

# Finite Element Analysis of Winch Machine for Erection of Transmission Tower

Mr. Wankhede Avinash<sup>1</sup>, Prof. Dr. Gawande Rupesh, Prof. Fulmali S.M<sup>3</sup>

<sup>1</sup>M.Tech. Student of CAD/CAM, BDCOE, Sewagram, India

<sup>2</sup>Associate Professor at Mechanical Department, BDCOE, Sewagram, India

<sup>3</sup>Assistant Professor at Mechanical Engineering Department, BDCOE, Sewagram, India

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**Abstract** - Winch machine is arrangement of tools and tackle for lifting and lowering the objects and widely used in the field of engineering mechanisms. It is designed as pulling devices, consisting of rope winding around a horizontal drum turned typically by motor. It is classified into seven major types depending on drive system, such as electrical winch, mechanical drum-style winch, mechanical capstan-style winch, hydraulic winch, mechanical hand-operated winch, mechanical portable winch and hybrid winch. A winch is made up of many components like drum, shaft, rope, winch gearbox and drive system etc. In recent trend to fulfil the shortfall of energy throughout the country and under developed countries business of construction of EHV Transmission line is undergoing on war foot basis & it's required a specially designed winch machine to achieve the great result with proper safety in work. This review is conducted to study the areas of improvement in the design of winch system to develop the high performance winch for the building/construction of EHV transmission tower

**Key Words:** Winch, Transmission tower, Winch drum

## 1. INTRODUCTION

### 1.1 Methods of EHV tower erection

Tower erection is the process of lifting the tower parts sections and assembled as per the drawing specifications. It is majorly includes three process of tower building (a) Manual method (b) Motorized winch (c) Helicopter method. All these three method having limitations as mentioned below

- Manual method: - In this method erection work done with the help of manpower and moving tractor (partially). Basic loophole & limitations are skilled manpower, unsafe working and right of way (ROW) required for tractor moving.
- Motorized winch: - This is compact size model of winch, it have a one or two small size pulley arrangement to pass over the cable smoothly. As there doesn't have any drum arrangement the cable life reduces in high extent. The arrangement is also more complicated to make the winch in steady position. These complications make its unsafe as well as less progressive
- Helicopter method: - This is one of the most expensive methods used for the erection of the tower in section wise. In this method helicopter is used for lifting the section wise tower portion and directly installed on the main body with the help of highly skilled manpower. But due to cost factor it is not much popular in Indian business.

### 1.2 Finite Element Method:

The Finite Element Method is a technique used to derive an approximate solution of any complex engineering problem that can be reached by subdividing the problem into smaller, more manageable elements i.e. finite elements. The behavior of structure can be easily predicted by solving linear equation's sets in the form of matrix algebra for those finite elements.

In FEM, the simulation models may belong to mechanics, acoustics, thermal field, electromagnetic fields or coupled problems. In mechanical problems the elements may be model membranes, beams, plates, solids, fluids etc.

This method contains conversion of the available component data into matrices & interpolating differential equations and their processing. The pre-processor is used to develop the finite element model. The pre-processor requires direct user input data which includes Coordinate system, Meshing, Nodes & Elements, Geometrical & Material Constants, Loading conditions etc. After completing this phase, the finite element model is set to solve. The output data is arranged into tabular or graphical form by postprocessor In case of structural problems, the nodal displacements & stress values at nodal points are given in the tabular form. The knowledge of finite element method is helpful in analysis of the component to be studied, because it is the basic tool used for simulation software.

## 2. LITERATURE REVIEW

Overall design of winch system is generally confirmed to Indian Standard codes. Study of such codes is carried out first to know basic design procedure. Determination of various dimensions of components is based on standard formulae and codes from Indian standards. The present design of rope drum and shaft is to be made to withstand the load due to lifted material. This requires good understanding of loading conditions, rope drum assembly and wire rope selection

For further study it is required to understand all theories of failure so as to calculate the stresses induced in rope drum and shaft analytically and to apply correct failure criterion. The knowledge of techniques used for shaft failure analysis and simulation methods adds to better visualization of experimentation. To know the design analysis and simulation procedure, it is important to know the basic Finite Element Method which is embedded in simulation software. A step by step description of method improves the conceptual understanding.

## 3. METHODOLOGY

The methodology comprises detailed study of rope drum, shaft, articulating components and their assembly. As the material load is determined, it will directly give the value of force acting on wire rope. The load on rope drum and wire rope does not exceed 4 ton, hence a 4 sieve pulley arrangements of rope is sufficient to bear the load.

