ME 401 : SUMMER TRAINING REPORT

A project report submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology

By

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(Roll No. 210103099)

Under the supervision of

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Project Title

Life & Reliability Enhancement of Furnace Walking Beam Tie Rod

Department of Mechanical Engineering

Indian Institute of Technology Guwahati

Guwahati-781039, Assam, India

May 2024 – July 2024

CERTIFICATE

(This certificate is to be obtained*, in the original letterhead of the Head of the Department of the Organization where an IIT Guwahati student undergoes and completes his/her internship programme)

UG/03 Form

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Sub: Certificate in regard to completion of Internship programme by Mr./Ms..Saurabh..Kumar...

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This is to certify that Mr./Ms...Saurabh..Kumar............................., bearing IIT Guwahati's Roll No....210103099................, did his/her Summer Internship Programme in our organization, from 20th May, 24. to 17th July, 24. He/She completed Internship Programme in our organization, in the area of Furnace Walking Beam., New Bar Mill.

His/Her conduct and performance during the said Internship Programme was found to be:

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MANISH KUMAR

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Head
M&U MM - NBM

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to Tata Steel Jamshedpur for providing me with the opportunity to intern at the prestigious organization. This internship has been an invaluable experience, allowing me to apply theoretical knowledge to real-world challenges.

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Thank you all for making this internship a truly enriching experience.

Saurabh Kumar

210103099

ABOUT TATA STEEL

Tata Steel, a flagship company of the Tata Group, is one of the world's leading steel manufacturers, with a global footprint and a rich legacy of over a century. Founded in 1907 by Jamshedji Tata, Tata Steel has played a pivotal role in the industrialization of India and has grown to become a key player in the global steel industry.

Headquartered in Mumbai, India, Tata Steel operates in over 26 countries with key manufacturing facilities in India, Europe, and Southeast Asia. The company is renowned for its innovation, sustainability initiatives, and commitment to quality, making it one of the most respected and ethical brands in the industry.

Tata Steel's integrated operations span the entire value chain of steel manufacturing, from mining and processing of raw materials to the production and distribution of finished steel products. The company's product portfolio is extensive, catering to a wide range of industries including automotive, construction, consumer goods, and industrial machinery.

In India, Tata Steel is synonymous with innovation and sustainability. The company has pioneered numerous initiatives to reduce its environmental impact, including the use of green technologies and renewable energy sources. Its focus on corporate social responsibility (CSR) has also set benchmarks in areas like education, healthcare, and community development.

The New Bar Mill at Tata Steel's Jamshedpur plant, where this project was conducted, is a state-of-the-art facility designed to produce high-quality reinforcement bars. It reflects Tata Steel's commitment to adopting the latest technologies and maintaining world-class operational standards. The mill plays a crucial role in the company's efforts to meet the growing demand for high-grade steel rebar products in both domestic and international markets.

Tata Steel's dedication to excellence, sustainability, and social responsibility continues to drive its growth and success in the global steel industry, ensuring its position as a leader in the sector for years to come.

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ABSTRACT

The project titled "Life and Reliability Enhancement of Furnace Walking Beam Tie Rod" was initiated in response to a sudden tie rod failure two years ago at the New Bar Mill, which resulted in significant operational losses. The primary objective was to enhance the life and reliability of the furnace walking beam tie rod, a critical component in the mill's operations.

The approach involved a comprehensive analysis of past failure data, along with the verification of the tie rod design using Finite Element Analysis (FEA). Additionally, detailed studies were conducted on potential welding defects, vibrational impacts, and hydraulic components associated with the tie rod system. The findings revealed that welding defects were a key contributor to the premature failure, significantly reducing the component's lifespan. Another issue identified was the unsynchronized motion of hydraulic cylinders, which led to operational delays.

Based on these findings, several recommendations were made, focusing on design improvements, measures to be taken and refinements in hydraulic circuits. To address welding issues, a Welding Procedure Specification (WPS) was developed as a checklist to ensure consistent welding quality. Furthermore, to provide a real-time overview of the furnace's operational health, a Furnace Health Index was conceptualized and a prototype for its implementation was developed.

This project aims to mitigate the risks of future failures and enhance the overall reliability and efficiency of the furnace walking beam system.

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1. Introduction

New Bar Mill lies in the steel manufacturing division in the Tata Steel JSR value chain. The value chain shown below gives the brief idea of working of the plant. New Bar Mill is a dedicated mill to produce reinforcement bars of various grades and dimensions based on lastest technology and improved quality of rebars.

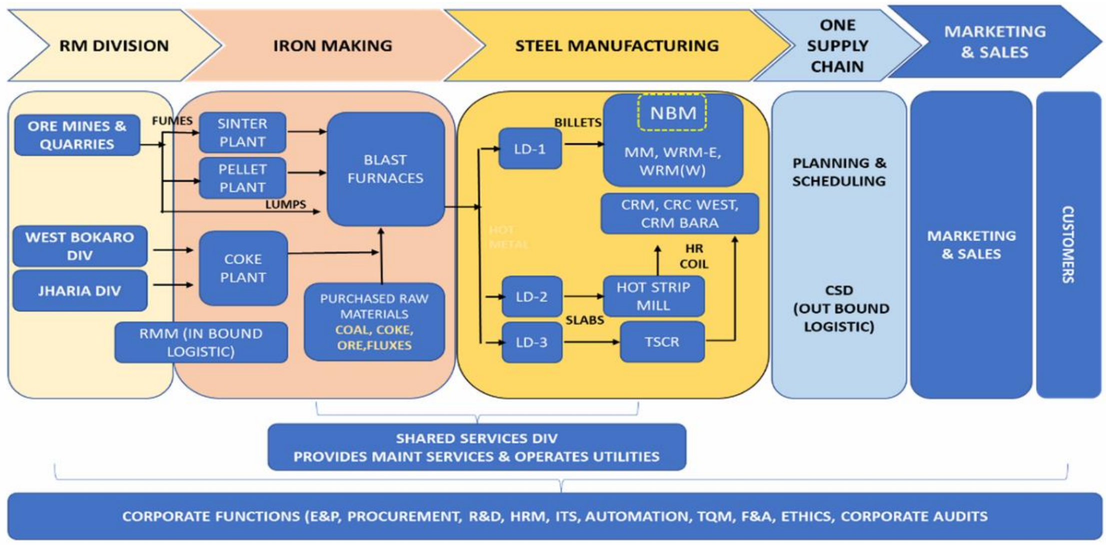


Fig. Tata steel JSR value chain

1.1 An Introduction to New Bar Mill & TATA TISCON

Tata Steel, the 10th largest steel producer in the world, is one of the first few companies in India to introduce Thermo Mechanically Treated reinforcement bars, using the latest technology - the ‘Tempcore Process’ (introduced in India for the first time by Tata Steel under license from Centre de Rechaerche Metallurgiques (CRM), Belgium), which imparts high strength to the bar as against cold twisting, a traditional manufacturing process.

TATA TISCON 500D is a cut above the traditional rebars in the market owing to low levels of Sulphur & Phosphorus (S&P) which are harmful impurities in steel. High levels of Phosphorus can lead to ‘cold shortness’ in steel where the steel tends to become very brittle under extreme cold conditions and thus vulnerable to cracking. High level of Sulphur can lead to ‘hot shortness’ in steel, a condition in which the melting point of steel gets lowered thereby reducing its strength dramatically under high temperature conditions. However, lower levels of S&P can be achieved only through advanced steel making technology. Such low S&P levels, as specified in the 500D specifications of BIS, are almost impossible to be achieved through normal scrap & induction furnace route.

Tata Steel has set up a new bar mill with the latest technology supplied by Morgan, USA in 2005. The mill consists of Billet storage facilities in Billet Yard, 150 t/hr capacity furnace supplied by Bricmont USA, eight stand Roughing Mill, eight stand Intermediate Mill with power slitter, two 6 stand NTM`s. The mill layout is a continuous type. The mill is equipped with state of art cooling bed with Braking Pinch Rolls facilities. TATA TISCON 500D rebars are 'hot rolled' from steel billets and subjected to PLC controlled on-line thermo-mechanical treatment in three successive stages:

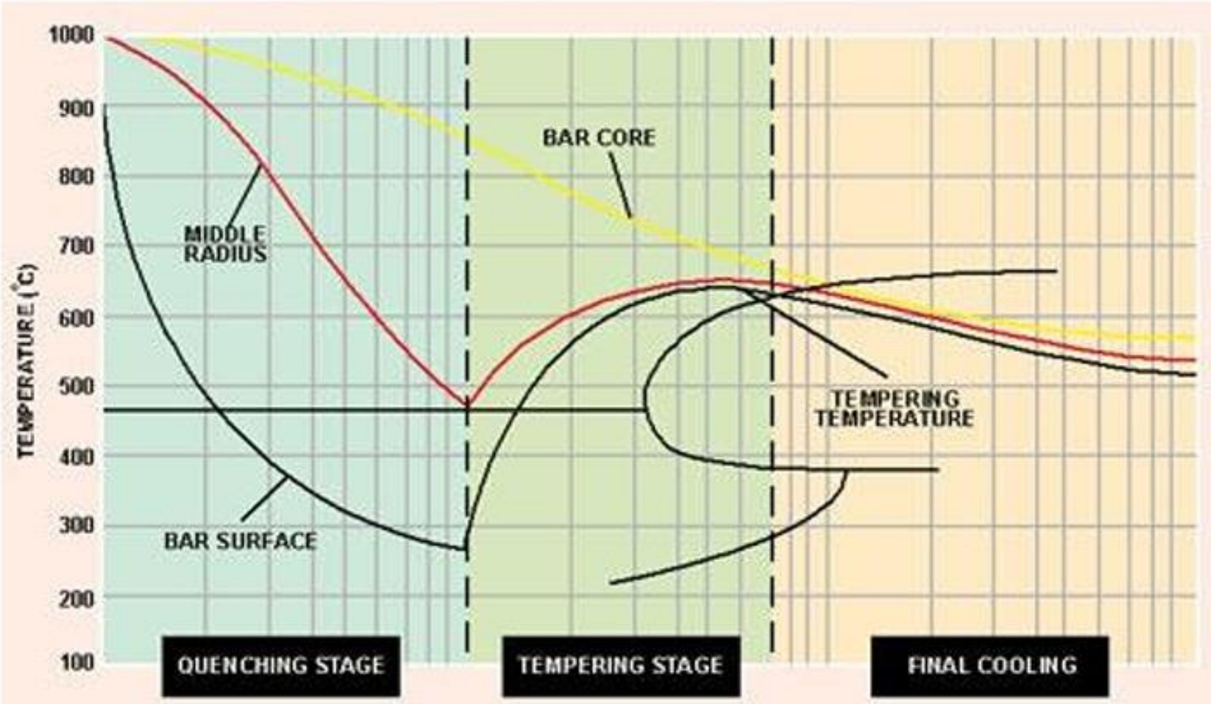


FIG.

(a)Quenching - The hot rolled bar leaving the final mill stand is rapidly quenched by a special water spray system. This hardens the surface of the bar to a depth optimised for each section through formation of martensitic rim while the core remains hot and austenitic.

(b) Self Tempering - When the bar leaves the quenching box, the core remains hot compared to the surface, allowing heat to flow from the core to the surface, causing tempering of the outer martensitic layer into a structure called 'Tempered Martensite.' The core still remains austenitic at this stage.

(c) Atmospheric Cooling - This takes place on the cooling bed where the austenitic core is transformed into a ductile ferrite-pearlite structure. Thus the final structure consists of an optimum combination of a strong outer layer (tempered martensite) with a ductile core (ferrite-pearlite). This gives TATA TISCON 500D its unique combination of higher strength and ductility.

1.2 New Bar Mill : Process Flow

NBM receives its raw material which is billets from LD-1 (a mill at Tata Steel JSR which manufactures billets from iron) and then these billets are reheated in the furnace for making reinforcement bars of diameter 8mm, 10mm, 12mm and 16mm. After achieving required heating, billets move for rolling purpose into 8 roughing mill stand and 8 intermediate mill stand. From there it get divided into 2 lines which later get divided into 2 each. Then it proceeds to cooling bed where appropriate cooling is done as per requirements and to strapping machines and get dispatched. Our area of study is Walking Beam Reheating Furnace.

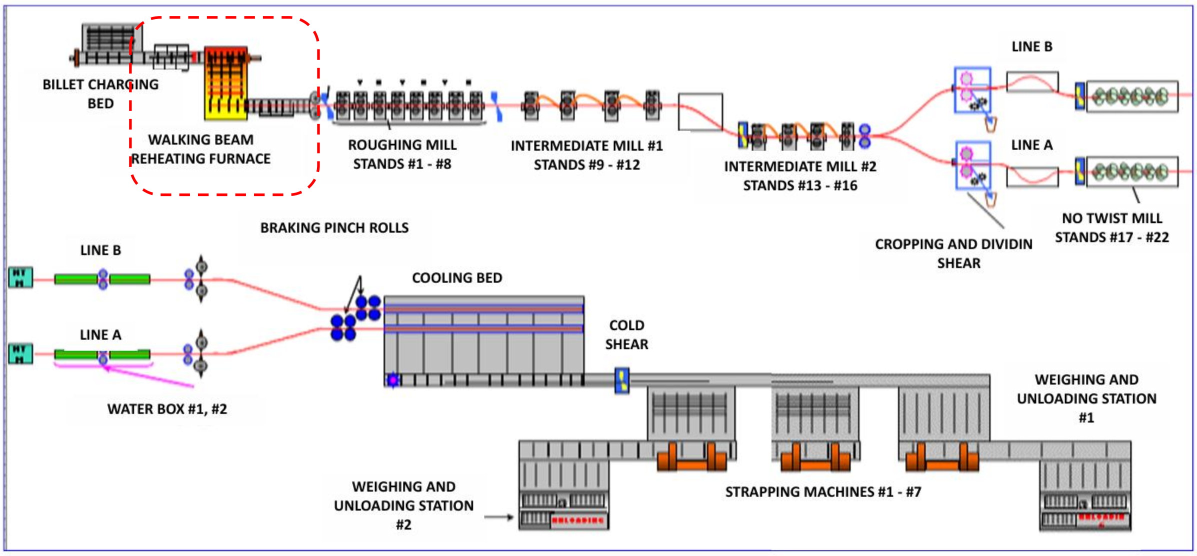
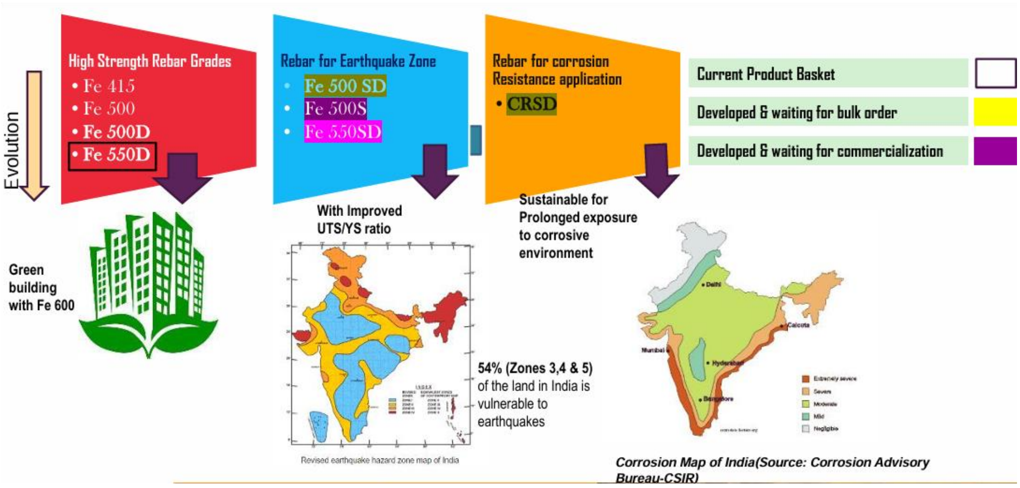


Fig.

