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Health Monitoring of Surface Wear of TiN and AlCrN Based PVD Coated Bearings Using Statistical Values of Vibration Signals

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Abstract

The main aim of this paper is to emphasize the effectiveness of the statistical parameter based vibration signal analysis in predicting the surface wear of coatings for bearing applications. The suitability of coating materials such as titanium nitride (TiN) and aluminium chromium nitride (AlCrN) for the bearings is tested in this work. Physical vapour deposition (PVD) method of coating is employed since it provides less coating thickness in microns. After running the coated and uncoated bearings in the test rig for certain number of hours, raw vibration signals are captured and decomposed into Intrinsic mode functions (IMF) using Empirical mode decomposition (EMD) technique developed in MATLAB R2013b. Statistical parameters such as rms, skewness, crest factor, kurtosis and impulse factor values are extracted from decomposed vibration signals. These parameters of EMD signals of AlCrN coated bearings showed varying trend as these are very sensitive to the surface wear propagation. TiN coated bearings offered better wear resistance. SEM and EDS analysis are carried out to support the results of vibration signal analysis. Results provide good fault diagnostic information of the worn out surfaces of the coatings using the proposed method, thus improving the condition monitoring capability of the bearing system.

The work had been presented at an international conference ***Fatigue Durability India 2015****, 28-30th May 2015, JN TATA AUDITORIUM, Indian Institute of Science, Bangalore.*

Introduction

Bearings constitute one of the most important parts in machinery. Even with the availability of high quality bearing steel, new alloys and heat treatments, it has not yet become possible to achieve the improved performance of the bearings under the most demanding operating conditions like higher wear and corrosion resistance, non-electrical conductivity, increase in physical rating life etc. Surface engineering is the practice of altering the chemical and/or topographical properties of the surface of a component or device.

Plasma spraying technology is one kind of surface engineering technology which is utilized in almost all industrial fields. A wide range of materials, such as ceramics, cermets, pure metals or alloys and polymeric materials can be deposited by this technique[1-4]. Gold and Loos[5] studied the wear resistance of PVD coatings CrAlN,WC/C,TiAlN,ZrN,ZrC,W-C:H for cylindrical roller thrust bearings and concluded that the main reason for the early failure of the PVD coating on the micro blasted surface was the greater roughness.

Peng and Kessissoglou[6] researched and established a correlation between wear debris and vibration analysis. Wear source assessment was carried out by analysis of chemical composition and particle morphology, which provided information regarding wear mechanism. Vibration data was measured and analyzed in conjunction with wear source analysis, thus utilizing the effectiveness of both the methods. Vibration signal analysis becomes too complex in the presence of faults though they can be measured easily. In this context researchers had to pay attention on signal processing tools such as short time Fourier transform (STFT), wavelet analysis, acoustic analysis etc. J Liu et al.[7] analyzed the wavelet spectrum method for the diagnosis of bearing faults. This technique starts from investigating the resonance signatures over selected frequency bands to extract the representative features. Test results show that this technique is an effective bearing fault detection method, which is especially useful for non-stationary feature extraction and analysis.

Li Guo-lu et al.[8] studied the acoustic emission monitoring and failure mechanism analysis of Fe-based alloy coating for roller bearings. Authors concluded that both AE amplitudes and counts are sensitive to damage degree. And, the variation of the AE amplitudes and counts is different during different fatigue damage stages.

However in the view of enhancing the fault diagnostic information of wear growth in bearing surfaces, advanced signal processing technique viz. EMD method has been considered in the present work. The fourth normalized statistical moment i.e., kurtosis is the major diagnostic index and it has been widely used for detection of rolling element bearing damage [9-11]. The statistical analysis method utilizing parameters such as crest factor, the distribution of moments and kurtosis were used to detect the presence of defects in a rolling element bearing applying sound pressure and vibration signals [12]. Hence, results focused on statistical parameter analysis which provides good fault diagnostic information in bearing system using the proposed method.

