International Journal of Research in Engineering, Science and Management
Volume-1, Issue-12, December-2018
www.ijresm.com | ISSN (Online): 2581-5792

Structural and Modal Analysis of Electric Overhead Travelling Crane

D. Rama Chary[1], Y. Krishnaiah[2], Kasuba Sainath[3]
[1]*Student, Dept. of Mechanical Engineering, Sreyas Institute of Engineering & Technology, Hyderabad, India*
[2,3]*Associate Professor, Dept. of Mechanical Engineering, Sreyas Institute of Engg. & Tech., Hyderabad, India*

***Abstract*: Cranes are industrial machines that are mainly used for movements of materials on construction sites, production halls, assembly lines, storage areas, power stations and similar locations. Its design features vary widely based on its main operational specifications, such as type of crane structure movement, weight and type of load, crane position, geometric characteristics, operating regimes and environmental conditions.**

A hook is an instrument consisting of a length of material that contains a curved or indented part, so that this part can be used to hold another object. In one set of uses, one end of the hook is pointed, so that this end can pierce another material, which is then held back by the curved or notched part. In the industries, crane hooks are one of the important components. They are used to transfer materials that have heavy loads

***Keywords*: electric overhead travelling crane, structural analysis, modal analysis**

1. Introduction

Cranes are industrial machines that are mainly used for movements of materials on construction sites, production halls, assembly lines, storage areas, power stations and similar locations. Its design features vary widely based on its main operational specifications, such as: type of crane structure movement, weight and type of load, crane position, geometric characteristics, operating regimes and environmental conditions.

A hook is an instrument consisting of a length of material that contains a curved or indented part, so that this part can be used to hold another object. In one set of uses, one end of the hook is pointed, so that this end can pierce another material, which is then held back by the curved or notched part. In the industries, crane hooks are one of the important components. They are used to transfer materials that have heavy loads.

The crane hooks are responsible components subject to failure due to stresses in the accumulation of heavy loads. The area of the cross section, the material and the radius of the crane hook are the design parameters for the crane hook. The failure of a crane hook depends mainly on three main factors: size, material, overload.

The design of the hook of the electric crane that is moved above has been realized. The dimensions of the hook were determined for different load capacities. Various dimensions have been found for cross-sections of various shapes for crane hooks. After designing the system, the stress and deflection are calculated at critical points using ANSYS and optimized.

Today, aerial cranes are used in almost all manufacturing sectors. Aerial cranes are commonly used for refining steel and other metals such as copper and aluminum. At each stage of the manufacturing process, until it leaves a factory as a finished product, the meta is managed by a bridge crane. It also finds its use in other production and assembly departments, such as assembly lines, storage areas, power plants, etc.

Lifting is the process of lifting something or a load or a person from a lower position to a higher position with the help of some device or mechanism.

A. *Lifting devices*

A lifting device is used to raise or lower a load by means of a drum or a lifting wheel around which the rope or chain is wound. It can be operated manually, electrically or pneumatically and can use chain, fiber or cable as a means of lifting. Example: elevators, cranes.

The lifting part of an EOT crane is analyzed here

The lifting part of the EOT crane consists of the following parts

- Lifting motor
- Exchange
- Drum
- Pulleys
- Metal cable
- Hook

A lifting motor is used as a driving system for the mechanism. The engine is coupled to a gearbox

2. Literature survey

A. *Classification*

Depending on the type of installation, they are divided into four types,

1) *Single-girder crane*

The crane consists of a single bridge beam supported on two carriages. It has a lifting mechanism of the carriage that runs on the lower flange of the bridge beam.

- Single-span bridge cranes generally have a maximum space between 20 and 50 feet with a maximum lift of

International Journal of Research in Engineering, Science and Management
Volume-1, Issue-12, December-2018
www.ijresm.com | ISSN (Online): 2581-5792

15-50 feet.

