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PREDICTING EFFECT OF VARYING LOAD, VELOCITY AND NUMBER OF CYCLES ON DEPTH OF WEAR OF $CUPB_{24}SN_4$ METAL LINED BUSH BY ENDURANCE TEST

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ABSTRACT

Hydrodynamic $CuPb_{24}Sn_4$ material Journal bearings are widely used in automobile and industrial application because of its excellent compatibility, conformability, dirt embeddability, 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 $CuPb_{24}Sn_4$ material which is found in 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 kilometers run.

The aim of present experimental work to determine the effect of variable load, sliding velocity of shaft and Number of cycles on depth of wear of lining thickness of $CuPb_{24}Sn_4$ material bush bearing under Endurance Test. The study predict sliding wear behavior of $CuPb_{24}Sn_4$ material under a varying Load cycles which is combination of results of Engine cylinder pressure at rated power, maximum torque idle speed. The endurance test run continuously for 36 hours for speed ranges from 1200 rpm to 3600 rpm and load ranges from 9800 N 11883 N for a sample. The effect of number of cycles on depth of wear (d_w) of lining thickness is accounted for same load cycles and number of cycles varying from $2.52x10^7$ to $2.16x10^8$. The relationship between depth of wear of lining thickness (d_w) versus Varying load, shaft speed, and time is established by using the experimental results from endurance test and good agreement between prediction and experimental results was obtained. The endurance results indicate that the critical parameter affecting on depth of wear of lining thickness of bush material is time followed by velocity and load. This study is helpful to finding practical life of bush bearing under varying conditions for particular depth of lining material.

Keywords: crank shaft bush bearing, Endurance test, depth of wear, lining thickness

1. INTRODUCTION

Oil lubricated bearings employing sintered $Cu\text{-}Pb_{24}\text{-}Sn_4$ metal are widely used in many automobile, industrial, marine, machine applications. Particularly in automobile single cylinder engine the crankshaft supported by bushing of $Cu\text{-}Pb_{24}\text{-}Sn_4$ lining material because of its good fatigue strength and cavitation erosion resistance, compatibility and conformability. These bearing are normally operated 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 crankshaft 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.

The most common form of wear is that damage to the surface, and is loss or displacement of material which affect on performance of the part. Generally volume of material removed or volume of material displaced is measured to account the wear but in case of wear of bushing material lining the wear is in micron which increase in clearance and change the contour of surface and geometry of surface. Hence in this experimentation wear is measured as depth of wear at define point. 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. Duckworth and Forrester [1] has analyze the wear in lubricated bearing while Dufrane *et al* [2] proposed theoretical model of worn bearing and analyzed wear pattern of steam turbine bearing and presented that wear occurred symmetrically at the bottom of the bearing. Bouyer J and Filon M, [3] presented influence of wear on steady state characteristics of bearings which concluded that wear defect could lead to an increase in thermodynamic performances, wear defect lead to a significant fall in maximum temperature and also to decrease in average operating temperature however the dissipated power increases slightly. Bouyer J and *et al*.,[4] analyzed behaviors of two lobe worn hydrodynamic journal bearing and presented that the influence of wear on operating condition is significant when number of cycles more than 1000, even after wear depth reaches around 10% of bearing operating radial clearance the worn bearing will remain usable and safe, while K.Tamura *et al*., [5] focused on effect of cyclic load and cyclic speed on sliding wear characteristics of bearing lined with white metal that there is unique relationship between the mean stress and cut-off life without depending on stress ratio, the cut-off life becomes shorter with increase in revolutions. Y. Tachi *et al*., [6] presented a cumulative law for sliding wear which is useful for the prediction of the effect of interferential shear stress on rate of steady state wear of tin based white metal, also developed relationship between cut -off life, shaft revolutions and interferential shear stress.

The aim of present work was to analyze the influence of varying Load, Velocity and Number of Cycles on depth of wear of $CuPb_{24}Sn_4$ metal lined bush by endurance test for real condition. The sample of bush of Gl-400 engine of "PIAGGIO" auto rickshaw is dynamically tested on test bed coupled with dynamometer and subjected to the defined "load-speed" cycles for 300 minutes to 1000 minutes. The experimental results compared with mathematical results and found good agreement. Three samples of different lining thickness of same material were tested and the numbers of trials for Load, Shaft speed and time variables were conducted as per "Taguchi Method" [7] and it was observed as L9 orthogonal array.

