A

Dissertation Report

On

# Fault Detection of Two Stage Reduction Gearbox Using Vibration Analysis Techniques

*Submitted in Fulfillment of*

*The Requirements for the award of Degree of*

**Master of Technology in Design Engineering**

By

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# CERTIFICATE

This is certified that the dissertation report entitled **"Fault Detection Of Two Stage Reduction Gearbox Using Vibration Analysis Techniques"** prepared by **SANMATI KURKUTE** (ID-2014PDE5020), in the partial fulfillment of the award of the Degree **Master of Technology** in **Design Engineering** of Malaviya National Institute of Technology Jaipur is a record of bonafide research work carried out by him under my supervision and is hereby approved for submission. The contents of this dissertation work, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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# DECLARATION

I **Sanmati Kurkute** hereby declare that the dissertation entitled **“Fault Detection Of Two Stage Reduction Gearbox Using Vibration Analysis Techniques”** being submitted by me in partial fulfillment of the degree of **M. Tech (Design Engineering)** is a research work carried out by me under the supervision of **Dr. Amit Singh,** and the contents of this dissertation work, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma. I also certify that no part of this dissertation work has been copied or borrowed from anyone else. In case any type of plagiarism is found out, I will be solely and completely responsible for it.

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**Sanmati Kurkute**

# ABSTRACT

These anticipate work concentrated on the configuration and testing of gearbox. Gearboxes are essential things in numerous industrial applications. In this way the enthusiasm for their wellbeing checking is developing and powerful strategies and methods are the target of past and future studies. Here we are going to detect various distinctive faults which occur in gearbox. There are essentially three types of shortcoming happens. These faults are somewhat worn teeth, cracked teeth or broken teeth. With the assistance of vibration study through vibration data acquisition equipment we can plan such sort of framework which can identify what type of deficiency a gearbox has. A two stage reduction gearbox is utilized as a part of the present study. The test setup contains a multistage gearbox, driven by an electric motor. The gearbox contains total four spur gears with the provision of replacement of normal gears by faulty gears for testing purpose.

Readings for normal condition of gears and faulty condition of gears were obtained using accelerometer and data acquisition unit, which is connected to the PC. Post processing of signals was done in LabVIEW software. The method proposed “Adaptive Time Frequency Representation” was verified using software and results showed that the method gave good results.

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# 1. INTRODUCTION

The objective of this thesis is to elaborate the importance of vibration signal measurements in these modern days as applicable to industries and mechanical machine productions. The aim is to explain in detail how these vibration measurement techniques are performed to obtain different fault features related to machine under consideration. The health monitoring or condition monitoring is already a much practiced issue inside many of mechanical plants and industries, performed by either skilled employees or experts from the field.

However, the techniques based on the automatic recognition of the pattern are recently introduced in this field. Effective services and maintenance in todays production systems are important from the profitability point of view of any firm. Measurements of vibration signatures gives us a good indication of machine condition and makes us easier to plan the maintenance schedule, so that we can focus mainly on those resources that are responsible for machine failure.

The vibration analysis is to look for the changes in the vibration pattern that are happening and then relating them back to the original design condition of the mechanical component. The various parameters of the obtained vibration signals gives us the inside current condition of the machine.

This vibration pattern is able to tell us,

-faults with rolling elements,

-faults with coupling,

-faults related to alignment and imbalance,

-faults in lubrication,

- Faults in meshing of elements (if there are any).

To get the introduction of these vibration analysis techniques, Consider any real life example having rotating or reciprocating elements, Let it be a domestic mixer or a two wheeler engine. These both devices produce noise and vibrations. These vibrations are related to their rotating speed i. e. by running mixer at high speed the sound signals generated are also of high frequencies. A two wheeler engine is again more complex, since the overall vibrations are contributed by many sources of vibrations inside the two wheeler engine body.

A two wheeler driver is familiar with the normal usually recognized vibrations .But, When his bike gets older, then due to wear out of material and other faults generated, he may be able to hear the strange vibration signal noises out of the familiar regular normal noise. Though the fault may be of low spectrum frequency but it may come out somewhat highly energetic due to other contributing frequencies , contributed by fluid pump or any other gear box fault noises or bearing failure noises, etc.

When any fault gets developed on it, then we can get an unfamiliar spectrum emerged. If he knows the bike functioning, he may try to solve the issue by himself. The method to diagnose the fault may include, to insert any screw driver or some equivalent mean to get the picture clear when the bike is running with no load condition. After diagnosing it fully, It may result in cleaning the dust collected over there or tightening of the screw-bolt that is loosened or some lubrication problem

However the lubrication problem is comparatively small but may lead to damage the bearings or whole gear box. Hence in this case a tool of vibration measurement can play a vital role.

A model preparation and practical work related to this project is done in the Metrology Laboratory at **Malaviya National Institute of technology, Jaipur**. I measured the vibration levels using accelerometer by mounting it on the body or frame of the Gear Box model that I prepared. These vibration signals were first saved in the computer for further processing and then various techniques were applied on this raw signal to extract features of that complicated and noisy signal using the software Lab VIEW. The output of this analysis and demonstration was a broken gear tooth and a gear tooth crack problem on the gear mounted in arrangement to give required reduction.

## 1.1: Condition Monitoring

Condition based maintenance is today becoming a very efficient tool for maintenance in industries. In earlier days industries were using 'Run To Break' type monitoring for maintenance criteria, but it has drawbacks such as it takes large operating time to shutdown which will have serious consequence on safety and may cause production loss. Another one is Preventive maintenance in which maintenance is carried out between two short time intervals of failures.

But is the case when the machines are running for 12 months a year, in that case we require a method which will determine the current internal condition of the running machine. For this type of maintenance, there are two techniques namely vibration analysis and lubricant analysis.

Thus available techniques for maintenance are,

1.1.1. Run-to break maintenance:

As explained above, in this type of maintenance the machine is run until it gets failure. Thus it takes longest time to maintenance of all the methods. Thus it has also the largest time to repair; time to repair also gets increased. This method proved to be inefficient one. Though it is used in industries such as sewing machine. i. e. industries having small machine in large quantity.

1.1.2. Time based preventive maintenance:

In this method, maintenance is carried out after certain interval of time which may be considered as time between two failures. But it is assumed that 1-2% machines may have failure during that interval of maintenance.

The advantage of his type of maintenance is that we can plan a maintenance schedule and hence catastrophic failure can be reduced. This type of maintenance technique is appropriately applied where time to failure of machine is known or is predictable.

1.1.3. Condition Based Maintenance:

The other name for Condition Based monitoring is a Predictive Maintenance in which break down is predicted using condition monitoring and also monitoring takes less time. This technique has more advantages over all other maintenance techniques. In addition to monitoring a machine, it also states the remaining life of machine under consideration.

## 1.2: Condition Monitoring Methods

Condition monitoring depends on having the capacity to state present condition and anticipate the future state of machines while in operation. In this manner it implies that data must be acquired remotely about inside impacts while the machines are in operation. The two primary methods for acquiring data about inward conditions are:

1. Vibration Analysis:

A machine in standard condition has a certain vibration signature. Fault improvement changes that mark in a way that can be identified with the deficiency. This has offered ascend to the term 'mechanical mark investigations.

2. Lubricant Analysis.

The lubricant likewise conveys data from within to the outside of working machines as wear particles, concoction contaminants, etc. Its utilization is basically confined to circling oil greasing up frameworks, although some investigation can be completed on oil oils.

