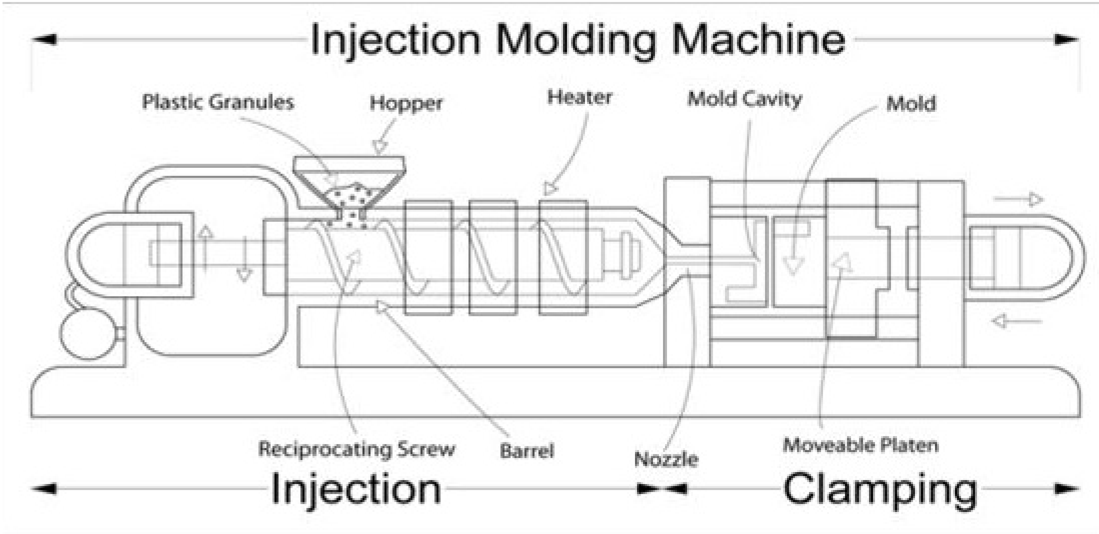

Figure 1.1: Injection Molding Machine[11]

A large variety of molding machines are manufactured in the country with the indigenously developed technology as well as in collaboration with the world leaders to indigenously manufacture machines of world standards. Clamping force, low pressure molding machines, gas injection molding machines, multi component molding machines, co-injection molding machines or some very special tailor-made machines dedicated to specific end-uses and polymers.

The facilities for mold making have also developed over the years and even the most difficult and sophisticated molds are now being designed and fabricated in India. Injection moulded components are a feature of almost every functional manufactured article in the modern world, from automotive products through to food packaging. This versatile process allows us to produce high quality, simple or complex components on a fully automated basis at high speed with materials that have changed the face of manufacturing technology over the last 50 years or so.

1.2 Objectives

When the toggle linkages become fully extended, the moving platen closes the mold for the accommodation of the molten material, it experiences the force provided by the toggle linkages and the reactions offered by the mold itself. So, deformations are observed at the various parts of the moving platen, and platen experiences stresses.

The present project aims to:-

- Finite Element Analysis of existing movable platen of 500T magna toggle injection molding machine
- Redesign the movable platen of 500T magna toggle injection molding machine by changing the tie-bar distance.
- Finite Element Analysis of the redesigned model.
- Optimization of new design to improve the reliability and to optimize the weight.

1.3 Methodology

In this experimental investigation procedure described below has been used to obtain the Research Objectives.

- Prepare CAD model of movable platen of existing 500T magna toggle machine.
- Static Structural Analysis carries out for that platen by using FEA package.
- Redesign of the movable platen by changing the tie-bar distance and prepare the redesigned model by using CAD package.
- Carry out static structural analysis of redesigned model for stress and deflection analysis.
- Optimization has been done on the basis of the values achieved in stress and deflection analysis.

1.4 Structure of Thesis

The thesis constitutes of various chapters and the description as follow:-

- Chapter 1 is describing an overview of the needs of injection molding project, objective of the research work and methodology.
- Chapter 2 presents a detailed literature survey of theoretical and experimental study on modeling and analysis process.
- Chapter 3 contains calculation of forces applied on moving platen of injection molding machine.

- Chapter 4 presents Finite Element Analysis of existing and redesigned moving platen by using Ansys Workbench 14.5
- Chapter 5 contains Finite Element Analysis of optimized model of movable platen.
- Chapter 6 presents the conclusion and future work.

Chapter 2

Literature Review

2.1 Components of Injection Molding Machine

Injection system

The injection system consists of a hopper, a reciprocating screw and barrel assembly, and an injetion nozzle, as shown in Fig. 2.1. This system confines and transports the plastic as it progresses through the feeding, compressing, degassing, melting, injection, and packing stages.

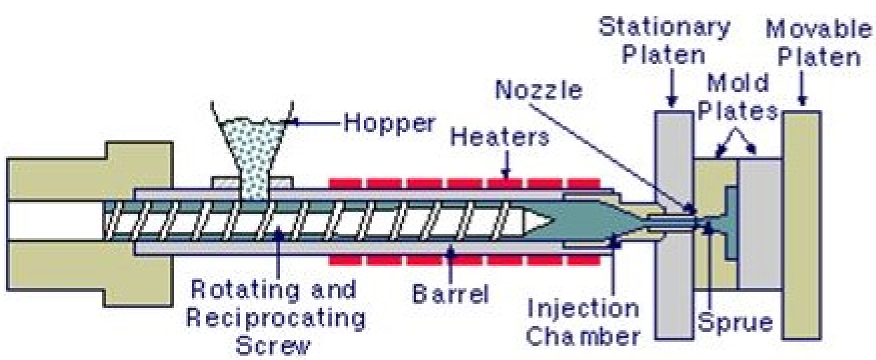

Figure 2.1: Injection System[11]

- **Inline single cylinder concept**

A central large cylinder is connected in-line with the feed screw and then the hydro motor is fitted there. This makes the overall length of the Injection unit more, which ultimately increases the machine length.

- **Twin cylinder concept**

There are two cylinders parallel to centre line of the injection unit, which moves the platen coupled with the screw. The hydro motor is mounted on this platen which makes the unit shorter.

Different parts of injection units are as follows:-

2.1.1 Hopper

Thermoplastic material is supplied to molders in the form of small pellets. The hopper on the injection molding machine holds these pellets. The pellets are gravity-fed from the hopper throat into the barrel and screw assembly.

2.1.2 Barrel

As shown in Fig 2.1, the barrel of the injection molding machine supports the reciprocating plasticizing screw. After the injection unit builds a shot, the barrel stores the melted material until it is injected into the mould. It is heated by the electric heater bands.

2.1.3 The Reciprocating Screw

The reciprocating screw shown in Fig 2.2 is used to compress, melt, and convey the material. The reciprocating screw consists of three zones (illustrated below):

- The Feeding Zone
- The Compressing Zone
- The Metering Zone

While the outside diameter of the screw remains constant, the depth of the flights on the reciprocating screw decreases from the feed zone to the beginning of the metering zone. These flights compress the material against the inside diameter of the barrel, which creates viscous (shear) heat. This shear heat is mainly responsible for melting the material. The heater bands outside the barrel help to maintain the material in the molten state. Typically, a molding machine can have three or more heater bands or zones with different temperature settings.

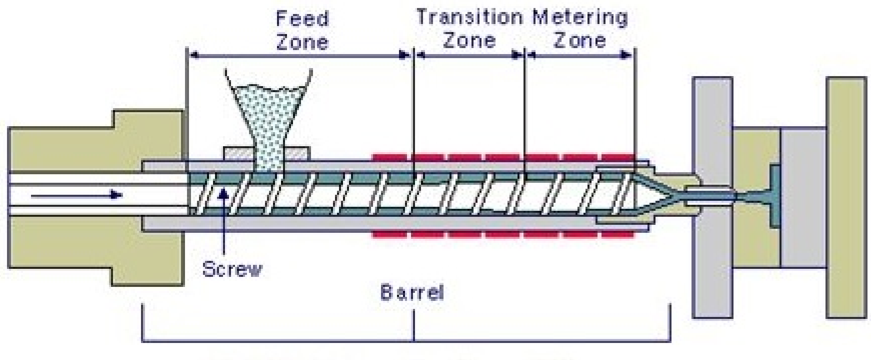

Figure 2.2: Reciprocating Screw[13]

2.1.4 Slider set

The screw is having a check valve assembly (consisting of ring, seat and tip) which allows the material to pass through during the refilling, but will not allow it to flow back during the injection. The material can flow back into the screw flights in absence of such screw tips which allow only part of the total shot weight to be pushed out of the nozzle.

2.1.5 Heaters and Thermocouples

Ceramic band heaters are fitted on the barrel which provides the heating to the plastics materials which is being conveyed by the screw. The actual temperature of the Barrel is sensed by the thermocouples fitted on the barrel. The barrel is divided into three zones, based on the screw design, which can be set at varying levels depending upon the plastics.

2.1.6 The Nozzle

The nozzle connects the barrel to the sprue bushing of the mold and forms a seal between the barrel and the mold. The temperature of the nozzle should be set to the material's melt temperature or just below it, depending on the recommendation of the material supplier. When the barrel is in its full forward processing position, the radius of the nozzle should nest and seal in the concave radius in the sprue bushing with a locating ring. During purging of the barrel, the barrel backs out from the sprue, so the purging compound can free fall from the nozzle. These two barrel positions are illustrated in Fig 2.3.

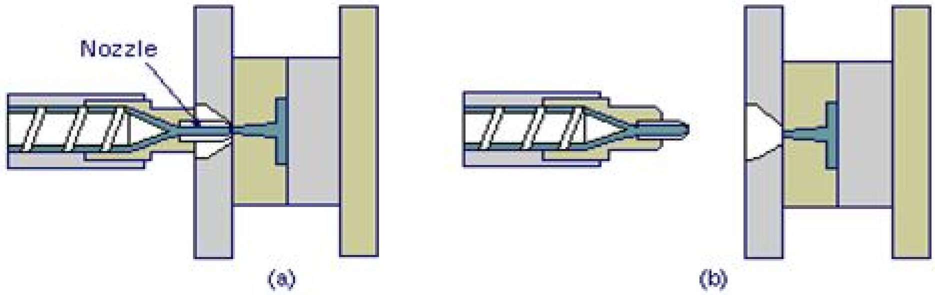

Figure 2.3: Nozzle[13]

2.1.7 Mold System

The mold system contains different parts like tie bars, stationary and moving platens, as well as molding plates (bases), sprue and runner systems, ejector pins, and cooling channels, as shown in Fig 2.4 .The mold is essentially a heat exchanger in which the molten thermoplastic solidifies to the desired shape and dimensional details defined by the cavity.

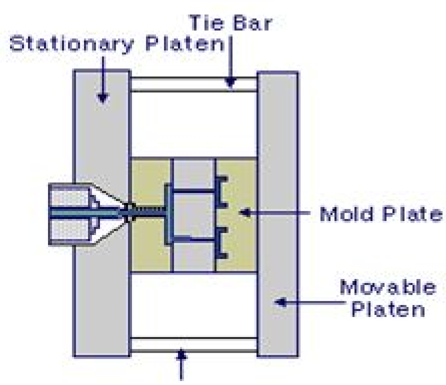

Figure 2.4: Mold System[13]

The mold system shapes the plastics inside the mold cavity and ejects the moulded parts. The stationary platen is attached to the barrel side of the machine and is connected to the moving platen by the tie bars. The cavity plate is generally mounted on the stationary platen and houses the injection nozzle. The core plate moves with the moving platen guided by the tie bars. Occasionally, the cavity plate is mounted to the moving platen and the core plate and a hydraulic knock-out (ejector) system is mounted to the stationary platen.

2.1.8 Cooling Channels

Cooling channels are passageways located within the body of a mold, through which a cooling medium (typically water, steam, or oil) circulates. Their function is the regulation of temperature on the mold surface. Cooling channels can also be combined with other temperature control devices, like bafflers, bubblers, and thermal pins or heat pipes.

2.1.9 Hydraulic System

The hydraulic system on the injection molding machine provides the power to open and close the mold, build and hold the clamping tonnage, turn the reciprocating screw, drive the reciprocating screw, and energize ejector pins and moving mold cores. A number of hydraulic components are required to provide these powers, which include pumps, valves, hydraulic motors, hydraulic fittings, hydraulic tubing, and hydraulic reservoirs.

2.1.10 Control system

The control system provides consistency and repeatability in machine operation. It monitors and controls the processing parameters, including the temperature, pressure, injection speed, screw speed and position, and hydraulic position. The process control has a direct impact on the final part quality and the economics of the process. Process control systems can range from a simple relay on/off control to an extremely sophisticated microprocessor-based, closed-loop control..

2.1.11 Clamping system

The clamping system opens and closes the mold, supports and carries the constituent parts of the mold, and generates sufficient force to prevent the mold from opening. Clamping force can be generated by a mechanical (toggle) lock, hydraulic lock, or a combination of the two basic types.

2.1.12 Moulded System

A typical moulded system consists of the delivery system and the moulded parts, as shown in Fig 2.5.

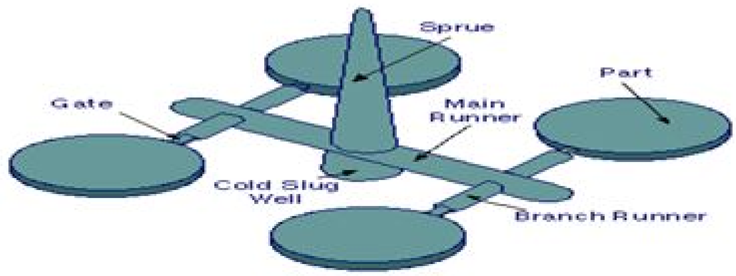

Figure 2.5: Moulded System[13]

2.1.13 Delivery System

The delivery system, which provides passage for the molten plastic from the machine nozzle to the part cavity, generally includes:

- Sprue
- Cold Slug Wells
- A Main Runner
- Branch Runner
- Gates

The delivery system design has a great influence on the filling pattern and thus the quality of the moulded part.