2. TEST AND EXPERIMENTAL PROCEDURE

The chemical composition of lining material $Cu\text{-}Pb_{24}\text{-}Sn_4$ of bush used in endurance test Rig is shown in Table1 and microstructure of material presented in figure 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 figure 3. The specification of engines was single cylinder GL-400 air cooled gasoline engine, Bore : 86 mm, Stroke: 68 mm, Power output : 9 HP, Rated RPM : 3600

The Eddy Current type dynamometer measures torque produced by engine which can be converted into power of the engine. The control panel of dynamometer was an interface through which variables like load, engine rpm etc was set. The parameters like coolant temperature, oil temperature, oil pressure, exhaust back pressure, exhaust temperature, engine blow by etc. were also measured.

Table 1: Chemical composition of lining material of bush bearing

Sr. No.	Test Conducted	Observations
1	Chemical Analysis	
	% Sn	4.64
	% Pb	24.60
	% P	0.008
	% Fe	0.02
	% Si	0.001
	% Zn	0.003
	% Cu	Balance (70.80)
2	Hardness in HV 1	70 – 75 HV 1
3	Micro Structure	It shows Sn – Pb phase is having acicular in shape & having uniform distribution in Copper matrix.

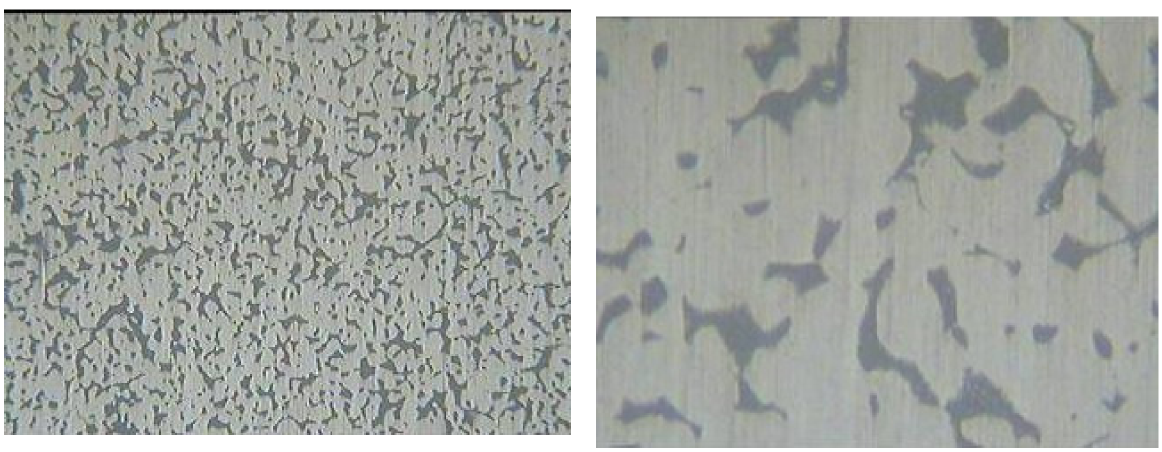

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Figure 1 : Microstructure of Lining Material

The Endurance test setup is shown in figure 2. 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 developed view in figure 3. The surface roughness is measured specifically on these points by using Taylor-Hobson Surtronic3$^+$ Surface Roughness Measuring Instrument**.** The depth of cu-pb-sn lining thickness of bush is measured specifically at above mentioned 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 viscosity, flow rate, was maintained as per the given norms for the GL-400 Engine. The speed variation is $\pm$10 rpm, load variation is $\pm$0.2N, Temperature variation is $\pm$0.5^{o}c