- Can handle 1-15 tons with bridge speeds approaching a maximum of 200 feet per minute (fpm), cart speed of around 100 fpm and lift speeds of between 10 and 60 fpm.
- They are candidates for a light to moderate service and are profitable for use as backup cranes (not used frequently).
- Single-beam cranes reduce the total cost of the crane on crane components, track structure and construction.

Fig. 1. Single girder crane

2) Double-beam bridge crane

The crane is made up of two bridge beams supported on two end trucks. The car runs on tracks at the top of the bridge beams.

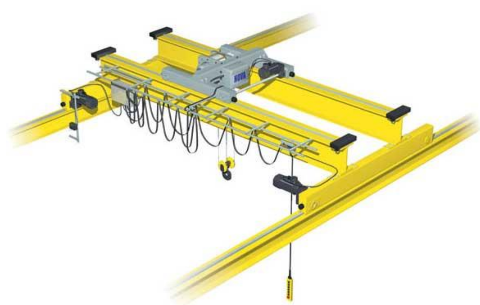

Fig. 2. Double beam crane

- Double-range cranes are faster, with maximum deck speeds, truck speeds and lift speeds approaching 350 fpm, 150 fpm and 60 fpm respectively.
- They are useful cranes for a variety of levels of use ranging from infrequent and intermittent use to continuous severe service. They can lift up to 100 tons.
- These can be used in any capacity where a very high lifting of the hook is required because the hook can be raised between the beams.
- They are also very suitable when the crane must be equipped with corridors, crane lights, cabins, magnetic cable reels or other special equipment

3) Gantry cranes

These cranes are essentially the same as ordinary aerial cranes, except that the bridge for transporting the cart or trolleys is rigidly supported on two or more legs moving on fixed rails or on another binary. These "legs" eliminate the track and column support system and are connected to end trucks that move on a rail embedded in the floor or on it.

Fig. 3. Gantry cranes

4) Monorail

For some applications, such as the production assembly line or the service line, only one hoist is required. The lifting mechanism is similar to a single-beam crane, with the difference that the crane does not have a movable bridge and the lift truck operates on a fixed beam. The monorail beams are usually beams I (conical flanges, various combinations and variations of the types mentioned have been made to obtain the desired crane).

Fig. 4. Monorail

- Crane (machine)

The stress of the material or of the crane will fail. Main article: aerial crane and aerial crane, also known as a bridge crane, is a type of crane where

- Gantry cranes

The terms gantry cranes and bridge cranes (or overhead cranes) are often used interchangeably, since both types of cranes include their workload.

- Crane (guide)

A railway crane (name of a mobile crane or wrecker, the name of UK damage crane) is a type of crane used in a railway for one of three main purposes: handling of goods.

B. Configuration of the EOT crane

1. Running (U / R)
2. Superior performance (T / R)

1) Under the operating cranes

Under Running or Under Langed, cranes are distinguished by the fact that they are supported by the roof structure and run on the lower flange of the track beams. Under the crane in operation, they are normally available in standard capacities up to 10 tonnes (special configurations up to 25 tonnes and sections over 90 feet). The suspended overhead cranes offer excellent side access, close games and can lean on the suspended tracks of existing building members, if appropriate.

Under Running Crane offers the following advantages

- Very small approach dimensions of the trolley that

mean maximum exploitation of the width and height of the building.
- The possibility of using the existing roof beam to fix the crane track.

Below are some limitations for Under Running Cranes
- Height of the hook: due to the position of the track beams, the height of the hook is reduced.
- Roof load: the load applied to the roof is greater than that of a crane that slides over it.
- The lower load of the flange of the track beams requires accurate sizing; otherwise, it can "take off" the spoke flanges.

