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VIBRATION AND NOISE SIGNAL ANALYSIS OF A GEARBOX HAVING DELRIN GEAR WITH BROKEN TEETH DEFECT

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Abstract - *The main objective of this study is to perform vibration and noise analysis of gearbox with healthy and faulty Delrin gears (gear with broken teeth), which can be helpful in pre-emptive recognition of system failure. Whenever the natural frequency of the system coincides with the excitation frequency then the amplitude of vibration reaches maximum causing catastrophic failure of the system. Because of the severity of the effect of vibration on engineering systems it is necessary to carry out vibration and noise tests to avoid failure. The vibration and noise signals were collected from healthy and faulty Delrin gears which were operated under different speed and torque conditions. The vibration and noise signals were sensed by accelerometer and microphone from the gearbox casing, and the signals were recorded using data acquisition system. The results show the gearbox vibration characteristics using time domain analysis, frequency domain analysis and order tracking analysis parameters. And noise characteristics using octave band analysis parameter. A Comparison is done between the signals of healthy and faulty Delrin gear and analysis of the signals show distinct differences in the vibration and noise characteristics between healthy and faulty gear systems.*

***Key Words*: Gearbox, Delrin gears, Time domain analysis, Frequency domain analysis, Octave band analysis.**

1. INTRODUCTION

The gearbox is the primary tool of power transmission. Gears are one of the most significant parts in mechanical transmission systems. [1] It is critical element in a variety of industrial applications, transportation, aerospace, energy, agricultural sectors, wind generation and other fields. Smooth operation and high efficiency of gears are necessary for the normal running of machines. Therefore, gear analysis is an important activity in the field of condition monitoring and fault diagnosis. Early detection of local gear faults in industrial environments is very important to optimize the maintenance schedule and reduce the operating cost of gearbox damage. Failures of the gearbox may cause injury to human beings and important economic losses. To avoid the consequences of any harmful accidents, several techniques are developed in condition monitoring to detect faults as early as possible. Vibration signal analysis is the most common gear detection technique for gear damage detection. [2]

Delrin acetal homopolymer also called Delrin Polyoxymethylene [POM-H] is one of the most crystalline engineering thermoplastics available. It is a highly adaptable material which offers an excellent balance of properties that bridge the gap between metals and plastics. It is the stiffest and strongest unreinforced engineering polymer available which is natural replacement for metals. The need for reduced energy consumption and cost through metal-replacement with lightweight engineering polymers is a confirmed trend in the automotive industry, and is increasingly gaining ground in general engineering and many other industry sectors. Delrin possesses high tensile strength, creep resistance and toughness. It also exhibits low moisture absorption. It is chemically resistant to hydrocarbons, solvents and neutral chemicals.

The Tooth breakage may be the result of high overloads, repeated overloads causing low-cycle fatigue, or multiple repeated loads leading to high cycle fatigue of the material. Where high stress concentration exists together with highest tensile stress from bending or from the surface defects. The crack slowly propagates over 80 to 90% of the life. Then crack propagates fast and suddenly results in fracture of the tooth.

Vibration monitoring and analysis is done because, Vibration is a proven parameter which could be used to monitor the conditions of rotating machinery. Various mechanical faults can be detected by vibration measurement and analysis. Most of the failures in rotating machinery are due to, damaged bearings, gears, belts, vanes of impellers and shafts, assembly faults like unbalance, misalignment, mechanical looseness, bent shaft, and oil whirl in hydrodynamic bearings. All these factors affect the vibration emitted from the machines. Therefore vibration is a good indicator of health of a machine. Due to vibration monitoring of a machine we get the following information: When to change a bearing, gear, belt or carrying out major maintenance activities, how to avoid rejects, defective parts produced by the machine, how to achieve zero breakdown, how to improve productivity.

