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CONDITION MONITORING AND FAULT DIAGNOSIS OF POWER TRANSMISSION SHAFT USING VIBRATION SIGNATURE ANALYSIS

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***Abstract** - The objective of the work was to investigate using statistical tool for data interpretation for shaft condition monitoring conducted by experimentally. The developed methodology termed vibrating sensor and signal processing based on Taguchi's method in order to reduce the cost and faster diagnosis of fault. Using advanced signal processing method for identifying faults on shaft such as location fault, severity fault, loading condition and slip magnitude. The all fault introduce experimentally and monitoring the current signals. Results show only location of fault and severity of fault main parameters effect on increasing amplitude leading to damage and also confirmed by ANOVA. The influence of two parameters at a time on both frequency and amplitude are plotted on contour plots, which show clear joint contribution of two parameters.*

***Keyword:** Frequency, amplitude, Taguchi, ANOVA, condition monitoring*

I. INTRODUCTION

The health condition of the machine components can be investigated experimentally by using vibration signal analysis at specific frequencies [1]. The development of such novel technologies is fuelled in advanced industries such as aerospace, space, marine etc [2]. Shaft miss-performance such as crippling, wobbling and unbalancing is influencing the performance of compressor and turbine power flow. The miss-performance due to misalignment [3], shaft fatigue, overloading, unbalancing, poor lubrication and meting parts. There is urgent need to find the specific fault in shaft, their failure modes, plan to prevent the failure and online maintenance efforts [4-5]. More than 40% machines are failed directly or indirectly due to shafts performance. Hence this study was focused on preventive maintenance of shafts.

In other hand, premature failures due to electrical power problems [6-7] like: poor power quality, resistance unbalance, impedance unbalance insulation failure, excessive Loading / current and overheating [8-10]. Detecting, correcting and predicting the above conditions are very important to improve the life of the machine components and even their noise and vibration. Some time, there is confusion between the electrical and mechanical system noise hence essentially classification is required between them [11]. for example among the mechanical sources , shafts [12], various siren effects, rebounding of brushes etc. Similar mechanical sources of noise also apply to non-electrical machines. Electro-dynamic unbalanced forces generate specific frequency of vibration significantly high in the machine components. Such vibration is especially seen when the motor is supplied by electronic rectifiers [13].

Many industries reported successful monitoring systems particularly paper [14], metal [15] and chemical manufacturing lines. Some industries developed condition monitoring for compressors [16], ball-bearings [17] gear-box, even spindles of lathe [18] etc. Predicting failure of machine components is more essential task in industries to improve production along with life of the components. Taguchi technique is one of statistical tool and it reduces the experimental trails drastically, and could be used online or off-line to predict sensitivity of the faults under investigation. The objective of the research work was to investigate condition monitoring and faculty detection of power transmission shaft based on the signal processing technique using Taguchi technique.

II. EXPERIMENTAL STUDIES

In order to predict or diagnose the fault of power transmission shaft with higher accuracy, the line diagram of test set up shown in Fig. 1. The experimental setup consists of DC motor of 0.5 hp coupled with gear box, tested shaft belt brake dynamometer, vibration pick-up (piezoelectric), data acquisition and computer with MATLAB software. The constant speed maintained throughout experiments and experimental parameters are given in the Table 1.

Table 1. Parameters of experimental induction motor

Level	Parameters			
	Fault location	Severity fault	Loading condition	Slip
1	0.25	0.5	0.25	0.00
2	0.50	1.0	0.50	0.20
3	0.75	1.5	0.75	0.40
4	1.00	2.0	1.00	0.60

