Design of a hydraulic test rig to test Vortex type Flowmeters

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***Abstract*—Vortex type Flow meters are one of the control equipment ranges manufactured and marketed by Forbes Marshall, India. Testing of these components is necessary as they are manufactured by the casting process. Casting processes leave a number of defects in the product, including blowholes. During operation, the Vortex type Flow meter are subjected to steam flowing at high pressures, whose flow rates are to be measured. Under such high pressure, the casting defects may cause the steam to leak out through the blowholes, in a phenomenon called 'sweating'. It is, hence, necessary to ensure the safety of the Vortex type Flow meter under operating conditions, by testing them in a rigorous but controlled environment, on a test rig.**

The project entails conceptualization, design, fabrication and testing of the test rig. The project is in conjunction with the Corporate Engineering Department (Tool Room) of Forbes Marshall. The existing test uses hydraulic cylinders to hold in place, and apply resistance pressure, to water in the test piece. These forces may cause distortion or buckling stresses within the test piece and so, an alternative was required. The concept of the new test rig is to clamp and hold the test piece using clamps, and then applying resistance pressure using the hydraulic cylinder. Thus, the hydraulic cylinder only functions as a seal to the high pressure steam inside the test piece and the holding job is done by the clamp. This eliminates the possibility of compressive stresses in the test piece. Then, high pressure can be applied in the test piece, using water and it can be tested for sweating or welding defects. The test rig will be designed keeping the functionality as the primary aim, but also considering the ergonomics and comfort of the operator. The design stage is based purely on mechanical design concepts, like bending, buckling, design of clamping mechanism and design of fixtures

for smaller and complex geometries. The design is analyzed using ANSYS by Finite Element Method for Structural Analysis. The resultant displacements are checked against 0.2mm permissible deflection, with a Factor of safety of 25%.

Index Terms—Vortex Flow meter, Blowholes, sweating, rigorous, complex, buckling

INTRODUCTION

Forbes Marshall is a leader in the area of process efficiency and energy conservation for the process industry. The company has sixty years of experience building steam engineering and control instrumentation solutions with focused investments in manufacturing and research and development. They deliver quality solutions in 18 countries. Their business practices and processes have combined into a singular philosophy of being trusted partners who provide innovative solutions.

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For over half a century, Forbes Marshall has been building steam engineering and control instrumentation solutions that work for process industry. Forbes Marshall's goal is to provide solutions in Energy, Efficiency and Process Automation, using the best technology the world has to offer. Today they comprise of twelve business divisions; most of them partnering with the world technology leaders in respective fields, manufacturing products that cover the entire spectrum of energy generation, energy efficiency, control and instrumentation for the process and power industry. They are committed for creating a progressive work culture that uniquely puts people first.

In the last five decades Forbes Marshall has grown from a modest, Mumbai based trading company to a multi-divisional, ISO 9001 certified global company manufacturing advanced engineering products for process and power industries across the World. Forbes Marshall is probably the only company in the world to have extensive expertise in both steam and control instrumentation.

The different tie-ups concerns under Forbes Marshall are as follows:

- Forbes Marshall ARCA
- Forbes Marshall CODEL
- Krohne Marshall
- Spirax Marshall
- Forbes Vyncke

1.2 BACKGROUND [7] [8]

The Variable Area Flow meter is one of the oldest and most mature principles in flow measurement. Right from the outset, the Vortex type flow meter convinced with its simple design: a float rises inside a tube as the flow increases and its position on a scale can be read off as the flow rate. Vortex type flow meters were quite popular because they provided a local readout and a simple means of flow control for a wide variety of gases viscous and non-viscous liquids; and they were relatively inexpensive. Vortex flow meter makes use of Karman effect. According to this principle, flow will alternately generate vortices when passing by a bluff body. A bluff body is a piece of material with a broad, flat front that extends vertically into the flow stream. Flow velocity is proportional to the frequency of vortices. Flow rate is calculated by multiplying the area of the pipe times the velocity of the flow.

Testing of these components is necessary as they are manufactured by the casting process which leaves a number of defects in the product. Previously the Vortex type flow meter test rig was push type rig. For this type of test rig, the

Vortex type flow meter's flange was fixed to the bottom side flange with the help of nuts and bolts. This process is time consuming. Also when the operator operates the rig with hydraulic power pack the Vortex type flow meters may buckle due to the forces applied from both side on flange. So it becomes necessary to design the test rig which will reduces these problems.

