ANALYSES OF WATER CONTAMINANTS LUBRICATED DEEP GROOVE BALL BEARING THROUGH VIBRATION, SHOCK PULSE AND TEMPERATURE MEASUREMENT

Vinay Kumar Patel[1], Mr. Akhilesh Soni[2]

[1]*M.Tech. Scholar, Dept. Of Mechanical Engineering, MANIT Bhopal, Madhyapradesh, INDIA*
[2]*Assistant Professor, Dept. Of Mechanical Engineering, MANIT Bhopal, Madhyapradesh, INDIA*

---***---

Abstract - *In rotating machinery, automobiles and aerospace, rolling element ball bearing are common in rotating machine. For friction less and continuous running bearing is lubricated with grease and oil. Greases are contaminated with various solid and liquid particles. This is one of the main reason for bearing failure, here we analyze and study the effect of liquid contaminant in lubrication through vibration, shock pulse and temperature measurement. Water is contaminated/ entrapped in greases due to rain, human error, experiment etc. The ability of a lubricating grease to withstand, reject or absorb water is different for different greases. Hence we investigate the effect of liquid contamination with salt at different forms in lubricant and its behavior on ball bearings. The experimental test has to be performed on 6206 SKF deep groove ball bearings and the trends in the amount of vibration, shock pulse and temperature affected by the contamination of the grease determined. Vibration were analyzed with respect to root mean square (RMS) values of amplitude in terms of velocity, shock pulse in term of pulse per second, temperature in term of °C and what is effect of contaminants on the performance of ball bearing, determined.*

Key Words: **6206 deep groove ball bearing, liquid contamination, greases, vibration, shock pulse and temperature.**

1. INTRODUCTION

Lubrication in rolling bearing is essential for low friction, proper operation and long life of machine element used in automobiles, aerospace like airplane, aircraft and ship etc. The bearing works properly, it is required maintenance strategies. In bearing operation three maintenance strategies is used-1. Run to break, 2. Preventive maintenance, 3.Condition based maintenance. In order to obtain the greatest effectiveness of the bearing in the operation, condition-based maintenance methods are being widely used. Detection of the probable faults when they are at early stages can prevent the failure and consequently, extra imposed costs. Condition Monitoring (CM) monitors the current condition and predicts the future condition of bearing while in operation. The most common and reliable techniques for obtaining information about internal conditions are vibration, debris, shock pulse and lubricant analyses. Vibration measurement works on the principal of signals and it's able to find 90% of fault machinery by signals processing techniques. If diagnose the fault at early stage, corrective action can be applied and increase the machinery life. It gives response immediately to any change of condition of ball bearing; therefore vibration monitoring is most widely used. It is found that 85 to 90 % bearing is lubricated with grease. Due to continuous running of ball bearing (surface contact), uneven environment and human error etc. lubricant greases are contaminated. Contaminants in grease strongly affect the performance, rated life time and behavior of ball bearing. Contaminants may be solid or liquid. Solid contaminant like small particles (56μm, 75 μm, 106 μm) produced noise and mechanical vibration. These vibrations affect the performance and reduced the rated life of ball bearing up to 22%. The term inadequate lubrication may classify in to eight categories- 1. Overfilling 2. Incorrect grease 3. Incorrect lubrication system and intervals 4.mixing greases 5.under filling 6.Debris contamination 7.Worn out greases 8.Water contamination. Water effect on grease can be analyzed with respect to the fresh grease. Fresh grease is butter colour and smooth as compared to water grease, which is milky white in colour.

Fig -1: Fresh grease

Fig -2: Water contaminated

Here, we perform the experiment on the liquid contaminated grease on ball bearing through vibration, shock pulse and temperature measurement. Water is entrapped in greases in many forms like sea water, mineral water and pond water etc. Ball bearing is lubricated with grease. If greases are contaminated with liquid particles, it may be possible to presence of unwanted (insoluble) constitutes in water, this may affect the bearing housing and produce additional vibration and noise. Also affect the shock pulse and temperature reading. Thus require immediate maintenance action for continuous running of ball bearing.