1.3 NBM : Products



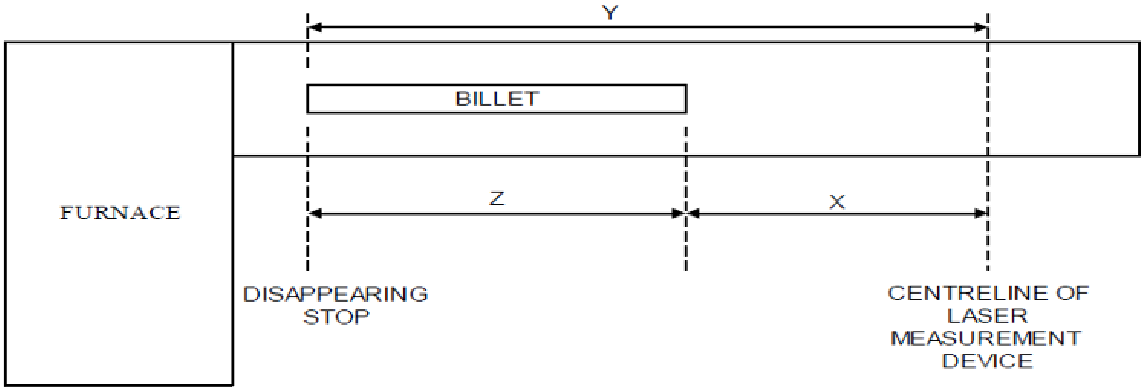
Fig

1.4 Mill Providing and Furnace

Billets are received from LD # 1-CC# 2 by loco & captive wagons and stored in the NBM Billet Yard. Stacking is done by o-h cranes (two-20t+15t).

Billets are transferred to walking beam billet charging skid by the cranes. Skids are arranged perpendicular to the furnace charging tables so that billets are advanced across the level of the skids to the tables. Finger stopper holds the billets until ready for deposit onto the furnace charging table. Billet front end hits against the disappearing stopper, and properly positions itself for length measurement.

As the billet stops, the laser signal is monitored; this signal is converted into a distance measurement (X). The distance between the laser measurement system and the disappearing stop is known (Y) The system can then calculate the Billet length: - Y-X =Z.



Billet in the range of 11.65-11.98M will be charged automatically in ‘Load Mode’ or with ‘Mill Call’; an alarm is generated for billet length below 11.75 m and above 12.00 m. Length beyond 11.65 or 11.98M cannot be bypassed. The billets are discarded onto the tray and stored at different locations identified for long length/Short length/Bend and other defects. This is to standardize the length and to ensure that no abnormal length is charged in Furnace, thereby eliminating the chances of billet touching the wall.

- Bend : Straightening M/C bed
- Long: Bed Adjacent to Discarder tray and then to CC#2 for trimming
- Short: Bed Adjacent to Discarder tray and then to CC#2
- Others: Bin#AA01 for dispatch to outside party

Billet Crowder bar is used to align the charged billets inside the furnace. After the Billet is positioned on the Charge Rolls inside the Furnace, the “Charge Complete” bit is set true and the Walking Beam can begin a cycle. After reheating the billet gets discharged from the furnace through the furnace discharge roll table and proceed to rolling process.

1.5 Bricmont Reheating Furnace

It is a Top & Bottom fired walking beam type furnace.

DIMENSION	W = 12.60 Mtrs:. L = 18.375 Mtrs
HEATING CAPACITY	150 TONS/Hr
FUEL	Mixed Gas@3800Kcal/Nm3
CHARGE & DISCHARGE	SIDE (In furnace rolls)
TEMPERATURE	1150OC (Max). At Soaking zone
TYPE OF HEATING	From side walls. (32 Burners)
HEAT RECOVERY	Recuperator
NO. OF SKIDS	09 (Moving = 04 & Stationary = 05)
FUEL RATE	0.294 mkcal/t of steel

REFRACTORY:

ROOF: - Super duty Plastic

SIDE WALL: - 42% Al2O3 Insulating Fire Bricks

HEARTH: - High Strength HHD Castables

SKIDS: - Low cement Castables/Ceramic Fibers.

1.5.1 Walking Beam: Billet Movement inside furnace

There are 5 discrete positions the Walking Beam can be in:

1. Down/Retracted Position - The Walking Beam is in its lowest position and is fully retracted, closest to the charge end of the Furnace.

2. Retracted/Up Partial Position - The Walking Beam is fully retracted, closest to the charge end of the Furnace, and the Walking Beam elevation is at the same level as the stationary skids. When the Walking Beam is in this position the Charge Rolls will be stopped and the Discharge Rolls will be turning at their minimum speed. This is considered the "Home Position" of the Walking Beam. Before the MH system can be switched to automatic the Walking Beam must be in this position.

3. Retracted/Up Full Position - The Walking Beam is retracted and raised to its maximum elevation. This position is selected after the Mill has called for a Billet and/or a walk sequence has begun.

4. Up Full Position/Forward - After the Walking Beam reaches the previous position, the command to go to the Forward position is set true. In this position the Walking Beam will be at its maximum elevation and full forward position. When the Walking Beam is in this position the Charge Rolls will be turning at their minimum speed and the Discharge Rolls will stop turning.

5. Down Position/Forward - After the Walking Beam reaches the previous position, the Down Command is issued. At that time the Furnace discharge door will be given an open command. Once the door open and the Walking Beam Down indications are received, the Discharge Rolls will match Mill speed and direction. At the same time the Charge Rolls will be given the charge speed set point.

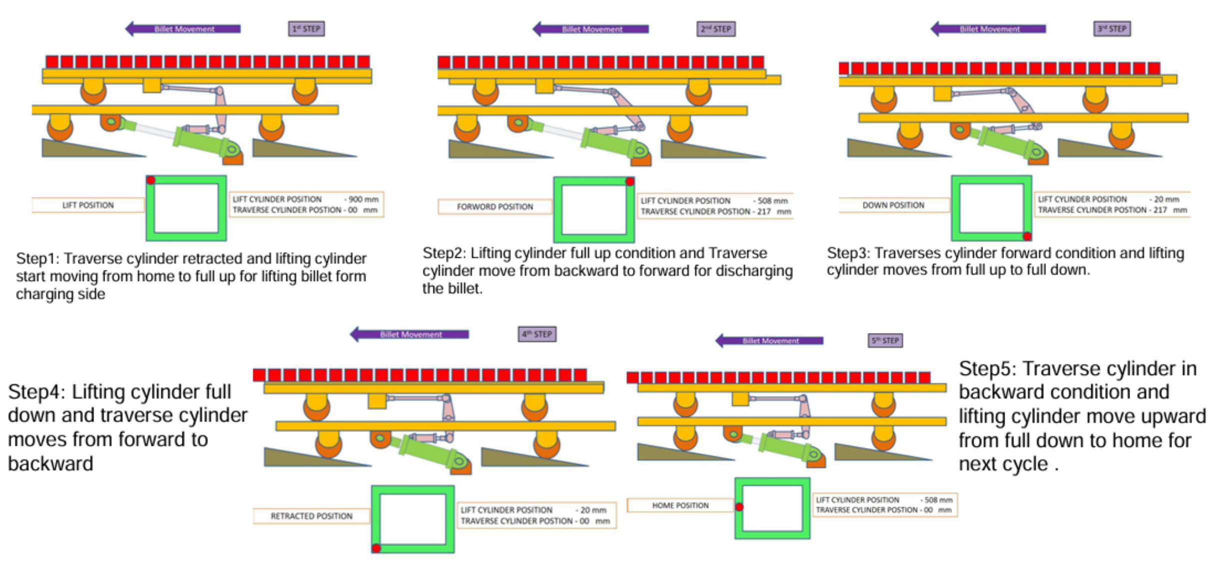


Fig. walking beam mechanism

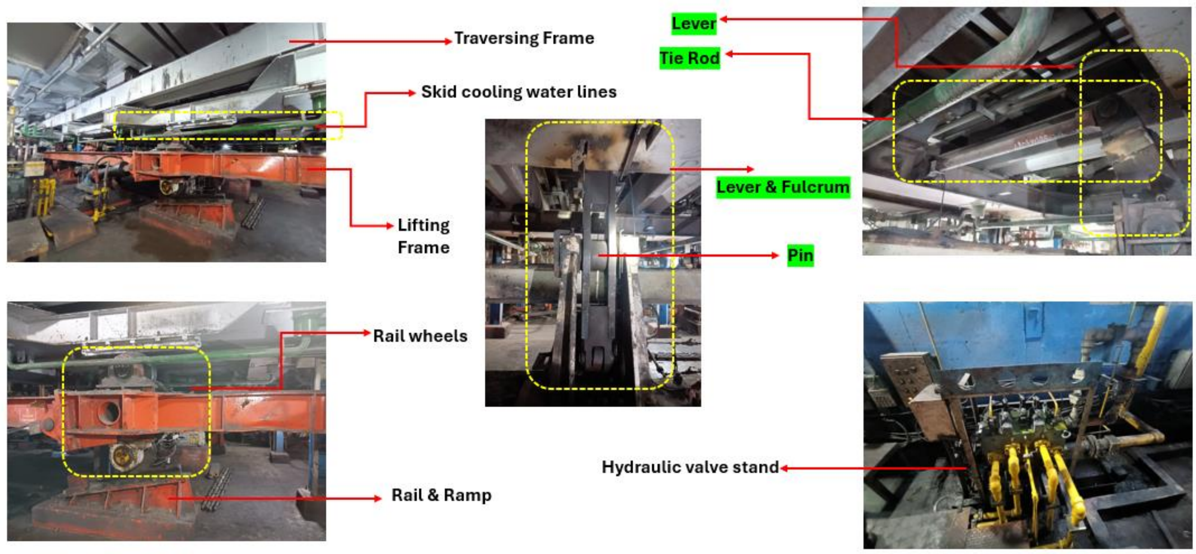


Fig. components of walking beam (Highlighted: critical components as per analysis)

Various mechanical components of walking beam are:

- Tie Rod
- Lever
- Fulcrum & pin
- Lift frame & Traverse frame
- Rail-Wheel- Ramp assembly
- Hydraulic cylinders, valves and entire circuits
- Various other linkages and joints

1.6 Project Motivation

Two years ago, the sudden failure of a furnace walking beam tie rod at Tata Steel's New Bar Mill caused significant operational disruptions and financial losses. This event highlighted the urgent need to enhance the life and reliability of this critical component. Additionally, recurring delays in the mill, caused by the unsynchronized motion of hydraulic cylinders, further impacted productivity and led to additional losses.

The motivation for this project is to address these challenges by analyzing past failures, improving tie rod design, mitigating welding defects, and proposing solutions for hydraulic synchronization issues. The ultimate goal is to prevent future failures, reduce downtime, and enhance the mill's overall efficiency.

1.7 Outline of Report

The report is structured according to the DMAIC methodology, which focuses on Define, Measure, Analyse, Improve, and Control phases. The **Introduction** will provide background on the project, including its objectives and the importance of the furnace walking beam tie rod and hydraulic system in Tata Steel's New Bar Mill operations.

In the **Define** phase, the report will articulate the problem statement, addressing the sudden failure of the tie rod and operational delays caused by unsynchronized hydraulic cylinders. This section will also highlight the other delays during the analysis and will try to get into its root cause.

The **Measure** phase will detail the data collection process, covering failure and other relevant data and operational metrics related to both the tie rod and the hydraulic system. Key performance indicators such as strain in tie rod which is the first cause of any type of failure prediction, welding quality, and hydraulic synchronization will be defined, along with the tools and techniques used to gather this information.

In the **Analyze** phase, the report will delve into the root cause analysis, which includes Finite Element Analysis (FEA) of the tie rod design, a study of welding defects, vibrational analysis, and a detailed examination of hydraulic synchronization issues. The findings from these analyses will be summarized to pinpoint the main causes of failure and delays.

The **Improve** phase will present recommendations for enhancements, including design improvements for synchronization, the development of a Welding Procedure Specification (WPS) checklist, and suggestions for optimizing hydraulic system synchronization. Additionally, a prototype for a Furnace Health Index will be introduced, alongside a plan for implementing real-time monitoring of critical components.

Finally, the **Control** phase will focus on establishing measures to maintain these improvements over time. This includes monitoring the tie rod's health using the Furnace Health Index, enforcing regular welding inspections, and ensuring continuous synchronization of the hydraulic system. The report will conclude with a summary of the project outcomes, key learnings, and future recommendations.

2. Delay Report Analysis

This section aims to investigate the recurring operational delays at the New Bar Mill, which have significantly impacted productivity and financial performance. These delays were primarily linked to overall problems in the mill whose effect can be seen as operational delay and therefore a good way to define the problem and then work on its improvement. This section will explore the root causes of these delays, assess their impact on mill operations, and provide a base of the problems to be addressed and enhance overall efficiency.

First of all we would analyze the delay data of last two financial years and then we would focus only on mechanical issues in the furnace. The result of analysis has been shown below in the concise manner indicating all delays that has occurred in the mill.

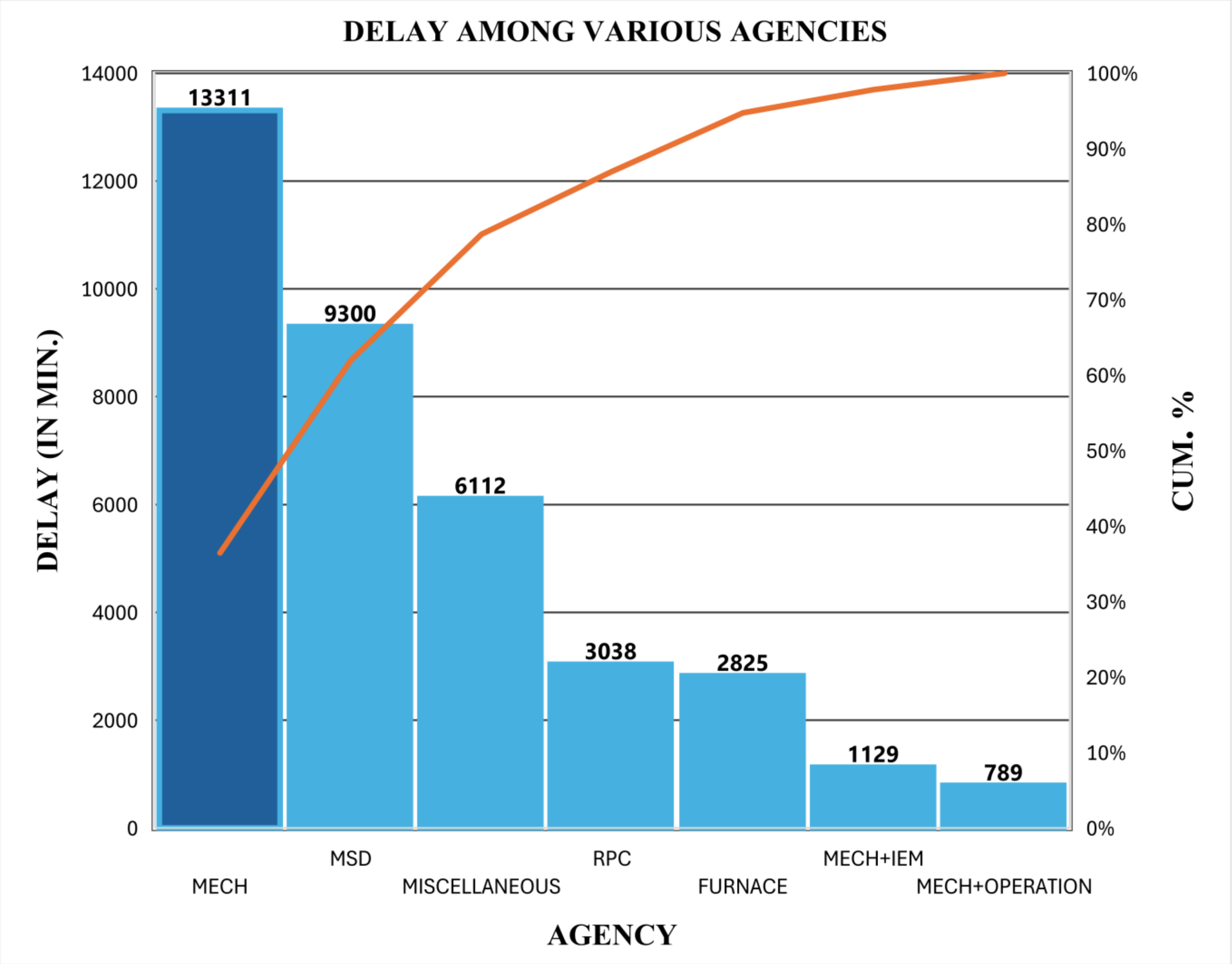


Fig. Graph showing delays among various agencies (source : RYMMS Delay Report)

Here, Major shut down(MSD) is not a problem but a measure of maintenance, RPC is (Roll pass change) is for diameter change, again not a problem but a genuine time required for set up change, miscellaneous are those which can't be classified in either and furnace delay mentioned here is majorly operational delay. Other lower delays and delays of shutdown has been ignored. Our area of concern is mechanical delay and therefore we will continue to go deep in mechanical delay analysis.

