Effect Of Variable Load, Speed And Viscosity Of Lubricating Oil On Depth Of Wear Of Linining Thickness Of Crank Shaft Bush Bearing

S.B.Chikalthankar[1], V.M.Nandedkar[2] and B.V.Munde[3]
[1&3]Department of Mechanical Engineering, Government College of Engineering, Aurangabad (India)
[2]Department of Production Engineering, SGGSI&T, Nanded (India)

Abstract

Hydrodynamic $CuPb_{24}Sn_4$ journal bearings are considered to be a vital component of all the rotating machinery, because of its simplicity, low cost and efficiency. It is used to support radial loads under high speed operating conditions. During this transient period, direct contact between the journal and bearing induces high friction and bushes become progressively worn-out, thus inducting certain disabilities. The bushes are provided with a lining thickness of $CuPb_{24}Sn_4$ material which is found in the range of 450 to 600 micron. The aim of present experimental work is to determine effect of variable load, speed and viscosity of lubricant on depth of wear of lining thickness (d_w) of $CuPb_{24}Sn_4$ material bush used in indigenously designed Test Rig which is widely used as bush material in automobile engine. Taguchi L_9 (3^3) orthogonal array was used for the experimental plan. The mathematical model for input parameters and depth of wear obtained from regression analysis to predict values of depth of wear. S/N ratio and ANOVA analysis were used to obtained significant parameters influencing depth of wear.

Keywords: Crank shaft bush, test rig, depth of wear, lining thickness, viscosity of lubricant.

1. INTRODUCTION

Hydrodynamic $CuPb_{24}Sn_4$ journal bearings are considered to be a vital component of all the rotating machinery, because of its simplicity, low cost and efficiency. It is used to support radial loads under high speed operating conditions. During this transient period, direct contact between the journal and bearing induces high friction and bushes become progressively worn-out, thus inducting certain disabilities. The bushes are provided with a lining thickness of $CuPb_{24}Sn_4$ material which is found in the range of 450 to 600 micron [5]. Wear in journal bearing is a phenomenon that often occurs in bearings that have been working over long periods, on huge machinery. Oil lubricated bearings employing sintered $CuPb_{24}Sn_4$ material are widely used in many automobile, industrial, marine and automotive applications. These bearings normally operate in stable, hydrostatic condition wherein proper film thickness of oil is formed and maintained between shaft and bearing [3]. The study concerning the problem of wear was led by Dufrane in 1983 who analyzed a worn bearing in a steam turbine. They were the first to propose a geometrical model taking into account the worn region of a bearing, in order to include it in calculations. They paid particular attention to the mechanisms that lead to wear, for a bearing operating at low speed. Bouyer and Filon (2002) presented influence of wear on steady state characteristics of bearings. Behaviors of two lobe worn hydrodynamic journal bearing were proposed by Bouyer et al. (2006). Tamura et al. (2004) focused on effect of cyclic load and cyclic speed on sliding wear characteristics of bearing lined with white metal. Tachi et al. (2005) predicted a relationship between frictional stress, cut-off life and shaft revolutions. The effect of pressure, Shaft velocity and surface finish on depth of wear of lining thickness of engine $CuPb_{24}Sn_4$ bush material was predicted by

Chikalthankar and Nandedkar (2011) experimentally. The aim of the present work was to analyze the influence of deterministic variable load, speed and viscosity of lubricating oil on depth of wear of lining thickness of crank shaft bush bearing.

Taguchi method is the powerful design of experiment (DOE) tool for engineering optimization of a process. This is important in investigating the effect of multiple factors on the performance as well as to study the influence of individual factors to determine which factor has more influence which less. The tool used in taguchi method is the orthogonal array. Orthogonal array is the matrix of numbers arranged in column and rows.Taguchi method employed S/N to quantify the present variation. These S/N ratios are meant to use as measure of effect of noise factors on performance characteristics. Analysis of variance (ANOVA) is the statistical treatment most commonly applied to get percentage contribution of each factor on depth of wear of lining thickness of $CuPb_{24}Sn_4$ bush material.

