STRESS ANALYSIS AND OPTIMIZATION OF ROLLING MILL HOUSING USING CAE

A Thesis report submitted
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Submitted By
PUNEET KATYAL
Roll No. 8028110

Under the supervision of

Sh. S.K.GUPTA
Professor, MED.
JMIT, RADAUR

Sh. J.S.SAINI
Lecturer, MED.
T. I. E. T. Patiala

MECHANICAL ENGINEERING DEPARTMENT
THAPAR INSTITUTE OF ENGINEERING AND TECHNOLOGY
(Deemed University)
PATIALA-147004, (INDIA)

CERTIFICATE

This is to certify that the Thesis entitled "**STRESS ANALYSIS AND OPTIMIZATION OF ROLLING MILL HOUSING USING CAE"** being submitted by **Mr. PUNEET KATYAL** in partial fulfillment of the requirements for the award of the degree of **MASTER OF ENGINEERING in CAD/CAM & ROBOTICS of THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY (Deemed University), Patiala (India),** is a bonafide work carried out by him under my guidance and supervision.

Sh. S.K.GUPTA
Ex Design Engg.
SAIL & Visiting Professor
JMIT, RADAUR

Sh. J.S.SAINI
Lecturer, MED.
T. I. E. T. Patiala

(Dr. N. K. NAYAR)
Professor& Head, MED
T.I.E.T. Patiala-147004

(Dr. D. S. BAWA)
Dean Academic Affairs
T.I.E.T. Patiala-147004

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PUNEET KATYAL

ABSTACT

Rolling is defined as a process in which metal is formed through a pair of revolving rolls with plain or grooved barrels. The metal changes its shape gradually during the period in which it is in contact with the two rolls. Rolling is a major and a most widely used mechanical working technique. A Rolling mill is a complex machine for deforming metal in rotary rolls and performing auxiliary operations such as transportation of stock to rolls, disposal after rolling, cutting, cooling, melting. The problem of failure of Rolling Mill Housing was there in industry, which can be efficiently solved by using CAE.

The present work involves the optimization of Rolling Mill Housings design for rigidity, to control the deflection of the housing for better gage control of the material being rolled. The Housing stress distribution has been analyzed using analysis software CATIA from which maximum static stress at critical areas have been calculated. Structural behavior of housing under the given loading and boundary conditions using an analytical model is very difficult. Therefore 3D solid model was chosen in order to predict the stress and strain response detail.

We have made a prototype of Rolling Mill Housing of optimized design of 1:10 scale so as to verify our results that have been given by the analysis of Rolling Mill Housing on analysis software.

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CHAPTER: 1

INTRODUCTION

This thesis deals with the analysis of Rolling Mill Housing. Brief overviews of the basics related to analysis of Rolling Mill Housing are given in this chapter.

1.1 Classification of Rolling Mills

Rolling mills are generally classified according to their product or their layout or temperature and are specified by the number of rolls in each stand.

1.1.1 On The Basis of the Product

- Roughing or cogging mills: it includes mills producing semi products like blooms, slabs, billets, and tube billets.
- Section mills: it includes mills producing rails, heavy, medium and light structural sections, round and square bars and wire rods, strips.
- Plate and sheet mills including wide and medium strip mills.
- Tube mills including plants for production of both seamless and welded tubes.
- Special mills for production of machine parts like wheel tyres, balls, gears, periodic profiles

1.1.2 On The Basis of Temperature

- Hot Rolling: Rolling of metal is carried out at temperature above the recrystalization temperature. For example: Roughing, billet, merchant and tube rolling mills.
- Cold Rolling: Rolling of metal is carried out at temperature below the recrystalization temperature. For example: Sheet and tube rolling mills.

1.1.3 On The Basis of Layout of Stands in the Mills

- Linear mill: in this a number of stands are placed in one line driven through each other by a single motor. The stands may be in the same line or in two or more such lines.
- Open continuous mills: in such a mill a number of stands may be placed in tandem. However rolling is carried in single stand at a time.
- Continuous mills: in this metal is rolled simultaneously in more than one stand. This is the most modern type of mill, which gives the largest possible speed and output, and occupies the least space.

1.1.4 On The Basis of Number of Rolls

According to this the stand may be termed as two-high, four-high, twelve-high or twenty-high. Mills having six or more rolls are generally termed as cluster mills.

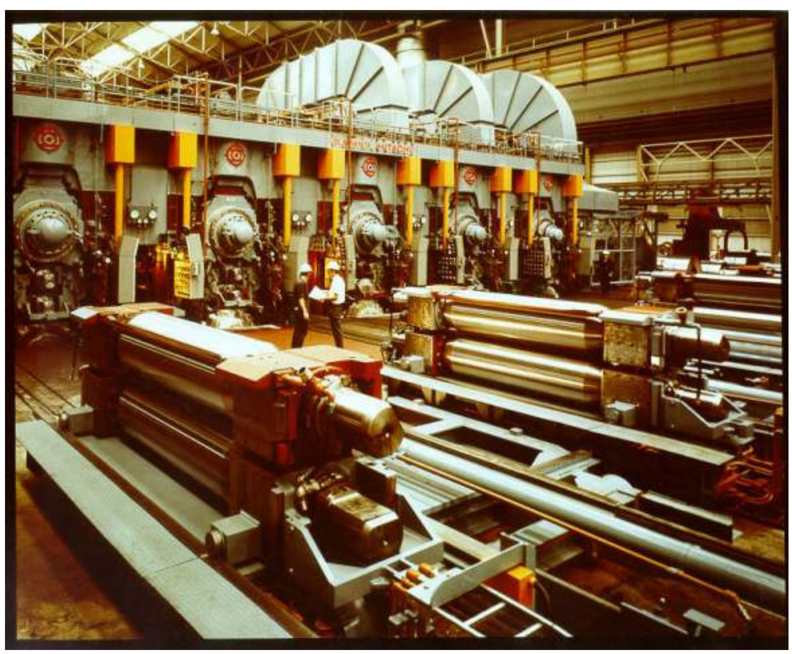

Figure 1.1 Rolling Mills

1.2 Housing of Rolling Mill

Housing for setting the rolls in correct vertical and horizontal position are important elements of the rolling stand. The housing of rolling stand requires high rigidity, sufficient strength for taking the loads, simplicity of design and minimum cost of production. Figure 1.2 shows housing of rolling mill.

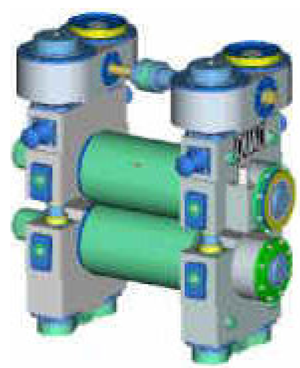

Figure 1.2 Housing of Rolling Mill

1.2.1 Types of Housings

- **Closed Type Housing**: One piece cast housings of simple form (rectangular section) are used for heavy roughing mills, e.g. blooming, slabbing, billet and plate mills. These are called 'Closed Type Housing'.

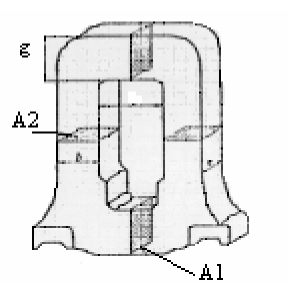

Figure 1.3 Closed-Top Roll Housing

- **Open Type Housing**: The housings which have a removable top for easy removal of rolls are called 'Open Type Housing'. When the housings have to withstand large horizontal forces, the pillars are made with an I-section. The integrally cast construction presents many difficulties in manufacturing. In such case the housing can be made up of two forged pillars bolted to two cast cross beams.

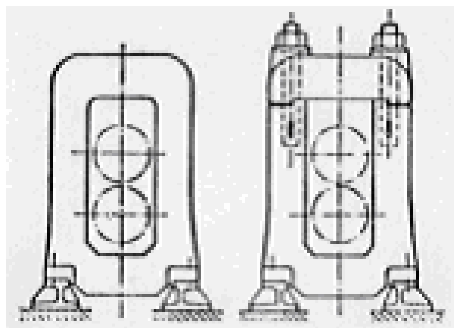

Figure 1.4 Closed-Top Roll Housing And Open-Top One.

1.2.2 Functions of Housings

Housings are elements in a rolling mill, which house the chock assemblies, the adjusting and other mechanisms, and retain them in their proper positions. Their construction and dimensions thus have to take into account the sizes of various other elements. The forces, which act on the rolls during rolling, are completely transferred on to them through the nut of the adjusting mechanism. in addition, there exists a tendency for the stand to return as a result of the torques acting on the rolls, which get transmitted to the frame in case of bearing seizures or when rolls are unable to pass the metal due to lack of sufficient power .The housings therefore should be adequately clamped to the foundation to withstand the overturning moments. The frame is also to be checked for stresses as well as rigidity.

1.3 Experimental Methods for Determination of Stress

There are a number of methods that are used for finding the value of stress in a part. Some of the methods that are most commonly used are briefly discussed below.

Strain Gauges: A strain gauge may be defined as any instrument or device that is employed to measure the linear deformation over a given gauge length, occurring in the material of a structure during the loading of the structure. This definition is quite broad; in fact it covers the range of instruments included between the linear scale and the precise optical and electrical gauges now available. The many types of strain gauges available are quite varied, both in application and in the principles involved in their magnification systems. Depending upon the magnification system, the strain gauges may be classified as follows:

- Mechanical
    - Wedge and screw.
    - Lever-simple and compound.
    - Rack and pinion.
    - Combination of lever and rack and pinion.
    - Dial indicators.
- Optical.
- Interferometric type.
- Electrical.
    - Inductance.
    - Capacitance.
    - Resistance.
    - Piezoelectric.
- Magnetic.
- Acoustical.

- Pneumatic.
- Scratch type.
- Photostress gauge.

Photoelasticity: this method depends upon the property of certain transparent solids by which they become doubly refractive under the action of stress, the magnitude of the optical effect bearing a definite relation to that of the stress. The optical phenomenon, known as Sir David Brewster first discovered the “photo-elastic effect” in 1816 in sheets of stressed glass. Brewster, however, did not succeed in obtaining a uniform stress in his model and was not able to make any quantitative estimate of the relation between the stress and the optical effect produced. In 1820 Biot demonstrated that a strip of glass became doubly reflecting when set into a state of longitudinal vibrations. Fresnel attempted to measure the changes in the velocities of the two oppositely polarized rays in glass without any decisive results. Neumann presented the first theory of the photoelastic effect in 1841 and expressed the velocities of the two waves in terms of the three principal strains in the medium. In 1853, Maxwell presented a theory in which the velocities were related to the principal stresses. Both these theories produced relations of precisely similar form and were equally applicable to an isotropic linear and elastic material under any system of combined stress.

1.4 Numerical Methods for Analysis

In engineering analysis a theoretical model was the first choice for researchers and scientists because of accurate and unique solution. But in pragmatic design problem, the theoretical model was scarcely utilized to predict physical response because of the complex geometrical design and path. Therefore powerful numerical method was introduced to engineers to overcome difficulty.

Some of the numerical approaches are

1.4.1 Finite difference method.

1.4.2 Finite volume method.

1.4.3 Boundary element method.

1.4.4 Finite element method.

In the design of engineering structures, numerical simulations play an increasingly important role. This can be attributed to the high costs or practical difficulties related to experiments, which have to confront rapid advances in the computational power and the resulting decrease in the costs for computer simulations.

1. 4.1 Finite Difference Method

This is used where the behavior of the object under load can be mathematically formulated. If this leads to a governing differential equation where closed form solution is not easily available, approximate method of solution must be employed. The derivatives of the functions appearing in the differential equations are approximated by Taylor series expansion of unknown function.

1. 4.2 Finite Volume Method

Finite volume method have first been developed by engineers in order to study complex coupled physical phenomenon whenever the conservation of extensive quantities (masses,energy,impulsion) must be carefully checked by the approximate solution. Another advantage of such scheme is that large variety of meshes can be used. The basic idea is to integrate the partial differential equation in each control volume and then approximates the fluxes across the volume boundaries. The Finite Volume Method can discredited partial differential equations using triangles, quadrilaterals or other polyhedron in 3D. Thus the Finite Volume Method has become the major discretization technique for conservation laws in computational flow dynamics.

1. 4.3 Boundary Element Method

A basic feature of all boundary element methods is their use of fundamental solutions, which are analytically free space solutions of the governing differential equation under the action of point source. In this method the easy data preparation is due to reduction of one dimension. It makes it attractive for special practical use. Main drawback of BEM is that it is very difficult to apply in the field of complicated design. In general the main advantage of BEM is that it is used for calculating forces and displacement on the boundary.