Sound is a simple harmonic acoustic vibrations expressed in terms of tones, sound is single frequency (sinusoidal). Sound is produced due to variation in pressure, stress or particle displacement of a medium. Variation is caused by disturbance created by a vibrating object. Disturbance causes a pressure oscillations travel through medium to receiver. Airborne noise is usually caused by vibration of solids and fluids. Structure borne noise travels great distances, vibration travel a long way before reaching large surfaces generate airborne noise (block vibration as close to source as possible). Noise is unwanted sound which effects the hearing ability of a human being, Noise also has effects on conversation, voice communication is garbled in noisy environment. Normally communication between persons at about 60db(A) at 1m distance. Shouting is inevitable if noise exceeds about 75db(A). If environmental noise is 90db(A) even shouting is useless for distances beyond 1m. Noise analysis refers to extraction of information and meaning from sound signals for analysis, classification, storage, retrieval, synthesis, etc.

Benefits of vibration and noise analysis and a good maintenance program are: Prolonged machinery life, minimizes unscheduled down time, eliminates unnecessary overhaul, eliminates standby equipment, provides more efficient operations, increases machinery safety, improves quality performance and hence customer satisfaction.

2. METHODOLOGY

2.1 Gear Preparation

a. Health Gear

Fig -1: Delrin Gear

Fig -2: Delrin Pinion

Table -1: Specifications of Gear Pair

Sl. No.	Parameter	Gear	Pinion
1	Number of Teeth	45	28
2	Module (mm)	2.5	2.5
3	Pressure Angle (deg)	20	20
4	Face Width (mm)	25	25
5	Pitch Circle Diameter (mm)	112.5	70.0
6	Center Distance (mm)	91.25	91.25

b. Defective Gear

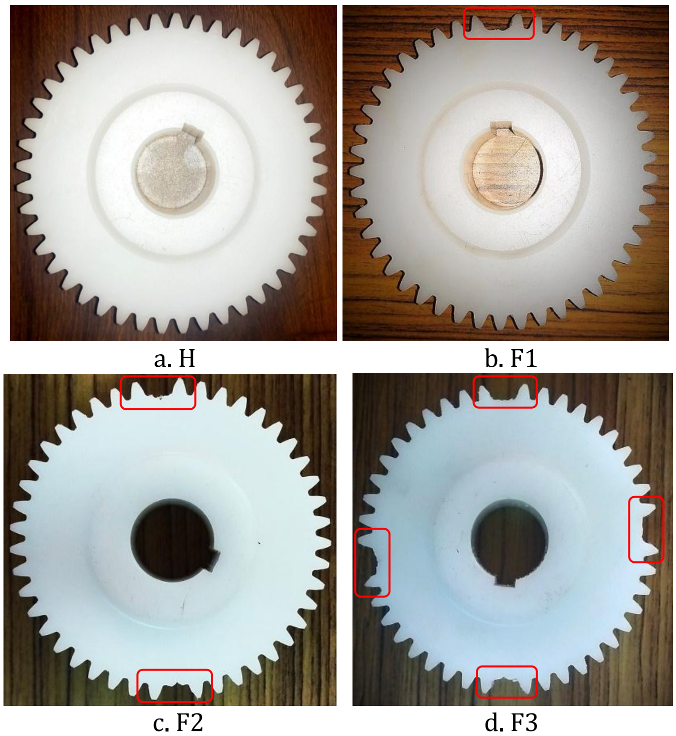

Fig -3: Different Types of Faulty Delrin Gears.

Gears designation is shown in table 2,

Table -2: Gear Designation

Healthy gear	H
Gear with one broken tooth	F1
Gear with two broken teeth	F2
Gear with four broken teeth	F3

Gear Preparation (Delrin Gears):

The gear is manufactured as per the specifications in table-1. The turning of rod is done with the help of Lathe machine to above given specifications with tolerance. The gear cutting is done with the help of Hobbing machine. The keyway cutting is done with the help of slotting machine.