2. REQUIRED MATERIALS AND INSTRUMENTS

The experiment has been performed on the workshop setup, for this purpose some materials are required. With the help of SPM T30, take the reading of vibration, shock pulse and temperature of 6206 deep groove ball bearing. The list of required materials and instrument are given below-

Water Diesel Pond Salt Tape

Li grease Ca grease 6206 bearing SPM T30 machine

Dial gauge Wt. M/c Mixer Air nozzle Laser alignment

Fig -3: Materials and instruments

3. EXPERIMENTAL SETUP

Experiment has been performed on workshop setup. It uses 6206 deep groove ball bearing and SPM T30 for reading of parameters. The experimental setup are given below-

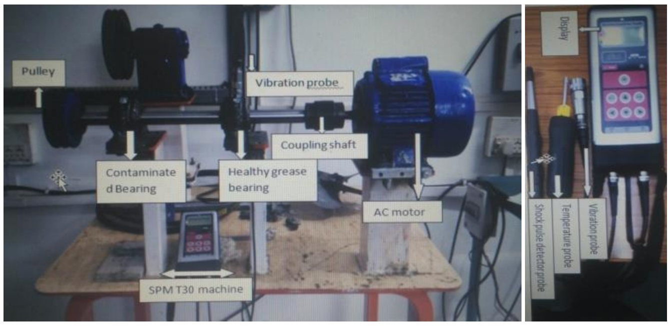

Fig -4: Experimental Setup

4. SAMPLE PEPARATION

The test sample has been prepared for experiment. Mineral and pond water with salt at different concentration level is used in greases for contamination. Total 14 samples has been prepared, 12 contaminated grease sample and 2 healthy grease sample. The sample name and it's constitute are given in the table-

Mineral water = M, Lithium based grease = L, Pond water = P, Calcium based grease = C, Salt = S Sample no. = 1,2,3,4......

TABLE-1: Samples constitute and its name

S. No	Water (% of grease in gm)	Salt in % of grease	Grease type	Sample name
1.	Nil	L	L	L
2.	Mineral water (20 %)	5	L	MS_1L
3.	Mineral water (20%)	10	L	MS_2L
4.	Mineral water (20%)	15	L	MS_3L
5.	Pond water (20%)	5	L	PS_1L
6.	Pond water (20%)	10	L	PS_2L
7.	Pond water (20%)	15	L	PS_3L
8.	Nil	Nil	C	C
9.	Mineral water (20%)	5	C	MS_1C
10.	Mineral water (20%)	10	C	MS_2C
11.	Mineral water (20%)	15	C	MS_3C
12.	Pond water (20%)	5	C	PS_1C
13.	Pond water (20%)	10	C	PS_2C
14.	Pond water (20%)	15	C	PS_3C

5. EXPERIMENTAL DATA

Experimental data are shown below on the table for each type of test sample. The table included vibration, shock pulse and temperature reading. In the table-

VR = Vibration reading in mm/sec. SPR = Shock pulse reading in pulse/sec. TR = Temperature reading in °C. V = Vertical direction. MSB = Motor side bearing. H = Horizontal direction. OSB = other side bearing. A = Axial direction. CB = Contaminated bearing. First reading is taken after 5 minute running of experimental setup and next four reading is taken in the interval of 1 hours.

TABLE-2: Test sample L

S. No.	VR						SPR				TR	
	MSB			OSB			MSB		OSB			
	V	H	A	V	H	A	dBm	dBc	dBm	dBc	MSB	OSB
1.	1.2	0.8	0.9	0.8	1.3	1.1	21	12	23	11	26	26
2.	0.9	0.7	0.9	0.9	0.8	0.9	20	11	19	10	33	34
3.	0.8	1.0	0.6	0.5	0.7	0.6	19	9	18	12	36	36
4.	0.7	0.9	0.8	0.8	1.1	0.7	17	12	19	10	38	39
5.	0.9	0.7	0.5	1.0	0.9	0.8	18	10	18	7	39	40

TABLE-3: Test sample MS_1L

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dBm	dBc	dBm	dBc	MSB	CB
1.	0.9	0.7	0.9	1.1	0.9	1.2	18	10	23	17	27	27
2.	1.1	0.8	0.9	1.2	1.4	0.8	16	12	21	14	33	36
3.	0.7	0.9	0.8	0.6	0.9	1.0	17	9	18	14	36	38
4.	0.5	0.6	0.9	0.8	0.6	0.9	19	12	19	12	37	42
5.	0.8	0.5	0.7	0.8	0.9	0.7	16	10	20	11	39	43

TABLE-4: Test sample MS_2L

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dBm	dBc	dBm	dBc	MSB	CB
1.	0.9	0.7	0.8	1.1	1.3	0.9	18	10	27	18	27	27
2.	0.8	0.6	0.9	1.8	1.3	1.4	14	11	22	15	32	37
3.	0.9	0.6	1.0	0.8	1.2	1.1	16	5	20	10	35	41
4.	0.6	0.8	0.9	1.0	0.9	0.7	13	9	21	14	38	45
5.	0.7	0.8	1.1	0.6	1.2	0.9	11	7	20	12	40	45