2.1 Mechanical Delay

Since our area of study is reheating furnace, therefore we need to categorize and focus on mechanical delays that occurred in furnace. This will give a quick idea of problems in the furnace. On classifying the mechanical delays into furnace mechanical delay and mechanical delays in other sections of mill, we came up with the statistics that about 13% of the total mechanical delay occurs in furnace. So now we'll continue to go inside these 13% of delays and identify the exact reasons of delays.

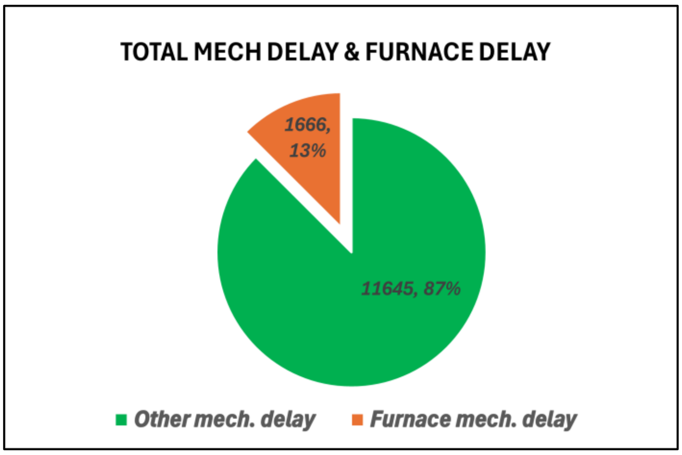


Fig. classifying mechanical delays in furnace from total mechanical delay

2.2 Furnace Mechanical Delay

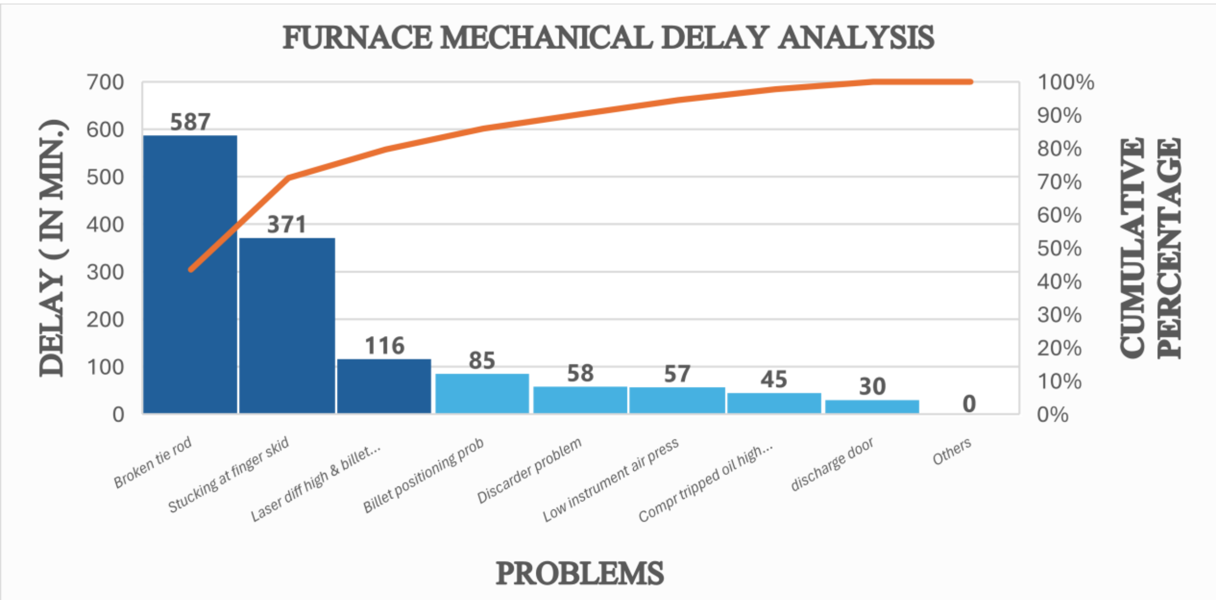


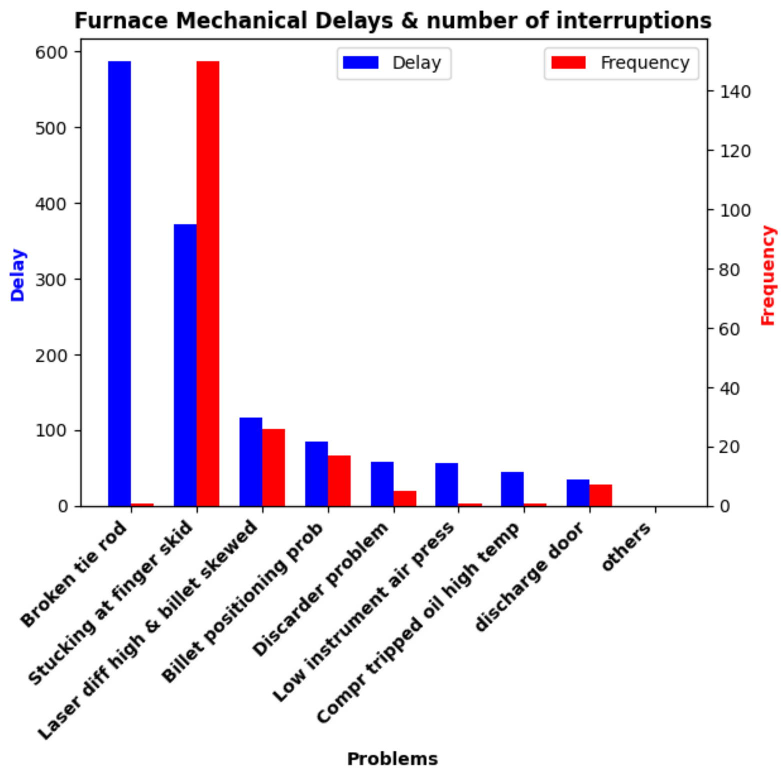
Fig. Furnace Mechanical delays

The above graph shows the furnace mechanical delays due to various problems. These delays ar due to :

- Failure of Tie Rod
- Billet stucking at finger skids
- High laser difference & billet skewness
- Billet positioning problem
- Discarder problem
- Low instrument air pressure
- Compressed tripped oil high temperature
- Discharge door problems

From the above graph we can observe that 80% -90% of the delays in furnace is because of 3 major problems i.e.

- Failure of Tie Rod
- Billet stucking at finger skids
- High laser difference & billet skewness



This graph shows the number of interruptions with delays corresponding to each of above-mentioned problems. It is to be noted that a problem which is very frequent and causing big delays are having serious issues with its implementation and need to be changed immediately. The problem which are either low interruptions and high delay or high interruptions and low delay need to be addressed properly and the fourth group that is with low delay and low interruptions are of not much concern.

Fig. Furnace mech delay & number of interruptions

To get the idea of distribution of problems as Low delay high frequency, high delay low frequency, low-low and high -high, we'll plot it on frequency- delay axes.

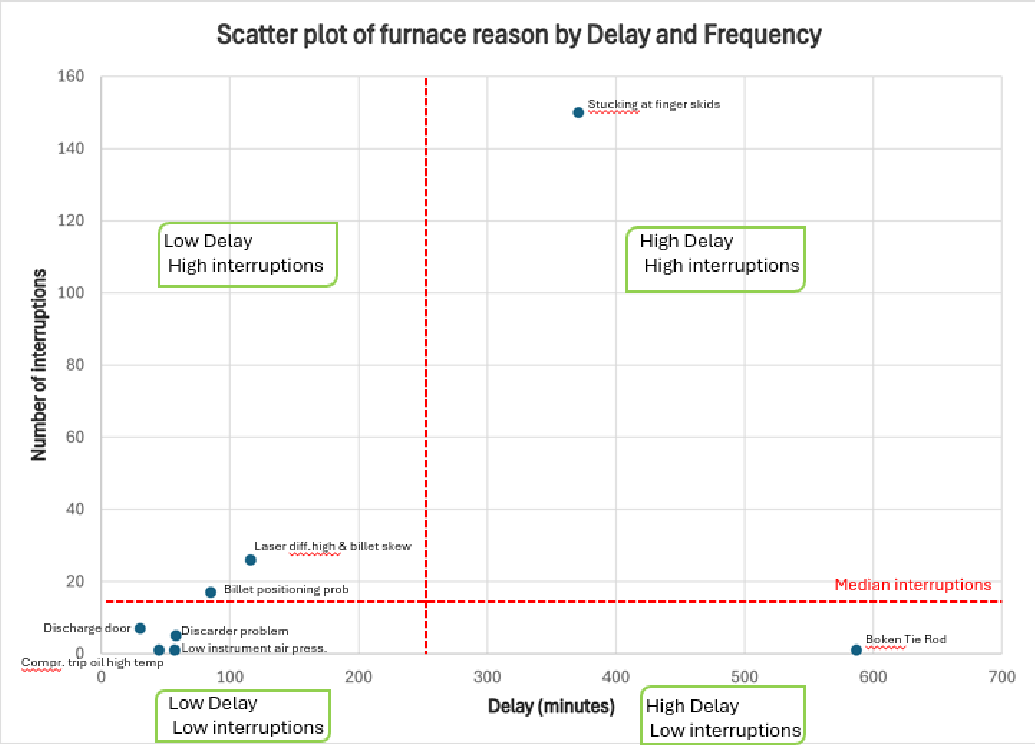


Fig. classification of furnace reason by delay and frequency

2.3 Conclusion

There are many reasons for delays in the Furnace but the major ones are following :

- Low Billet temp.
- Discharging problem
- Tie rod Failure
- High Laser difference
- Billet stucking at finger skids
- Billet positioning problem

Only Mechanical reasons

Considering Delays due to mechanical reasons it converges to :

- Discharging problem
- Tie rod Failure
- High Laser difference
- Billet stucking at finger skids
- Billet positioning problem

Low Delay High Freq.
High Delay Low Freq.

Considering Low Delay High Freq. & High Delay low Freq. problems and we are left with:

- Tie rod Failure
- High Laser difference
- Billet positioning problem

Converges to

Henceforth, Major area of study from increasing production point of view converges to:

- Tie Rod Failure
- High laser difference
- Billet positioning problem

out of which high laser difference is just the effect of improper billet placement on the skids, will see how further in the study.

Problem identification:

1. **TIE ROD FAILURE**
2. **BILLET POSITIONING PROBLEM**

3. Tie Rod Failure (problem #1)

Tie Rod is a component of walking beam which serves the purpose of link to transfer motion from hydraulic cylinder to the traversing frame. The forward and backward motion of traverse frame is controlled by one horizontal hydraulic cylinder which is connected to lever which in turn is connected to tie rod providing motion to traverse frame. At any instant of time there are total of 75 billets in the furnace that is moved by walking beam. Weight of 1 billet is nearly about 2 tons and other materials like skids, refractory, water for sealing etc. sum up to nearly 2 lakh kg. This huge weight has to be moved by walking beam mechanism and for horizontal motion this is done horizontal cylinder transferring motion using tie rod, lever, fulcrum, etc. Due to this heavy load these components are quite important and critical.

To analyse the problem, one of the best tools is Cause-Effect diagram or Fishbone diagram. Let's take a look at cause-effect diagram for Tie Rod Failure.