2.1.14 Cold Runners

After molding, the cold-runner delivery system is trimmed off and recycled. Therefore, the delivery system is normally designed to consume minimum material, while maintaining the function of delivering molten plastic to the cavity in a desirable pattern.

2.1.15 Hot Runners

The hot-runner (or runner less) molding process keeps the runners hot in order to maintain the plastic in a molten state at all times. Since the hot runner system is not removed from the mold with the moulded part, it saves material and eliminates the secondary trimming process.

2.2 Clamping Unit

The clamping unit of an injection molding machine accommodates the injection mold. It provides the motion needed for closing, clamping,opening and produces the forces which are necessary to clamp and open the mold. Its principal components are: -

2.2.1 Movable Platen

The back half of the mold is mounted to the moving platen by the use of clamps and bolts. This platen is supported on the tie rods and moves forwards to close the mold and backwards to open the mold.

2.2.2 Stationary Platen

The stationary platen is that portion of the injection molding machine where the mold and the nozzle of the barrel/cylinder unit meet. The platen has a hole in the center of it where the mold, which has a locating ring mounted on this front half, is fitted.

2.2.3 The Mold

The mold is a steel tool designed to form plastics material into the desired shape or size. In choosing the correct mold steel, the processor must take into account the plastics material being used, the hardness of the steel, the wear resistance, machinability, ease of polishing, shock resistance, etc. The basic injection mold is made in two halves: -

- The Front Half
- The Back Half

2.2.4 Toggle Mechanism

The toggle mechanism ties the moving platen and the die height adjust platen together. It is this mechanism that maintains clamp tonnage during the injection sequence.

2.2.5 Clamp Cylinder

It is this cylinder that causes the mould to open and close. When the clamp is closing, the cylinder rod pushes the cross-head upward, which causes the toggle mechanism to extend. When the clamp is opening, the cylinder rod pulls the cross-head down-ward, which causes the moving platen to pull away from the stationary platen.

2.2.6 Crosshead

The cross-head is the mechanical link, or coupling, between the clamp cylinder and the toggle mechanism.

2.2.7 Hydraulic Ejector Mechanism

The ejector mechanism is used to force parts from the mould after the moulding process is completed. This mechanism includes two cylinders (for SIGMA 30-110, 1 cylinder for Sigma 150 onwards, Omega and Magna). Knockout bar is supplied in option if multiple ejection points are necessary. The back and forth movement of the centre ejector rod causes the ejector pins in the mould to move back and forth, thus forcing the parts from the mould. The transducer attached with the moving centre rod monitors the position of the ejector stroke.

2.2.8 Strain Rods (Tie-bars)

All three clamp platens are tied with four strain rods. The strain rods also act as guide bars for the moving platens. It is the strain force acting on the tie rods, which determines the overall clamping force acting on the mould.

2.2.9 Die-height Mechanism

For toggle machines, to accommodate molds of various sizes, one has to move the complete clamping mechanism either back or forth. This requires a feature called die-height adjustment. Hydro motor drives the main gear couples with the driven gears fitted on die-height nuts by a chain. Thus rotation of the hydro motor causes rotation of the nuts which either thread out or thread in depending upon the direction of rotation.

2.3 Types of Clamps

2.3.1 Mechanical

Most mechanical clamps are toggle clamps. The links of the toggle are activated by the use of a small hydraulic cylinder. Since the extended toggle is always the same, the nuts on the tie rods are used to adjust the clamp for different mold heights. Adjustments normally have to be made after the molding cycle has begun because of the heat transferred to the mold.

2.3.2 Hydraulic

Straight hydraulic clamping is relatively easy and trouble free. Most machines using hydraulic clamping are larger than those using toggles because of the larger cylinder and ram. The clamp force is easily adjustable.

2.3.3 Hydro-Mechanical

These types of clamps combine the best attributes of the previous two. After the toggles links have been fully extended, hydraulic force is exerted to build up clamp tonnage. As with the straight hydraulic, clamp force is easily adjustable.

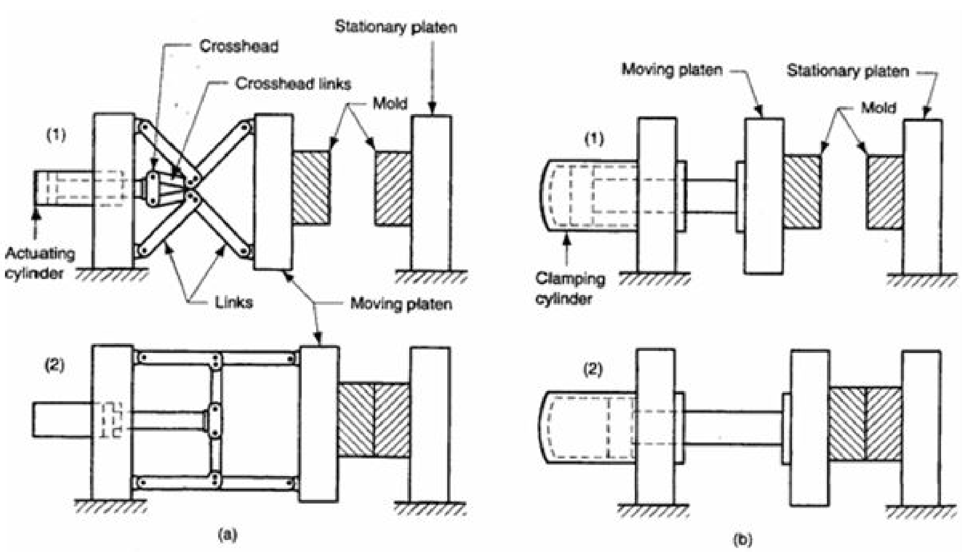

Figure 2.6: Mechanical Clamps (a) Toggle Type (b) Ram Type[11]

2.4 Specifications

2.4.1 Clamping Force

The clamping force expressed in ton and if this is not adequate, the two halves of the mold will open because of force applied by the melt injected into the mold.

2.4.2 Injection Capacity

It is generally expressed in maximum shot weight in terms of grams of general purpose polystyrene. It is important to note that there need not be any direct relationship between injection shot capacity and clamp tonnage.

2.4.3 Distance between Tie-bars

This is very important since the distance between the tie-bars govern the size of the mold that can be mounted on a machine.

2.4.4 Day-Light Opening

The maximum distance that can be obtained between the stationary platen and the moving platen when actuating mechanism is fully retracted without ejector bar and/or spacers is called daylight opening and the specified distance helps to determine the maximum height of a molded product possible.

2.4.5 Plasticizing Capacity

It is expressed as kg/hour for polystyrene with the screw running as an extruder.

2.4.6 Injection Rate

Injection rate is the maximum speed at which general purpose polystyrene can be injected through the nozzle and the expressed as in^3/min or cm^3/sec at a stated pressure, which in turn determines the injection cycle of a product.

2.4.7 Injection Pressure

For plunger machines, the injection pressure is the pressure in psi or kg/cm^2 on the injection plunger. For the reciprocating screw, it is the pressure on the material ahead of the screw.

2.5 Injection Moulding Cycle[11]

The injection moulding cycle is an intermittent cycle. The injection moulding process can be performed in cycles which would be as follows :

1. Mould Close
2. Tonnage
3. Injection - Pack and Hold
4. Cooling (Refilling)
5. Mould Open
6. Ejection

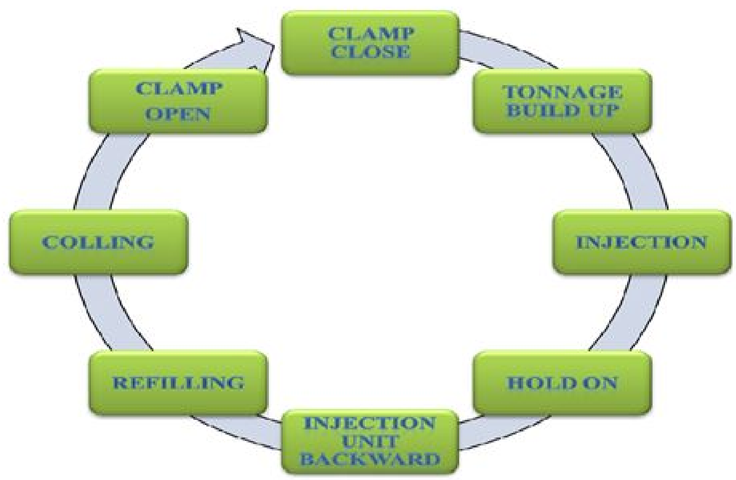

Figure 2.7: Injection Moulding Cycle

2.5.1 Mould Closing

When a machine cycle begins, oil is directed to the cap end of the clamp cylinder. This causes the cylinder rod to extend. The cylinder rod pushes on the cross-head, and the force of this push is transferred through the toggle linkage to the moving platen. Therefore, the moving platen is forced to move toward the stationary platen.

2.5.2 Mould Safety

Before the mould halves touch, the speed of the platen movement is decreased to keep the mould halves from slamming together. The clamp pressure used at this time is also reduced in order to protect the mould in the event that some obstruction comes between the two mould halves.

2.5.3 Tonnage

After the mould halves touch, the pressure in the clamp circuit is increased to provide the force necessary to lock the toggle linkage. When the linkage is locked over, maximum tonnage is built. (Maximum tonnage is dependent on the position of the die height adjust platen) This tonnage is maintained until the injection sequence is completed and the parts produced have been allowed to cool.

2.5.4 Injection

Once the mould has been closed and the tonnage is built, the next stage would be to ensure that the nozzle is in contact with the mould, and that sufficient nozzle contact force has been built up so as not to allow any plastics material drool out from the nozzle contact area during the injection. This may require the injection unit (sled) to move forward, if it is in back position. Once the unit is in forward position, the Injection phase starts. Injection phase has been divided into 3 stages. 1. Fill 2. Pack 3. Hold. During the fill stage the material is pushed into the cavity with various speeds as set on the controller. The pressure with which the mould is filled can be limited for this stage. However the set maximum filling pressure should be slightly more than the actual filling pressure. The different settings of the velocity during the filling stage depend on the type of product and this can be profiled to suit the product. The Pack and Hold stage of the Injection phase ensures that the material injected into the mould remains under controlled forces (pressures) till the gate of the product is solidified, and the material does not come flow back.

2.5.5 Cooling (Refilling)

The injected part should be allowed to sufficiently cooled before it is ejected. This portion of the cycle consumes most of the time. To control the cycle time, this period gets maximum focus. During the cooling period, the screw is rotated to plasticise the plastic granules and prepare the machine for the next shot. The screw speeds can be controlled depending upon the type of material used and temperatures set. Back pressure is applied during refilling to ensure good melt quality with proper mixing. This is normally used with the granules with master batches. Melt decompression (suck back) is used to relieve the melt accumulated in front of the screw, so that residual pressures do not force the material out of nozzle, when the unit is retracted or mould is open.

2.5.6 Mould Opening

The clamp opening movement begins when oil is directed to the rod end of the clamp cylinder. This creates a pulling force on the crosshead. As the crosshead is pulled downward, the moving platen is pulled away from the stationary platen. This opens the mould.

2.5.7 Ejection

The moulded part is pushed out from the mould by the ejector mechanism.

2.6 Application of Plastic Injection Moulding Machine

- Automotive Structural Parts
- TV Cabinets
- Computer Monitor Housings
- Rigid Packaging Containers

Figure 2.8: Injection Moulding Machine Applications

2.7 Literature Review of Published Study

- Sasikumar et al.[1] analyzed 150T injection molding machine for premature failure of a tie-bar. The tie bar was made of AISI 4140 steel material which has the yield strength of 750-900MPa. The crack of the tie-bar initiated due to cyclic fatigue loading during process. The fatigue crack started at the root of the tie-bar and the final fatigue failure has occurred because of ductile fracture. The overload can be the reason for that failure. The other reason may be torsional stress with high stress concentration. Because of un-even tension in four tie-bars, there is a high stress concentration.

- Huang Hai-bo and Xue Dong-hui[2] have done the topology optimization for movable platen of 80 ton plastic injection molding machine. The movable platen has a size of 532mm wide, 532mm length, and 430mm high. This machine is 80 ton injection machine, so it can provide maximum of 80 tons clamping force. The topology optimization has been done in the commercial software optistruct. The refined structure is redesigned by experience. The comparison has been done between original and optimized parts by the result of FEM analysis. The results concluded that max displacement positions of the two structures were almost same, but the optimized structure has 53kg less weight than the original one. The stress value was larger than the original structure, but it was less than the yield stress value of material.

- Shu Huang Sun[3]has done the topology optimization for the stationary platen of 90tons injection molding machine. The typical stationary platen has a size of 520mm wide, 520mm high and 180mm thick. The concept of self-organization method was used for the topology optimization, in which modification of young's modulus for each element has been done according to the ratio of its stress and the average stress of the entire model after each FEM analysis. Ansys 5.5 was used for the FEM analysis. There were a total of 4560 elements in the initial FEM model, while after completing the self-organization method and 52 iterations, only 1854 elements remained. In other words, only 40% of the total volume remained. Topology design optimized material allocation, strengthening locations of high loads and minimizing material usage at other locations. By applying this method deflection could be reduced of stationary platen and tie-bars without much cost affection.

- Chakherlou et al.[4]carried out an investigation of the effect of clamping force on the bolted plates. Both experimental and numerical methods are used for fatigue behavior. A holed plate was clamped using a deadbolt and a freak, and then tested in a fatigue testing machine. The fatigue testing has been done by making by three batches of specimens each subjected to different clamping force. The results of numerical and experimental are compared and concluded that the compressive stresses are generated around the plate hole because of clamping force which ultimately improves fatigue life of bolted plates.