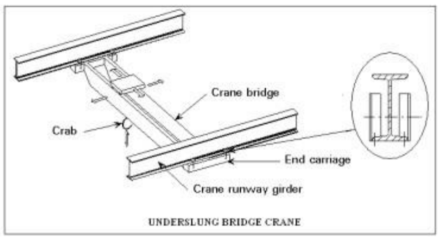

Fig. 5. Under running crane

2) Top racing cranes

The crane bridge moves on tracks mounted on a rail beam supported by columns or columns of the building designed specifically for the crane. Top Running Cranes is the most common form of crane design in which crane loads are transmitted to the building's columns or to the independent structure. These cranes have the advantage of a minimum of free space / maximum lift height.

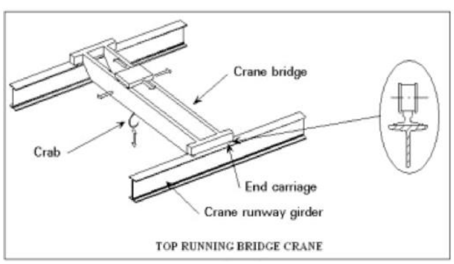

Fig. 6. Top racing cranes

C. Nomenclature

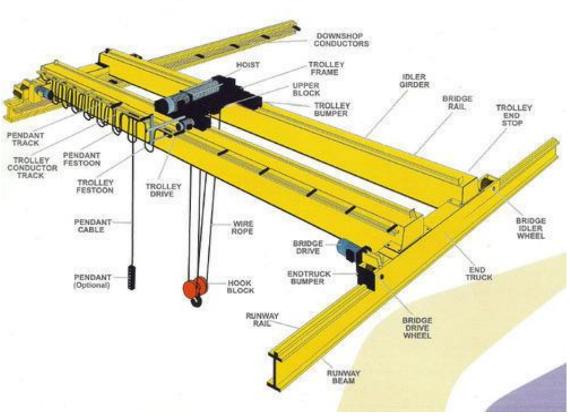

Fig. 7. Nomenclature of a crane

1) Bridge

The main structure of displacement of the crane that extends over the width of the bay and moves in a direction parallel to the track. The bridge consists of two end trucks and one or two beams of the bridge depending on the type of equipment. The bridge also supports the car and the lifting mechanism to lift and lower the load.

2) End of truck

Located on both sides of the bridge, the extreme trucks house the wheels on which the entire crane travels. It is a set composed of structural elements, wheels, bearings, axles, etc., which supports the beams of the bridge or the crossbars of the trolley.

3) Arm (i)

The horizontal main beam of the crane bridge that supports the car and is supported by extreme trucks.

4) Trace

The rails, the beams, the supports and the frame in which the crane operates.

5) Draw the lane

The rail supported by the beams of the track on which the crane travels.

6) Lift up

The lifting mechanism is a unit consisting of a drive motor, a coupling, brakes, gears, drum, ropes and a load block designed to lift, maintain and reduce the maximum rated load. The lifting mechanism is mounted on the cart.

7) Cart

The unit carrying the lifting mechanism that travels on the rails of the bridge in a direction perpendicular to the carriageway of the crane. The car's frame is the basic structure of the car in which the lifting and moving mechanisms are mounted.

8) Bumper (Shock absorber)

A device to absorb energy to reduce the impact when a crane or a moving car reaches the end of its allowed path or when two mobile cranes or cars come into contact. This device can be connected to the bridge, trolleybus or route stop.

3. Theory

Traveling mobile electric crane Electric mobile crane the operating principle consists of three work movements.

1. Lifting crane above and below
2. Side movement of the car
3. Crane with long displacement longitudinal movement

1) Transmission of the lifting system

The driving force of the lifting mechanism is the engine. It transmits power at the end of the high speed gearbox shaft via gear coupling, compensation shaft and brake wheel joint. Then through the reducer to reduce the high rotation of the motor to the required rotation and output from the low speed shaft of the gearbox. The annular gear of the drum transmits the driving force to the drum unit, then through the cables and pulleys operate the crane hook up and down, ending up by lifting heavy objects up and down.