Each of these is examined in somewhat more detail in the accompanying, alongside two or three different techniques, execution investigation and thermography, that have more particular applications.

.

## 1.3: Typesiand Benefits of Vibration Analysis

### 1.3.1 Benefits Compared with Other Methods

Vibration investigation is by a wide margin the most predominant technique for machine condition checking because it has a number of advantages compared with the other methods. It reacts immediately to change and can in this way be utilized for lasting and also irregular observing. With oil investigation for instance, a few days frequently slip by between the accumulation of tests. Additionally in correlation with oil investigation, vibration examination will probably indicate the real defective part, the same number of direction, for example,will contain metals with the same chemical composition,whereas only the faulty one will show expanded vibration. Above all, numerous effective sign handling systems can be connected to vibration signals to extract even very weak fault indications from noise and other masking signals.Most of this book is worried with these issues.

### 1.3.2. Permanent versus Intermittent Monitoring

Critical machines often have permanently mounted vibration transducers and are continuously observed with the goal that they can be closed down quickly on account of sudden changes which may be a forerunner to calamitous disappointment. Despite the fact that programmed shutdown will in all likelihood upset generation, the noteworthy harm that could happen from calamitous failure would usually result in much longer shut downs and more costly damage to the machines themselves. Critical machines are often spared so that the reserve machines can be started up promptly to proceed with creation with at least interruption. Most basic fast turbo machines, in for example power generation plants and petrochemical plants, have built-in vicinity tests which consistently screen relative shaft vibration, and the associated monitoring systems often have automatic shut down capability. Where the machines have riggings and moving component heading, or to distinguish sharp edge blames, the for all time mounted transducers ought to likewise incorporate accelerometers.

## 1.4: Vibration Measurements

Vibration Transducers exist for measuring every one of the three of the parameters in which horizontal vibration can be communicated, to be specific uprooting, speed and increasing speed. In any case, the main commonsense (condition observing) transducers for measuring relocation, vicinity tests, measure relative dislodging instead of supreme removal, while the most widely recognized speed and quickening transducers measure total movement. Following are different types of sensors used for measurement of vibration signals:

### 1.4.1 Proximity Probes

Proximity tests give a measure of the relative separation between the test tip and another surface. They can be founded on the capacitive or attractive properties of the circuit including the hole to be measured, however by a wide margin the most omnipresent nearness tests are those in view of the progressions in electrical inductance of a circuit realized by changes in the hole. The medium in the gap must have a high dielectric value, but can be air or another gas,or for illustration the oil in fluid film heading. The surface whose separation from the test tip is being measured must be electrically leading, to permit the era of whirlpool streams by induction. A signal is generated by a 'proximitor' (oscillator/demodulator) at a high frequency and its plentifulness is specifically reliant on the extent of the crevice between the test and the estimation surface. Abundancy demodulation methods are utilized to recover the sign. A run of the mill test can quantify sensibly straightly in the hole range from 0.25 to 2.3mm with a greatest deviation from linearity of 0.025mm (1.1% of full scale) with an affectability of 200mV/mil (7.87V/mm). Along these lines, in the feeling of the proportion of greatest to least esteem, the dynamic extent is under 20dB, however in the feeling of the proportion of the most extreme to least segment in a range, this would be constrained by the nonlinearity to, best case scenario 40dB.

1.4.2 Velocity Transducers

Transducers do exist which give a signal proportional to absolute velocity. They are effectively a loud speaker coil in reverse and typically have a seismically suspended coil in the magnetic field of a permanent magnet attached to the housing of the transducer or the inverse, where the coil is rigidly attached to the housing and the magnet seismically suspended.

1.4.3 Accelerometers

Accelerometers are transducers which deliver a sign corresponding to speeding up. By a long shot the most well-known sorts for use in machine condition observing are piezoelectric accelerometers, which make utilization of the piezoelectric properties of specific precious stones and pottery. Such piezoelectric components create an electric charge corresponding to strain. An alleged "pressure" sort, the piezoelectric components are sandwiched between a mass and the base, the entire get together being cinched in pressure through a spring. This plan can likewise be considered as one representation of the general vibration transducer whose recurrence qualities are appeared.

## 1.5: Signals Generated by Rotating Machines

In condition checking, changes in vibration signs are credited to changes in condition, so it is imperative that different elements which cause changes in vibration signs are impressively diminished or dispensed with. Vibrations tend to change with the rate and heap of a machine, so this area basically considers the signs created by a pivoting machine working at consistent speed and load, for which the signs will commonly be stationary and/or cyclo stationary. At times, use can be made of non-stationary signs, for example, those produced by a machine under keep running up or drift down conditions, however such flags ought to be handled with the proper examination systems

### 1.5.1 Unbalance, Misalignment, Bent Shaft

All three of these faults manifest themselves at shaft speed and possibly the first few harmonics of shaft pace.

#### 1.5.1.1 Unbalance:

Unbalance causes excitation by strengths pivoting at the pole speed when the neighborhood focal point of mass (CoM) of the cross-area is not at the focal point of turn. The reaction relies on upon whether the inertias on the pole are restricted or circulated pivotally, and whether the pole is running beneath or over its first basic velocity. In the event that the pole is short and the dormancy confined, there will fundamentally be an outspread power turning at shaft speed, which energizes vibrations essentially in the two spiral bearings, yet almost no pivotally. Where the spiral solidness of the pole and bearing backings is high, the reaction vibration will be firmness controlled.

#### 1.5.1.2 Misalignment

When a pole has three or more course, for instance when two machines are coupled together , there is a potential for misalignment, which can be parallel misalignment, implying that one of the two shafts is dislodged horizontally, yet at the same time parallel to the next, or rakish misalignment, where the pivot of one is at an edge to that of the other. Such misalignment brings into the poles twisting deflections which are fixed spatially,but turning as for the poles. The impelled bowing minutes in this way rely on upon the bowing solidness of the pole and must be balanced by powers at the heading and the establishments. Where the pole solidness changes with pivot edge, as created for instance by a key way, the firmness will ordinarily differ twice per transformation thus the fixed removals will give fluctuating minutes and powers, and vibrations, shifting in light of current circumstances.

1.5.1.3 Bent Shaft

If a shaft that is initially balanced acquires a permanent bow for some reason, the results will be a combination of the effects of unbalance and misalignment. If the reason for the bow is related to the unbalance, as now and again of 'warm bow', where "rubbing" happens amongst rotor and stator, bringing about a nearby problem area and warm extension, there might be specific manifestations which help in the determination.

1.5.1.2 Cracked Shaft

Development of a split in a pole is a standout amongst the most genuine flaws to be recognized in condition checking, specifically of expansive rotors, for example, in turbo generators, thus it has been considered in depth. An immediate problem is that even a large crack has only a small effect on the natural frequencies of a pole and none when the break is shut. Cases have been recorded where a transverse break in a rotor had advanced through 25% of the width and just changed the basic pace by 2.6%

1.5.1.3 Rotor /Bearing/Foundation Models

From the examination it can be seen that unbalance, misalignment and broke shaft would all be able to offer ascent to changes at the pole velocity and its low music, and straightforward standards can't be given to recognize them. There is an inclination for unbalance to give a reaction essentially at 1X in the spiral heading, and for misalignment to give more reaction at 2X and in the pivotal bearing, yet exemptions proliferate. A breathing split will likely give more noteworthy changes at 3X, yet this is not one of a kind. For the most basic machines it is turning out to be more basic to create scientific models of the rotor/bearing/establishment framework in order to have the capacity to anticipate better the progressions given by different sorts and levels of flaws.