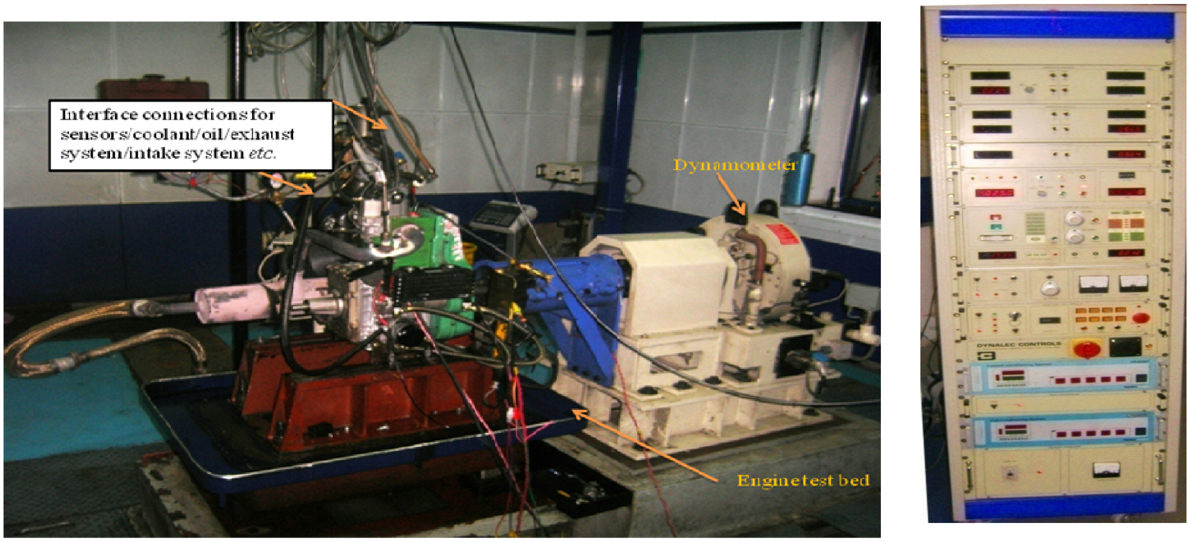

Figure 2: Engine Mounted on test bed Coupled with Dynamometer and control panel of dynamometer

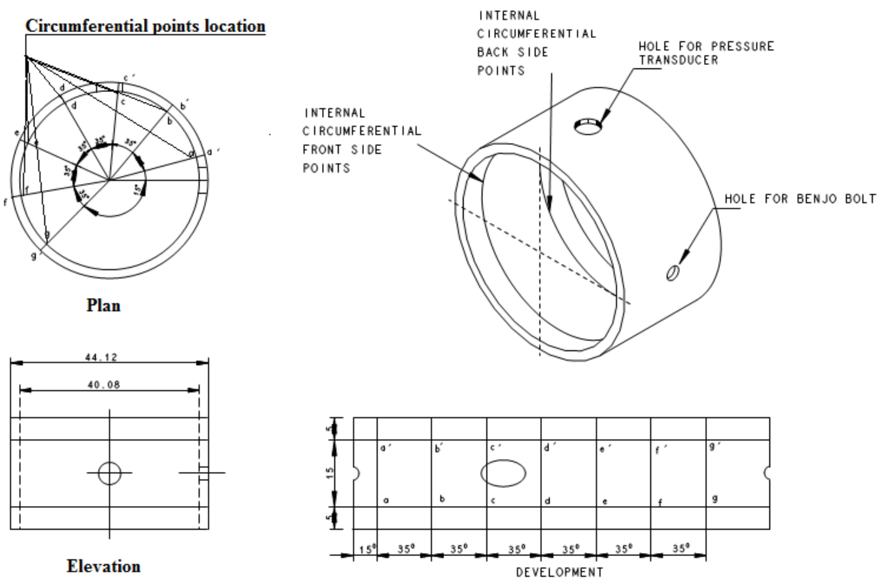

Figure 3 Schematic representation of bush

Load is influencing parameter on wear of bearing. The pressure developed in the hydrodynamic action is function of load. P-theta diagram shows the inside cylinder pressure with respect to crank angle. The cylinder pressure, exerted on piston produces force and same force is transmitted to the crankshaft main bearings through the crank slider mechanism. It is necessary to decide the load cycle of the bearing, to investigate it the P-theta diagram of engine was evaluated for cylinder pressure at rated power rpm, max torque rpm, random point rpm and idle engine rpm. The figure 4 representing all four conditions of P-theta diagram.