- B.C Vanam et al.[5] performed a finite element analysis of an isotropic rectangular plate. Finite Element Analysis has been carried out by considering the master element as a four node quadrilateral element. A mathematical software MATLAB has been used for FEA and the results obtained by classical method are very much same. Numerical results showed that, the outcomes obtained by Finite Element Analysis and ANSYS simulation results are in close with the results obtained from exact solutions from classical method. During the analysis, the optimal thickness of the plate has been obtained when the shell is subjected to different loading and boundary conditions.

- George Z. Voyiadjis and Pawel Woelke[6] presented a non-linear finite element analysis for the elasto-plastic behavior of thick shells and plates. The updated Langragian method is used for the small strain geometric non-linearities are taken into account. The treatment of material non-linearities has been done by a non-layered approach and plastic node method. Non-linear Finite Element Analysis has been used for assembly analysis to analyze the exact values of stress and deflection at the moving platen because there is a bonded contact between the mating components of assembly, therefore there will be a non-linear behavior of the analysis.

- Mold Flow Corporation, USA[7]said, the tie bars stretch, when the clamp force increase beyond the limit. It results the mould will open and that will increase the wall thickness of the part. As the part shrinks, the force applied at clamp decreases and the mould will close. The pressure distribution is un-even, so the stretching of the tie-bar is not uniform. the tie-bars have a displacement load applied to them will be like that

$$\frac{(Clamp\,force)*(length\,of\,the\,tie-bars)}{(Modulus(E)\,of\,the\,tie-bars)*(total\,transverse\,area\,of\,the\,tie-bars)}$$

- Chen and Lin[8] presented two approaches, Taguchi orthogonal array and genetic algorithms, for optimum design space due to tolerances allowed in preliminary designs. Experiments are done and results of those experiments are used to determine the optimum boundaries of the design space in Taguchi orthogonal array method. In genetic algorithms artificial neural network (ANN) is used to sort out the problems related to time consuming methods for finding out optimum topologies. The ultimate goal of this method is also to search optimum boundaries of the design space.

- Rajesh Purohit et al.[9] performed a finite element analysis of an automotive clutch assembly. The purpose of a clutch is to initiate motion or increase the velocity of a body generally by transferring kinetic energy from another moving body. In the present work a friction clutch assembly was designed and a model of the same was created in Solid Works Office Premium Software. Finite element analysis was performed in ANSYS software. It consist of three parts viz. clutch plate, pressure plate and diaphragm spring. Different materials are used for different parts, for clutch plate structural steel, for pressure plate cast iron GS-70-02 and for diaphragm spring they have used spring steel. The plots for Equivalent von-Mises stress, total deformation and stress tool (factor of safety) were calculated and analyzed. The finite element analysis showed that the designed friction clutch assembly is safe.

- S.W.zhang et al.[10] presented static structural analysis and optimization for ITER upper Edge Localized Modes coil. ITER Edge Localized Modes coils are used to suppress Edge Localized Modes (ELM), which are located between the vacuum vessel (VV) and shielding blanket modules. There is high radiation levels, high temperature and high magnetic field. To verify the design structural feasibility of the upper ELM coil under EM and thermal loads, thermal, static and fatigue structural analysis have been performed in detail using ANSYS. Optimization proves that adding fillet, increasing the thickness of the connecting plate of the bracket and lowering the connecting plate for the bracket are needed. After these efforts, the stress of the IMIC can meet the static and fatigue criteria and this means the basic structure is valid.

Chapter 3

Force Analysis

3.1 CAD Modeling of a Moving Platen

Moving platen is supported on the tie-rods and moves forward to close the mold and backwards to open the mold. When the clamp is closing, the cylinder rod pushes the cross-head upward, which causes the toggle mechanism to extend. When the clamp is opening, the cylinder rod pulls the cross-head downward, which causes the moving platen to pull away from the stationary platen. Modeling for moving platen of 500T injection molding machine has been done in Creo Parametric 2.0 as shown in Fig. 3.1

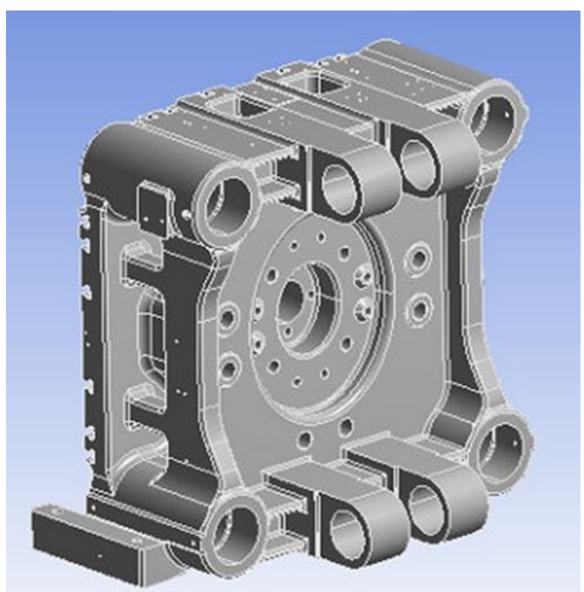

Figure 3.1: Movable Platen

3.2 Forces applied on Moving Platen

The pressure in the clamp circuit increased to provide necessary force to lock the toggle linkages, which known as Tonnage. Tonnage force applied at mechanical clamps of moving platen. The injection pressure is applied at the mold side of the moving platen. Maximum size of mold can be placed on movable platen depends on tie-bar distance. The calculation for forces present below :-

Tonage Force = 500 T

Force Applied on Clamp Side in Newton = 500*1000*9.81

= 4905000 N

Force Applied on movable platen for quadratic model = 1226250 N

3.3 Different Types of Mold Cases

- **Minimum Mold Case :** The minimum mold can be attached with the moving platen is 2/3 of the tie-bar distance on both side, horizontally and vertically.
- **Long Horizontal Mold Case :** In this case perticularly, the dimension of mold is 2/3 of tie-bar distance vertically, while horizontal distacne is taken similar to centre to centre distance between two tie-bar holes, which is maximum horizontal possible mold case.
- **Long Vertical Mold Case :** The dimension of mold is 2/3 of the tie-bar distance horizontally, but vertical distance is taken similar to the centre to centre distance between two vertical tie-bar holes, which is maximum vertical possible mold case

3.4 Acceptance Criteria

The relationship between S_e and $S_{e'}$ is as follows :

$\mathbf{S_e = K_a K_b K_c K_d K_e S_{e'}}$

where,

K_a= Surface Finish Factor

K_b= Size Factor

K_c= Loading Factor

K_d= Temperature Factor

K_e= Reliability Factor

$S_{e'}$= Endurance Limit Stress of a rotating beam specimen subjected to reversed bending stress (N/mm^2)

S_e= Endurance Limit Stress of a particular mechanical component subjected to reversed bending stress (N/mm^2)

$$K_a = (a)(S_{ut})^b \tag{3.1}$$

- By putting the values a = 4.51 , b = -0.265 and S_{ut}= 414 in above equation (3.1), get the surface factor K_a= 0.9134
- For Axial loading, there is no size effect. So, Size factor is taken as unity. K_b= 1
- For axial condition, Loading Factor K_C= 1
- Temperature Factor K_d= 1
- Reliability Factor K_e= 0.814

$$S'_e = (0.5)(S_{ut}) \tag{3.2}$$

Endurance Limit (S'_e) can be found out by using the above equation (3.2). Ultimate Tensile Strength (S_{ut}) for S.G.Iron is 414 Mpa. From the equation get the value of S'_e= 207 Mpa.

$$S_e = K_a K_b K_c K_d K_e S'_e \tag{3.3}$$

By substituting all the values in equation (3.3), get the value for endurance limit stress of a particular mechanical component, S_e= 130.82 Mpa, which is also an allowable stress for that particular component.

Chapter 4

Finite Element Analysis of Movable Platen

4.1 Material Data (S.G. Cast Iron)

S.G Cast iron is defined as a high carbon containing, iron based alloy in which the graphite is present in compact, spherical shapes rather than in the shape of flakes, the latter being typical of gray cast iron . As nodular or spheroidal graphite cast iron, sometimes referred to as ductile iron, constitutes a family of cast irons in which the graphite is present in a nodular or spheroidal form. The graphite nodules are small and constitute only small areas of weakness in a steel-like matrix. Because of this the mechanical properties of ductile irons related directly to the strength and ductility of the matrix presentas is the case of steels.

One reason for the phenomenal growth in the use of Ductile Iron castings is the high ratio of performance to cost that they offer the designer and end user. This high value results from many factors, one of which is the control of microstructure and properties that can be achieved in the ascast condition, enabling a high percentage of ferritic and pearlitic structure.

Young's Modulas	1.7e+005 MPa
Poisson's Ratio	0.27
Denisity	7100 kg/m^3
Ultimate Tensile Stress	414 MPa
Yield Strength	275 MPa
Elongation	10 %

Table 4.1: Material Data of S.G. Cast Iron

Properties of S.G. Cast Iron

A number of properties such as mechanical, physical and service properties are of important in assessing materials suitably for any application. The mechanical properties of interest are tensile strength, proof stress, elongation, hardness, impact strength, elastic modulus, and fatigue strength, notch sensitivity while the physical properties of interest are damping capacity, machinability and conductivity. The service properties generally involved are wear resistance, heat resistance,Corrosion resistance. S.G. Cast iron has the higher fluidity at molten state which makes it idle for casting process.

4.2 Boundary Conditions

4.2.1 Symmetry

The use of symmetry is a very efficient means of simplifying a model, both in terms of size and run time .If geometry and boundary conditions are, or can be approximated as being ,identical across one, two or three axes simplify the model. There are following types of symmetry:

1. **Planer or Reflective symmetry :** This is the most common type of symmetry found in finite element models. Reflective symmetry is a condition where the same pattern is seen to be mirrored in a plane. It is important to apply a symmetric constraint to all new edges and surfaces that are created due to taking advantage of the symmetry property. In this case, the vertical constraint is to prevent any horizontal move- ment, while the horizontal constraint would be to prevent any vertical movement.

2. **Axis symmetry or Rotational symmetry :** If a shape can be defined by rotating a cross-section about a line then it is said to be axis- symmetric. If the loads and boundary conditions are also axis-symmetric in nature, then an axis-symmetric analysis may be carried out.

3. **Cyclic symmetry :** Cyclic symmetry is the geometric repetition in the form of cyclic sectors. The structure is composed of a series of identical sectors that are arranged circumferentially to form a ring.

It can use the inherent geometric symmetry of a body to model only a portion of the body for simulation.Using symmetry provides the benefits of faster solution time and less use of system resources. The quadretic model of movable platen by using symmetry is as shown in fig

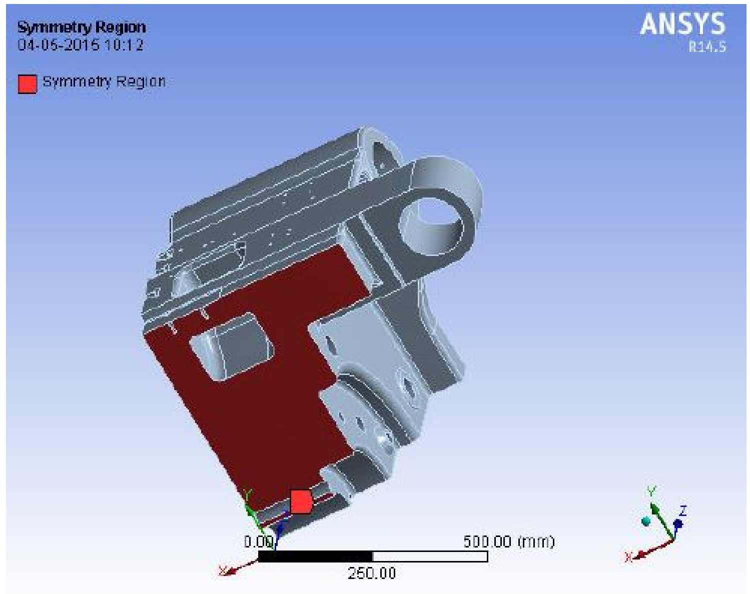

Figure 4.1: Symmetry 1

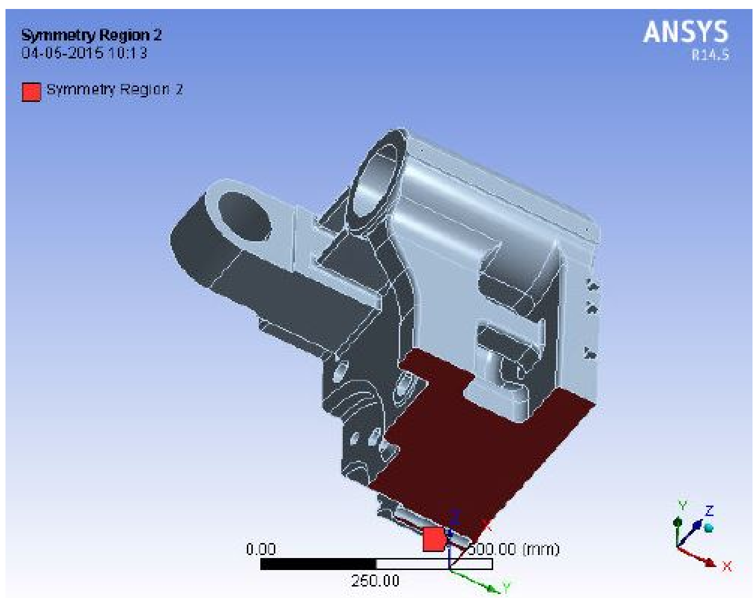

Figure 4.2: Symmetry 2

Object Name	Symmetry 1	Symmetry 2
State	Fully Defined	
Scoping Method	Named Selection	
Named Selection	ZX Plane	XY Plane
Type	Symmetric	
Coordinate System	Global Coordinate system	
Symmetry Normal	Y Axis	Z Axis

Table 4.2: Symmetry

4.3 Mesh Generation

In order to carry out a finite element analysis, the model we are using must be divided into a number of small pieces known as finite elements. Since the model is divided into a number of discrete parts, FEA can be described as a discritization technique. In simple terms, a mathematical net or "mesh" is required to carry out a finite element analysis. The yield strength or yield point of a material is defined in engineering and materials science as the stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed, some fraction of the deformation will be permanent and non-reversible.