2) Transmission of the trolley displacement system

The driving force of the crane is the engine. It transmits power at the end of the high speed gearbox shaft by coupling the brake wheel, the compensation shaft and the half gear coupling. Then through the reducer to reduce the high rotation of the motor to the required rotation and the output from the low speed shaft of the gearbox. And then, by means of a half-gear joint, the compensation axis, the gear coupling coupling with carriage wheels, to rotate the drive wheels of the truck, so that the transport carriage carries heavy objects lateral movement.

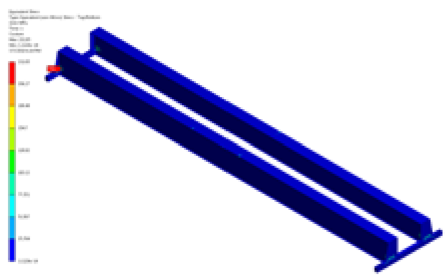

Fig. 8. Transmission of the trolley displacement system

3) Transmission of the crane displacement system

The driving force of the crane is the engine. It transmits power at the end of the high speed gearbox shaft by coupling the brake wheel, the compensation shaft and the half gear coupling. Then through the gearbox to reduce the high rotation of the motor to the required rotation, and the output for low speed shaft of the gearbox and then for complete coupling with the crankshaft wheel shaft, to guide the crane by turning wheels, in so as to finish the bridge carrying heavy objects with lateral movements.

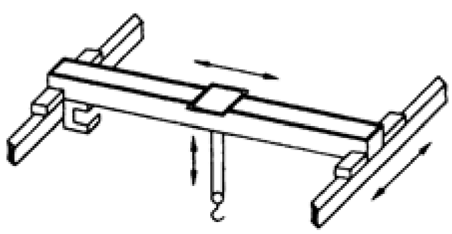

Fig. 9. Transmission of the crane displacement system

A. Structural results

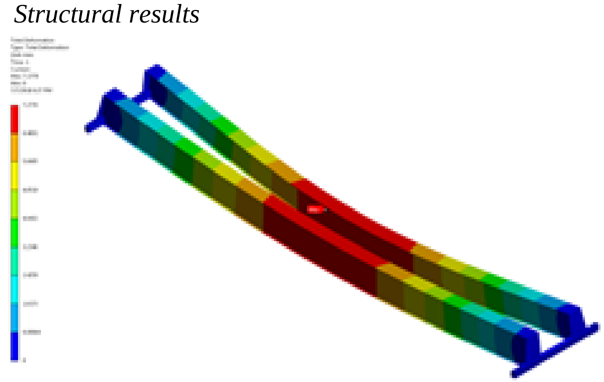

Fig. 10. Equivalent (Von-Mises) Stress

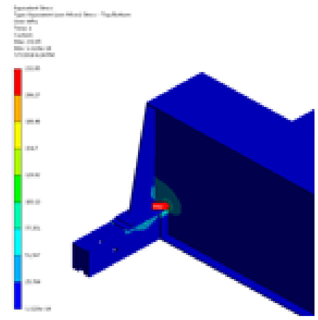

Fig. 11. Deformation

Table 1
Design calculations

Specifications	
Material	IS2062 E250 (FE 410W) B
Class of Crane	M5
Safe Working Load (Te) SWL(W_1)	15 Ton
Span	21 meter
Distance of Main Hook From Wheel	0.837 meter
Self-Weight of End Carriage	1500 Kg
Impact Factor	1.32
Duty Factor	1.06
Lifting Height of the crane (H)	15 meter
Crane Standard	IS:807
Trolley Weight	12.5 ton
Trolley wheel Base	900