Table 1 Specification of Bush and Shaft

Specification	Outside diameter(mm)	Inside diameter (mm)	Width (mm)	Surface finish
Bush	44.00 ±0.1	40.00±0.02	25.00 ±0.1	50-75
Shaft	NA	39.900±0.01	NA	25-50

2. TEST AND EXPERIMENTAL PROCEDURE

The specification of shaft and bush material as per industry norms is mention in Table 1. The test specimen employed is a copper-lead-tin bushing of GL-400 engine used in PIAGGIO rickshaw manufactured by Greaves limited. The schematic representation of test rig is shown in fig.1.

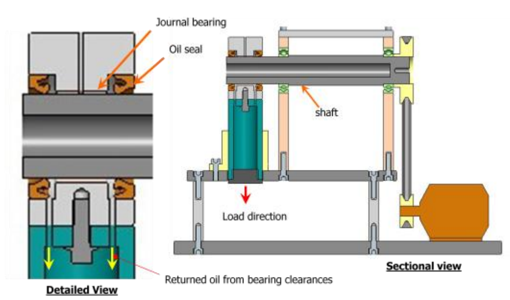
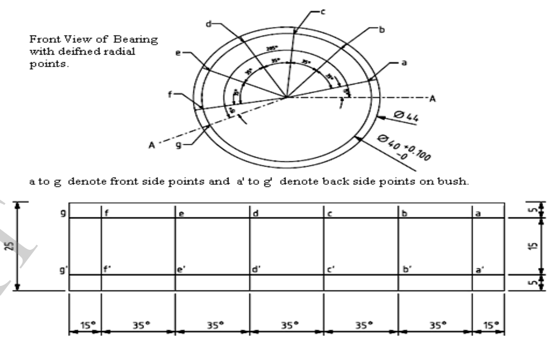


Fig. 1 Schematic representation of test rig

The shaft is driven by permanent magnet DC motor of capacity 1 HP. The numbers of samples were taken three of different surface finish. The parameters are variable load, speed and viscosity of lubricating oil which affecting on depth of wear of lining thickness of crank shaft bush bearing. The surface temperature of bush is measured at 5 location points with 5 RTD (Resistance temperature detectors) while in test circumferentially to find highest temperature zone. The pressure is measured by using pressure transmitter "MBS 3000" and pressure point is selected opposite to load line The bush is marked circumferentially with the points a, b, c, d, e, f, g from "Front" and a', b', c', d', e', f', g', from "Rear" side as shown in Fig. 2. The surface roughness is measured specifically on these points by using Taylor-Hobson Surtronic3+ surface roughness



measuring instrument. The depth of wear of $CuPb_{24}Sn_4$ lining thickness of bush is measured specifically at above points in front and rear side by

Fig. 2 Bearing front view and developed view

using ultrasonic thickness measuring instrument before and after trial run. The servo premium lubricating oils are used which is of three different SAE grades. The oil flow rate is maintained variable with the gear pump employed to GL-400 Engine.