2.2 Experimental setup

Fig -4: Experimental Setup of Gearbox Test Rig

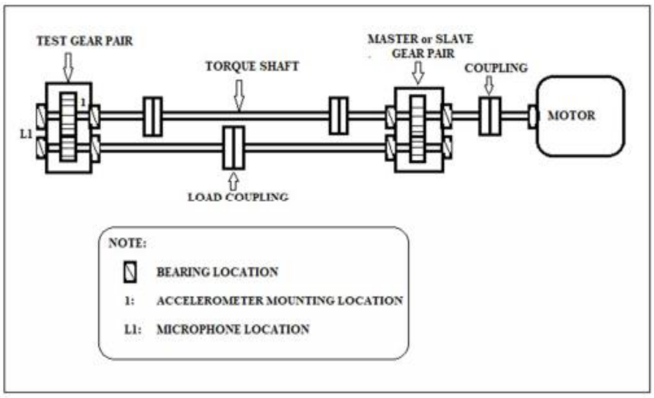

Fig -5: Schematic Representation of Gearbox Test Rig

Gearbox test rig has been utilized to carry out the vibration analysis of gearbox in the present work. The test rig consists of two spur gear pairs one serves as test gear pair and the other as master or slave gear pair. Both the gear pairs have the teeth ratio of 45/28. The load is applied on pinion through the load coupling assembly using the loading arm.

The experiment conducted for both health and faulty Delrin gears for various conditions such as,

- For Speeds: 200RPM – 900RPM with an increment of 100RPM (steps).
- For Load: No load, 5Kg and 10Kg respectively.
- For Defects: No defects, 1 broken tooth, 2 broken teeth, and 4 broken teeth.

The load applied on the load coupling through-loading arm converts it into torque,

Table -3: Load and Torque

Load(Kg)	No Load	5	10	15
Torque (N-m)	0	20.8463	41.6925	63.5388

3. RESULTS AND DISCUSSION

A. Frequency Response Functions (FRF)

Frequency Response Functions (FRF) is a transfer function, expressed in the frequency domain. The transfer function is the representation of the relationship of the input and output of structure or other system simulated by vibration. It is the ratio between the Fourier spectrum of the output, to that of the input. Information obtained from transfer function is input-output relationship (gain, compliance, mobility etc.), phase relation between input and output, resonance frequencies, damping (by curve fitting).

Coherence function is derived from cross power spectrum. Coherence function is a measure of power in the input signal caused by the output. If coherence function is 1, then all the output power is caused by input. And if the coherence function is 0, then one of the output is caused by input. Coherence is a function of frequency.

