International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.3, No.6, June 2014 DOI:10.15693/ijaist/2014.v3i6.85-91

Modal Analysis of Universal Joint Shaft for Rolling Mill

G. R. Nikhade,
Assistant Professor, Dept. of Mechanical Engg.RCOEM,Nagpur (India)

S Deshmukh,
U G Student, Dept. of Mechanical Engg. RCOEM,Nagpur (India)

M Mukesh
U G Student, Dept. of Mechanical Engg. RCOEM,Nagpur (India)

V Jain
U G Student, Dept. of Mechanical Engg. RCOEM,Nagpur (India)

***Abstract*—The properties of steels made by rolling of billets are mainly dependent on the process of forming. The performance of the rolling mill depends on the Universal joint shaft through which the power is transmitted to the rollers of a mill. This paper mainly focuses on the modal analysis of universal joint shaft for rolling mills because this shaft is subjected to vibrations caused due to the jerk produced during the passing of billet through the rollers.**

Index terms -Universal shaft, rolling mill, modal analysis.

I. Introduction

Rolling is a process of changing the cross section of a work piece by compressing it. The rolling process is classified based on the rolling temperature. For cold rolling, the rolling temperature is T_R to 0.3 T_M, for hot rolling, the temperature is $0.5T_M$ to $0.75T_M$; T_R being the room temperature and T_M, the melting temperature of the steel. A rolling mill is used for making long products of various cross sections. The cross section of the product remains constant throughout the length. Various cross sections like, circular, square, I- section, T-sectioned various other unsymmetrical sections can be formed by rolling process.

The rolling mill comprises various types of drives. The most common is the drive by means of a shaft. One end of the shaft is coupled to the gear box or the motor and the other to the roller of the mill. The shaft is generally a universal joint shaft, to counter for the angular misalignments due to the billet entry, explosion of sir gaps in billets, etc.

Numerous ways have been developed by various researchers for finding the forces and torque required for rolling operation. Sims assumed that in most cases, the roll bite angle is small. Bland and Ford added to Orwans assumptions that roll pressure equals the vertical stress component. Alexander treats two possible types of friction, either Coulomb friction model or sticking friction.[6]

For the analysis of shaft of a rolling mill, the torque required for rolling is an important aspect. For bar and section rolling, empirical relations, which are valid for flat or sheet rolling cannot be used directly. Certain assumptions are to be made to use these relations for rod rolling. The basic assumption is the equivalent rectangle method. Equivalent rectangle is the rectangle of same area as that of the rod, but with different cross section. [1]

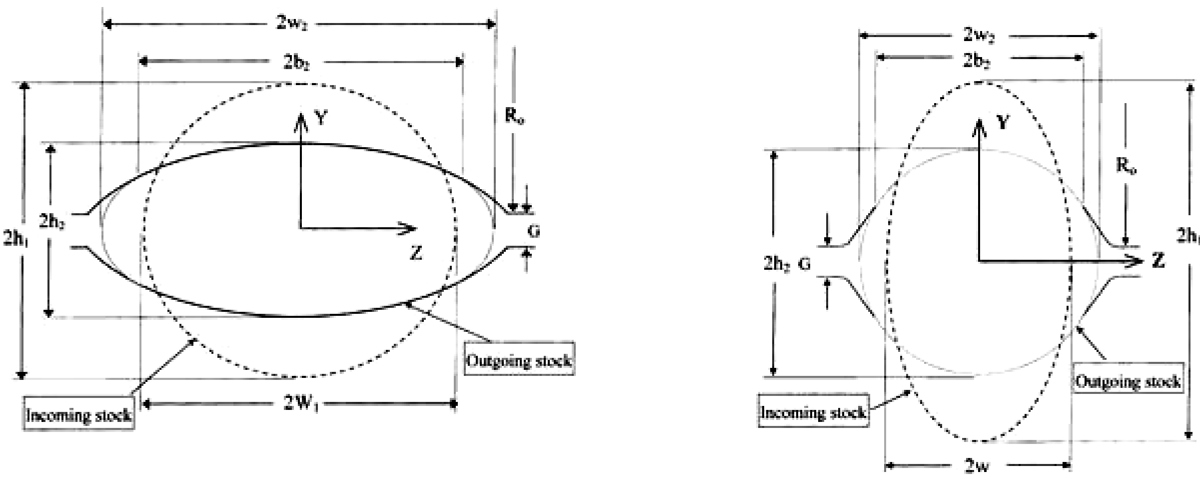
This paper includes mathematical formulation to determine the torque required for rolling at the rolling temperature in section II. In section III and IV free-free analysis and normal mode analysis is performed to determine different mode shape. Further results are presented in section V and lastly the conclusions drawn based on the proposed work is mentioned in section VI.

