Design and Analysis of Ball Mill For Paint Industries

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Abstract—The work present in this paper focuseson the ball mill used in paint industries for optimizing the parameter like i) Selecting optimum thickness of mill, ii) selecting optimum diameter of gear shaft. iii) Selecting optimum diameter of idle shaft. By optimizing above parameter we can reducing running cost of ball mill. Optimizing is done by Modeling and Analysis of parts of ball mill by using 'Finite Element Method'.

Keywords:-Parameters, ball mill, modeling and analysis

I. INTRODUCTION

Ball mill is vital equipment used in industries for mineral dressing, ore processing, fertilizers, paint industries, food and diary, pharmaceuticals and many others. In ball mills, the energy input to the pigment dispersion is provided by the rotation of the mill, so that the hard balls within the mill are tumbled with, or onto, the pigment in the mill. Using mills, hardened steel balls are caused to impact vertically upon the pigment charge. Local overheating of the particles can occur. This local overheating is difficult to remove. Also, the mixing of the particles is very low. In the rotating mills, the steel balls roll along a circular arc on the inner wall of the mill chamber, and the pigment charge is spread on the inner surface of the chamber. This ensures that the heat generated within the chamber is removed by conduction through the cylindrical wall, and there is a good dispersion of the pigment particles. However, the rotating mills are not able to provide the impact energy of the balls that is achieved in the ball mills.

II. WORKING OF BALL MILL

The main body of the ball mill is a low-speed rotary cylinder mounted on two large bearings horizontally. Inside the cylinder feed proper grinding medium-steel balls. The medium will be lifted to certain height under the action of centrifugal force and friction and drop or fall. The materials to mix are fed to the cylinder in succession and disperse by medium, then discharged through overflow and continual feeding force, and enter the next procedure.

III. TYPES OF BALL MILL

Ball mills are used for grinding things down or for mixing things up. They grind ores down to powders before they are chemically processed, they grind grains down to flours for baking and they mix up paints so they are smooth enough to apply. All ball mills consist of rotating cylinders that contain hard (usually metallic) balls that do the grinding.

A. *Horizontal Ball Mills:*

Horizontal ball mills are the most common type. The basic design is the same but the details can vary slightly. A drum, which is usually detachable, has a door that can be used to load in the material to be processed. Sometimes -- like for paint mixers -- there will be a screen that keeps the metal balls in place. When the substance to be processed (and the balls) is in the drum, the door is closed and the drum is reinstalled -- horizontally -- on the mill where it is rotated until the job is done. Some ball mills have a timer and some have a window where the processed material can be viewed.

B. *Vertical Ball Mills*

Small vertical ball mills are about the size of a blender and are intended for laboratory or shop use. They are small enough to fit on a lab table or workbench and only big enough to process the small quantities need for desktop applications -- they are not intended for commercial or industrial use. These ball mills are often called planetary ball mills. The rotating drums are not usually detachable -- the material is poured into the top and the cap is replaced, like a kitchen blender. Like all ball mills, the speed and ball size have an effect on how the vertical ball mill works. Vertical ball mills often come with a variety of ball sizes (and have variable speed settings) for more efficient processing.

C. *Industrial Ball Mills*

Industrial ball mills are much larger than the other types of ball mills. They vary in size from approximately the size of a refrigerator to approximately the size of a bus. They are always horizontal. What distinguishes the industrial ball mill (besides its large size) is that they have multiple chambers and have a forced-air system constantly moving material through the rotating drum. The different chambers are separated by screens of progressively smaller mesh. The chambers contain balls of progressively smaller size. The size of the balls and the screen mesh keeps the balls in their own chamber. Material is forced from one chamber to the next as it is ground small enough to fit through the mesh screens.

IV. DESIGN PARAMETERS

– Diameter of ball mill :
– Length of ball mill
– Shaft diameter
– Length of shaft
– Speed of ball mill
– Media size and shape

Since the optimum number of revolutions per minute (rpm) for a ball mill is directly related to the ball mill radius, these two factors are grouped together to study. Consider for a moment the path travel by a typical ball in a half-full ball mill. At a low angular velocity (low rpm) this ball will be gradually lifted up on a one side of a mill to a higher and higher level. Finally a point is reached where it no longer has any support from below. At this point it joints its neighbors in cascade of balls falling and tumbling down over each other along the sloping surface of the ball of the ball charge to the low side of the mill. This process is continuously repeated.