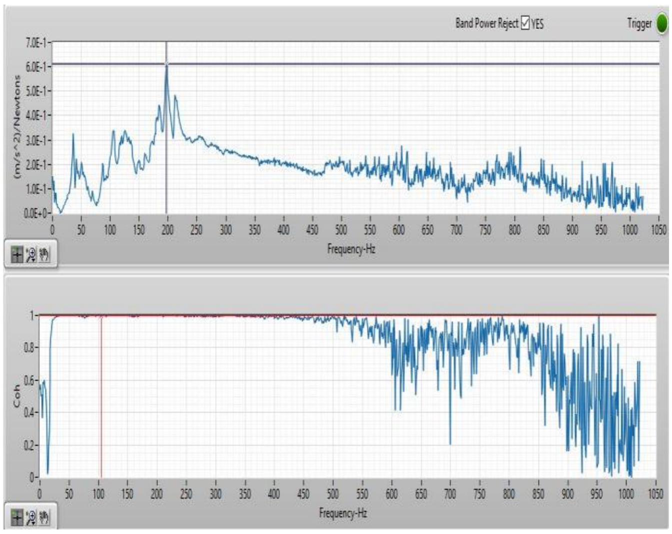

Fig -6: FRF Signal Magnitude and Coherence

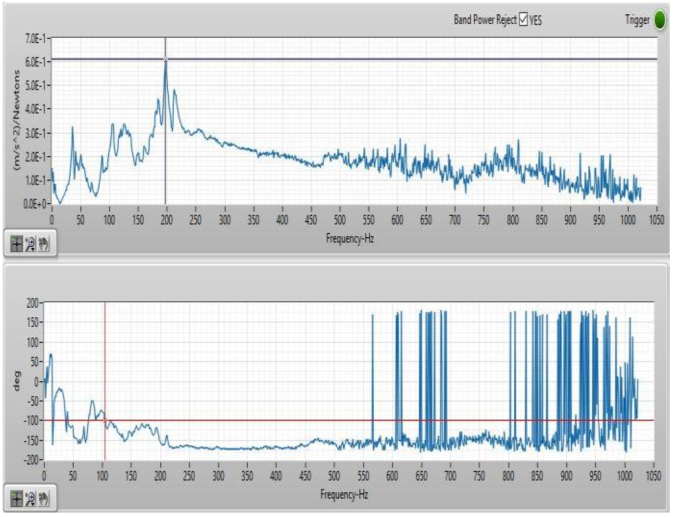

Fig -7: FRF Signal Magnitude and Phase Angle

Phase is a measurement, not a processing method. Phase measures the angular difference between a known mark on a rotating shaft and the shaft's vibration signal. This relationship provides valuable information on vibration amplitude levels, shaft orbit, and shaft position and is very useful for balancing and analysis purposes.

Figure 6-7 shows FRF signal obtained from impact hammer test of the gearbox. From the FRF analysis, the Gearbox Natural Frequencies obtained are 35Hz, 86Hz, 105Hz, 185Hz, 195Hz and 213Hz.

B. Time Domain Analysis

The sample time record of the input signal is displayed on the single frame. The analyzer is used in oscilloscope mode. When time waveform is obtained in FFT analyzer the anti-aliasing filters are to be made ineffective to view all the frequencies.

