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Detection of Gear fault using vibration analysis

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Abstract - The new generation of condition monitoring and diagnostics systems differs by the detailed solution of diagnostic problems that allows making a step from machine vibration state monitoring to the monitoring of the machine technical condition. Most rotating machine defects can be detected by such a system much before dangerous situations occur. It allows the efficient use of stationary on-line continuous monitoring systems for condition monitoring and diagnostics as well. A real-time system for condition monitoring of Gearbox can reduce expenses of maintenance of it used in industry. It is based on vibration signature analysis concept using the vibration information as acquired from the various bearing locations of a Gearbox. The aim of vibration monitoring is the detection of changes in the vibration condition of the object under investigation during its operation. The cause of such changes is mainly the appearance of a defect. The vibration measurements can be conducted without any change in the operation mode of the object The objective of this paper is to detect the fault in Gearbox by the interpretation of vibration data and spectrums. The spectrums shows the fault in Gearbox when Gearbox is operated at different Gears on full loads.

Keywords - Vibration Analysis, Spectrums Before breaking (BB) ,After breaking (AB), Gear Drive end(GDE), Gear Non Drive end (GNDE).Motor drive end (MDE) Motor Non drive end (MNDE)

I. INTRODUCTION

The monitoring of a Gearbox condition is a vital activity because of its importance in power transmission in any industry. Techniques such as wear and debris analysis, and acoustic emissions require accessibility to the Gearbox either to collect samples or to mount the transducers on or near the Gearbox. Vibration analysis is one of the most important condition monitoring technique that are applied in real life. Most of the defects encountered in the rotating machinery give rise to a distinct vibration pattern (vibration signature) and hence mostly faults can be identified using vibration signature analysis techniques. Vibration Monitoring is the ability to record and identify vibration "Signatures" which makes the technique so powerful for monitoring rotating machinery.Vibration analysis is normally applied by using transducers to measure acceleration, velocity or displacement. The choice largely depends on the

ration covers region

measure of absolute position, covers frequencies from 0 up to 200Hz. The signals are normally processed and stored using spectrum analysis methods which takes incoming signal and breaks it into its individual frequencies by using Fourier analysis. It relies on the ability to link particular frequencies to particular components such as bearing or Gears. However, spectra generate large volumes of information which requires expert staff or software to interpret them.

II. HISTORY

The use of vibration analysis as one of the fundamental tools for condition monitoring has been developed extensively over a period of approximately 50 years. With the parallel developments in electronic equipment, transducers, computers and software nowadays machine supervision is almost completely automated. From 1960 to the mid 1970s simple practical methods were used, along with careful watch on the machine's behavior, often

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reinforced by frequent maintenance.. This required highly skilled and experienced maintenance staff to ensure efficient operation and to avoid catastrophic failures.

During the 1970s there were basic developments in analogue instrumentation and mainframe computers. Several accelerometers, velocity transducers and displacement pickups were developed and adapted to the requirement of industrial applications Onboard microprocessors gave instruments the ability to capture data, analyze it via suitable algorithms, then store and display the information. A very significant feature of frequency analysis was efficient computation of the FFT (Fast-Fourier-Transformation) of multi channel measurements within seconds respectively minutes and the ability to store data for further decisions. Long-term data storage became an accepted practice.From the mid 1980s onwards the developments have been associated with the desktop computer, its interfaced equipment and software. Many manufacturers have produced hand-held instruments for the instant measurement, recording and analysis of variables.

The 1990s are characterized by minimizing the instrumentation and the data acquisitions and data process units. At the mid of the 1990s the remote monitoring was initiated with central control units to interlink the knowledge and experiences of customers, the machine manufacturer and liability insurance companies. In contrast, early condition monitoring systems relied on a few experts having specialist knowledge of the instrumentation and analysis techniques.

While vibration analysis was used former mainly to determine faults and critical operation conditions. Nowadays the demands for condition monitoring and vibration analysis are no more

frequencies being analyzed. □Accele
from 0 up to and beyond 20kHz.□Velocity covers
frequencies typically from 2 Hz to 2kHz.□Displacement, a

limited trying to minimize the consequences of machine failures, but to utilize existing resources more effectively. This paper describes the practical aspect of vibration phenomena and the measurement requirements of a general monitoring system consisting of data collection with data reports in digital manner, followed by the acquisition of the vibration values for faulty and good Gears.

III. LITERATURE REVIEW

Most modern techniques for Gear diagnostics are based on the analysis of vibration signals picked up from the Gearbox casing. The common target is to detect the presence and the type of fault at an early stage of development and to monitor its evolution, in order to estimate the machine’s residual life and choose an adequate plan of maintenance. It is well known that the most important components in Gear vibration spectra are the tooth meshing frequency and its harmonics, together with sidebands due to modulation phenomena. The increment in the number and amplitude of such sidebands may indicate a fault condition. Moreover, the spacing of the sidebands is related to their source [1]. The simple spectral analysis is generally unable to detect Gear failures at an early stage; for this reason, many researchers have proposed the application of other vibration analysis techniques for the early detection of fault symptoms. The aim of this paper is to assess and compare the detection and diagnostic of Gears, on the basis of experimental results. Cepstral analysis has been widely applied to Gear monitoring.

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The cepstrum is well suited for the detection of sidebands in vibration spectra and for the estimation of their evolution during Gear life. In addition, since the cepstrum estimates the average sideband spacing over a wide frequency range, it allows very accurate measurement of the sideband periodicity. It is therefore applicable to both detection and diagnosis of Gear faults[1-3]. The amplitude and phase demodulation of one of the tooth meshing harmonics is a well known Gear monitoring technique [4, 5].

This technique requires the time synchronous averaging of the vibration signal in order to remove any periodic events not exactly synchronous with the Gear of interest and to reduce the effects of noise and vibration sources other than Gear pairs [1, 4]. The averaged signal is then band pass filtered around one of the larger meshing harmonics and the amplitude and phase modulation are obtained by means of a procedure based on the Hilbert transform. The cyclo stationary process theory has been recently applied to Gear monitoring. In particular, the Spectral Correlation Density (SCD) function of Gear vibration indicates the correlations between meshing harmonics and their sidebands [6, 7], that are just the spectral characteristics primarily affected by Gear faults. Thus the SCD function permits Gear fault detection and identification of the damaged element. Local faults in Gears (e.g. crack in a Gear tooth) produce impacts [1]. As a result of this excitation, transient modifications of vibration signals may be observed. Therefore, the vibration signal can be considered as non-stationary. However, most of the widely-used signal processing techniques, are based on the assumption of stationarity and globally characterise signals. Thus they are not fully suitable for detecting short-duration dynamic phenomena; as a matter of fact, the time-localization of transient events is impossible. On the other hand, the application of time-frequency distribution techniques - such as Wavelet Transform (WT) - is highly suitable [8-10]. By means of this time-variant method it is possible to detect and localize the presence of cracks in Gears. In this paper, spectrum analysis techniques are applied to experimental vibration data, concerning a Gear pair affected by crack at the root of one of the teeth. The capability of fault detection and diagnosis are discussed and compared; in particular, the fault severity is assessed by considering two different Gear defects. Gear box is run at second and third Gear which are faulty Gears. The effect of choosing different transducer locations and different processing options are also shown.