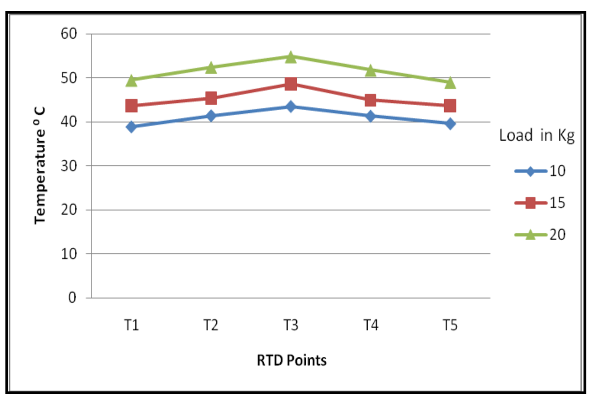


Fig. 3 Temperature Variations At 500 Rpm Load

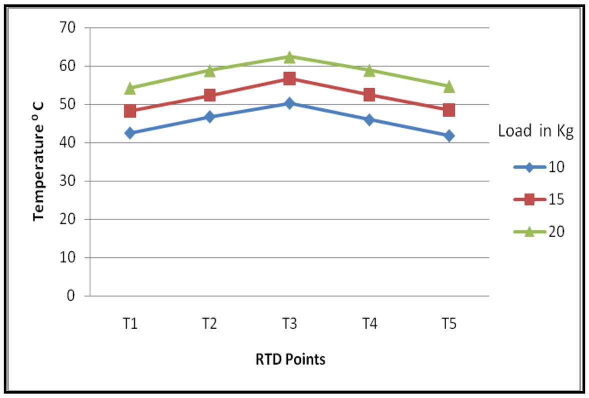


Fig. 4 Temperature Variations At 1000 Rpm Load

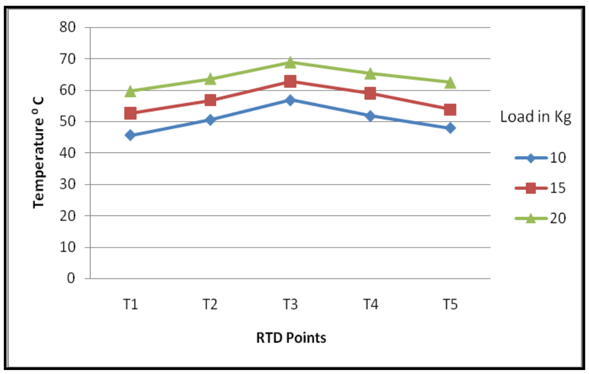


Fig. 5 Temperature Variations At 1500 Rpm Load

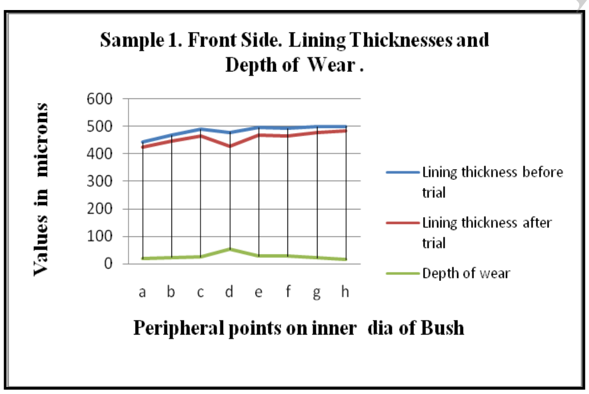


Fig . 6 Total Depth of Wear Along Circumferential Points on Front Side

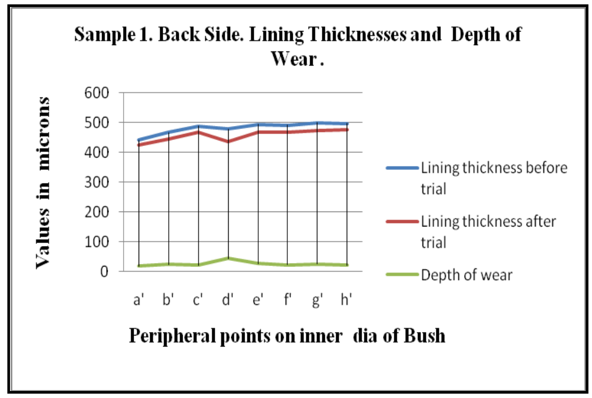


Fig . 7 Total Depth of Wear Along Circumferential points on Back Side

Table 2 Assignment of factors in L9 OA

Trial	P (Load) N	V (velocity of journal) m/s	Viscosity (mm²/s)	Depth of wear (micron)
1	1	1	1	19
2	1	2	2	25
3	1	3	3	32.5
4	2	1	2	24
5	2	2	3	31
6	2	3	1	24.3
7	3	1	3	30
8	3	2	1	22
9	3	3	2	28

3. REGRESSION ANALYSIS

Mathematical model for variable load, speed and viscosity of lubricating oil of hydrodynamic journal bearing are obtained from regression analysis to predict depth of wear of lining thickness of crank shaft bush bearing.

Table 3 Regression statistics

Multiple R	0.993824
R square	0.987686
Adjusted R square	0.980298
Standard error	0.62483
Observations	9

Table 4 ANOVA

DF	DF	SS	MS	F	Significance F	
Regression	3	156.5768	52.19288	133.685	3.41E-05	
Residual	5	1.952062	0.390412			
Total	8	158.5289				
	Coefficient	Standard error	t_{stat}	P-value	Lower 95%	Upper 95%
Intercept	4.510322	1.283212	3.51487	0.017012	1.211722	7.808922
X Variable1	0.01233	0.005201	2.351662	0.065425	-0.00114	0.025598
X Variable 2	1.870543	0.244687	7.644666	0.00061	1.24156	2.499534
X Variable 3	1.101961	0.06002	18.35984	8.82E-06	0.947674	1.256248