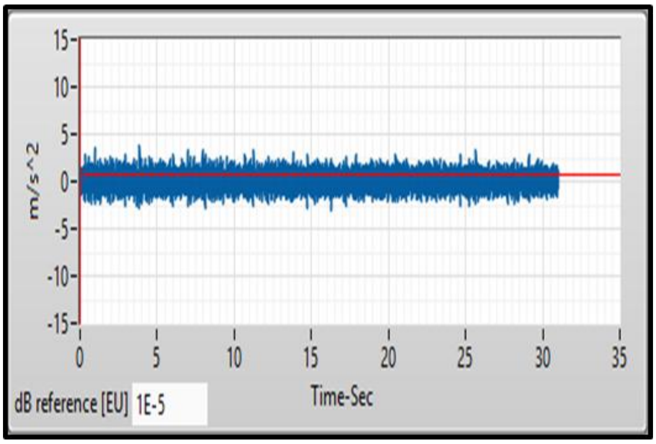

Fig -8: Time Domain Signal of Gearbox for Healthy Gear

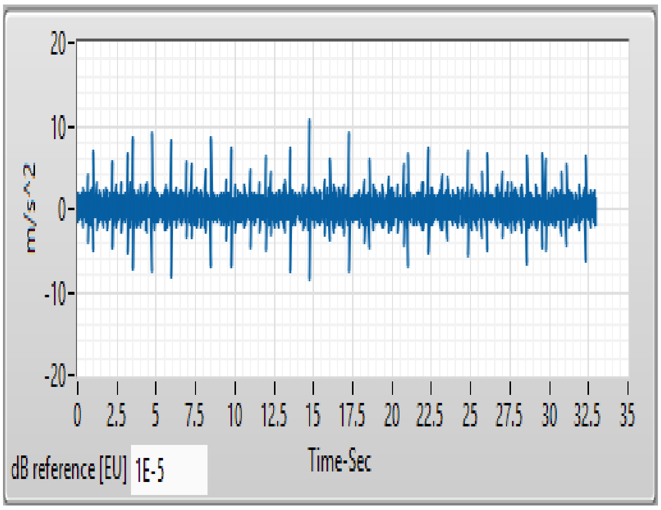

Fig -9: Time Domain Signal of Gearbox for Faulty Gear

Time domain signal indicates the severity of vibration for healthy and faulty condition of gearbox. As shown in fig-8 there is no sudden rise in amplitude or pulse in the signals that indicates healthy condition of the Delrin gear. Fig-9 shows one amplitude or pulse for a revolution of shaft which indicates one broken tooth in the gear train. Also two and four pulses created for every revolution of shaft indicates the presence of two and four broken teeth in the gear pair respectively.

C. Frequency Domain Analysis

Frequency domain signals obtained after carrying out FFT of time domain signals are as shown in figure-10 and 11 for gearbox with healthy and faulty gears at 400 RPM and 10KG load.

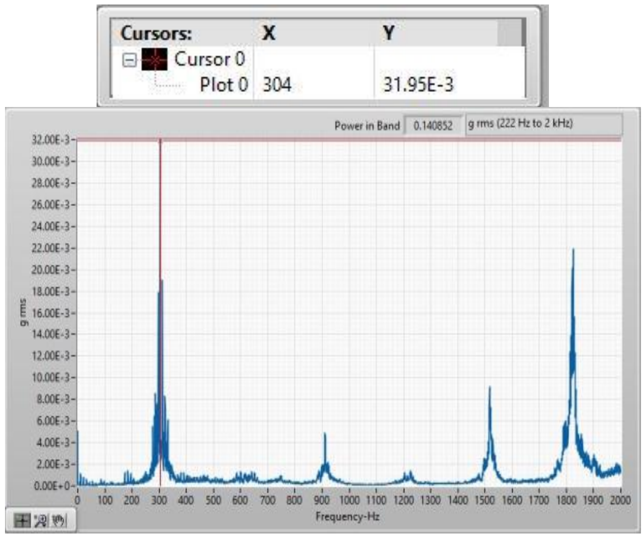

Fig -10: FFT Signal of Healthy Delrin Gear at Speed of 400RPM and 10KG Load

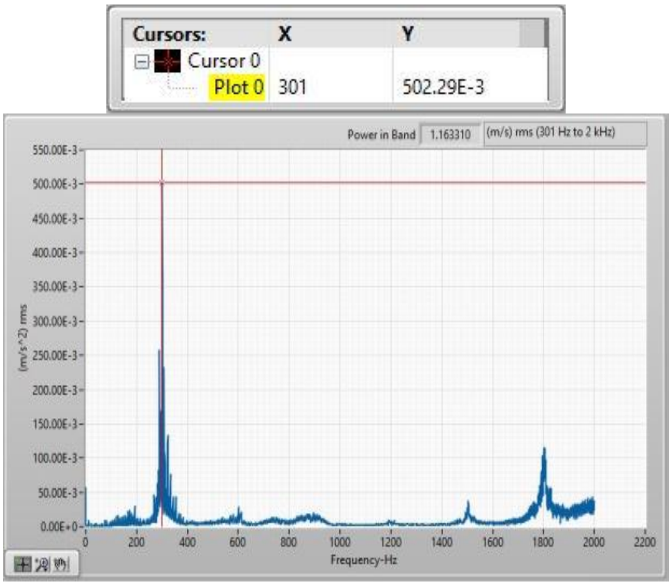

Fig -11: FFT Signal of Faulty Delrin Gear at Speed of 400RPM and 10KG Load

For the gear speed of 400RPM, the corresponding Gear Mesh Frequency (GMF) is 302Hz. Dominant peaks can be observed at GMF. The severity of vibration increasing with the number of broken teeth, the vibration level of healthy Delrin gear is low as shown in fig-10 when compared to other faulty Delrin gear conditions shown in fig-11.