The smallest ball size commensurate with proper cascading and proper drainage of the dispersed mill base should be used. when a ball size is once established as best for given dispersion, it does not vary appreciably for a different mill size. Grinding media are supplied in three major shapes: spherical, nodular or irregular, and cylindrical. There is considerable controversy concerning the effect of the ball shape on the particle size distribution that is provided.

V. DESIGN OF BALL MILL

Design of ball mill for the capacity of 440 liters ($0.44m^3$) for mixing of alkyd resin, pigment and solvent.

A. Design Of Mill:

Assuming, length of mill= outside diameter of mill [8]

Volume=$\pi R^2 L$

$\therefore 0.44 = 2\pi R^3$

∴R=412 mm

∴D=824mm≈825mm

So, inside diameter of mill is 825mm.

From the empirical relation, thickness of mill would be 10mm.

Outside diameter = length of mill=850mm.

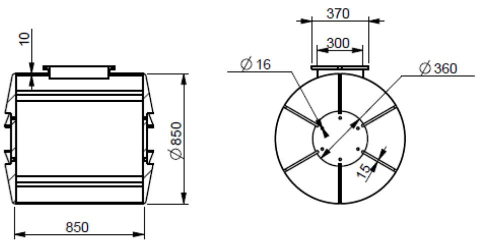

Fig. 1: Mill and cover plate diagram

B. Power Required To Operate The Ball Mill With Optimum Ball Charge[10]:

The following computation method for obtaining the power required to operate a commercial ball mill of radius R is predicted on the assumption that the ball mill is half filled with balls, there is a cascade angle of 45^o, and the mill base just covers the top layer

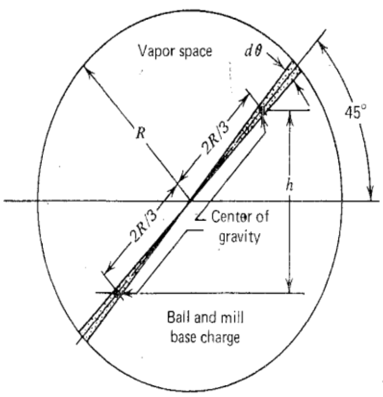

Fig.1: Optimum cascading of mill for power consumption

of the ball. Let the average density of the ball mill base mixture be ρ'. As the mill turns with the uniform velocity at the optimum rpm value, cascading takes place as the balls are continuously rotated into cascading zone. The energy input required to do this can be thought of as equivalent to that required to continuously move a wedge of ball (with mill base) from the lower half to the top half of the sloping cascade surface (see given Fig).The differential volume of this narrow Wedge is equal to $\pi R^2 L\, d\theta/2\pi$ where L is the effective inside length of the ball mill. In turn, the differential weight dW of the load in the wedge section is given by Eq.

$$\therefore dw = \frac{\rho' R^2 L\, d\theta}{2}$$

From physical principles it can be demonstrated that the center of gravity of differential wedge lies at a distance $2R/3$ from the mill axis. In moving this wedge from the lower to the higher cascade level, this center of gravity is displaced a vertical distance h equal to $2(2R/3)\sin 45^o = 0.943R$. The corresponding work input dE is equal to the product dW. $0.943R$. Substituting the value for dW given by Eq. in this work input expression gives in below eq. for the differential energy required to produce this lifting effort.

$$dE = \frac{0.943\rho' R^3 L\, d\theta}{2}$$

The number of differential wedges rotated into the position for cascading each second is given below.

$$\text{Differential wedges per second} = \frac{2\pi rpm}{60 d\theta}$$

The power required to lift this number of wedges per second through the height of $0.943R$ is given in below eq.

$$P = \frac{0.943\rho' \pi L R^3 rpm_0}{60}$$

$$P = \frac{0.943 \times 5 \times 10^{-6} \pi \times 0.850 \times 0.418^3 \times 30}{60}$$

$$P \approx 4.53 \text{ KW}$$

This equation gives the theoretical power requirements for a ball mill of radius R and length L, when running at optimum rpm with the mill half filled with mill base and balls (cascade angle of 45^0).