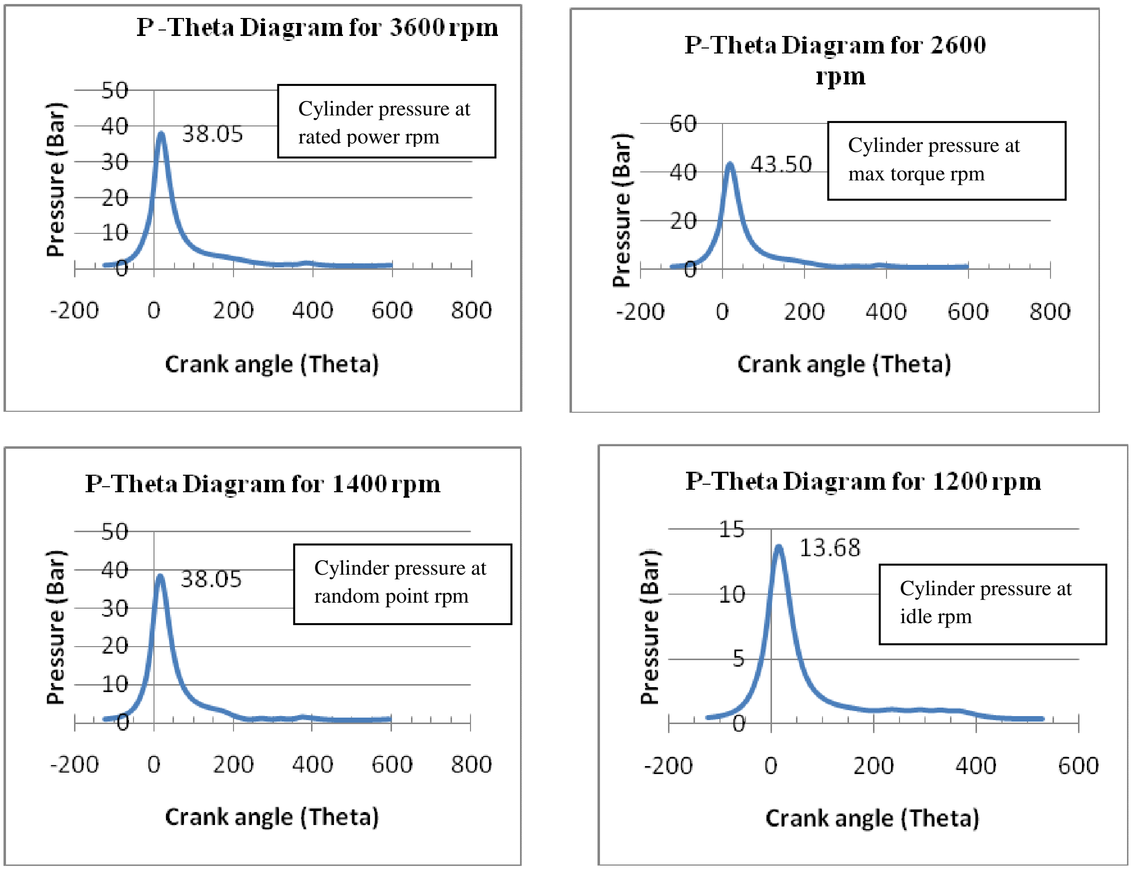

Figure 4: P-Theta diagrams at different rpm

Above four cases are the key points considered from P-theta diagram to map the engine performance and get the maximum pressure exerted on the piston. By using data force on bush bearing is evaluated as Force = pressure x piston top area, it found 22.06 kN and hence on each bearing it is treated as 11kN.

The detail bearing performance results obtained from software are same as theoretical calculations. The Maximum load on each bearing observed in result is 11883.7 N because the frictional losses and inertia forces are considered which are not accounted in theoretical calculations.