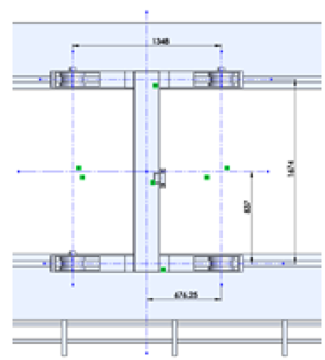

Fig. 12. Trolley position on double girder assembly

1. Wheel Base = 1.348 m
2. Wheel Span = 1.674 m
3. X = 0.676 m, Y = 0.837 m

According to application area of the Bridge crane, it should be sustain the wind load as well as the actual condition load, so the allowable stress for designing the Bridge crane are calculated as under,

$$\sigma_a = \sigma_{ut} / (C_{df} \times C_{bf} \times C_{sf}) \quad (1)$$

Factors for finding Allowable Stress

$\sigma a = \sigma ut/(Cdf \times Cbf \times Csf)$

$\sigma_a = 410/(0.85 \times 2.5 \times 1.12)$ $\sigma a = 172.27\ N/mm^2$

$\tau =$ Shear stress

$\tau = 0.50 \times \sigma_t$

$= 0.50 \times 172.27$

$= 86.13\ N/mm^2$

Table 2
Data

σ_{ut}	Ultimate tensile stress for the Bridge crane, N/mm^2	410
C_{df}	Duty factor for the load lifting motion in the vertical direction	0.85
C_{bf}	Basic stress factor for the given loading condition	2.50
C_{sf}	Safety factor for using the material FE410	1.12

B. Design calculation of the beam

Based on the structure and application, the load diagram for the crane is shown as under.

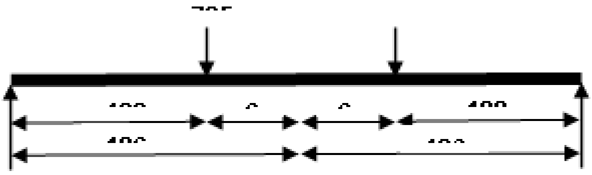

Fig. 13. Position of maximum bending moment

M_1=bending moment generated on the beam based on the Live load.

$$M_1 = \Psi \, X \frac{\left((Wd+Wt)\ x \left(s-\left(\frac{Tc}{2}\right)\right)^\wedge 2\right)}{8\ X\ S} \quad (2)$$

$$M_1 = 1.32\ X \frac{\left((110.362+27.590)\ x \left(21000-\left(\frac{1348}{2}\right)\right)^\wedge 2\right)}{8\ X\ 21000} \quad (3)$$

Where,
S - Span
T_c - Trolley Wheel Centre to Centre
W_d - Design Load – 1.5 * 73575 = 110.3625 KN
W_g - Self Weight of Girder – (Wcr – Wt) – (2 * Wec) = 41.261 KN
W_t - Self Weight of Trolley – 0.25 x Wd = 27.590 KN
W_{cr} - Self Weight of Crane – 0.75 x Wd = 82.771KN
W_{wm} - Maximum Wheel Load - 1.07 x (Wd+ Wt/4) = 36.902 KN
W_{ec} - Self Weight of End Carriage – 6.96 KN
M_1 - Bending Moment due to Live Load
M_2 - Bending Moment due to Impact Load
M_3 - Bending Moment due to self-weight of Girder
M_{max} - Maximum Bending Moment
Z - Section Modulus
σ_a - Allowable Stresses
σ_b - Maximum Bending Stresses
I_{xx} - Moment of Inertia at X-axis.
R_c - Rated Capacity
S.F. - Service Factor
"Ψ" - Dynamic Coefficient Factor

Bending moment calculations

Design Load on each girder
W_d = FOS x Rated capacity
= (1.5 x 15000 x 9.81)/4
= 55.181 KN
Bending moment due to live load
M_1 = 447812.789 KN mm
Bending Moment due to Impact Load
M_2 = 0.25 x 447812.789
= 111953.197 KN.mm
Bending Moment due to Self-mass of girder
$W_g = (W_{cr} - W_t)-(2 \times W_{ec})$
= 41.261 KN
$M_3 = 1.1 \times (W_g \times S)/8$
= 1.1 x (41.261 x 21000) / 8
= 119141.137 KN.mm
Maximum bending moment generated in the crane are as under
$M_{max} = M_1 + M_2 + M_3$
= 447812.789 + 111953.197 + 119141.137
= 678907.123 KN.mm
"I" Section used in the Crane Assembly is as under.