The art of using FEM lies in choosing the correct mesh density required to solve a problem. If the mesh is too coarse, then the element will not allow a correct solution to be obtained. Alternatively, if the mesh is too fine, the cost of analysis in computing time can be out of proportion to the results obtained. In order to define a relevant mesh, some idea of the parameter distributions (stress, temperature, pressure, etc.) within the component is required.

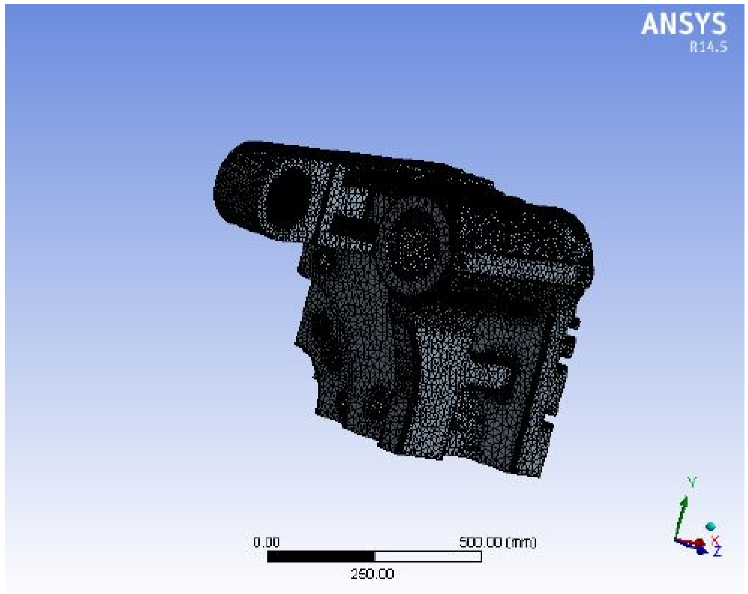

Figure 4.3: Mesh Generation

Object Name	Mesh
Physical Preference	Mechanical
Relevance	0
Relevance centre	Fine
Element Size	10 mm
Shape Checking	Standard Mechanical
Straight Sided Elements	No
Initial Size Seed	Active Assembly
Smoothing	High
Nodes	542999
Elements	328813

Table 4.3: Mesh Data

4.4 Boundary Conditions

4.4.1 Displacement

In Global coordinate system x direction is axis of sliding of platen. So, platen should not move in y and z direction. The movable platen is fixed with tie-bars, so select 1 vertex which is fixed in x direction and free in y and z direction as shown in fig. 4.4

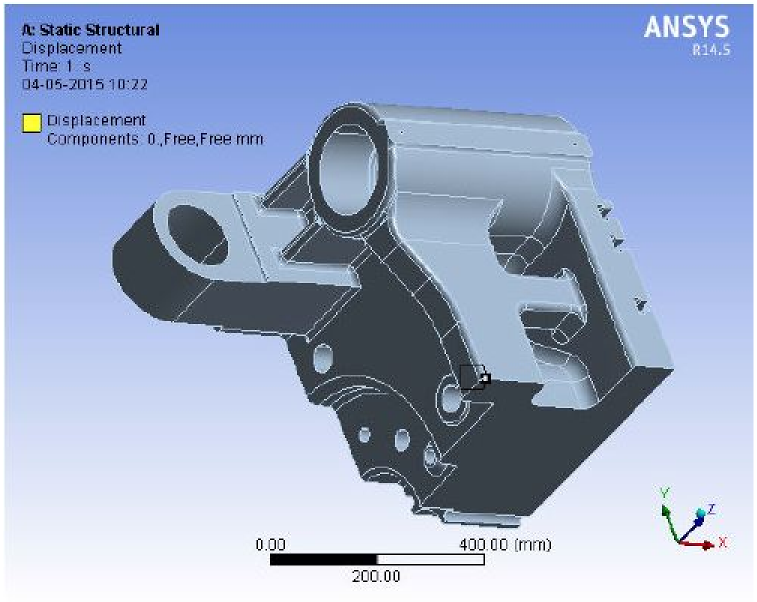

Figure 4.4: Displacement

Object Name	Displacement
State	Fully Defined
Scoping Method	Geometry Selection
Geometry	1 Vertex
Defined by	Components
Type	Displacement
Coordinate System	Global Coordinate System
x Component	0
y Component	Free
z Component	Free

Table 4.4: Displacement Data

4.4.2 Force Applied at Mold Side

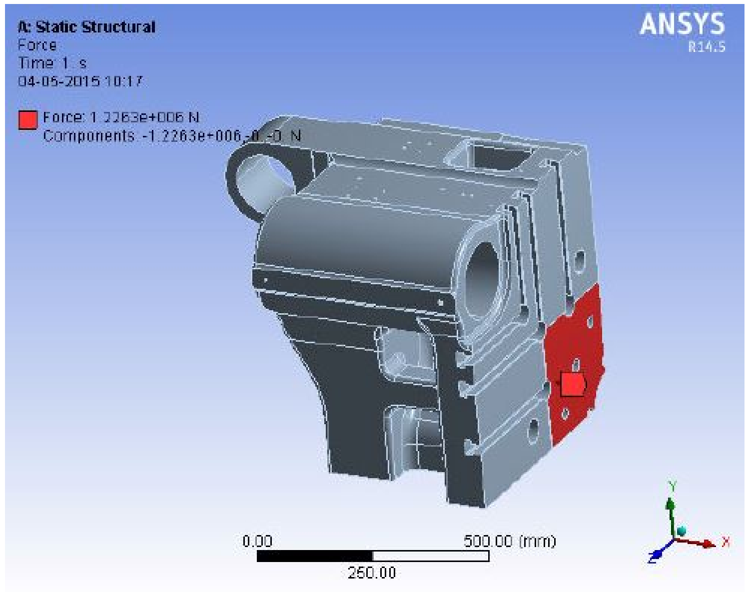

Figure 4.5: Injection Force

Object Name	Force
State	Fully Defined
Scoping Method	Geometry Selection
Geometry	1 Face
Defined by	Components
Type	Force
Coordinate System	Global Coordinate System
x Component	-1.222e+006 N (ramped)
y Component	0
z Component	0

Table 4.5: Injection Force Data

4.4.3 Clamping Force

Bearing Load is given to movable platen to apply clamping force, which is also known as tonnage force. The Bearing Load has been given at some angle because the toggle linkages attached with movable platen are not in the straight horizontal position, they are inclined at some angle. The angled force will not allow the mold to open in overloading condition. The Bearing Load applied is as shown in Fig. 4.6

Tonage Force = 500 T

Bearing Load Applied on Clamp Side in Newton = 500*1000*9.81

= 4905000 N

Bearing Load Applied on movable platen for quadratic model = 1226250 N

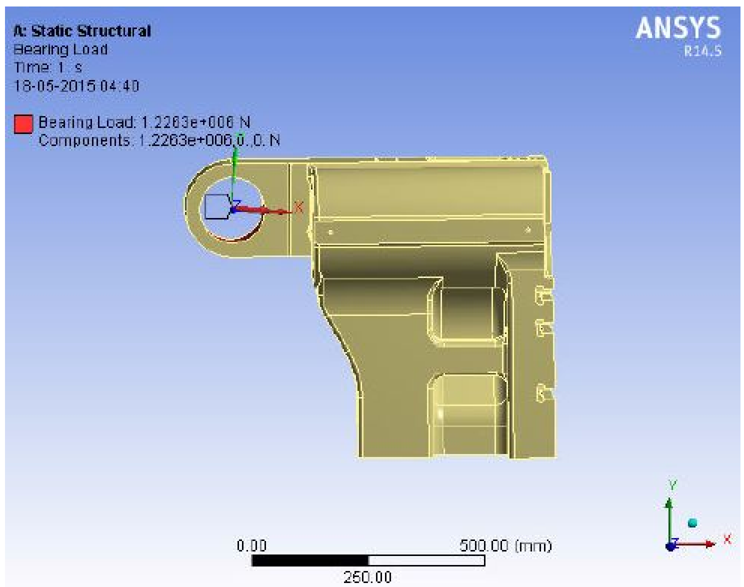

Figure 4.6: Bearing Load

Object Name	Bearing Load
State	Fully Defined
Scoping Method	Geometry Selection
Geometry	2 Faces
Defined by	Components
Type	Bearing Load
Coordinate System	Coordinate System
x Component	1.2263e+006 N
y Component	0
z Component	0

Table 4.6: Bearing Load Data

4.5 Result Analysis of Existing Movable Platen

4.5.1 Minimum Mold Case

- **Total Deformation :** Deformation in continuum mechanics is the transformation of a body from a reference configuration to a current configuration. A configuration is a set containing the positions of all particles of the body. Contrary to the common definition of deformation, which implies distortion or change in shape, the continuum mechanics definition includes rigid body motions where shape changes do not take place. Fig 4.7 shows total deformation which is 0.38418 mm occurring at clamp hole surface which is negligible.

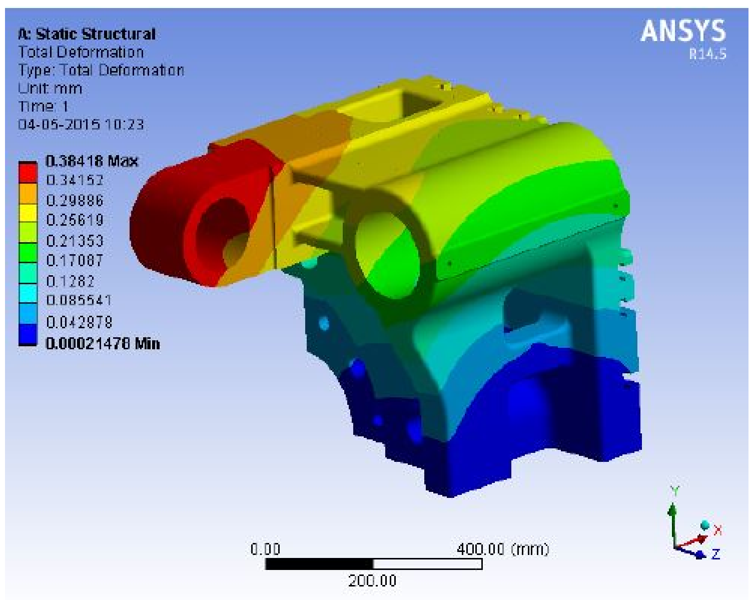

Figure 4.7: Total Deformation For Existing Minimum Mold Case

- **Maximum Principal Stress :** The yield strength or yield point of a material is defined in engineering and materials science as the stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed, some fraction of the deformation will be permanent and non-reversible. Fig 4.8 shows maximum principal stress for minimum mold case is 126.68 MPa. which is within permissible limit.