TABLE-5: Test sample MS_3L

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dBm	dBc	dBm	dBc	MSB	CB
1.	0.6	1.1	0.7	0.8	1.4	1.1	15	10	32	15	26	27
2.	0.7	0.9	0.6	1.8	0.8	2.1	13	11	24	13	33	38
3.	0.8	0.7	1.2	1.2	1.3	1.0	14	12	27	14	38	44
4.	0.6	0.7	0.9	0.9	0.8	1.4	15	10	21	12	40	48
5.	0.8	1.1	0.8	1.3	0.7	0.9	12	8	22	14	40	49

TABLE-6: Test sample PS_1L

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dBm	dBc	dBm	dBc	MSB	OSB
1.	0.7	0.8	1.0	1.0	0.8	1.1	15	9	25	16	26	27
2.	1.1	0.7	0.7	0.9	1.3	1.4	13	8	21	12	33	36
3.	0.9	0.6	0.8	1.3	0.9	0.7	12	10	20	15	35	39
4.	0.9	0.7	0.9	1.1	1.0	0.9	14	7	18	12	38	43
5.	1.2	0.9	0.6	0.9	1.2	0.8	13	8	17	11	39	44

TABLE-7: Test sample PS_2L

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dBm	dBc	dBm	dBc	MSB	OSB
1.	0.9	1.1	0.7	0.8	1.6	1.0	16	9	28	18	27	26
2.	0.6	0.7	0.9	2.0	0.6	1.7	13	10	23	12	33	38
3.	1.1	0.8	0.6	1.4	1.5	0.9	16	6	24	15	35	43
4.	0.5	0.9	0.8	0.6	0.9	1.3	12	7	22	13	38	47
5.	0.8	1.2	0.8	1.4	1.3	0.5	14	8	24	11	40	47

TABLE-8: Test sample PS_3L

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dB_m	dB_c	dB_m	dB_c	MSB	OSB
1.	0.8	0.7	1.1	1.3	0.9	1.6	17	8	32	23	26	27
2.	0.8	1.2	0.9	0.9	2.4	1.4	12	9	27	20	33	38
3.	0.9	0.6	1.2	1.2	1.6	1.7	15	11	24	18	35	45
4.	0.7	0.8	0.9	1.4	1.3	1.3	16	12	26	16	36	50
5.	0.6	0.8	1.1	0.9	0.9	1.0	11	7	27	18	39	51

TABLE-9: Test sample C

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dB_m	dB_c	dB_m	dB_c	MSB	OSB
1.	0.8	0.7	1.1	1.3	0.9	1.6	17	8	32	23	26	27
2.	0.8	1.2	0.9	0.9	2.4	1.4	12	9	27	20	33	38
3.	0.9	0.6	1.2	1.2	1.6	1.7	15	11	24	18	35	45
4.	0.7	0.8	0.9	1.4	1.3	1.3	16	12	26	16	36	50
5.	0.6	0.8	1.1	0.9	0.9	1.0	11	7	27	18	39	51

TABLE-10: Test sample MS_1C

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dB_m	dB_c	dB_m	dB_c	MSB	OSB
1.	0.9	0.7	0.8	1.0	1.1	0.6	18	12	24	12	27	26
2.	1.1	0.6	0.7	1.2	0.8	1.4	17	11	19	11	34	36
3.	0.6	0.8	0.9	1.0	1.3	0.7	14	5	18	15	37	39
4.	0.7	0.6	1.1	0.9	0.9	1.1	16	7	20	8	37	41
5.	0.8	0.9	0.8	1.1	1.0	1.2	15	10	19	12	39	42

TABLE-11: Test sample MS_2C

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dB_m	dB_c	dB_m	dB_c	MSB	OSB
1.	0.8	1.1	0.7	1.0	1.1	0.8	16	10	28	17	26	26
2.	0.6	0.7	0.9	1.2	1.6	0.6	13	10	23	15	32	37
3.	1.2	0.8	0.6	1.0	0.8	1.2	11	9	21	12	35	41
4.	0.5	0.9	0.7	1.3	1.1	0.9	15	11	20	11	38	45
5.	0.8	1.0	0.8	0.9	1.2	0.8	12	8	18	12	40	45

TABLE-12: Test sample MS_3C

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dB_m	dB_c	dB_m	dB_c	MSB	OSB
1.	0.7	0.9	1.0	0.9	1.0	1.2	18	9	31	20	27	27
2.	1.1	0.7	0.7	1.6	0.8	2.0	14	8	27	12	33	39
3.	0.8	0.6	0.8	1.3	1.4	1.2	12	5	26	15	38	45
4.	0.9	0.9	0.9	0.9	1.0	0.8	10	6	24	13	39	48
5.	1.0	0.5	0.6	0.8	0.7	1.1	11	7	23	11	40	49