Fig. 14. "I" Section

Dimension of the double box section

Now to find out the stress generated in the I Section by the following equation.

Stress and Deformation for double box section

Now the stress generated in the beam is 121.96 N/mm^2 and the allowable stress is 172.27 N/mm^2. Which is higher than the generated bending stress. So the selected section is safe. The weight of the "I" section is found out to be 26976 kg.

Stress and Deformation for "I" Section 700×400

$$M_{max} = 678907123\ N.mm$$

$$\sigma_b = \left(\frac{M_{max}}{I}\right) \times \text{Radius of Gyration} \quad (4)$$

$$\sigma_{b=}\left(\frac{678907123}{1519507977.53}\right) \times = 116.514 \frac{N}{mm^2}$$

$$\tau = 0.5 \times \sigma_b = 0.5 \times 116.514 = 58.257$$

Now the stress generated in the beam is 116.516 N/mm^2 and the allowable stress is 172.27 N/mm^2. Which is higher than the generated bending stress. So the selected section is safe. The weight of the "I" section is found out to be 24455 kg

4. Modal analysis

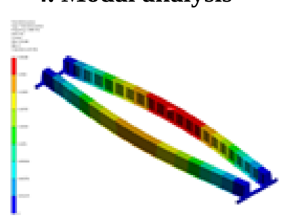

Fig. 15. First natural frequency

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Volume-1, Issue-12, December-2018
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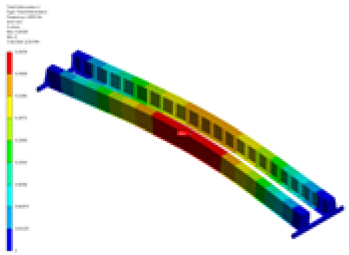


Fig. 16. Second natural frequency

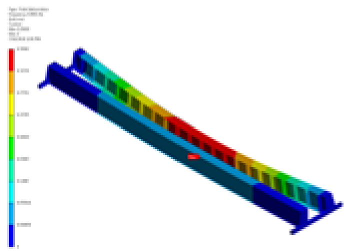


Fig. 17. Third natural frequency

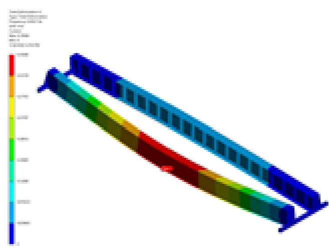


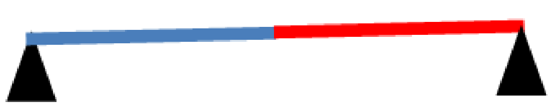
Fig. 18. Fourth natural frequency

A. Natural frequency of girder by using lumped mass matrix approach

Calculating the natural frequency of girder by using Lumped Mass Matrix Approach
Consider the simply supported beam
Length of the beam, L = 21 m
Young's modulus, $E = 2 \times 10^{11}$ Pa
Cross sectional area, $A = 0.08323 m^2$
Moment of inertia, $I = 0.00151\ m^4$
Density, $\rho = 7850\ kg/m^3$
Moments of inertia of the area, at the centroid

$I_{xx} = 1519507977.530\ mm^4$
$I_{yy} = 16393699678.983\ mm^4$

$d1_y$, θ1 d2y, θ2 d3y, θ3 1 2 3 L_1 = 10.69 m L_2=10.69m



Boundary conditions

At node 1: $d1_y = 0$
At node 2: $d3_y = 0$

Element stiffness matrix is given by

$$[K_e] = [EI/L^3]\begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix}$$

For element one applying Boundary conditions, we get

$$[K_1] = [EI/L^3]\begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix}$$

$$[K_1] = [EI/L^3]\begin{bmatrix} 12 & -6L \\ -6L & 4L^2 \end{bmatrix}$$

$$[K_1] = \left(\frac{2 \times 10^{11} \times 0.00151}{10.693^3}\right)\begin{bmatrix} 12 & -6L \\ -6L & 4L^2 \end{bmatrix}$$