In analytical design of rope drum and shaft, first basic load value is determined. Then, the appropriate wire rope is selected based on Indian standard criteria. The dimensions of rope drum directly depend on the size (diameter) of wire rope. But, the number of wire rope turns on rope drum is calculated with reference to height of lift. Further, the shaft is designed in accordance with the value of torque on rope drum based on standards and analytical design formulae.

The computer aided model of calculated and derived dimensions of rope drum and shaft assembly is then prepared in CATIA V5. This model is converted in to IGS and STP format so as to input it to finite element analysis software ANSYS.

The experimentation of this work consists, manufacturing of reduced size model with analogous loading conditions. The model would be tested for stresses induced in it when it is subjected to calculated loads. The same experiment model is to be simulated in finite element analysis software in order to cross check the results. The validation is achieved if experimental and finite element analysis results are matched within permissible limits. This will prove the loading conditions being appropriate and same method would be applied for actual CAD model of rope drum and shaft assembly to carry out finite element analysis and predict the results.

## 4. ANALYTICAL DESIGN

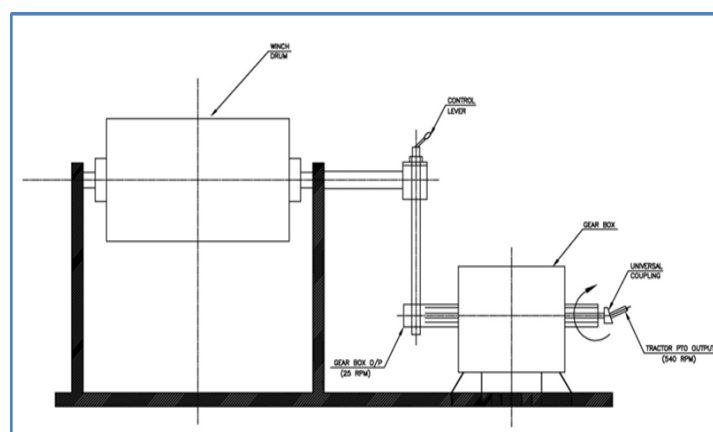


Fig 01: General Arrangement of the Winch System

### I. Basic load calculation

We have consider 4 Mt load for the lifting through this winch system.

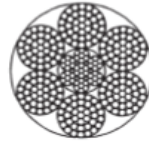
Maximum load of mass to be lifted =  $m = 4 \text{ Mt} = 40000 \text{ N}$

Weight of the rope =  $110 \text{ mtr} \times 0.54 \text{ Kg/mtr} = 59.5 \text{ Kg} = 585 \text{ N}$

Total load on lifting (T) =  $40000 + 585 = 40585 \text{ N}$

## II. Selection of Rope [3,4,5,6,18]

As per the specifications, standard wire rope size of nominal diameter 12 mm and type 6 × 19 with steel core is selected. This wire rope has tensile strength and minimum breaking force equal to 1800 MPa and 73.6 kN respectively



Efficiency of wire rope when it is bent around rope drum,  $\eta = 0.94$

Consider 4 sieve pulley arrangements

Thus, tension in wire rope

$$P = \text{Load to be lifted} / (4 * 0.94)$$

$$= 40585 / 3.76$$

$$= 10793.19 \text{ N}$$

This value must have to be lesser than the safe working load

Recommended factor of safety for general rope applications  $f_s = 6$

Safe working load = SWL

$$= F_b / f_s = 73600 / 6$$

$$= 12266.67 \text{ N}$$

Hence, tension in the wire rope < safe working load.

The selected wire rope is safe and acceptable.