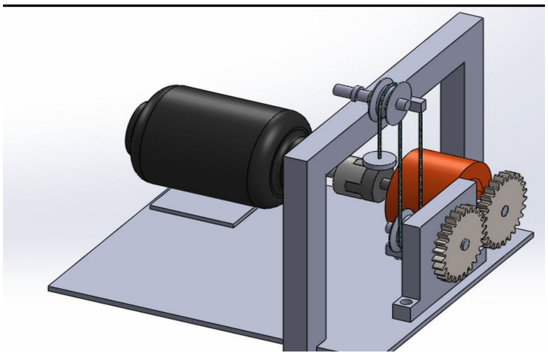

Fig. 1 Experimental setup

III. DESIGN OF EXPERIMENTS

In this research work, Fault location, severity of fault, loading condition and slip were considered to determine their effect on the performance of the shaft by means of frequency as well as amplitude of the vibration signals. To conduct full factorial it needs 256 experiments, which increases both cost and time of the experiments. Hence, Taguchi technique was used to reduce the number of experiments process. Also it gives signal-to-noise (S/N) ratio based on the experiments data. S/N ratio was used for optimization of experiments.

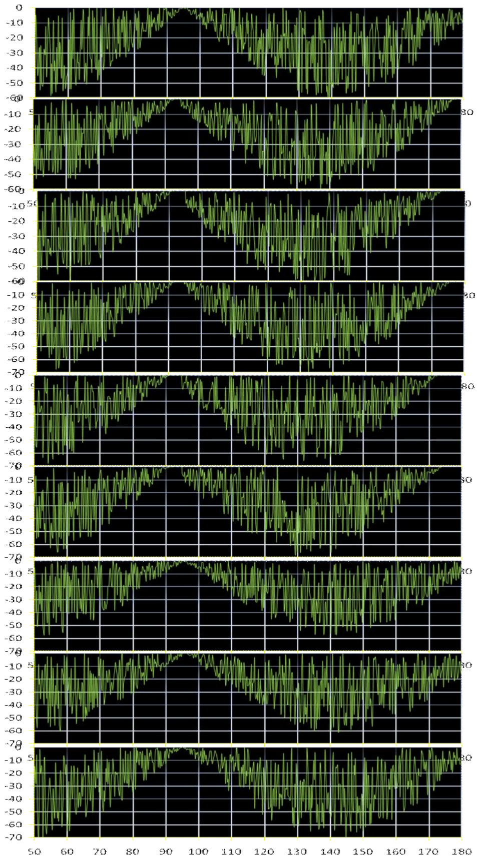

Fig. 2 Power spectrum of fault shaft with various fault given in Table 2

Table 2. The vibration test results

Exp	A	B	C	D	Fre	Am
1	0.25	0.5	0.25	0.0	68	75
2	0.25	1.0	0.50	0.2	60	68
3	0.25	1.5	0.75	0.4	168	74
4	0.25	2.0	1.00	0.6	160	68

5	0.50	0.5	0.50	0.2	187	76
6	0.50	1.0	0.25	0.6	170	70
7	0.50	1.5	1.00	0.0	29	76
8	0.50	2.0	0.75	0.2	23	72
9	0.75	0.5	0.75	0.6	108	74
10	0.75	1.0	1.00	0.4	97	68
11	0.75	1.5	0.25	0.2	129	73
12	0.75	2.0	0.50	0.0	123	71
13	1.00	0.5	1.00	0.2	29	69
14	1.00	1.0	0.75	0.0	23	67
15	1.00	1.5	0.50	0.6	108	69
16	1.00	2.0	0.25	0.4	97	65

In this study was aimed to predict the fault using vibration signals. The amplitude is obtained by the experimental vibration signals. Fault location, severity of fault, loading condition and slip were considered as control factor with three levels show in Table 2. A Taguchi L16 orthogonal array design was used.