## 1.6: Vibrations from Gears

Riggings are broadly utilized as a part of machines to transmit power starting with one shaft then onto the next, more often than not with an adjustment in velocity and torque. The lion's share of apparatuses have conjugate profiles such that kinematically there will be a consistent yield speed for a steady info speed. The most well-known apparatus tooth profile is involute, as the pace proportion is then unfeeling to little varieties in focus separation, in spite of the fact that the 'weight point' changes.

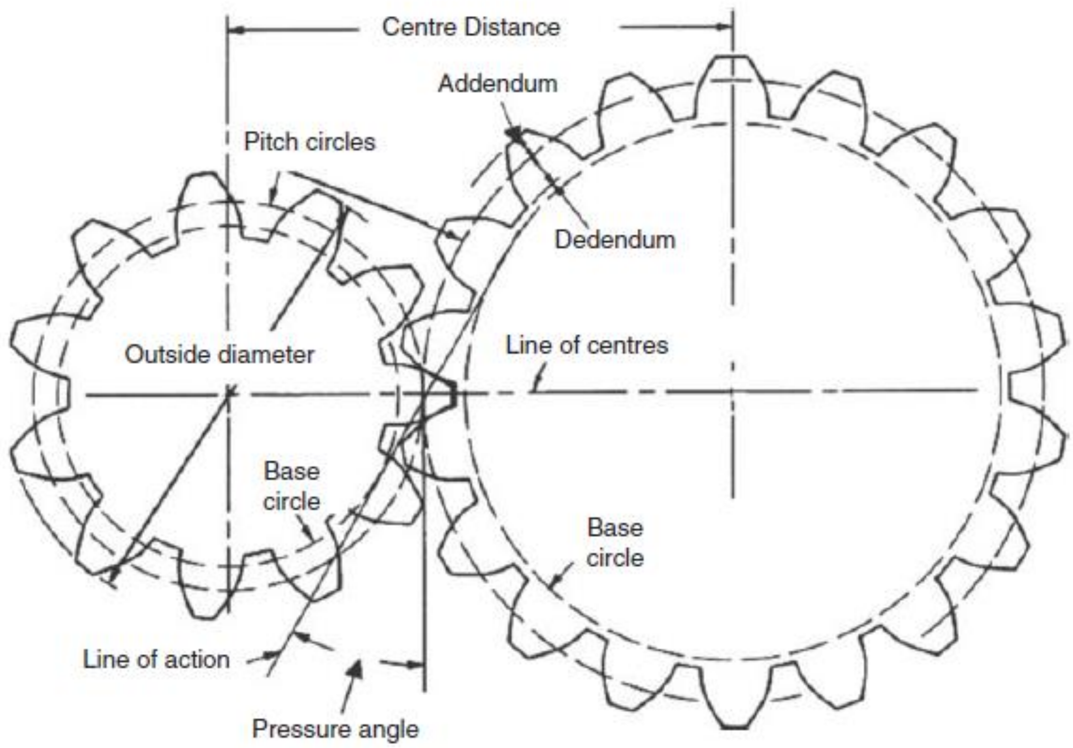



Figure:1: Gear Action

1.6.1 Rolling Element Bearings

Moving component direction are a standout amongst the most broadly utilized components as a part of machines and their disappointment a standout amongst the most successive purposes behind machine breakdown. Be that as it may, the vibration signals produced by deficiencies in them have been broadly considered, and effective indicative strategies are presently accessible as examined . It will be demonstrated that investigation of the envelope signals gives more indicative data than examination of the crude signs. The chart shows that as the moving components strike a neighborhood issue on the external or internal race, a stun is presented that energizes high-frequency resonances of the whole structure between the bearing and the response transducer. The same happens when a deficiency on a moving component strikes either the inward or external race. As clarified, the arrangement of broadband blasts energized by the stuns is further balanced in abundancy by two variables:

The quality of the blasts relies on upon the heap borne by the moving element , and this is regularly regulated by the rate at which the flaw is going through the heap zone. Where the issue is moving the exchange capacity of the transmission way fluctuates concerning the fixed positions of reaction transducers.

### 1.6.2 Electrical Machines

Electrical machines, engines and generators, have vibrations prompted by electromagnetic strengths notwithstanding the standard powers from mechanical impacts, for example, unbalance, misalignment, etc.

Just AC (Alternating Current) machines are dealt with here, as they are by a long shot the most common, notwithstanding for variable rate applications since the advancement of force gadgets. There is a key contrast between synchronous engines (and generators), where the rotor keeps running at synchronous rate, and actuation (non concurrent) engines, where the rotor keeps running at marginally not exactly synchronous rate. In both cases there is a turning attractive field in the stator, whose velocity relies on upon the quantity of posts.

. In the event that parts at mains recurrence are found in measured vibration signals, suspicion ought to promptly fall on the estimation framework, as they would typically originate from electrical obstruction impacts, for example, 'ground circles'.

## 1.7: Signal Processing Tool

### 1.7.1 Fourier Series

The fundamental idea of Fourier investigation is to express flags as a summation of sinusoidal segments, and with couple of exemptions for all intents and purposes all signs can be deteriorated along these lines.

Fourier's unique investigation (now called Fourier arrangement) was connected to limited length signals In machine vibration investigation it is utilized fundamentally for occasional signs, as created by a machine pivoting at consistent rate.

### 1.7.2 The Discrete Fourier Transform

The inspected time signals in Section above are on a fundamental level of unbounded length, however when the record length is limited, this prompts the same circumstance as with the Fourier arrangement in that the range is discrete and the time record verifiably intermittent.

This rendition, known as the discrete Fourier change (DFT), relates most nearly to the Fourier arrangement in that the forward change is separated by the length of record N to give accurately scaled Fourier arrangement segments. On the off chance that the DFT is utilized with different sorts of signs, for instance homeless people or stationary irregular flags, the scaling must be balanced in like manner as talked about underneath. Note that with the exceptionally mainstream signal handling bundle MATLAB, the division by N is done in the backwards change. This implies the forward change is more like the Fourier necessary, however it then requires scaling for each situation, as it must be duplicated by what might as well be called dt, that is the example interimt, to scale and effectively measurement the necessary.

### 1.7.3 The Fast Fourier Transform

The quick Fourier change (FFT) is just an exceptionally proficient calculation for ascertaining the DFT Equations. Beginning with the framework form in the least complex structure (the purported radix 2 calculation), the FFT depends on N being a force of 2 and factorizes an adjusted rendition of the network Wkn into log2 N frameworks each with the property that increase by them just requires N complex operations as contrasted and the N2 operations required for direct increase by Wkn. Therefore the aggregate number of complex operations is lessened from N2 to N log2 N, a sparing by a component of more than 100 for the common situation where N = 1024 (= 210).

### 1.7.4 Hilbert Transform

The Hilbert change can be said to be the relationship between the genuine and nonexistent parts of the FT of an uneven capacity. For instance, any motivation reaction capacity is causal what's more, therefore uneven in the time area, and this implies the genuine and nonexistent parts of the relating recurrence capacity (e.g. that appeared in Figure 3.15) are connected by a Hilbert change. That there ought to be a relationship gets to be apparent when it is viewed as that a causal capacity is comprised of even and odd parts which are indistinguishable for positive time, what's more, in this manner cross out for negative time,a Hilbert change can be accomplished all the more essentially by changing into the recurrence area, moving the period of positive recurrence parts by $-\pi/2$ and of negative recurrence segments by $+\pi/2$, and after that changing back to the time space.