Now, each wire diameter in wire rope

$$= 0.45 d = 0.45 \times 12$$

$$= 5.43 \text{ mm}$$

$$\text{Metallic area of wire rope} = 0.40 d^2$$

$$= 0.40 \times 12^2$$

$$= 57.6 \text{ mm}^2$$

## III. Design of Winch Drum:

### Diameter & Groove size [3,2,18]

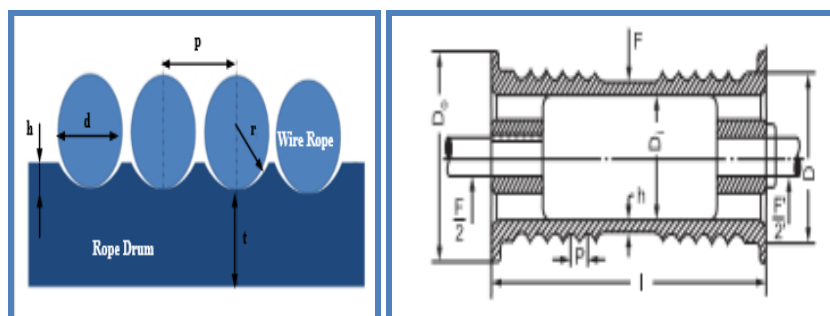


Fig 02: Dimension of Rope drum

As per IS specification  $D/d$  ratio shall not be less than 18

Select  $D/d = 27$  for further calculations

Thus following dimension parameters of rope drum are required to be calculated.

Inner diameter of rope drum at bottom of groove,  $D = (D/d \text{ ratio}) \times d = 27 \times 12 = 324 \text{ mm}$

Minimum radius of groove,  $r = 0.53 \times d$

$$= 0.53 \times 12 = 6.36 \text{ mm}$$

Minimum depth of groove  $h = 0.35 \times d$

$$= 0.35 \times 12 = 4.2 \text{ mm} \cong 4 \text{ mm}$$

Outer diameter of rope drum  $D_o = D + (6d)$

$$= 324 + (6 \times 12)$$

$$= 396 \text{ mm}$$

$$\text{Pitch of the groove } p = 1.08 \times d$$

$$= 1.08 \times 12$$

$$= 12.96 \text{ mm}$$

#### IV. Minimum no. of wire rope turns on rope drum,[3]

$$n = \frac{iS}{\pi D} + 2$$

$$= 110000 / (3.14 \times 324) + 2$$

$$= 110 \text{ turns}$$

Length of drum, l

$$l = \left( \frac{2iS}{\pi D} + 7 \right) p = 892.54 \text{ mm}$$

#### V. Thickness of drum [3,8,19]

Assume thickness of drum = 30 mm

Based on the DNV design codes:

The hoop stress in the winch drum,  $\sigma_h \text{ (Mpa)} = C \left( \frac{T}{d \times t} \right)$

$\sigma_h$  = hoop stress in winch drum (MPa),

T = Load on the rope, Newton

d = diameter of the rope, mm.

t = thickness of winch drum, mm

C = 1 for 1 layer & 1.75 for more than 1 layer

According to the guidelines, the maximum permissible hoop stress  $\sigma_{pe}$  should not exceed 80% of the material yield stress ( $\sigma_{pe} \leq 0.80 \sigma_y$ ).

In this case, the material yields stress. Selecting grey cast iron G4000 with yield stress 276MPa

Hoop stress in the winch drum,[3,18,17]

$$= \sigma_h \text{ (Mpa)} = 1.75 \left( \frac{40585}{12 \times 30} \right)$$

$$= 197.28 \text{ Mpa}$$

Permissible hoop stress = 0.80 x 276

= 220.80 Mpa

Stresses developed on the drum [3,17,18]

$$\text{Crushing Stress} = \frac{P}{t \times p}$$

$$= 40585 / (30 \times 12.96)$$

= 104.38 MPa

Torque on rope drum

$$= T = \frac{P \times (D + d)}{2}$$

$$= 40585 \times (324 + 12) / 2$$

$$= 40753 \text{ N-mm}$$

$$= 40.75 \text{ N-m}$$

Selection of the shaft [3,7,9,18]

Selecting the diameter of Indian standard code ds=20mm

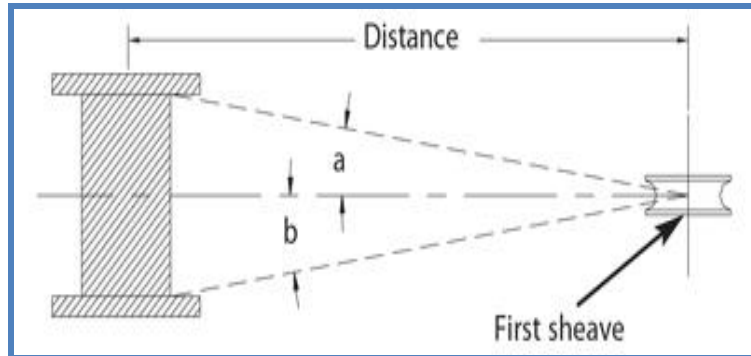
Transmissible torque value

$$= \frac{(9.80665 \pi \times ds^3)}{4000}$$

$$= 61.61 \text{ N-m}$$

Here, transmissible torque value > torque on rope drum. Thus, the shaft is acceptable.