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IV. EXPERIMENTAL SETUP

The experimental set up consists of a four pole three- phase induction motor coupled to a 4-speed automotive Gearbox. The coupling used is a shaft coupling. The input speed of the Gearbox is the mechanical speed of the induction motor. Induction motor is also connected to dimmer stat which controls the power to the motor by varying the input voltage which further drives the Gearbox output shaft. Then there are current probes to measure the current response. Voltmeter and an Ammeter are used here for measuring voltage and current readings.

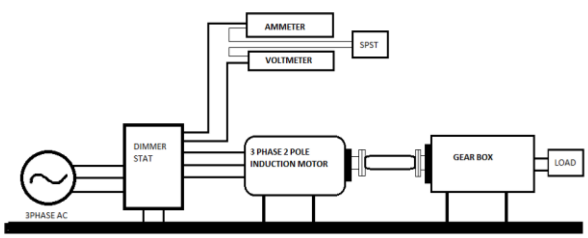

Fig 1: Schematic diagram of Experimental setup.

Description of various parts of the experimental setup is as follows:

Three Phase Induction Motor

The motor has the following Configuration, Make : Siemens
Rated Power : 1.48 kW.
Rated Speed : 1440rpm Frequency : 50 Hz.
Voltage : 440 V.
Current : 0.5 A.

Dimmer Stat

Connection for Max output voltage to input equal

Input at A1 A2 A3 415 3ø -50/60HZ
V- Output at E1 E2 E3 0-415 Volts

Connection for Max output voltage higher than input

Input at B1 B2 B3 415 3ø -50/60HZ
V- Output at E1 E2 E3 0-470 Volts
Output current 15amp per line

4.3. Gearbox

Fig 2: DIMMER STAT used in the experiment

The DIMMER STAT used in the experiment has the following configuration

Type : 15D-3P
Max KVA : 12.211

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A Gearbox or transmission provides speed and torque conversions from a rotating power source to another device using Gear ratios. The most common use is in automobiles where the transmission adapts the output of the internal combustion engine to the drive wheels. Such engines need to operate at a relatively high rotational speed, which is inappropriate for starting, stopping, and slower travel. The transmission reduces the higher engine speed to the slower wheel speed, increasing torque in the process. The Gearbox used in the experiment is a 4-speed manual transmission automotive Gearbox is shown in fig 3.

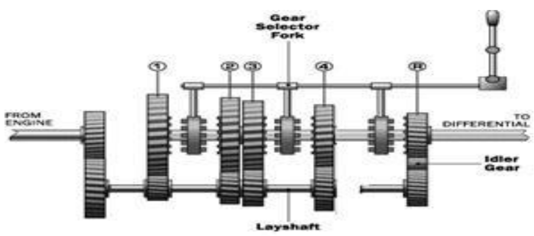

Fig.3: 4-speed manual transmission Gearbox

4.4: Shaft coupling

Shaft coupling is a coupling used to connect two rotating shafts of different diameters. The shaft is connected to one end at the motor and the other end at Gearbox.

Fig.4: shaft coupled to motor and Gearbox

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Assembly of Motor & Gear box

The setup was placed on a Cast iron rectangular block. Induction motor and Gearbox were connected on the rectangular block. Channel was used for placing the 3- phase induction motor so that the motor and the Gearbox are properly aligned with each other. Both the motor and Gearbox are coupled by a shaft so that the Gearbox is fixed completely and does not vibrate during high rotational speeds. Loading arrangement is done with a pulley connected to spring balances at Gearbox output shaft.

Fig 5: The Final fabricated set-up.

FFT Analyser:

Sendig model 911 with McMe 2.0 Software

Fig.6: Fast Fourier transformer

Fig.7: Gears before removing teeth.

V. EXPERIMENT PROCEDURE

The basic aim of the experiment was to detect the Gear fault . For this the arrangement was done and the motor connected to Gearbox made to run at constant motor speed which was controlled by the dimmer stat. output shaft of the Gearbox is connected with springs loads. Readings were taken for the 4 different Gears on full load around 4 kg on the normal Gearbox and then 2 teeths are removed from the 2nd and 3rd Gears by using gas welding Again readings are taken for the 4 different Gears at full loads.i.e 4 kgs. The results are given in the table below:

Fig.8: Gears after removing teeth

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1st Gear

S.NO	Direction	Parameters	MNDE		MDE		GDE		GNDE	
			B.B	A.B	B.B	A.B	B.B	A.B	B.B	A.B
1	HORIZONTAL	Acceleration	144	34.5	12.6	51.1	39.4	196	45.2	183
		Velocity	21.4	10.8	26.4	21.5	28.9	18.6	15.0	120
		Displacement	416	134	484	224	484	4769	145	6819
2	VERTICAL	Acceleration	11.4	39.9	9.40	22.5	24.0	176	40.2	287
		Velocity	4.40	13.2	11.9	24.3	7.34	20.9	19.1	191
		Displacement	51.0	95.2	187	191	95.8	131	31.8	7925
3	AXIAL	Acceleration	18.3	67.9	16.4	32.0	40.6	70.2	17.1	75.2
		Velocity	9.33	16.6	13.9	17.7	61.0	24.5	28.2	12.5
		Displacement	150	129	219	169	1077	214	506	273

2nd Gear

S. No	Direction	Parameters	MNDE		MDE		GDE		GNDE	
			B.B	A.B	B.B	A.B	B.B	A.B	B.B	A.B
1	HORIZONTAL	Acceleration	9.87	54.9	18.7	55.8	59.4	250	42.9	197
		Velocity	19.8	10.2	16.3	17.2	14.9	25.8	14.1	207
		Displacement	352	129	306	245	249	288	327	2501
2	VERTICAL	Acceleration	10.9	42.3	8.71	20.9	31.5	178	35.2	275
		Velocity	3.45	17.8	8.51	18.4	6.92	10.4	17.2	89.5
		Displacement	52.7	86.0	147	195	100	244	291	8426
		Accelerat	20.6	57.6	14.7	40.8	41.8	99.8	172	67.7

3	AXIAL	ion								
		Velocity	11.3	22.6	11.2	25.5	52	27.6	27.9	21.5
		Displacement	168	207	158	138	889	305	528	140

3rd Gear

S.No	Direction	Parameters	MNDE		MDE		GDE		GNDE	
			B.B	A.B	B.B	A.B	B.B	A.B	B.B	A.B
1	HORIZONTAL	Acceleration	10.3	36.5	15.4	73.3	46.0	179	51.3	200
		Velocity	24.0	9.25	24.1	9.62	27.4	24.4	20.8	83.1
		Displacement	459	104	425	152	463	844	421	7526
2	VERTICAL	Acceleration	11.6	50.3	8.85	26.9	31.3	223	50.6	188
		Velocity	4.07	13.9	10.6	20.0	7.45	24.8	16.9	91
		Displacement	47.3	117	180	187	117	143	277	7018
3	AXIAL	Acceleration	26.5	56.2	13.7	40.0	42.6	55.5	16.7	62.6
		Velocity	9.01	12.2	12.0	16.8	50.2	17.4	25.0	17.4
		Displacement	170	200	221	217	918	259	439	134