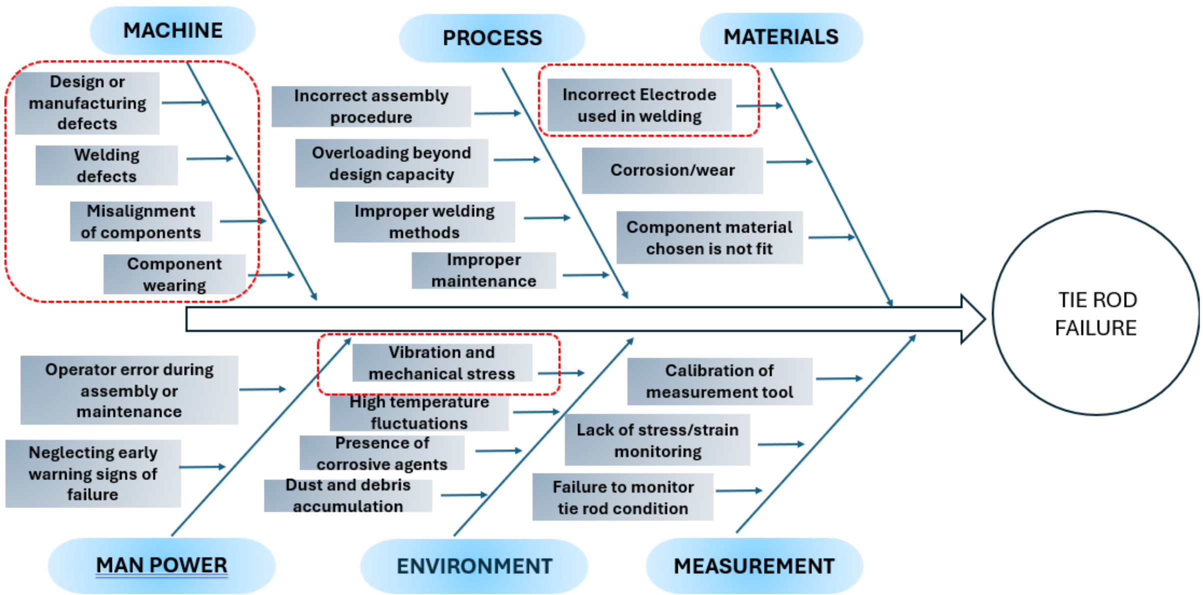
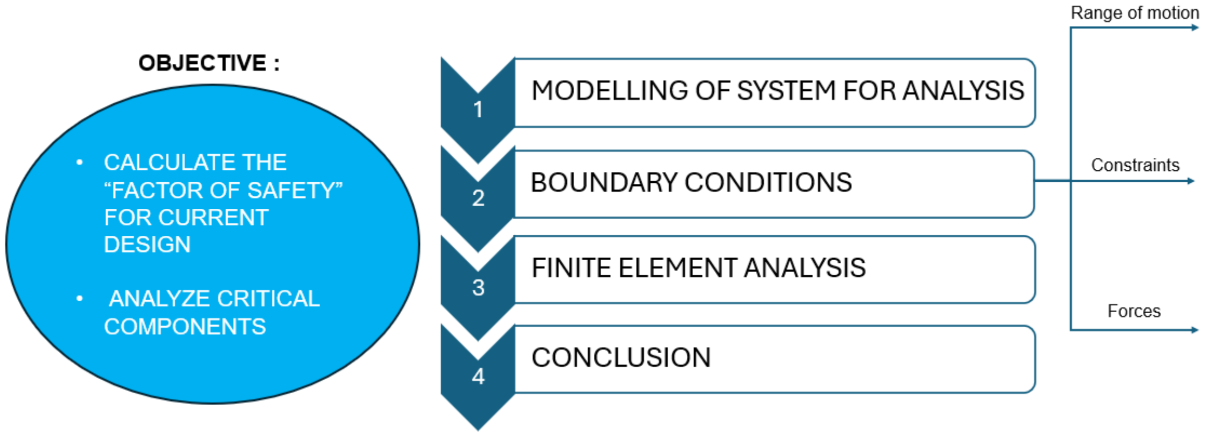


Fig. Cause and Effect diagram for Tie Rod Failure

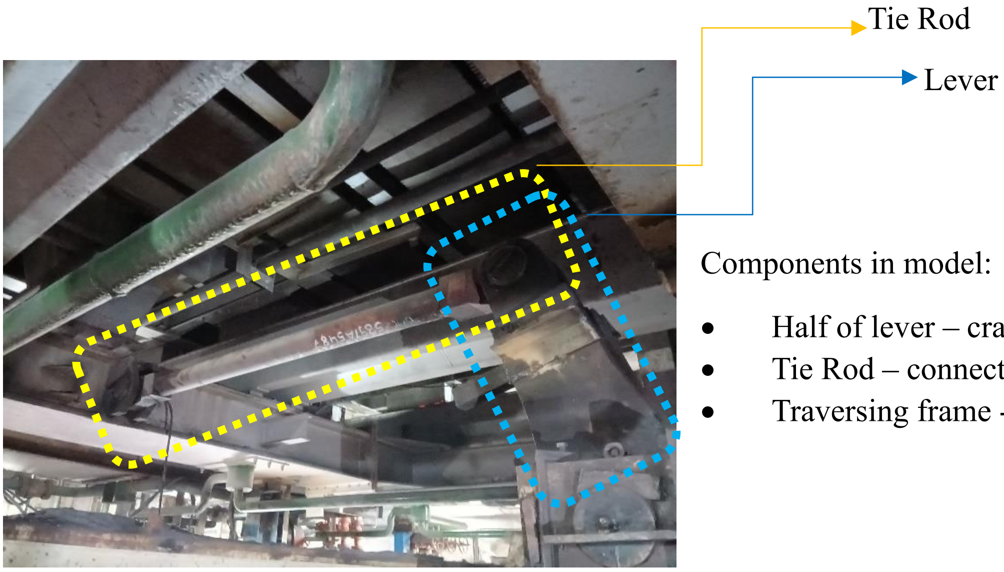
From the cause-effect diagram we can possibly analyse the possible causes of failure. Out of all these, not all these parameters are under our control and some factors are purely operational not mechanical and therefore the parameters that should be carefully studied is machine aspects, welding aspects, vibrational aspects as highlighted in the diagram. Machine here refers to all components i.e. tie rod and other components. Basically it refer to design aspects of components and therefore we will go through each of above one by one. Starting from Design Aspect then to welding aspect and at end vibrational study to conclude first problem.

3.1 Design Aspects



3.1.1 Modelling of Walking Beam Mechanism

Walking beam traverse frame's up-down and forward-backward motion can be modelled as slider crank mechanism with variable offset. If we closely look at the working we would observe that tie rod becomes active only during traversing phase not the lifting phase and traversing phase occurs two times in a cycle, one is forward stroke for which offset is constant and second is backward stroke for which, offset also remains constant but different to forward stroke means two different value of offset. So we can model the system for 2 different stroke of constant offset slider crank for ease of calculation.



Components in model:

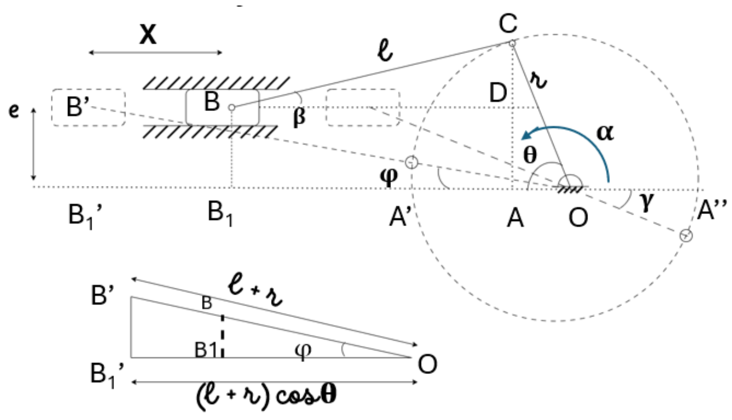
- Half of lever – crank
- Tie Rod – connecting rod
- Traversing frame - slider

Fig. Actual image of components

- Offset (e) in backward stroke is equal to e1 = 814mm
- while in forward stroke it is e2 = (e1 + lift of lifting frame)= 1014mm

3.1.2 Boundary conditions

(i) Range of motion:



The known parameters are dimensions of components i.e l, r and e.

Also, we know the traversing range i.e. X and so we can calculate the value of Θ from geometry.

For this we need to find:

X = f (l, r, e, Θ)

From above geometry and simple manipulation one can easily show that:

$$X = \sqrt{(l+r)2 - e^2} - \sqrt{l^2 - (r\sin\theta - e)2} - r\cos\theta$$

$$\frac{dX}{dt} = \left[\frac{r\cos\theta(r\sin\theta - e)}{\sqrt{l^2 - (r\sin\theta - e)^2}} + r\right]\omega$$

$$\frac{d^2X}{dt^2} = \left[\left\{\frac{(r^2\cos 2\theta + e.r\sin\theta) + (\frac{r^2}{2}\sin 2\theta - e.r\cos\theta)^2}{\sqrt{l^2 - (r\sin\theta - e)^2}}\right\} + r\cos\theta\right].\omega^2$$

$$+\alpha\,.\left[\frac{r\cos\theta\,(r\sin\theta - e)}{\sqrt{l^2 - (r\sin\theta - e)^2}} + r\sin\theta\right]$$

Geometric Details:

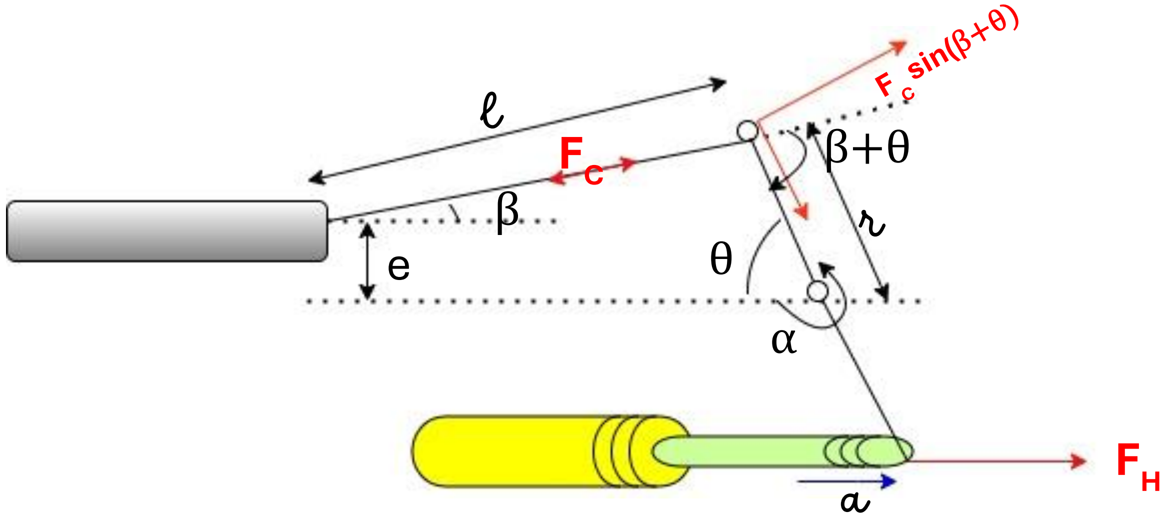
- L = 2630 mm; r = 915 mm; e = 814mm;
- Lift = 200 mm; Traverse range, X_e= 216 mm travel;
- $(OA)_{initial}$ = 67 mm; $(AB_1)_{initial}$ = 2628 mm;
- $(CD)_{initial}$ = 101 mm;

After doing all the calculations from starting position to final position where Xe = 216 mm, we can calculate the value of initial crank angle and final crank angle (Θ). Skipping the calculation part, the final obtained results are:

$$\boxed{\theta \in [\,72.5° , 85.8°\,]}$$

Crank in our model and lever in actual has range of motion in above given range.

(ii) Force Calculation (2nd B.C) :



Assumptions : $\Delta\theta$ is small (reasonable since only 13°) and conditions are static (since very slow movement, 20 cm advancement in 46 seconds)

- Torque $(\tau) = \{F_H Sin(\theta) - F_C sin(\beta+\theta)\} \, . \, R$
- $I \times \alpha = \{F_H Sin(\theta) - F_C sin(\beta+\theta)\} \, . \, R$
- $F_C = \dfrac{F_H Sin(\theta) - (I\times\alpha)/r}{sin(\beta+\theta)}$

From geometry :

- $Sin\beta = \dfrac{(r\times \sin\theta)-e}{l}$ $\qquad$ $Cos\ \beta = \dfrac{\sqrt{(l^2-(r\times\sin\theta-e)^2)}}{l}$

Therefore,

$$F_C = \frac{F_H Sin(\theta) - (I\times\alpha)/r}{\{(r\times sin\,\theta)-e\}\times cos\ \theta - \sqrt{(l^2-(r\times sin\,\theta-e)^2)}\times sin\theta}$$

Parameters Known :

1. F_H = cylinder press. × area
2. l, r, e1,e2 from drawings
3. θ as found previously

- Offset (e) in forward stroke is equal to e1 = 814mm
- While in backward stroke it is e2 = (e1 + lift of lifting frame)= 1014mm

Parameters Unknown :

1. Ang. Acceleration ($\boldsymbol{\alpha}$)
2. Moment of Inertia of Lever ($\boldsymbol{I}$)

In order to find the value of force, first we have to find the value of unknown parameters. So we'll first calculate the unknowns not from traditional way but from the bottom up approach.

Unknown 1: Calculation of angular acceleration lever

To calculate the angular acceleration of lever, we'll first calculate the acceleration of rod end of horizontal cylinder and then because of our assumption of small crank angle change, we can consider this acceleration to be tangential acceleration of lever and so angular acceleration can be found by just dividing by radius.

In order to have an error free value of acceleration, we'll calculate the acceleration values from the effects not from the loading conditions i.e. from the velocity sensor we can get the velocity plot of the rod end of cylinder and if velocity plot is known then acceleration can be easily found. We'll take the raw data from sensors then plot it after smoothing operation since these are discontinuous data points to get a proper velocity plot.

Smoothing is done by taking cubic interpolator.

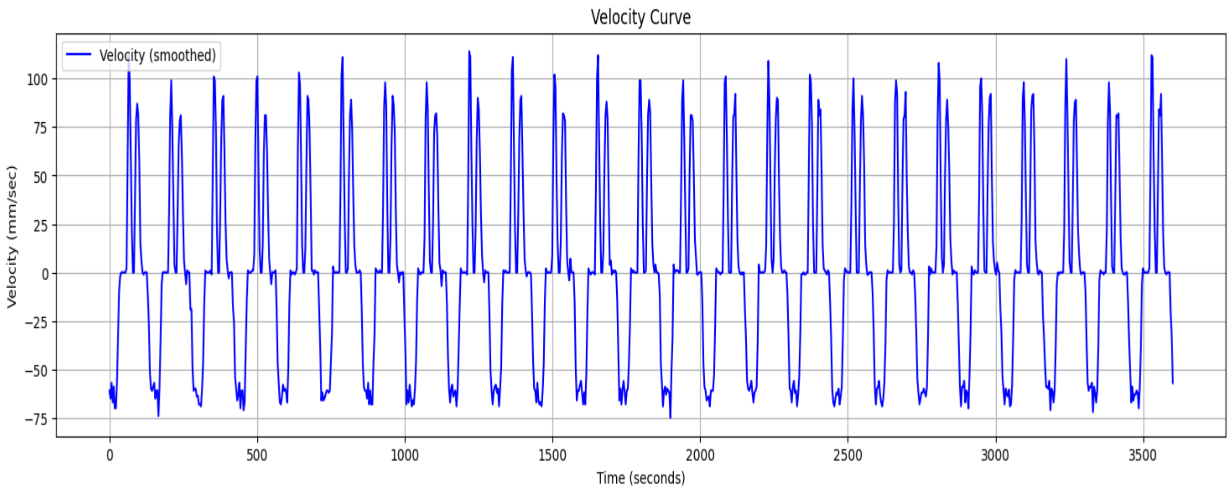


Fig. Smoothed velocity plot of rod end of horizontal cylinder

Since the velocity plot is periodic, analysis of one cycle will give us similar results. Lets take a look at one cycle of velocity plot.

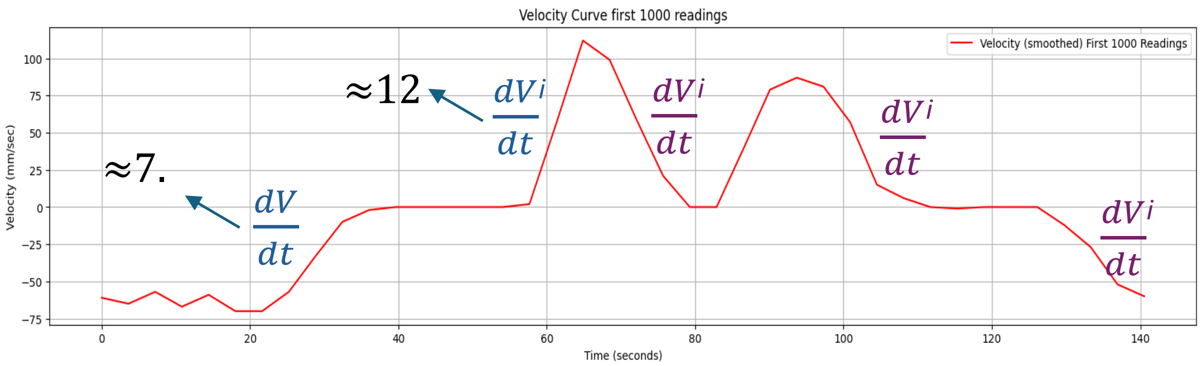


Fig. Velocity of one cycle

Manual derivative calculations over few cycles and their mean would provide us a better understanding of acceleration variation. Using this approach the obtained acceleration is :

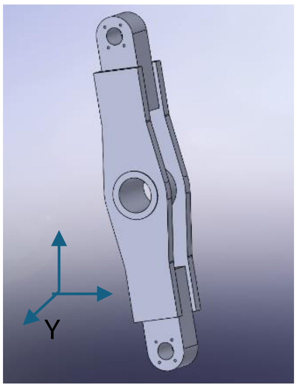
- Estimate of acceleration:
  - Forward= 10-15 mm/sec^2 &
  - Backward= 8- 12 mm/sec^2

$$\boxed{\alpha = \frac{a}{r}}$$

Unknown 2: Calculation of Moment of Inertia of Lever

In order to calculate the moment of inertia of Lever we can use the solidworks software which can easily calculate these properties if we have its CAD and material specifications. So firstly we would create a CAD model of our component based on the geometries and dimensions from drawing sheet. Due to confidentiality, specifications can't be mentioned here but after CAD modelling and all material specification we get the following results.