D. Order Tracking or Angular Domain Analysis

The vibration trend of order signal is same as spectrum signal. The speed of faulty gear shaft is counted as first order. And every 45^{th} order represent gear mesh frequency irrespective of shaft speed. The fundamental speed of gear serves as first order. The GMF is in 45^{th} order which depends on the number of teeth in a tracking gear and its harmonics appear at 90^{th}, 135^{th}, 180^{th} orders etc. the difference between GMF and its sidebands are easily identified in order analysis.

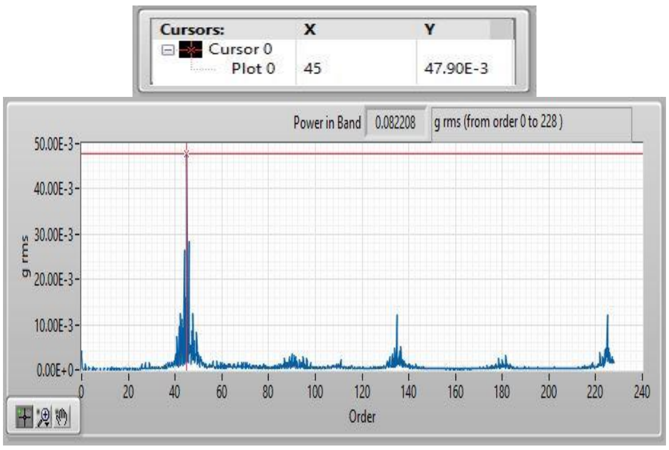

Fig -12: Order Signal of Healthy Delrin Gear at Speed of 400RPM and 10KG Load

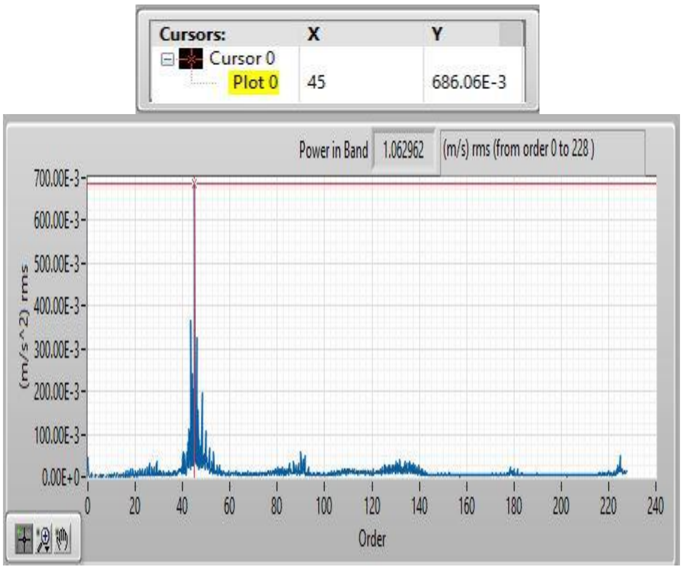

Fig -13: Order Signal of Faulty Delrin Gear at Speed of 400RPM and 10KG Load

Figure-12 and 13 clearly shows that there is signification increase in acceleration value when compared between Healthy 45th order spectrum and with Faulty (Broken Teeth defect) 45th order spectrum.

E. Octave Band Analysis

Sound pressure level could be represented as,

$$L_p = 10 \log_{10} (P_{rms}/P_0)^2$$

$$L_p = 20 \log_{10} (P_{rms}/P_0) \text{ in decibels.}$$

The denominators is a reference quantity, in this case, reference pressure $P_0 = 20 \times 10^{-6}$ N.m^2. This value is a threshold of hearing at 1000Hz. It is expressed in Pascal or N/m^2 and is a scalar quantity.

Noise measurements is made for many purposes to quantify the noise (legal conformance), environmental pollution, safety consideration etc., to analyze the noise for noise control, to know the frequency contents and amplitude, to understand the characteristics of noise. Simple measurements are made with sound level meters for quantifying the noise for environmental pollution evaluation and safety consideration in noisy workplaces. Detailed measurements are made when noise control is a goal.