4th Gear

S.No	Direction	parameters	MNDE		MDE		GDE		GNDE	
			B.B	A.B	B.B	A.B	B.B	A.B	B.B	A.B
1	HORIZONTAL	Acceleration	15.4	22.0	11.9	28.2	48.2	82.2	60.5	75.8
		Velocity	22.2	8.88	23.5	18.7	26.0	13.3	23.7	15.4
		Displacement	396	81.7	422	258	479	166	440	264
		Accelerat	10.	15.6	9.59	14.4	34.2	63.8	47.3	78.4

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2	VERTICAL	ion	8							
		Velocity	4.00	8.20	10.6	19.7	6.05	21.3	18.8	15.7
		Displacement	41.1	88.7	176	108	90.4	245	311	183
3	AXIAL	Acceleration	162	20.1	10.6	23.3	46.2	46.0	24.8	52.1
		Velocity	7.16	24.5	9.62	21.7	58.8	22.7	30.1	19.3
		Displacement	103	150	151	237	1105	291	522	142

B.B-Before breaking A.B-After breaking

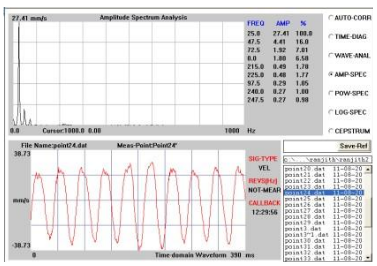
VI. OBSERVATIONS

Before breaking the teeth, the shaft at the MNDE&MDE is not aligned wrt to the Gear drive shaft. Hence the vibration readings are high before breaking the Gear teeth at MNDE&MDE in horizontal direction.

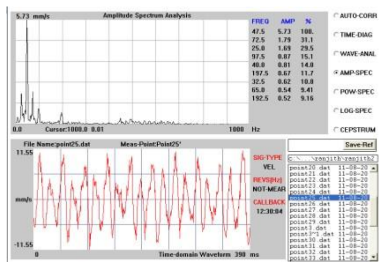
After breaking the Gear teeth vibration readings shows high values in vertical and axial direction at GNDE&GDE due to non-uniform rotation of Gears about the axis of shaft.

Spectrums before removing teeth:

1st and 4th Gear teeth are not changed, after breaking the Gear teeth of 2nd and 3rd lubrication is applied and shaft is alighned.Hence the vibration of 4th Gear are reduced in horizontal, vertical and axial direction at GNDE. Breaking of Gear teeth is not effected in axial direction since they are spur Gears .After observing the Gearbox when running at 2nd &3rd Gears the vibrations in radial direction (horizontal, vertical) are very high.



1st Gear MNDE hor



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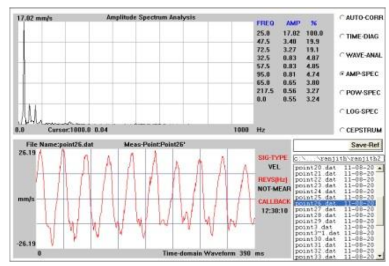
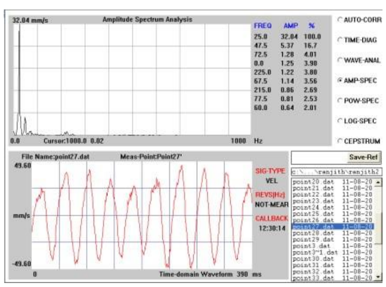


1st Gear MNDE axi



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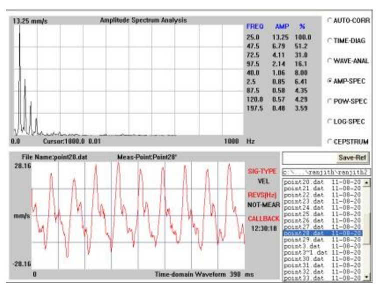

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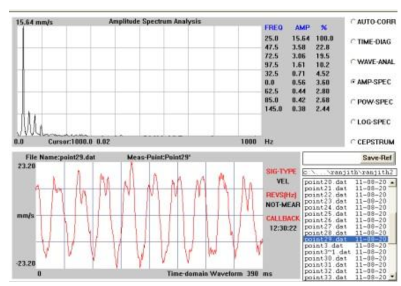

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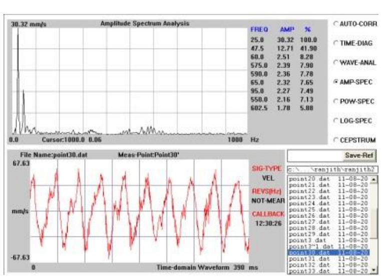
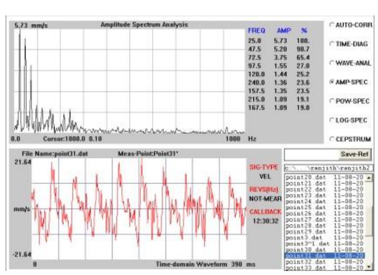


1st Gear GDE hor



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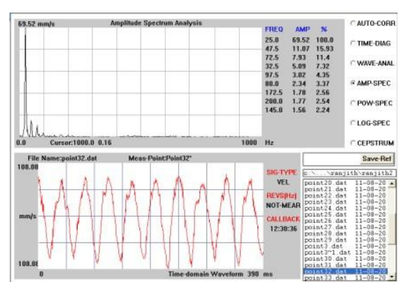

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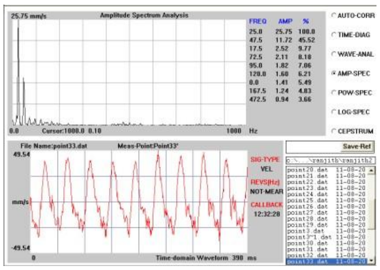

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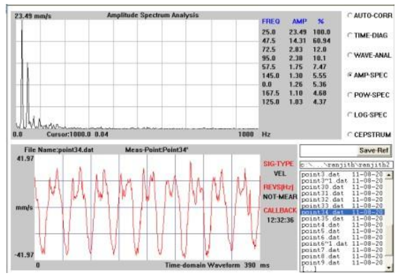

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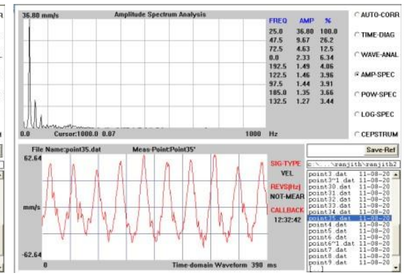