For element three applying Boundary conditions, we get

$$[K_2] = [EI/L^3]\begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix}$$

$$[K_2] = [EI/L^3]\begin{bmatrix} 12 & 6L \\ 6L & 4L2 \end{bmatrix}$$

$$[K_2] = \left(\frac{2 \times 10^{11} \times 0.00151}{10.693^3}\right)\begin{bmatrix} 12 & 6L \\ 6L & 4L^2 \end{bmatrix}$$

Global stiffness matrix is given by

$$[K] = [K_1] + [K_2]$$

$$[K] = \left(\frac{2 \times 10^{11} \times 0.00151}{10.693^3}\right)\begin{bmatrix} 12 & -6L \\ -6L & 4L^2 \end{bmatrix} + \left(\frac{2 \times 10^{11} \times 0.00151}{10.693^3}\right)\begin{bmatrix} 12 & 6L \\ 6L & 4L^2 \end{bmatrix}$$

$$[K] = \left(\frac{2 \times 10^{11} \times 0.00151}{10.693^3}\right) x \begin{bmatrix} 12 & -6L \\ -6L & 4L^2 \end{bmatrix} + \begin{bmatrix} 12 & 6L \\ 6L & 4L^2 \end{bmatrix}$$

$$[K] = \left(\frac{2 \times 10^{11} \times 0.00151}{10.693^3}\right) x \begin{bmatrix} 24 & 0 \\ 0 & 8L^2 \end{bmatrix}$$

Lumped mass matrix is given by

$$[Me] = [\rho AL/2]\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$[M_1] = \left[\frac{7850 \times 0.08323 \times 10.693}{2}\right]\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$$

$$[M_1] = \left[\frac{7850 \times 0.08323 \times 10.693}{2}\right]\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$$

$$[M] = \left[\frac{7850\ x\ 0.08323\ x\ 10.693}{2}\right]\begin{bmatrix}2 & 0\\0 & 0\end{bmatrix}$$

Global mass matrix

$[M] = [M_1 + [M_2]$

$$[M] = \left(\frac{7850\ x\ 0.08323\ x\ 10.693}{2}\right)\begin{bmatrix}1 & 0\\0 & 0\end{bmatrix} + \left(\frac{7850\ x\ 0.08323\ x\ 10.693}{2}\right)\begin{bmatrix}1 & 0\\0 & 0\end{bmatrix}$$

$$[M] = \left(\frac{7850\ x\ 0.08323\ x\ 10.693}{2}\right)\begin{bmatrix}2 & 0\\0 & 0\end{bmatrix}$$

Characteristic equation is given by

$I\ [K] - \omega^2\ [M]\ I = 0$

$$\left(\frac{2\ x\ 10^{11}\ x\ 0.00151}{10.693^3}\right)\ x\ \begin{bmatrix}24 & 0\\0 & 8L2\end{bmatrix} - \omega^2\left(\frac{7850\ x\ 0.08323\ x\ 10.693}{2}\right)\begin{bmatrix}2 & 0\\0 & 0\end{bmatrix} = 0$$

$$\omega^2 = \frac{1.35\ x\ 10^{15}}{1.588\ x\ 10^{12}}$$
$= 29.22$ rad/sec

$f = 29.22 / (2 * \pi)$

Natural Frequency (f) = 4.65 Hz.

5. Conclusion

From the finite element analysis and calculations, the following conclusions have been drawn.

First Natural Frequency	
Theoretical Approach	Simulation Result
4.65	3.44

- In structural analysis of the grider beam, stress calculated in theoretical approach and stress obtained in simulation approach are under safe and allowable limits.
- For above rotor model, the theoretical approach & simulation approach first torsional frequency are shown below.

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