So it becomes necessary to design a functional test rig concept which is different from already existing ones that will avoid application of excessive compressive forces on it, eliminating any possibility of buckling. Also the excessive time required for testing the Vortex type flow meters reduces extensively

1.3 PURPOSE AND SCOPE OF STUDY

The project proposes the design, test, manufacture and assembly of a functional Hydro-test Rig to test Vortex type flow meter of various end flange diameters, produced by Forbes Marshall. The primary aim of the project is to design a test set up that eliminates the buckling problem encountered in the previous test rig, which may cause undesirable stresses in the test piece. Further, the project aims to reduce effort of the workers, by using a holistic approach in the design, increasing safety and reducing fatigue.

After the manufacturing and assembly of the test rig, it will be rigorously tested for functionality and safety. The data acquired will be interpreted and future scope of the project will be concluded upon by the requirement of production department.

1.4 ANALYSIS OF NEED

The objective of this Project is to design the clamp type test rig for Vortex type flow meter. Vortex type flow meters are the flow measurement equipment and are installed in connection with the pipeline. During operation, the Vortex type flow meters are subjected to water flowing at high pressures, whose flow rates are to be measured. Under such high pressure, any casting or welding defects may cause the water to leak out, potentially endangering the safety of the process equipment. It is, hence, necessary to ensure the safety of the Vortex type flow meter under operating conditions, by testing them in a rigorous but controlled environment, on a test rig.

The advantages of redesigning the test rig can be listed as follows:

- Use of clamps will eliminate the buckling force induced within the test piece during testing
- The time required for testing of each piece will be reduced by an average of 3 minutes due to provision of pallets and clamp fixing linkages
- The operator fatigue will be reduced due to removal of repetitive work of affixing the Vortex type flow meter flanges to the bottom flange
- Operator efficiency will increase due to provision of foot operated hydro power packs with pressure gauges
- The overall ergonomics of the test rig has been improved
- The general procedure that will be adopted for designing of the test rig will include calculation of test pressure to be applied on the test piece from company data sheets, finalization of concept and components of the test rig, design of components and instrumentation in the test rig, 3D and 2D detailed modeling of the parts, selection of hydraulic and pneumatic components, manufacturing and assembly of the test rig, testing and interpretation of results.

EASE OF USE

2.1 NEED OF HYDRAULIC TEST RIG [7]

Testing of Vortex type flow meter (components) is necessary as they are manufactured by the casting process which leaves a number of defects in the product. Previously the Vortex type flow meter test rig was push type rig. For this type of test rig, the Vortex type flow meter's flange was fixed to the bottom side flange with the help of nuts and bolts. This process is time consuming. Also when the operator operates the rig with hydraulic power pack the Vortex type flow meters may buckle due to the forces applied from both side on flange. So it becomes necessary to design the test rig which will reduces these problems.

So it becomes necessary to design a functional test rig concept which is different from already existing ones that will avoid application of excessive compressive forces on it, eliminating any possibility of buckling. Also the excessive time required for testing the Vortex type flow meters reduces extensively.

2.2 TECHNICAL ASPECTS OF THE TEST RIG [8]

Vortex type flow meters are the most widely used type of variable-area (VA) flow meter. In these devices, the Vortex flow meter makes use of Karman effect. According to this principle, flow will alternately generate vortices when passing by a bluff body. A bluff body is a piece of material with a broad, flat front that extends vertically into the flow stream. Flow velocity is proportional to the frequency of vortices. Flow rate is calculated by multiplying the area of the pipe times the velocity of the flow.

In some cases, vortex meters require the use of straightening vanes or straight upstream piping to eliminate distorted present a problem for vortex meters, because they generate vortices irregularly under low flow conditions. The accuracy of vortex Flow meters is from medium to high depending on model and manufacturing. In addition to liquid and gas flow measurement,

vortex flow meters are widely used to measure steam flow. Vortex flow meters are well suited for measuring steam flow, and they are widely used for this purpose. Steam is arguably, the most difficult fluid to measure. This is due to the high pressure and high temperature of steam, and because the measurement parameters vary with the type of steam. Main type of steam includes wet steam, saturated steam and super heated steam. Steam is often measured in process plants and for power generation. Vortex and DP

Flow meters are primary used to measure steam. Magnetic flow meters cannot measure steam flow. In addition to their steam flow at varying velocities, steam is often measured coming from boiler.