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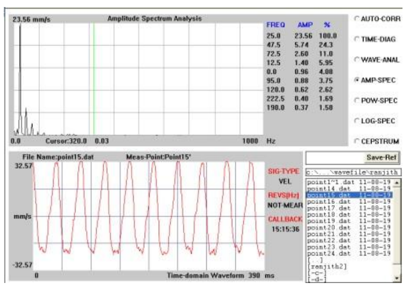
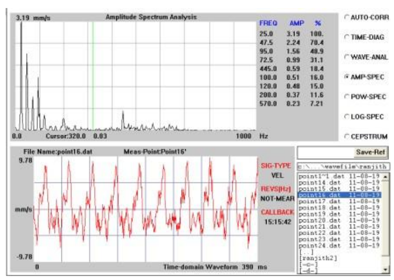


2nd Gear MNDE hor



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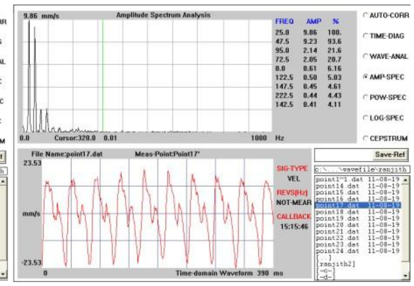

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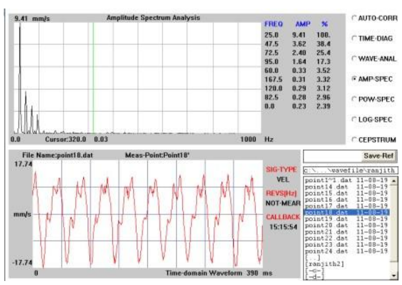
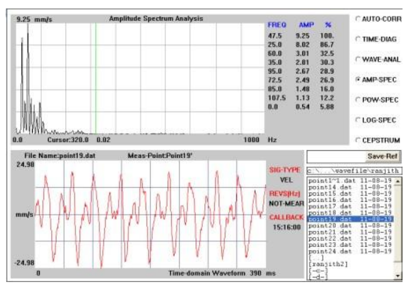


2nd Gear MDE hor



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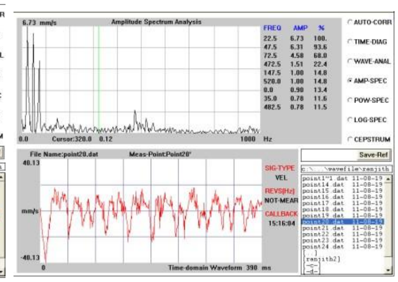

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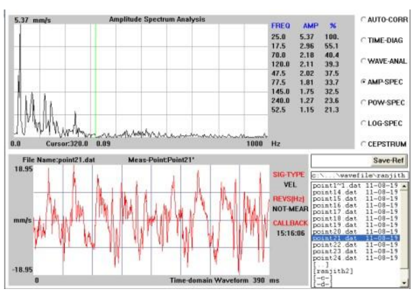
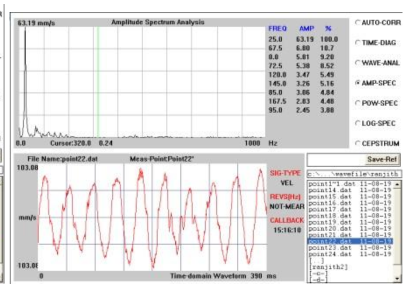


2nd Gear GDE hor



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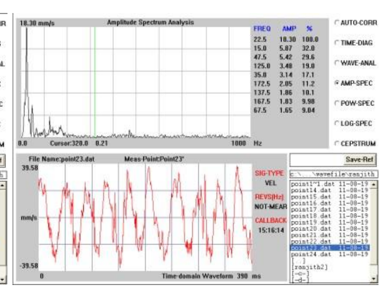

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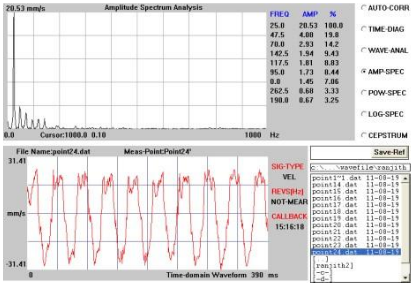

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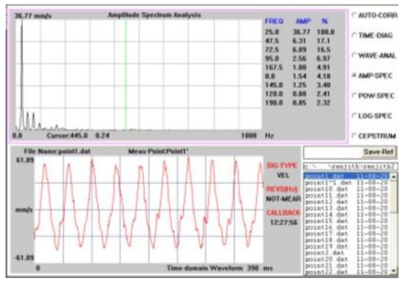

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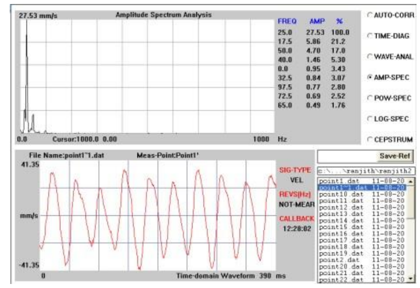

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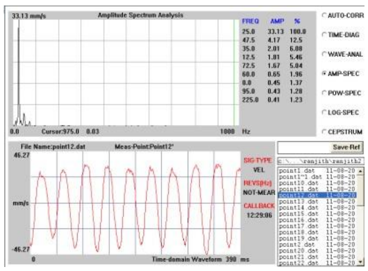
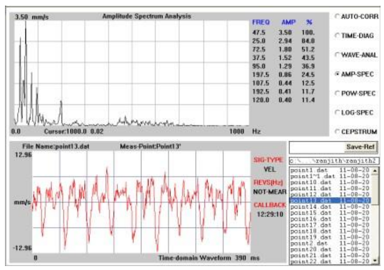


3rd Gear MNDE hor



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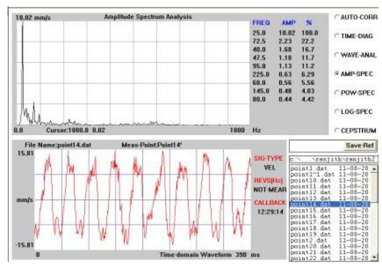

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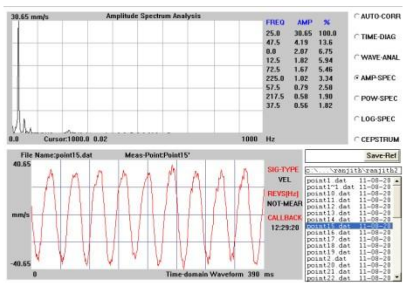

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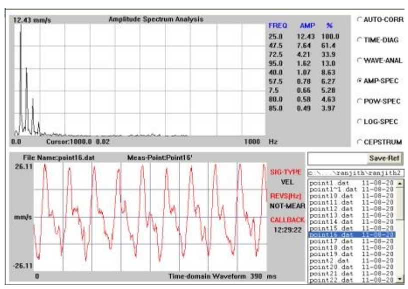
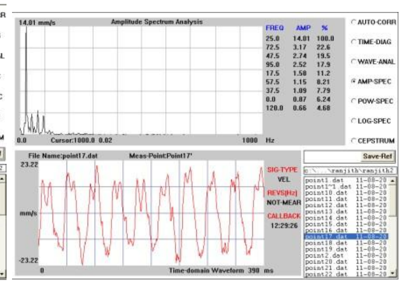