1.7.5 Demodulation

Adjustment happens when a generally sinusoidal sign, an alleged 'bearer signal', has its plentifulness or recurrence set aside a few minutes. In the principal case it is known as sufficiency adjustment, and in the second it can be considered as a recurrence or stage tweak. Stage adjustment is the deviation in stage (precise removal) from the straightly expanding stage of the transporter, while recurrence tweak is the distinction in quick recurrence (rakish speed) from the steady bearer recurrence. Consequently, recurrence tweak is the subsidiary of stage adjustment.

1.7.7 Time Synchronous Averaging

The exemplary method for isolating intermittent signs from foundation commotion (and everything else not intermittent with a specific key recurrence) is by time synchronous averaging (TSA). It has been utilized over numerous years for extricating the vibration signal comparing to a specific gear in a gearbox.

Practically speaking it is finished by averaging together a progression of sign sections each relating to one time of a synchronizing signal.

1.7.8 Adaptive Noise Cancelation

Versatile clamor cancelation (ANC) is a method where an (essential) signal containing two uncorrelated segments can be isolated into those parts by making utilization of a (reference) signal containing one and only of them. The reference signal does not need to be indistinguishable to the comparing part of the essential sign, simply identified with it by a straight exchange capacity.

### 1.7.9 Time–Frequency Analysis

In principle the FT requires mix over record-breaking, yet we are all mindful that the ear can distinguish changes in recurrence with time (e.g. music), thus an investigative method has been looked for which coordinates the ear's capacity to take after changing recurrence designs.

### 1.7.10 The Short Time Fourier Transform

A straightforward methodology is to move a brief span window along the record and acquire the Fourier range as an element of time movement. This is known as the brief span Fourier change (STFT).

Be that as it may, the vulnerability guideline implies that the recurrence determination is the corresponding of the viable time window length, and this doesn't appear to accord with the ear's valuation for the tonal nature of a note regardless of the fact that it goes on for a brief timeframe. Indeed, even in this way, the STFT is now and again valuable for following changes in recurrence with time, even with the limitation of determination.

### 1.7.11 Wavelet Analysis

Another way to deal with time–frequency examination is to disintegrate the sign as far as a family of "wavelets" which have a settled shape, yet can be moved and enlarged in time. Orthogonal wavelets are the most proficient to utilize when examination/union is to be performed (e.g. in the wake of denoising), or when the noteworthy components of the sign are to be spoken to with a base number of parameters (e.g. as inputs to simulated neural systems).

### 1.7.12 Wavelet Denoising

One of the essential uses of wavelets in machine diagnostics is in denoising of signs in both time and recurrence spaces at the same time. Most wavelet denoising is an augmentation of the work of Donoho and Johnstone, who characterized two sorts of thresholding to expel commotion, this being characterized as any segments with plentifulness not exactly a specific limit esteem. In supposed 'hard thresholding' the held segments are left unaltered, yet in 'delicate thresholding', the commotion gauge (the limit worth) is subtracted from them likewise (symmetrical treatment of positive and negative qualities ). More propelled techniques are constantly being created.

Figure demonstrates the aftereffect of denoising speeding up signs from a gearbox with a mimicked tooth root split, utilizing a proposed new double tree complex wavelet change (DTCWT).

## 2.LITERATURE REVIEW

**2.1** Enayet B. Hashim, Shirish L. Shah, Ming bJ. Zuo and A. Shoukat Choudhary (2006), In their paper proposed a new technique named 'Time-Frequency Domain Averaging'. This new technique is able to measure extract all information from noisy signals vibrations generated by meshing gears over one complete revolution and thus helps to gather signals produced by individual gears.

The drawback of this method is it cannot detects faults at an early stage.

Following figure represents the Time Frequency Domain Averaging technique in short.

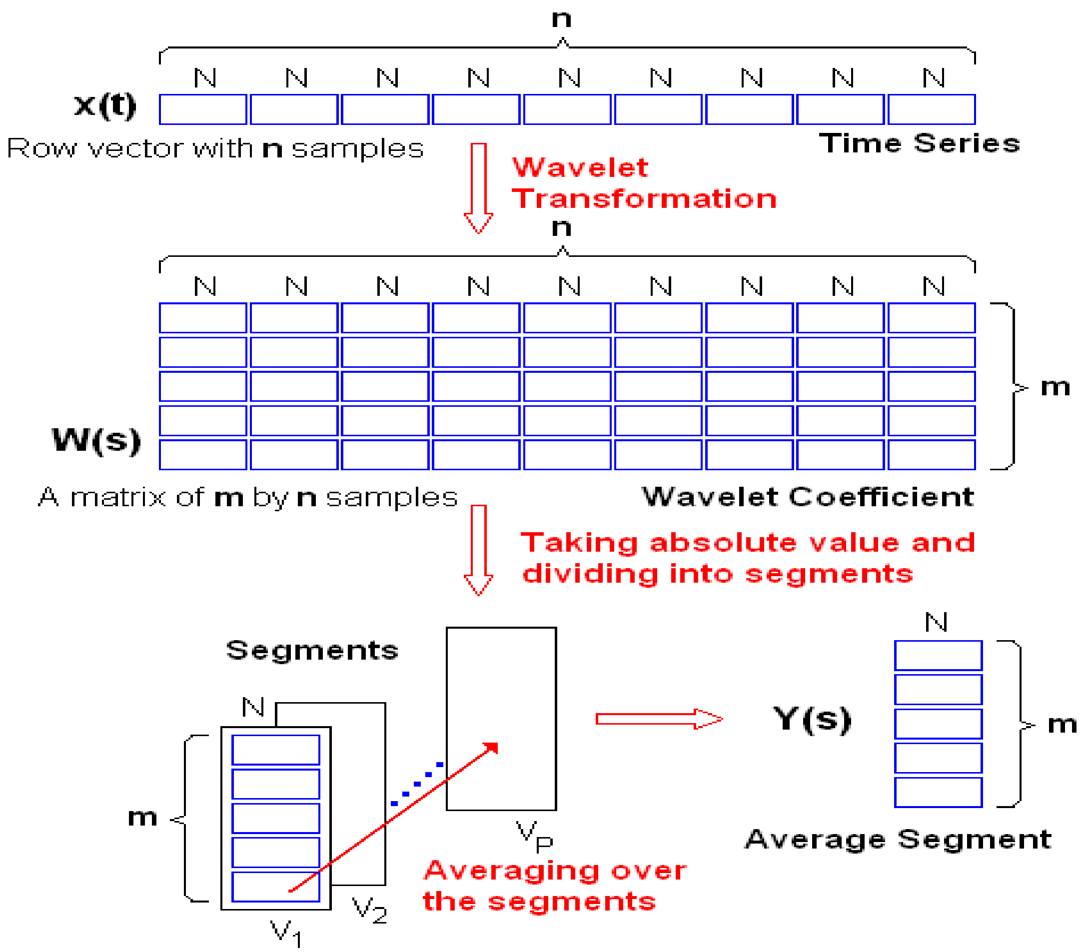



Figure: 2: Wavelet Analysis

In their pilot plant case study, they used a gear box with 3 shafts and 4 gears (a, b, c, d).The configuration of the gear box used to extract data was as following,