Assuming average density = total mass of lever / volume of lever



Mass = 7513393.63 grams

Volume = 105359616.55 cubic millimeters

Surface area = 3249569.14 square millimeters

Center of mass: (millimeters)
X = 0.00
Y = 0.00
Z = 160.67

Center of mass: (millimeters)
X = 0.00
Y = 0.00
Z = 160.67

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)
Taken at the center of mass.

Ix = (0.00, 1.00, 0.00)	Px = 130324758377.27
Iy = (0.00, 0.00, 1.00)	Py = 2476902641964.79
Iz = (1.00, 0.00, 0.00)	Pz = 2502400300970.41

Moments of inertia: (grams * square millimeters)
Taken at the center of mass and aligned with the output coordinate system. (Using positive tensor notation.)

Lxx = 2502400300970.41	Lxy = 0.00	Lxz = 0.00
Lyx = 0.00	Lyy = 130324758377.27	Lyz = 0.00
Lzx = 0.00	Lzy = 0.00	Lzz = 2476902641964.80

Moments of inertia: (grams * square millimeters)
Taken at the output coordinate system. (Using positive tensor notation.)

Ixx = 2696350602117.28	Ixy = 0.00	Ixz = 0.00
Iyx = 0.00	Iyy = 324275059524.15	Iyz = 0.00
Izx = 0.00	Izy = 0.00	Izz = 2476902641964.80

Fig. Results from SolidWorks

Therefore, I = 130324758.37727 Kg*mm^2

Force Analysis:

After finding all unknown parameters, we can calculate the force in the connecting rod from the expression mentioned above of Fc. The plot of force experienced by connecting rod with crank angle has been plotted in MATLAB and the results are as follows:

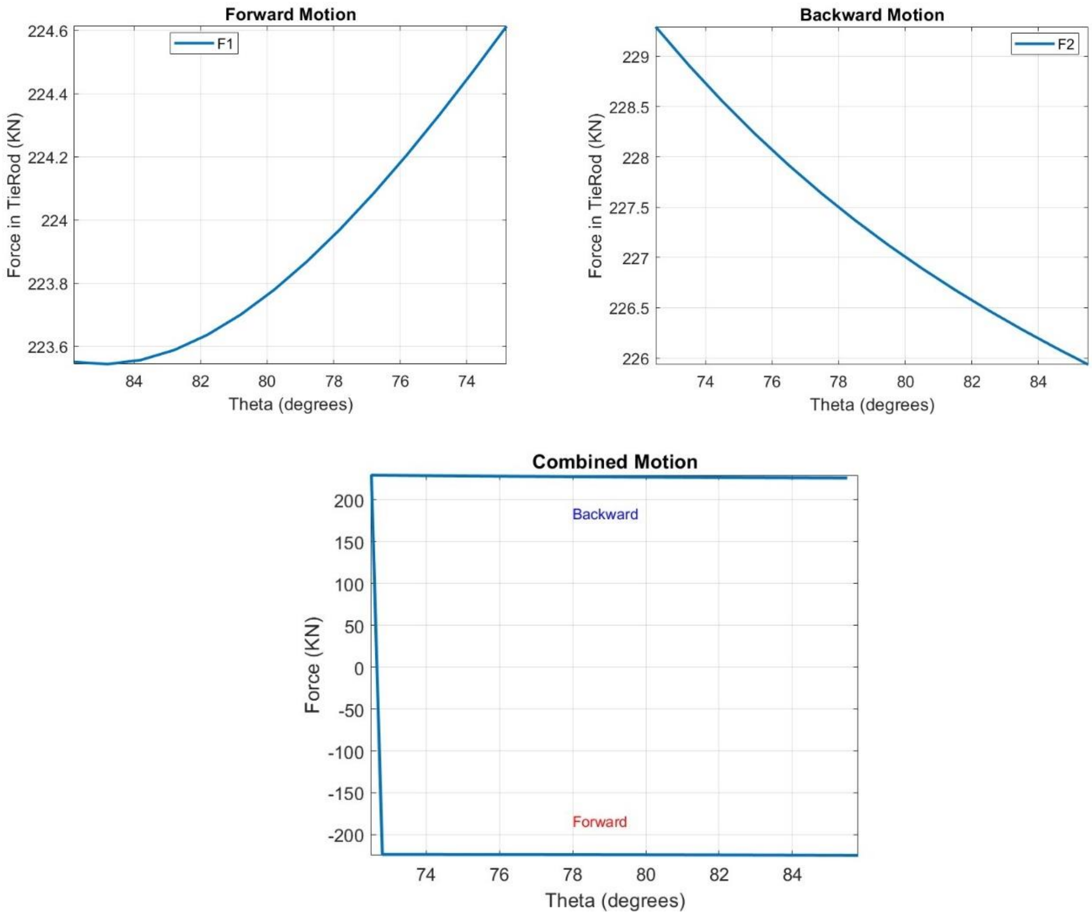


Fig. Plot of Force vs crank angle

In our combined motion analysis, we have defined tensile forces as positive and compressive forces as negative. Observations of the plot indicate that the variation in force experienced by the connecting rod (specifically, the tie rod) is relatively minor compared to the force magnitude. Therefore, for the purposes of our analysis, we can assume a constant force acting on the connecting rod throughout its cycle. To ensure safety, we will use the maximum force value for our analysis. This approach is reasonable given the small stroke length and nearly identical configurations.

Therefore,

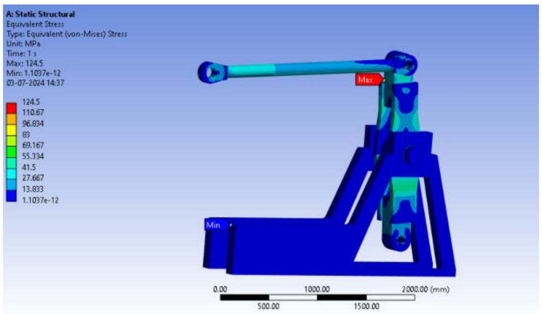
$$F_{max} \sim 225 \text{ KN} - 230 \text{ KN}$$

Here we neglected jerk impacts as during our acceleration calculation we took discrete gradients to avoid jerks and used mean over cycles.

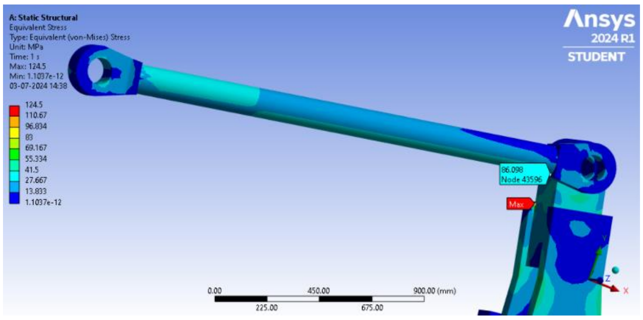
It is to be noted that due to heavy loads and runaway loads, motions are not smooth but sometimes jerky in nature which also contributes to extra impact on the system. But to avoid complex calculations we provide a descent Factor of Safety to compensate these.

3.1.3 Finite Element Analysis

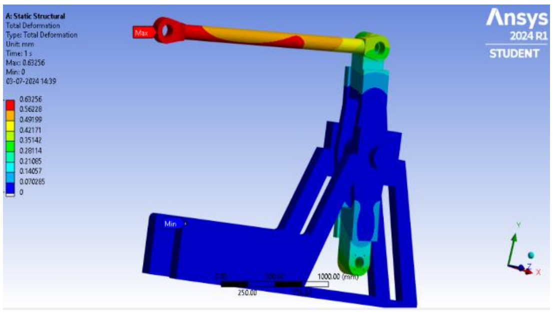
In our analysis, we employed the ANSYS software package for Finite Element Analysis (FEA) to evaluate the stresses and Factor of Safety for the system under consideration. The process began with the creation of a detailed CAD model, which was then imported into ANSYS. We applied various boundary conditions to simulate real-world constraints and loading scenarios, assuming a static structural framework for the analysis. The FEA provided insights into stress distribution and enabled us to calculate the Factor of Safety, ensuring that the design meets the required safety standards under the specified loading conditions.



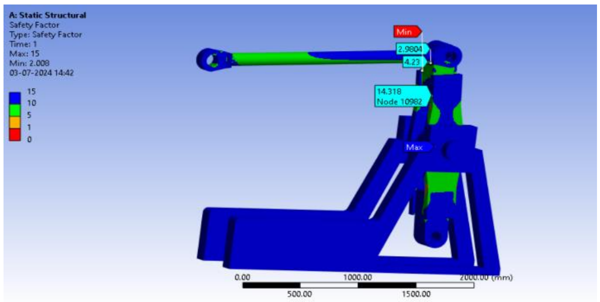
(a)



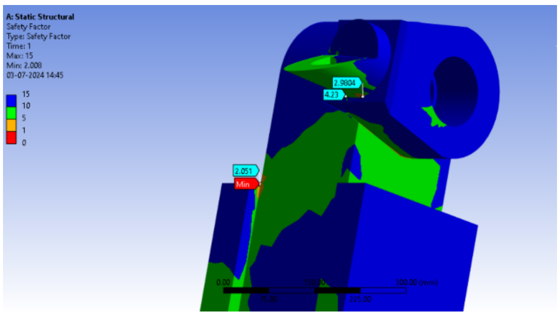
(b)



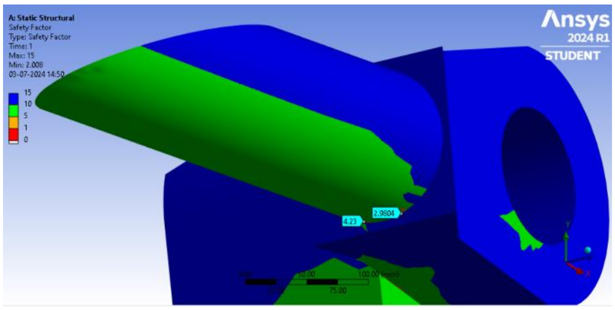
(c)



(d)



(e)



(f)

Fig. (a)&(b) Equivalent stress (c) Total deformation (d) Factor of safety (e)&(f) FOS at sections near joint area

3.1.4 Conclusion

From the above analysis we observed that factor of safety is minimum at weld joint for connecting rod which is equal to 2.9 and for the entire system factor of safety is minimum at lever-plate joint which is 2.1. This critical value at lever-plate joint is quite less than at welding joint which may be result of approximated CAD model of lever like fillets are not of proper dimensions, nuts and bolts are not included, lever-plate are in contact with the help of these nuts and bolts which are assumed as simple joint during FEA as our area of concern is connecting rod. Therefore, neglecting the FOS of 2.1, still the FOS for connecting rod is nearly 3 which is a descent factor of safety and therefore we can conclude that this failure is not because of the design issues. But since FOS is critical at joint and failure in past also took from the same location proves our analysis as well.

One clear indication of failure after getting good FOS is the welding joint. Either welding joint has some defects or material has exceeded its normal life. An Ultrasonic Test of spare part of Tie Rod has been done and its findings are shown below. It also indicates some defects in the weld which might reduce the life of component significantly. However, at that point it has been remarked as "acceptable" but the defects may have initiated cracks at some point of time due to such huge loads.

SL NO	DESCRIPTION/LOCATION	LENGTH	OBSERVATION	REMARKS
01	Traverse Tie Rod weld joints	0.75 mtr.	Pularm side minor defect found ,depth 15-17 mm, length 10 mm and opposite side spot defect found ,depth 10-11 mm.	Acceptable
02	Traverse Tie Rod pin	250 mm	NO Recordable Defect was observed.	Acceptable

Fig. Ultrasonic test results

A good FOS despite taking maximum stress values (indicating a safe design) and presence of welding defect, failure of tie rod from welding joint and FEA shows the joint to be a critical component, all together makes a good understanding of failure. The premature failure could be either due to

- Defects in welding or
- Increased loading conditions

The above conclusion suggests that there need to be a proper checks for welding defects and for preventing failure or tracking the conditions of component we must have its strain or strain rate data. If any mechanical component fails due to any reasons, the very first sign will be the change in strain values and strain rates. The abnormality in strain and strain rates good give us a brief view of condition of that component.

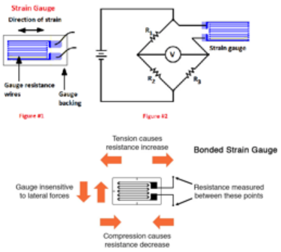
Keeping these points in mind, we'll move to recommendation part for this analysis.

3.1.5 Recommendations:

Recommendation 1: Real time monitoring of stress/strain/strain rate on Online Server

CHOICE 1-
Strain Gauge:

- Measures strain by detecting change in electrical resistance.
- Ideal for static and dynamic strain measurements.

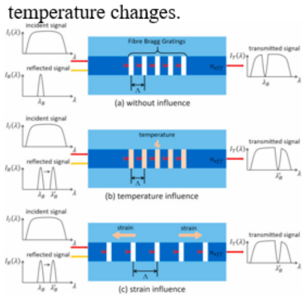


$$\frac{\Delta R}{R} = K.\epsilon$$

Where,
R = resistance
K = Gage factor
ϵ = strain

CHOICE 2-
Fibre Bragg Gratings (FBG) :

- An optical fiber sensor with periodic variations in refractive index.
- Reflects particular wavelengths of light, and shifts in these wavelengths indicate strain or temperature changes.