II. Mathematical Formulation

A. Nomenclature

Lr	*Contact length*
h, w	*Height, width of work piece*
R	*Radius of roller*
R_o	*Outer radius of roller*
b	*Projected width of work piece groove contact*
ϵ	*Strain*
$\bar{\epsilon_r}$	*Resultant strain*
$\dot{\varepsilon}$	*Strain rate*
$\bar{\dot{\varepsilon}_r}$	*Resultant strain rate*
t_p	*Time of pass*
N	*Speed of shaft ,rpm*

σ_p	*Stress at rolling temperature*
$\acute{\sigma}$	*Deviatoric stresses*
n	*Strain hardening coefficient*
m	*Strain rate coefficient*
F	*Rolling force*
M	*Rolling torque*
1, 2	*Suffixes*
x, y, z	*Directions along the resp. axes*



(a) (b)

Figure. 1: Workpiece profile geometry (a) oval pass, (b) round pass

B. Contact length or the roll bite length:

$$L_r = \sqrt{2R_i(h_1 - h_2)} \quad (1)$$

For the equivalent rectangle assumption, the section height 2h at any distance x from the entry can be given by

$$h = h_1 - \frac{L_r}{R_i}x + \frac{x^2}{2R_i} \quad (2)$$

The section maximum width $2w$ is approximated tohave a parabolic distribution along the roll bite length, given by

$$w = w_1 - 2(w_1\text{-}w_2)\frac{x}{L_r} + (w_1 - w_2)\frac{x^2}{{L_r}^2} \quad (3)$$

Equation (3) is formed such that it satisfies the boundary conditions $w = w_1$ at $x = 0$ and $w = w_2$ at $x = l_r$ *and* $\frac{dw}{dx} = 0$ at $x = l_r$ which are the conditions taken by default while analysing or formulating the rolling process for sheet rolling. The projected area of work piece-roll contact surface on the x-z plane is approximated to a semi elliptic

shape of a width 2b at exit and 2b at any section at distance x from the entry can be expressed as,

$$b = b_2\sqrt{\frac{2x}{L_r} - \frac{x^2}{L_r}} \quad (4)$$

C. Calculation of strain and strain rate

Strain and strain rate along the height and width of the work piece can be expressed as follows:

$$\boldsymbol{\epsilon}_y = \ln\left(\frac{h}{h_1}\right); \boldsymbol{\epsilon}_z = \ln\left(\frac{w_1}{w_2}\right) \quad (5)$$

The volume of the work piece remains constant during the complete rolling process.

Thus,

$$\boldsymbol{\epsilon}_x + \boldsymbol{\epsilon}_y + \boldsymbol{\epsilon}_z = 0 \therefore \boldsymbol{\epsilon}_x = -(\boldsymbol{\epsilon}_y + \boldsymbol{\epsilon}_z) \quad (6)$$

Neglecting the shear strain components, the effective strain can be obtained as

$$\overline{\boldsymbol{\epsilon}_r} = \sqrt{\frac{2}{3}\left({\boldsymbol{\epsilon}_x}^2 + {\boldsymbol{\epsilon}_y}^2 + {\boldsymbol{\epsilon}_z}^2\right)} \quad (7)$$

D. Calculation of effective strain rate

Strain rate or the effective strain rate is the rate of change of strain, and can be given by

$$\dot{\varepsilon} = \frac{\varepsilon}{t_p} \quad (8)$$

Where, ε is the strain and t_p is the time required for a paint or the work piece to pass through contact length. [3]
t_p Can be calculated by the relation

$$t_p = \frac{60 \times L_r}{2\pi N R_e} \tag{9}$$

$$R_e = \frac{R_i + R_o}{2} \tag{10}$$

Thus, the strain rates can be calculated by using equation (7) and it can be expressed as,

$$\dot{\varepsilon_y} = \frac{\varepsilon_y}{t_p};\ \dot{\varepsilon_z} = \frac{\varepsilon_z}{t_p} \tag{11}$$