C. Critical Speed Of Mill[10]:

$$rpm_0 = \frac{20.4 - 1.8R}{\sqrt{R}} = 29.44 rpm \approx 30\ rpm$$

Now, the balls occupy 60% and mill base 40% of total volume.

The average density of total charge= (0.6×7.8) + (0.4×0.8) =5 g/cm^3

D. Design Of Cover Plate:

From the mill, outside diameter of plate=850mm

Inside diameter of plate=100mm. thickness of plate is 10mm.

∴Weight of mill= (volume) V× (density)ρ =218.479 kg

∴Weight of square liners inside mill =V× ρ

=0.025× 0.025 × 0.025 × 0.085 × 7.8

=4.1437kg

∴Weight of cover plate= V× ρ =54.56kg

∴Weight of balls= V× ρ =1029.6kg

∴Weight of material= V× ρ =70.4kg

∴Weight of flange= V× ρ =4.211kg≈5kg including nut & bolts weight

∴Total load on the shaft

=218.479 + (2×54.56) + 1029.6+70.4 + (5× 2) + (4× 4.1437)

=1453.57 kg≈ 1455kg

For the safety,

∴ Total load = steady load + working load

= 1455+ (0.25× 1455)

=1820 kg

E. Design Of Shaft For Rotating At Optimum Speed [11]:

Twisting moment on the shaft at rotating optimum speed

$$P = \frac{2\pi NT}{60}$$

$$T = \frac{4.53\times60}{2\pi\times30} = 1443.217 \text{ Nm}$$

Bending moment on the shaft due to uniform distributed loading

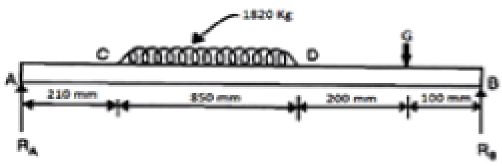

Fig. 3: load diagram

Ra + Rb = (1820× 0.85) + 200 = 1747 kg
Where,G = 200kg(load of gear)
Taking moment @ A
Rb× 1.36 = (200 × 1.26) + (1547× 0.635)
Rb = 907.606 kg
Finding bending moment at various points
B.M. @ A & B would be zero.
B.M. @ G = 907.60× 0.1 = 90.76 kgm
B.M. @ D = -(200× 0.2) + (907.60× 0.3) = 232.28 kgm
B.M. @ C = -[(1820× 0.85× 0.85/2) + (200 × 1.05)] +(907.60× 1.15)
= 176.265 kgm

1) Equivalent Twisting Moment (Combine Torsional And Bending Loading) [11]:

$$Te = \sqrt{(Kt \times T)^2 + (Km \times M)^2}$$

where,gradually applied or steady load
K_t=1 and K_m=1.5

$$T_e = \sqrt{1443.17^2 + (238.28 \times 9.81 \times 1.5)^2}$$

=3791.676 Nm

Now, calcuate diameter of shaft
$Te = \pi/16\times \tau D^3$

$$D^3 = \frac{3791.676\times16}{\pi\times 42\times 10^6}$$

D = 0.07718 m
≈ 77.18 mm

2) Equivalent Bending Moment (M_e) [11]:

$$M_e=1/2\ [(Km\times M) + \sqrt{(Kt\times T)^2 + (Km \times M)^2}\ ]$$

$$=1/2\ [(238.28\times 1.5 \times 9.81) + 3791.676\ ]$$

=3648.9831 Nm

$$M_e = \frac{\pi}{32}\sigma_b D^3$$

Where, σ_b=56 MPa
D=0.8722m = 87.22mm ≈ 90 mm

F. Design Of Flange[11]:

Outside diameter of flange = 4× diameter of shaft =360 mm
Thickness of flange = 0.25 × diameter of shaft =22.5 mm

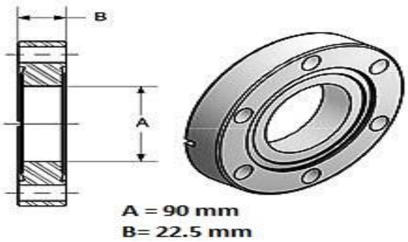

Fig. 2: flange

Design of bolts
P.C.D. of bolt circle = 3 × D = 270 mm
Nominal diameter of bolts
∴ $Te= \pi/4 \times d_1^2 \times n\times \tau \times p.c.d./2$
∴ d_1= 14.88 mm ≈ 16 mm
Where, number of bolts are 6.
Taking IS 3653-1966 for the bolts.