1. 4.4 Finite Element Method

Finite element method has become a powerful tool for the numerical solution of a wide range of engineering problems. Applications range from deformation and stress analysis to field analysis of heat flux, fluid flow, magnetic flux, seepage and other flow problem. In this method of analysis, a complex region defining a continuum is discredited into simple geometric shapes called **Finite Elements**. Finite element method solves for forces and displacement over the entire object. Since most visual applications tend to be more interested over the entire object, Finite element method seems promising. Finite element method is used for solving many industrial problems like Automobile frames, optimization of mechanical parts, artificial limbs etc. Rolling mill housing is one of them.

1.5 CATIA Overview

CATIA is a general purpose finite element modeling package for numerically solving a wide variety of mechanical problems. These problems include: Static/Dynamic Structural Analysis (both linear and non-linear), heat transfer and fluid problems, as well as electromagnetic problems.

1.5.1 CATIA

Finite element analysis software enables engineers to perform the following tasks:

- Build computer models or transfer CAD models of structures, products, components, or systems.
- Apply operating loads or other design performance conditions.
- Study the physical responses, such as stress levels, temperature distributions.
- Optimize a design early in the development process to reduce production costs.
- Do prototype testing in environments where it otherwise would be undesirable or impossible.

1.5.1.1 Structural Analysis

Structural analysis is probably the most common application of the finite element method. The term structural (or structure) implies not only civil engineering structures such as bridges and buildings, but also naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

1.5.1.1.1 Types of Structural Analysis

The primary unknown (nodal degrees of freedom) calculated in a structural analysis is displacement. Other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements.

The following types of structural analyses can be performed:

Static Analysis-Used to determine displacements, stresses, etc. under static loading conditions, both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.

Transient Dynamic Analysis- Used to determine the response of a structure to arbitrarily time-varying loads. All nonlinearities mentioned under Static Analysis above are allowed.

1.5.1.2 Design Optimization

Design optimization is a technique that seeks to determine an optimum design. By "optimum design," It mean, one that meets all specified requirements but with a minimum expense of certain factors such as weight, surface area, volume, stress, cost, etc. in other words, the optimum design is usually one that is as effective as possible.

Virtually any aspect of design can be optimized: dimensions, shape (fillet radii), and placement of supports and cost of fabrication, natural frequency, material property, and so on. The CATIA program offers two optimization methods to accommodate a wide range of optimization problems.

The **'sub problem approximation 'method** is an advanced zero-order method that can be efficiently applied to most engineering problems.

The **first order method** is based on design sensitivities and is more suitable for problems that require high accuracy.

For both the sub problem approximation and first order methods, the program performs a series of analysis-evaluation-modification cycles. That is, an analysis of the initial design is performed, the results are evaluated against specified design criteria, and the design is modified as necessary. The process is repeated until all specified criteria are met.

CHAPTER-2

LITERATURE REVIEW

2.1 Literature Review: This chapter discusses briefly the work done by various researchers in the areas of define problem.

Remn-Min Guo [1] generated a method by combining the Goodman line technique, and the cumulative damage method to estimate the housing life. A method was also developed to estimate the upper and lower bounds of the housing life using the average equivalent stress. These methods can be extensively used in all machine elements subjected to cyclic loads.

The extensive usage of the Goodman line technique in conjunction with Miner's accumulative damage method provides a method to estimate the housing life knowing the force spectrum and the material S-N curve or Basqin equation. A force spectrum including instantaneous force changes could be established by combining the average in-coil force variation and coil-to-coil force variation.

The former was obtained directly from the force and/or strain gauge measurement. In order to detect the dynamic change during impact, the FM tape with high frequency data collection was recommended. The coil-to-coil force variation could be obtained from the rolling schedule calculation or the load cell readings for various material, width, and gauge. The amplitude stress was computed from the amplitude to mean ratio.

Further mathematical derivation and assumptions leads to the upper and lower bound estimation of the life expectancy. Using this preliminary estimation can eliminate the measurement of the in-coil force variation, which is in general costly and timely. The averages mean force could be calculated directly from the rolling schedules according to expected product mix. The average amplitude force could be roughly estimated by observing the strip chart of the rolling force. A detailed finite element analysis on the mill housing was necessary to convert the force into the stress using the proportion rule. If the lower bound exceeds the expected life, there was no reason to go for the upper bound or even the accurate solution; otherwise, the further studies could be required.

In presenting and discussing structural analysis and design an engineer/analyst is always emphasizing the importance of strength and stiffness and endeavoring to get a balance between them both that suits the design in hand. It seems logical therefore in presenting structural optimization that both these crucial items be objectives of the process rather than having one as the objective and the other as a constraint as has traditionally been the case. It initially feels more appropriate to be trying to maximize stiffness whilst simultaneously maximize the strength. Also the goal of maximizing strength of a structure should, to the authors mind, be in the form of minimizing the maximum stress under all load cases. Traditionally structural optimization has targeted stress equalization or the achievement of "fully stressed" design as the stress objective/constraint. The authors consider that such an objective, especially coupled in with FEA still can lead to high localized stresses which therefore do not improve the strength of the structure. G. P. Steven [2] aimed at exploring the application of the evolutionary structural optimization method to such multicriteria design problems.

To evaluate the overall effect on the design of material variation due to these two optimality criteria, a weighting scheme was adopted, whereby the weight factors emphasize and/or balance the stiffness and stress criteria. The work can accommodate various situations involving shape and topology design with multiple criteria. Also the important practical aspects of possible multiple peak stresses and multiple load cases were taken into account. A number of examples demonstrate the capabilities of the proposed method for solving multicriteria design optimization structural design problems.

J. H. Rong[3] proposed an improved method for evolutionary structural optimization against buckling for maximizing the critical buckling load of a structure of constant weight. First, based on the formulations of derivatives for eigenvalues, the sensitivity numbers of the first eigenvalue or the first multiple eigenvalues (for closely spaced and repeated eigenvalues) were derived by performing a variation operation. In order to effectively increase the buckling load factor, a set of optimum criteria for closely spaced eigenvalues and repeated eigenvalues were established, based on the sensitivity numbers of the first multiple eigenvalues. Several examples were provided to demonstrate the validity and effectiveness of the proposed method

Kurt Maute [4] presented an interactive method for the selection of design criteria and the formulation of optimization problems within a computer aided optimization process of engineering systems. The key component of the proposed method was the formulation of an inverse optimization problem for the purpose of determining the design preferences of the engineer. These preferences were identified based on an interactive modification of a preliminary optimization result that was the solution of an initial problem statement. A formulation of the inverse optimization problem was presented, which was based on a weighted-sum multi-objective approach and leads to an explicit optimization problem that was computationally inexpensive to solve. Numerical studies on structural shape optimization problems show that the proposed method was able to identify the optimization criteria and the formulation of the optimization problem, which drive the interactive user modifications.

Theodore G.ToRidis [5] formulated a general method of elastic-inelastic analysis of rigid frames, which was based on the finite element method, and the concept of initial strain as applied to plastic strains. The analytical expressions obtained in this manner were used as a basis for the development of a general purpose computer program . This program enabled the user to exercise several options corresponding to the static, free vibration, elastic dynamic and plastic dynamic analysis of two and three-dimensional framed structures.

William Prager [6] encountered typical difficulties in the formulation of problems of optimal structural design .For the optimal design of a statically determinate or indeterminate truss of given layout, a method was presented by which necessary and sufficient conditions for global optimality may be derived when an upper bound is prescribed for the compliance of the truss under one or several sets of loads and a lower bound is prescribed for the cross sectional area of each bar. The extension of the method to other structures and constraints was briefly discussed with reference to the literature, and the general form of the resulting optimality conditions is given.

Rafael Febres [7] discussed a model of the behavior of metallic structures subjected to flexural effects . The model focused on the description of failure due to local buckling. It was assumed that the main inelastic phenomena involved in the process: plasticity and local buckling, could be lumped at inelastic hinges. The model took into account that in planar frames, two local buckling could appear in the plastic hinge region: one due to a positive moment the other one related to a negative moment. The elastic behavior of frame members with two local buckling was assumed as unilateral. The plastic behavior was described using the concept of equivalent moment on a damaged plastic hinge. A new hypothesis, that authors have called "counter-buckling", was introduced. The counter-buckling concept states that as a consequence of the evolution of one local buckling, the other one results partially blocked. The notion of counter-buckling was used to describe local buckling evolution during cyclic loadings. Finally, the model was verified through the numerical simulation of several experimental tests on frame members and framed structures.

K. G. Mahmoud [8] recognized that structural optimization using mathematical programming techniques can be employed efficiently only in conjunction with explicit approximate models. In the work an efficient optimization methodology combining a finite element-based approximate analysis model, a sequential quadratic programming algorithm incorporating an active set strategy and a direct method of design sensitivity analysis was developed. The methodology involves the solution of a sequence of explicit high-quality approximate problems subject to given move limits in the design space. A new technique for constructing approximation functions with a high quality adaptive capability to the original functions was proposed by using the values of the state variables (displacements and/or stresses) and their derivatives at points obtained in the process of optimization. Other approximation techniques had been presented and comparisons had been made using real-life automobile structures to demonstrate the power and generality of the approximation concepts in structural optimization.

V. Braibant [9] was focused on the use of optimization techniques in the framework of Computer Aided Design and Finite Element Methodology. A design model was developed which could be used for structural sizing as well as for shape design. An essential aspect of the work was sensitivity analysis, which consists of computing derivatives of the functions which define the optimization problem. Attention was restricted on static linear problems involving shape variables. A new and rather general mathematical programming method was described. For structural sizing as well as for shape optimal design, the method generalizes previous approaches and had excellent convergence properties. A sample of numerical applications was given showing the efficiency and reliability of the proposed formulation. Finally, the concept of interactive redesign allowing the designer to monitor the optimization process on a graphic terminal was envisaged. It was expected that in the future the concept will lead to integration of structural optimization methods into Computer Aided Design systems.

The design problem of frames with beams subject to stress, displacement, and buckling constraints in the paper was treated as two-level structural optimization**.** The weight of structure, the areas of cross-sections for the independent elements were in system level taken as objective function and system design variables, respectively. They would satisfy the overall deformation and the overall buckling constraints. At the component level the objective was to minimize the weight of each independent element, and the cross-sectional dimensions were the component design variables. The local stress and bucklings in each independent element were component constraints. Yunliang Ding [10] added an additional constraint corresponding to system design variable into component level to assure consistency between system and component variables.

M. E. M. El-Sayed [11] presented a method for considering fatigue life requirements in the optimal design of structures. The basic concept was to use the load history data combined with the finite element stresses of the structure and the material fatigue properties to calculate the fatigue life during the optimization process. The life requirement was considered as side constraints and the structure weight as the objective function. To demonstrate the concept, the optimization task with fatigue life constraints and the fatigue life calculation, based on the contemporary approach, were discussed.

M. Haririan [12] described procedures for design sensitivity analysis and optimization of nonlinear structural systems with the computer program Adina. Formulation of the structural optimization problem, design sensitivity analysis with nonlinear response using incremental finite element procedures, and two strategies to use Adina for design optimization are described. A database and a modem database management system were used to couple Adina with design sensitivity analysis and optimization modules. Comparison of optimum designs with linear and nonlinear structural responses for trusses with material and geometric nonlincarities were given.

Michael A. Vehmeier[13] proposed the new method to optimize both the structural parameters and time-invariant control gains while including the effects of transient loads. The control force gains were written as explicit functions of the response and were included in the equation of state, which in turn is directly embedded into the augmented performance index. Variations were taken with respect to all of the design variables (state, co-state, structural parameters, and position and/or rate feedback control gains) to generate the governing equations for the system. A computer code was developed to solve the resulting equations and simultaneously solve for the optimal control gains and structural parameters using gradient-based search techniques. The resulting structure was optimal for the specified service environment (initial conditions and/or transient loads) with constant control force gains (position and/or rate feedback).

2.2 Objective of present work:

The present work involves the optimization of Rolling Mill Housings design for rigidity, to control the deflection of the housing for better gage control of the material being rolled. The Housing stress distribution has been analyzed using analysis software CATIA from which maximum static stress at critical areas have been calculated. Structural behavior of housing under the given loading and boundary conditions using an analytical model was very difficult. Therefore 3D solid model was chosen in order to predict the stress and strain response detail.