Again, by law of conservation of volume, the strain rate in x direction can be given as,

$$\dot{\epsilon_x} = -(\dot{\epsilon_y} + \dot{\epsilon_z}) \tag{12}$$

Resultant strain rate,

$$\bar{\dot{\varepsilon_r}} = \sqrt{(\dot{\epsilon_x}^2 + \dot{\epsilon_y}^2 + \dot{\epsilon_z}^2)} \tag{13}$$

E. Calculation of stresses at rolling temperature

At a temperature of 1000^{O}C and carbon content of 0.2%, [4, 5].

$$\sigma_p = \sigma_f * f_r * f \left(\frac{kgf}{mm^2}\right) \tag{14}$$

$$T_p = 0.95 \times \frac{C + 0.41}{C + 0.32} \tag{15}$$

For, T $\geq T_p$,

$$\sigma_t = 0.28 * exp\left(\frac{5}{T} - \frac{0.01}{C + 0.05}\right)$$

$$m = (-0.019C + 0.126)T + (0.075C - 0.05)$$

$$n = 0.41 - 0.07C$$

$$f = 1.3 \times (5\varepsilon)^n - 1.5\varepsilon$$

$$f_r = (\frac{\dot{\varepsilon}}{10})^m$$

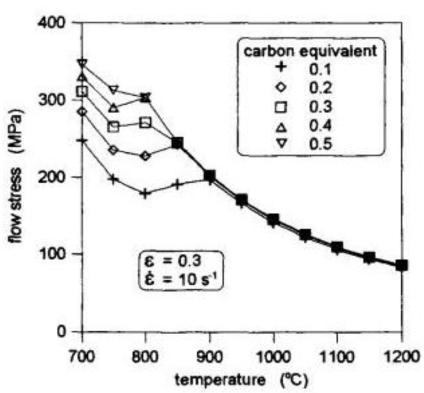


Figure 2: Temperature flow stress relation for steels at

For T $< T_p$, the equations to be followed are:

$$\sigma_t = 0.28 * q(c,t)\exp\left(\frac{c + 0.32}{0.19\,(c + 0.41)} - \frac{0.01}{c + 0.05}\right)$$

$$q(c,t) = 30(c + 0.9)(T - 0.95 * \frac{c + 0.49}{c + 0.42})$$

$$f_r = \left(\frac{\dot{\varepsilon}}{10}\right)^m . \left(\frac{\dot{\varepsilon}}{100}\right)^{m/2.4} . (\frac{\dot{\varepsilon}}{1000})^{m/15}$$

$$m = (0.081C - 0.154)T - 0.019C + .207 + \frac{0.027}{C + 0.32}$$

F. Calculation of deviatoric stress components

These components in the 3 directions x, y and z can be found by Levy-Mises flow rule expressed as follows:

$$\acute{\sigma_x} = \frac{2}{3}\frac{\overline{\sigma}}{\bar{\dot{\sigma}_r}}\dot{\varepsilon_x};\ \acute{\sigma_y} = \frac{2}{3}\frac{\overline{\sigma}}{\bar{\dot{\sigma}_r}}\dot{\varepsilon_y} \tag{16}$$

G. Calculation of roll load, torque and power

Roll load

$$F = -2\int_0^{L_x} \sigma_y b\, dx \tag{17}$$

Negative sign indicates that the load is compressive in nature.

Roll torque

$$\mathrm{M} = -4\int_0^{L_x} \sigma_y b\,(L_r - x)\, dx \tag{18}$$

Rolling power

$$P = \frac{M * V_2}{R_e} \tag{19}$$

The parameters mentioned in Table 1 are used for the calculation of roll torque, load and power.

Table 1: Parameters and their values

Parameter	***Value***
h_1, h_2	*29.73 mm, 17.67 mm*

w_1, w_2	*29.73 mm, 32.6 mm*
R_i	*167.53 mm*
R_o	*180.25 mm*
Work piece temperature	*1000^o C*
Work piece material	*SAE 1020*

The roll torque, load and power calculated about are required for reducing the area of the work piece.The torque and load are provided by two rollers, which are connected to two universal joints shafts. Hence, the torque provided by each shaft is halved [2].

III. FREE – FREE ANALYSIS

Free-free analysis is performed to extract the rigid body modes from the modeled assembly. All constraints specified on the model are removed before performing the free – free Analysis. This analysis is also used to check whether all the components are properly connected with each other. The natural frequencies of the first six fundamental modes are found approximate to be zero.