Choice of the method

The signal processing method based on Hilbert- Huang Transform is considered a great breakthrough of linear, stationary

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and non- stationary signals. For instantaneous frequency method owning physics sense is not applicable to arbitrary signal except mono component signal, whereas the signals such as nature and engineering field obtained commonly do not satisfy the mono-component signal requirement.

Hence, EMD is needed to decompose the signal f(t) into a series of mono-component contributions designated as IMFs (Intrinsic Mode Function) using a procedure known as sifting process. For example; to decompose a signal f(t) the sifting process is carried out by constructing the upper and lower envelope of f(t) by constructing local maxima and local minima through a cubic spline. The mean of the two envelopes is then computed from the original time history. The difference between the original time history and the mean value c_1 is called the first IMF if it satisfies the following conditions: (i) within the data range, the number of zero crossings is equal or differs by only one and (ii) the envelope defined by local maxima and the envelope defined by the local minima are symmetric with respect to the mean. The difference between f(t) and c_1 is then treated as new time history and subjected to the same sifting process, giving the second IMF. The EMD procedure continues until the residue becomes so small that it is less than a predetermined value of consequence or the residue becomes monotonic function. The original time history f(t) is finally expressed as the sum of the IMF components plus the final residue.

$$f(t)=\sum_{j=1}^{n} c_j(t)+r_n \qquad (1)$$

Where r_n is the residue after the 'n' IMFs have been extracted[13].

Experimental

Preparation of Coatings

Physical vapour deposition method is employed to prepare the coatings of TiN and AlCrN on the outer race of the bearing. The process of depositing materials directly from the vapor phase comprises the methods such as evaporation, sputtering and ion plating. The coated outer race of the bearing is shown in Fig.1.

Figure 1: Bearing outer race coated with TiN

Experimental Test Rig

The test rig employed in this study is as shown in Fig. 2. The test-rig consists of a shaft supported on two bearings. At one end there is self-aligning ball bearing and at the other end there is roller bearing which is to be tested. The roller bearing is tested at constant load of 100 N and at a constant speed 1000 rpm.

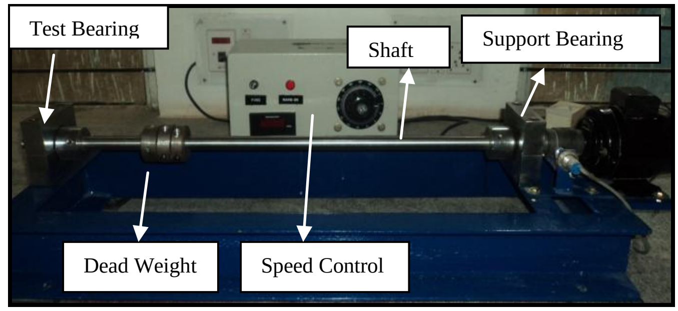

Figure 2: Experimental bearing test rig

The Specifications of the test bearing used in the experiment are listed in Table 1. Uncoated bearing and bearings coated with TiN and AlCrN are run in the test rig for 20 hours at constant speed and constant load to seed the wear condition in them.

Table 1: Specifications of the test bearing

Feature	Details
Bearing type	Roller (SKF N-304)
Number of rollers	10
Outside diameter	52 mm
Inside diameter	20 mm
Pitch diameter	36 mm
Roller diameter	07 mm

Instruments and Sensors

A commercial data acquisition system OROS with 4 channels (model Sl.No-900159) was used to acquire the vibration data from the bearing. B&K 4525 accelerometer is mounted on the bearing housing and used to capture vibration data. The signals are amplified before being fed into a personal computer for further processing.

Results and Discussions

Vibration Analysis

Figs. 3 and 4 depict unprocessed vibration signals from healthy and worn out AlCrN coated bearings. The X-axis in the time domain indicates time in seconds and Y-axis is acceleration in m/s2. The kurtosis values computed from these vibration signals do not reveal any significant diagnostic information.