We have made a prototype of Rolling Mill Housing of optimized design of 1:10 scale so as to verify our results that have been given by the analysis of Rolling Mill Housing on CATIA analysis software.

CHAPTER-3

ANALYSIS

3.1 Concept of Stress and Stress Analysis

Two types of forces that act on a body may be distinguished as internal or external. The internal forces are the reactive forces that are set up in the body due to externally applied forces. The internal forces are numerically equal to the external forces. The internal force set up in the body per unit area is called stress. The external forces may be classified as surface or body forces. The surface forces are the forces distributed over the surface or boundary of the body. These forces arise due to pressure exerted by one body on the other body. The surface forces are described in terms of forces per unit area and as such are often called applied stresses.

The word 'analysis' means separation of body into components. To analyze the stress means to determine the share of stress at every point in the body. For the general case of a complete stress analysis of a body the values of six stress components, three normal cartesian stress components and the corresponding three shear stress components, are required to be determined at every point on the body.

3.2 CALCULATION OF ROLL LOAD

The Rolling Load in a Rolling Mill can be calculated by the methods used by Tselikov [14].Since the forces on the roll neck and in the Housing posts are identical, and the strength of the neck (with a constant relation between its diameter and length) is approximately proportional to d^2

Where d = diameter of Roll neck bearing.

For various mills Roll load depends on the Roll material as:

1. For iron rolls approximately

   $F = (0.6 \text{ to } 0.8)\, d^2$ …………………… (3.1)

2. For carbon steel Rolls

   $F = (0.8 \text{ to } 1.0)\, d^2$ ………………… (3.2)

3. For Rolls of Chromium Steel (Four high mills)

$F = (1.0 \text{ to } 1.2)\, d^2$ ………………… (3.3)

We are making use of four high mills with Chromium Steel Rolls so Roll load is calculated from the equation 3.3 i.e. $F = (1.0 \text{ to } 1.2)\, d^2$

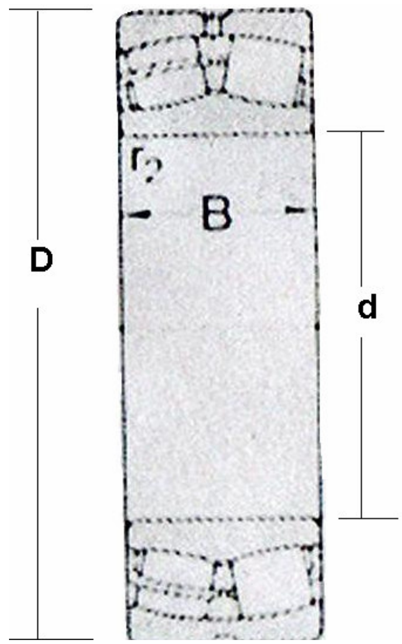

Figure 3.1 Spherical Roller Bearing

Since each roll neck consists of two bearings 23056 mounted on each roll neck so specification of bearing used is [15]:

d = diameter of Roll neck bearing = 280 mm

D = outer diameter = 420 mm

B = width = 106 mm

C = Dynamic capacity = 1520000 N

Therefore $F = (1.0 \text{ to } 1.2)\, d^2$ = (78400 to 94080) (9.81) = (769104 to 922924) N ……… (3.4)

Also the Rolling Load in a Rolling Mill is calculated from the dynamic capacity of the Roll bearings and their service life. In order to achieve a service life of about 3 Lakhs hrs minimum at 30 R.P.M the ratio of bearing capacity to load applied can be calculated from life calculation chart as shown in figure 3.2

Therefore C/P = 6.5

Therefore P = 1520000/6.5 = 233 KN

We are making use of four bearings so Total load is P * 4 = 930 KN (appr.) ………… (3.5)

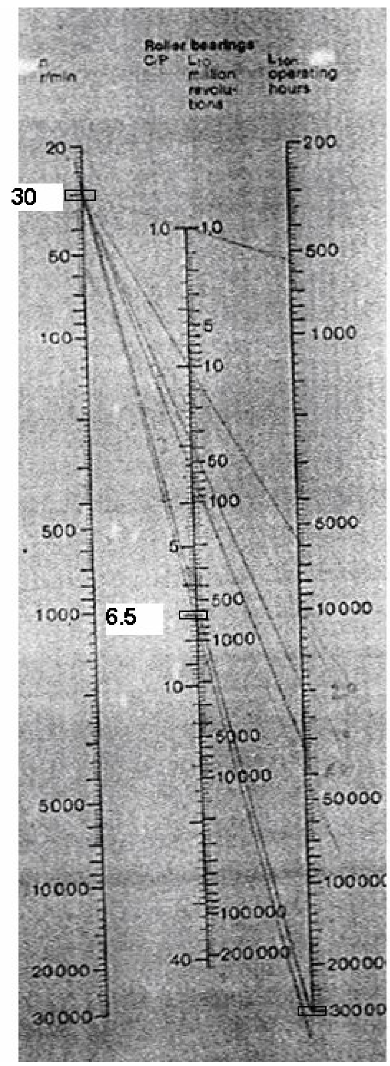

Figure 3.2 Life Calculation Chart of Roller Bearing

Comparing equations 3.4 and 3.5 we make use of 900 KN of Rolling load in our Housing design. This Rolling Load of 900 KN is transferred from the top chock to Housing which has spherical seating on the screw and through lower chock to Housing because it rests on a spherical liner as shown in figure 3.3

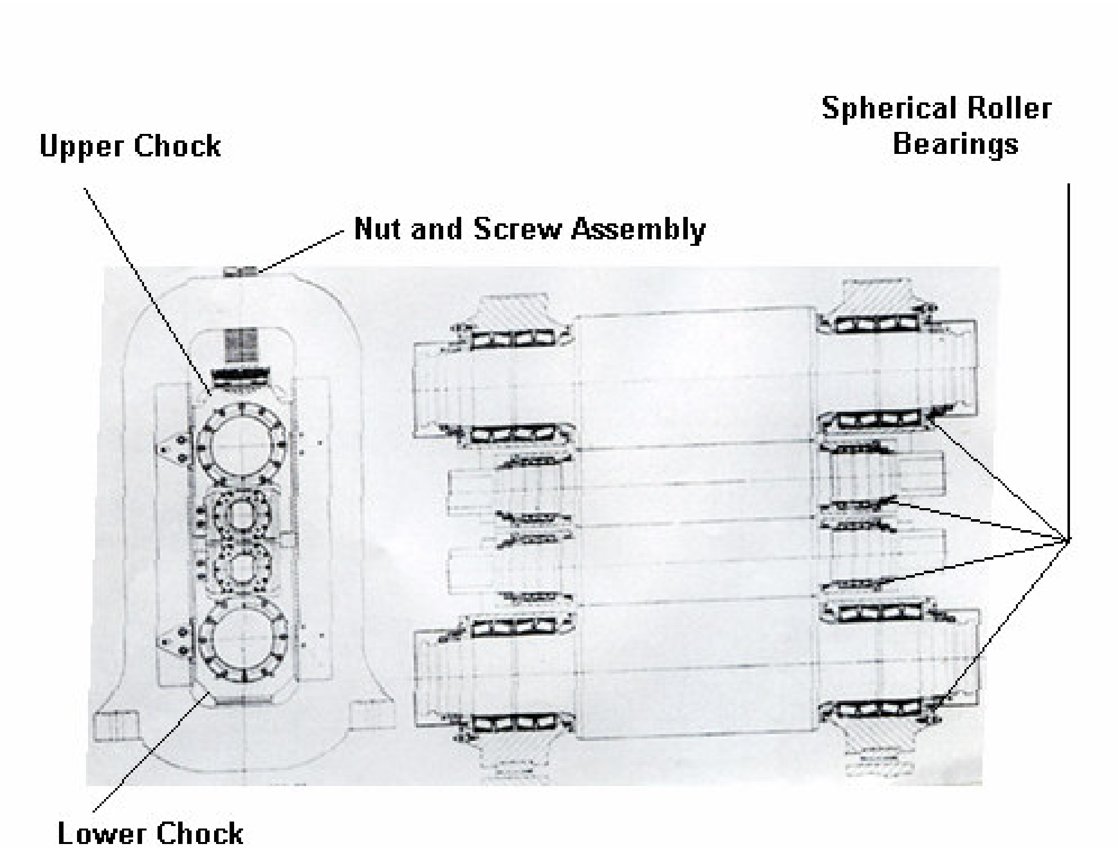

Figure 3.3 Rolling Mill showing the load transferred from the Rolls to the Housing

CHAPTER: 4

RESULTS AND DISCUSSION

4.1 Introduction

The full rolling load is taken by the roll neck bearings, which are supported in the chocks; the bottom chock rests on a spherical liner, which in turn is supported by the bottom beam of the housing. The top chock has spherical seating on the screw. This load imparts a tensile stress to the vertical pillars, a compressive stress to the screw and causes bending of top and bottom housing beams. Because of the bending of the housing beam, the posts will tend to bend inwards, and the way in which the housing distorts depends on the relationship between the resistance to bending of the vertical posts and the resistance to bending of the beams. The post will experience direct tensile stresses and bending stresses at the inner and outer end of the post. There will be compressive stresses at outer end and tensile stresses at the inner end of the posts. If the posts are rather slender and the bridges heavy, the bending of bridges will be small, but there will be considerable bending of the posts. On the other hand, if the posts are heavy and the bridges are light then the bridges will bend considerably but will tend to bend as a built in beam and there will be little bending of the posts. This phenomenon is known as hour-glassing effect.

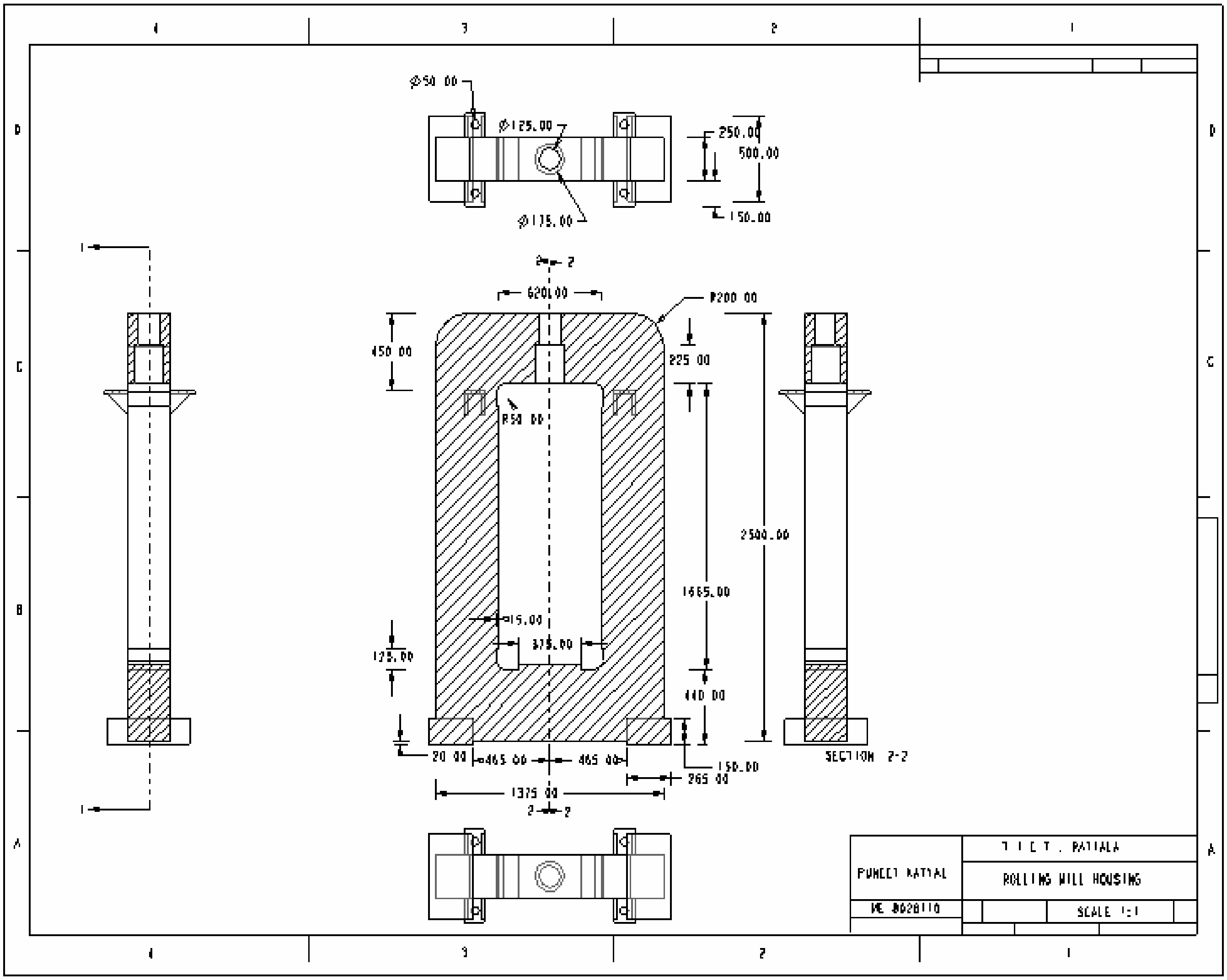

Figure 4.1 Drawing of Rolling Mill Housing before Optimization

4.2 Steps of analysis of Rolling Mill Housing

1. **Build the Model:** First of all we have made a 3D model of Rolling Mill Housing on CATIA. In building a model we have used various modeling tools.