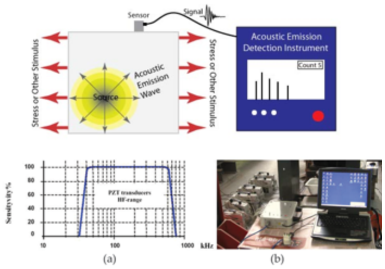


$$\lambda_B = n_{eff} \cdot \Lambda$$

Where,
λ_B = Bragg wavelength
n_{eff} = eff. refracting index
Λ = grating period

CHOICE 3-
FBG with Acoustic Emission sensors:

- Combines FBG with AE for comprehensive monitoring.
- AE sensors detect high-frequency elastic waves generated by crack formation or propagation



Probable Architecture of Strain gauge implementation:

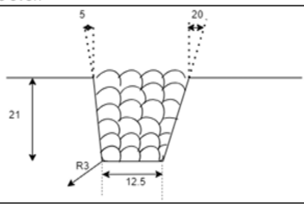
Strain guage

Fibre Bragg Grating

Acoustic Emission Sensors

Choices	STRAIN GAUGE	FIBRE BRAGG GRATINGS (FBG)	FBG WITH ACOUSTIC EMISSION
Installation	Simple	Moderate	complex
Cost	2,00,000 INR	14,00,000 INR	25,00,000 INR
Sensitivity	High	Very High	Highest
Cracks measure	No	No	Yes
Suitability	General	Harsh Environments	Damage detection
Sensing point	Single	More than one	More than one
Space occupied	Moderate	Compact	Moderate

Recommendation 2: Welding Procedure Specification (WPS):

Welding Procedure Specification (WPS) **Walking Beam Tie Rod ,NBM**	
Welding Process	Shielded Metal Arc Welding (SMAW)
Welding Standards	1. Welding shall conform to IS:9595 2. Fabrication shall conform to IS:7215
Base Material	1. GRADE i. Rod Eye - IS:1875 Cl IV ,forged,normalised & machine ii.Tube - IS:1161 ASTM A-106 Gr.B, cut & machining 2. THICKNESS i. Rod Eye - 140 mm ii.Tube - 25.4 mm
Electrode	• E7018 • Diameter : 2.5 mm for Root & 3.2 mm for filler • AWS Class : E7018/E7018-1 • ASME : SFA A5.1 • Certificatiion : AWS A5.1/A5.1M:2004
Electrode Properties	• Tensile Strength ,Kpsi: 70 min • Yield Strength, Kpsi: 58 min • Elongation in 2"(%): 22 min
Electrode Chemistry	• C-0.15, Mn-1.60, Si-0.75, S-0.035, Ni-0.30, Cr-0.20, Mo-0.30, V-0.08 • Combined limit for Mn+Ni+Cr+Mo+V : 1.75
Electrode Baking	• 1 hr at 300 deg. C in mother oven After 1 hr maintain at 100 deg. C in portable oven
Joint Design	• Filler : Multipass Stringer beads & • Root Welding 

Pre Weld preparation	Surface cleaning to remove contaminants Proper alignment and fit-up
Post Weld Heat Treatment	Not required For weld thickness > 38 mm, mandatory
Current	AC-DCEP
Weld position	1G (Recommended)
Welder Certification	Welder must be certified to AWS D1.1 standard Re-certification every 2 years
Non Destructive Test (NDT)	
DPT for Root Weld	No Indication should be there
UT for weld after completion	
DP at final	

Welding Parameters					
Diameter		**Process**	**Volt**	**Amps(flat)**	**Amps(V/OH)**
in	**mm**				
3/32 .	2.4	SMAW	21-25	65-80	65-75
1/8 .	3.2	SMAW	21-25	90-110	80-95
5/32 .	4	SMAW	21-26	135-160	120-140
3/16 .	4.8	SMAW	22-26	160-210	140-160

Developed By :
Saurabh Kumar
Inspire Intern, 24

Verified By:
Mr. Nirmal Kumar
Ar. Manager Tribology (MED), Tata Steel

Recommendation 3: Maintenance of Furnace Health Index (FHI) and availability on server

- Easy to interpret data and identify problems.
- Alarm system for exceeding threshold.
- Predictive analysis can be added to predict future health of components.

(Discussed in the upcoming sections)

Recommendation 4: Phased Array UT of Tie Rod at regular interval

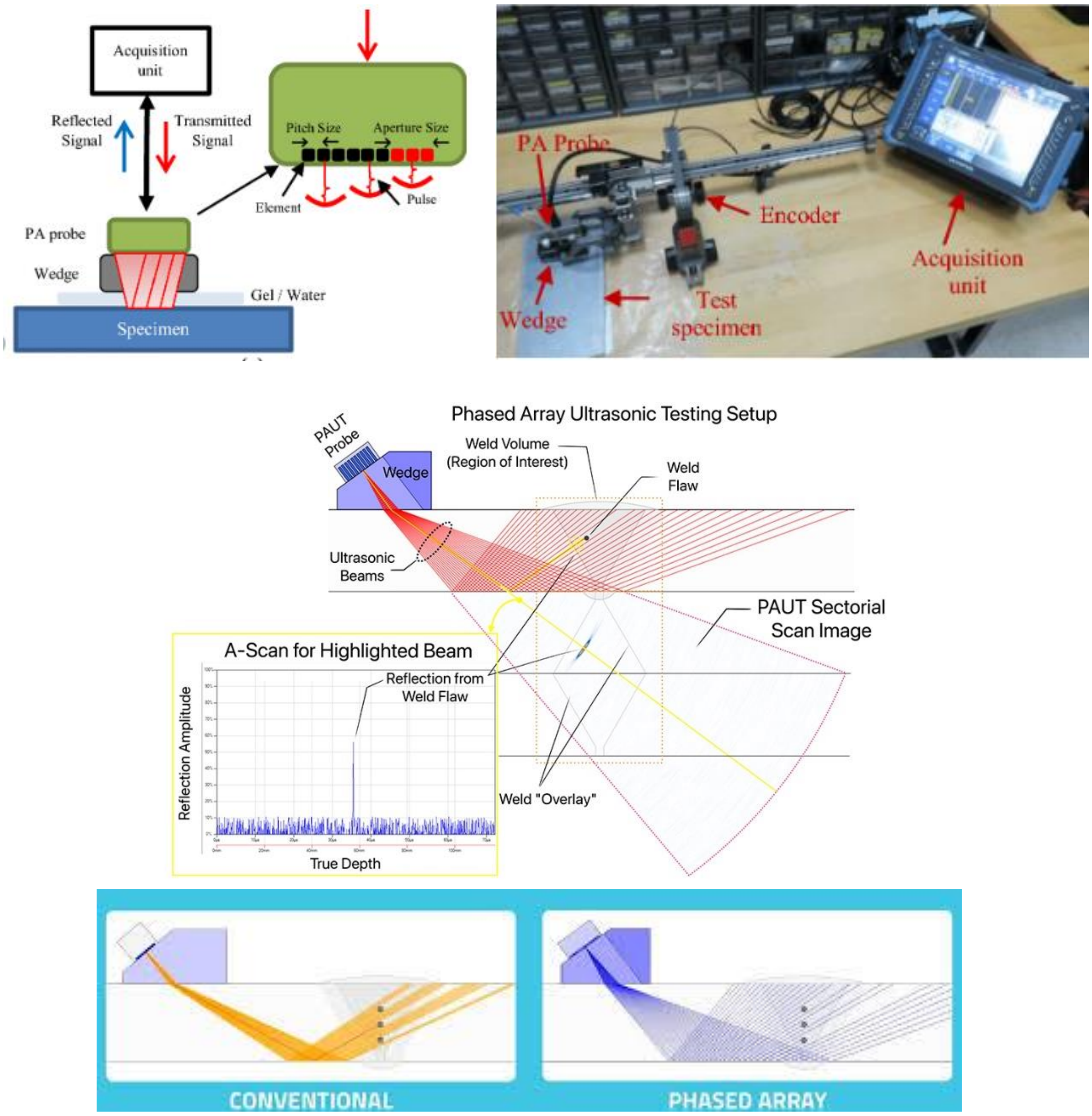


Fig. Phased Array Ultrasonic testing setup and method involved

- PAUT uses multiple ultrasonic elements with electronic time delays to create a sweeping, focused beam for detailed internal imaging.
- PAUT offers high-resolution real-time images, while conventional UT provides simpler A-scan displays.
- Cost of PAUT is high nearly 15-50 lacs INR but the cost of one test in very less nearly 2000 INR, since once installed can be used for multipurpose.

3.2 Vibrational Analysis of System

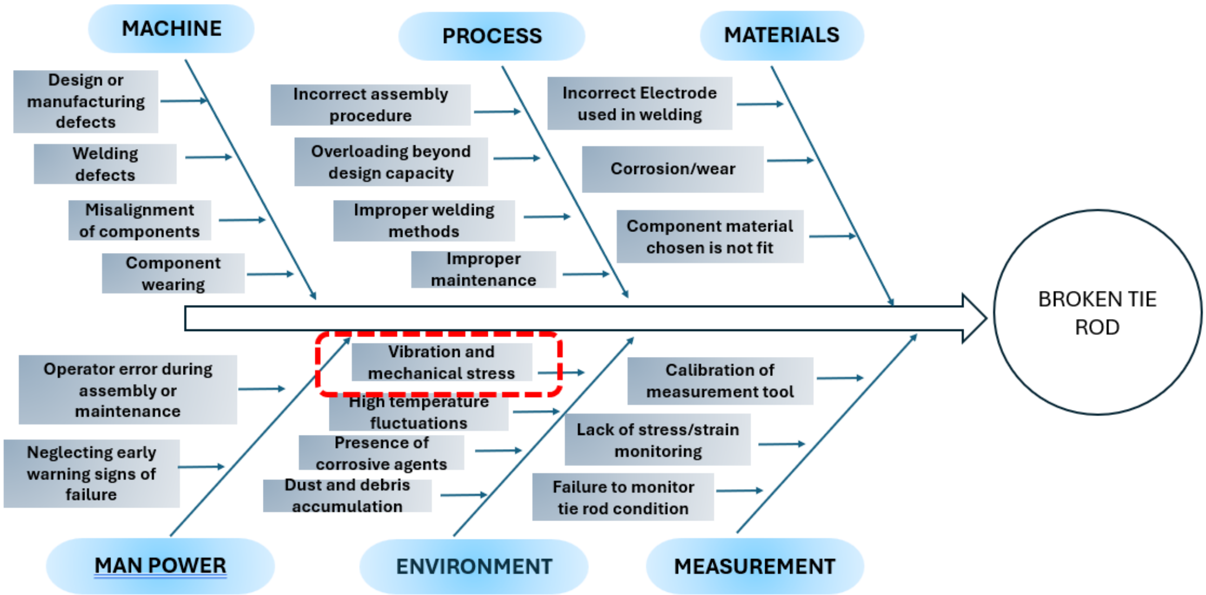


Fig. Fishbone diagram for tie rod failure

3.2.1 Motion Amplification Study

Motion amplification is an advanced technique utilized in industrial settings to detect and analyze vibrations in systems with multiple degrees of freedom. The process begins with capturing high-speed video footage of the system using cameras that record at high frame rates. This video is then processed with specialized software that analyzes pixel-level changes between frames to detect subtle movements. The software amplifies these tiny displacements, making minute vibrations visible and allowing for detailed examination.

By visualizing these amplified vibrations, engineers can identify and diagnose issues such as misalignment, imbalance, or resonance that might be too subtle for traditional sensors to detect. This technique provides a clearer understanding of complex vibration patterns and helps in pinpointing the root causes of mechanical problems. The enhanced visibility enables more targeted maintenance and optimization efforts, improving the reliability and performance of industrial systems.

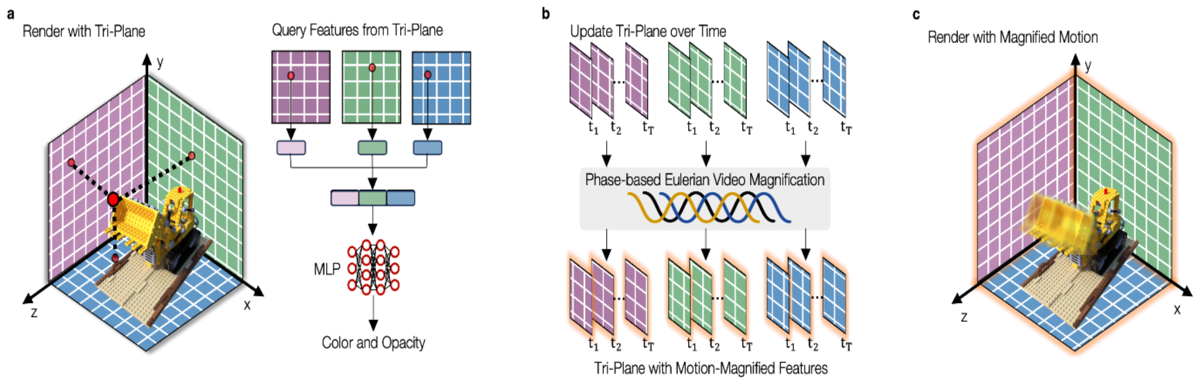
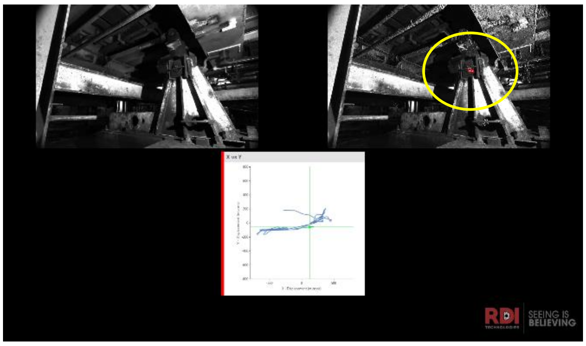
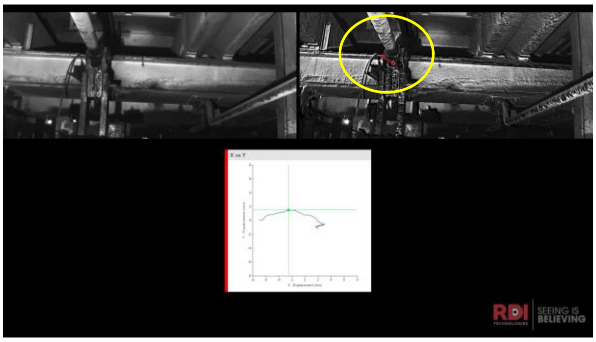


Fig. 3-D Motion amplification principle

Key Findings :



(a)



(b)

(c)

Fig. Vibrations detected at joint of lever and fulcrum i.e near pin in (a), at the link joint of tie rod and lever (b) and at base of fulcrum in (c)

The key findings of the study are:

1. Play between fulcrum pin and lever.
2. Vibrations at Tie Rod & Lever joint.
3. Vibrations at Base of Fulcrum

3.2.2 Recommendation 5

- Increasing Frequency of Motion Amplification Study
- Strengthening the base structure & UT of Concrete.
- Taking required actions during shutdown.

4 . Billet Positioning (Problem #2)

It refers to the set of problems that arises due to improper placement of billets inside the furnace. In the walking beam mechanism, the billets rest on fixed skids and in each cycle moving skids first lift the billets as lifting frame goes up and then billets move forward as traversing frame moves and then comes downward to place it back on fixed skids as lifting cylinder retracts and so the billet advances in each cycle. But the problem arises when while placing lifting cylinders are not in synchronisation and if one cylinder extended to full but other is lagging and the next operation of movement of traverse frame started then this inclination in vertical plane causes skewness of billet in horizontal plane.

4.1 How Billets gets skewed?

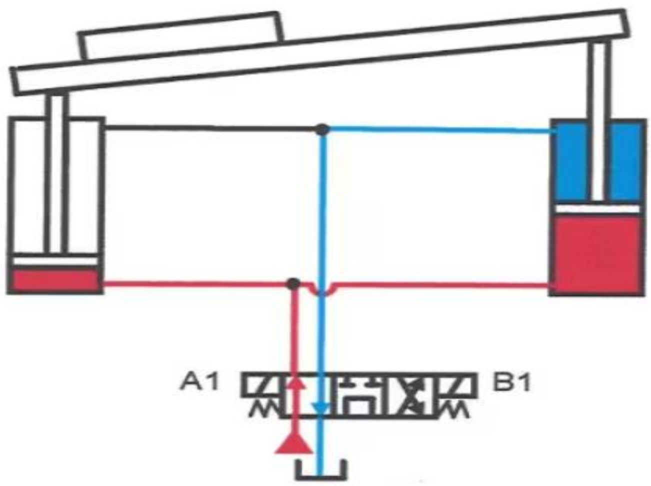


Fig. Demonstration of how asynchronization cause billet skewness

As shown in the above diagram this type of asynchronization cause billet inclination in vertical plane and at this instant of time the traverse cycle started, the side which is in more contact with frame moves more and sometimes even traverse frame itself gets skewed in horizontal plane. This skewness is measured by taking difference of values recorded by laser sensors at head and tail of billet.

