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Predicting effect of pressure, shaft velocity and surface finish on depth of wear of lining thickness of engine bushing by experimentation

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Abstract

Hydrodynamic Cu-Pb-Sn material journal bearings are widely used in automobile and industrial application because of its simplicity, efficiency and low cost. The bearing is often subjected to many stops and starts with unknown load cycles. During this transient period, friction is high and bushes become progressively worn-out, thus inducting certain disabilities. The bushes are provided with a lining of Cu-Pb-Sn material which is found in the range of 450 to 600 micron. The bearing designers are not provided the attention toward this dimension as in practice the failure of bushes observed by seizer, scoring, pitting, cavitations, loss of Babbitt due to high fatigue loads etc. The total depth of wear of healthy journal bearing is observed 150 to 180 micron up to 40000 kms run. The aim of present experimental work is to determine the effect of variable load, sliding velocity of shaft and deterministic surface roughness (R_a) of lining material on sliding wear behaviour and depth of wear of lining thickness(d_w) of Cu-Pb-Sn material bush, which is widely used as bush material in automobile engine. The highest temperature zone was determined and the bush samples are marked circumferentially as a, b, c, d, e, f, g in front side and a', b', c', d', e', f', g' rear side in that region. The relationship between depth of wear of lining thickness (d_w) versus load, shaft speed, surface roughness is established by using the experimental results and regression model. The numerical result indicates that the surface roughness is most important bearing characteristics and the combined effect of load, shaft speed and surface roughness on depth of wear of lining material particularly in high temperature zone.

Keywords: Crank shaft bush, test rig, depth of wear, lining thickness, surface roughness.

Introduction

Oil lubricated bearings employing sintered Cu-Pb-Sn metal are widely used in many automobile, industrial, marine and machine applications. Particularly in automobile single cylinder engine, the crankshaft supported by bushing of Cu-Pb-Sn lining material and these bearing are normally operate in stable hydrostatic condition wherein a proper oil-film thickness is formed and maintained by using gear pump. The influencing parameters on wear of automobile bearing are studied in recent works due to fact that manufacturers try to improve performance of the journal bearing and reduce cost of bearing induced in manufacturing and maintenance. Duckworth and Forester (1957) have analyzed the wear in lubricated bearing while Dufrane *et al*. (1983) proposed theoretical model of worn bearing. Bouyer and Filon (2002) presented influence of wear on steady state characteristics of bearings. Behaviours 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 aim of the present work was to analyze the influence of deterministic surface finish, variable load and speed on depth of wear of lining thickness of Cu-Pb-Sn material bushing of Gl-400 engine of "PIAGGIO" auto rickshaw in realistic condition, the bushing is dynamically tested on indigenously design test rig for real situations in engine and results are compared with available literature.

Table 1. Chemical composition of specimen.

Cu%	Pb %	Sn %	Co %	Ni %	Zn %
2.22	>0.130	>0.285	<0.0015	<0.0023	<0.0010

Test and experimental procedure

Specimen & measuring system

The chemical composition of lining material Cu-Pb-Sn of bushing used in test rig (copper-lead-tin alloy) is shown in Table 1. The test specimen employed was a copper-lead-tin bushing of GL-400 engine used in PIAGGIO rickshaw manufactured by Greaves limited. The schematic representation of bush with the specification is shown in Fig. 1. The detail specification of bush and shaft is presented in Table 2. 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 as shown in Fig. 2. 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. 1. The surface roughness is measured specifically on these points by using Tayler-Hobson Surtronic3$^+$ surface roughness measuring instrument. The depth of cu-pb-sn lining thickness of bush is measured specifically at above points in front and rear side by using ultrasonic thickness measuring equipment before and after trial run. Load applied while in test does not exceeding yield stress of the bush lining material. All measuring instruments are calibrated as per IS standards. The oil flow rate was maintained constant with the gear pump employed to GL-400 Engine. The speed

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Fig. 1. Schematic representation of bush.