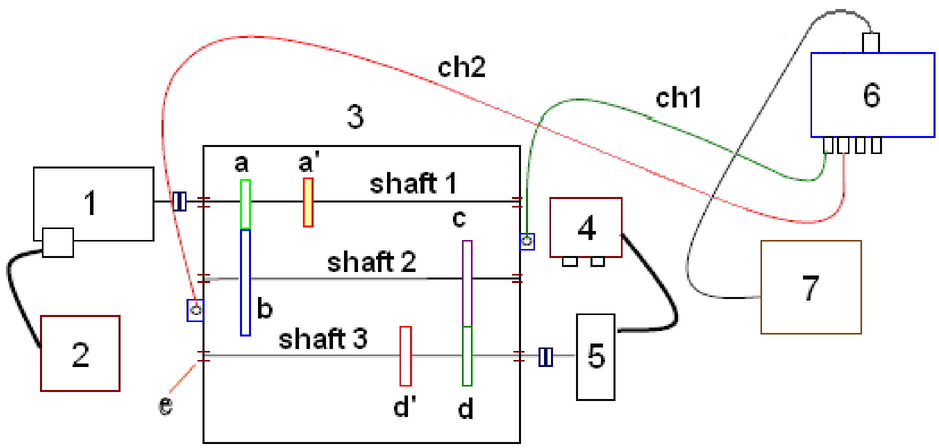



Figure:3: Actual Model

Whenever there is a fault in any gear of the test rig, Time Frequency Domain Averaged plot gives a peak in the plot.

Missing tooth has produced a largest peak while a chipped tooth has produced peaks at gear meshing frequencies as shown in following graphs.

1. Gearbox with all normal teeth:

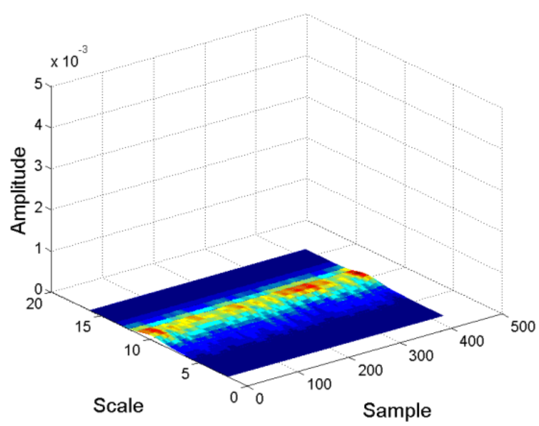



Figure:4:Normal Gears Readings

2. Gearbox having one tooth chipped on a gear:

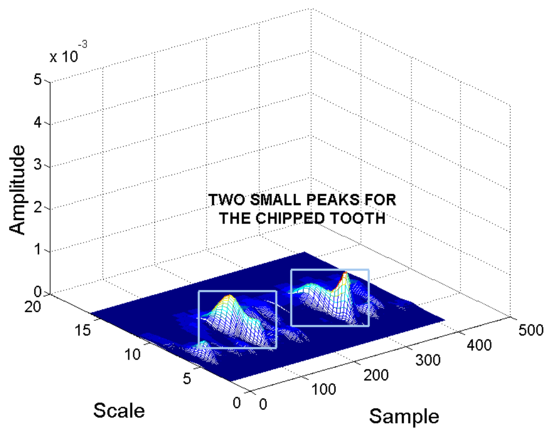



Figure:5:Chipped Tooth Readings

3. Gearbox with one missing tooth on a gear :

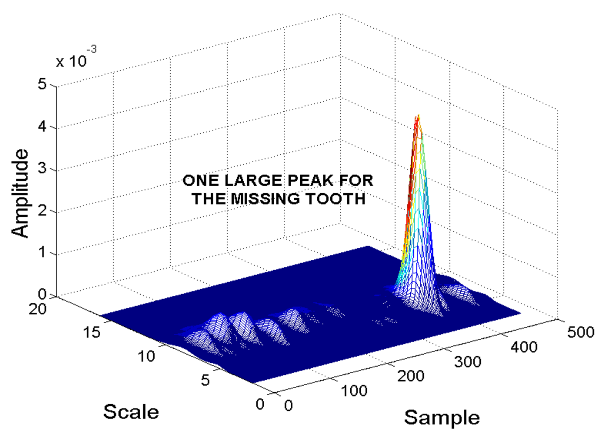



Figure:6: Missing Tooth Gear

4. Gearbox with a gear having chipped tooth and another one having missing tooth:

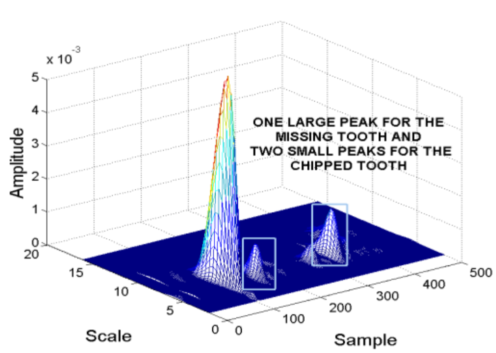
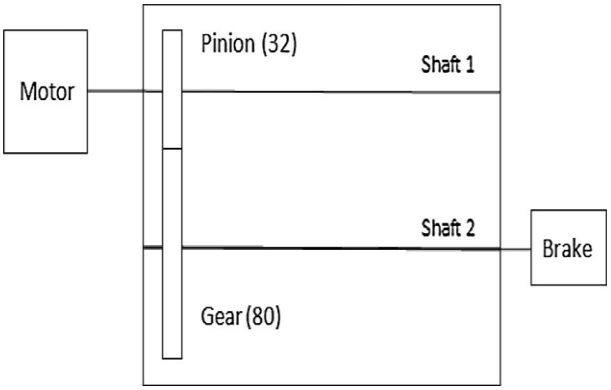



Figure:7: Combined missing and cracked tooth Readings

From the plots, The technique not only could detect the large faults ex: missing tooth but also sensitive towards small chipping of the tooth.

**2.2** Nizar Ahamed, Anand Parey and Yogesh Pandya in their paper developed a methodology called Time Synchronous Averaging method for fault detection of a gearbox at various loads and speed conditions.

