Acoustic Analysis Using Sound Level Meter to Determine the Period of Usage of the Spindle Bearing of a Radial Drilling Machine

S. CHARLES[(1)], Joslin D. VIJAYA[(2)]*

[(1)] *Department of Mechanical Engineering, SNS College of Technology*
Coimbatore – 641 035, Tamilnadu, India

[(2)] *Department of Mechanical Engineering, JCT College of Engineering and Technology*
Coimbatore – 641 105, Tamilnadu, India
*Corresponding Author e-mail: joslinvijayamech@rediff.com

The condition monitoring techniques like acoustic emission, vibration analysis, and infrared thermography, used for the failure diagnosis of bearings, require longer processing time, as they have to perform acoustical measurement followed by signal processing and further analysis using special software. However, for any bearing, its period of usage can be easily determined within an hour, by measuring the bearing sound, using sound level meter (SLM). In this paper the acoustical analysis of the spindle bearing of a radial drilling machine was performed using SLM, by measuring the sound pressure level of the bearing in decibels, for different frequencies, while muting all the other noises. Then using an experimental set up, two database readings were taken, one for new bearing and the other for completely damaged bearing, both are SKF6207, which itself is the spindle bearing. From these three sets of sound pressure level readings, the period of usage of the spindle bearing, was calculated using an interpolation equation, by substituting the life of the bearing from the manufacturer's catalogue. Therefore, for any machine with a SKF6207 bearing, its usage time can be estimated using the database readings and one measurement on that machine, all with the same speed.

Keywords: acoustical condition monitoring; radial drilling machine; spindle bearing; sound level meter; sound pressure level; sound muting transducer.

1. Introduction

The advancement in technology has brought out several production and maintenance systems in industries, and for preventive maintenance, condition monitoring (SHENG *et al.*, 2011) is the most recently developed technique to carry out the failure diagnosis on various components of all machines. If the machines of a company have to be operated continuously without failure, in order to achieve the maximum production and profit, condition monitoring can provide the best solution. It will detect any defect in a machine at an early stage of failure, so that the defect can be rectified before breakdown, without stopping the production, which will help to avoid the unnecessary machine downtime and maintenance costs. In any machine, the rotating components will be damaged initially, and so it is essential to adopt preventive maintenance using condition monitoring techniques for these components. As all the rotary components of machines will be fit-

ted in bearings, condition monitoring for bearings is considered to be the most important activity in the maintenance system of a company. When the bearings wear out, they produce vibration and noise and so they are generally condition monitored either by using vibration analysis or acoustic analysis. Comparing these two condition monitoring techniques, the acoustic signals can be measured at a distance of one meter from the bearing surface with the help of microphones, whereas for measuring vibration signals the sensors or accelerometers have to be fitted on the surface of the bearing (DEVI *et al.*, 2010). So when the machines are working in an environment of high temperature or humidity, the measuring instrument cannot be fitted on the bearing surface and so it will be possible to perform only acoustic condition monitoring. Therefore, it is suggested that acoustic condition monitoring is very effective and may provide a powerful tool to indicate various types of progressing defects in bearings (YANFANG *et al.*, 2016) and other rotating components

(Popoli, 2000). Measuring the sound pressure level using sound level meter for acoustic condition monitoring of bearings is a very simple and faster method. The SLM will measure directly the sound pressure level of any sound in decibels for various frequencies, transfer the readings in a table, and draw graphs for these readings in computer using software like Delta Ohm Noise Studio software.

The drilling machine (Hajra Choudhury *et al.*, 2013) is indispensable in any industry, as it can do a lot of operations such as drilling, reaming, boring, counter boring, counter sinking, spot facing, tapping, trepanning, undercutting, grinding, lapping, honing, etc. So for obtaining the maximum production in the industry, the drilling machine is to be kept in an optimum working condition, with uninterrupted availability, for the entire life of the machine. The spindle is a rotating component run by the drive motor of the drilling machine through a gear box. The spindle is fitted in two deep groove single row ball bearings and it holds the drill tool to perform the drilling operation. The spindle bearing will be the first to fail in any drilling machine making a continuous knocking and rubbing sound, and so acoustical condition monitoring is performed for this bearing. When the defect in the bearing deteriorates, the sound produced by the bearing also increases proportionately.