TABLE-13: Test sample PS_1C

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dB_m	dB_c	dB_m	dB_c	MSB	OSB
1.	0.7	0.8	1.0	1.0	0.9	0.8	16	10	25	13	26	27
2.	1.1	0.7	0.9	1.2	1.3	0.9	14	8	20	12	33	36
3.	0.9	0.6	0.8	1.0	0.8	1.3	15	9	18	11	35	40
4.	0.8	0.7	0.9	1.0	0.7	0.9	12	10	19	12	38	42
5.	1.2	0.9	0.7	1.1	0.9	0.8	13	11	20	13	39	43

TABLE-14: Test sample PS_2C

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dBm	dBc	dBm	dBc	MSB	OSB
1.	0.6	1.1	0.7	0.9	1.2	1.0	18	8	31	15	27	26
2.	0.7	0.8	0.6	0.8	1.8	1.7	14	10	24	12	33	37
3.	0.8	0.7	1.1	1.3	0.9	0.7	15	9	21	14	35	43
4.	0.8	0.7	0.9	1.1	1.4	0.9	12	7	20	12	38	46
5.	0.7	1.1	0.8	1.1	1.2	0.8	13	7	23	15	39	47

TABLE-15: Test sample PS_3C

S. No.	VR						SPR				TR	
	MSB			CB			MSB		CB			
	V	H	A	V	H	A	dBm	dBc	dBm	dBc	MSB	OSB
1.	0.9	1.1	0.8	1.2	1.1	1.0	15	6	33	18	26	27
2.	1.1	0.6	0.7	2.2	1.3	1.6	13	9	27	17	33	40
3.	0.6	0.9	0.9	0.8	1.3	1.1	16	6	24	15	34	46
4.	0.7	0.6	1.1	1.0	0.8	0.9	13	7	26	16	36	49
5.	0.8	0.9	0.8	0.9	1.2	0.8	12	8	27	15	40	51