Experimental setup consist of single stage gearbox as shown below,



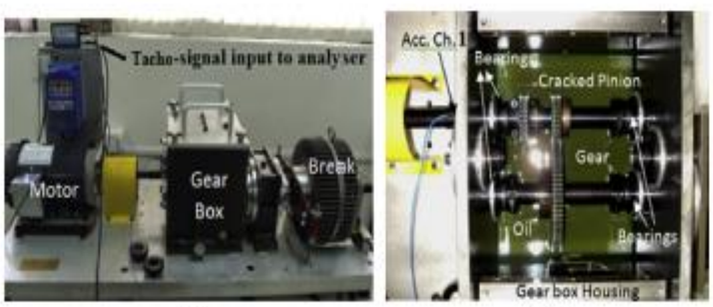




Figure:8:Actual Model

The results obtained were as following,

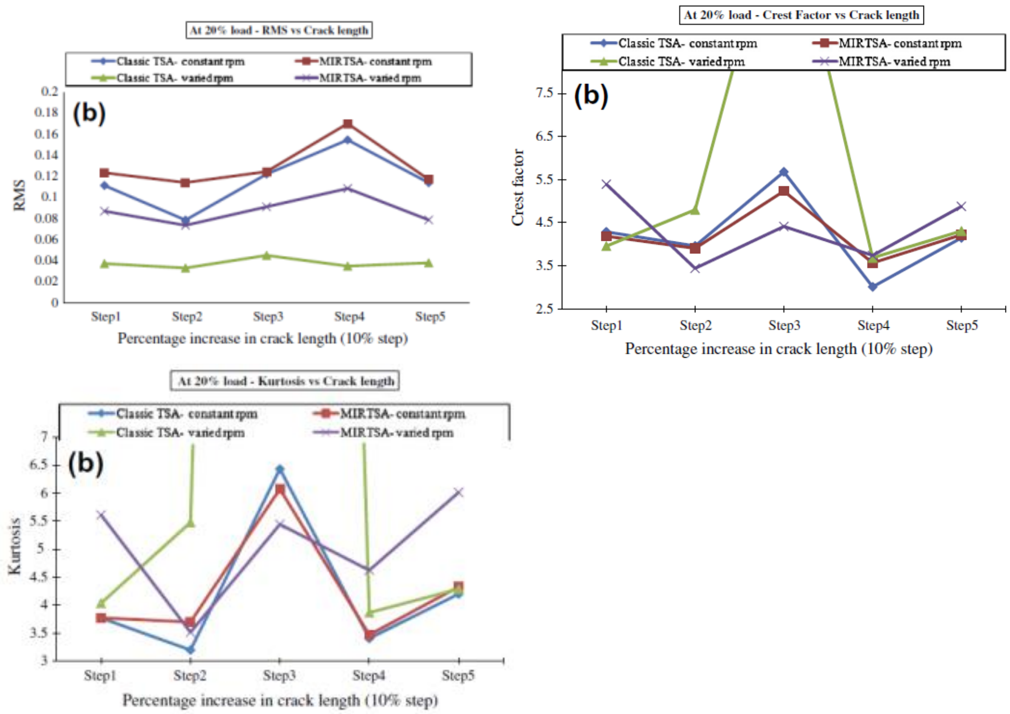



Figure:9:Readings

From the above results, it can be seen that Kurtosis value shoots up for a cracked tooth of a gear. The RMS plot is very useful from the fault detection point of view, while the Crest Factor and Kurtosis does not serve the purpose.

**2.3** Hanxin and Ming J. Zuo (2009), In their paper proposed a method for detection of gear crack from the measured vibration signal, The method is based on Adaptive Wavelet Transform and Hilbert Transform. Hilbert Transform is a good method for signal demodulation for fault diagnosis of gear. This method has a high capability to detect the gear fault.

In experimental setup, they mounted two accelerometers along both horizontal and vertical directions. There are three shafts with five gears mounted, to form a two stage gearbox. Using rotational speed of motor and number of teeth of driver and driven gears, The speed and characteristics frequency of individual gear is determined.The experimental setup was as following,

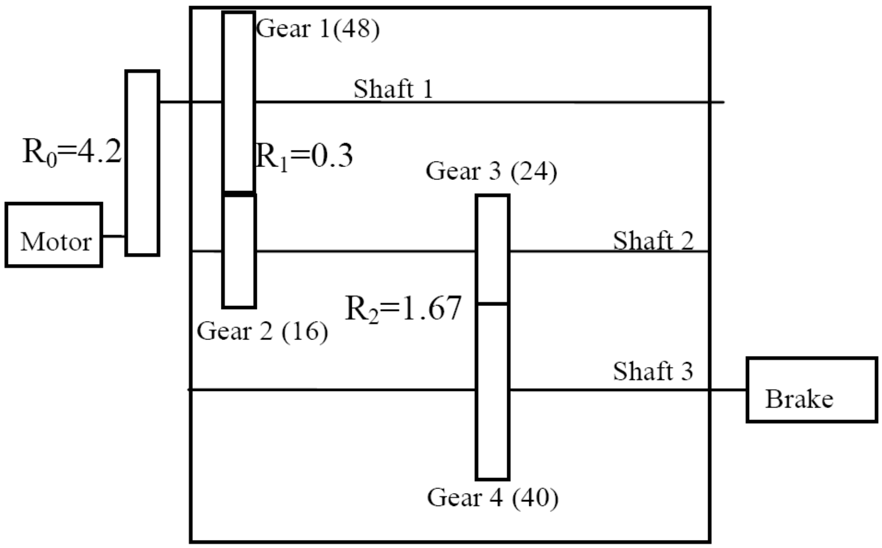



Figure:10:Actual Model

Gear number 3 has to be selected to simulate. The crack along the normal curve of teeth has occurred.

From the obtained experimental vibrations signals. The gear having local fault (ex. crack), generates the sidebands. These sidebands may be shaft rotational speed or one of its multiple. From the following graph of the Adaptive Wavelet Transform the shaft rotational frequency which is 5.71 Hz is easily identifiable and hence a clear indication of the gear tooth crack.

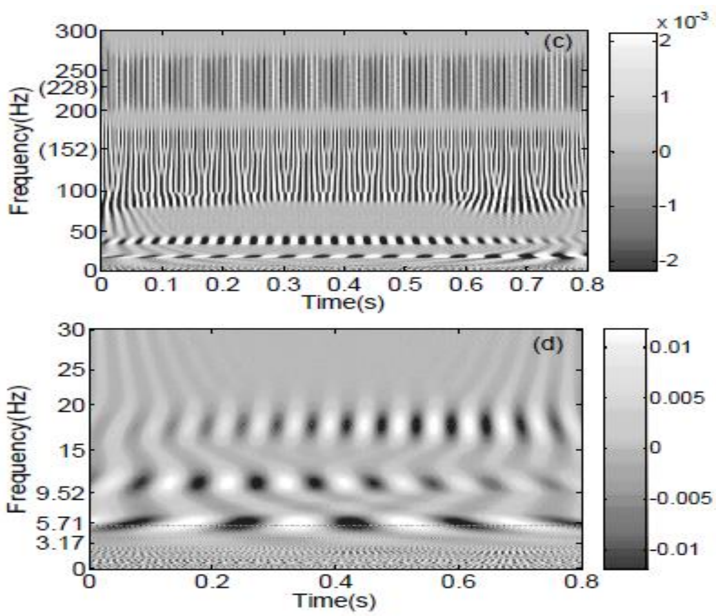



Figure:11:Time Frequency Plot

**2.4** Hui Li, Yuping Zhang And Haiqi Zheng, In their paper presented a unique method to process the non-stationary raw vibration signals of a gear drive effectively during the running period. The combined method containing Angle Domain Average and Continuous Wavelet Transform for the gear box fault detection. The raw vibration signals with constant time increment were sampled and then again sampled with constant angle increments i. e. time domain signals were converted to angle domain. At the end these signals were studied using Continuous Wavelet Transform. In Aangular Sampling, readings were taken in digital format with equal spacing of angular displacements.

Below is a time domain raw signal obtained (Fig. 1) and Resampled Data (Fig.2). From Fig. 3, We can see that there are 30 peaks related to 30 teeth of gear.