IV. RESULTS AND DISCUSSION

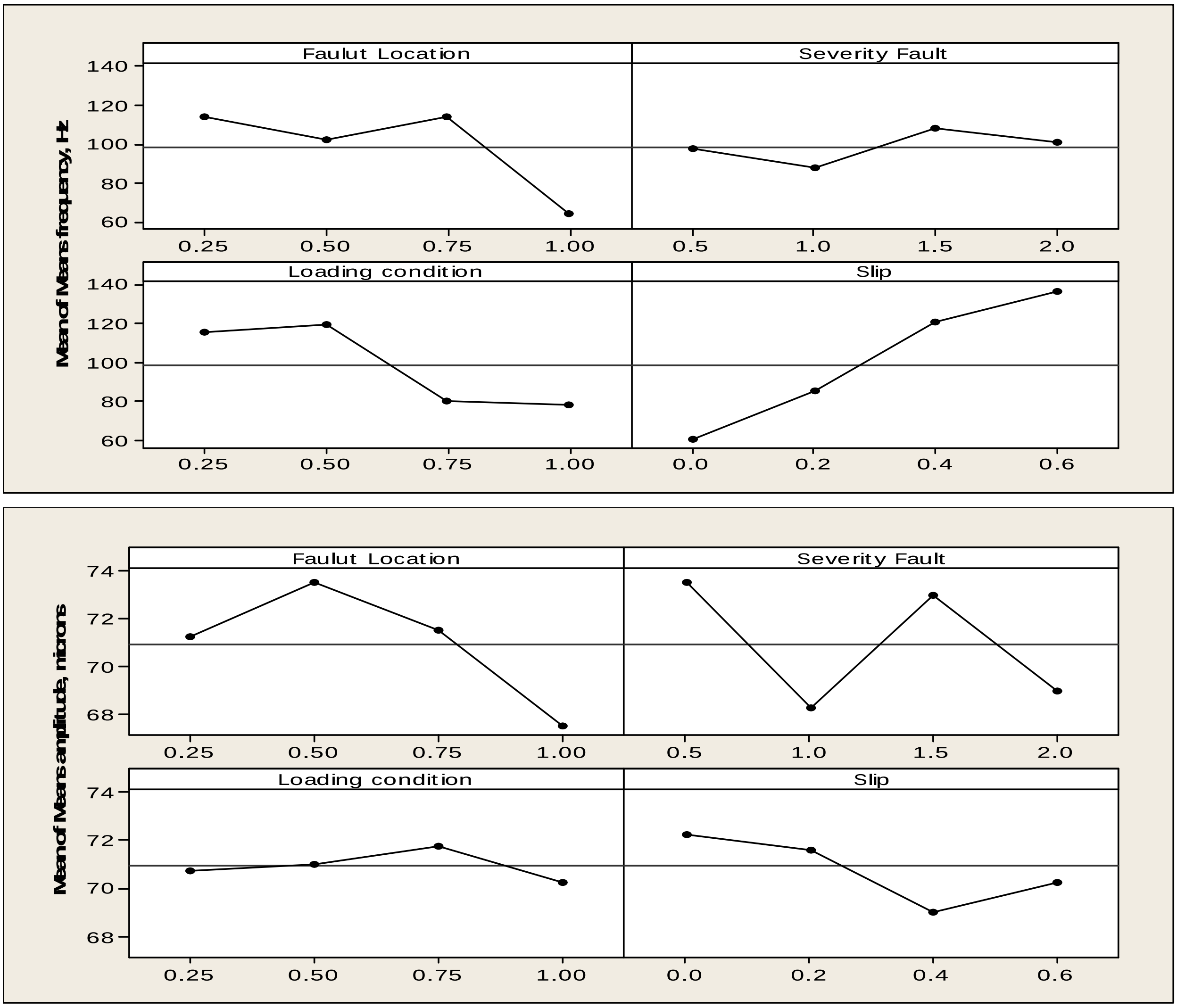

Fig. 3. Effect of type of fault on a) frequency and b) amplitude of vibration signals