## VI. Check for fleet angle



**Fig 03:** Fleet angle

Fleet angle is the angle between the wire rope and imaginary line extending perpendicular to the drum. The fleet angle varies with the distance between the lead sheave and the drum. The proper fleet angle helps the wire rope to wind evenly onto the drum, and helps to reduce wear to the wire rope, drum, and lead sheave. Too large a fleet angle will cause the wire rope to wind loosely, overlap and possibly jump the flange and cause severe damage to the equipment. A maximum fleet angle of 0.5° to 1.5° for smooth drums, and 2° for grooved drums, helps the wire rope wind uniformly.

By setting up the winch machine 30 meter away from under tower.

$$\tan A = 0.447/30 \text{ Fleet angle } A = 0.85^\circ$$

Hence OK

## VII. Selection of worm gear box [20,21]



**Fig 04:** Worm Gear Box

$$\text{Work} = \text{Force} \times \text{distance} = 40585 \times 110 = 4464350 \text{ N-m}$$

$$\begin{aligned} \text{Power} &= \text{Work}/\text{Time} \\ &= 4464350/300 \text{ (@ } 20 \text{ m/min hence, for 90 meter 300 sec)} \\ &= 14881.16 \text{ N-m/sec (14.88 KW)} \end{aligned}$$

$$\begin{aligned} \text{Torque} &= \text{Force} \times \text{Radius of drum} \\ &= 40585 \times 0.162 \\ &= 6574.77 \text{ N-m} \end{aligned}$$

$$\begin{aligned} \text{Ratio required} &= \text{input speed}/\text{output speed} \\ &= 500/25 = 20:1 \\ &= \text{nearest standard available ratio } 20:1 \end{aligned}$$

$$\begin{aligned} \text{Lifting load with moderate shock Mechanical service factor} &= 1.25 \text{ (From data table for 8 hr/day)} \\ \text{Equivalent output power (Mechanical)} &= 14.88 \times 1.25 = 18.6 \text{ Kw} \\ \text{Equivalent output torque (Mechanical)} &= (6574.77 \times 18.6)/25 = 4891.62 \text{ Nm} \end{aligned}$$

$$\begin{aligned} \text{Thermal service factor} &= 1.62 \text{ (From data table for } 50^\circ \text{ C)} \\ \text{Equivalent output power (Thermal)} &= 14.88 \times 1.62 = 24.10 \text{ Kw} \\ \text{Equivalent output torque (Thermal)} &= (4891.62 \times 24.10)/25 = 4715.52 \text{ Nm} \end{aligned}$$

Refer at input ratio 20:1 at input speed of 500 rpm, as per calculation we

Required 4891.62 N-m output torque hence, we select higher gear unit from ELECON CatLog data with size no. 10.5,

ratio 20:1 having output mechanical torque = 8423.1 Nm. and input power 21.00 KW

Required input power = (Calculated equivalent torque x rated input power) / (rated output torque x service factor) = (6574.77 x 14.88) / (4891.62x 1.25) =16 KW Available input source can easily produce required power hence OK

### 5. COMPUTER AIDED MODEL

With reference to above calculations, all dimensions of assembly are determined. Hence, a computer aided model is prepared in CATIA V5 software in assembly mode. The components of assembly are shown in fig

1. Created body part with PAD Command in CATIA with file format .CAT
2. Created shaft with pad command in CATIA with file format .CAT
3. Created rope drum with shaft command in CATIA with file format .CAT
4. Assembled parts in assembly environment by using assembly constraints.
5. Save file in IIGES Format (initial graphics exchange specification)

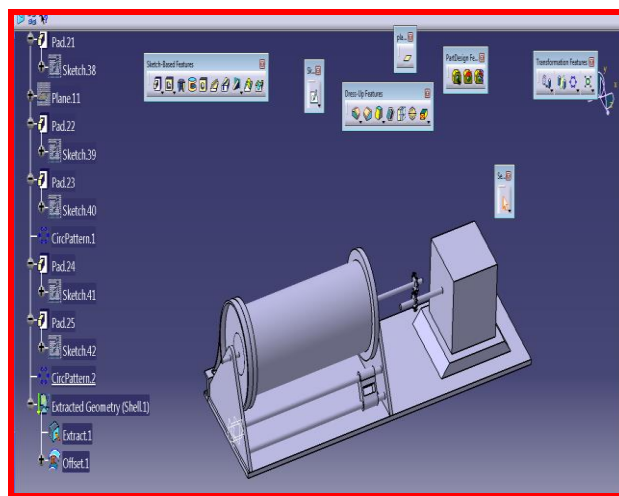


Fig 05: 3D model of winch system arrangement

### 6. FINITE ELEMENT ANALYSIS [1,3]

The finite element analysis is carried out by applying load in wire rope along middle turns grooves as the material load is assumed to be lifted by 100 meters and held in to position. The value is 42 N.