The Table No. 2 shows the maximum bearing load, , minimum, oil film thickness, maximum oil pressure, oil temperature rise, average oil volume flow rate, hydrodynamic flow rate ratio, oil dynamic viscosity, friction torque and frictional power loss

Endurance test cycle for analysis of effect of varying load, speed and number of cycles on depth of wear of lining thickness was design on real running conditions of engine. The idle speed 1200 rpm is allowed to 30 second then it is increased to maximum speed and maximum load and it is allowed to 3500sec then it drop to idles speed next 30sec. The Figure 5 shows the Endurance Test Cycle

Table 2: Bearing Performance Results obtained from GT suit software

Attribute Value	Unit	1200 RPM / Case# 1	1400 RPM / Case# 2	2600 RPM / Case# 3	3600 RPM / Case# 4
Maximum Bearing Load	N	4171.19	10553.5	11883.7	9799.39
Minimum Oil Film Thickness	micron	4.86467	2.92205	3.62598	4.43446
Maximum Oil Pressure	bar	132.611	424.505	401.444	293.411
Thermally Balanced Oil Temperature	degC	86.9681	87.6348	89.451	91.6697
Oil Temperature Out	degC	88.7689	90.1203	93.7151	98.1704
Oil Temperature Rise	degC	3.60162	4.97101	8.5283	13.0013
Average Oil Volume Flow rate	liter/hr	6.6599	8.0937	13.76	16.4646
Pressure/Hydrodynamic Flow Rate Ratio		1.5023	1.25217	1.0421	0.836984
S Factor in Oil Flow Eq.		0.0	0.0	0.0	0.0
Oil Dynamic Viscosity	Pa-s	0.0127638	0.0125474	0.0119802	0.0115392
Friction Torque	N-m	-0.0861371	-0.113981	-0.191735	-0.256914
Friction Power Loss	W	11.8848	19.9829	58.0622	106.596

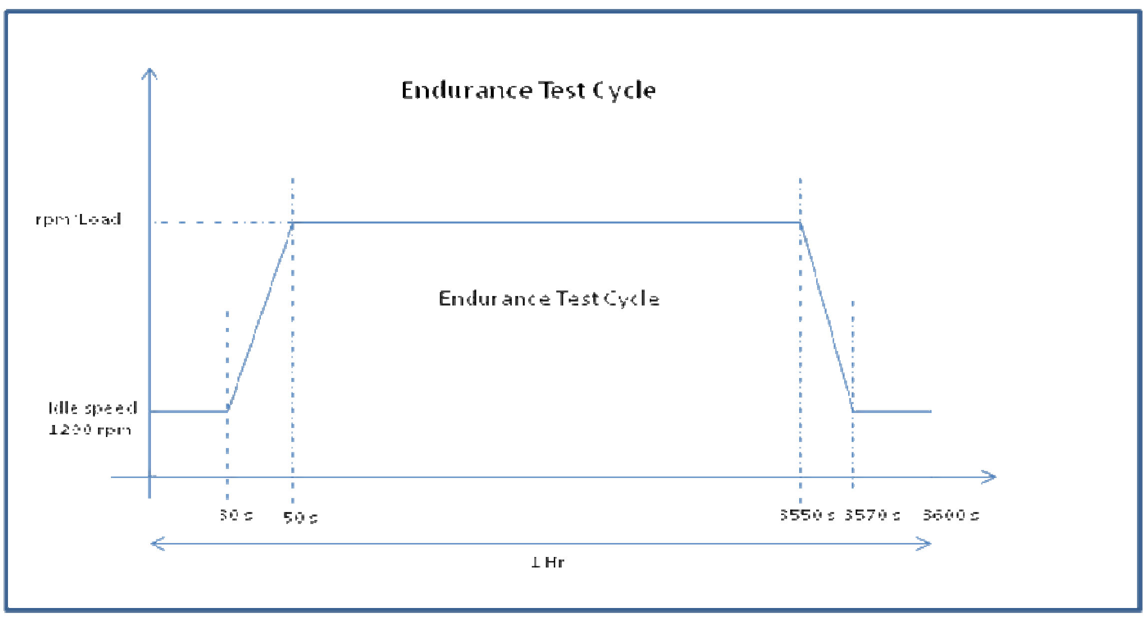

Figure 5: Endurance Test Cycle

3. EXPERIMENTAL RESULTS

The main three factors affecting on depth of wear of lining material of bush was considered from the available literature that are varying load, speed and number of cycles. In order to minimize number of test run required the design of experiments technique [8] (DOE) of "Taguchi" was used while experimentation. As number of controllable factors was three and their three levels were selected the running of experimentation based on" L9 Orthogonal Array" The test results observed on three samples are presented in table 3 which shows three factors and three levels.