In this experimental work acoustical condition monitoring (Senthilraja, Vinoth, 2015) was carried out on the spindle bearing of Kovosvit, a VR4 type radial drilling machine, using a sound level meter and determining the period of usage of the bearing. The life of the bearing is known from the specifications in the bearing manufacturer's catalogue, and so before the bearing fails completely or when it is nearing the end of its life time, the bearing can be changed, whenever there is a regular shutdown in the company or during a holiday, avoiding the unnecessary downtime.

The sound will be produced in three rotating components in a drilling machine and they are the spindle bearing, drive motor, and the gear box. So the sounds from the motor and the gear box have to be muted using a muting transducer and then sound pressure level of the spindle bearing should be measured using the sound level meter (Peterson, 2013). The muting transducer is a noise cancelling device. The microphone used is designed to filter the noise from the desired sound. The electronic circuit generates the anti-noise waveform which effectively negates the input noise waveform. Using the microphone placed near the noise source will yield the best results.

2. Experimental work

The initial task of the experiment was to identify a motor with a speed available in Kovosvit, a VR4 type drilling machine. As almost all the operations are carried out at 1440 rpm in this drilling machine, a motor with this speed was found out. Using this 1440 rpm motor, an experimental setup was fabricated, with the motor shaft coupled to a stainless steel shaft of 35 mm diameter which is the spindle diameter of the radial drilling machine. This assembly was installed in a base frame made with mild steel channels, and two plummer blocks were fitted on the frame to hold the outer races of SKF 6207 ball bearings.

The experimental set up was taken to the industry where the Kovosvit was selected for the experiment to have the same environmental conditions during measurement. Initially two new SKF 6207 ball bearings were purchased and fitted on the shaft of the experimental setup and placed in the plummer blocks. A microphone of the sound muting transducer was fastened on the motor, to cancel the sound from the motor. All the fans and other machines of the industry were switched off and its doors and windows were closed. Then the motor and the muting transducer were switched on and the sound pressure level (Ambekar, 2006) was measured with a sound level meter, keeping it on tripod stand, at a distance of one meter from the bearings. Then the new bearings were removed and two completely damaged SKF 6207 bearings, purchased from a marketplace, were fitted on the experimental setup and similarly the sound pressure level readings were taken.

The two sets of readings taken in the experimental setup, for new and completely damaged bearings, are set as database readings for the SKF 6207 bearing for 1440 rpm. For any machine with a SKF 6207 bearing, running at 1440 rpm, these database values can be used to determine the period of usage of the bearing, by taking only one set of reading on this machine bearing, while muting all the other sources of sound. Figure 1 shows the muting circuit used in the muting transducer.

After the completion of the two sets of readings in the experimental setup, the sound level meter and the muting transducer were shifted to the Kovosvit, VR4 type radial drilling machine, to measure the sound pressure level of its spindle bearing. At the outset, one of the two microphones in the output of the muting transducer was fastened to the drive motor and the other microphone was attached to the gear box. All the fans and other machines in the industry were switched off and their doors and windows were closed. After selecting the spindle speed of 1440 rpm in the drilling machine, the drilling machine and the muting transducer were switched on. Then the sound pressure level of the spindle bearing was measured with the sound level meter, placing it on a tripod stand at a distance of one meter from the spindle bearing. The measurement was taken when the spindle was running at 1440 rpm idly, without performing the drilling operation. All the readings were taken in the one third
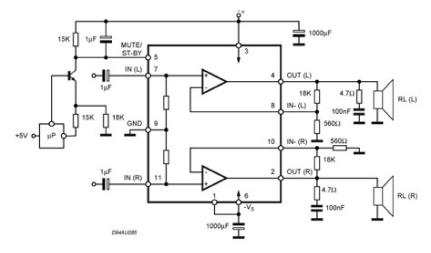
Fig. 1. Muting circuit.