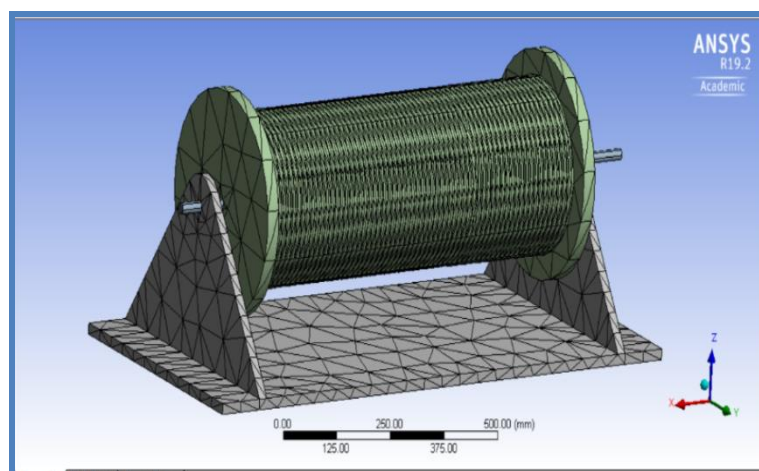


Fig 06: Meshing of the model

By selecting the boundary condition for the entire drum length and applied the pressure on the drum surface and the shaft.

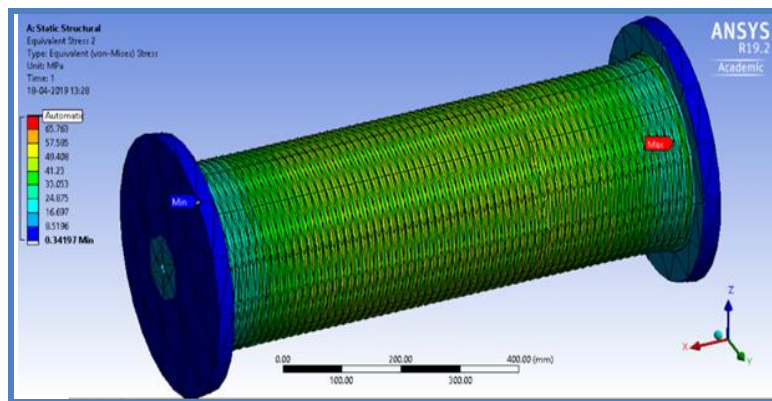


Fig 07: Maximum stresses on drum

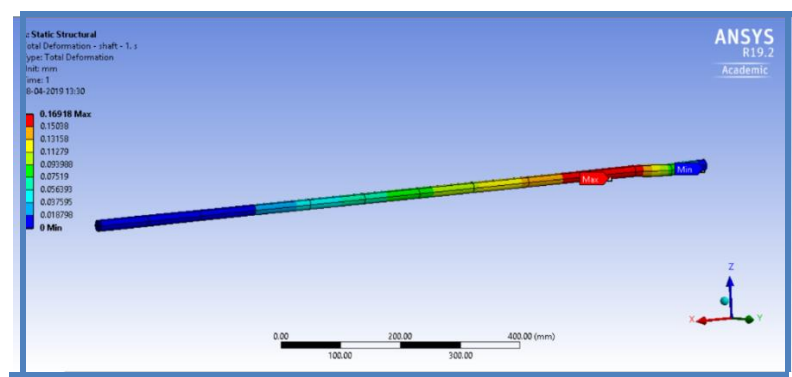


Fig 08: Maximum shaft deflection

Finite element analysis of assembly shows that, maximum stress condition on the rope drum and shaft shown in Fig. 07 & 08. The values are within limit it means the system is safe in the load condition.