Table 3: Summary of Endurance test data for crankshaft bearing of GL 400 engine (L9 OA)

Trial	P (load) N	V (Velocity of journal) m/s	T (Time) Min	Wear (micron)
1	9800	2.93	300	20
2	9800	5.442	700	31
3	9800	7.536	1000	38
4	10553	2.93	700	30
5	10553	5.442	1000	37
6	10553	7.536	300	26
7	11883	2.93	1000	36
8	11883	5.442	300	23
9	11883	7.536	700	34

The combined relationship between cyclic load, speed of shaft and time and depth of wear of lining material is decided by using regression analysis method. The combined effect of above variables on depth of wear of lining thickness of bushing material is quantitatively modeled by using above method [9]. Predicting depth of wear of lining thickness of bushing material is aim of this experimental work under the influence of cyclic load, shaft speed and time.

Depth of wear for GL400 engine crank shaft bush $Cu\text{-}Pb_{24}\text{-}Sn_4$ material is calculated by using the formula for calculating m1, m2 and m3

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

We get m1 = 0.0128, m2 = 0.032, m3 = 0.104

Therefore the wear rate equation becomes,

$$d_w = K\ P^{0.0128}\ V^{0.032}\ T^{0.104}$$

Now K is found by substituting actual values of variables in the above equation for all nine treatments and average was calculated as K = 13.146

Thus generalized depth of wear equation for PIAGGIO (GL400) Bush $Cu\text{-}Pb_{24}\text{-}Sn_4$ material is given as $d_w = (13.146)\ P^{0.0128}\ V^{0.032}\ T^{0.104}$

the mathematical relation between three variables is estimated by value of one variable with other variables of distribution after fitting an equation by using regression statistic. Table 4 represents regression statistics for Endurance test data.

Table 4: Regression Statistics for endurance test data

Multiple R	0.9743105
R Square	0.94928095
Adjusted R Square	0.91884952
Standard Error	0.027844467
Observations	9

By observing the regression statistics table it is seen that the value of R^2 (Coefficient of determination) is more than 0.85 So, the relationship established is acceptable.
The analysis of variance is carried out for splitting variability into component sources as take summary of variability in all observations and partitions it into separate sources [10]. Table 5 represents ANOVA for Endurance test data.

Table 5: ANOVA for endurance test data

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.072555691	0.02418523	31.19409619	0.001158613
Residual	5	0.003876572	0.000775314		
Total	8	0.076432263			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.475775	0.009281	159.00203	1.866E-10	1.45191	1.49963
X Variable 1	0.012888	0.011367	1.1338503	0.3082765	-0.01633	0.04210
X Variable 2	0.031963	0.011367	2.8118591	0.0374660	0.00274	0.06118
X Variable 3	0.104426	0.011367	9.1864093	0.0002564	0.07520	0.13364

By observing the ANOVA table it is seen that the values obtained for X variables are same as that obtained by the mathematical calculations.

4. RESULT AND DISCUSSSION

The mathematical results of depth of wear (d_w) in micron is compared with experimental results. The Table 6 showing comparison of measured values depth of wear of lining thickness (d_w) in all nine trial runs after experimentation and predicted values of depth of wear of lining thickness (d_{wp}) by mathematical model

Table 6: Comparison of Measured d_w and Predicted d_{Wp} of $Cu\text{-}Pb_{24}\text{-}Sn_4$ bearing material

Trial No.	**dw**	**P**	**V**	**T**	$\mathbf{P^{0.0128}}$	$\mathbf{V^{0.032}}$	$\mathbf{T^{.0.104}}$	$\mathbf{d_{Wp}}$	$\mathbf{d_{Wp}\text{-} d_W}$	**%Error**
1	20	9800	2.93	300	1.125	1.035	1.810	27.70	7.70	27.79
2	31	9800	5.442	700	1.125	1.056	1.976	30.85	0.15	0.47
3	38	9800	7.536	1000	1.125	1.067	2.051	32.36	5.64	17.44
4	30	10553	2.93	700	1.126	1.035	1.976	30.28	0.28	0.92
5	37	10553	5.442	1000	1.126	1.056	2.051	32.05	4.95	15.44
6	26	10553	7.536	300	1.126	1.067	1.810	28.57	2.57	9.01
7	36	11883	2.93	1000	1.128	1.035	2.051	31.47	4.53	14.40
8	23	11883	5.442	300	1.128	1.056	1.810	28.32	5.32	18.79
9	34	11883	7.536	700	1.128	1.067	1.976	31.25	2.75	8.78
% Average Error =12.56										