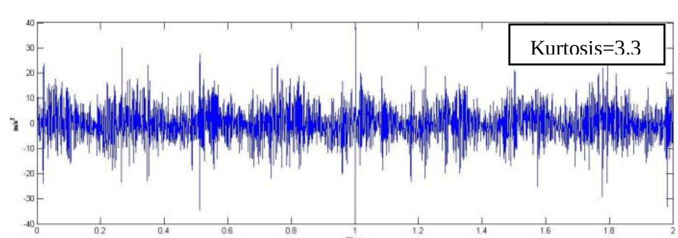

Figure 3: Vibration signals of healthy AlCrN coated bearing in the time domain

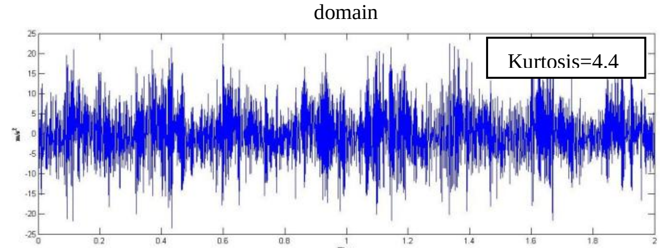

Figure 4: Vibration signals of worn out AlCrN coated bearing in the time domain

Hence, the acquired vibration signals are decomposed into 12 IMFs using EMD method developed in MATLAB R2013b. Intrinsic mode functions after sixth IMF (c_7 to c_{12}) fall below roller pass frequency region and hence these modes have been ignored. Generally higher frequency harmonics encompass fault diagnostic information of roller bearings / gears, because of the presence of roller pass frequencies/ gear mesh frequencies.

The mode function selection is important and it depends on the nature of the signal under investigation. In the present study, the frequency value of first IMF corresponds to one of the harmonics of roller pass frequency. Hence, IMF1 is used to detect and diagnose the fault growth in bearing system.

Table 2: RMS values comparison

Cases	RMS values of Raw signals	RMS values of IMF1 obtained from EMD signals
Healthy Uncoated	4.8854	6.0173
Wornout Uncoated	11.3412	1.7906
Healthy TiN Coated	6.0314	2.8818
Wornout TiN Coated	7.0370	1.9635
Healthy AlCrN Coated	6.6222	2.8124
Wornout AlCrN Coated	8.3785	1.9488

Table 3: Crest factor (CF) values comparison

Cases	CF values of Raw signals	CF values of IMF1 obtained from EMD signals
Healthy Uncoated	4.27799	3.5314
Wornout Uncoated	6.9568	4.7282
Healthy TiN Coated	5.2294	4.091
Wornout TiN Coated	7.7366	5.4804
Healthy AlCrN Coated	5.9345	5.6445
Wornout AlCrN Coated	8.6685	6.5283

The higher order statistical values such as root mean square values (RMS) and crest factor of raw vibration signals under given test conditions are considered for assessment of wear propagation on bearing surface. These are shown in Tables 2 and 3 respectively in comparison with the values of IMF1 of EMD signals. But the values from EMD reduce after decomposition and are found to be less than the raw vibration signal, hence are not suitable for bearing fault detection.

But, only kurtosis values of EMD based method showed better increase in trend as shown in Fig.5, due to sensitivity of this method. Higher kurtosis values are obtained which can be used to detect propagation of bearing faults at the early stage.

It can be observed from Fig.5 that IMF1 shows rapid increase in trend compared to kurtosis values of unprocessed signals as depicted in Fig.3 and Fig.4, because this IMF contains higher harmonics of roller pass frequencies.

SEM and EDS Analysis

The surface morphologies were observed using scanning electron microscope (SEM) for bearing samples which are cut from outer race using slow speed wire electro discharge machining (EDM) process and compositions of worn out coatings were analysed by energy dispersive microscopy (EDS).