3rd Gear MDE ver



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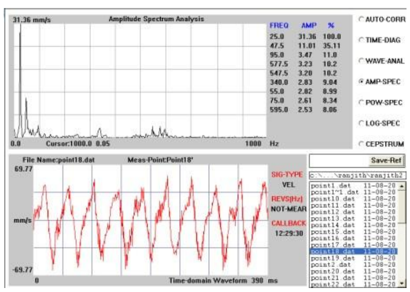

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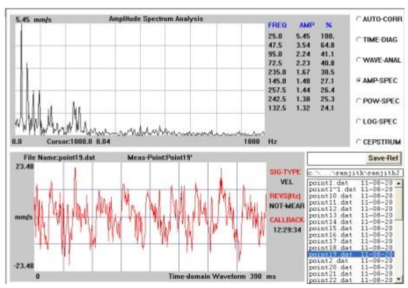

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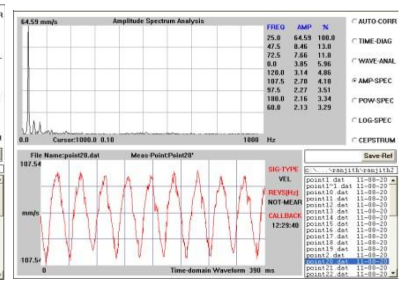

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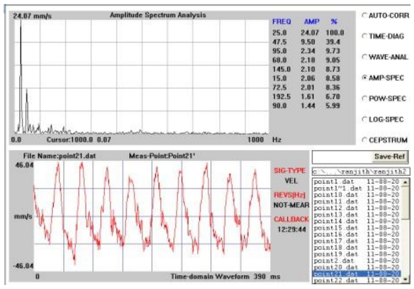

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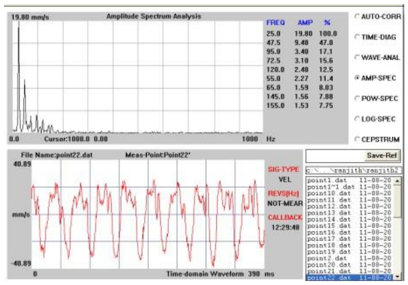

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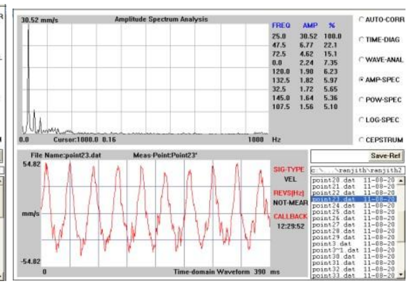

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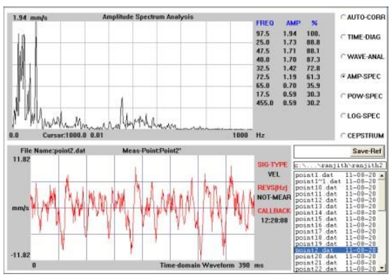

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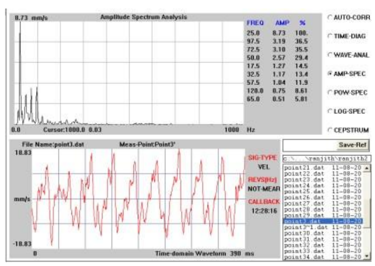

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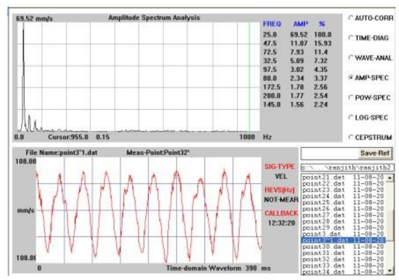

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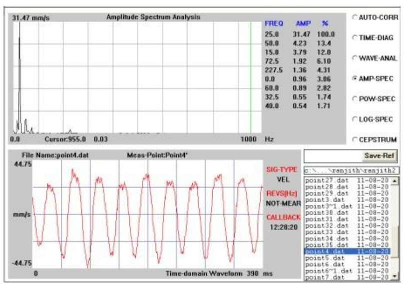

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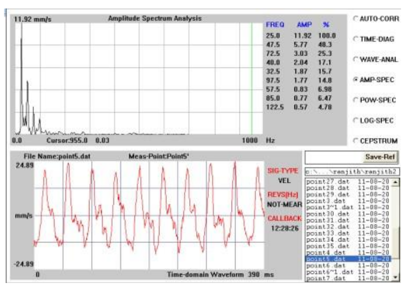

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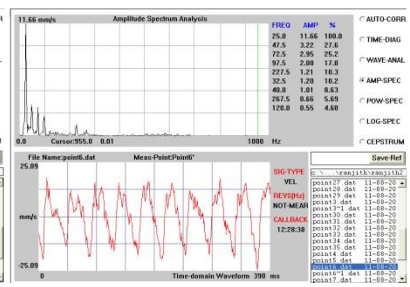

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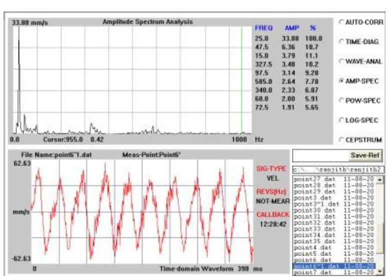

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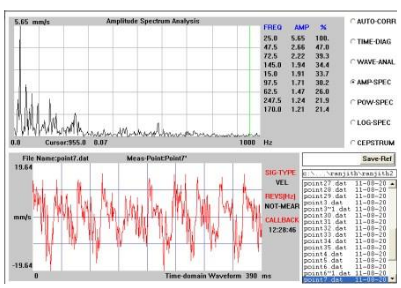

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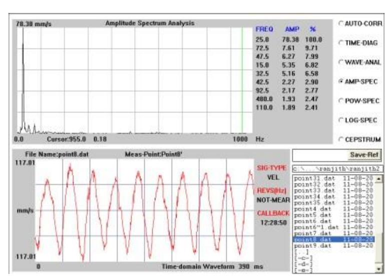

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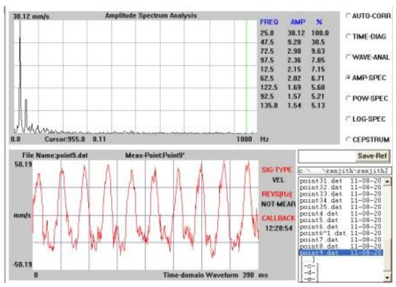
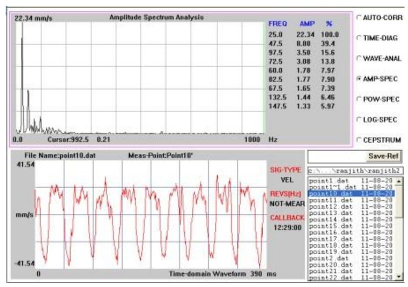
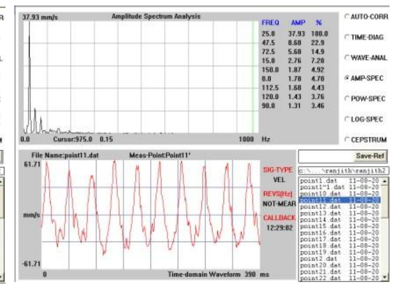
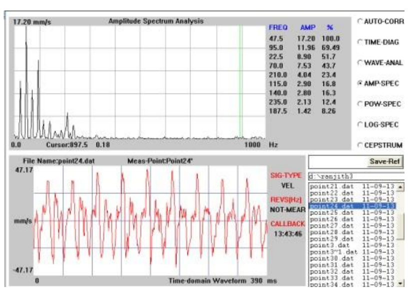