By comparing the experimentally measured depth of wear (d_w) and mathematically predicted depth of wear (d_{wp}) for PIAGGIO (GL400) Rickshaw bush bearing $Cu\text{-}Pb_{24}\text{-}Sn_4$ lining material, it is seen that average error is 12.56%.

The wear of lining thickness occurred symmetrically at the highest temperature zone in all three samples. The evolution of wear based on load (P), shaft speed (v) and Time (T) 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 misalignment 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 20 to 37 microns while predicted depth of wear was27.70 to-32.36 microns.

The operating characteristics of the bearing in real condition are nearly same as the endurance test and there is no modification for any sample test. The each sample is subjected to rigorous $2.5x10^7$ cycles to$8.4x10^7$ cycles in order to get more significant effect on depth of wear. The pressure field in bearing mid plane is slightly modified due to increase in wear thereby clearance. The trial results of rpm and speed translated to number of revolution of shaft. The table 7 represents endurance test data for number of revolutions of shaft, measured depth of wear and predicted depth of wear of lining material and figure 6 shows comparison of all results.

Table 7: Endurance test data for number of revolution of shaft Vs Depth of wear

	Time	**rpm**	**No of rev**	**Measured wear**	**Predicted wear**
Sample 1	300	1400	2.52E+07	20	27.69
	700	1400	5.88E+07	30	30.27
	1000	1400	8.40E+07	36	31.47
Sample 2	300	2600	4.68E+07	23	28.32
	700	2600	1.09E+08	31	30.85
	1000	2600	1.56E+08	37	32.05
Sample3	300	3600	6.48E+07	26	28.57
	700	3600	1.51E+08	34	31.25
	1000	3600	2.16E+08	38	32.35