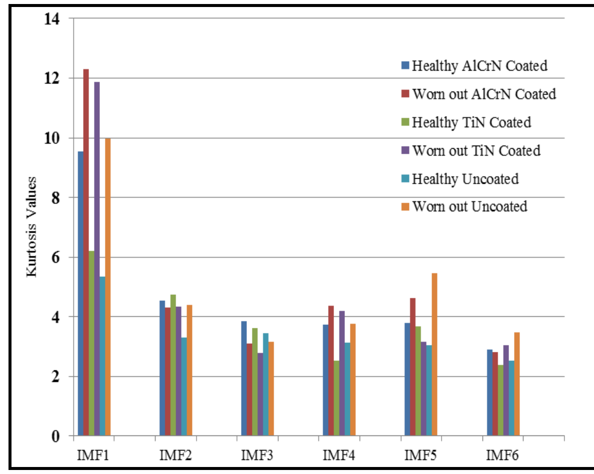

Figure 5: Comparison of kurtosis values of IMFs for different coating cases

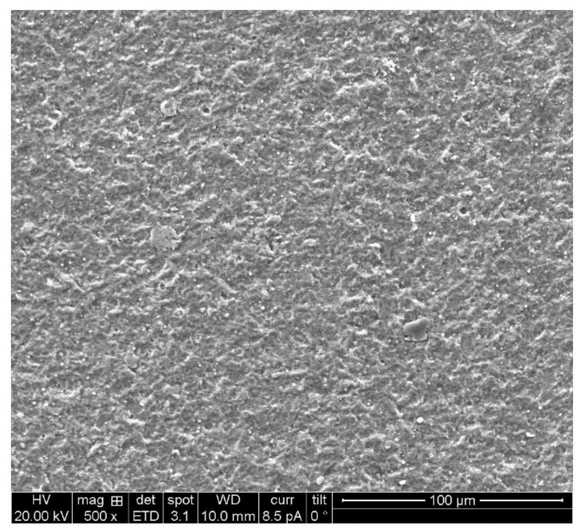

Figure 6: Surface morphology of worn out surface of TiN coated bearing sample

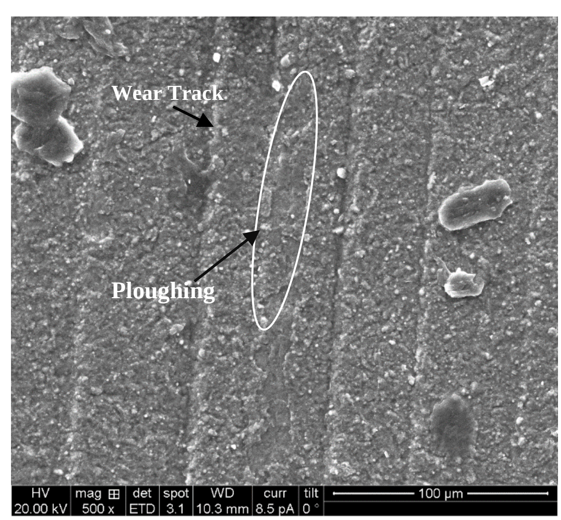

Figure 7: Surface morphology of worn out surface of AlCrN coated bearing sample

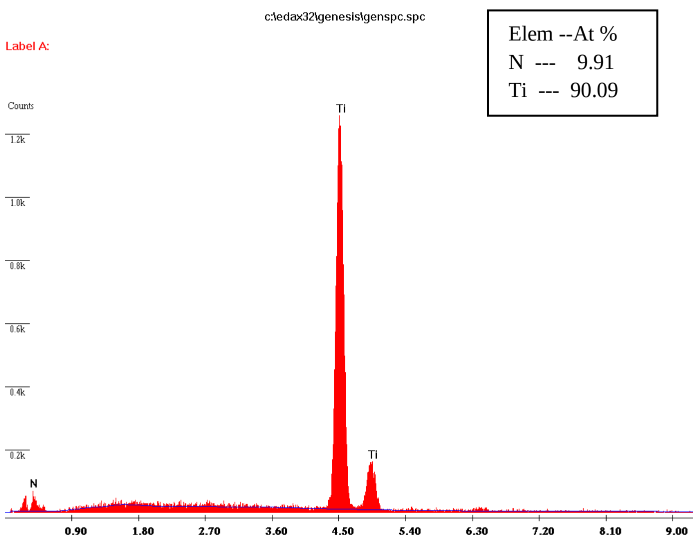

Figure 8: EDS pattern of TiN

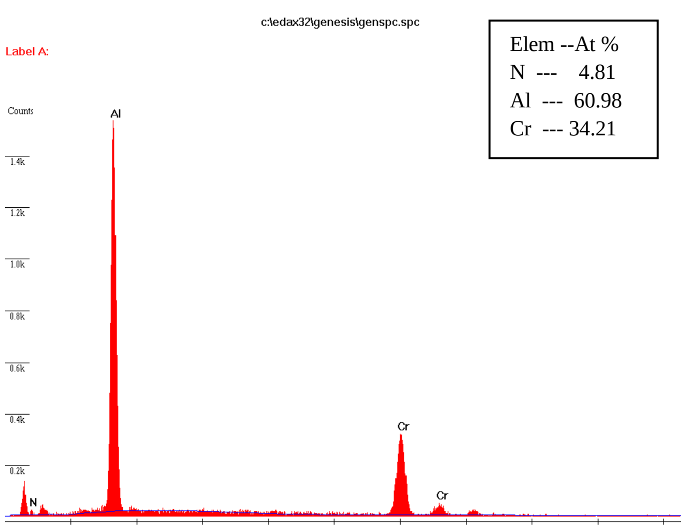

Figure 9: EDS pattern of AlCrN

SEM Morphology for AlCrN clearly shows that wear tracks are formed on the coating surface and also ploughing took place on surface at certain places as shown in Fig.7 compared to morphology of TiN surface Fig.6 .It is basically because of the reason that Al content is more in the coating as it is evident from EDS pattern shown in Fig.9. It offered very less wear resistance and it was also evident from rapid increase in kurtosis values of AlCrN coated bearings in vibration analysis. EDS pattern of TiN as shown in Fig.8 depicted that the content of Ti is much more than that of element N.

Conclusions

1. Initially, kurtosis values of unprocessed vibration signals have been extracted to obtain bearing fault severity information. But kurtosis values of these vibration signals failed to show the rapid increasing trend along with wear propagation.
2. The higher order statistical values such as root mean square values (RMS) and crest factor of raw vibration signals and EMD signals are extracted. These values from EMD method are found to decrease because of decomposition process inherent in the method. Hence, these parameters are not considered for wear diagnostics.