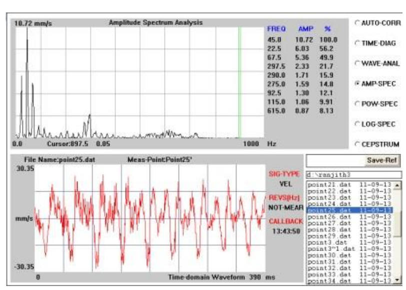


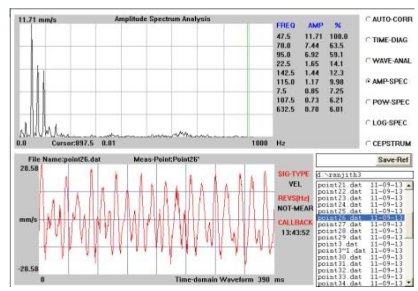


4th Gear GNDE hor 4th Gear GNDE ver 4th Gear GNDE axi

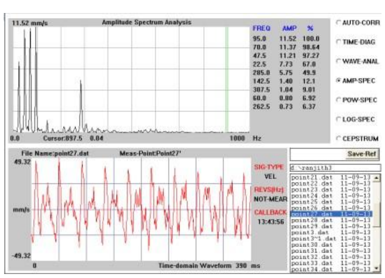
Spectrums after removing teeth:

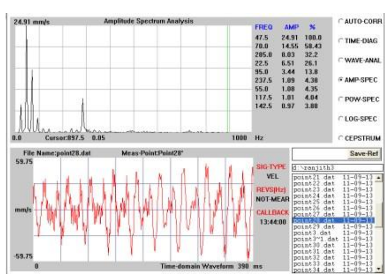


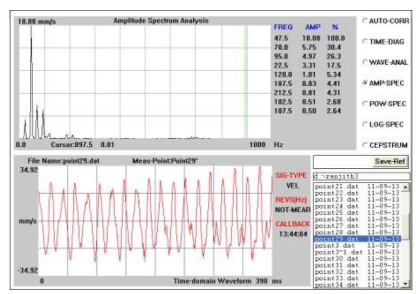




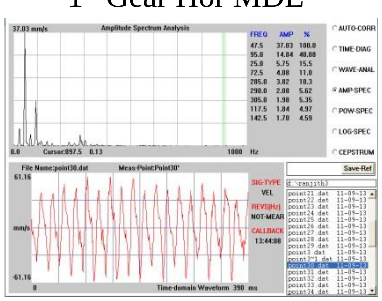
1st Gear Hor MNDE 1st Gear Ver MNDE 1st Gear Axi MNDE

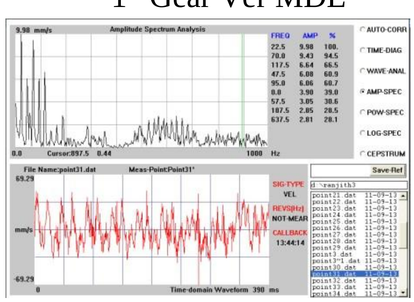


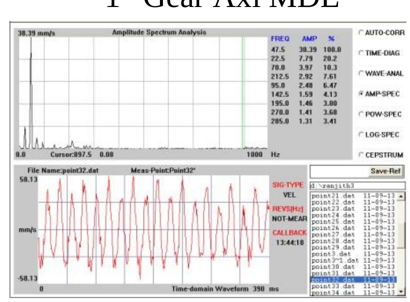




1st Gear Hor MDE 1st Gear Ver MDE 1st Gear Axi MDE







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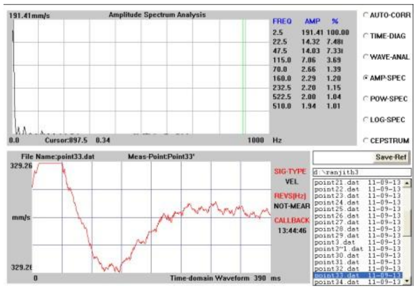

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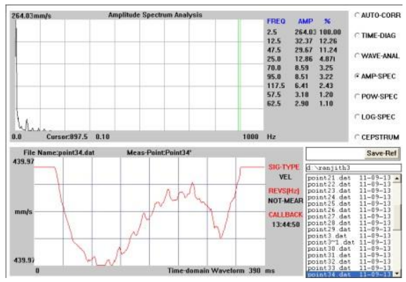

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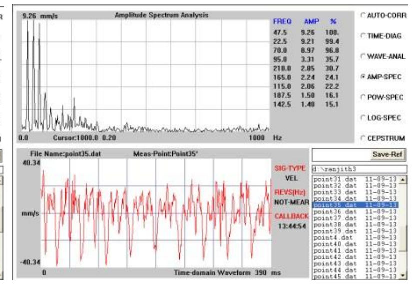

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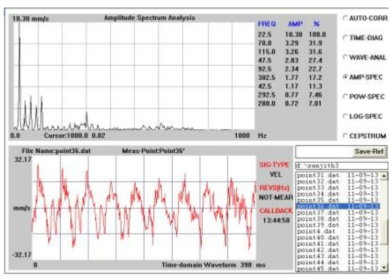

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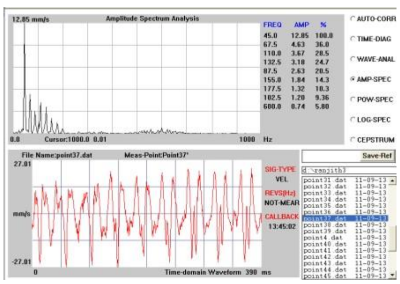

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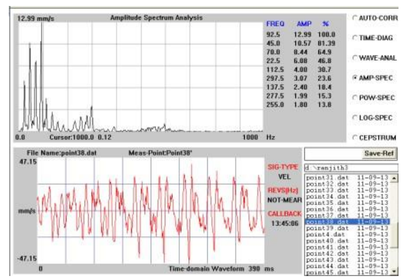

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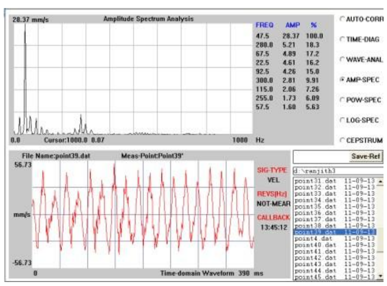