2. **Defining Element Types**: The element library of analysis software contains more than 100 different element types. Each element type has a unique number that defines the element category. We have selected a structural solid (Brick 20 noded) because we have to analyze 3D model of Rolling Mill Housing.

3. **Defining the Material Properties:** we have selected Mild Steel as a material for 3D solid model of Rolling Mill Housing. The value of properties corresponding to Mild steel material like young's modulus ,poissons ratio, Density or yield strength have to be fed to Rolling Mill Housing model.

Young's Modulus	2 E11 N/m2
Poisson Ratio	0.266
Density	7860 kg/m3
Yield Strength	2.5e+008 N/m2

Table 4.1 The Structural properties of the Mild Steel material

4. **Meshing of Model:** We discritized the whole solid model into small elements. Depending upon the requirement of the accuracy of results the fineness of meshing varies. More finer is the meshing more we are closer to the actual results.

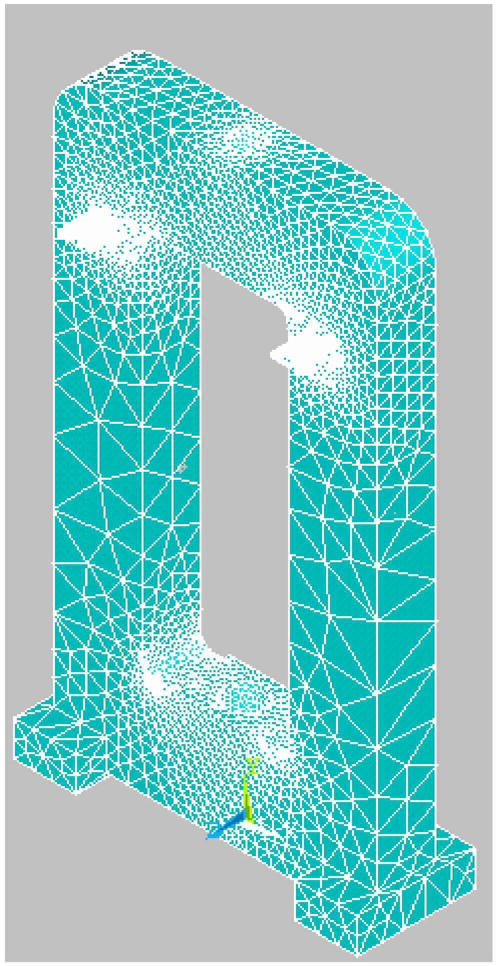

Figure 4.2 Meshing of Rolling Mill Housing

5. **Boundary Conditions:** The full rolling load is taken by the roll neck bearings, which are supported in the chocks; the bottom chock rests on a spherical liner, which in turn is supported by the bottom beam of the housing. The top chock has spherical seating on the screw. So we apply constraints on the model like we fix the base of Rolling Mill Housing and apply maximum rolling load of +900 KN on the cross section where the top chock rests and -900 KN on seating where the bottom chock rests as shown in figure 4.3.

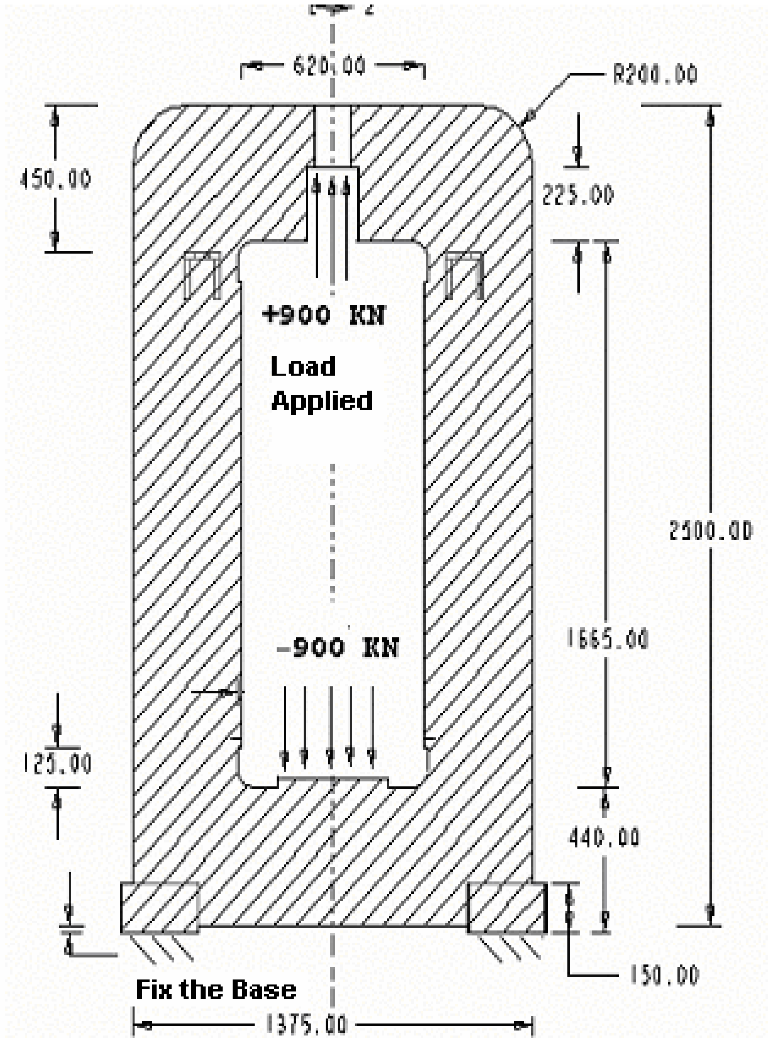

Figure 4.3 Boundary Conditions on Rolling Mill Housing

6. **Solver:** Solver is used to solve the simultaneous equations that the finite element method generates. The results of the solution are:

    - Nodal degree of freedom values, which form the primary solution.
    - Derived values, which form the element solution.

7. **Postprocessor:** Post processing means reviewing the results of an analysis. It is probably the most important step in the analysis, because we will came to know to understand that how the applied loads affect our design, how good our finite element mesh is, how high are the stresses in the region, and so on.