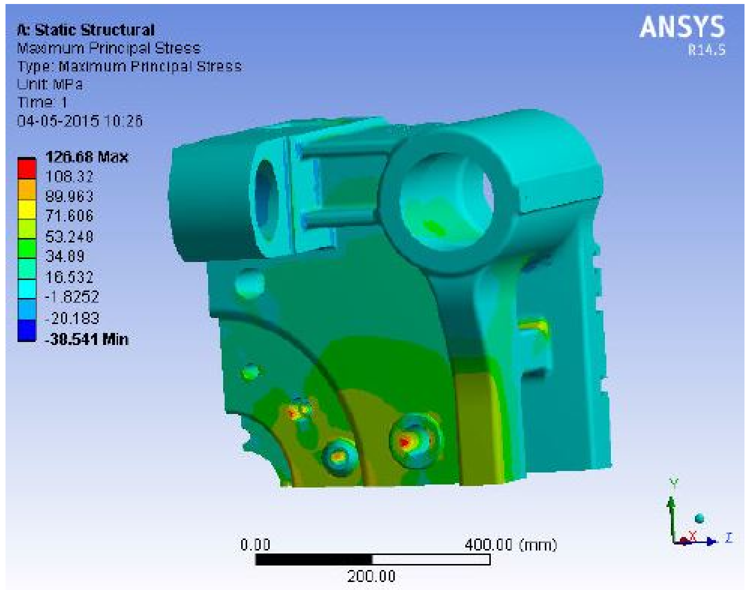

Figure 4.8: Maximum Principal Stress For Existing Minimum Mold Case

4.5.2 Long Horizontal Mold Case

- **Total Deformation :**

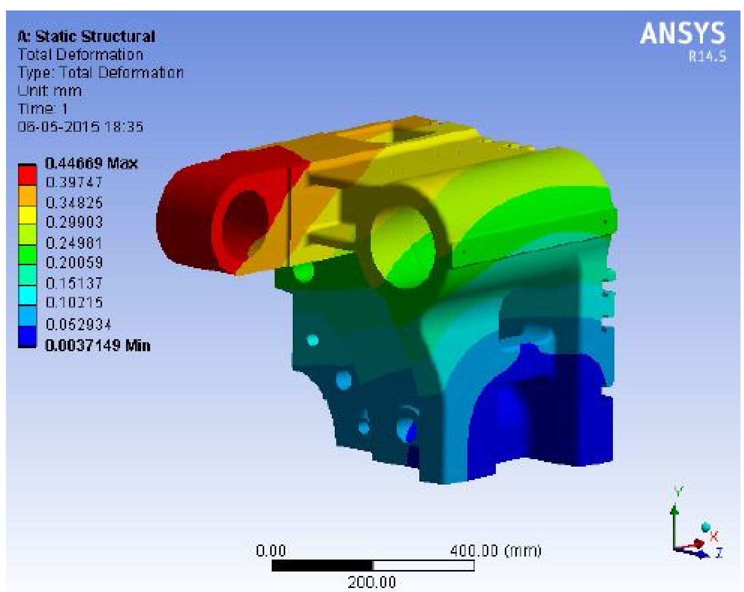

Figure 4.9: Total Deformation For Existing Long Horizontal Mold Case

- **Maximum Principal Stress:**

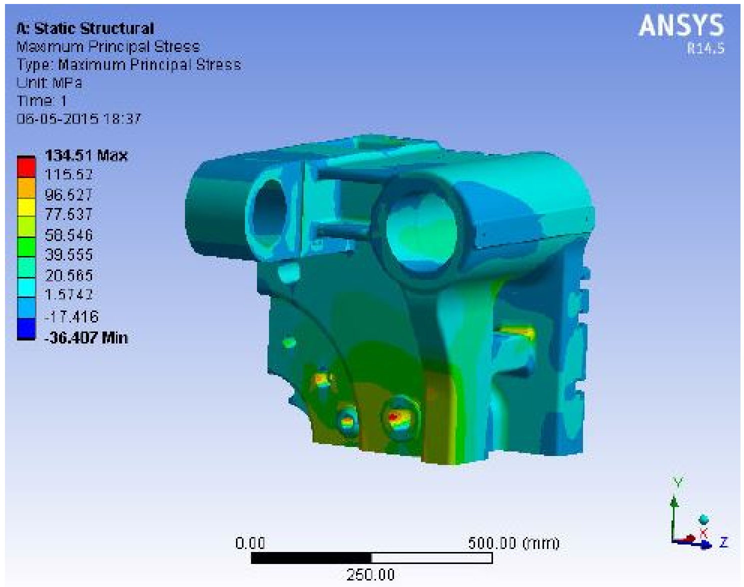

Figure 4.10: Maximum Principal Stress For Existing Long Horizontal Mold Case

4.5.3 Long Vertical Mold Case

- **Total Deformation :**

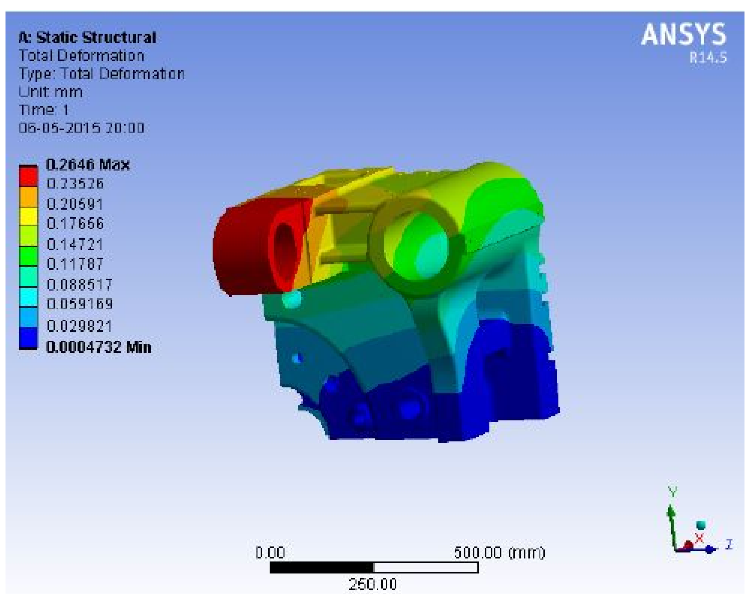

Figure 4.11: Total Deformation For Existing Long Verical Mold Case

- **Maximum Principal Stress :**

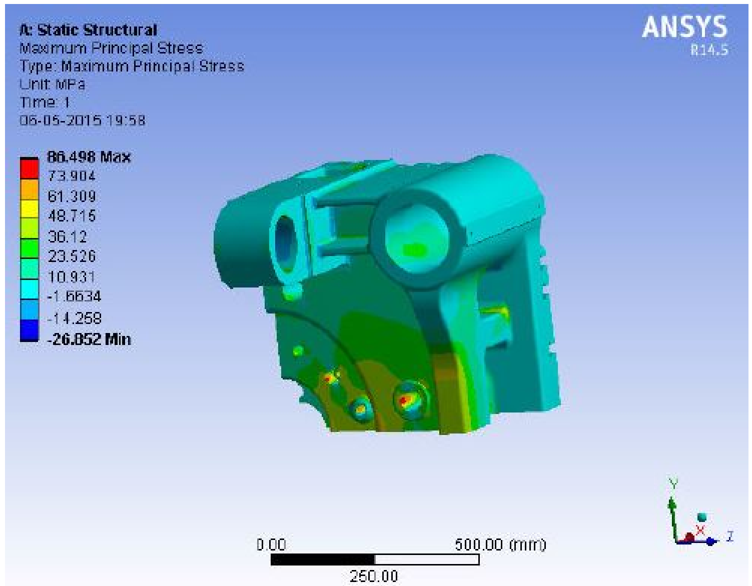

Figure 4.12: Maximum Principal Stress For Existing Long Vertical Mold Case

4.6 Result Analysis of Redesigned Movable Platen

The movable platen of injection molding machine has been redesigned by changing the tie-bar distance. Redesigned model has been analyzed in Ansys workbench 14.5 for stress and deformation values. The results get from analysis are as below:

4.6.1 Minimum Mold Case

- **Total Deformation :** As shown in fig. 4.13 deformation for the square mold case, which is mimimum mold possible to attach with movable platen, is 0.43504 at clamp hole surface.

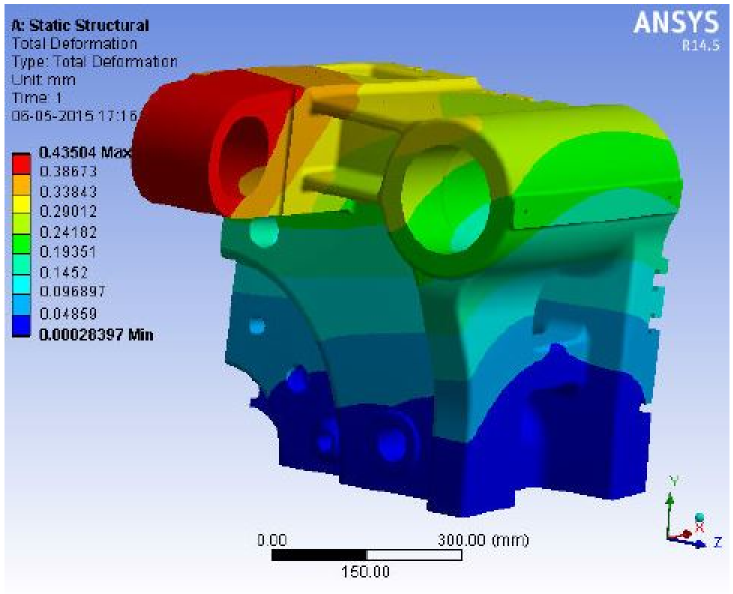

Figure 4.13: Total Deformation For Redesigned Minimum Mold Case

- **Maximum Principal Stress :** The stress value obtained for redesigned model is 124.78MPa as shown in Fig. 4.14 which is acceptable.

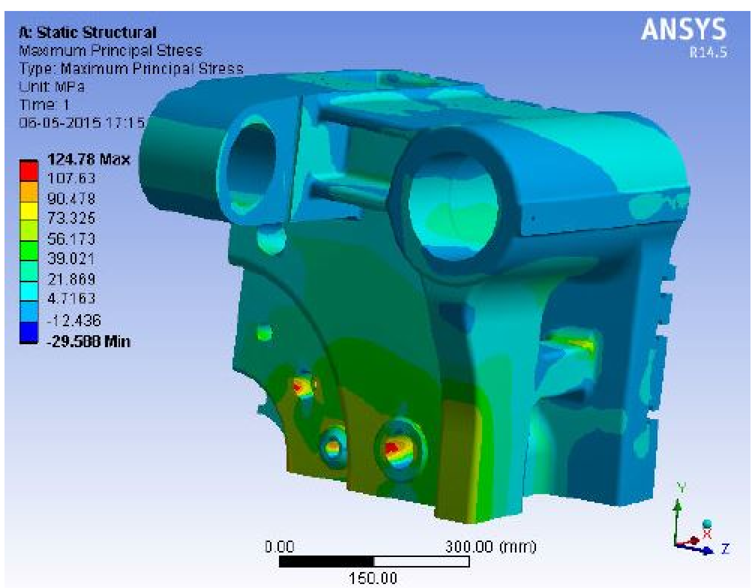

Figure 4.14: Maximum Principal Stress For Redesigned Minimum Mold Case

4.6.2 Long Horizontal Mold Case

- **Total Deformation**

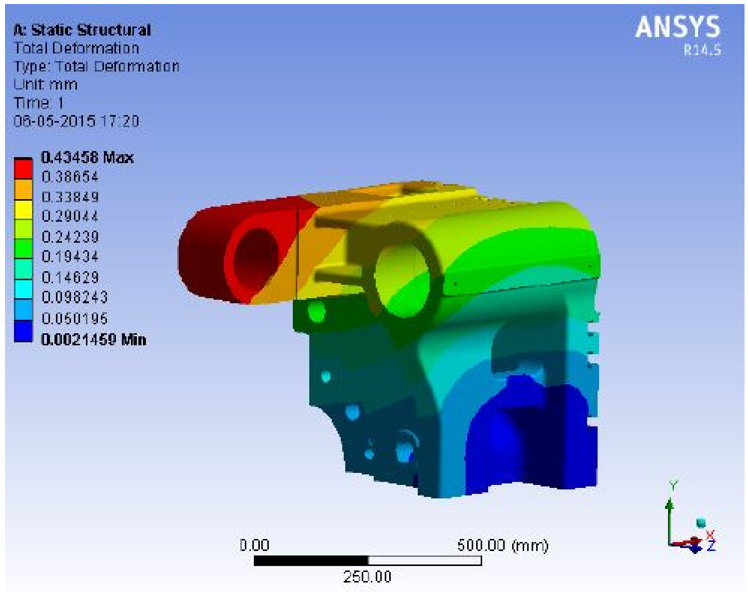

Figure 4.15: Total Deformation For Redesigned Long Horizontal Mold Case

- **Maximum Principal Stress**

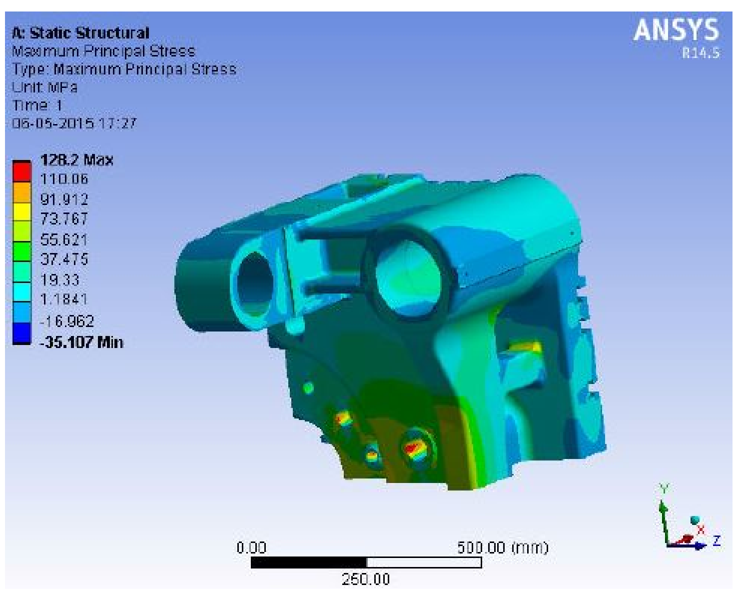

Figure 4.16: Maximum Principal Stress For Long Horizontal Mold Case

4.6.3 Long Vertical Mold Case

- **Total Deformation**

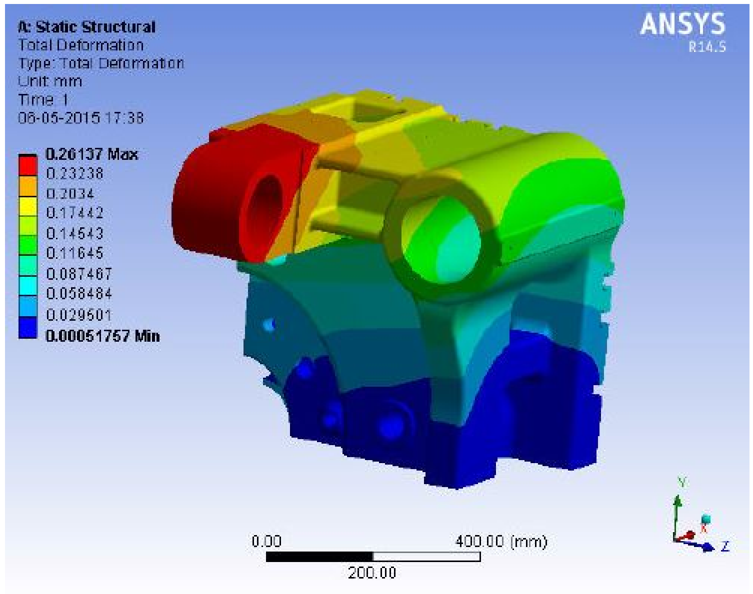

Figure 4.17: Total Deformation For Redesigned Long Vertical Mold Case

- **Maximum Principal Stress**

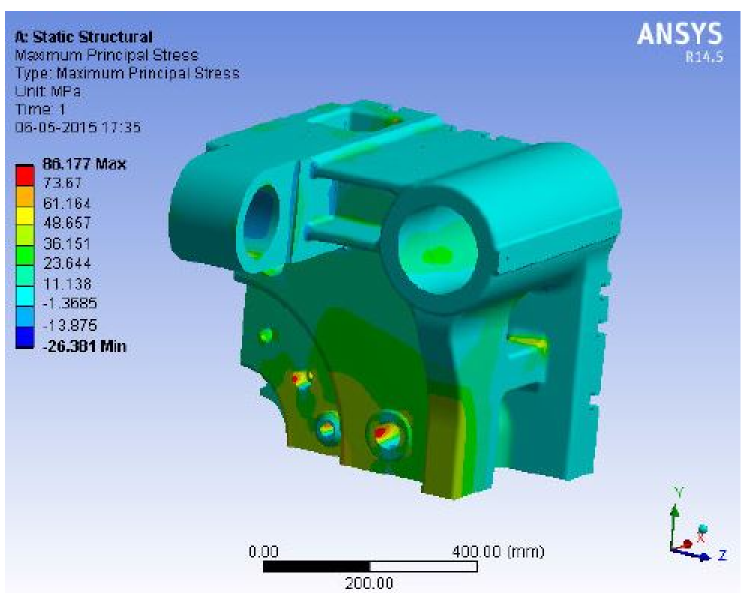

Figure 4.18: Maximum Principal Stress For Redesigned Long Vertical Mold Case

4.7 Comparison of Results

	Existing Movable Platen			Redesigned Movable Platen		
	Minimum Mold	Long Horizontal Mold	Long Vertical Mold	Minimum Mold	Long Horizontal Mold	Long Vertical Mold
Total Deformation (mm)	0.38418	0.44669	0.2646	0.43504	0.43458	0.26137
Maximum Principal Stress (MPa)	126.68	134.01	86.498	124.78	128.2	86.177