The power spectrum of healthy shaft is obtained and analyzed, (Fig. 2). The four type of defects with four magnitude were introduce to shaft for conducting experiments. All defective shafts generate air gap with mechanical vibrations. This gap causes change in power spectrum of the signals due to fault location, severity of fault, loading condition and slip with various conditions by conducting experiments. The few obtained spectrum are given in Fig. 2. The spectrum of defect shaft with 0.25 fault location (experiment-1) shows the fault frequencies at 72, 156 and 162 Hz and the amplitude -70 to – 76 dB. Fig. 2 shows the amplitude as function of frequency, the frequency plots shows clearly various fault conditions, electrical current and voltage; power graphs did not show significant clearance between the faults conditions. The voltage curves fluctuating due to experienced sharp power supply. Higher peak amplitude attained at lower frequency which leads to quite small spectra. Shaft fault parameters influence on frequency and amplitude of vibration signals are given in the Fig. 3. The optimal parameters levels of each fault type could be seen in the Table 1 and Fig. 3(a) and 3(b). The mean of mean of each fault parameters have been calculated by using of arithmetic mean at respective levels. Easily it identifies the severity in both frequency and amplitude curves. Especially, the amplitude curves give correct identification of severity. The midpoint fault location (0.50) shows severity in amplitude at lower frequency. 0.5 severity fault, 75 % load and 0 slip shows severe amplitude error. In other hand, the frequency lower at 1.00, 1.00, 1.00 and 0.0 of location fault, severity fault, loading conditions and slip respectively. Experimental studies indicate that the prediction of condition monitoring had improved, which was in agreement with previous results [19]. The fault location and severity fault main contributor of premature failure of machine parts, which also confirmed in ANOVA investigation shown in next session. Both loading conditions and slip has very less effective towards the vibration magnitude. Even higher load the amplitude of signal is much lower than that of other loading conditions. The weight age of each parameter was discussed in ANOVA results.

Table 3 Analysis of variance for frequency using adjusted SS for the experiments

Source	DF	Seq SS	Adj SS	Adj MS	F	%P
Fault Location	3	6701	7879	2626	0.50	14.3
Severity Fault	3	905	1584	528	0.10	1.9
Loading condition	3	5845	8800	2933	0.56	12.5
Slip	3	17571	17571	5857	0.12	37.6
Error	3	15724	15724	5241		
Total	15	46746				

The Fisher's (F) values for fault factors are given in Table 2 and Table 3 for frequency and amplitude response respectively. High effective influencing factors are fault location and severity fault on the amplitude response. But slip dominants on frequency responses and there is no contribution to amplitude. The 'F' value was computed for each fault parameters. The obtained value of F < 1 was less than the given values (Table 2), hence these parameters less significant influencing parameters to frequency responses. In other hand in amplitude Table 3 the F values much more than that of 3.0, hence all parameters are influencing on amplitude parameters. The F values have 99.5% confidence level. Thus, based on the % of contribution (%P) of fault factors of only D (37.6%) were significant while the factors A (14.3%), B (1.9%) and C (12.5%) were less contribution towards frequency response. On other hand factor B has 49.3 % contribution followed factor A (42.5 %), D (5.4 %) and C (2.6 %) towards amplitude response.

Table 4. Analysis of variance for amplitude using adjusted SS for the experiments

Source	DF	Seq SS	Adj SS	Adj MS	F	%P
Fault Location	3	75.188	71.887	23.962	301.93	42.5
Severity Fault	3	87.187	83.887	27.962	352.33	49.3
Loading condition	3	4.687	7.42	1.573	19.98	2.6
Slip	3	9.637	9.637	3.212	40.48	5.4
Error	3	0.238	0.238	0.079		
Total	15	176.93				

Fig. 4 and Fig 5 show the two factor affecting at time on frequency and amplitude respectively during vibration tests. Fig. 4(a) shows fault location and severity fault on frequency. It shows three concentric circles, dark circle shows maximum frequency and light green lower frequency. The maximum frequency could be seen at fault