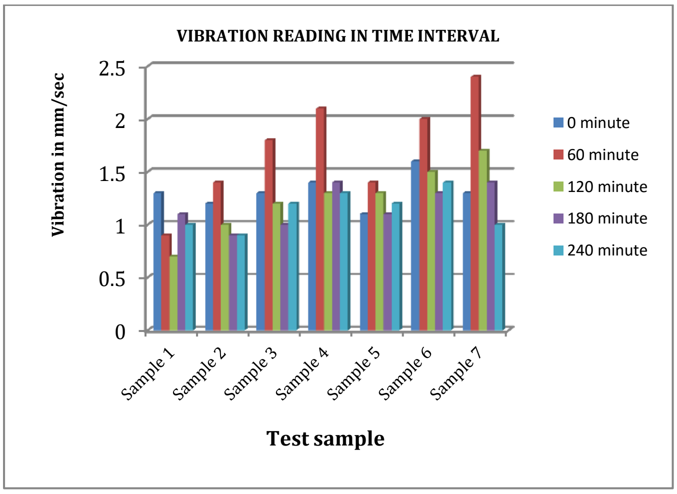

Fig -5: Maximum vibration of Li based grease in interval

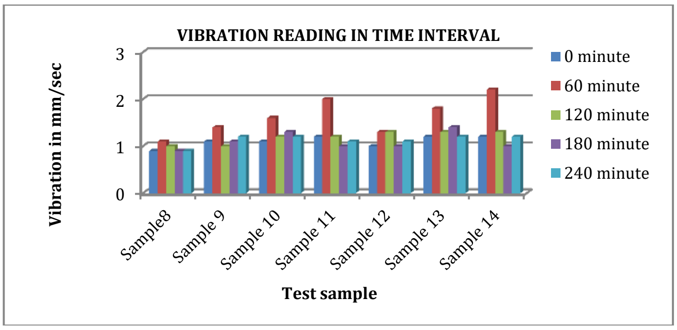

Fig -6: Maximum vibration of Ca based grease in interval

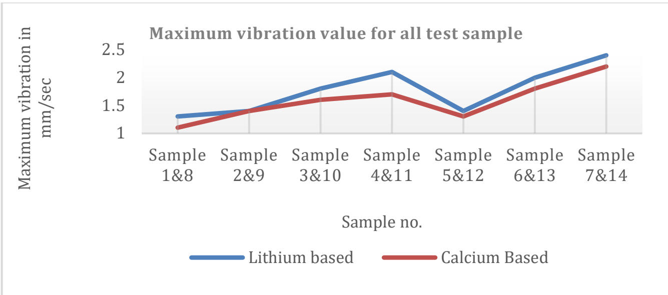

Fig -7: Comparison of max. Vibration b/w diff. sample

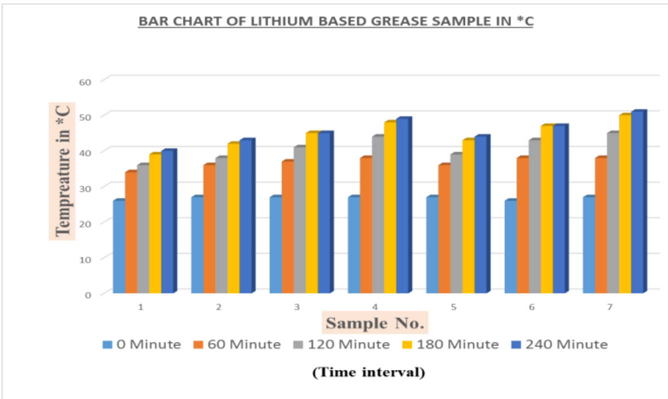

Fig -8: Maximum temp. of Li based grease in interval

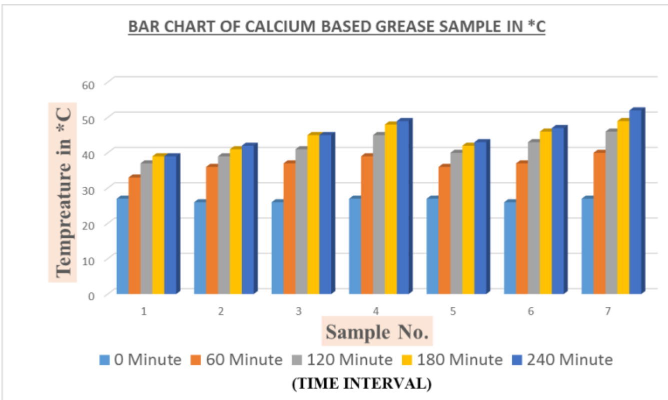

Fig -9: Maximum temp. of Ca based grease in interval

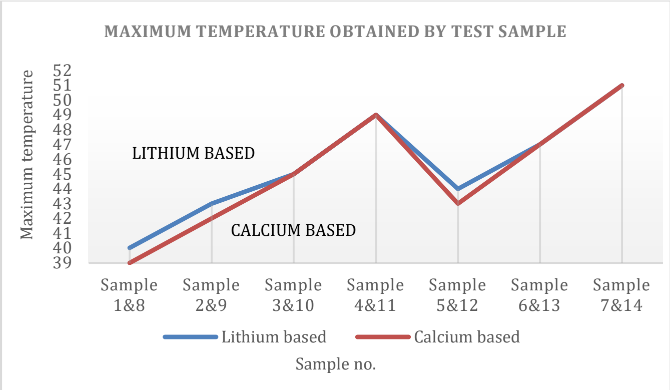

Fig -10: Comparison of max. Temperature b/w diff. sample

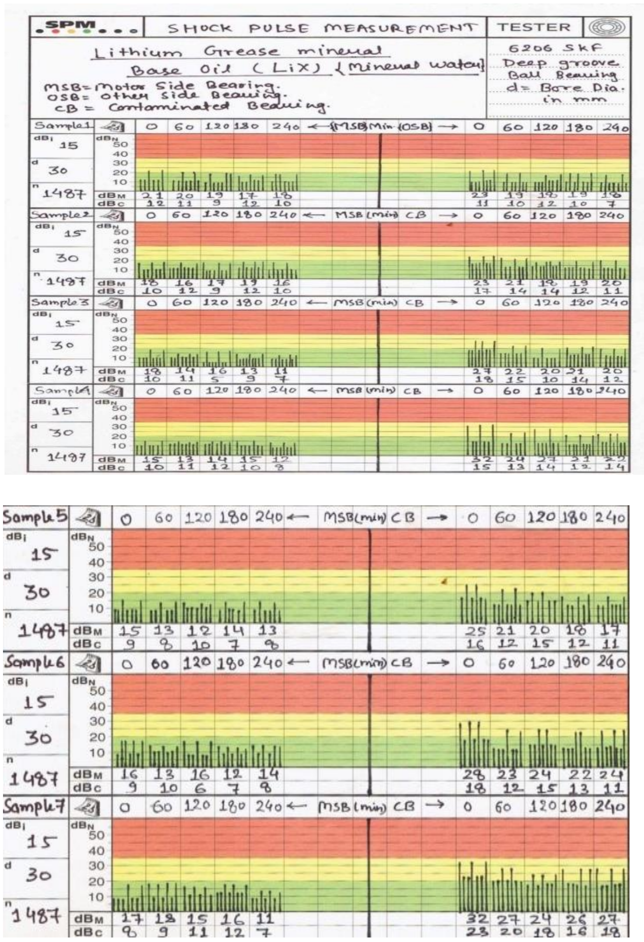

Fig -11: Shock pulse reading of Li based grease in interval

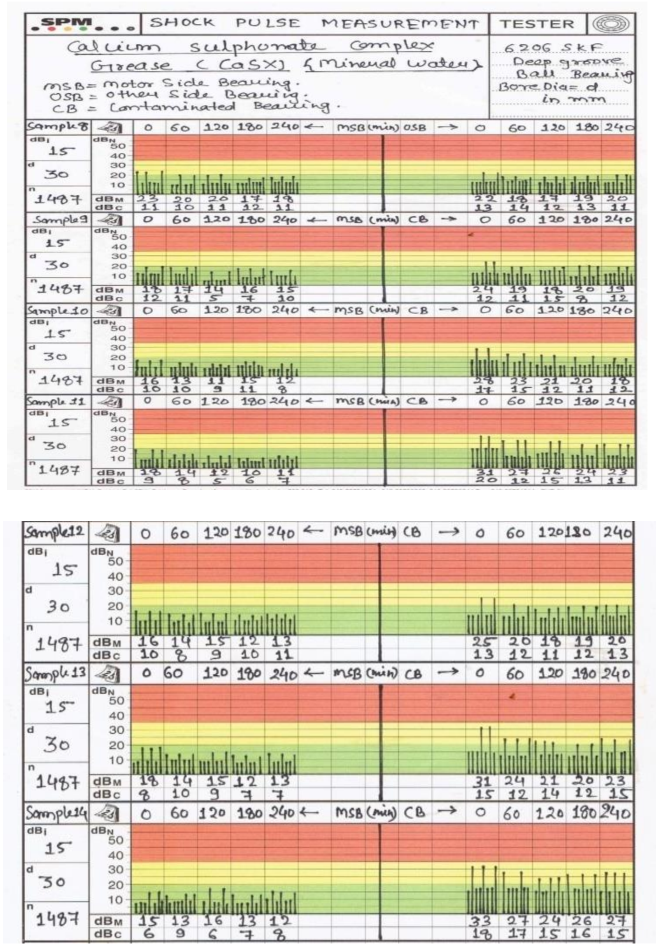

Fig -12: Shock pulse reading of Ca based grease in interval

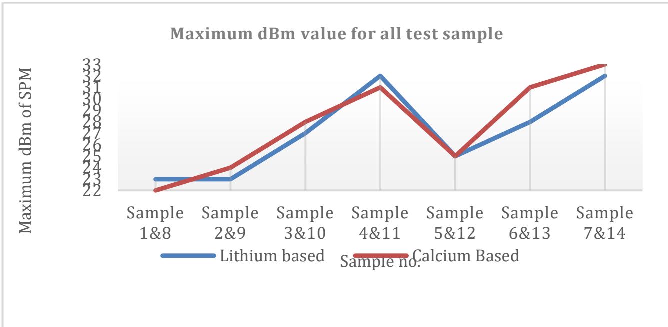

Fig -10: Comparison of max. shockpulse b/w diff. sample

6. RESULT

6.1 Vibration

From the experiment, the RMS value of vibration obtained through SPM T30 in term of velocity. The vibration value observed in 3 different directions (axial, vertical and horizontal) on each ball bearing. Table 2 and table 8 show the vibration reading of contaminated free greases ball bearing and other table show the vibration reading of contaminated greases ball bearing. The explanation of these reading is given below-