4.3 The Stress Analysis of Rolling Mill Housing before optimization

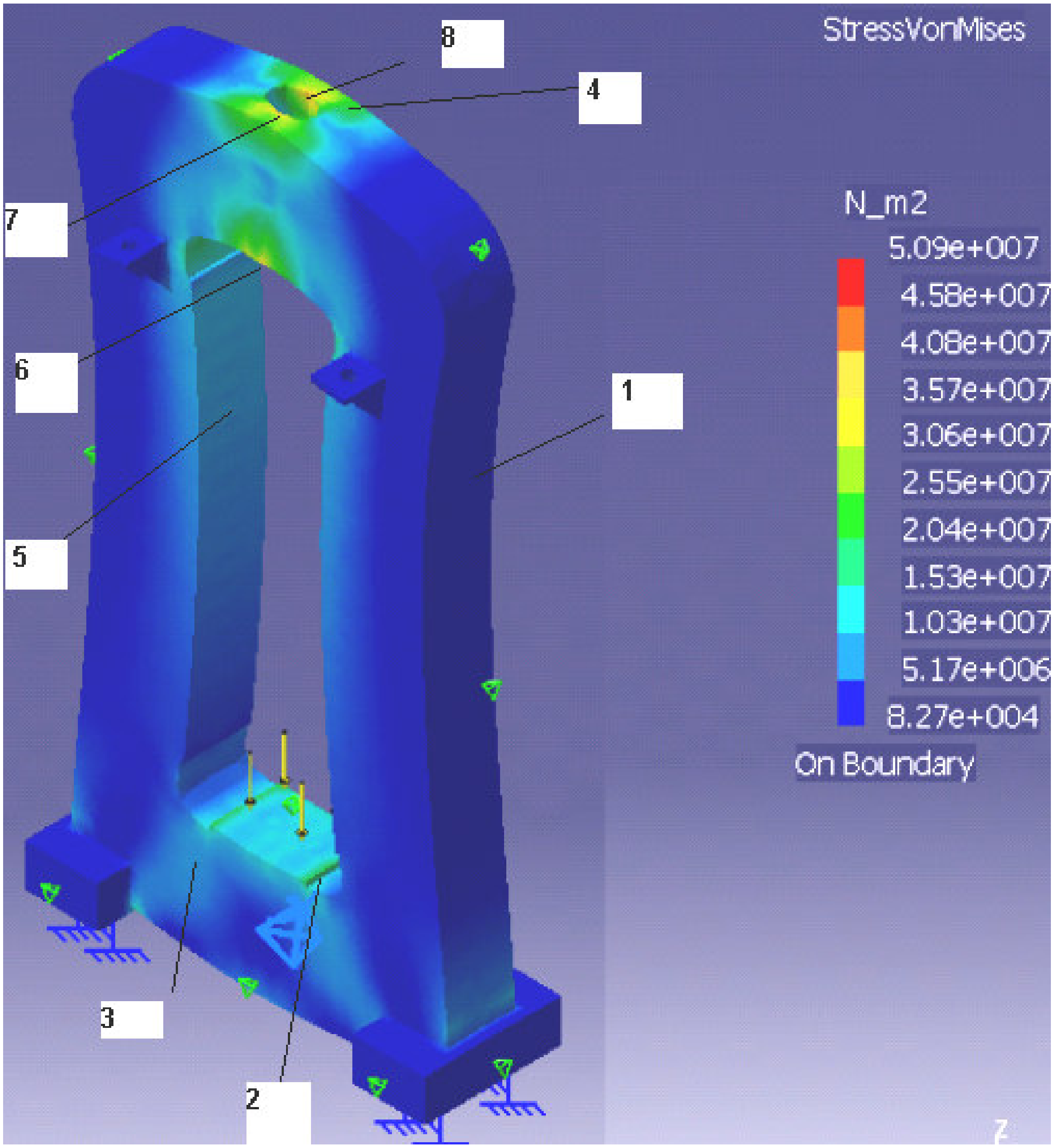

Figure 4.4 Von Mises Stress Analysis of Rolling Mill Housing before optimization

4.4 The Deformation of Rolling Mill Housing before optimization

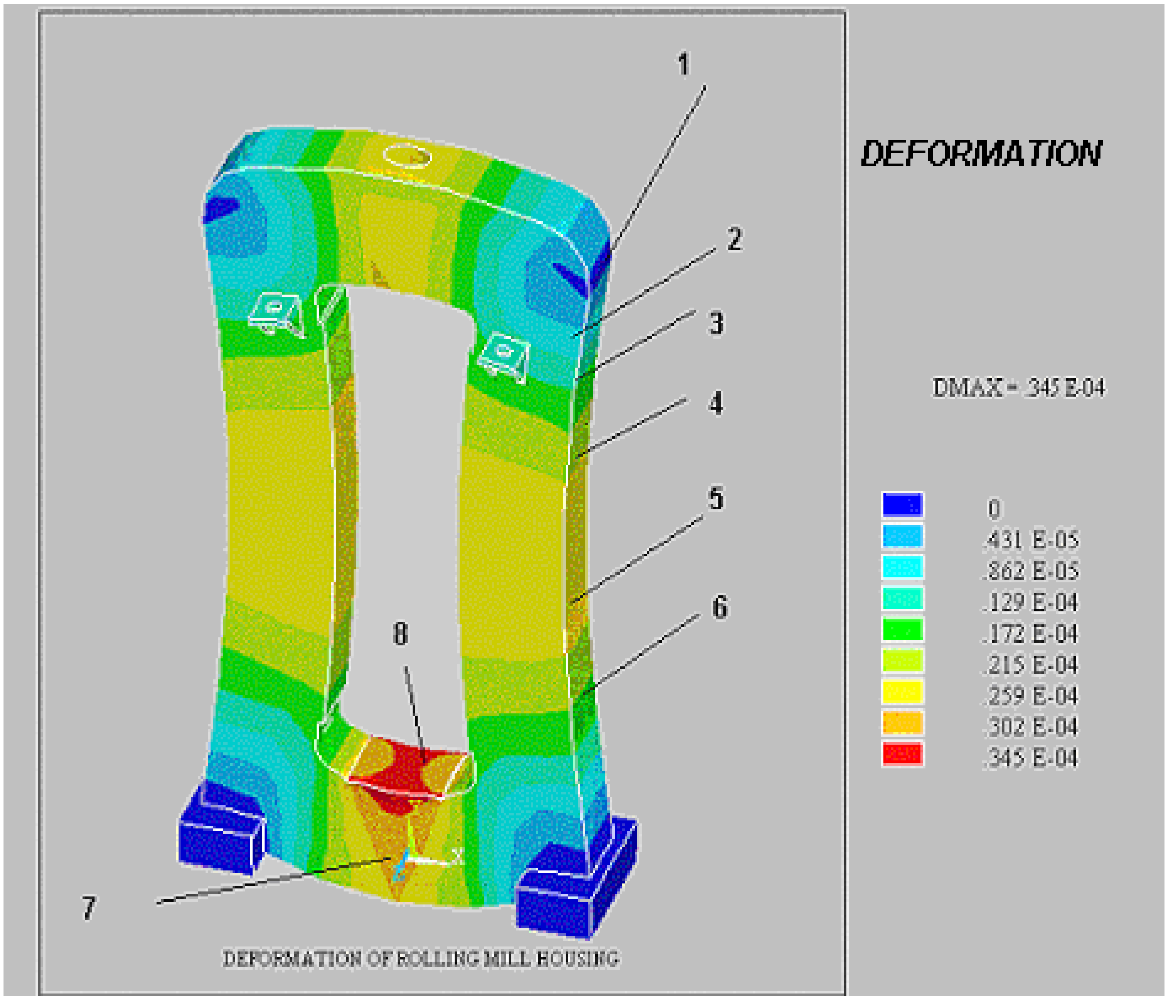

Figure 4.5 Deformation of Rolling Mill Housing before optimization

From the deformation of the Rolling Mill Housing it is clear that the load imparts a tensile stress to the vertical pillars, a compressive stress to the screw and causes bending of top and bottom bridges. Because of the bending of the bridges the posts will tend to bend inwards.

4.5 Optimization procedure:

Design optimization is a technique that seeks to optimize the design in terms of strength, rigidity and weight. By "optimum design," we mean a design that meets all specified requirements but with a minimum expense of certain factors such as weight, surface area, volume, stress, cost, etc.

In choosing permissible stresses it should be born in mind that the Housing is most expensive and important part of a rolling mill. For this reason it should be so strong that even though the roll may breaks the housing does not deform plastically. If the rolling mill housing fails the cost and time of replacement will be excessively high. Not only the process of manufacturing of rolling mill housing involves a huge weight but also cost of machining, drilling, boring, tapping, surface finishing and holding to close tolerances is quite high and time consuming. Increase of housing cross section above the strength required for high rigidity is not justified. The deformation of the housing is only a small part of the deformation of rolling mill stand. To protect the stand it should be proof against damage from fatigue and also against damage from overloading, which in practice is very often unavoidable owing to incorrect entry of metal into the rolls, variation in input thickness and for other reasons.

The stresses in the posts are within control limits so no needs for changing its design but the beam of the housing experienced higher stresses at the place where nut of the housing screwed is nested in the beam therefore design of the beam has to be optimized.

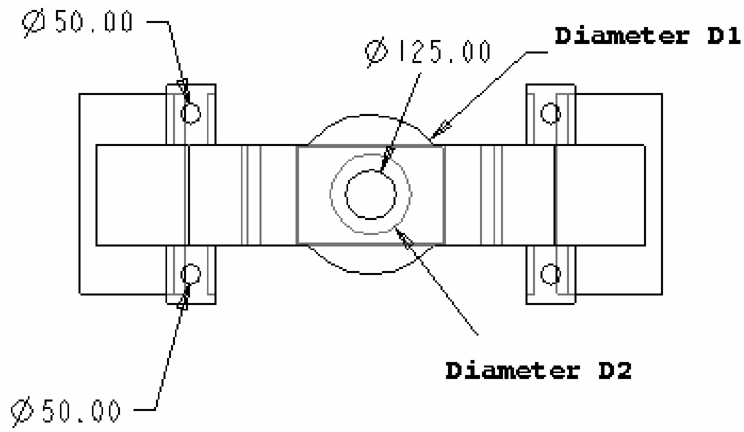

Figure 4.6 Design variables for Optimization of Rolling Mill Housing

The optimization procedure consists of following steps.

1. **Design Variables**: These are independent quantities that are varied in order to achieve the optimum design. Upper and lower limits are specified to serve as “constraints “on the design variables. These limits define the range of variation for the Design variables.

   D1 and D2 are chosen as design variables for optimization of rolling mill housing as shown in figure 4.6.

   Where D1 = diameter of uniform circular cross section added around the nut in mm

   D2 = diameter of hole where nut rests in mm

   $350 < D1 < 480$

   $175 < D2 < 240$

2. **State variables:** These are quantities that constraint the design. They are also known as dependent variables. A state variable may have a maximum and minimum limit, or it may have one limit. Rolling Mill Housing model has two State variables: σ (total stress) and δ (deflection).

   30 – 40 N/mm^2 is the recommended stresses in the housing which should be as uniform over the cross section so as to make it balanced housing design.

   Therefore $30 < \sigma < 42$ N/mm^2

For thin rolled products the total deflection of the rolling mill system should be such that the stock material is able to remain with-in close tolerances. Maximum limit of deflection for roll mill housing should be limited to 0.01 mm for rolling 0.3 mm material.

Therefore $\delta < 0.01$ mm

3. **Objective Function:** It is the dependent variable that we are attempting to minimize. It should be a function of design variables that is changing the values of design variables should change the value of objective function. The weight of the housing is considered as the objective function. Weight of the steel is 7.85 gm/cc .Therefore weight of the Rolling mill housing is (7.85 e -3) V

Where V= volume of rolling mill housing

The design variables, state variables and objective function are collectively referred as the optimization variables. After optimization the values of Design variables, State variables so that objective function is obtained keeping in mind the constraints imposed on the optimization of Rolling Mill Housing are:

D1 = 400 mm

D2 = 200 mm

σ = 32.2 N/mm^2

δ = 0.905 E -5 mm

The stresses have decreased and are more uniform than the earlier ones. Although the weight of the housing has increases by about 70 kg, i.e. an increase of 3.5% but the decrease in the stresses will ensure that no plastic deformation will take place even if the load increases by 36%.

Since the values of the optimization variables are within control limits therefore design of Rolling Mill Housing has been optimized.