UNITS

Units used are:-
For mass tones.
For pressure bar (kg/cm2)
For Stresses (N/mm2)
For Force Newton (N)

LITERATURE REVIEW

4.1 WORKING PRINCIPLE

The concept of the new test rig is to clamp and hold the test piece using locaters of variable diameters, and then applying resistance pressure using the hydraulic cylinder. Thus, the hydraulic cylinder only functions as a seal to the high pressure water inside the test piece and the holding job is done by the locater. This eliminates the possibility of compressive stresses in the test piece. Then, high pressure can be applied in the test piece, using water with the help of Hydraulic Power Pack, and it can be tested for sweating or welding and casting defects.

The test rig will be designed keeping the functionality as the primary aim, but also considering the ergonomics and comfort of the operator. The design stage is based purely on mechanical design concepts, like bending, buckling, design of clamping mechanism, and design of fixtures for smaller and complicated geometries.Equations

4.2 SELECTION OF MECHANISM & WORKING PRINCIPLE

The test rig works on the principle of non destructive testing the vortex type flow meter which is an essential part of the boiler equipment will be tested in the mechanism. The rig works the following way:-

The flow meter under test is filled with water this water is under pressure, pressuring is achieved with the help of the pump. Therefore the work piece i.e. the vortex type flow meter filled with water under pressure is placed under a commendable value of clamping force. Now the object along with water is under the action of the clamping force, the flow meter if fitted with flanges on either sides and is generally casted in a mould the pressure difference generated due to the action of the clamping force causes water to come out of the minor cracks, pores and leaks, blow holes produced due to casting. Preventing the leakage of the fluid flowing through it.

The concept of the test rig is to clamp and hold the test piece using locaters of variable diameters, and then applying resistance pressure using the hydraulic cylinder. Thus, the hydraulic cylinder only functions as a seal to the high pressure water inside the test piece and the holding job is done by the locater.

An AUTOCAD diagram/Design of selected mechanism is shown in figure bellow-

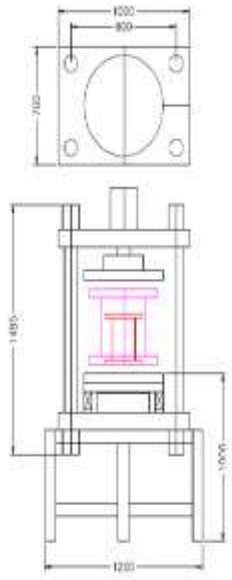

Figure1. 2D CAD Model

3.3 DESIGN CONSIDERATION

The test rig will be designed keeping the functionality as the primary aim, but also considering the ergonomics and comfort of the operator. The design stage is based purely on mechanical design concepts, like bending, buckling, design of clamping mechanism, and design of fixtures for smaller and complicated geometries. The design is analyzed using ANSYS for Structural Analysis. The resultant displacements will be checked against 0.2 mm permissible deflection. The Factor of safety for tie rods is 2.5 for Top and Bottom plate is 1.25.

CALCULATIONS

1. CLAMPING FORCE (F_c) IN TONES BY CONSIDERING FOS of 1.25 -

F_c= (hydrolic force)H_p×(mean diameter)D_m ×(area)A ×(fos)1.25/1000 , Tone

2. Power Pack Pressure-

P= (clamping force) F_c×1000×л×20^2 kg/cm^2

3. Thickness of Top And Bottom Plate-

Calculation Based On Deflection
CONSIDERATION
Assuming the bottom plate to be simply supported

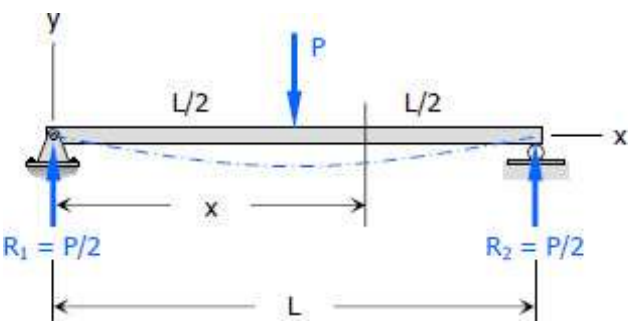

Figure2.simply supported beam

The deflection criteria make use of Macaulay's method to calculate the thickness of plate .