octaves (VEGGEBERG, 2008), as it is more accurate than single octave measurement. In the one third octaves, each of the single octave band is split into three, giving a more detailed description of the frequency content of the noise. The drilling machine with the sound level meter placed on the tripod stand at a distance of one meter from the spindle bearing and the muting transducer with the two microphones fastened one on the motor and the other on the gearbox, and performing the sound pressure level measurement, is shown in Fig. 2.
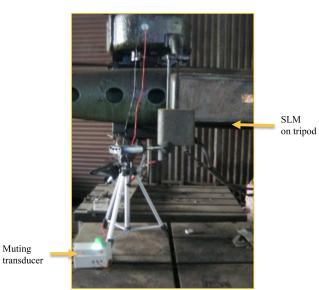

Fig. 2. Acoustic measurement with sound level meter.

The SLM had totally measured three sets of readings, two from the experimental setup and one from the drilling machine, and each set of readings has the sound pressure level in decibels for 31 frequencies ranging from 20 to 20,000 Hz. These three sets of readings were transferred to the computer, and tabulated using Delta Ohm Noise Studio software, and they are shown in Table 1.

Table 1. Sound Level Meter readings.

S. No	Frequency [Hz]	Sound pressure level [dB]		
		New bearing	Completely damaged bearing	Spindle bearing of drilling machine
1	20	25.56	51.14	77.68
2	25	27.61	48.39	72.26
3	31.5	34.92	49.01	65.05
4	40	38.83	52.66	70.02
5	50	43.60	61.06	70.25
6	63	46.27	61.12	63.54
7	80	48.35	60.39	69.15
8	100	49.80	62.40	73.68
9	125	51.92	60.95	77.26
10	160	50.98	62.70	75.46
11	200	58.52	65.44	73.29
12	250	57.11	74.51	75.06
13	315	59.41	75.92	76.71
14	400	64.34	77.90	78.56
15	500	60.42	91.44	84.21
16	630	58.29	93.97	85.52*
17	800	67.98*	102.24	83.53
18	1000	66.32	100.25	79.00
19	1250	64.04	100.90	77.06
20	1600	60.52	101.49	76.97
21	2000	61.32	101.84	76.51
22	2500	62.31	103.18*	76.49
23	3150	60.88	102.24	76.42
24	4000	60.48	101.13	71.84
25	5000	57.87	96.84	71.00
26	6300	51.39	97.12	69.18
27	8000	54.27	93.65	62.65
28	10000	55.69	88.24	56.91
29	12500	58.67	86.18	58.20
30	16000	60.70	86.11	55.03
31	20000	48.82	81.60	57.85

* Peak value.

3. Results and discussions

The column three in the table shows a set of sound pressure level readings of the new bearing, and in the column four, the set of sound pressure level readings of the completely damaged bearing which were obtained from the experimental setup is given. The last column is the set of readings from the spindle bearing of the Kovosvit, VR4 type radial drilling machine.

It could be observed that for each set of readings there is one peak value and the peak values increase proportionately with the period of usage of the bearing. From the three sets of readings in the table the following peak values were obtained:

- Peak value of sound pressure level of the new bearing x_0 = **67.98 dB**.
- Peak value of sound pressure level of the completely damaged bearing x_1 = **103.18 dB**.
- Peak value of sound pressure level of the spindle bearing of the Kovosvit, VR4 type radial drilling machine x_2 = **85.52 dB**.

Using these peak values calculations were performed to determine the number of hours the spindle bearing had been used in the radial drilling machine. From the manufacturer's catalogue, the life of the bearing was found to be six years.