- -Due to presence of liquid contamination in greases, effect on the vibration reading of bearing is not noticeable like solid particles (max. 2.2 mm per sec), but this is sufficient to affect the performance of ball bearing.

a) Lithium based contaminated bearing reduced the bearing life up to 23.68%.
b) Calcium based contaminated bearing reduced the bearing life up to 12.77%.

- -As the contaminant concentration increases, there is appreciable increment in the vibration value (1.2 to 2.4 for lithium based grease sample and 1.1 to 2.2 for calcium based grease sample).
- -The value of vibration in first interval increases, after that decreases. Due to salt dissolved into water and water is spelled out from the greases (For test sample 8- 1.6, 2.4, 1.6, 1.4, 1.0 mm/sec).
- -As compared to mineral water, pond water test sample gave the high vibration reading (in mineral water sample max. vibration 2.1 and pond water sample 2.4 mm/sec).
- -Lithium grease viscosity (50 mm^2/sec) is lower than calcium grease (60 mm^2/sec), but vibration reading is high as compared to calcium grease sample (lithium grease sample 2.4 and calcium grease sample 2.2 mm^2/sec). Thus we can say that viscosity increases, vibration decreases.
- -Viscosity also affect the bearing life (Lithium grease sample reduced performance up to 30.26% and calcium grease sample reduced performance up to 12.76%).

6.2 Temperature

-When contamination is added to greases, temperature goes up to 51°C, it's clearly defined that contamination effect the bearing temperature and it increases.