IV. NORMAL MODES ANALYSIS

With constraints at Eye Plate Bearing locations, the Natural Frequencies & Mode shapes of the assembly are as shown in figure 4:

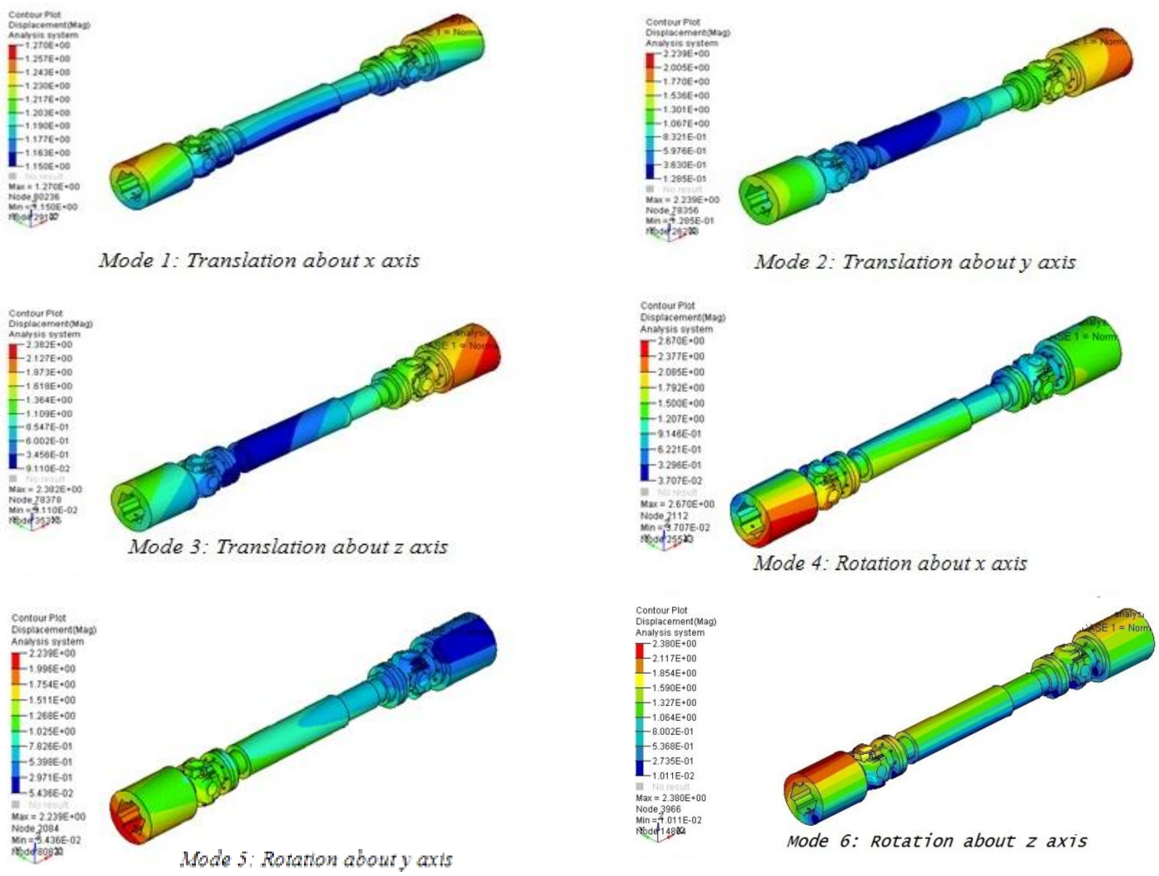


Figure 3: Translational and rotational modes of the shaft

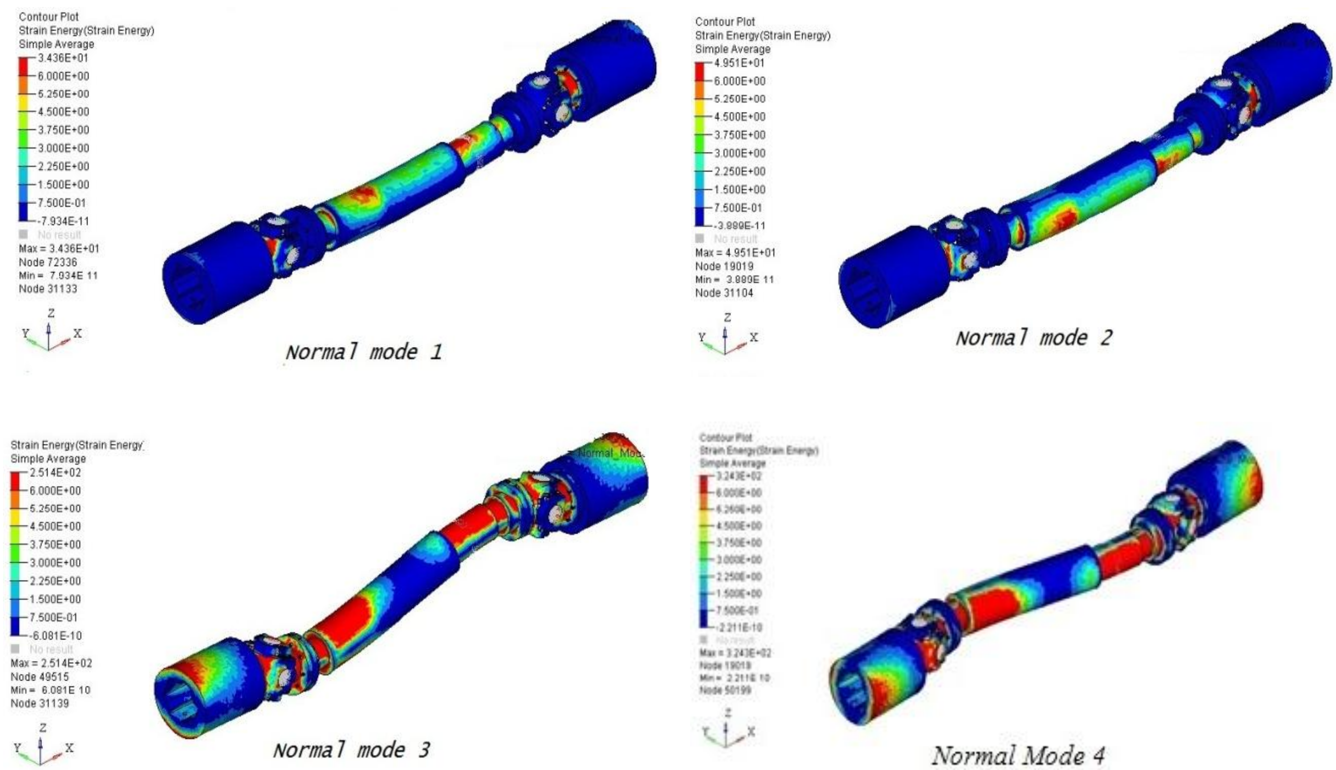


Figure 4: Normal modes of the shaft

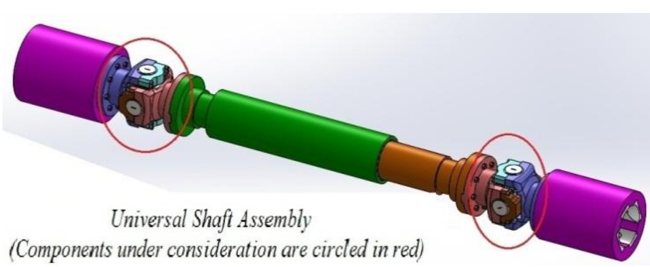


Figure 5: Universal Shaft Assembly

Figure 5 shows the complete Universal Shaft Assembly. In this analysis, the mating surfaces of the yoke pin and the eye plate is considered as other areas do not exhibit significant strain energy.