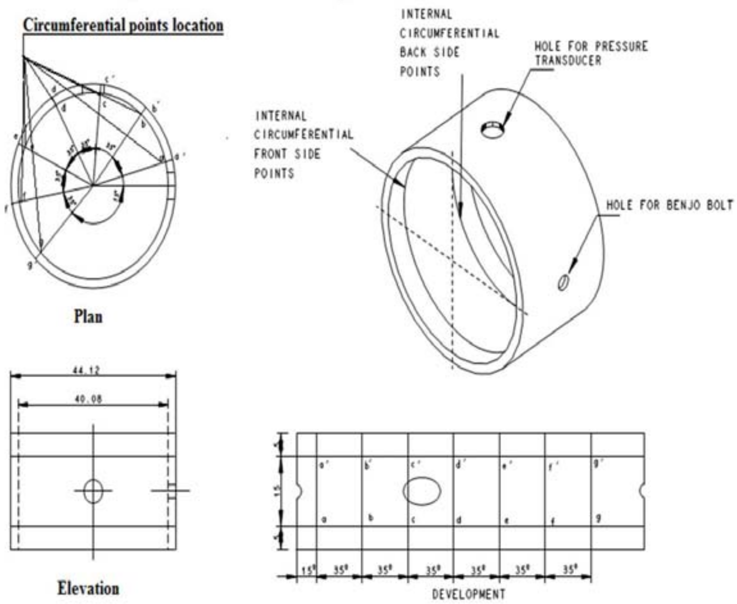


Fig. 2. Schematic diagram of test rig.

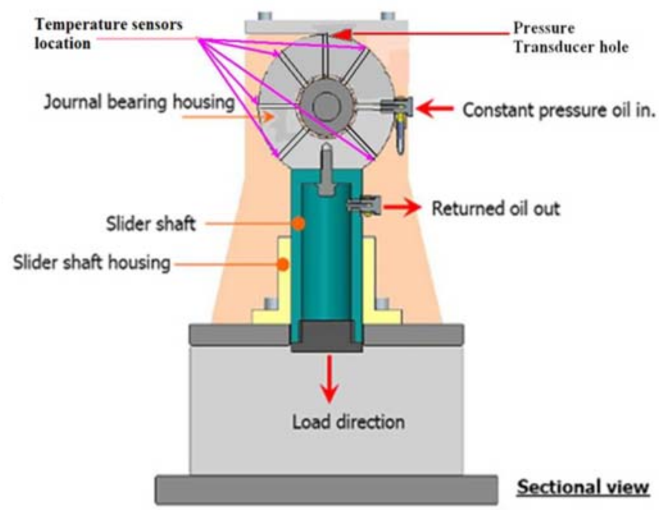


Fig. 3. Temperature variation with different loads, speed 1200 rpm.

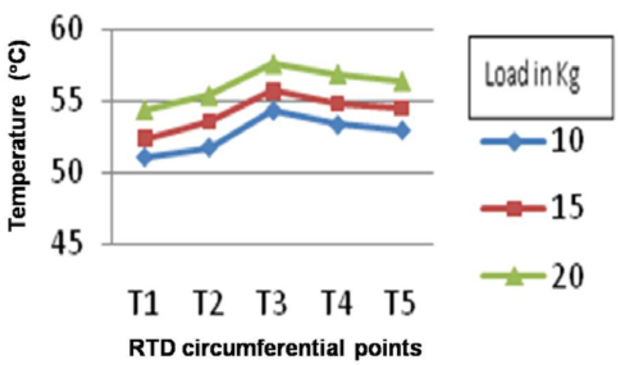


Fig. 4. Temperature variation with different loads, speed 1800 rpm.

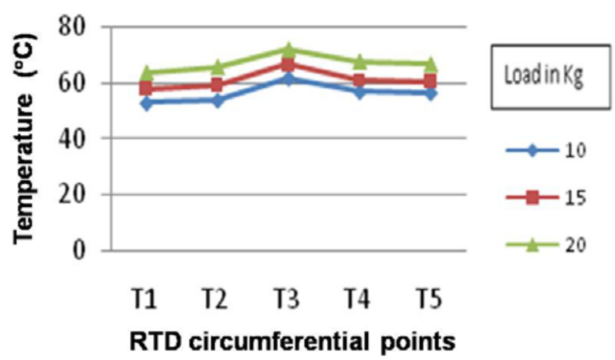


Fig. 5. Temperature variation with different loads, speed 2400 rpm.