Thus it forms the equation,

$$\mathbf{d_{wp} = 4.510322 + 0.01223P + 1.870543V + 01.101961v}$$

Table 5 Comparison of measured d_W and predicted d_{WP}

Sr. No.	d_w	d_{wp}	d_{wp}-d_w	% Error
1	19	19.95	0.95	5.000
2	25	25.58	0.58	2.32
3	32.5	33.25	0.75	2.307
4	24	24.23	0.23	0.958
5	31	31.87	0.87	2.806
6	24.3	24.45	0.25	0.823
7	30	30.52	0.52	1.733
8	22	22.10	0.10	0.454
9	28	28.75	0.73	2.607
% Average Error = 2.112				

By comparing the measured d_w and predicted dwp bush bearing material, it is seen that average error is 2.112 %.

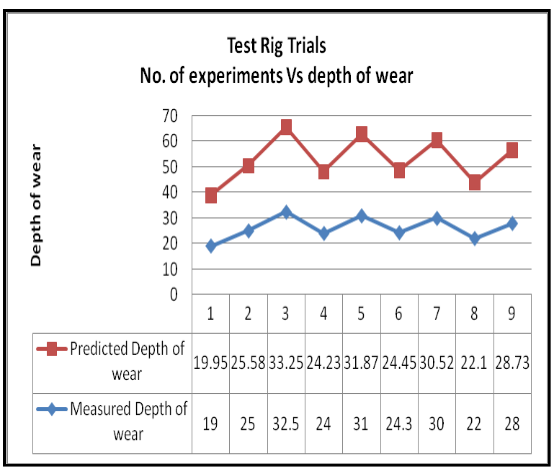


Fig. 8 Comparison of measured depth of wear versus predicted depth of wear

In multiple linear regression analysis, R^2 is value of the correlation coefficient and should be in between 0.85 and 1. In this study, results obtained from depth of wear in good agreement with regression model ($R^2 > 0.85$) i.e. matched very well with the experimental data. So the relationship established is acceptable.

4. ANALYSIS OF S/N RATIO

The aim of any experiment is always to determine the highest possible S/N ratio for the result. A high value of S/N implies that the signal is much higher than the random effects of the noise factors or minimum variance. As mentioned earlier three quality characteristics, i.e. the lower is better, the higher is better and nominal is best. A lower depth of wear is always preferred for long bearing life, with reduced maintenance and man power hence lower is better S/N characteristics can be expressed as,

$$\mathbf{MSD} = \mathbf{L_j} = \left(\frac{1}{n}\sum_{i=1}^{n} yi^2\right)$$

Where,
n = number of test in a trial,
$y_{i=}$ the value for the i^{th} test in that trial,
$L_{j=}$ overall loss function
Signal to noise ratio according to lower is better quality characteristics as follows,

$$\mathbf{S/N = -10 \log (MSD)}$$

MSD = mean square deviation for output characteristics.