During Modal Analysis, the mating surface of the yoke pin with the Eye Plate; and the contact surface between the bearing housing and the mating eye plate area is observed to be highly strained (as shown in the fig. below) because of the up- down movement of the juncture and hence has a greater possibility of failure when undergoing several working cycles.

International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.3, No.6, June 2014 DOI:10.15693/ijaist/2014.v3i6.85-91

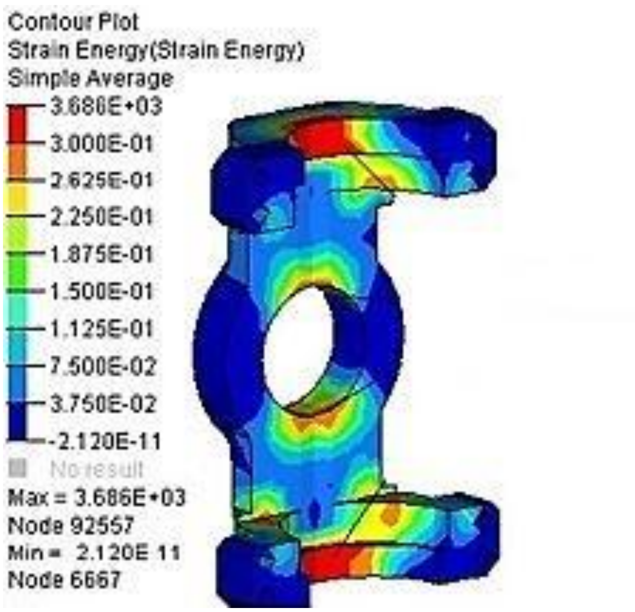


Figure 6: Eye plate (Highly strained areas shown in red colour)