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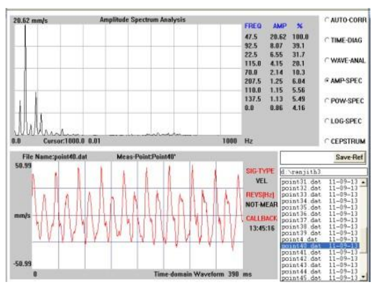

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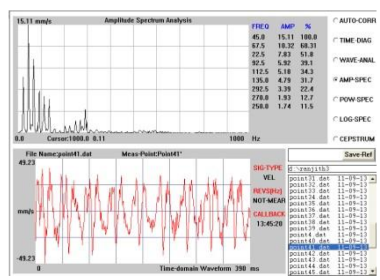

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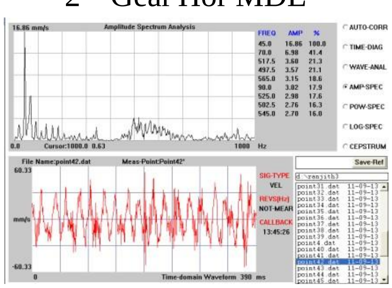

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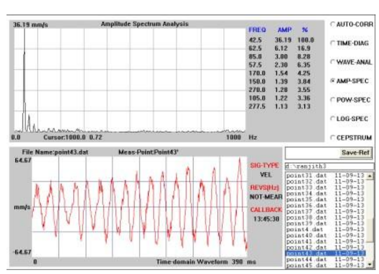

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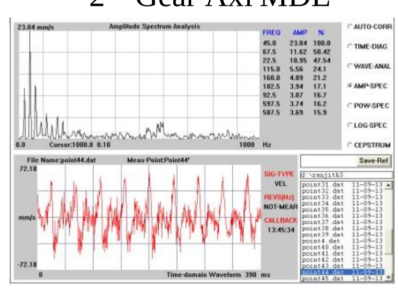

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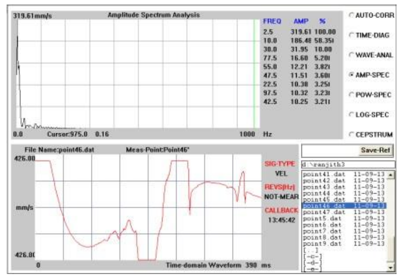

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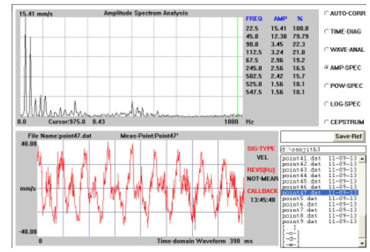

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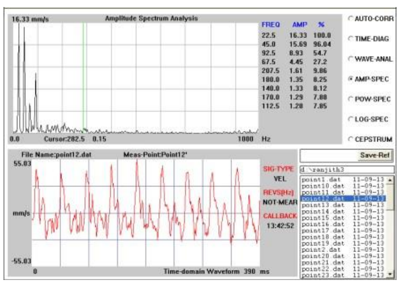

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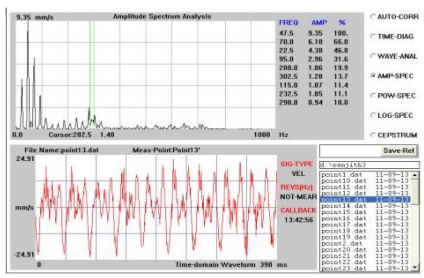

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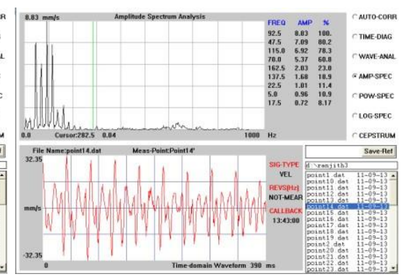

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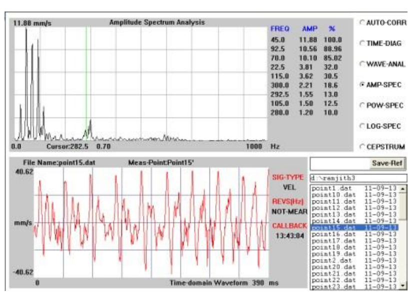

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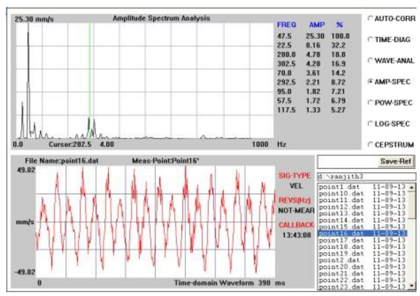

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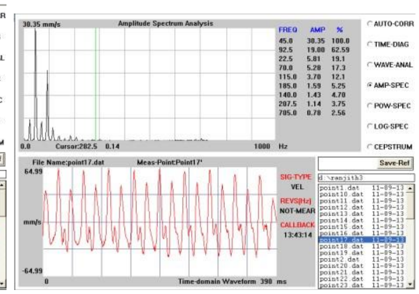

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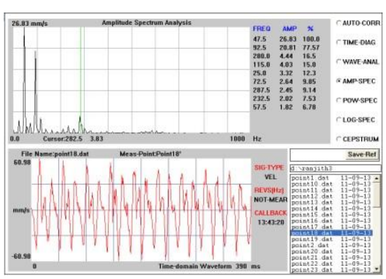

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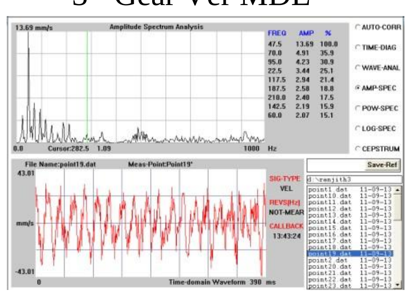

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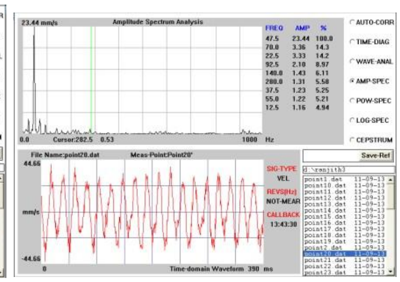

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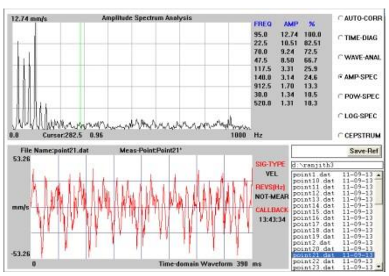

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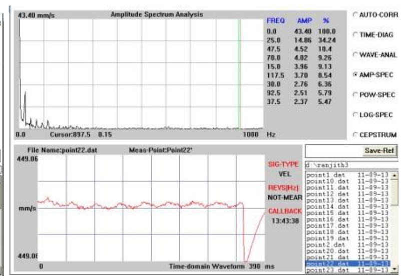