G. Design Of Gear And Belt Drive[11]:

Speed reduction occurs in 2 stages to start mill at 30 rpm
Initially speed reduction done by belt drive to avoid accident major diameter of pulley(D_1)& minor diameter (D_2) = 80mm
N_1 = speed of motor = 1440 rpm
N_2 = speed of pulley
$N_1D_1=N_2D_2$
∴ N_2= 1440 × 80/D_2
From selecting speed ratio= 7:1
N_2=210 rpm
∴ D_2=558.57 mm ≈ 560 mm

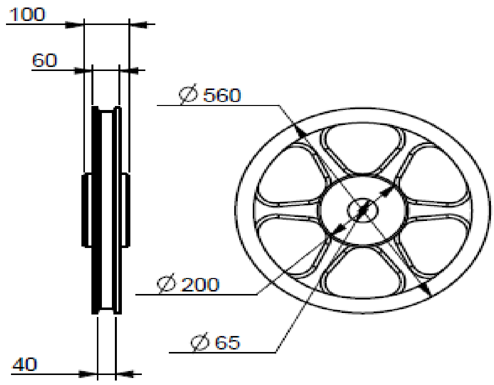

Fig. 3: driven pulley diagram

For the speed reduction selects spur gear drive
Speed ratio=7:1
P=4.53 kw, N_p=210 rpm, T_p=14 teeth, b=14 module
Now, pitch line velocity $V=\frac{\pi DN}{60} = \frac{\pi\times m14\times210}{60}$ = 0.1539m m/s
Working under steady load condition and 8-12 hours per day
Service factor C_s=1, W_t = p/v× C_s =29460.68/m N

$$C_v = \frac{3}{3+V} = \frac{3}{3+0.1539m}$$

Tooth from factor for pinion

$$Y_p=0.154 - \frac{0.912}{T_p} = 0.0888$$

Tooth form factor for gear,

$$Y_G=0.154 - \frac{0.912}{T_G} =0.1446$$

Where, $\sigma_{op} \times y_P = 120 \times 0.0888 = 10.656$

$$\sigma_{oG} \times y_G = 100 \times 0.1446 = 14.46$$

Here, $\sigma_{op} \times y_P < \sigma_{oG} \times y_G$, therefore pinion is weaker .
Lewis equation of pinion.

$$W_T= \sigma_{wp} \times b \times \pi \times m \times y_p = (\sigma_{op} \times C_v) \times b\pi m y_p$$

$$\frac{29460.68}{m} = 120 \times \frac{3}{3 + 0.1539m} \times 14m \times \pi \times m \times 0.0888$$

$1406.026m^3$= 4533.998m+ 88382.04
Using hit and trial method
m=4.24mm
Face width b=14m=60mm
P.C.D. of gear and pinion
D_p= mT_p=112mm, D_G=mT_G=784mm

H. Selection Of Bearing[11]:
Standard Roller Bearing
Bore diameter=90mm
Outside diameter=190mm, width=43mm

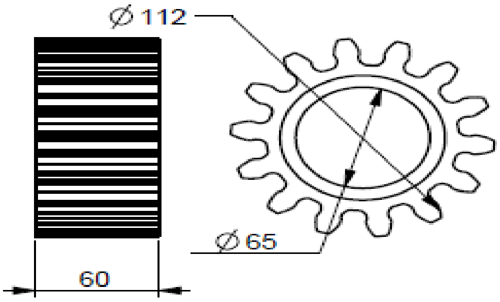

Fig. 4: pinion diagram

VI. FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) has become commonplace in recent years, and is now the basis of a multibillion dollar per year industry. Numerical solutions to even very complicated stress problems can now be obtained routinely using FEA, and the method is so important that even introductory treatments of Mechanics of Materials.