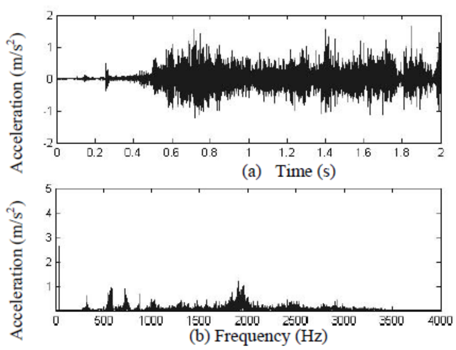


Fig.1 Time-domain signal for healthy gear and FFT

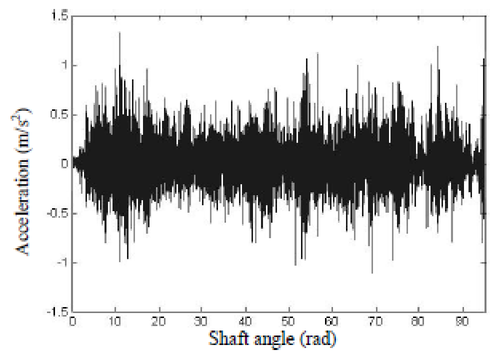


Fig.2 Angular resample signal

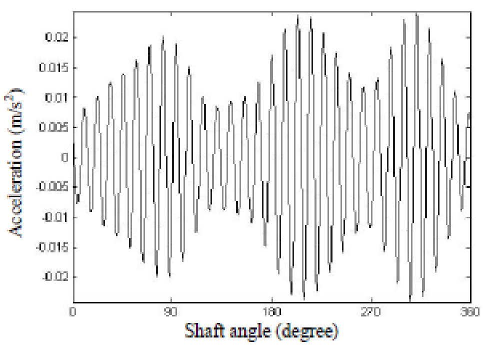


Fig.3 Angle domain average signal for healthy gear

Figure:12: Angle Domain Representation

Following Figures shows Wavelet Transform of Amplitude and Phase signals.

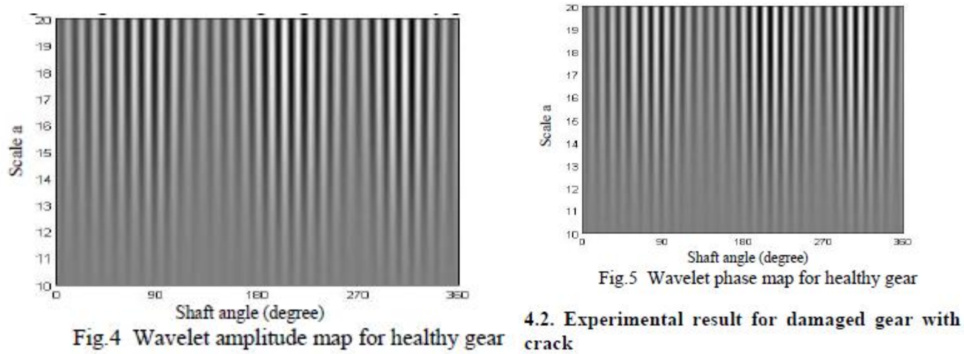



Figure:13: Amplitude Phase Representation

Following angle domain averaged signal shows an abrupt change in the amplitude at 90° indicating the position of crack,

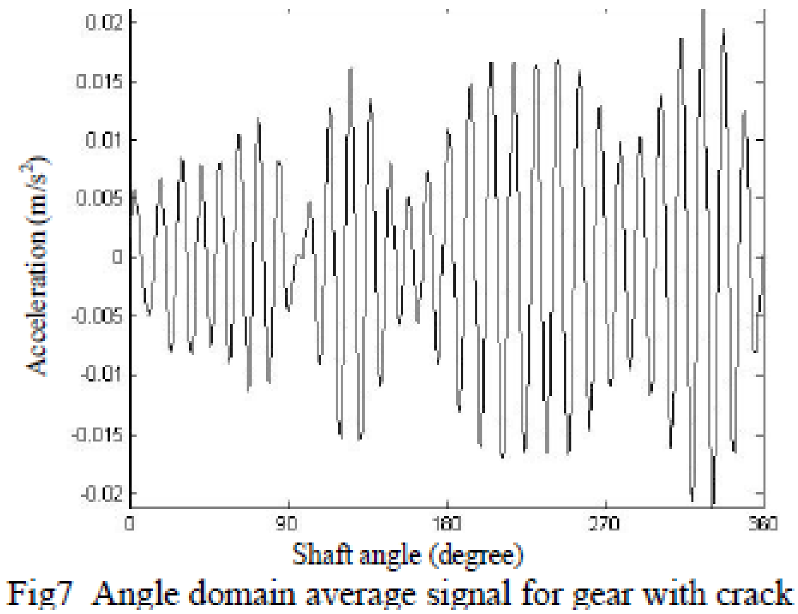
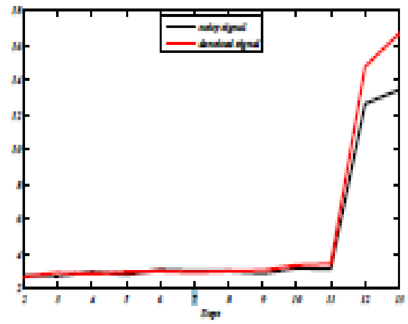



Figure:14: Angle Domain Averaged Signal

Above results shows that Angle Domain Averaging (ADA) and Continuous Wavelet Transform are good methods to detect the gearbox failure.

**2.5** Hafida Mahgoun, Rais Elhadi and Ahmed Felkaout in their paper used a method called Empirical Mode Decomposition (EMD) and Fast Fourier Transform (FFT) for post processing of the vibration signals obtained. At the end the technique is also compared to Wavelet Transform(WT) using experimental signals.

The results obtained are,



Kurtosis value of the acceleration signal from day 2 to day 11 before and after de-noising.

Figure:15:Kurtosis Plot

From the above results it can be seen that, Kurtosis values starts increasing for a faulty gear tooth after seventh day. Hence this method gives good result only for long running of the test rig.

**2.6** Ali Rostami, Rohallah Panahi, jalaleddin ghezavati and Mohammad Homaei intheir paper used a new technique called Hilbert Transform to post process the noisy vibration signals obtained from faulty and normal gearbox at various loadings. FFT diagram is plotted using MATLAB software.

The graph plotted is as follows,

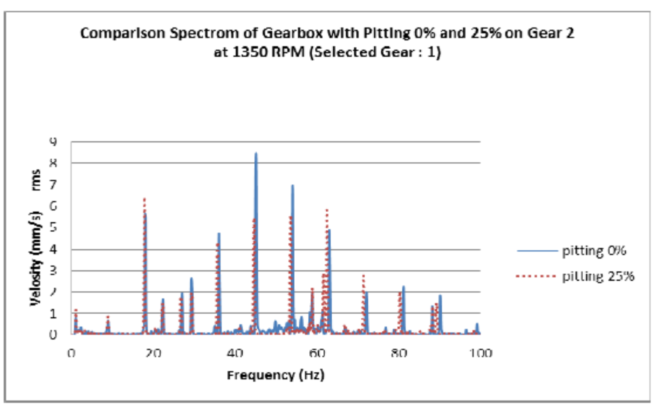



Figure 5-3: The signal from the faulty gear box (25% of teeth have been removed.)

Figure:16:Faulty Signals

From the above diagram, we can see thet time period of the graph is 3 seconds which is equivalent to 54 turns of a faulty gear.

**2.7** Wei Teng, Feng Wang, Kaili Zhang, Yibing Liu and Xian Ding in their paper stated that Hilbert Transform method used for the detection of gear box fault reguires human intervention. They have used method called Emperical Mode Decomposition (EMD) to decompose the acquired vibration signals into Intrinsic Mode Functions (IMFs).