An interpolation equation is used to find the number of years N the particular bearing is used and it is as follows:

$$N = \frac{x_2 - x_0}{x_1 - x_0}L, \tag{1}$$

where x_0 is the peak value of sound pressure level of the new bearing, in decibels, x_1 is the peak value of sound pressure level of the completely damaged bearing, in decibels, x_2 is the peak value of sound pressure level of the spindle bearing of the Kovosvit, VR4 type radial drilling machine, in decibels, L is the life of the bearing in number of years.

Using Eq. (1), the number of years the spindle bearing is used is

$$[(85.52 - 67.98)/(103.18 - 67.98)] \times 6 = \textbf{2.99 years}.$$

The total number of working hours, for the drilling machine per year:

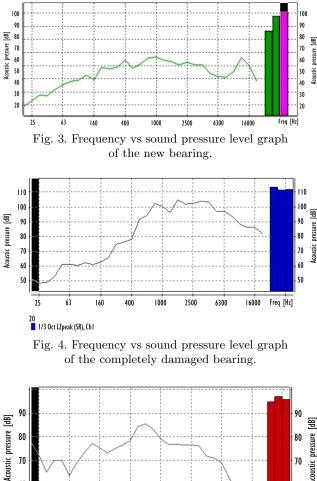[8 hours per day × 300 working days per year (excluding all holidays)] = 2,400 hours.

Therefore, the number of hours the spindle bearing is used makes

$$2.99 \times 2400 = \textbf{7176 hours}$$
$$= 7176 \times 1440 \times 60 = \textbf{620} \times \textbf{10}^6 \textbf{ cycles}$$

(1440 rpm is used for measurement).

Using the three sets of readings in the tables, the following three graphs were drawn with the help of

Delta Ohm Noise Studio software. The three peak values can also be obtained from the graphs shown below.

Fig. 3. Frequency vs sound pressure level graph of the new bearing.

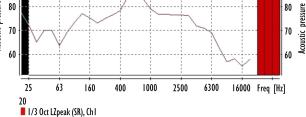Fig. 4. Frequency vs sound pressure level graph of the completely damaged bearing.

Fig. 5. Frequency vs sound pressure level graph of the spindle bearing of the Kovosvit, VR4 type radial drilling machine.

The National Physical Laboratory, India, has provided a service where verification of various parameters regarding the performance of a sound level meter were compared to the requirements of BS 7580. Table 2 shows the uncertainties associated with the use of a sound level meter.

The notation was assumed for corrections associated with: δ_{ad} – the adjustment of the sound level meter during calibration with a sound calibrator, δ_{cal} – the calibration of the sound calibrator, δ_{lin} – the linearity on the sound level meter reference range, δ_{dl} – the linearity on other range settings of the sound level meter, δ_{rms} – the detector characteristics, δ_{res} – correction associated with the resolution of the display, δ_{dir} – the directivity of the microphone, δ_{obs} – the in-

Table 2. Uncertainties of Sound Level Meter.

Quantity	Standard uncertainty, ± dB	Probability distribution	Distribution devisor	Uncertainty contribution, ± dB
δ_{ad}	0.05	Rectangular	$\sqrt{3}$	0.03
δ_{cal}	0.05	Normal	2	0.03
δ_{lin}	0.10	Normal	1	0.10
δ_{dl}	0.17	Normal	1	0.17
δ_{rms}	0.19	Normal	1	0.19
δ_{res}	0.05	Rectangular	$\sqrt{3}$	0.03
δ_{dir}	0.14	Triangular	$\sqrt{6}$	0.06
δ_{obs}	0.20	Rectangular	$\sqrt{3}$	0.12
δ_{case}	0.01	Rectangular	$\sqrt{3}$	0.01
δ_{temp}	0.12	Triangular	$\sqrt{6}$	0.05
δ_{pres}	0.07	Triangular	$\sqrt{6}$	0.03
δ_{mic}	0.10	Normal	2	0.05
	Total			0.87

fluence of the observer, δ_{case} – the sound level meter case, δ_{temp} – variations in ambient temperature, δ_{pres} – variations in ambient pressure, δ_{mic} – the calibration of the microphone.