A. Analysis Type:

A static structural analysis determines the displacements, stresses, strains, and forces instructures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)

A static structural analysis can be either linear or nonlinear. All types of nonlinearities are allowed - large deformations, plasticity, stress stiffening, contact (gap) elements, hyper elasticity and so on. This chapter focuses on linear static analyses,

B. Procedure Of Finite Element Analysis

In practice, a finite element analysis usually consists of three principal steps.[13]

1) *Per–Processing, Analysis & Post Processing:* 3 D Solid Modeling is done in Pro-e creo Software. Shaft is fixed at end as it works as axel. Uniform Distributed Load is given on the roller. The tetra hadron mesh is used. Triangle element is used for better result. Analysis is done in Anysis 14.0.

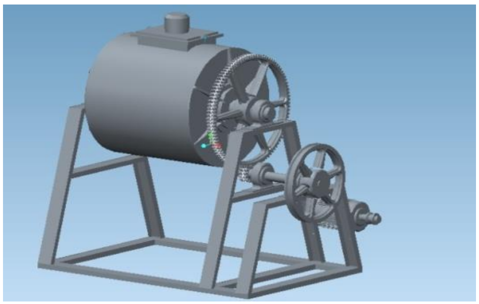

Fig. 5: CAD model of ball mill

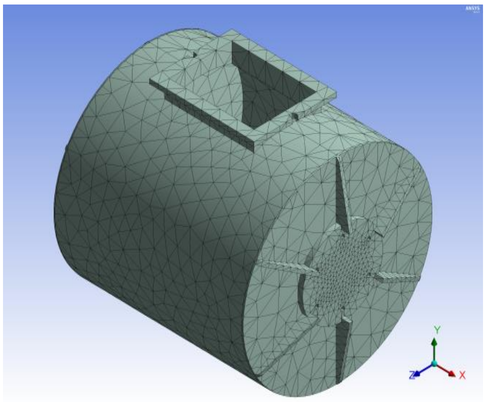

Fig. 6: meshing of mill

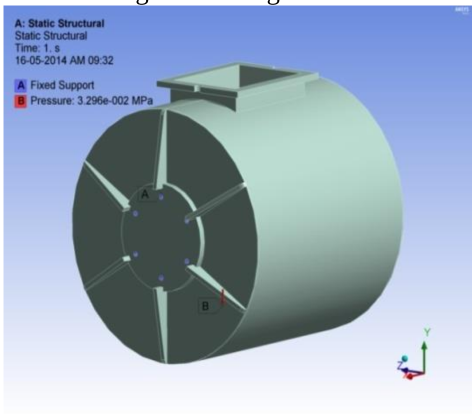

Fig. 7: support & pressure

2) *Analysis:* The dataset prepared by the pre-processor is used as input to the finite element code itself, which constructs and solves a system of linear or nonlinear algebraic equations

$$K_{ij}u_j = f_i$$

Where u and f are the displacements and externally applied forces at the nodal points. The formation of the K matrix is dependent on the type of problem being attacked, and this module will outline the approach for truss and linear elastic stress analyses. Commercial codes may have very large element libraries, with elements appropriate to a wide range of problem types. One of FEA's principal advantages is that many problem types can be addressed with the same code, merely by specifying the appropriate element types from the library.

3) *Post Processing:* In the earlier days of finite element analysis, the user would pore through reams of numbers generated by the code, listing displacements and stresses at discrete positions within the model.

It is easy to miss important trends and hot spots this way, and modern codes use graphical displays to assist in visualizing the results. A typical postprocessor display overlay colored contours representing stress levels on the model, showing a full field picture similar to that of photo elastic or experimental results.

Table for 12mm mill thickness analysis

Sr. No.	Thickness (mm)	Max.von mises stress(N/mm2)	Total deformation (mm)
1	12	4.1035	0.02048
2	10	4.7026	0.02498
3	8	5.402	0.03142