Sound pressure level is normally measured in most general noise measurements, effects of sound on human ear is related to pressure fluctuations caused by sound waves, easy to measure (simple techniques and instrumentation).

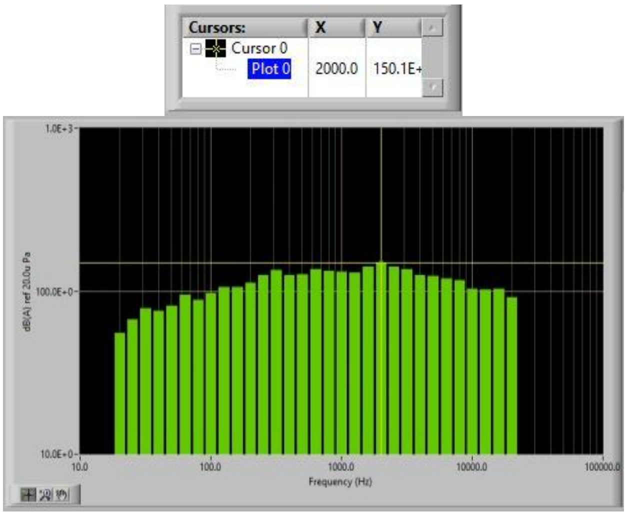

Fig -14: Sound Signal with 1/3 Octave for Healthy Delrin Gear at Speed of 400RPM and 10KG Load

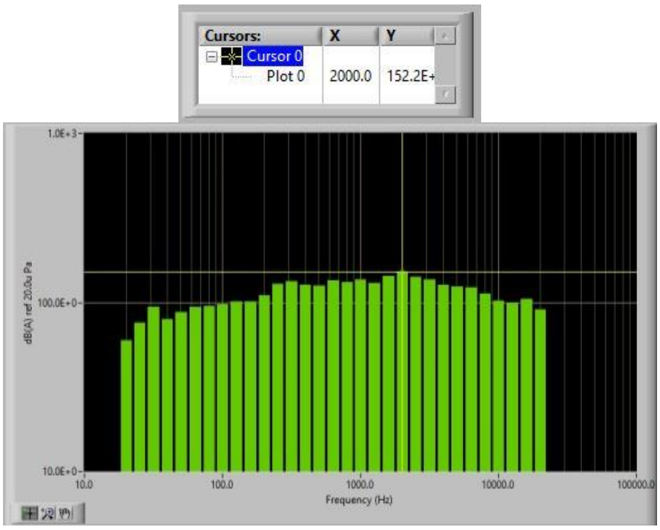

Fig -15: Sound Signal with 1/3 Octave for Faulty Delrin Gear at Speed of 400RPM and 10KG Load

4. CONCLUSIONS

Vibration is one of the significant factors causing unscheduled shutdown of mechanical systems. The present work throws light on vibration and noise characteristics of mechanical system.

Following conclusions are drawn from the vibration and noise characteristics of gearbox, obtained from the study.

A. By selecting appropriate non-metallic material and by the designing of gear as per standard procedure the % weight reduction can be achieved.
B. Time Domain Analysis gives number of pulses for every revolution of shaft, which depends on the number of broken teeth in the gear. This is clear indication of presence of broken teeth (defect) of the gear in the gearbox.
C. FFT signals show dominant peaks at gear mesh frequencies, whose magnitude are found to increase with the number of broken teeth. And the amplitude of sidebands will help in determining the defective gear.
D. The Broken teeth defect can be identified by FFT when we see peak at 1XGMF and have excited natural frequency of gear. And the Broken teeth defect can also be identified by close studying the time domain data.
E. The noise level increases for higher speed and higher load conditions. Noise signals are to be processed in anechoic conditions for eliminating the influence of surrounding noise effects, so that the noise due to faulty gears are distinctly recognized.

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