-For the entire test sample initial temperature is 26 to 27 °C. When setup is running continuously without contamination lubricated bearing temperature is increases up to 27 to 39 °C in given time interval.

-Temperature effect for pond and mineral water is different for different concentration level of salt and water. It increases up to 48 to 51 *C (it is negligible).

6.3 Shock pulse

-With increasing the percentage of concentration level of contamination in greases, normalizing dBm values are increasing for ball bearing (dBm values increases from 23 to 32 dBn).

-For all test sample dBm and dBc values are decreasing with given time interval, this is due to homogeneity of contamination, dissolution and spelling of water particles (32 to 21 dBn).

-Type of water also affects the reading of dBm (for mineral water in calcium test sample 31dBn to 33 dBn pond water test sample).

-The main purpose of shock pulse reading to find the lubrication condition or presence of contamination. If

a) dBm value in green zone 0 to 20 dBn, bearing in good condition.
b) dBm value in yellow zone 21 to 34 dBn, crucial condition.
c) dBm value in red zone 35 to above dBn, bad condition.

In above data, when added contamination in greases, shock pulse reading always in yellow zone. This indicates presence of contamination in bearing.

7. CONCLUSION

Ball bearing was tested in order to study the vibration, shock pulse and temperature value caused by presence of contaminant like water and salt in the different greases. The vibration was analysed in term of its RMS value, shock pulse in term of pulse per second and temperature in term of °C. All the result shows a regular pattern in the reading. With increasing the contamination concentration level in greases, the value of vibration, shock pulse and temperature are increases. Different greases shows differ the reading. Lithium based grease gave the high vibration reading as compared to calcium grease, but shock pulse and temperature reading are not differed. Even withvery low time of test (up to 4 hrs.), significant variation was observed since the grease loses its property like colour and performance. Lithium based grease sample reduced the bearing life up to 23.63%, whereas calcium based grease sample up to 12.67%. Without contaminated bearing gives low vibration reading (1.1 mm/sec), SPM indicate good lubricated bearing (always in green zone) and temperature probe gives low temperature reading up to 39°C. When contamination added in lubrication, vibration (2.4 mm/sec), shock pulse (yellow zone) and temperature (51°C) increases. Due to continuous running of bearing in a sample, vibration and shock pulse reading goes down after some times and become constant (in 3 to 4 hrs.), due to homogeneity of contamination in greases. But temperature is increases continuously and become constant after 4 hours or show less variation (1 to 2 °C).

8. FUTURE WORK

This thesis work can be accelerated or reference for future work. Following things can be extended on this work-

-By using the **Condmaster®Pro** software, draw the vibration graph in time domain and compare with solid contaminated ball bearing graph (reading).
-Other type of ball bearing can be tested on the workshop setup.
-Other type of methods like debris wear, stator current can be applied.
-What is the effect of temperature on ball bearing and induced thermal stress on ball bearing can be calculated.
-Both, solid and liquid contamination of greases is considers and finds the result what is effect on performance of ball bearing.
-Displacement and acceleration parameter of vibration may be considered for vibration analysis.

REFERENCES

[1] R. B. Randall. (2011). Vibration-based Condition Monitoring. First ed., Illinois: John Wiley & Sons, Ltd, Publication.

[2] Reza golafshan, (2015) "VIBRATION-BASED FAULT DETECTION FOR BALL BEARINGS", page no.1-8.

[3] JuhaMiettinen& Peter Anderson, "Acoustic emission of rolling bearings lubricated with contaminated grease." Tribology International 33 (2000) 777–787.

[4] "ISO 13373-1 Condition monitoring and diagnostics of machines – Vibration Condition monitoring" In International Standards Office, London: HMSO, 2002.

[5] S. H. Ghaffari "A Fault Diagnosis System for Rotary Machinery Supported by Rolling Element Bearings", PhD Thesis (2007).

[6] Latino, C. J. (1999). Hidden treasure: eliminating chronic failures can cut maintenance costs up to 60%. Report, Reliability Center, Hopewell, Virginia, Vol. 199, pp. 115-121.

[7] W. He, Z.-N. Jiang and K. Feng. (2009) "Bearing fault detection based on optimal wavelet filter and sparse code shrinkage Measurement" vol. 42, no. 7, pp. 1092-1102.

[8] Lugt PM. "Grease lubrication in rolling bearings", John Wiley & Sons, Ltd.; 2013 (Tribology series).

[9] N. Tandon and A. Choudhury. (1999). A review of vibration and acoustic Measurement methods for the detection of defects in rolling Element Bearings. Tribology International, vol. 32, no. 8, p. 469-480.

[10] M.M. Maru, R.S. Castillo, "Study of solid contamination in ball bearings through vibration and wear analyses", Tribology International 40 (2007) 433–440.