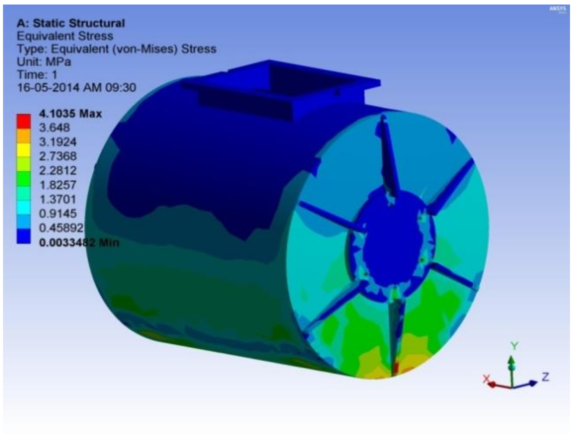

Fig. 8: 12mm thickness mill von misses stresses

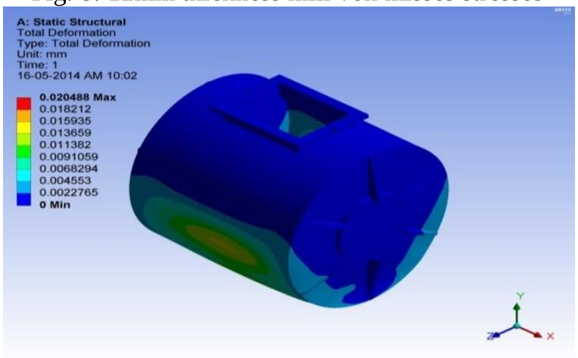

Fig. 9: 12mm thickness mill deformation

VII. CONCLUSION

From the design and analysis of ball mill it is seen that from the below graph the power affect the physical parameter like thickness of mill and diameter of the shaft which is used for the rotating of ball mill at optimum speed. Because if we will change mill length and diameter than the capacity will also change.

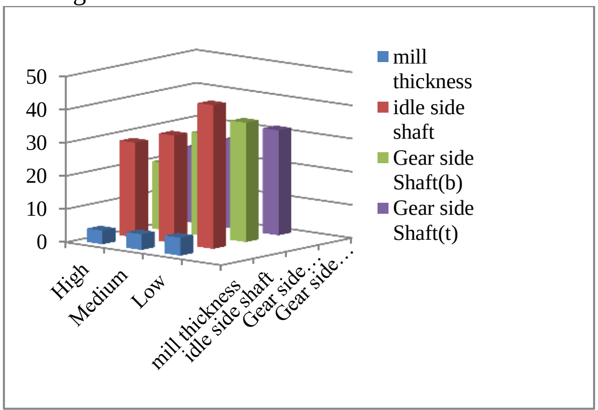

Fig. 12: von mises stress (MPa) due to load

For selection of parameter like thickness of mill, idle side shaft and gear side shaft is selecting according to analysis. From FEA it can be seen that as thickness of mill increases von misses stress and deformation decreases. For idle shaft diameter increases von misses, stress and deformation increases and maximum deflection occurs at the end of the flange. On the other end the shaft on the gear side analysis is taken under bending and twisting load. On the shaft diameter decreases von mises stress and deformation decrease. From the analysis we conclude that the maximum bending occurs at the contact of flange and shaft. Due to twisting the maximum shear stress occurs at the nearest to the flange and maximum deflection occurs on throughout the shaft due to twisting.

From the graph we shown that the von misses stress would be very low in the mill thickness
because the impact loads of ball during rotating could not be taken. The total deformation of thickness, idle shaft and gear side shaft within limits. So that select the optimum thickness and shaft diameter at both ends for the rotating ball mill at 30rpm.

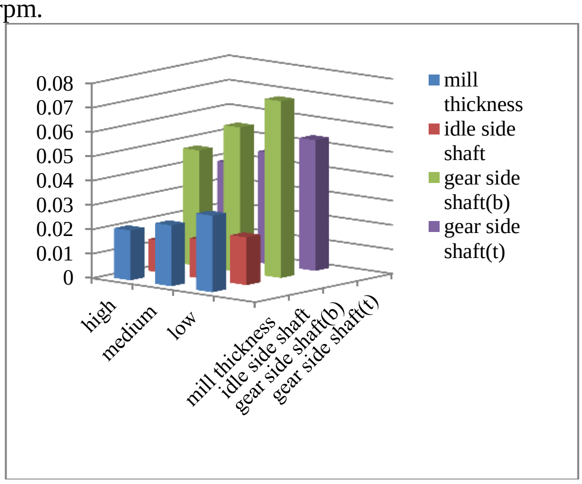

Fig. 10: total deformation (mm) due to load

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