Suppose if the database readings are taken in an anechoic chamber, the uncertainty readings are to be considered only for the drilling machine readings. Then x_2 = (Machine reading – 1.74) dB. In this experiment all the three sets of readings had been taken in the same environment; the corrections are not carried out. As in the interpolation equation only considers the difference between the readings , the same result will be obtained, even if corrections are done for all readings.

Moreover, field calibrations have to be done for the sound level meter before every measurement is performed. Also, once in two years the sound level meter should be sent to the company, where it was manufactured and the company calibration should be done.

4. Conclusions

From this experimental work it was found that, using sound level meter, the number of hours of usage of a bearing of any machine can be determined, using the peak values of the three sets of sound pressure level readings [(i) new bearing, (ii) completely damaged bearing, and (iii) the bearing used for a certain period]. Once the measurements are taken for new and completely damaged bearings in the experimental setup, they can be stored as a database in a system. At any time these two readings can be retrieved, to find the period of usage of the same type of bearing in any machine, when it is allowed to run at the same speed for which the database readings were taken. With these three sets of sound pressure level readings, the number of hours the bearing had been used till that point of time can be calculated immediately by using the inter-

polation equation. Hence the time required to do the acoustic analysis of a bearing is very much reduced in this method with SLM, and it may take only less than an hour to perform the measurement and the calculation. Therefore, this method is very simple and fast, as compared with vibration condition monitoring, acoustic emission method (ALSHAMMARI, ADDALI, 2015), and infrared thermography method (SEO *et al.*, 2012) for the condition monitoring of bearings. The muting circuit used in this experiment is an existing one, and more powerful circuits can be developed for further improvement.

References

1. AMBEKAR A.G. (2006), *Mechanical vibrations and noise engineering*, Prentice-Hall of India Private Limited, India.

2. ALSHAMMARI F., ADDALI A. (2015), *Bearing condition monitoring with acoustic emission techniques*, International Journal of Mechanical, Aerospace, Indus-

trial, Mechatronic and Manufacturing Engineering, **9**, 12, 2081–2085.

3. DEVI S., SIVA KUMAR L., SHANKER N.R., PRABAKARAN K.A. (2010), *A comparative study between vibration and acoustic signals in HTC cooling pump and chilling pump*, IACSIT International Journal of Engineering and Technology, **2**, 3, 273–277.

4. HAJRA CHOUDHURY S.K., HAJRA CHOUDHURY A.K., NIRJHAR ROY (2013), *Elements of workshop technology*, 6th Ed., Media Promoters & Publishers Pvt. Ltd., Mumbai, India, pp. 239–277.

5. PETERSON A.P.G. (2013), *Handbook of noise measurement*, 9th Ed., GenRad, Concord, Massachusetts.

6. POPOLI W. (2000), *Spindle-bearing basics*, Manufacturing Engineering, **125**, 5, 52–52.

7. SENTHILRAJA C., VINOTH L. (2015), *A review on fault diagnosis of ball bearing using sound and vibration signals*, International Journal of Innovative Research in Science, Engineering and Technology, **4**, 13, 381–393.

8. SEO J., CHOI N., KIM W., HONG D. (2012), *Infrared thermography quantitative diagnosis in vibration mode of rotational mechanics*, Journal of the Korean Society of Non-destructive Testing, **32**, 3, 291–295.

9. SHENG C., LI Z., QIN L., GUO Z., ZHANG Y. (2011), *Recent progress on mechanical condition monitoring and fault diagnosis*, Procedia Engineering, **15**, 142–146.

10. VEGGEBERG K. (2008), *Octave analysis explored*, Evaluation Engineering, **47**, 8, 40–43.

11. YANFANG D., ZUDE Z., MINGYAO L. (2016), *A new model based machine tool spindle bearing preload optimization method*, International Journal of Engineering and Technology, **6**, 11, 416–423.