Table 4.7: Comparison of Stress and Deformation Values

- Maximum Principal Stress of the redesigned model of movable platen is below the permissible limit for all the three cases, which means design is safe for failure.

Chapter 5

Design Optimization

5.1 Approach for Optimization

In engineering design, there is an improvement of praposed design that results in the best properties for minimum cost known as optimization. The first task is to develop a preliminary design. After that variations in some dimensions of the design can be evaluated. The degrees of freedom, known as variables, will be permitted to be changed. But at the same time, it is required not to exceed certain boundary values. When the degrees of freedom have been set for the best possible properties, the design is said to have been optimized.

5.2 Existing Model and Properties

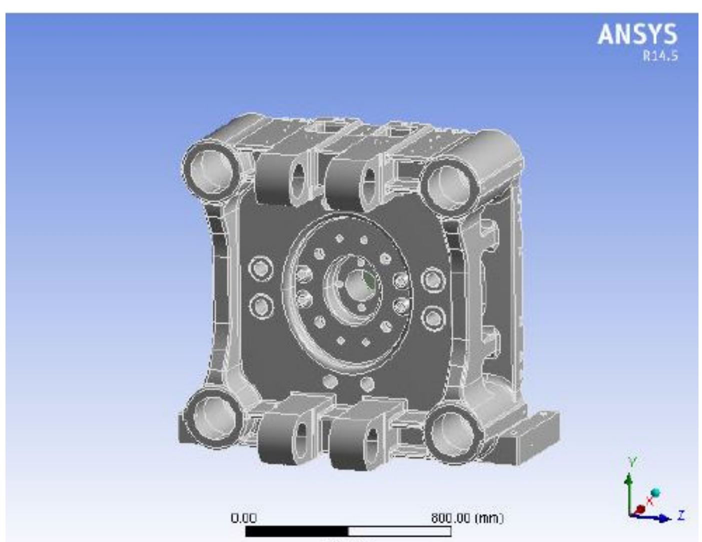

Figure 5.1: Movable Platen

Quarter Model of Movable Platen

The symmetry tool has been used for simplifying model in terms of size and run time. It provides the benefits of faster solution time and less use of system resources. It makes the quarter model of movable platen as shown in fig. 5.2

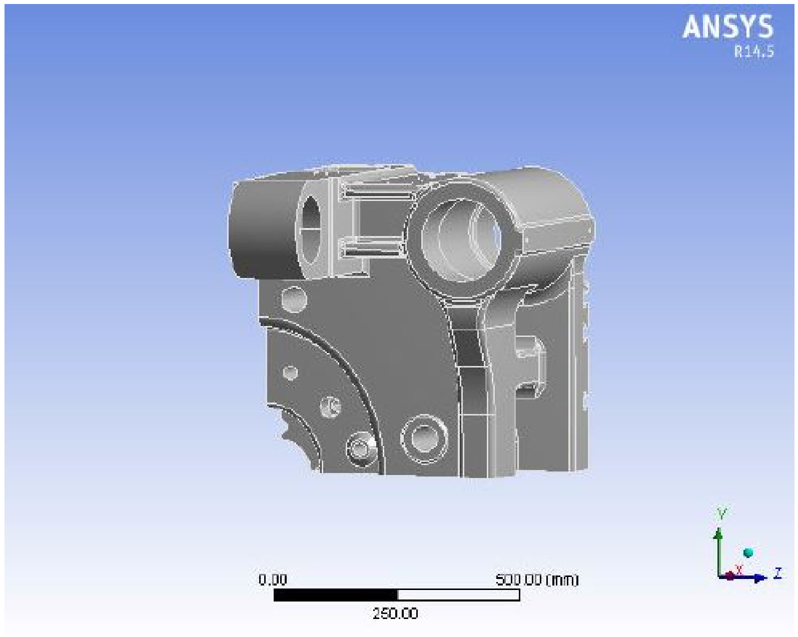

Figure 5.2: Quarter Model of Movable Platen

5.3 Design Modification for Optimization

Design has been modified to optimize the weight of movable plate. Different iterations are tried by varying the size of pocket, which ultimately reduce the mass of movable platen. The iterations taken into consideration are as shown below:

5.3.1 Iteration 1

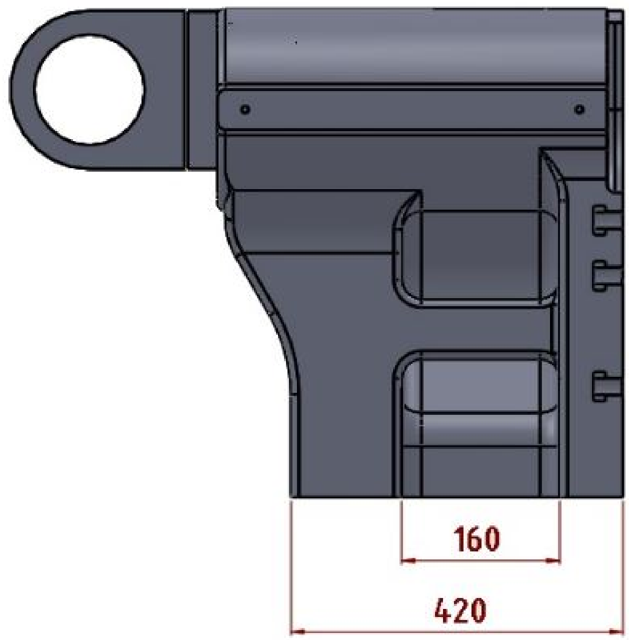

Figure 5.3: Iteration 1

Properties for quarter model of movable platen are as below:

- Volume : $1.138e^{+008}mm^3$
- Density : $7.05e^{-006}Kg/mm^3$
- Mass : 802.3 Kg

5.3.2 Iteration 2

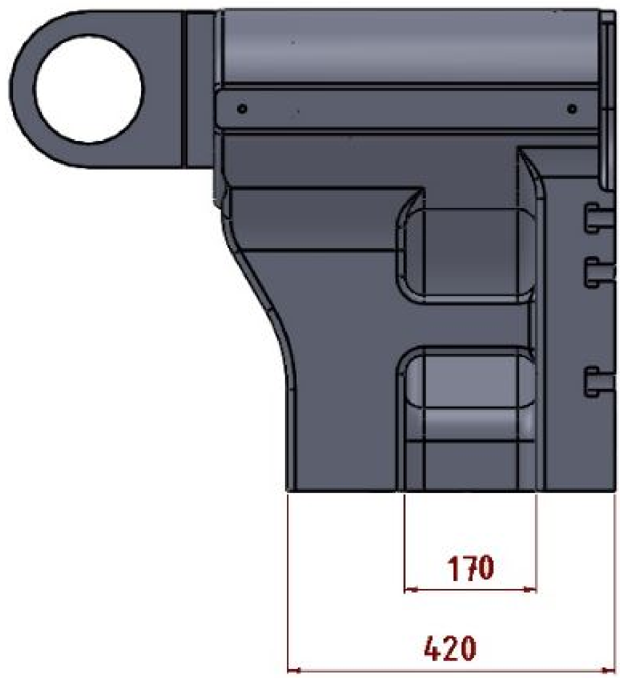

Figure 5.4: Iteration 2

Properties for quarter model of movable platen are as below:

- Volume : $1.1335e^{+008}mm^3$
- Density : $7.05e^{-006}Kg/mm^3$
- Mass : 799.12 Kg

5.3.3 Iteration 3

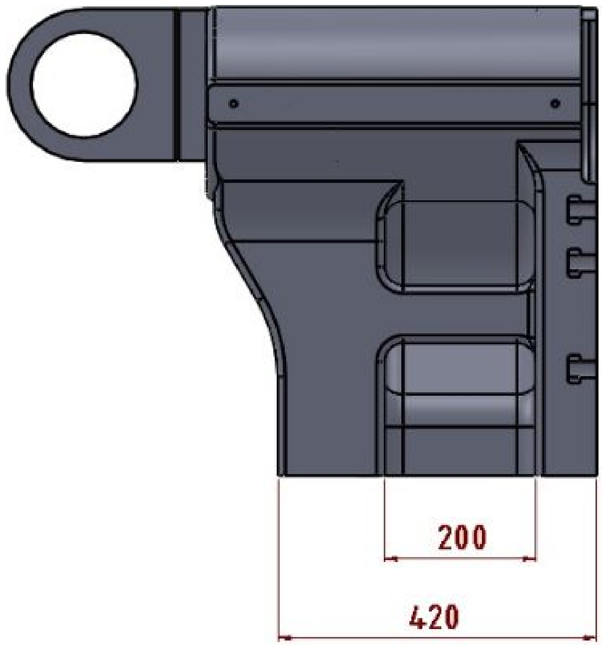

Figure 5.5: Iteration 3

Properties for quarter model of movable platen are as below:

- Volume : $1.1144e^{+008}mm^3$
- Density : $7.05e^{-006}Kg/mm^3$
- Mass : 785.66 Kg

5.4 Finite Element Analysis of Optimized Platen

5.4.1 Results of Iteration 1

- **Maximum Principal Stress for Minimum Mold Case**

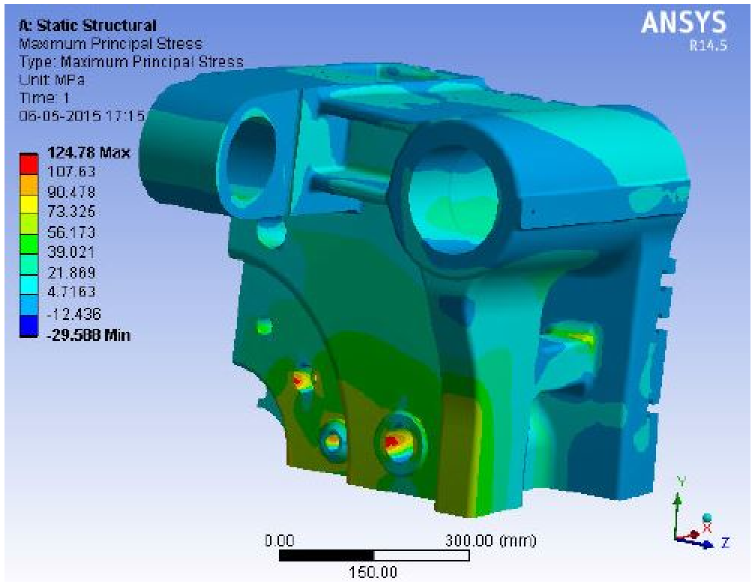

Figure 5.6: Maximum Principal Stress for Minimum Mold Case (Iteration 1)

- **Total Deformation for Minimum Mold Case**

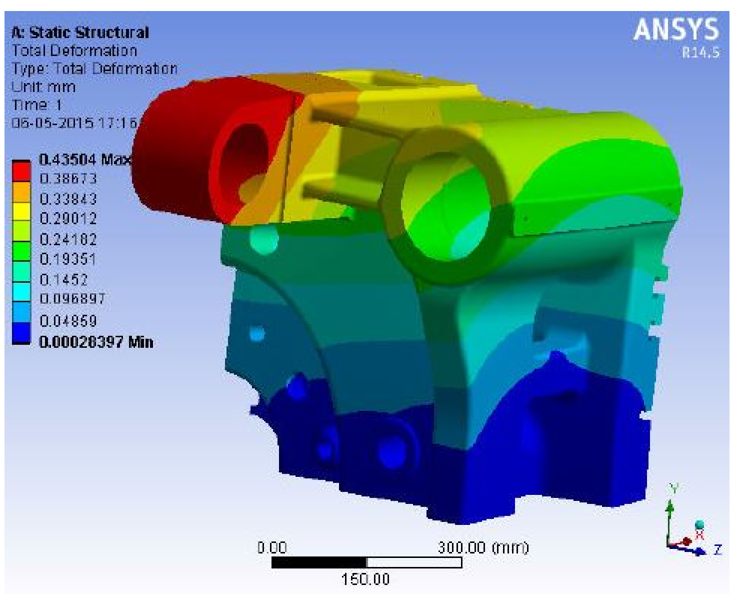

Figure 5.7: Total Deformation for Minimum Mold Case (Iteration 1)