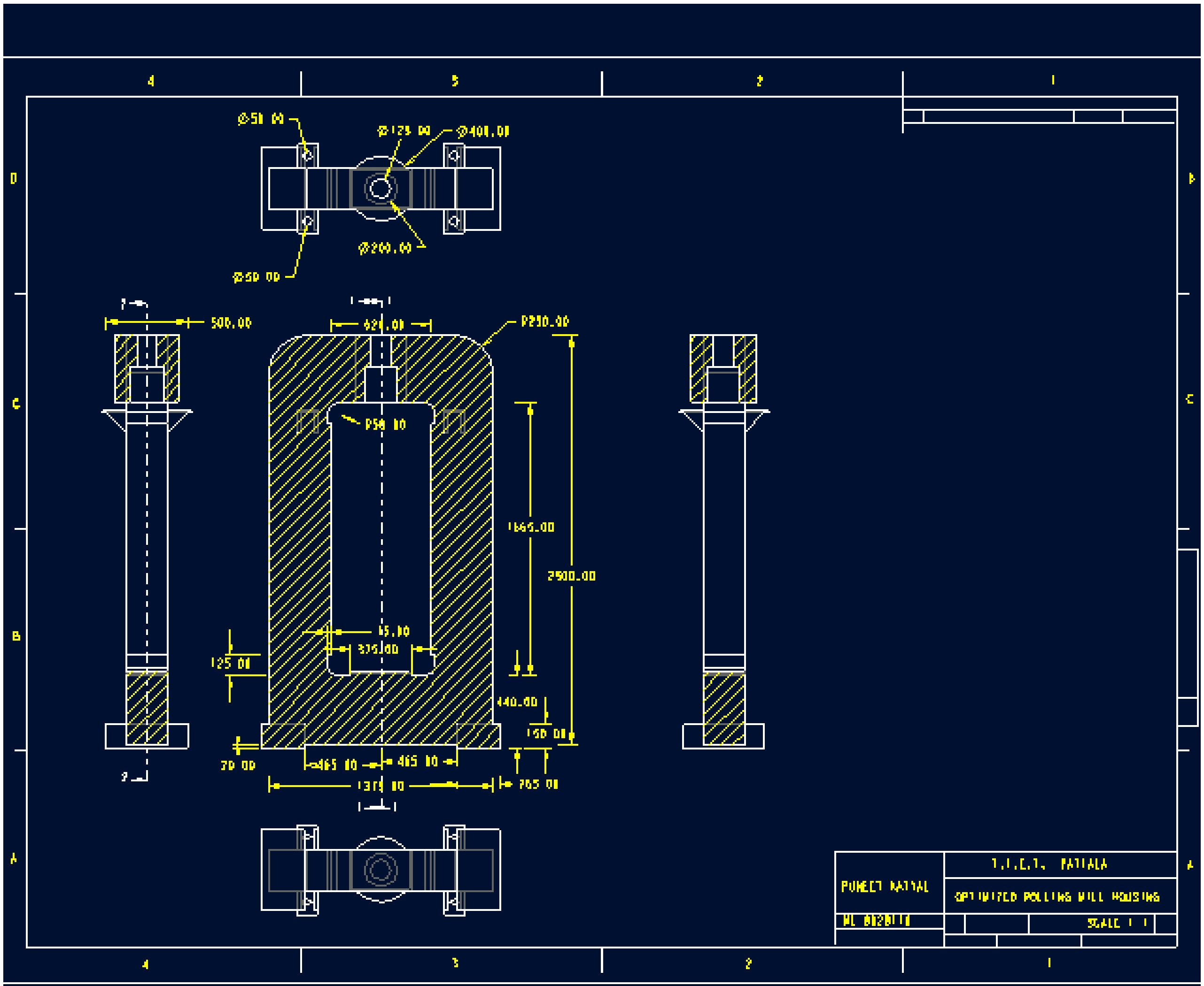

Figure 4.7 Drawing of Rolling Mill Housing after Optimization

4.6 The Stress Analysis of Rolling Mill Housing after optimization

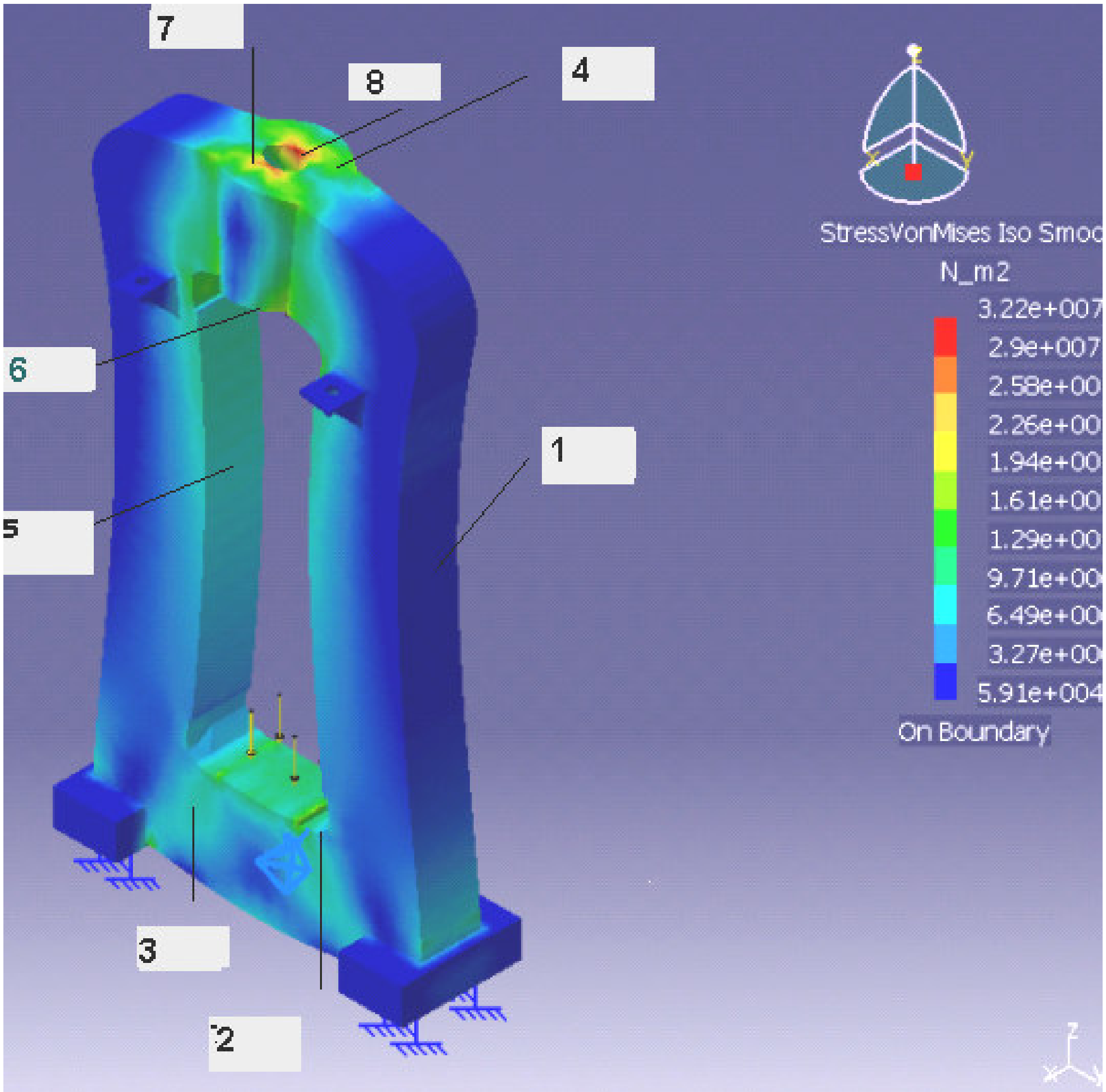

Figure 4.8 Von Mises Stress Analysis after Optimization

4.7 The Deformation of Rolling Mill Housing after optimization

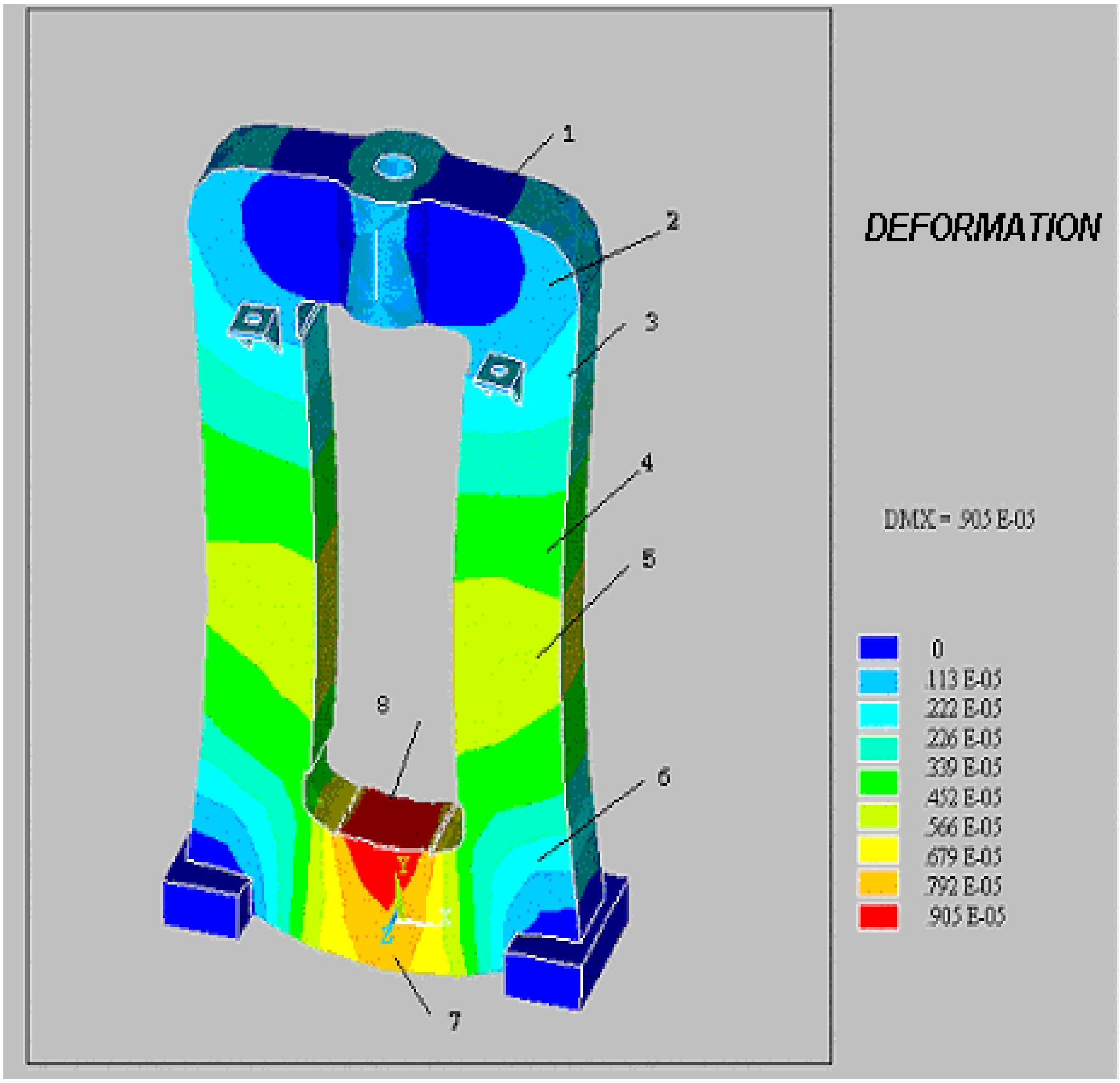

Figure 4.9 Deformation of Optimized Rolling Mill Housing

4.8 Software Results

We have compared the analysis results like stress distribution and deflection of Rolling Mill Housing under maximum loading conditions before and after the optimization. The data given by the table 4.2 and 4.3 have been taken from the values of the stresses and strains at different locations of the Rolling Mill Housing. These values vary from maximum to minimum showing the range of the distribution of the stress and deflection of Rolling Mill Housing before and after the optimization. It is clear from the graphs 4.10, 4.11 that the results we obtained after the optimization are satisfactory.

MAXIMUM STRESS (MPa) AT DIFFERENT LOCATIONS OF ROLLING MILL HOUSING		
DIFFERENT LOCATIONS OF ROLLING MILL HOUSING	**BEFORE OPTIMIZATION FIGURE 4.4**	**AFTER OPTIMIZATION FIGURE 4.8**
1	0.0827	0.0591
2	5.17	6.49
3	20.4	9.71
4	25.5	12.9
5	30.6	16.1
6	35.7	25.8
7	45.8	29
8	50.9	32.2

Table 4.2 Comparisons of Values of Stresses Before and After Optimization

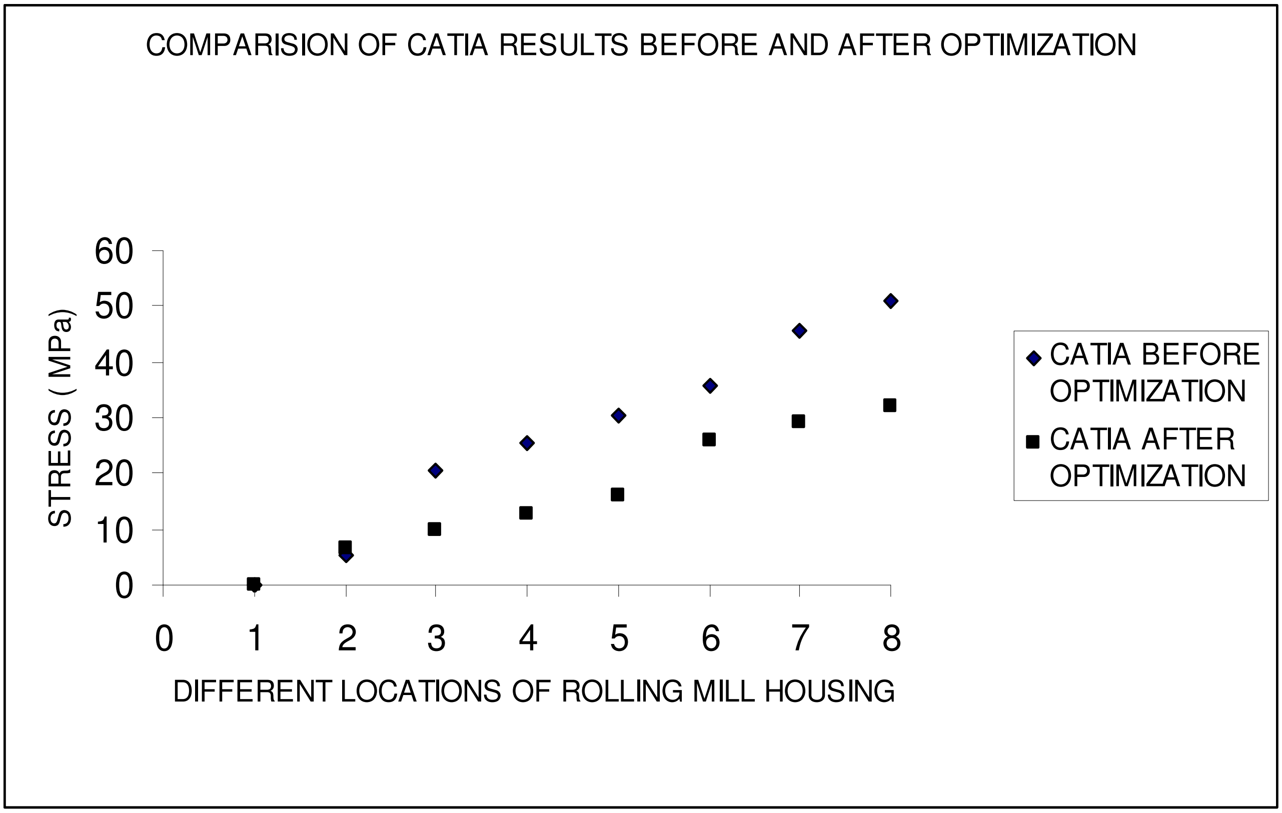

Figure 4.10 Graphs Showing the Comparisons of Values of Stresses Before and After Optimization

The recommended stresses in the Rolling Mill Housing are 30 – 40 Mpa which should be as uniform over the cross section so as to make it balanced housing design. The stresses in the posts are within control limits but the upper beam of the housing experienced higher stresses at the place where nut of the housing screwed is nested in the beam as shown by the location point 8 in the graph 4.10 before optimization .

Therefore It is clear from comparison of the stresses in Rolling Mill Housing before and after the optimization from the graph 4.10 that the stresses after optimization have considerably been reduced under the given boundary conditions because the steepness of the curve after optimization have been reduced and are within the recommended stresses.