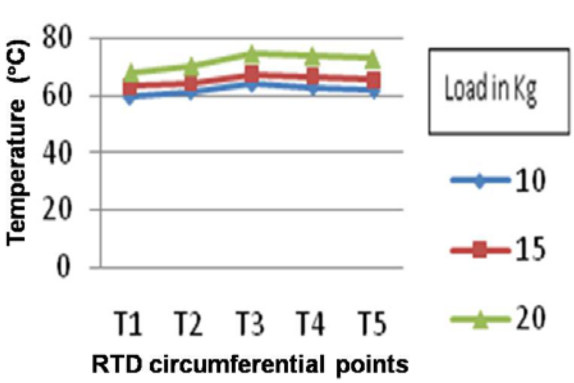
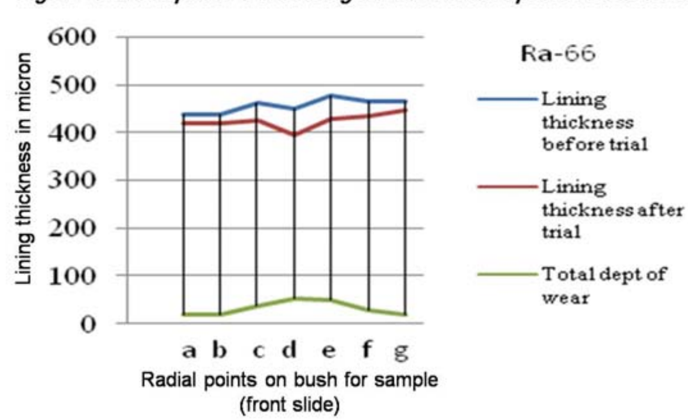


Fig. 6. Total depth of wear along circumferential points on front side.



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variation is ± 10 rpm, load variation is ± 0.2N, temperature variation is ±0.5°.

Table 2. Specification of bush & shaft.

Specification	Outside dia. (mm)	Inside dia. (mm)	Width (mm)	Surface finish(R_a)
Bush	44.00 ±0.1	40.00±0.02	25.00±0.1	50-75
shaft	NA	39.900±0.01	NA	25-50

Test rig & experimental procedure

The bushing studied has specification as per industry norms and the shaft material and its specification is mention in Table 2. The detail sectional schematic diagram of test-rig is shown in Fig. 2. The shaft was driven by constant electric servo motor, the experimentation was conducted to dynamic condition as it exists in engine. The numbers of samples are 3 of different surface finish. The main variables are 1. Load, 2. Shaft speed 3. Surface finish, which are affecting on depth of wear of lining material of bush. The numbers of trials selected for these 3 variables are as per "Taguchi method";it was observed as L9 orthogonal array.

Two types of experiments were carried out in present study: 1) Experiment under constant static load with various shaft speeds is carried out continuously for 180 min in order to clarify the effect of load, speed, surface roughness on depth of wear on lining thickness of bushing and circumferential surface temperature zone of bush. Three bush samples were selected with different surface roughness. The total depth of wear is measured after 540 min run of a sample. The constant supply of lubricant is ensured and the temperature is measured circumferentially after stable condition. 2) Experiment under constant shaft speed with variable loads is carried out continuously for 180 min to observe sole effect of load on depth of wear on lining thickness of bushing and circumferential surface temperature zone of bush.

Table 3. Design of experiment for crank shaft material.