- **Maximum Principal Stress for Long Horizontal Mold Case**

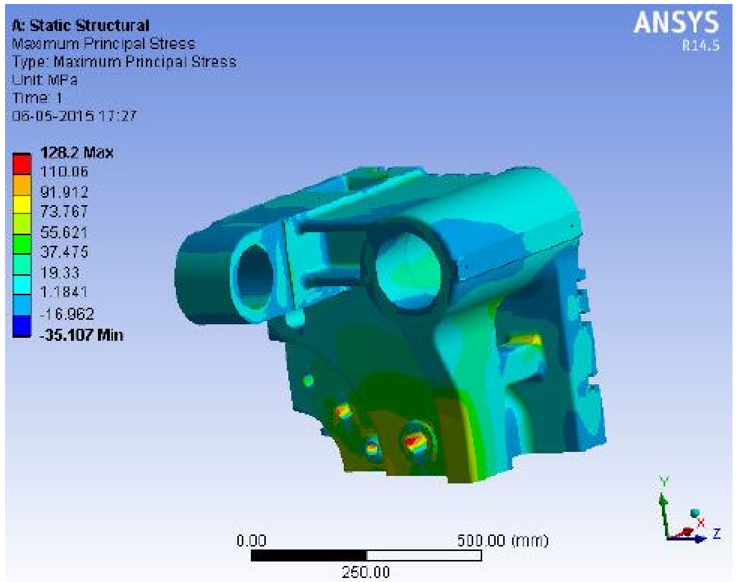

Figure 5.8: Maximum Principal Stress for Long Horizontal Mold Case (Iteration 1)

- **Total Deformation for Long Horizontal Mold Case**

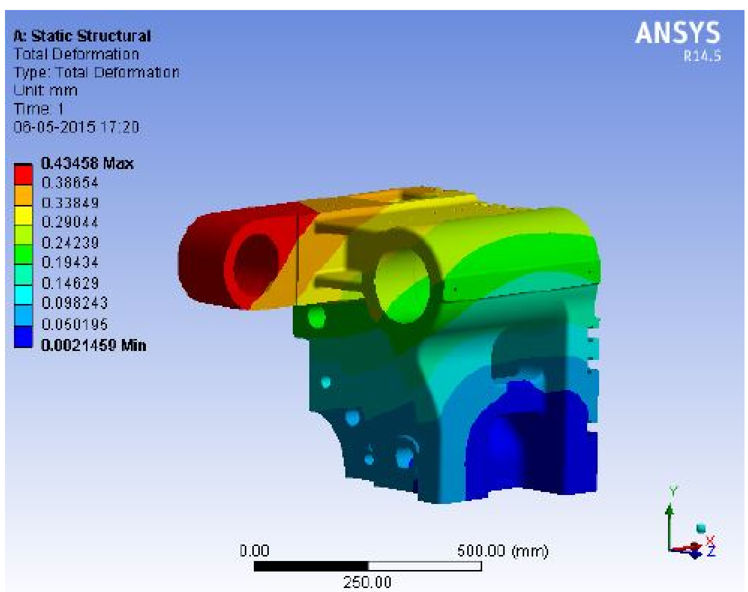

Figure 5.9: Total Deformation for Long Horizontal Mold Case (Iteration 1)

- **Maximum Principal Stress for Long Vertical Mold Case**

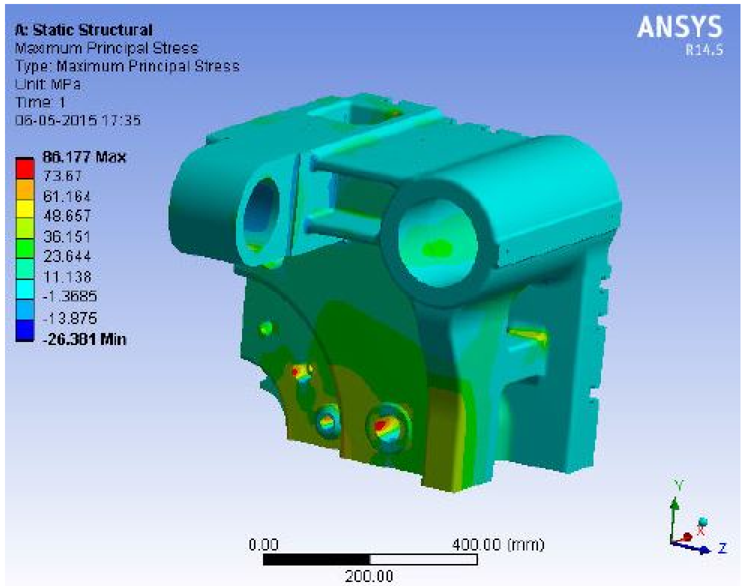

Figure 5.10: Maximum Principal Stress for Long Vertical Mold Case (Iteration 1)

- **Total Deformation for Long Vertical Mold Case**

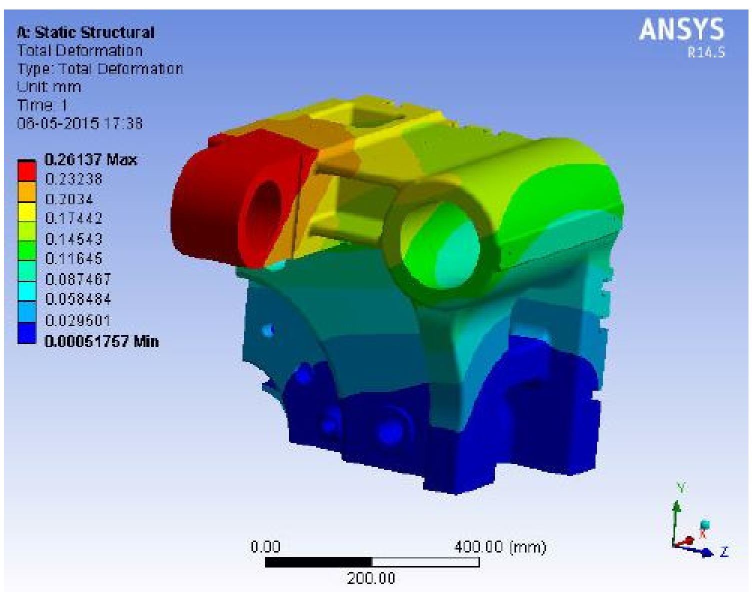

Figure 5.11: Total Deformation for Long Vertical Mold Case (Iteration 1)

5.4.2 Results of Iteration 2

- **Maximum Principal Stress for Minimum Mold Case**

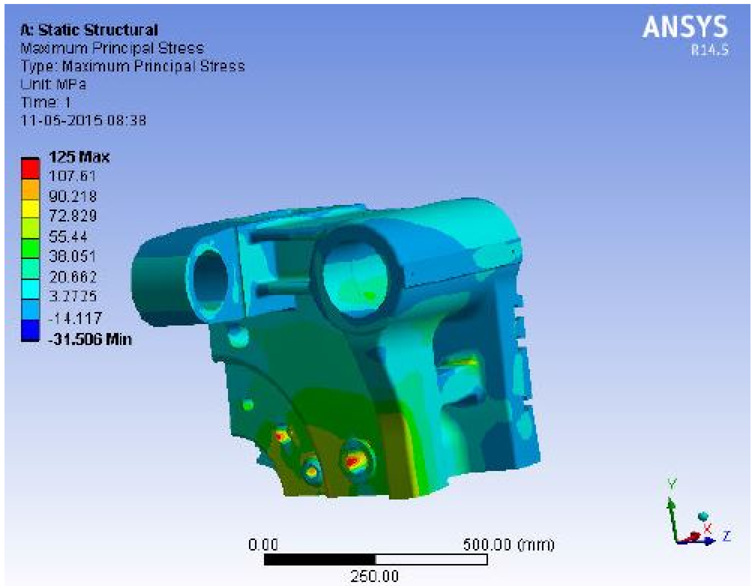

Figure 5.12: Maximum Principal Stress for Minimum Mold Case (Iteration 2)

- **Total Deformation for Minimum Mold Case**

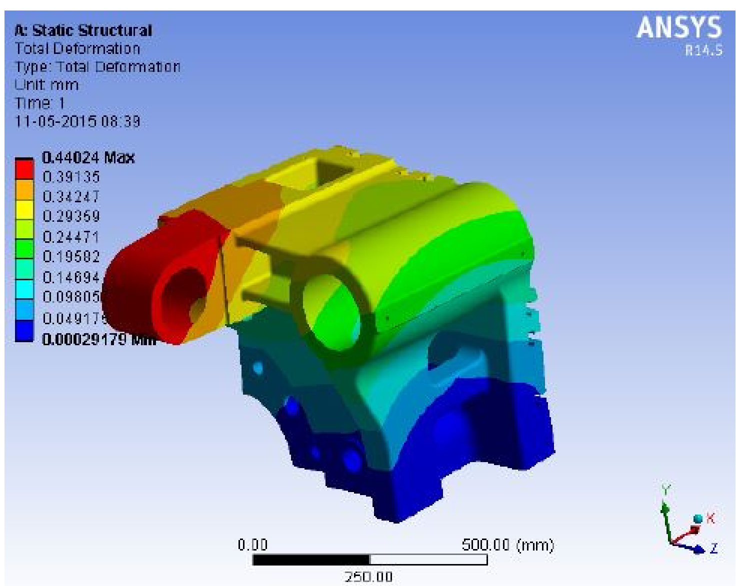

Figure 5.13: Total Deformation for Minimum Mold Case (Iteration 2)

- **Maximum Principal Stress for Long Horizontal Mold Case**

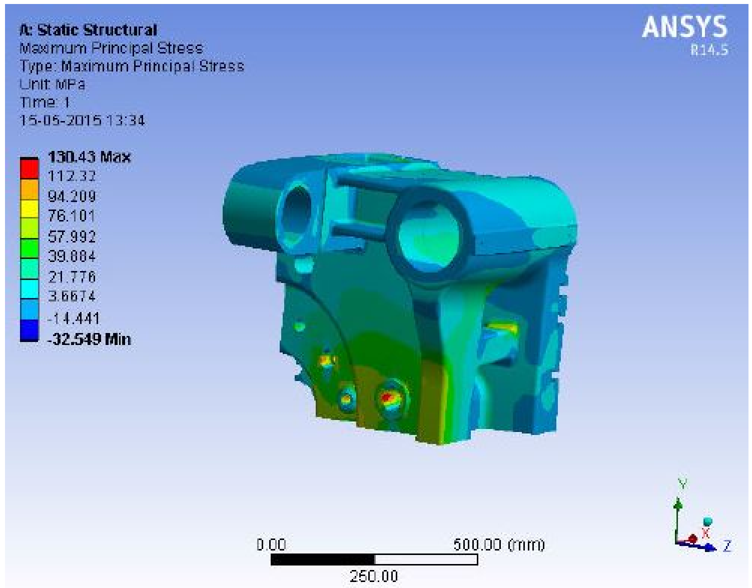

Figure 5.14: Maximum Principal Stress for Long Horizontal Mold Case (Iteration 2)

- **Total Deformation**

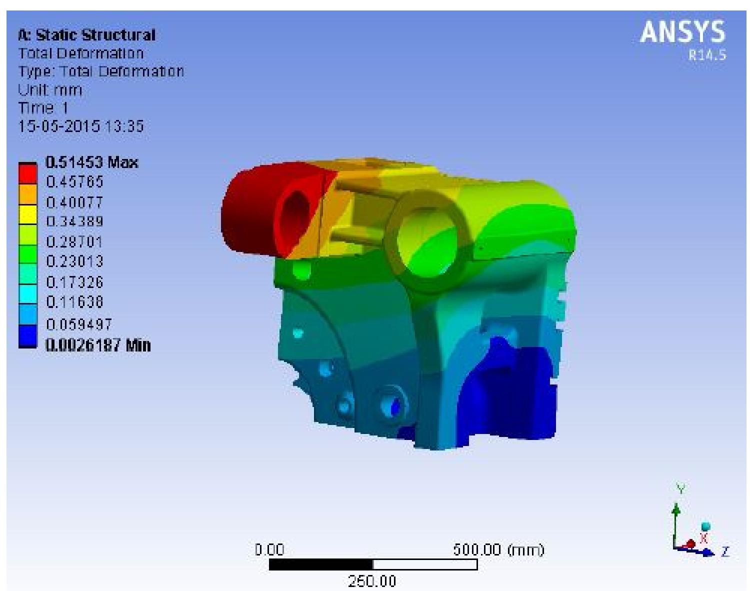

Figure 5.15: Total Deformation for Long Horizontal Mold Case (Iteration 2)

- **Maximum Principal Stress for Long Vertical Mold Case**

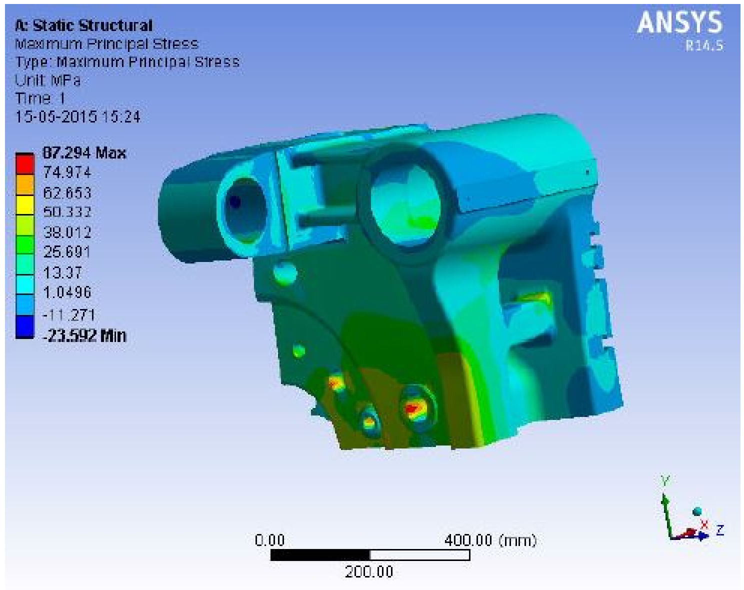

Figure 5.16: Maximum Principal Stress for Long Vertical Mold Case (Iteration 2)