3. EMD based method has been used to extract kurtosis values from the vibration signals. Kurtosis values of first intrinsic mode c1 of EMD based method reveal reliable diagnostic information of wear propagation on bearing surface and it provides comparatively much higher kurtosis values than unprocessed method, hence these values are considered as better ones in assessment of distributed faults in bearing system.
4. SEM analysis revealed that more wear tracks and surface damage occurred in AlCrN coated surface compared to TiN coated bearing surface. It is used in conjunction with vibration signal analysis.

References

1. Satish Tailor et al., Journal of Mat. Sc. & Sur. Engg, 2013,Vol. 1(1), p 15-22.
2. Satish Tailor et al., Trans. of the Indian Institute of Metals2015,. (In press)
3. Satish Tailor et al., Surface Engineering, 2014. (Online first published), Maney Publication.
4. Satish Tailor et al., Journal of Thermal Spray Technology. 2014. Vol. 23, Iss 7, pp 1081-1088.
5. P.W. Gold, et.al. (2002) Wear,465–472.
6. Peng Z,et.al (2002) Wear 1221–32.
7. Jie Liu, et.al (2008) Meas Sci Technol 015105 (9pp)
8. Li Guo-lu, et.al (2013) Trib Int 129–137.
9. D. Dyer, et.al (1977) Design Engineering Technical Conference of ASME.
10. R.B.W. Heng, et.al (1998) Int Applied Acoustics 21 l-226.
11. Sylvester A. Aye, et.al (2011) Proceedings of the World Congress on Engineering 2011, London, U.K.
12. R.B.W. Heng,et.al (1998) Int *Applied Acoustics* pp. 21 l-226, 1998.
13. Huang NE, et.al (1998) Proceedings of the Royal Society of London 903–95.