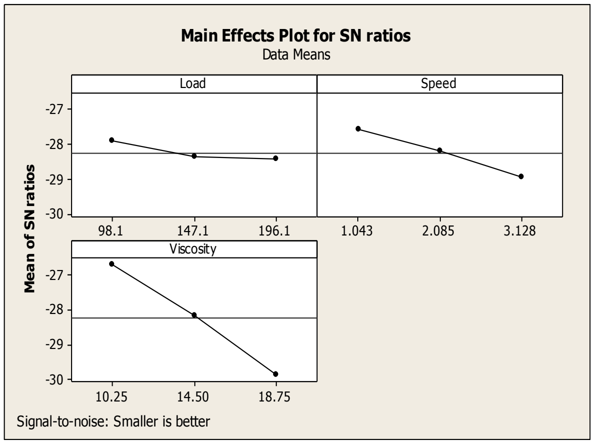


Fig. 9 Main effect plot for S/N ratio

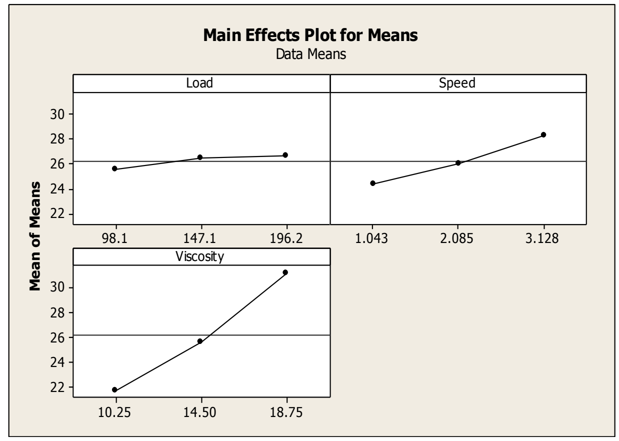


Fig. 10 Main effect plots for depth of wear

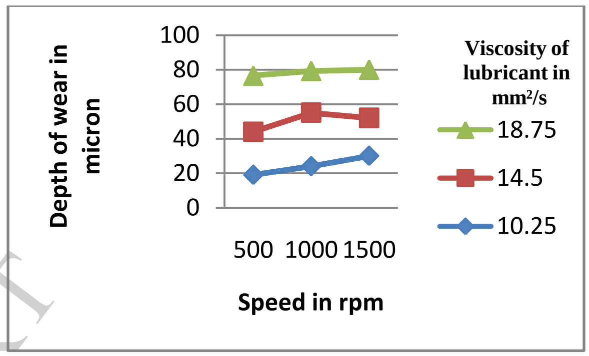


Fig. 11 Depth of wear Vs Speed for viscosity of lubricant

From the S/N ratio analysis, the optimal parameters are variable 196.2N Load (Level3), 3.128m/s Speed (Level3) and 18.75 mm^2/s Viscosity (Level3).

The influence of each control factor (load, speed and viscosity) on the depth of wear was analyzed from the S/N ratio response table, which expresses the S/N ratio at each level of control factor. The control factor influence is determined by its level difference values. A bigger control factor level difference means a greater influence on depth of wear. It has seen from table 6 delta difference between higher and lower value of S/N ratio, is higher for viscosity factor that is 9.40 then for factor speed is 3.93 and followed by load factor that is 1.17 so it is concluded that viscosity factor has greatest influence on depth of wear of lining thickness of bearing.

Table 6 S/N ratio main effect

Trial no	S/N	Load level1	Load level2	Load level3	Speed level1	Speed level2	Speed level3	Viscosity level1	Viscosity level2	Viscosity level3
1	-28.72	-28.72			-28.72			-28.72		
2	-29.57	-29.57				-29.57			-29.57	
3	-29.68	-29.68					-29.68			-29.68
4	-28.78		-28.78		-28.78				-28.78	
5	-29.74		-29.74			-29.74				-29.74
6	-29.44		-29.44				-29.44	-29.44		
7	-27.79			-27.79	-27.79					-27.79
8	-29.68			-29.68		-29.68		-29.68		
9	-30.50			-30.50			-30.50		-30.50	
Sum	-263.9	-87.97	-87.96	-87.97	-85.29	-88.99	-89.62	-87.84	-88.85	-87.21
mean	-29.32	-29.32	-29.32	-29.32	-28.43	-29.66	-29.87	-29.28	-29.16	-29.07
Total mean										
Δ			**1.17**			**3.93**			**9.40**	
Rank			3			2			1	

ISSN: 2278-0181
Vol. 1 Issue 8, October - 2012

From the main effect plot, factor A (load) – level 3 factor B (Speed) – level 3 and factor C (Viscosity) – level 3. As per taguchi method of DOE to get a optimal level of a parameter S/N ratio should have higher, means the level where S/N ratio is higher that the value parameter at that level will be optimum, from above graph it can be seen that in all three parameter level 3 has the highest S/N ratio for load at level 3 value is 196.2 N, for speed at level 3 value is 3.128 m/s and for viscosity at level is 18.75 mm²/s.

5. ANALYSIS OF ANOVA

ANOVA was used to determine the significant parameters influencing the depth of wear of lining thickness of bush bearing. The percent contribution of each factor in the total sum of square can be used to evaluate the importance of the factor change on the performance characterstic.Additionally the F value named after fisher can be used to determine which factor significantly affect the performance characterstic.Larger F value indicates that the variance of the input parameter makes a big change on the performance.