The equation is as follows:-

$Y = (WL^3)/48EI$

$0.2=(70\times9.81\times10^3\times1000^3)/((48\times260\times10^3\times(1000\times t^3/12))$

Thickness (t) = 128.902mm

Assuming the thickness of plate as 100mm for analysis purpose as it is easily available in market.

4. Calculation For Diameter of Tie Rod-

Number of tie rods (n) = 4

Force per tie rod= 70/4= 17.5 tone

FOS=2.5

Allowable stress=260Mpa

Stress= 260/2.5= 104Mpa

By considering Tensile Shear of Tie rod

Strss= Force/Area

$104=(17.5\times9.81\times1000)/(л/4 \times D^2)$

D= 45.8449 m

By considering standard value

D=50mm

5. Tie Rod Threading-

Using ACME threads-

$ϴ= 14.5^o$

μ=0.15

D_c=50mm

FOS=104Mpa

W=17.5 tone

Assuming

No of teeth in contact z= 10

Pitch P= 5mm

$D_o= 2P+ D_c= 60mm$

$Φ= tan^{-1}(0.15)= 8.53^o$

The shear area on the thread is ($л\ D_c t$) therefore the transverse shear stress in the screw is-

$г = W/ (лzt\ D_c)$

$104= (17.5\times9.81\times10^3)/(50\times л\times10\times t)$

t= 1.05mm

Selecting standard value

t=1.5mm

Under the action of load W the thread will tend to shear of-

$г = W/(л\ z\ t\ D_c)= (17.5\times9.81\times10^3)/(л\times50\times1.5\times10\times$

г = 72.8611Mpa

г < allowable stress

6. Selection of C-channel For Bench-

For the approximate load of 75tone including the load of design parts, The C-channel is selected from the IS 808: 1989 (Reaffirmed 1999). Light weight LC125 channel is selected for the load of 75tone.

5.3 2D CAD MODELING

1] Design of Top Plate-

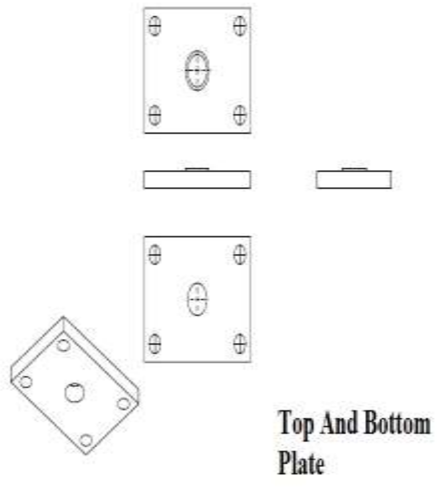

Fig. 3. Top and Bottom Plate Design

2] Design Of Tie Rod

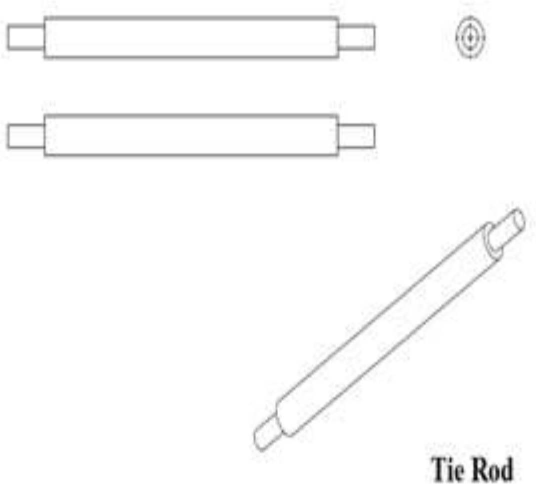

Fig. 4. Tie Rod Design

ANALYSIS

1] Static Analysis of Bottom Plate (Total Deformation)-

The static structural analysis is done against the acting force of 70 tones.