- **Total Deformation for Long Vertical Mold Case**

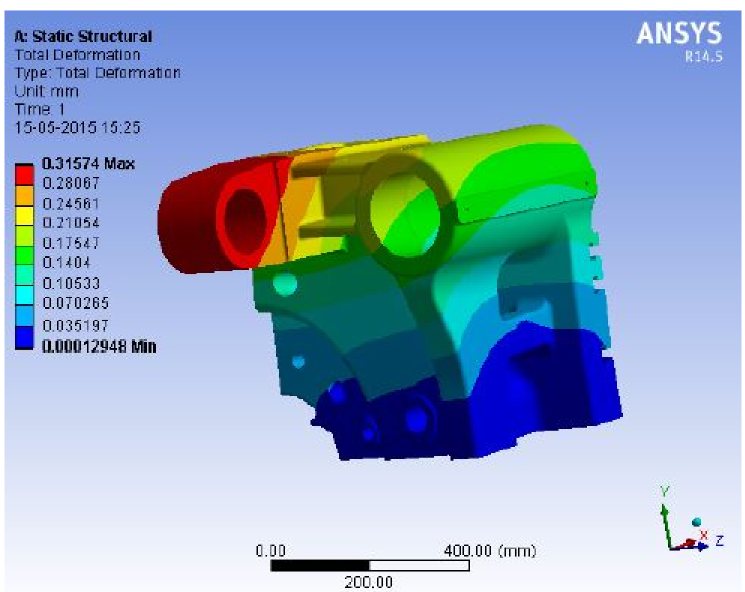

Figure 5.17: Total Deformation for Long Vertical Mold Case (Iteration 2)

5.4.3 Results of Iteration 3

- **Maximum Principal Stress for Minimum Mold Case**

The stress generated for Minimum Mold Case is 128.35 as shown in Fig. 5.18, which is below the permissible limit. So the design of movable platen is in safe side.

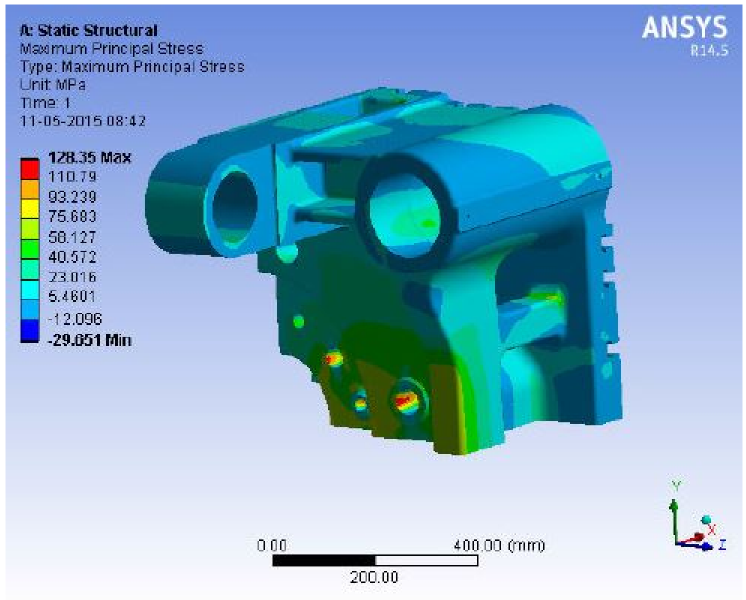

Figure 5.18: Maximum Principal Stress for Minimum Mold Case (Iteration 3)

- **Total Deformation for Minimum Mold Case**

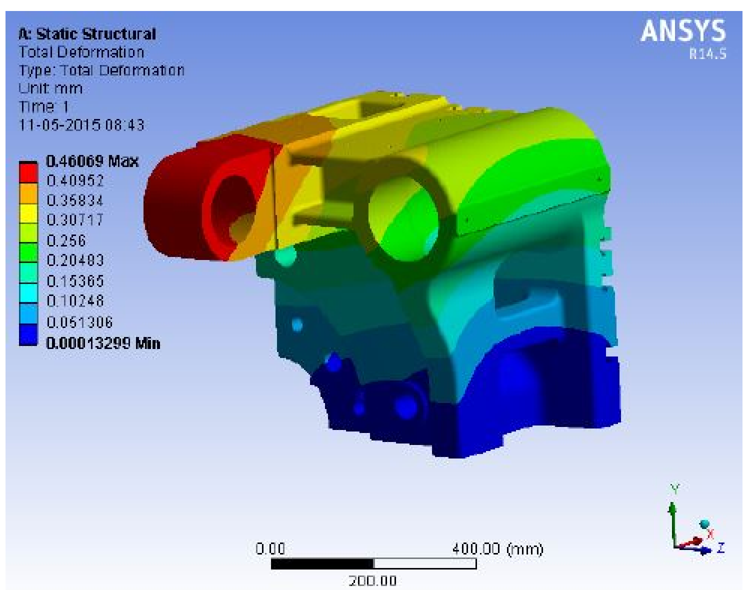

Figure 5.19: Total Deformation for Minimum Mold Case (Iteration 3)

- **Maximum Principal Stress for Long Horizontal Mold Case**

Maximum Principal Stress for Long Horizontal Mold Case is 135.94 as shown in Fig. 5.20, which is not below permissible limit. The optimized model is not safe for failure for the maximum horizontal mold case.

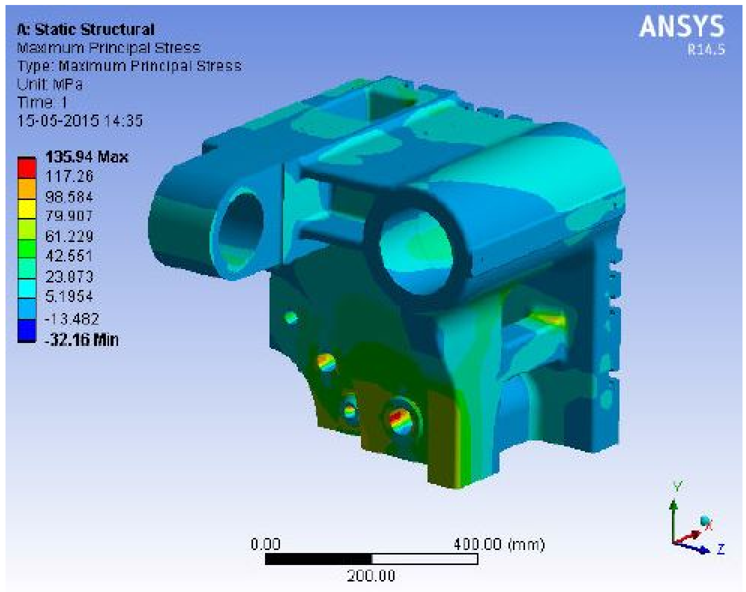

Figure 5.20: Maximum Principal Stress for Long Horizontal Mold Case (Iteration 3)

- **Total Deformation for Minimum Mold Case**

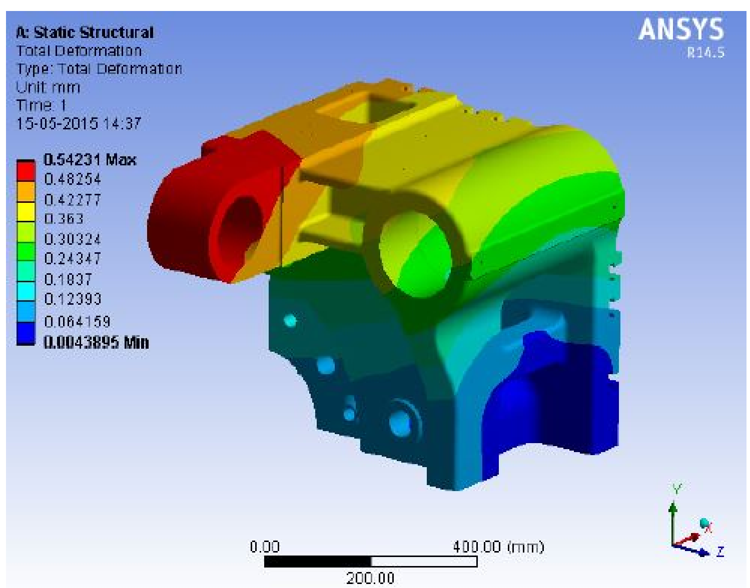

Figure 5.21: Total Deformation for Long Horizontal Mold Case (Iteration 3)

- **Maximum Principal Stress for Long Vertical Mold Case**

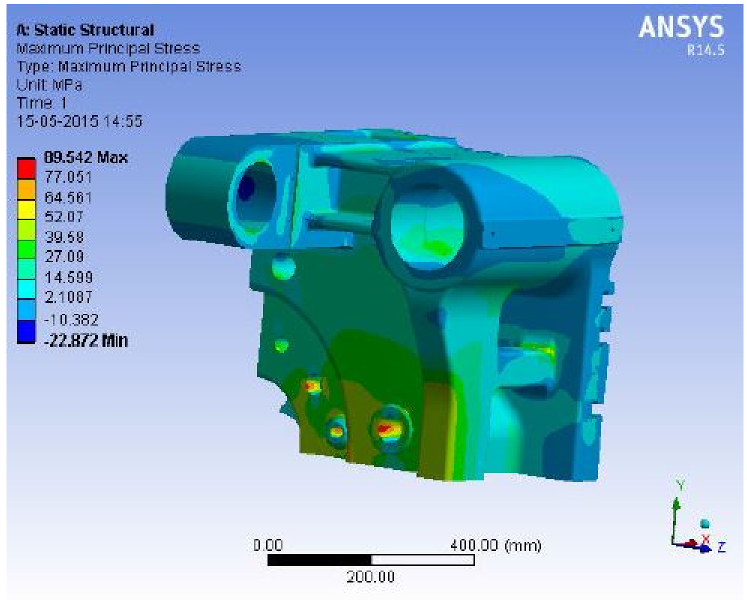

Figure 5.22: Maximum Principal Stress for Long Vertical Mold Case (Iteration 3)

- **Total Deformation for Long Vertical Mold Case**

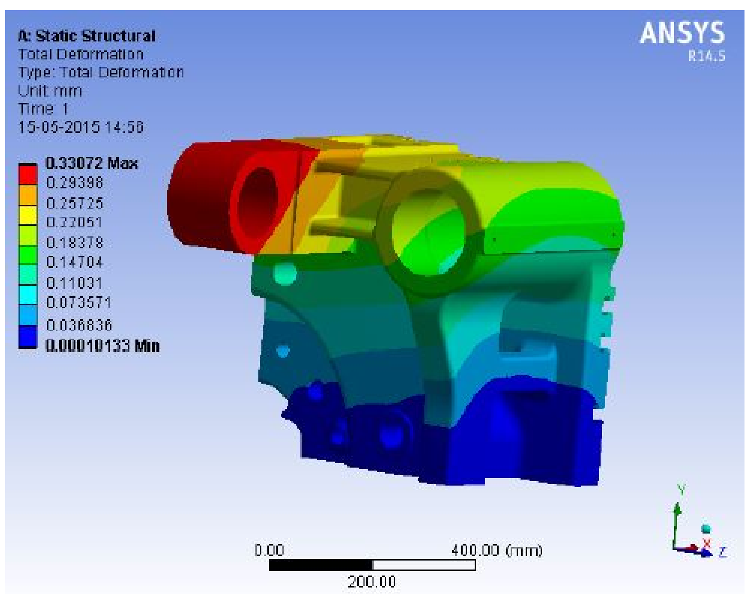

Figure 5.23: Total Deformation for Long Vertical Mold Case (Iteration 3)

5.5 Comparison of Results

	Redesigned Model			Optimized Model		
	Minimum Mold	Long Horizontal Mold	Long Vertical Mold	Minimum Mold	Long Horizontal Mold	Long Vertical Mold
Maximum Principal Stress (MPa)	124.78	128.2	86.177	125	130.43	87.294
Total Deformation (mm)	0.43504	0.43458	0.26137	0.44024	0.51453	0.31574
Mass (Kg)	802.30			799.12		

Table 5.1: Comparison of Results with optimized model

- Maximum Principal Stress of optimized model of movable platen for all the three cases is within permissible limit which is 130.82MPa. Mass has been reduced up to 3.18 Kg for quarter model of movable platen. So, total mass reduced for optimized model of movable platen is 12.72 Kg.

Chapter 6

Conclusion and Future works

6.1 Conclusion

- The modeling of moving platen of toggle type injection molding machine has been carried out by using Creo Parametric 2.0.
- The Finite Element Analysis of the existing moving platen for three different mold cases has been carried out with help of Ansys Workbench 14.5
- Redesigning of movable platen has done by changing the tie-bar distance.
- Finite Element Analyis has been done for redesigned model and compare the results with existing platen.
- The material has been removed from the suitable area of movable platen. Finite Element Analysis has been carried out for optimized model, the stress values have been found within the permissible value and design is safe for failure.

6.2 Future Work

- The optimization of redesigned model can be carried out more scientifically by using one of the existing methods of optimization.

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