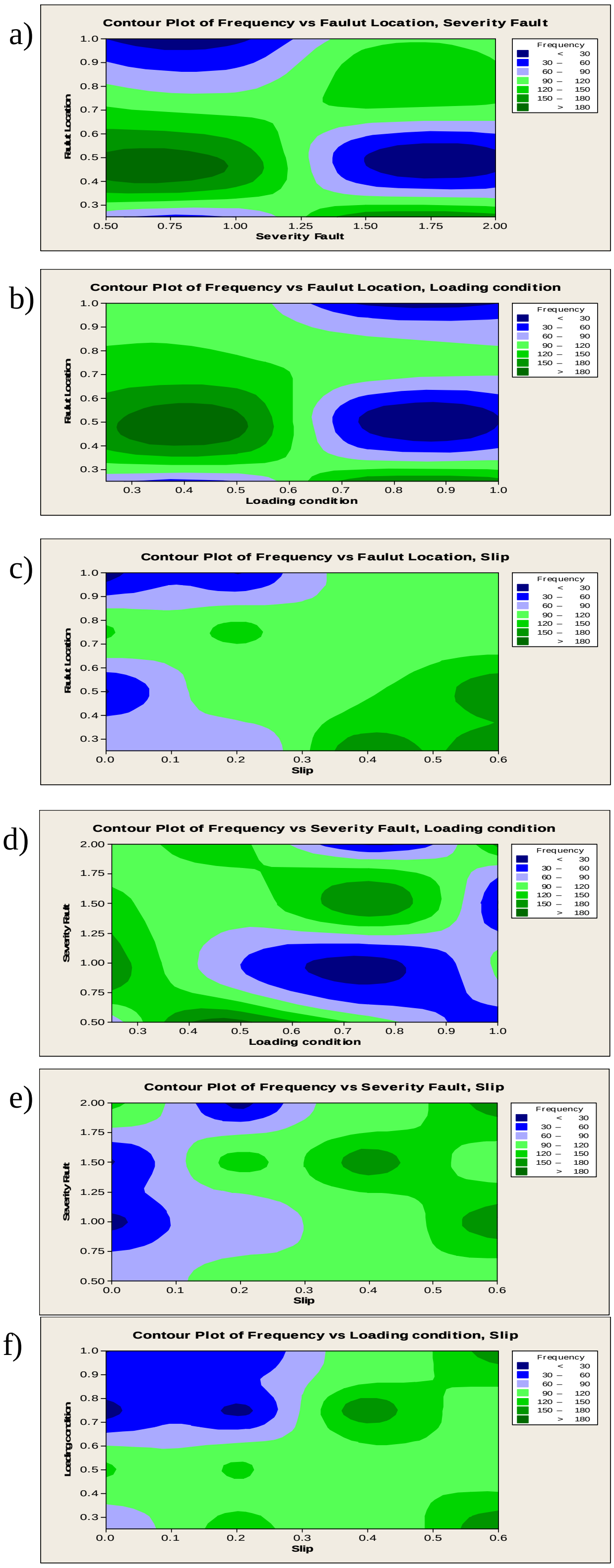

Fig. 4 Control plots for frequency response

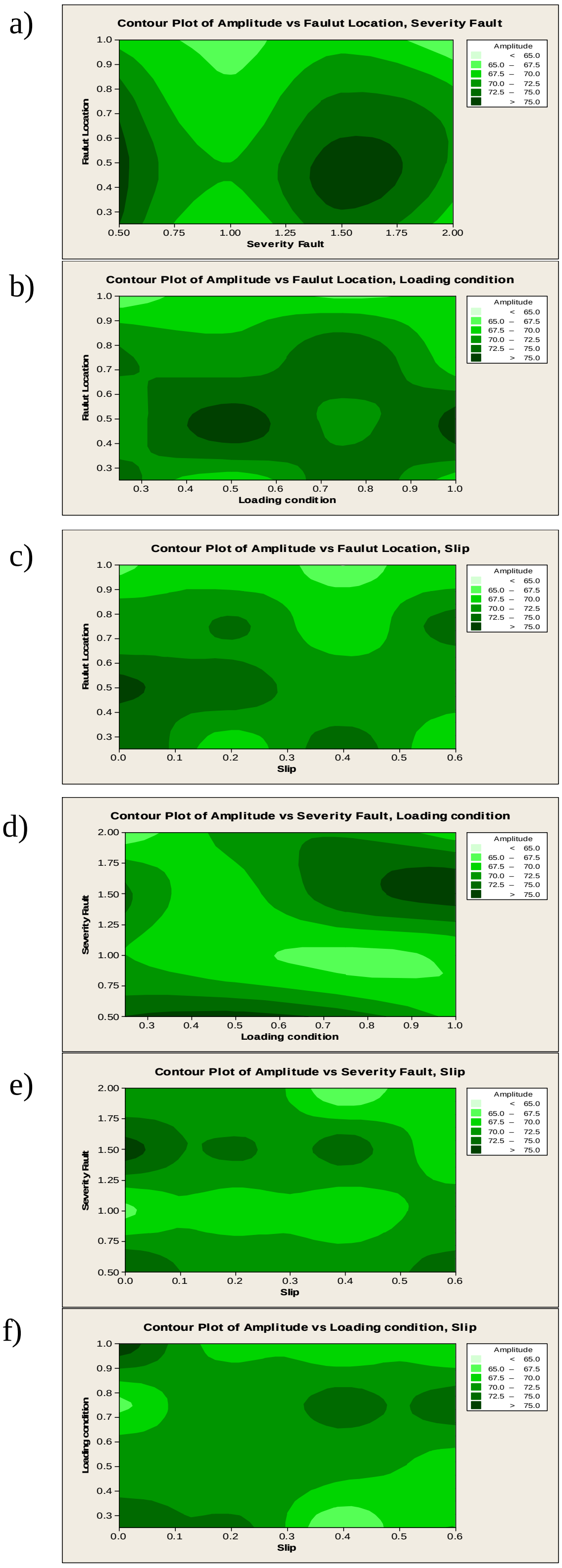

Fig. 5 Control plots for amplitude response

location 1 (at bottom) and severity at 1.75. It helps to identify both fault location and severity fault for any desired frequency from the graph. Similarly Fig. 4(b) shows fault location and loading conations on frequency response. Lower value of fault location and higher values of loading conditions are influencing on frequency response. Fig. 4 (c) both fault and slip do not affect on frequency hence the graph almost green colour. Fig. 4 (d) shows loading condition of 0.7 and severity fault of 1.00 shows maximum frequency response (dark blue colour). Fig. 4(e) shows the severity fault at 1 showing maximum but a very small region. Loading condition of more than 0.7 is more effective but 0.78 is more severe as shown in Fig. 4(f).

Fig. 5 (a) shows control plots of fault location and severity fault are influencing on amplitude responses. Fault location of 0.5 and severity fault of 1.50 show maximum amplitude responses. There is one full concentration circle and one semi concentration circles shown at different location of severity but same fault location of 0.5. The similar trend of fault location but different loading conditions of 0.5 is shown in Fig. 5(b). Fig. 5(c) shows that various region of amplitude from higher amplitude region to lower amplitude response regions. Fig. 5(d), (e) and (f) show no significant effect on amplitude response.

V. CONCLUSIONS

The research work was focused to develop an intelligent system for the condition monitoring for power transmission shaft using MAT LAB and statistical method (Taguchi and ANOVA). The developed methodology allows investigation influence various parameters on frequency and amplitude response. The Taguchi methodology allowed the verification of different fault parameters on change of frequency and amplitude responses of shaft vibration. The contour plots showed more clarity about parameters influencing on amplitude and frequency responses.

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