Trial	P	V	S_f	d_w	$\log_{10} d_w$
1	-1	-1	-1	11.34	1.0546
2	-1	0	0	15.67	1.1950
3	-1	+1	+1	18.00	1.2552
4	0	-1	0	16.34	1.2132
5	0	0	+1	18.17	1.2593
6	0	+1	-1	20.00	1.3010
7	+1	-1	+1	20.34	1.3083
8	+1	0	-1	21.00	1.3222
9	+1	+1	0	22.00	1.3424

Experimental results

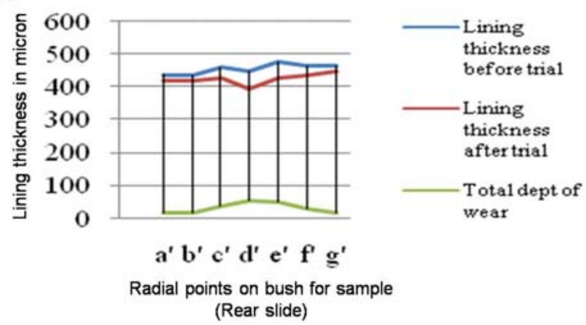
Temperature change in circumferential zone

A temperature change in circumferential direction during sliding process was investigated under various loads and constant speed. It was observed that the temperature rises up to 74.6° at 2400 rpm shaft speed. Particularly highest temp is observed at 3rd RTD location i.e. T3 which is point d and d' on front and rear end of bush and this rise in temperature is from 3-6°C in circumferential direction. The temperature rise generated earlier in wear process and its rate of increase is greater at higher load and higher speed. Fig. 3, 4 & 5 shows at constant revolution speed of shaft the temperature zone observed circumferentially on bush for various load is nearly same.

Combined effect of load, speed and surface finish on depth of wear of lining material

The experiments were carried out for three samples for limiting values of load-10, 15 and 20 Kg, shaft speed-1200, 1800 and 2400 rpm and surface finish of 66, 76 and 86 Ra value. The final results of depth of wear of lining thickness of bush over selected circumferential points of "sample 1" at front end a, b, c, d, e, f, g and at rear end a', b', c', d', e', f', g' are presented in Fig. 6 & 7.

Fig. 7. Total depth of wear along circumferential points on rear side.



It observed that the minimum total depth of wear of lining thickness of 'sample 1' is at point 'a' and 'g' which is '18' and '18.33' micron while maximum total depth of wear is at point d which is '53' micron. It is investigated that in dynamic condition wear process is uneven and variation in maximum shear stresses in circumferential direction which result in development of maximum temperature at point 'd' and maximum depth of wear of lining thickness is observed at point 'd'. It is due to coefficient of friction fluctuate during sliding wear process and is a function of compressive stress, while compressive stress is a function of load on bushing and revolution speed of shaft (Bouyer *et al.,* 2006). The results presented in Table 3 shows 3 factors and 3 levels as per 'Taguchi DOE method'. The combined relationship between load, revolution speed of shaft and surface finish of lining material is decided by using regression analysis method. The combined effect of variables on depth of wear of lining thickness of bushing material is quantitatively modeled by using the same method. Predicting depth of wear of lining thickness of bushing material is aim of this experimental work under the influence of load, shaft revolution and surface finish.

Depth of wear for PIAGGIO (GL400) crank shaft bush material:

Using the formula for calculating m1, m2 and m3,

$$m_1 = \frac{\left\{ \begin{array}{c} (X_{1,1}Y_1)+(X_{1,2}Y_2)+(X_{1,3}Y_3)+(X_{1,4}Y_4)+(X_{1,5}Y_5)+ \\ (X_{1,6}Y_6)+(X_{1,7}Y_7)+(X_{1,8}Y_8)+(X_{1,9}Y_9) \end{array} \right\}}{\left\{ \begin{array}{c} (X_{1,1})^2+(X_{1,2})^2+(X_{1,3})^2+(X_{1,4})^2+(X_{1,5})^2+ \\ (X_{1,6})^2+(X_{1,7})^2+(X_{1,8})^2+(X_{1,9})^2 \end{array} \right\}}$$

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It gives m1 = 0.078017, m2 = 0.05375 and m3 = 0.024167. Therefore the wear rate equation becomes $d_w = K\ P^{0.078017}\ V^{0.05375}\ S_f^{0.024167}$

Now K is found by substituting actual values of variables in the above equation for all 9 treatments and average was calculated. Average K = 19.89.

Table 4. Regression statistics.

Multiple R	0.9585634
R square	0.9188438
Adjusted R square	0.8701501
Standard error	0.0318312
Observations	9

Table 5. ANOVA for PIAGGIO (GL400) crank shaft bush material.