### 7. CONCLUSIONS

Finite element analysis is conducted by using ANSYS on rope drum and shaft. Static structural analysis such as modal analysis is conducted. The Vonmises stresses along with the deformations are obtained as post processed results from ANSYS are indicating that the Rope drum is obtaining the Vonmises stress a value of  $181.46 \text{ N/mm}^2$  which is does not exceeding the permissible hoop stress  $220.80 \text{ N/mm}^2$

The results obtained from Table Nos. 01 and graphs represented Chart: 01& 02, the maximum hoop stress 276 Mpa of the drum fabricated from gray iron G4000 & maximum permissible deflection of the shaft with gear mounting is 1 mm whereas analysis shows maximum deflection of 0.16mm. For the both analysis i.e rope and shaft achieved within limits

Table -1: FEM Results

Results				
Minimum	0. mm	0.34197 MPa	0. mm	3.4753e-010 Mpa
Maximum	0.17694 mm	73.941 MPa	0.16918 mm	181.46 Mpa
Average	8.3247e-002 mm	38.905 MPa	7.11e-002 mm	34.037 Mpa
Minimum Occurs On	body base	Drum	Shaft	body base
Maximum Occurs On	Drum		Shaft	

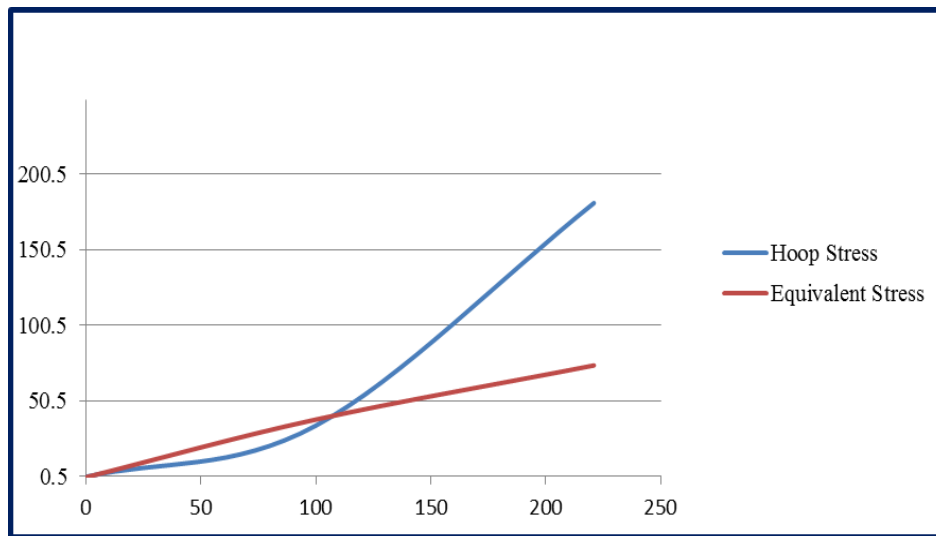


Chart -1: Stresses on the Rope Drum

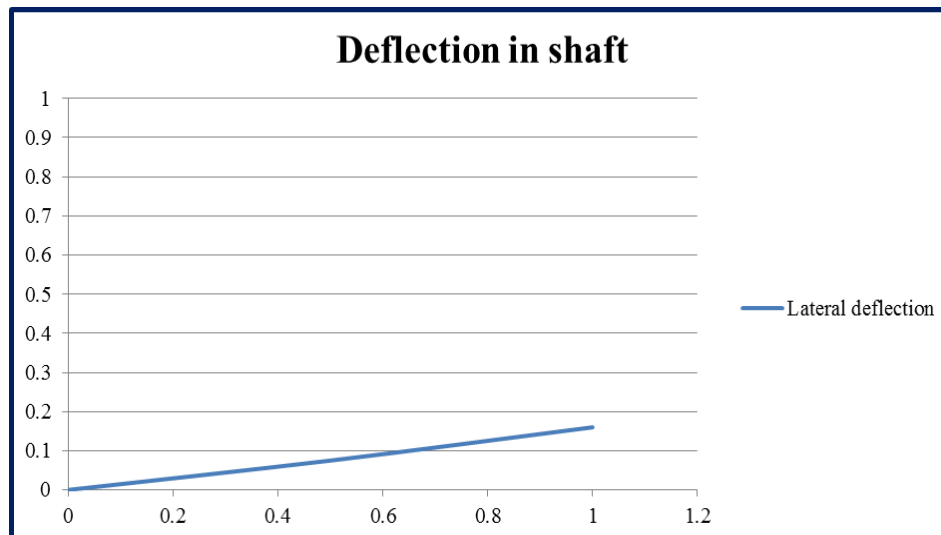


Chart -2: Deflection of shaft in loading condition

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