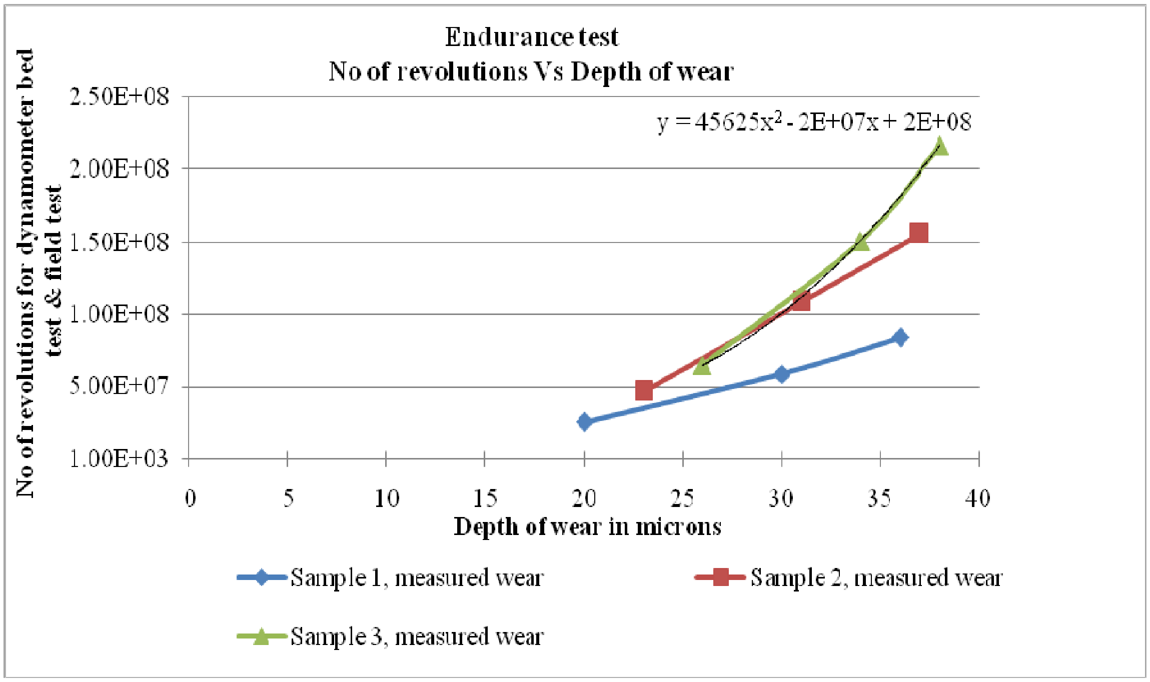

Figure 6: Comparison of depth of wear Vs no of rev. for test rig trial and endurance test

The shape of curve is close to Tachi et al [6] obtain for white metal there is good concordance of the experiments. The difference between the results are due to the material is different and pressure applied in Tachi et al experiment from 8 to 30 MPa and the number of revolutions are limited to 10^6 .In this experimentation was performed on real bearing whereas those of Tachi et al were done on small pad subjected to sliding. The figure 7 shows comparison of experimental and predicted depth of wear for all nine samples

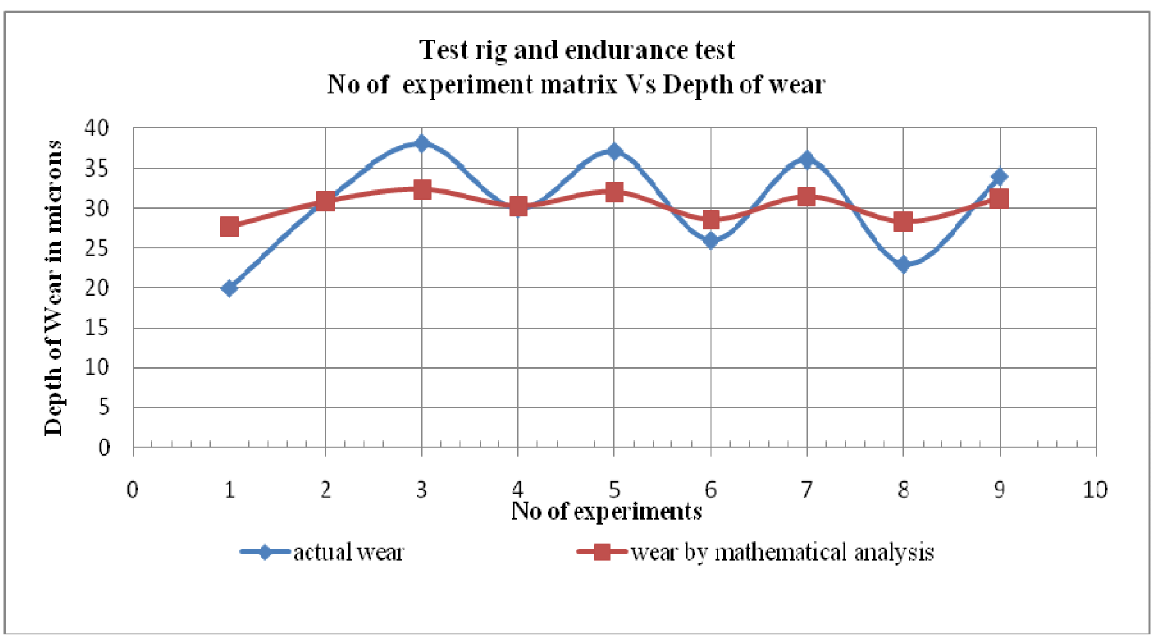

Figure 7: Comparison of Experimental and Predicted depth of wear for all nine samples

The magnitude of depth of wear of lining material $CuPb_{24}Sn_4$ of bush bearing increases with increase in load, shaft speed and number of cycles. The number of cycles plays significant contribution in wear of lining material $CuPb_{24}Sn_4$ of bush bearing. 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.

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APPENDIX

Notation

d_w	Depth of wear of lining material (µm)
V	Sliding velocity of shaft (m/s)
P	Load on Bearing, (N)
S_f	Surface roughness (Ra)
DF	Degree of freedom
SS	Sum of square
F	Ratio of SS and MS
R	Regression coefficient