DF	SS	MS	F	Significance F		
Regression	3	0.0573581	0.0191194	18.869859	0.003709788	
Residual	5	0.0050661	0.0010132			
Total	8	0.0624243				
	Coefficients	Standard error	t_{stat}	P-value	Lower 95%	Upper 95%
Intercept	1.250133333	0.01061039	117.821622	8.353E-10	1.222858458	1.277408208
X Variable 1	0.078016667	0.01299502	6.00358169	0.00184121	0.044611903	0.11142143
X Variable 2	0.05375	0.01299502	4.13619974	0.00903034	0.020345237	0.087154763
X Variable 3	0.024166667	0.01299502	1.8596867	0.1220199	0.009238097	0.05757143

Thus generalized depth of wear equation for PIAGGIO (GL400) bush material is given as

$$d_w = 19.89\ P^{0.078017}\ V^{0.05375}\ S_f^{0.024167}$$

By observing the regression statistics Table 4 it is seen that the value of R^2 is more than 0.85 so, the relationship established is acceptable.

Result and discussion

The mathematical results of depth of wear were compared with experimental result for conclusion (Table 5 and 6). Table 6 shows the comparison of measured values depth of wear of lining thickness (d_w) in 9 trial runs after experimentation and predicted values of depth of wear of lining thickness (d_{wp}) by mathematical model. Fig. 7 shows the graphical comparison for 9 trial runs. By comparing the experimentally measured d_w and mathematically predicted d_{wp} for PIAGGIO (GL400) Rickshaw bush lining material, it is seen that average error is 11.51%. The wear of lining thickness occurred symmetrically at the highest temperature zone in all three samples. The evolution of wear based on load (p), number of cycles of shaft (v)and surface roughness (s_f) of selected bush samples. The depth of wear (d_w) of lining thickness of bush particularly measured at front side on points a, b, c, d, e, f, g and at rear side on points a', b', c', d', e', f', g', as bush might have been subjected to small alignment along width. The important finding is that circumferential point d and d' found highest point of depth of wear which was also highest point of temperature. It is concluded that depth of wear of lining thickness in all nine trail ranges from 11.34-22.00 microns while predicted depth of wear was17.28-18.94 microns. The magnitude of depth of wear of lining thickness of bushing increases with increase in load, shaft speed and surface roughness of bush material. In future work the effect on depth of wear of lining thickness can be evaluated for various cycles of load for various surface texture (surface roughness) of bush for variable shaft speed and variable viscosity and flow rate.

Table 6. Comparison of measured d_w in experimentation & Predicted d_{wp} of lining thickness.

Trial no.	dw	P	V	S_f	$P^{0.078017}$	$V^{0.05375}$	$S_f^{0.024167}$	d_{Wp}	d_{Wp}- d_W	% Error
1	11.34	0.0985	2.503	0.66	0.835	1.051	0.990	17.28	5.94	34.37
2	15.67	0.0985	3.754	0.76	0.835	1.074	0.993	17.71	2.04	11.51
3	18.00	0.0985	5.005	0.86	0.835	1.090	0.996	18.03	0.03	0.17
4	16.34	0.1478	2.503	0.76	0.861	1.051	0.993	17.87	1.53	8.56
5	18.17	0.1478	3.754	0.86	0.861	1.074	0.996	18.31	0.14	0.76
6	20.00	0.1478	5.005	0.66	0.861	1.090	0.990	18.48	1.52	8.22
7	20.34	0.197	2.503	0.86	0.880	1.051	0.996	18.32	2.02	11.03
8	21.00	0.197	3.754	0.66	0.880	1.074	0.990	18.61	2.39	12.84
9	22.00	0.197	5.005	0.76	0.880	1.090	0.993	18.94	3.06	16.15

% Average error =11.51

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Appendix

d_w = Depth of wear of lining material (µm); d_{wp}= Predicted depth of wear (µm); V=Sliding velocity of shaft (m/s); P=Load on bearing (Kg); S_f =Surface roughness (Ra); DF=Degree of freedom; SS =Sum of square; F=Ratio of SS & MS; R=Regression coefficient.