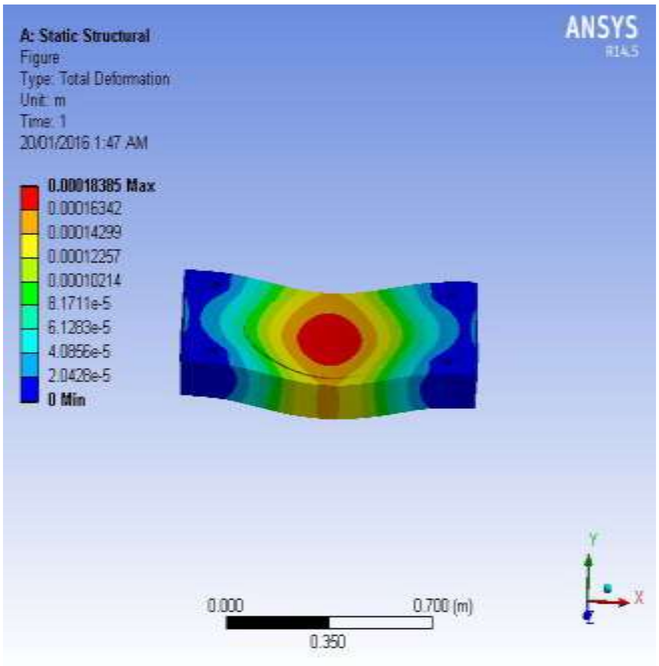

Fig. 5. Analysis Of Bottom Plate

The maximum deflection of bottom plate due to the acting force of 70 tons is 0.18mm which is less than allowable deflection of 0.2mm, Hence the plate is safe under the action of applied force

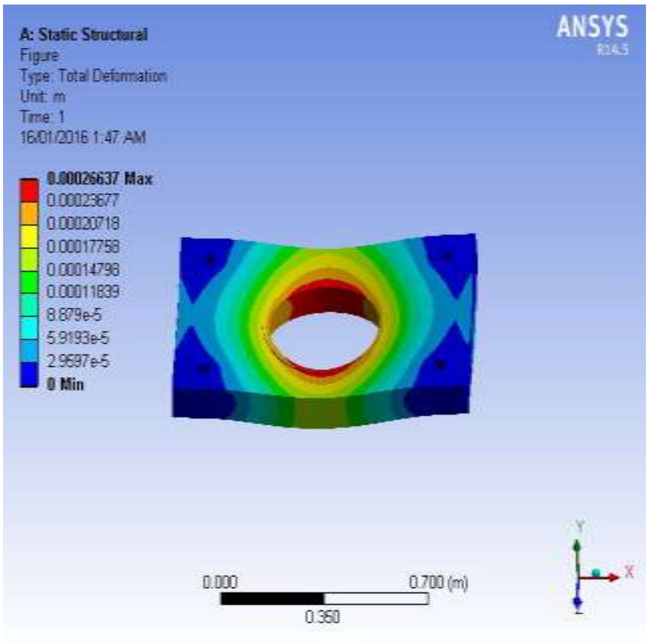

Fig. 6. Analysis Of Top Plate

The maximum deflection of bottom plate due to the acting force of 70 tones is 0.18mm which is less than allowable deflection of 0.2mm, Hence the plate is safe under the action of applied force

3] Static Analysis of Tie Rod (Maximum Shear Stress)-

The static structural analysis is done against the acting force of 17.5 tons per tie rod.

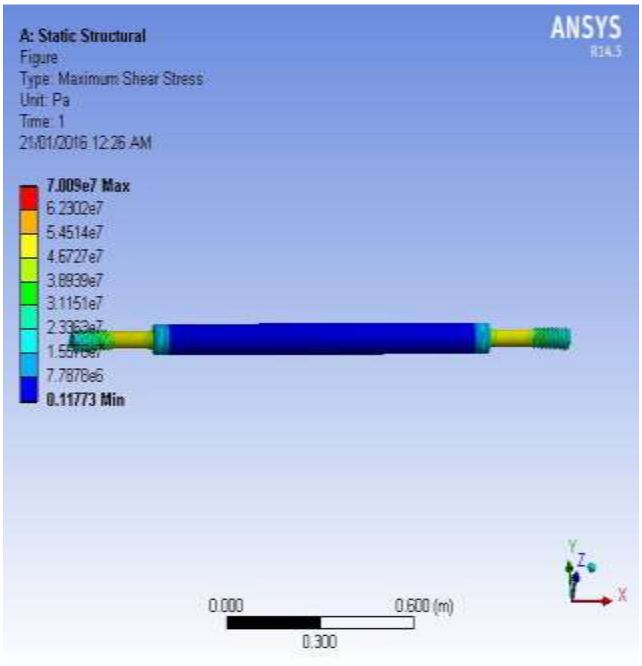

Fig. 7. Analysis Of Tie Rod

The maximum shear force induced in tie rod under the acting force of 17.5 tons per tie rod is 70.9Mpa which is less than the allowable stress of 72Mpa, Hence the tie rod is safe under the action of applied force.