4.2 Why Billet skewness is a problem?

This skewness of billet is undesirable because for discharging of billets from furnace it must align on discharge roll table properly with some acceptable tolerance value but if more then billets can not be discharged. Since there are no human interventions inside the furnace, everything is controlled by machines and control systems only, any type of issue inside the furnace needs to be handled carefully since any human can't enter inside and so causes delays in production.

If billets get skewed inside the furnace we have to take walking beam cycle back and adjust the movement manually to re-orient it in proper manner. But this is too applicable if skewness is small, otherwise for high skewness, production has to be stopped and after shutdown of furnace, human intervention can only resolve the issue.

4.3 Cause – Effect Diagram

Let's us understand the possible causes of this problem through cause-effect diagram.

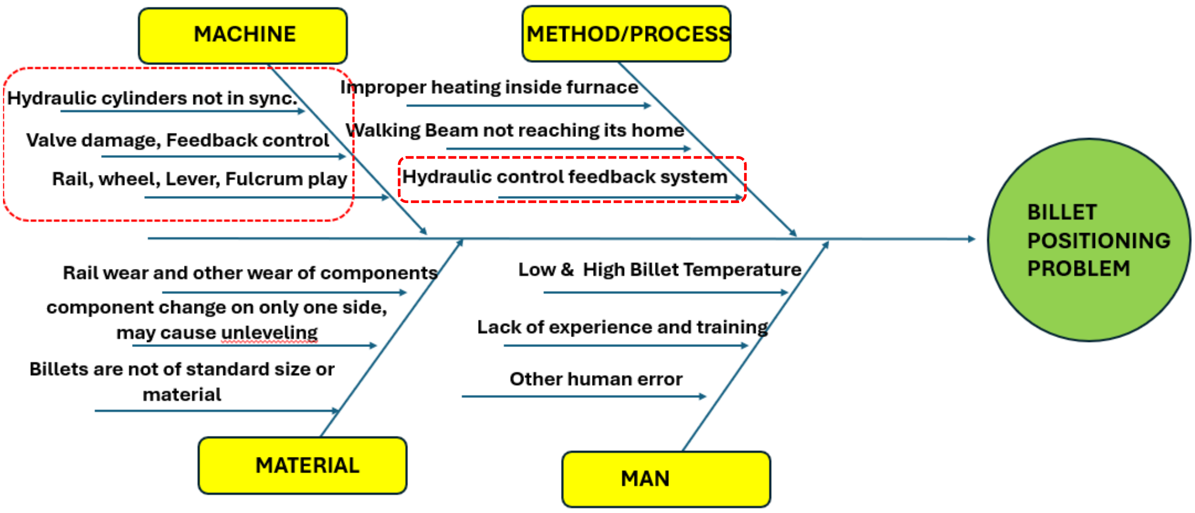


Fig. Cause – Effect diagram of Billet positioning problem

The parameters that are under our control are highlighted in the diagram above. Let's us take a look at hydraulic system set up.

4.4 Hydraulic System & Control Analysis

Components :

- 2 Hydraulic cylinders for Lifting
- 1 horizontal hydraulic cylinder for Traversing.
- Valves – Proportional, DC, Flow Control, Check
- Pumps, Tanks, Filters etc.
- Linear Variable Differential Transformer (LVDT)
- PLC & other electrical control devices

Fig. valve stand

Fig. Pumps,motor and other setup

Present Working Setup at NBM:

- Open loop control system with predefined paths.
- PLC and other electronic components work on predefined logic.
- LVDTs are present as its initial design was of closed loop control system.

4.5 Lifting cylinder position analysis

To analyse the asynchronous behaviour of lifting cylinders we took the data of position of cylinder rod end through LVDT and after smoothing the data, we plot the difference of position between west cylinder and east cylinder v/s index which is simply data points and to understand when the synchronization is more or less we also the exact position of one of the cylinder. This gives us a good understanding of both cylinders are in sync and when sync is not there and by how much and at which stage of cycle.

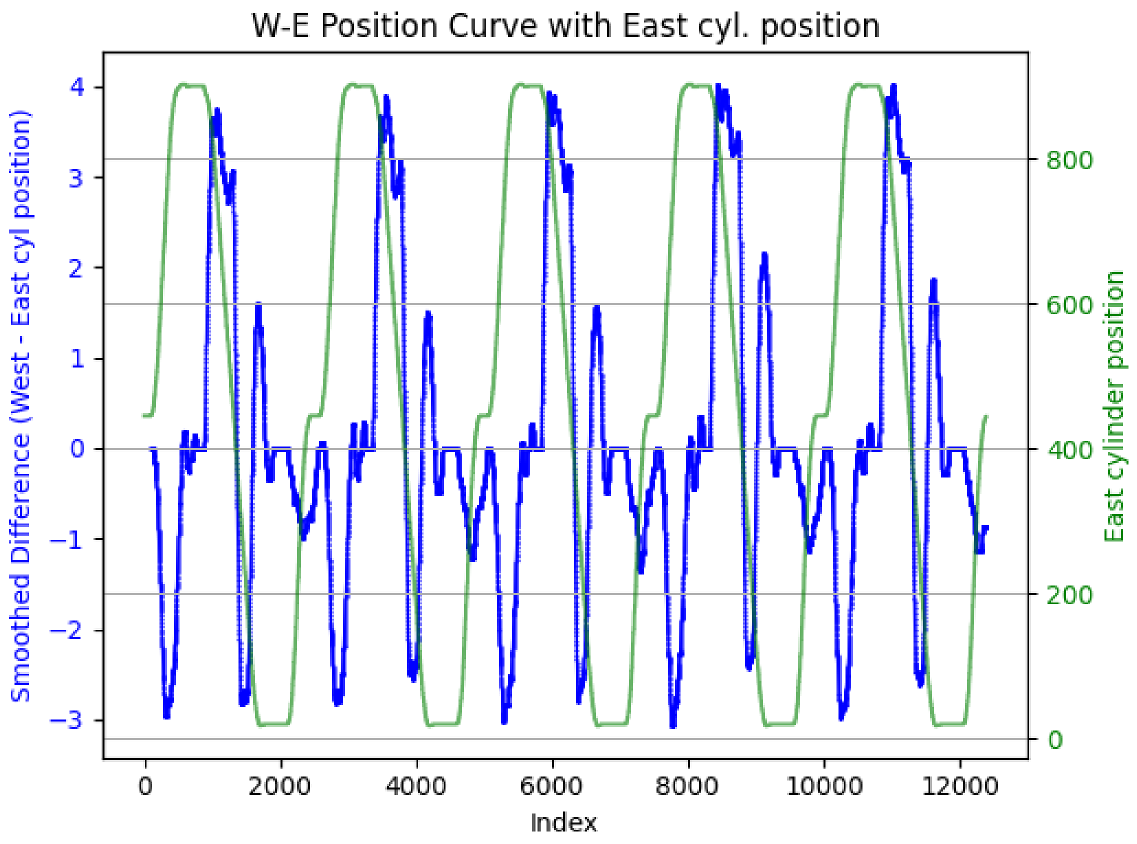


Fig. West & East cylinder position curve with East cylinder position

The plot clearly shows the asynchronous behaviour of cylinder, however the difference is very small but this small skewness can built up over cycles and lead to larger skewness which might be out of acceptable region.

4.5.1 Some other findings:

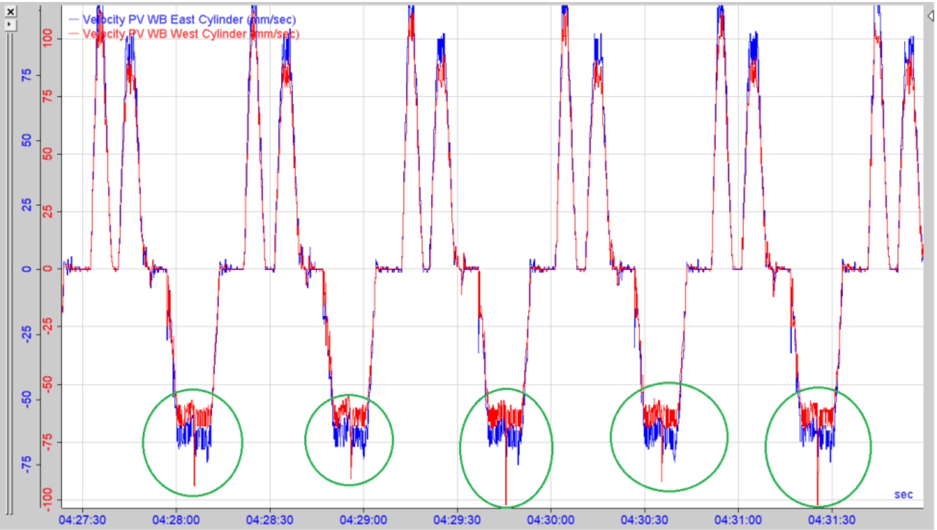


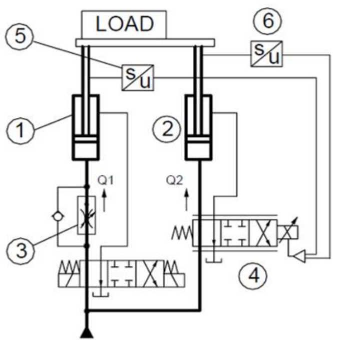
Fig. Velocity curve of cylinders

Above plot shows that there is an abrupt change in velocity of west cylinder when it reaches its minima indicating a sharp spike in the velocity curve. This indicates that there acts an impulsive force in West Cylinder when velocity reaches its minima like a jerk in the motion.

4.6 Possible Solution for precise control of lifting cylinder

To achieve a high precision of synchronization, we need to opt for Multiple closed loop feedback control system i.e servo control feedback system.This can provide high precision and accuracy and is the most widely used latest control technology.

Flow control valve (3) controls Q_1 and, therefore, the speed of cylinder (1) – Fig. 2.32. Follow-up electro-hydraulic control system controls Q_2 and, therefore, the speed of cylinder (2) – synchronized to speed of cylinder (1).



- 3 – Pressure compensated flow control valve
- 4 – Proportional valve
- 5 – Displacement transducer for cylinder (1)
- 6 – Displacement transducer for cylinder (2)

This arrangement gives an extremely accurate control of cylinder speed and position with an accuracy of better than 1%

Fig. 2.32. Closed-loop proportional control

But the cost of this setup for existing mill is way too high and therefore it is not feasible economically, only recommended when new mill is being established and so we have to look for certain alternative solutions.

4.7 Recommendations

Recommendation 6: Real time pressure mapping of both lifting cylinders

Choices	Advantages	Disadvantages	Application
Strain Gauge Type	High accuracy, stable performance, good for static and dynamic measurements	Sensitive to temperature variations, requires regular calibration	General industrial applications
Piezoelectric	Excellent for dynamic measurements, high-frequency response	Not suitable for static measurements, relatively high cost	Dynamic pressure measurements
Capacitive	High sensitivity, good long-term stability, low power consumption	Affected by changes in dielectric properties of the medium	Low-pressure applications, gas measurements
Resistive (Piezoresistive)	Good accuracy, linear output, relatively low cost	May require temperature compensation, can be affected by moisture	Wide range of applications, including automotive
Digital	Direct digital output, easy integration with control systems, often includes built-in diagnostics	Higher initial cost, limited to certain pressure ranges	Real-time monitoring, automated systems

Strain gauge pressure sensor:

Measures pressure by converting mechanical deformation into an electrical signal.

- **Type**: Strain Gauge
- **Cost**: $100 - $200
- **Pressure Range**: Suitable for high-pressure applications typical in hydraulic systems.
- **Accuracy**: High accuracy, suitable for both static and dynamic measurements.

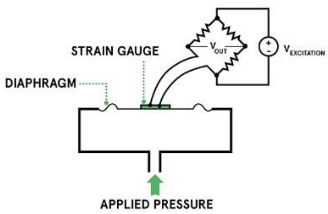


Fig. Strain gauge pressure sensor working

Recommendation 7: Installing a Master Cylinder

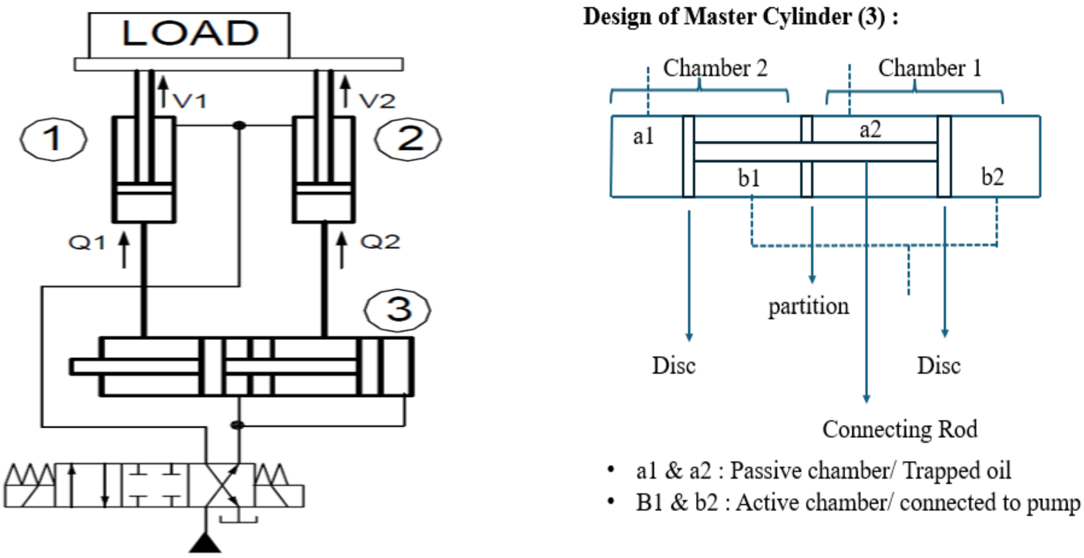


Fig. Master cylinder configuration circuit diagram and design

The master cylinder concept is employed in hydraulic systems to ensure equal fluid flow distribution to multiple cylinders, such as cylinder (1) and cylinder (2), regardless of the load position. In this configuration, the master cylinder functions as the primary source of hydraulic fluid, supplying an equal amount of flow to each connected cylinder. This ensures that the movements of both cylinders remain synchronized, achieving coordinated motion and preventing misalignment.

The accuracy of synchronization using a master cylinder can be as precise as 1%, which implies a minimal offset between the cylinders' positions. This level of precision is particularly important in systems where exact coordination is critical, such as lifting or positioning mechanisms. The master cylinder's ability to maintain equal flow distribution ensures consistent performance and enhances the reliability of the hydraulic system.

The synchronization of multiple cylinders using a master cylinder works by distributing equal hydraulic fluid to each cylinder simultaneously. When the master cylinder is actuated, it delivers the same volume of fluid to both cylinders, ensuring they extend or retract at the same rate. This equal flow compensates for any load differences, maintaining synchronized movement with high precision (typically within 1% accuracy). The system can also include feedback mechanisms to adjust the flow in real-time, further ensuring alignment. This approach is crucial for maintaining precise coordination in hydraulic systems.