MAXIMUM STRAINS (µs) AT DIFFERENT LOCATIONS OF ROLLING MILL HOUSING		
DIFFERENT LOCATIONS OF ROLLING MILL HOUSING	**BEFORE OPTIMIZATION (FIGURE 4.5)**	**AFTER OPTIMIZATION (FIGURE 4.9)**
1	0	0
2	4.31	1.13
3	8.62	2.22
4	12.9	2.26
5	21.5	3.39
6	25.9	4.52
7	30.2	7.92
8	34.5	9.05

Table 4.3 Comparisons of Values of Strains Before and After Optimization

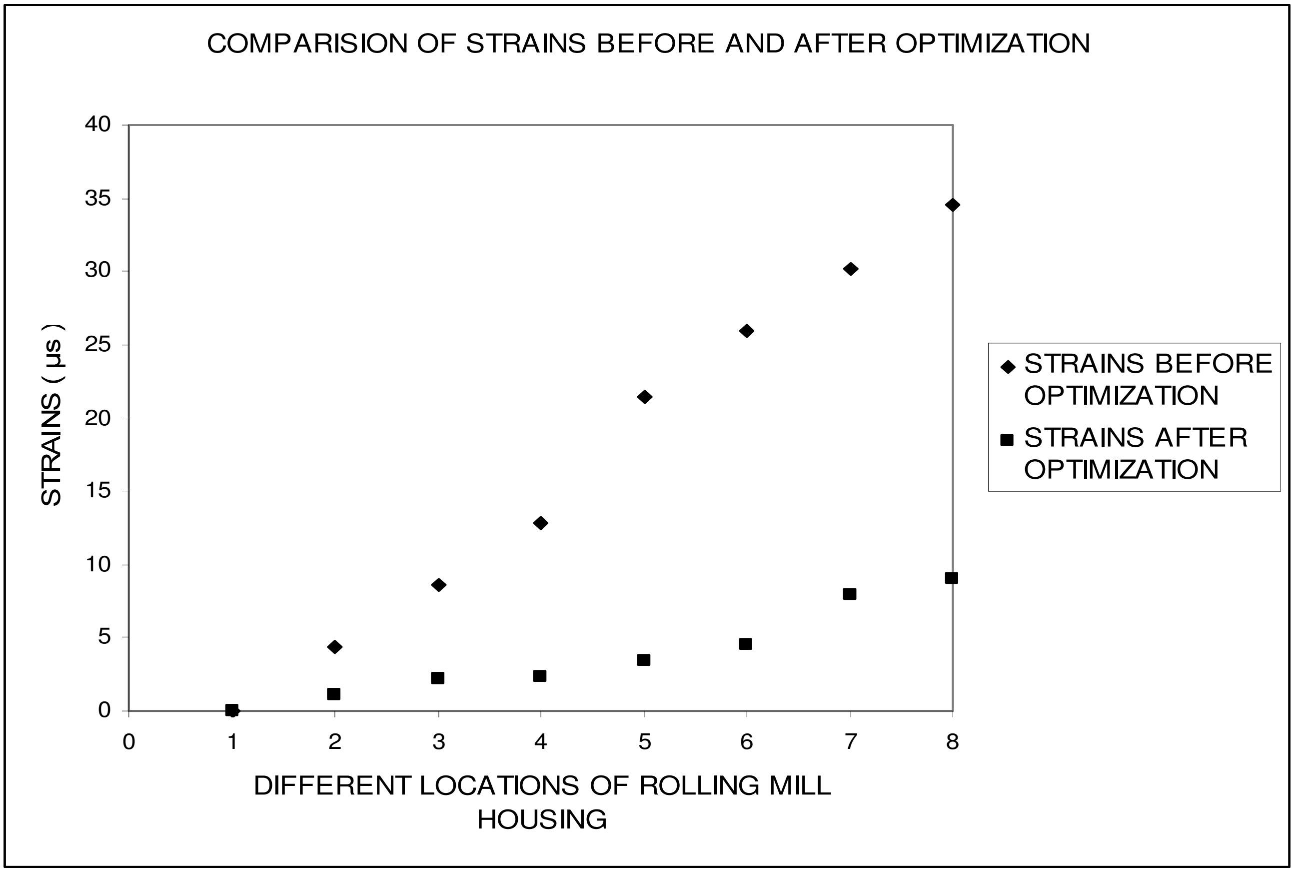

Figure 4.11 Graphs Showing the Comparisons of Values of Strains Before and After Optimization

It is clear from comparison of the Strains in Rolling Mill Housing before and after the optimization from the graph 4.11 that the Strains after optimization have considerably been reduced under the given boundary conditions because the steepness of the curve after optimization have been reduced .

4.9 EXPERIMENTAL RESULTS

We have made a prototype of Rolling Mill Housing of optimized design of 1:10 scale so as to verify our results that have been given by the analysis of Rolling Mill Housing on analysis software. In our experiment we cemented strain gauges at critical areas so as to verify our results with the softwares results.

4.9.1 EXPERIMENTAL SETUP

In our experiment we have applied load on our prototype of rolling mill housing by setting it on the universal testing machine. In our experiment we have cemented strain gauges at critical points and after calibrating our strain gauges we have find out strains at these points under different loads varying from 1-10 kN.

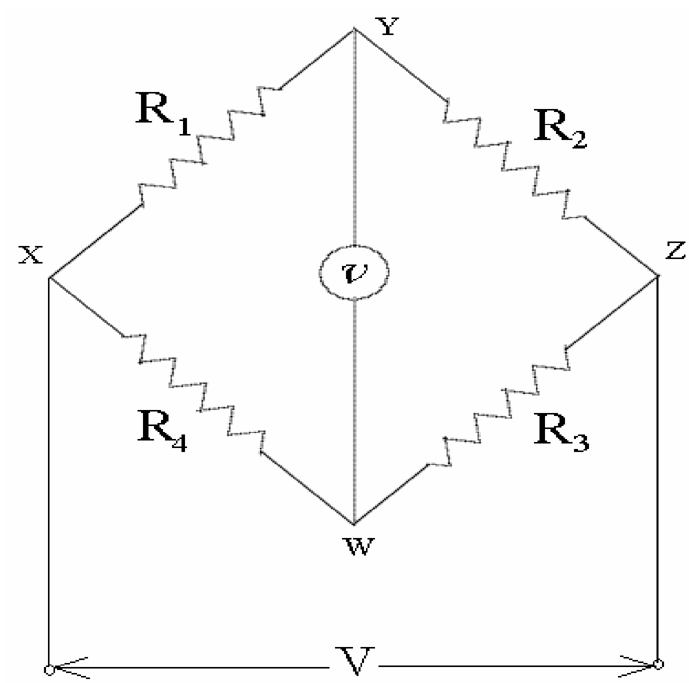

Figure 4.12 Circuit used in Strain Indicator

For calibrating our strain gauges we make use of strain inducator in our experiment. R_1, R_2, R3 and R4 are the resistances used in our circuit.

Under no load condition our bridge is in balanced position i.e. R_1* R3 = R_2 * R4.

V = Input voltage = 5 volt

v = Output voltage.

Type	BKCT-10
Resistance in Ohms	120.2 ± 0.2
Gauge Factor (G_f)	2.0 ± 2%
Gauge Length (mm)	10

Table 4.4 Specifications of Strain Gauges

We know that $v = V/4 * (\Delta R_1/R_1)$

Or $v = V/4 * G_f * (\Delta L/L)$

Strain $e = (\Delta L/L) = (4 * v) / (V * G_f) = 0.4\ v$

So we can find out the values of strains (e) under different loading conditions from the above expression. We know the value of modulus of elasticity E of material of the prototype so we can find out stresses at these critical points. After analysis on the software we came to know about the critical points on the Rolling Mill Housing. In our experimental set up we cemented strain gauges at these critical points and find out the value of strain and stresses under different loading conditions.