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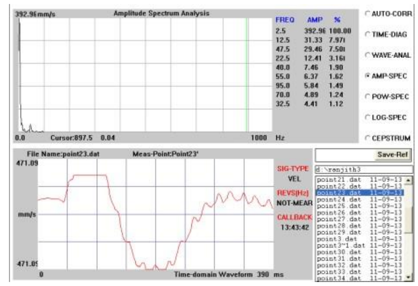

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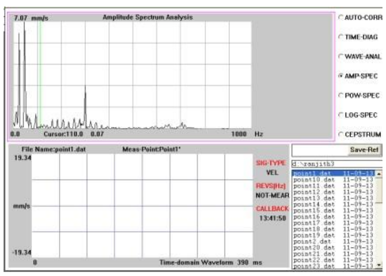

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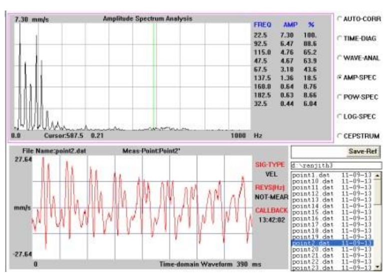

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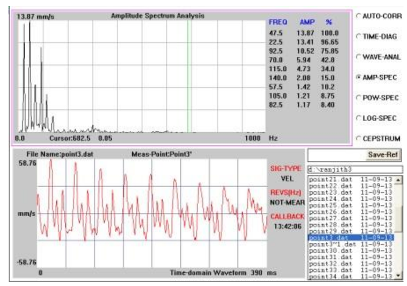

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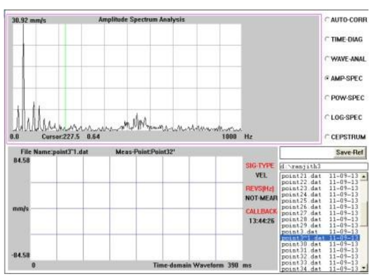

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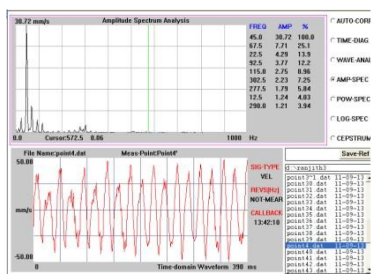

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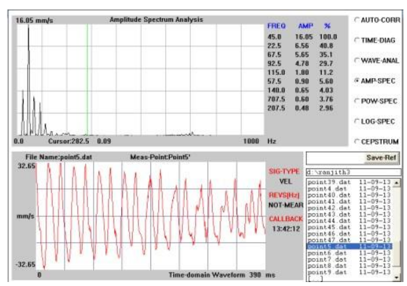

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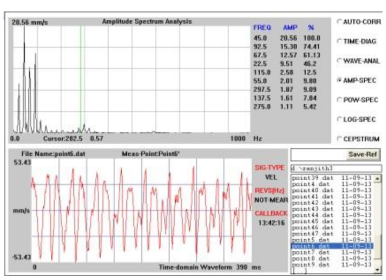

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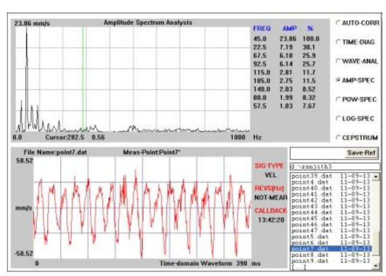

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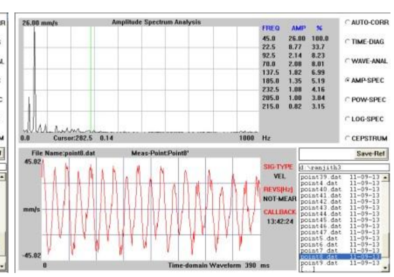

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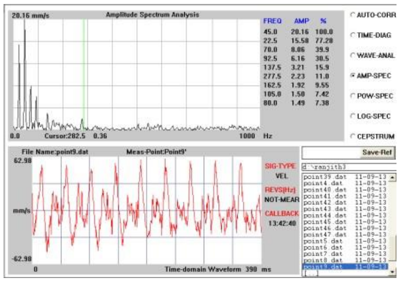
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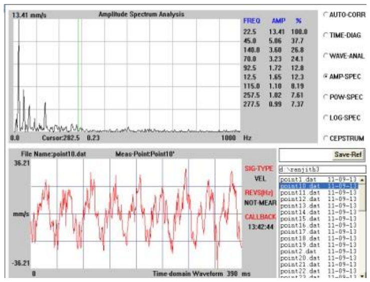
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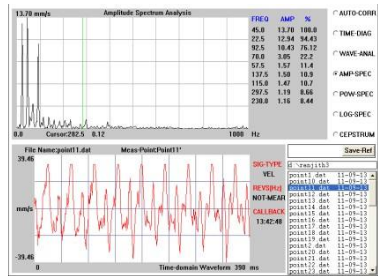
4th Gear Axi GNDE

Results from spectrums:

S.NO	2nd Gear Non Drive End				
	Direction	Harmonic frequency		Amplitude	
		B.B	A.B	B.B	A.B
1	H	1X	1/5X	20.53	43.62
2	V	1X	1/10X	36.77	319.61
3	A	1X	Approx 1X	27.53	15.41

S.NO	3rd Gear Non Drive End				
	Direction	Harmonic frequency		Amplitude	
		B.B	A.B	B.B	A.B
1	H	1X	4x	12.74	24.07
2	V	1X	0	19.80	43.4
3	A	1X	1/10x	30.52	392.96

Observation from spectrums:

- Gearbox is located at GNDE. By observing the spectrums at GNDE before breaking the peak amplitudes are at 1x.
- Since the Gear shaft is rotated approximately around 1500rpm the harmonics is 1500/60=25cps.
- By observing the spectrums at GNDE after removing Gear teeth the peaks are present at sub harmonics and multiples of frequencies. The cause of presenting the sub-harmonics &multiples of frequencies is due to the presence of fault in the Gearbox.
- The vibrations increased from 5times to 8times after observing the spectrums.

VII. FUTURE SCOPE

- Vibrations measured in this paper are based on broken gear teeth. This vibration monitoring technique can be applied to detect Backlash, Scoring, Pitting of the gear teeth.

- Vibration monitoring technique can be applied to any rotating machines.
- Change of dimensions of gear teeth in running condition due to thermal effects are not considered in this study which also effects the vibrations.

VIII. CONCLUSIONS

- It is observed that vibrational analysis is better compared to other monitoring techniques.
- To reduce costs and facilitate diagnosis, vibrational analysis is a very popular technique.
- It provides a highly sensitive, selective, and co- effective means for online monitoring of a wide variety of heavy industrial machinery.
- This paper has investigated the detection of Gear fault using vibration monitoring.
- An experimental study has been conducted on motor with Gearbox, measured quantities such as frequency and amplitudes.
- The peaks are present at sub-harmonics and multiples of frequencies. The cause of presenting the sub- harmonics &multiples of frequencies is due to the presence of fault in the Gearbox.

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