Table 7 Results of ANOVA

Factor	Degree of Freedom	Sum of squares	Mean square	% contribution	F-ratio
Load	2	0.498	0.382	2.066	4.328
Speed	2	2.831	2.716	14.658	24.608
Viscosity	2	15.087	14.972	80.751	131.126
Error	2	0.114	0.57		
Total	8	18.53			

According to this analysis, the most effective parameters with respect to depth of wear of lining thickness are viscosity, speed and load. Percentage contribution indicates the relative power of factor to reduce variation. For a factor with high percentage contribution, a small variation will have great influence on the performance. According to table Viscosity (80.751%) was found to be major factor affecting the depth of wear, whereas speed (14.658%) was found to be second ranking factor, the percentage contribution of load (2.112%) is much lower than two other parameters.

6. RESULT AND DISCUSSION

This experimental work present effects of variable load, speed and viscosity of lubricant on depth of wear on of lining thickness of $CuPb_{24}Sn_4$ bush bearing under dynamic condition. The mathematical results of depth of wear are compared with experimental results, comparison shows that measured value of depth of wear of lining thickness and predicted value of depth of wear by mathematical model are nearly 2.112% average error. The wear of lining thickness occurs symmetrically at the highest temperature zone for all 3 samples. The evaluation of wear are tested under variable load, speed and viscosity of lubricant. The depth of wear of lining thickness of $CuPb_{24}Sn_4$ material bush bearing is particularly measured at front side on points a,b,c,d,e,f and g and measured at rear side on points a',b',c',d',e',f' and g' as bush might have been subjected to small misalignment along width.

It is concluded that depth of wear of lining thickness in all nine trail ranges from 19-28 microns while predicted depth of wear was 19.95-28.73 microns. The magnitude of depth of wear of lining thickness of bushing increases with increase in variable load, shaft speed, while viscosity reduces the temperature of bush material. Hence also resulting reducing depth of wear. The optimal condition for depth of wear of lining thickness was 192.6 N Load (level 3), 3.128 m/s speed (level 3) and 18.75 mm²/s viscosity (level 3).

The operating characteristics of bearing in real conditions as nearly same as Test Rig conditions. Each sample is subjected to rigorous 25 cycles in order to get more significant effect of this variation on depth of wear. The shape of wear curve obtained have a good concordance of experiments conducted by Tachi et.al obtained for white metal. The difference between the results are due to the material is different and pressure applied and number of revolutions are different.

In future work depth of wear of may be evaluated for various surface textures vibrations and the effect of shear stress and shear strain.

APPENDIX

d_W = Depth of wear of lining material (μm)
d_{WP} = Predicted depth of wear (μm)
V = Sliding velocity of shaft (m/s)
DF = Degree of freedom
SS = Sum of square
F = Ratio of SS & MS
R = Regression coefficient.

REFERENCES

1. Dufrane KF, Kannel JW and McCloskey TH (1983), "*Wear of steam turbine journal bearings at low operating speeds*", J. Lubric. Technol. 105, pp.313-317.

2. Bouyer J, Fillon M and Pierre-Danos I (2006), "Behavior *of a two lobe worn hydrodynamic journal bearing*". 5th EDF & LMS Poitiers Workshop on "*Bearing Behavior under Unusual Operating Condition*", pp.11-16.

3. Tachi Y, Ishihara S, Tamura K, Goshima T and Mc Evily AJ (2005), "*Predicting sliding wear behavior of a tin-based white metal under varying pressure and speed conditions*". J. Engg. Tribol. 219, pp.451-457

4. S.B.chikalthankar and V.M. Nandedkar (2011), "*Predicting effect of pressure,shaft velocity and surface finish on depth of wear of lining thickness of engine bushing by experimentation*", IJST, pp.432-435.

5. C.Vidal,V.Infante,P.Pecas,P.Vilaca, "*Application of taguchi method in the optimization of friction stir welding parameters of an aeronautic aluminium alloy*", Departmento de engenharia Mecanica, Instituto superior tecnico, Av.Rovisco Pais,1096-001 Lisboa, Portugal.

6. Farzin H.Montazersadgh and Ali Fatima, "*Dynamic load and stress analysis of crankshaft*", 2007-01-0258, SAE International.

7. J. Bouyer, M. Fillon, "*Thermodynamic analysis of a worn plain journal bearing*", Tribology international 37(2004), pp. 129-136.