Advantages:

- Easy to install at NBM.
- Feasible from economic point of view as it is cheap
- Just few changes in existing circuit required.

Recommendation 7: Providing a Mechanical Guideway in front & back constraining the desired path

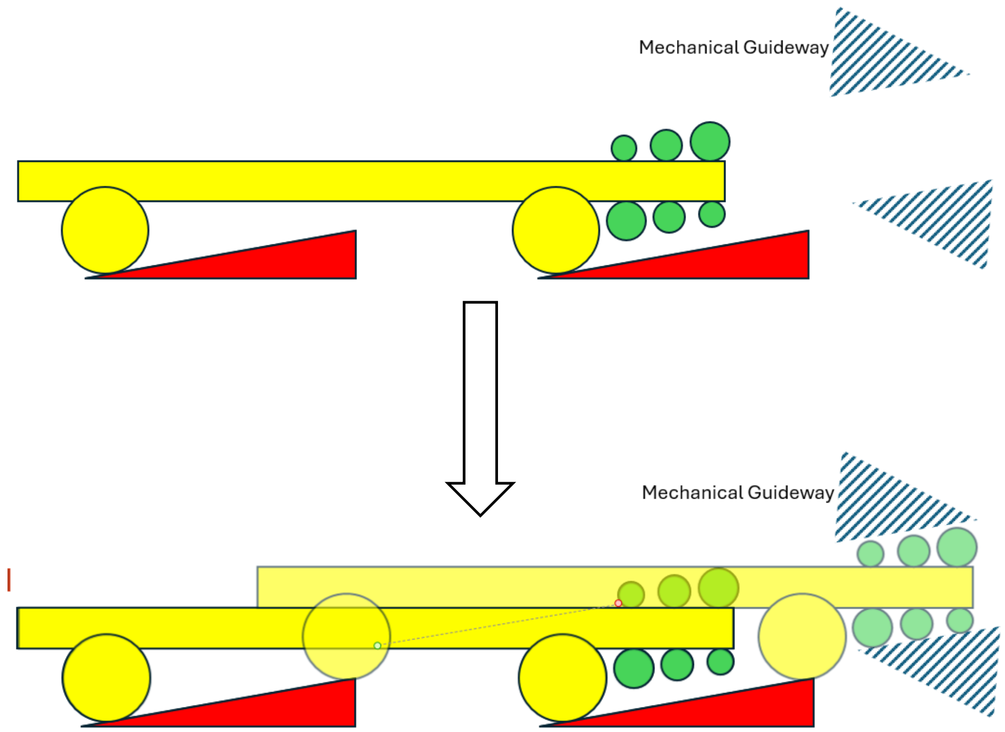


Fig. Protype of design of guideway to constrain the path of lifting frame

To address the issue of deviation of the lifting frame on one side, which may be caused by runaway load or any other unknown cause, it is recommended to install a mechanical guideway at both the front and rear ends of the system. This deviation could be eliminated by providing constraint from the upper side, which can stop sagging on one side of the lifting frame. Introducing a mechanical guideway will help constrain the frame's movement and ensure that it follows the desired trajectory, preventing any misalignment or one-sided sagging.

Implementing this guideway system will not only mitigate the issue of frame sagging but also improve the overall reliability and stability of the lifting mechanism. The added constraints will prevent uneven load distribution and minimize mechanical stress on critical components, reducing wear and tear over time. Only guideways will be effected whose regular check up can lead to finding of root cause as well.

5. Furnace Health Index (FHI)

5.1 Introduction to FHI

The Furnace Health Index (FHI) is determined based on the most critical parameters that directly impact system performance and lead to production delays. After detailed analysis of all delays and their causes, the most critical parameters that must be taken to design the health index of furnace should include the stress/strain values of the tie rods, pressure differences between the lifting cylinders, laser difference measurements, and billet temperature at stand #3. The FHI is a function of these four independent parameters: stress/strain (**α**), pressure difference (**β**), laser difference (**γ**), and temperature (**θ**).

Parameters for FHI :

1. Stress/strain values of tie rod
2. Pressure difference of both lifting cylinder
3. Laser difference values
4. Billet temperature @ stand#3

FHI = f (Strain, pressure difference, laser difference, temperature)

Each parameter is independent in itself, so we need to project them on common index/scale.

Individual Index :

1. Strain Index (**α**)
2. Pressure difference Index (**β**)
3. Laser difference Index (**γ**)
4. Temperature Index (**θ**)

Each parameter is projected onto a common index or scale to allow for a unified assessment of the system's health. The individual indices are defined as follows:

1. **Strain Index (α)**: Represents the normalized stress or strain values of the tie rods, indicating structural integrity.
2. **Pressure Difference Index (β)**: Reflects the pressure disparity between the lifting cylinders, highlighting potential imbalances.
3. **Laser Difference Index (γ)**: Captures variations in laser difference measurements, indicating alignment or positional deviations.
4. **Temperature Index (θ)**: Represents billet temperature at stand #3, critical for maintaining optimal process conditions.

The Furnace Health Index (FHI) is calculated as a weighted mean of the individual indices, taking into account the relative importance of each parameter to the overall system health. The individual indices—Strain Index (**α**), Pressure Difference Index (**β**), Laser Difference

Index ($\boldsymbol{\gamma}$), and Temperature Index ($\boldsymbol{\theta}$)—are combined using assigned weights that reflect their criticality to the furnace's performance.

Strain Index (α) :

$$\boldsymbol{\beta} = \frac{\mathbf{0.75\ (pressure\ difference)}}{\mathbf{Threshold\ difference}}$$

- **$\beta < 0.75$ status OK**
- **$0.75 < \beta < 0.9$ status WARNING**
- **$\beta > 0.9$ status ALERT**

Where, threshold can defined from data

Pressure difference Index (β) :

$$\alpha = \frac{\text{Actual strain} - \text{Minimum strain}}{\text{Elastic limit} - \text{Minimum strain}}$$

$\alpha < 0.75$ status OK

$0.75 < \alpha < 0.9$ status WARNING

$\alpha > 0.9$ status ALERT

Where, E.L = strain corresponding to E.L

Temperature Index (θ) :

$$\theta = \frac{0.75\ (T_{optimum})}{\text{Actual temp SD\#3}}$$

- $\theta < 0.75$ status OK
- $0.75 < \alpha < 0.8$ status LIMIT
- $\alpha > 0.8$ status ALERT

Where, $T_{optimum} = 1040°C$

Laser difference Index (γ) :

$$\gamma = \frac{0.75|d|}{40}$$

$\gamma < 0.75$ status OK

$0.75 < \gamma < 0.8$ status WARNING

$\gamma > 0.8$ status ALERT

Where, d = laser difference

$$\boxed{FHI = w_1\ \alpha + w_2\ \beta + w_3\ \gamma + w_4\ \theta}$$

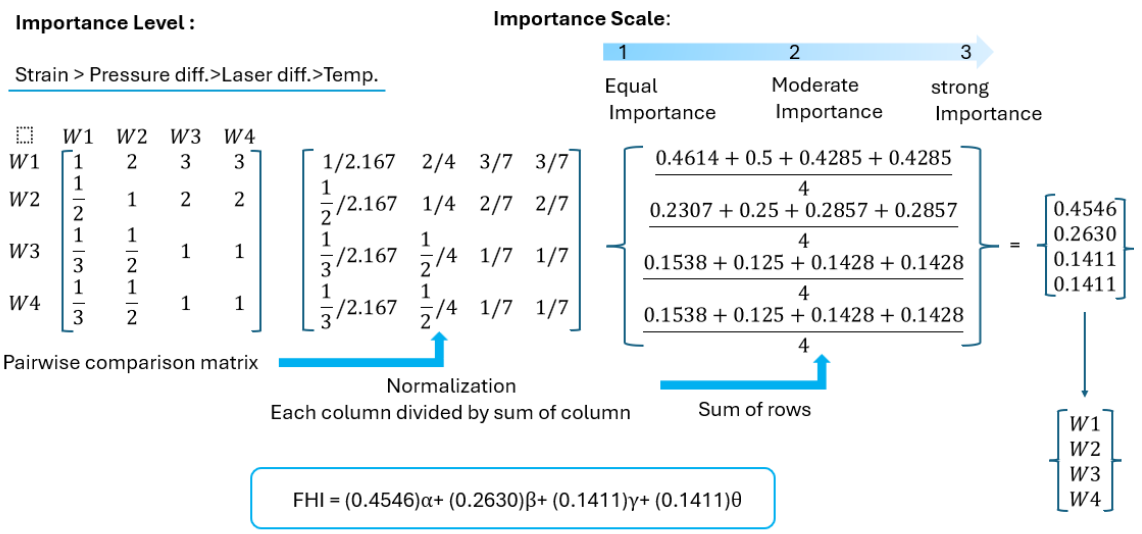
5.1 Analytic hierarchy process (AHP) for weights determination

The Analytic Hierarchy Process (AHP) is a structured technique used to determine the weights of the individual indices that contribute to the Furnace Health Index (FHI). AHP is particularly useful for making complex decisions by breaking down the problem into a hierarchy of more easily comparable elements. This approach helps in quantifying the relative importance of each parameter (strain, pressure difference, laser difference, and temperature) in the FHI calculation.

The process begins by establishing a pairwise comparison matrix, where each parameter is compared against every other parameter based on its contribution to furnace health. Experts assess the relative importance of each parameter, assigning values that reflect their comparative influence. This matrix is then used to calculate the priority weights for each parameter through a series of mathematical operations, ensuring consistency and objectivity in the weight determination.

By applying AHP, the assigned weights to each index—Strain Index (**α**), Pressure Difference Index (**β**), Laser Difference Index (**γ**), and Temperature Index (**θ**)—reflect their true impact on the overall system health, ensuring that the weighted mean of these indices accurately represents the Furnace Health Index.

Once we assign the weights, we can conclude the result and also redefine the importance based on the results. Also we can use a regression model if we have proper data to train and so improvements could be done at any time. Here is an approximate assignment of importance to all parameters based on delays and their impacts on the production and ease of production.



5.2 Online Availability and Alarm System for FHI

The Furnace Health Index (FHI) will be made available online through a server, allowing for real-time monitoring via web dashboards or mobile apps. An alarm system will trigger notifications via email, SMS, or pop-up alerts whenever FHI or any key parameter crosses predefined limits, enabling quick corrective actions.

5.3 Analysis of FHI Trends and Predictive Maintenance

Historical FHI data will be systematically analyzed to uncover trends and patterns in furnace performance. By examining past data, the system can identify recurring issues and predict future conditions, such as potential component failures or performance degradation. This analysis enables the development of predictive maintenance strategies, allowing for timely interventions based on forecasted needs. By addressing potential problems before they escalate, this approach helps extend the life of critical components, reduce unplanned downtime, and optimize overall furnace performance and reliability.

5.4 End User Product prototype

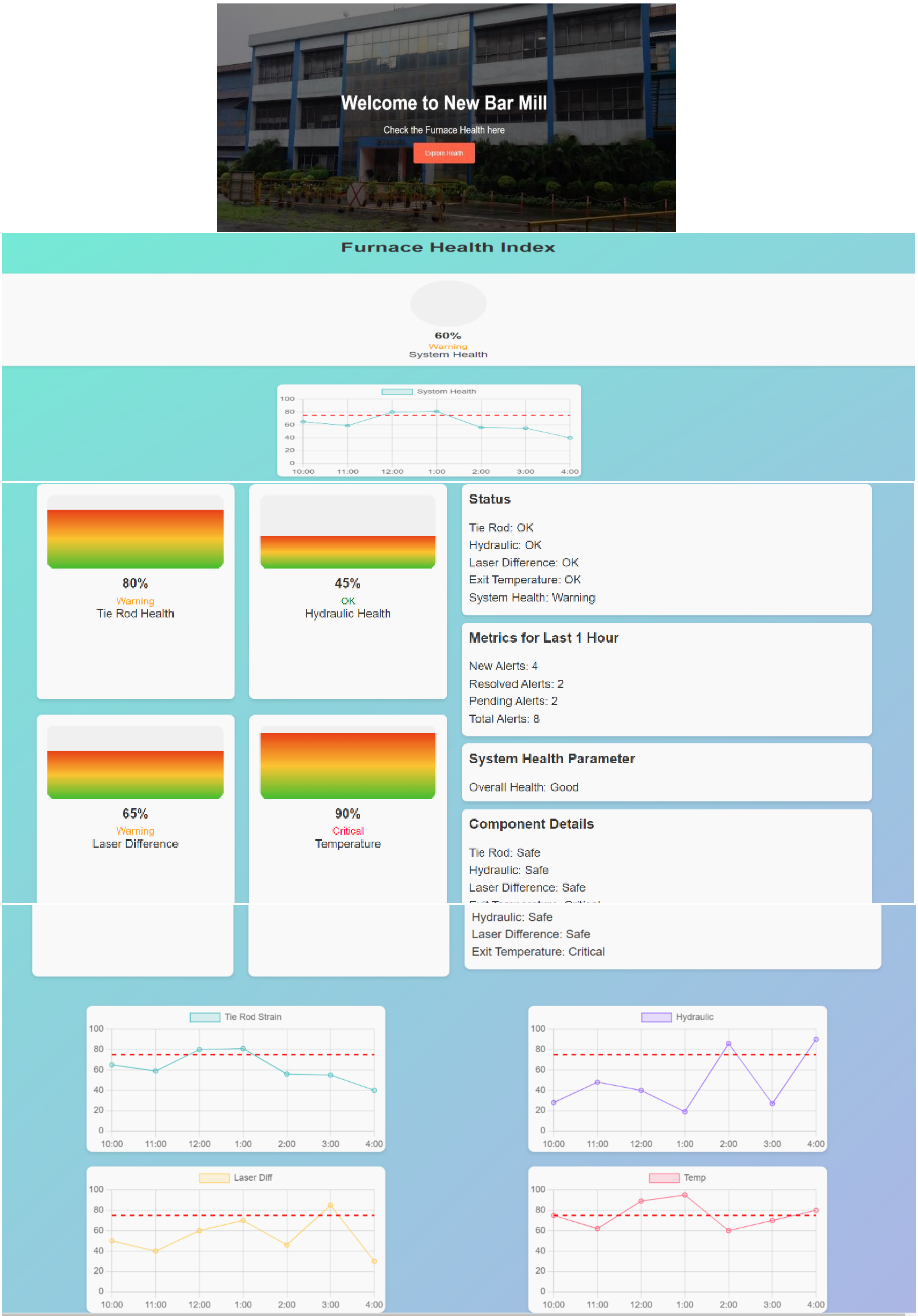


Fig. prototype for online server

6 . Summary

S. No.	PROBLEM	RECOMMENDATIONS
1	Stress concentration on Tie Rod & at welding joint	1. Recording of stress strain values using strain gauges and real time mapping on online Server. 2. Maintenance of FHI (Furnace Health Index) 3. PA-UT of tie rod for welding defects. 4. Welding Checklist
2	Cylinder/ Valve Stand pressure fluctuation, Jerks & desynchronization	1. Real time pressure mapping of cylinders on online Server 2. Installation of a Master cylinder 3. Installation of a mechanical guideway for lifting frame.
3	Traverse Fulcrum play	1. Increasing frequency of Motion Amplification Study 2. Strengthening of base & UT of concrete
4	Lack of Predictive measures	1. Using online server data for predicting upcoming strains, health and defects.

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THANK YOU