Static analysis of bench maximum shear stress.
Static structural analysis is done against 75 tones.

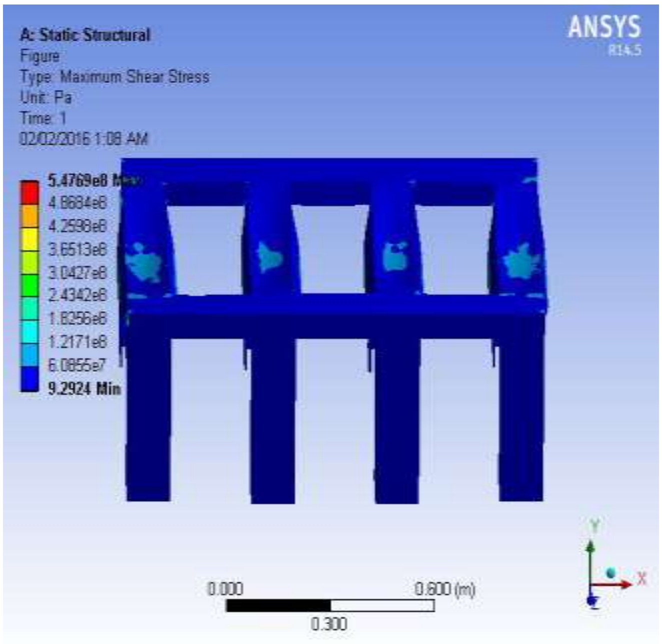

Fig. 8. Anslysis Of Bench

The maximum shear force induced in tie rod under the acting force of 75 tons is 330 Mpa which is less than the allowable stress of 350 Mpa, Hence the Bench is safe under the action of applied force.

OUTCOME

The excepted outcome of Design project is as follows-

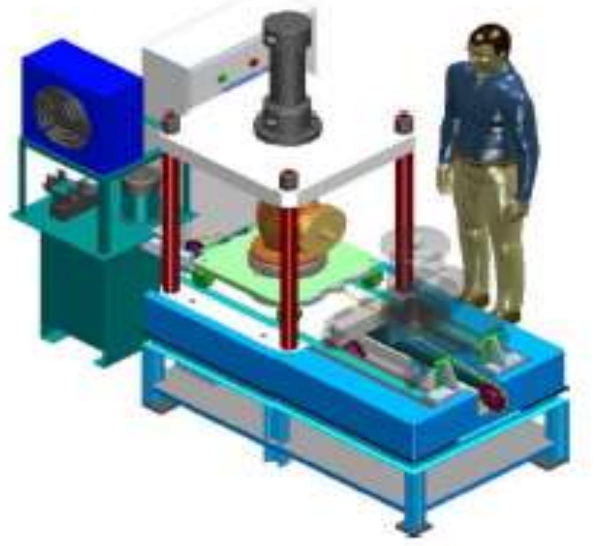

Fig. 9. Expected Output

ACKNOWLEDGMENT

First and foremost, I would like to express my sincere gratitude to my guide Prof S.S.Hirmukhe, for whom I have greatest amount of respect and admiration. He has not only afforded me the opportunity to work on this topic but also provided valuable guidance and support throughout my time as a student in Mechanical Engineering Department, Bhivarabai Swant College of Engineering and Research, Narhe, Pune (MS). His enthusiasm, interest and inspiration, was a constant source of motivation for my encouragement. I am greatly thanking him for sparing his precious time, help and patience in the betterment of my project work. I am sincerely thankful to Dr. D V Jadhav, Principal, and Prof. P. R. Kale, Head of Mechanical Engineering Department, for their kind guidance and support throughout this work.

I express my deep gratitude to all staff members of Mechanical Engineering Department for providing me valuable suggestions and help during my project work. I would like to thank to all my friends, especially Rohan Mirajkar Tanmay Boravke, who have helped me extensively right from the beginning of the project. And last but not least the backbone of my success & confidence lies solely on the blessing of my parents. I owe my loving thanks to them. They have lost a lot due to my work. Without their encouragement and understanding, it would have been impossible for me to finish this work.

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