V. RESULTS

Based on the above mentioned calculations, the following results found are shown in table 2:

Table 2: Various parameters and their values

L_r	*63.56 mm*
ϵ_y, ϵ_z, ϵ_x	*0.52, -0.0943, 0.4257*
$\bar{\epsilon}_r$	*0.5541*
t_p	*0.047 sec*
$\dot{\varepsilon}_y$, $\dot{\varepsilon}_z$, $\dot{\epsilon}_x$	*11.108* s^{-1}, *-2.014* s^{-1},*-0.094*$s^{-1,}$
$\bar{\dot{\varepsilon}}_r$	*11.84* s^{-1}
σ_p	*151.67 MPa*
$\acute{\sigma}_x$, $\acute{\sigma}_y$	*77.83 MPa, 95.07 MPa,*
Roll load F (for 1 shaft)	*63.4 KN*
Roll torque M (for 1 shaft)	*3420.8 Nm*

From the modal analysis, the frequencies obtained are as follows:

Table 3: Frequencies of various modes

Mode no.	1	2	3	4
Natural Frequency	121.9	122.3	305.5	313.9

The frequency obtained by Dunkerley's method is 129.4 Hz, where, the deflection is in y direction. Hence, the error when compared to mode 2 is 5.8%.

VI. CONCLUSION

On performing Modal Analysis, it is found that the natural frequency of the shaft found out with the help of analysis software and that by Dunkerley's equation is matching with negligible differences. The mating area of the yoke pin and the universal joint eye pin; the surface of the bearing housing and the mating area of the eye plate are highly strained. Thus, there is a high possibility of its early failure by wear when undergoing several working cycles.

ACKNOWLEDGEMENTS

Sincere Gratitude to M/s. Sunflag Iron and Steel Limited, Bhandara, Maharashtra (India) for sharing the data relating to rolling mill.

Profound thanks to Mr. AnkitAnand and Mr. MohitKathoke for their valuable contribution.

REFERENCES

[1]. Magnus Holmberg, "prediction of roll torque in hot rod and wire rolling" Örebro University Department of technology Örebro, Sweden

[2]. Laila S. Bayoumia, Youngseog Lee "Effect of interstand tension on roll load, torque and work piece deformation in the rod rolling process" Journal of Materials Processing Technology 145 (2004) 7–13

[3]. Youngseog Lee", Hong Joon Kim Sang Moo Hwang "An Approximate Model for Predicting Roll Force in Rod Rolling" *KSME International Journal, VoL*16 *No.4, 2002, pp. 501-511.*

[4]. Lenard J.G., Piterzyk M., Cser, L, "Mathematical and Physical simulation of the properties of hot rolled products", Elsevier Science Ltd., 1999. 74-76

[5]. Youngseog Lee, Rod And Bar Rolling, Theory and Applications, Mercel Dekker Inc.

[6]. J. G. Lenard, Premier on flat rolling, second edition, Elsevier Insights.

Authors' Profile

G. R. Nikhade is working as Assistant Professor in the department of Mechanical Engg. at SRCOEM, Nagpur. He received his Post-graduation in Machine Design from V. J. T. I., Mumbai in 2000. He is having total 13 years of teaching and consultancy experience. He has also published papers for 5 International

International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.3, No.6, June 2014 DOI:10.15693/ijaist/2014.v3i6.85-91

Journals.

S. D. Deshmukh is a student of ShriRamdeobaba College of Engineering and Management, Nagpur, Presently in the final year of Bachelors of Engineering in Mechanical Engineering. His areas of interest include Machine Design and Analysis.

M Mukesh is a student of ShriRamdeobaba College of Engineering and Management, Nagpur, Presently in the final year of Bachelors of Engineering in Mechanical engineering. His areas of interest include Design Analysis and Aeronautics.

V.K. Jain is a student of ShriRamdeobaba College of Engineering and Management, Nagpur, presently in the final year of Bachelors of Engineering in Mechanical engineering. His areas of interest include Thermal Analysis and Renewable Energy.