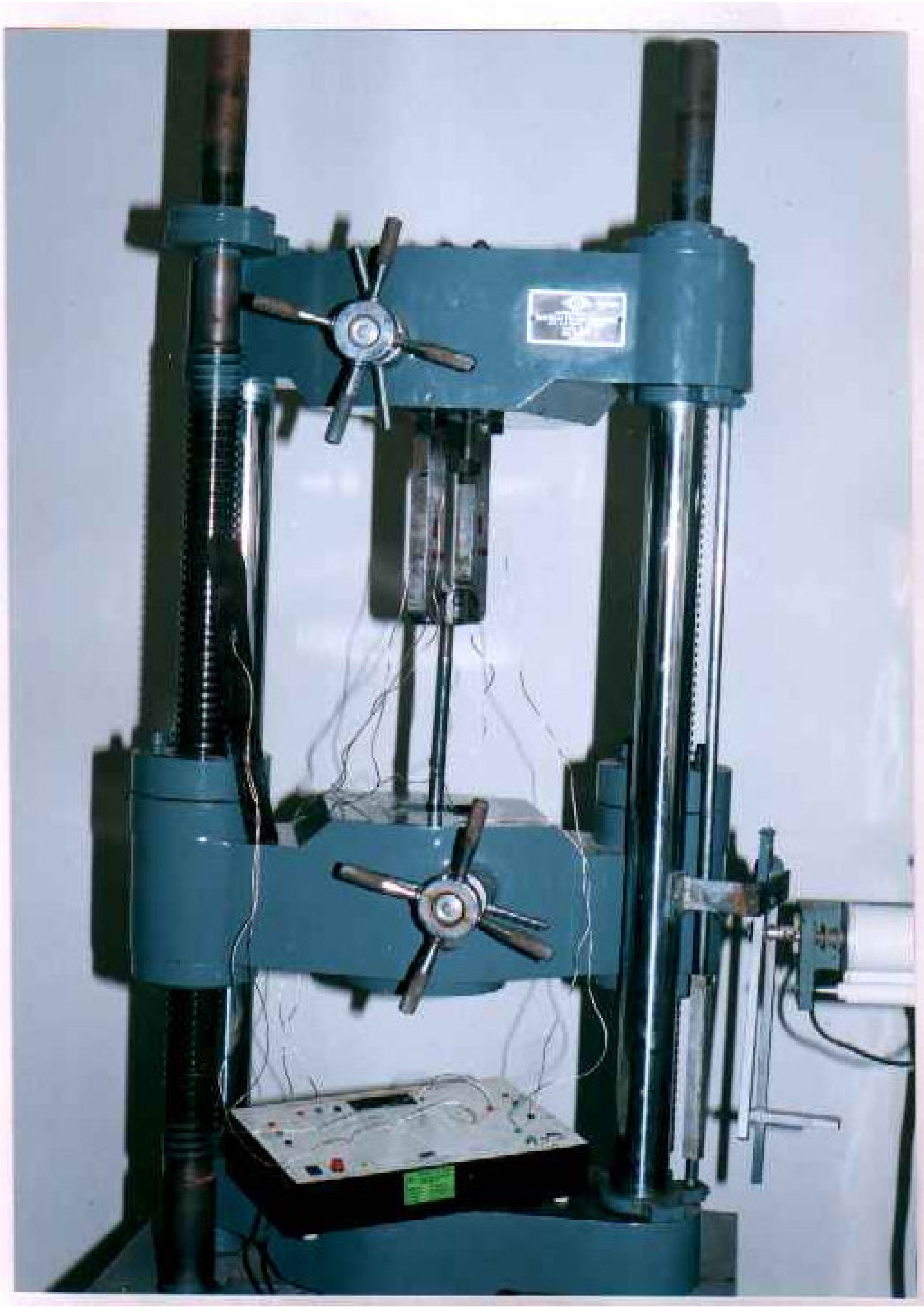

Figure 4.13 Experimental Setup

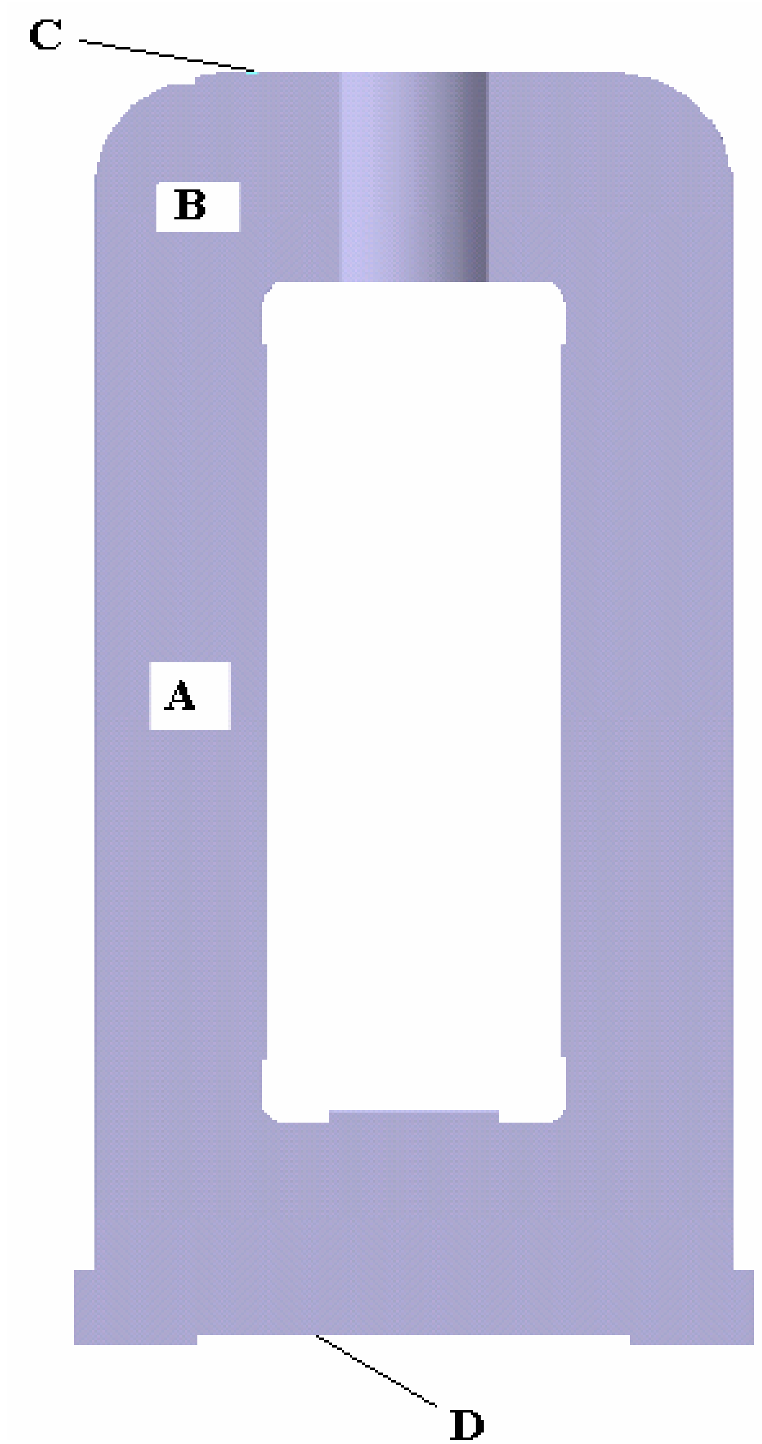

Figure 4. 14 Critical Points on the Rolling Mill Housing

LOAD (kN)	STRAINS AT CRITICAL POINTS (µs)			
	A	B	C	D
1	3.07	6.15	6.35	2.67
2	6.15	8.1	12.7	2.86
3	9.25	12.1	19	10.5
4	12.3	16.1	25.3	10.7
5	15.4	30.8	31.7	13.4
6	20.1	37	38	16.0
7	21.6	43.2	43.2	18.7
8	24.6	46	50.5	23.2
9	27.7	55.5	55.5	24.1
10	30.8	61.5	63.5	26.7

Table 4.5 Experimental Values of Strains at Critical Points under Different Loading Conditions

LOAD (kN)	STRAINS AT CRITICAL POINTS (μs)			
	A	B	C	D
1	3.9	6.5	7.15	3.71
2	6.5	8.19	11.23	4.63
3	9.67	13.2	18.2	9.8
4	12.7	15.9	27.3	11.7
5	15.9	33.1	30.7	14.1
6	20.5	35.8	41.0	15.7
7	22.1	42.2	42.2	17.1
8	25.0	47.4	53.1	24.2
9	28.3	53.2	60.4	26.43
10	39	6.5	71.5	37.1

Table 4.6 Values of Strains at Critical Points under Different Loading Conditions On Optimized Design of 1:10 scale from Catia Software

4.10 VALIDATION

In order to establish the validity of the computed results obtained from analysis software, the computed results are compared with the experimental results that are obtained from the experiment on the prototype of optimized design on universal testing machine. The solid line graph corresponds to computed results and dotted lines are corresponding to experimental results. It is clear that software results are in good correlation with the experimental results.

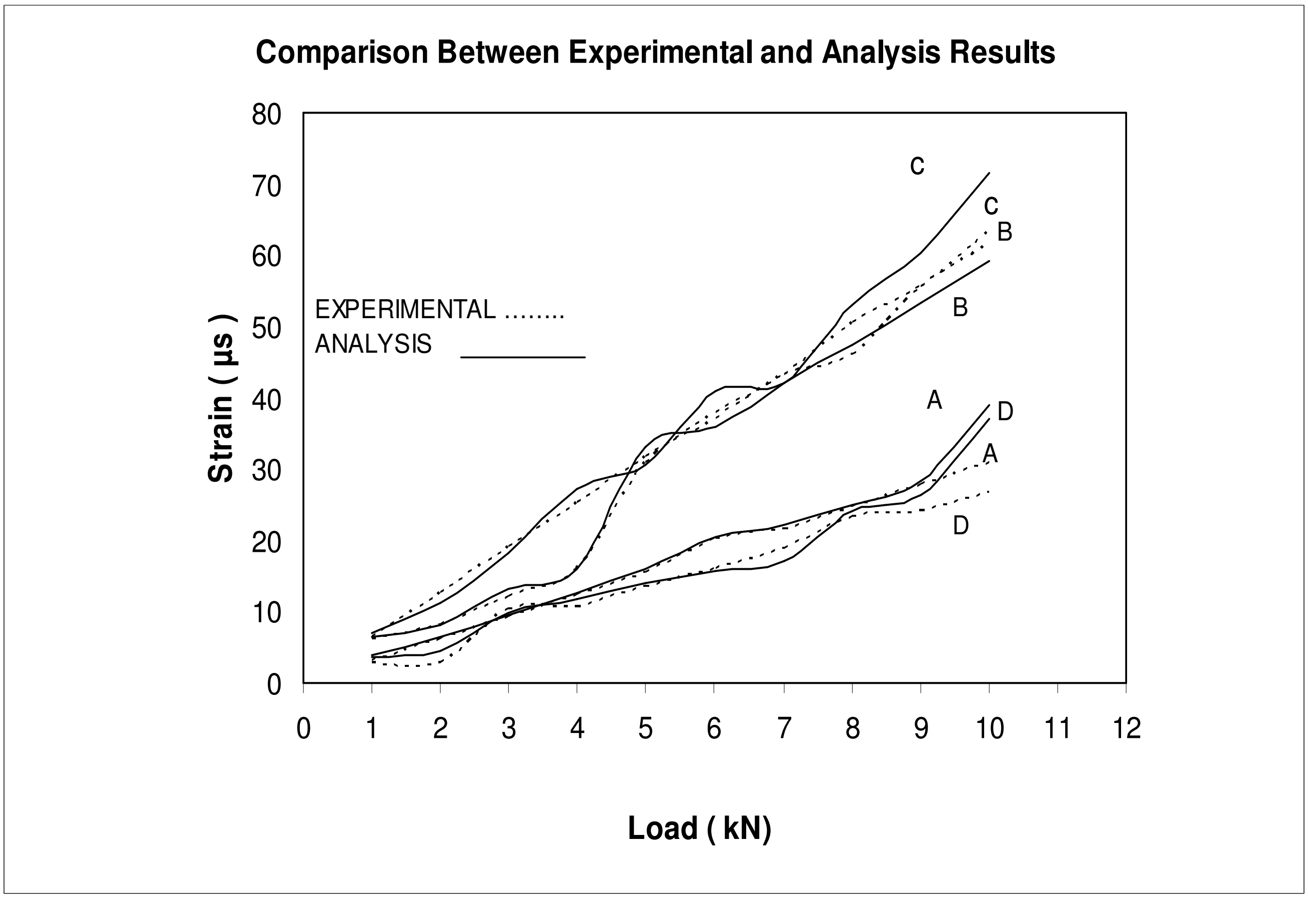

Figure 4.15 Graphs between Load and Values of Strains for Critical Points

Young Modulus	2 E11 N/m2
Poisson Ratio	0.266
Density	7860 kg/m3
Yield Strength	2.5e+008 N/m2

Table 4.7 The Structural properties of the Mild Steel material of the prototype

As we know the value of modulus of elasticity E of the material of the prototype so, we can find out the value of stresses at all critical points under different loading conditions.

LOAD (kN)	STRESS AT CRITICAL POINTS (Mpa)			
	A	B	C	D
1	0.615	1.23	1.27	0.534
2	1.23	1.62	2.53	0.572
3	1.85	2.42	3.8	2.09
4	2.46	3.23	5.06	2.14
5	3.08	6.17	6.33	2.67
6	4.02	7.4	7.6	3.2
7	4.31	8.64	8.86	3.74
8	4.92	9.2	10.1	4.64

Table 4.8 Experimental Values of Stress at Critical Points

LOAD (kN)	STRESS AT CRITICAL POINTS (Mpa)			
	A	B	C	D
1	0.78	1.30	1.43	0.742
2	1.30	1.64	2.25	0.93
3	1.93	2.64	3.64	1.96
4	25.4	3.18	5.46	2.34
5	3.18	6.62	6.14	2.82
6	4.1	7.16	8.2	3.14
7	4.42	8.44	8.44	3.42
8	5.00	9.48	10.6	4.84

Table 4.9 Values of Stress at Critical Points under Different Loading Conditions on Optimized Design of 1:10 scale in Catia Software

CHAPTER: 5

CONCLUSIONS AND FUTURE SCOPE

This chapter gives the conclusions as obtained from the results of the analysis of Rolling Mill Housing using finite element technique.

5.1 Conclusions

By simulation of the actual housing model on the software it was reveled that the beam of the housing experienced higher stresses at the place where nut of the housing screwed is nested in the beam. Analysis showed that beefing up of the beam at the place of the hole reduced the maximum stresses substantially. The dimensions of the beam were changed such that the minimum thickness of the material at the hole is 100mm. then a model reduced 1:10 scale with modified dimensions was fabricated and strain gauge testing revealed the close correlation between actual stresses measured and simulated stresses from the software.

5.2 Future Scope

Further work can be done so that housing experiences the same stresses at all sections which then be called a balanced housing. Further dimensions of the balanced housing can be proposed with respect of the diameter of nut and screw so that the housing failure does not take place in under loading.

REFERENCES:

1. **SDRC report project number 17140**, *'Final Report on ARMCO Mill Stand Evaluation',* June1990.

2. **G. P. Steven**, *'Multicriteria optimization that minimizes maximum stress and maximizes stiffness',* Computers & Structures Volume 80, Issues 27-30 , November 2002, Pages 2433-2448

3. **J. H. Rong**, *'An improved method for evolutionary structural optimization against buckling'* Computers & Structures ,Volume 79, Issue 3 , January 2001, Pages 253-263.

4. **Kurt Maute**, *'An interactive method for the selection of design criteria and the formulation of optimization problems in computer aided optimal design',* Computers Volume 82, Issue 1 , January 2004, Pages 71-79

5. **Theodore G. ToRidis**, *'Computer analysis of rigid frames, Computers',* Volume 1, Issues 1-2 , August 1971, Pages 193-221.

6. **William Prager** ,*'Conditions for structural optimality', Computers & Structures',* Volume 2, Issues 5-6 , 1972, Pages 833-840

7 **Rafael Febres**, *'Modeling of local buckling in tubular steel frames subjected to cyclic loading' ,* Computers & Structures ,Volume 81, Issues 22-23 ,September 2003.

8. **K. G. Mahmoud,** *'An efficient approach to structural optimization '* Computers & Structures Volume 64, Issues 1-4 , July-August 1997, Pages 97-112 Computational Structures Technology

9. **V. Braibant,** *'Optimization techniques: Synthesis of design and analysis',* Finite Elements in Analysis and Design Volume 3, Issue 1 , April 1987, Pages 57-78

10. **Yunliang Ding,** *'Multilevel optimization of frames with beams including buckling constraints',* Computers Volume, 1989, Pages 249-261

11. **M. E. M. El-Sayed**, *'Structural optimization with fatigue life constraints',* Engineering Fracture Mechanics Volume 37, Issue 6 , 1990, Pages 1149-1156

12. **M. Haririan**, *'Use of ADINA for design optimization of nonlinear structures',* Computers & Structures Volume 26, Issues 1-2 , 1987, Pages 123-133

13. **Michael A. Vehmeier**, *'A new method for simultaneous structural/control optimization'* Mathematical and Computer Modeling Volume 14 , 1990, Pages 248-253

14. **Tselikov, A.I.,** Theory of calculation of forces in Rolling Mills 1962.

15. SAE Bearings manual.

BIBLIOGRAPHY:

Cheung, Y.K and Yeo, M.F., *'A practical introduction to Finite Element Analysis'* Pitman pub, 1979.

Cooker's, *'Concepts and applications of Finite Element Analysis',* John Wiley & sons 1974.

Heubner, K.H., and Thornton, E.A. *'The Finite Element Method for Engineers',* John Wiley and sons, 1982.

Rao, S.S, *'The finite element methods in Engineering'* Pergamon Press, 1982.

Catia and Ansys user's manuals **Inc U.S.A**.

Robert C.Juvinall & Kurt M Marshak, *'Fundamentals of Machine component Design'*.