[11] Castillo, R.S., Maru, M.M. &Padovese, L.R., "Effect of lubricant oil viscosity and contamination on the mechanical signature of roller Bearings", Twelfth International Congress on Sound and Vibration, Lisbon, 11-14th July 2005.

[12] Timken Automotive TechTips Vol.3 Issue 5 2009.

[13] SKF Tech tip TT 09-004, March 2009.

[14] B. S. Nagarkoti, "Water resistance properties of grease- An outlook." Paper from NLGI-India 12th Lubricating grease conference, January 28-30, 2010.

[15] T.A. Blanchet, S.J. Shaffer, A.C. Christiaen and J.M. Kolly, "Grease-Lubricated Wear Of Aluminum Bronze for Jackscrew Application" Wear 255(7), 2003.

[16] Johan Leckner "effects of water contamination on greases" Axel Christiernsson International AB Nol, Sweden 25th ELGI Annual General Meeting the Netherlands 20th – 23rd April 2013.

[17] Yogesharao Y. More,Dr.D.Y.Patil&.A.P.Deshmukh "study of effect of solid contaminants in grease onperformance of ball bearing by vibrational analysis"international journal of innovations in engineering research and technology [IJIERT]ISSN: 2394-3696Volume 2, ISSUE 5, May-2015.

[18] Onkar L. Mahajan &Abhay A. Utpat"study of effect of solid contaminants in the lubricant on ball bearings vibration"International Journal of Instrumentation, Control and Automation (IJICA) ISSN: 2231-1890, Vol-1 Iss-3, 4, 2012.

[19] N. Tandon, K.M. Ramakrishna & G.S. Yadava"Condition monitoring of electric motor ball bearings for thedetection of grease contaminants"-Tribology International 40 (2007) 29–36, March 2007.

[20] Dinesh Kumar Tyagi& A. K. Jain"Experimental Studies on the Effect of Viscosity grade onMechanical Vibration Behavior of deep groove ball bearing"International Journal of Engineering Trends

and Technology (IJETT) – Volume 14 Number 2 – Aug 2014.

[21] C.Q. Yuan, Z. Peng, X.C. Zhou & X.P. Yan"Effects of temperature on sliding wear process under contaminatedlubricant test conditions" Elsevier 2004 wear.2004.05.014, 257 (2004) 812–822.

[22] N. Tandon& B. C. Nakara"Comparison of vibration and acoustic emission method for condition monitoring of rolling element bearing" ITMEC, Indian Institute of Technology, New Delhi. "Tribology International".

[23] D. Mba& Raj B.K.N. Rao "Development of Acoustic Emission Technology for Condition Monitoring and Diagnosis of Rotating Machines; Bearings, Pumps, Gearboxes, Engines and Rotating Structures"The Shock and Vibration Digest, 2006, Volume 38(1), pp3-16.

[24] Kulkarni Sam &S.B. Wadkar"Investigation for Distributed defects in Ball bearing using Vibration Signature Analysis" International journal of scientific research Volume: 2, Issue: 11, November 2013 ISSN No.2277-8179.

[25] P Shakya, A K Darpe & M S Kulkarni "Vibration-based fault diagnosis in rolling element bearings: ranking of various time, frequency and time-frequency domain data-based damage identification parameters" International Journal of Condition Monitoring, Volume 3, Issue 2 pp 768-781, October 2013

[26] SurojitPoddar&MadanLalChandravanshi"Ball Bearing Fault Detection Using Vibration Parameters"International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Vol. 2 Issue 12, December – 2013.

[27] D. Koulocheris, A. Stathis, Th. Costopoulos& D. Tsantiotis"Experimental study of the impact of grease particle contaminants on wear and fatigue life of ball bearings"Engineering Failure Analysis 39 (2014) 164–180.

[28] Dhanush N, Dinesh G, Perumal V, Mohammed Salman R & Nafeez Ahmed"Analysis of Deep-Groove Ball Bearing using Vibrational Parameters"International Journal of Innovative Research in Science, Engineering and Technology ISO 3297: 2007 Volume 4, Special Issue 3, March 2015 First National Conference on Emerging Trends in Automotive Technology (ETAT-2015).

[29] Sachin P. Godase, S. S .Nehe& B. Anatharama"Analysis of Effect of Solid Contaminants in Lubrication on vibration response of Ball bearing" International Engineering Research Journal (IERJ) Volume 1 Issue 7 Page 545-549, 2015, ISSN 2395-1621International Engineering Research Journal (IERJ) Volume 1 Issue 7 Page 545-549, 2015, ISSN 2395-1621.

[30] S. Devendiran & Dr. K. Manivannan "Vibration Based Condition Monitoring and Fault Diagnosis Technologies for Bearing and Gear Components" International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 6 (2016) pp 3966-3975.