Below is the schematic diagram of Wind turbine gearbox,

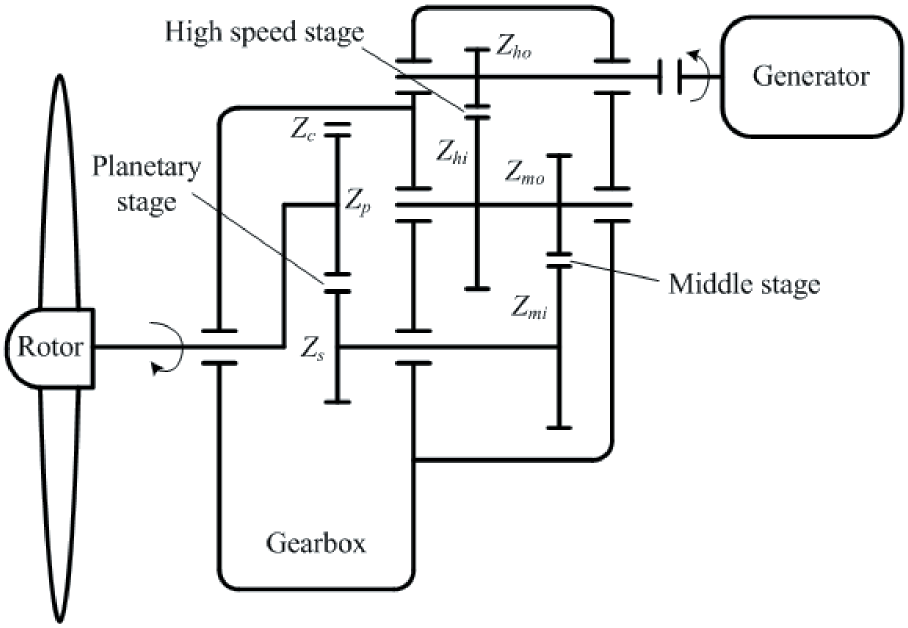



Figure:17:Helicopter Gear Box

From the plotted graphs as shown below, we can conclude that there can be fault present in the gears having high speed range.

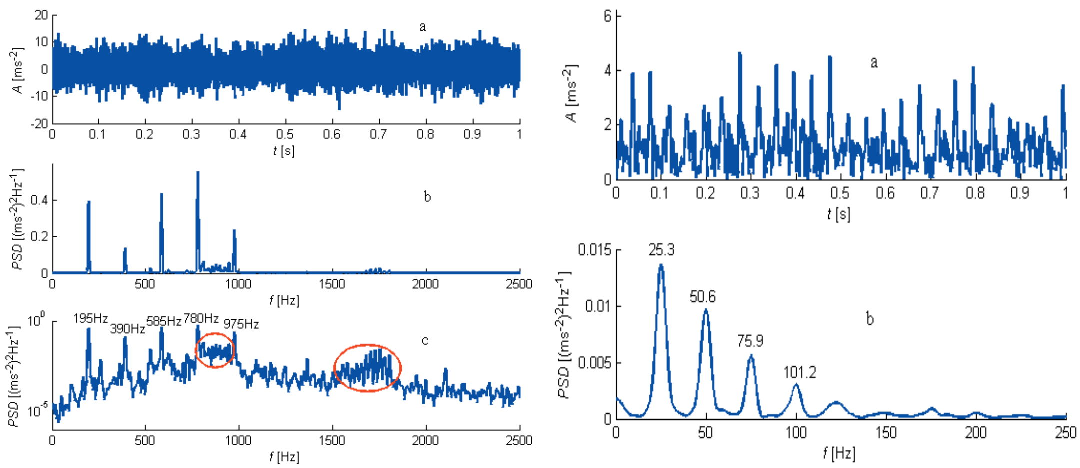



Figure:18: Processed Signals

EMD is a good method to detect fault in the gear of a wind turbine gearbox.

# 3. EXPERIMENTAL SETUP

The In the experimental setup, it consists of a single phase AC electric motor, which is coupled to a two stage reduction gearbox. A braking device is connected to the output shaft of a gearbox. A variable speed controller is connected to the electric motor and it varies the input speed of the motor. Further a Tachometer is used to measure the speed of the input shaft. The schematic of the experimental setup is somewhat like as shown below:

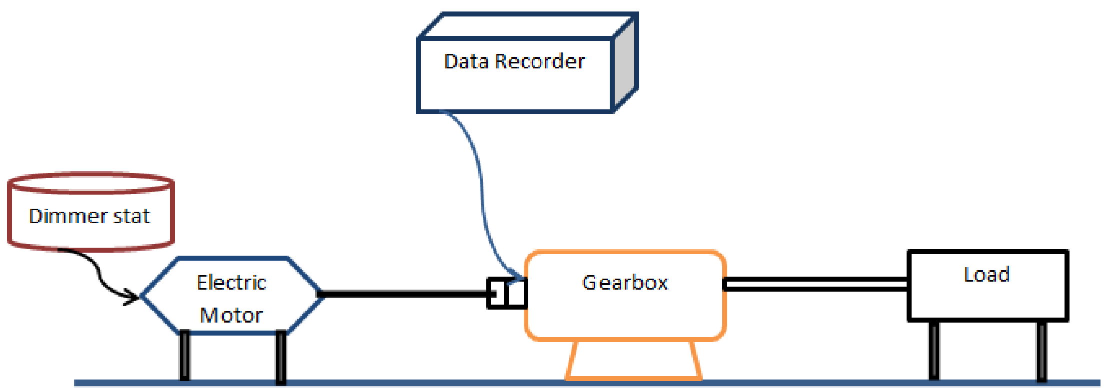



Fig. Schematic Diagram of Experimental Setup

Figure:19:Schematic Diagram Of Experimental Setup

The detailed description of the various other parts used in the experimental setup is as follows:

3.1. Single Phase Electric Motor:

The function of the electric motor is to convert the electrical energy into mechanical energy through the mean coupled to the motor spindle.

The configuration of the motor is:

Table:1:Electric motor specifications

| | |
|---|---|
| Rated Power: | 0.25 HP (or) 180W |
| Rated Speed: | 1440 RPM |

| | |
|---|---|
| Frequency: | 50 Hz |
| Making: | AUE Electric Motor Manufacturing Company |
| Voltage: | 230 V |
| Current: | 2.9 A |
| Weight: | 12 KG (Approx.) |


Figure:20: Electric Motor

3.2. Dimmer Stat or Variable Speed Drive:

Dimmer stat is an electronic device that controls the speed of electric motor by adjusting the power to be delivered.

The configuration of the Dimmer stat is:

Table:2:Dimmerstat specifications

| | |
|---|---|
| Rated Power: | |
| Type: | Portable Box Type Air Cooled |
| Frequency: Input:<br>Output: | 50-60 Hz<br>50-60 Hz |
| Making: | - |
| Voltage: Input:<br>Output: | 240 V<br>0-270 V |
| Current: | 0.6 – 22 A |
| Weight: | |

Following table gives the benefits of using Variable speed controller for the motor.

Table:3:Diference created

| Single speed drive motor | Variable speed drive motor |
|---|---|
| It starts the motor abruptly. Hence motor gets subjected to very high starting torque and surging problem. (Current may reach to 10 times that of full load current) | It gives very soft starting to the motor. Hence motor comes to operating speed gradually. |
| | |

Figure:21: Dimmerstat

3.3. Jaw Coupling:

Jaw coupling is used in power transmission applications. In addition to the torque transmission, it also helps in damping the vibrations generated and accommodates shaft misalignments. Jaw coupling contains two metallic hubs and one spider.

Figure:22:Jaw Coupling

3.4. Tachometer:

The function of the Tachometer is to record the RPM of shafts, Disks or any other such rotating element.

It displays RPM in Digital Dial.


Figure:23: Tachometer

3.5. Braking Device:

It is actually a circular plate provided with an arm. It is attached to the output shat of the gearbox. The function of the Braking Device is to operate the gearbox under various loads for testing purpose.

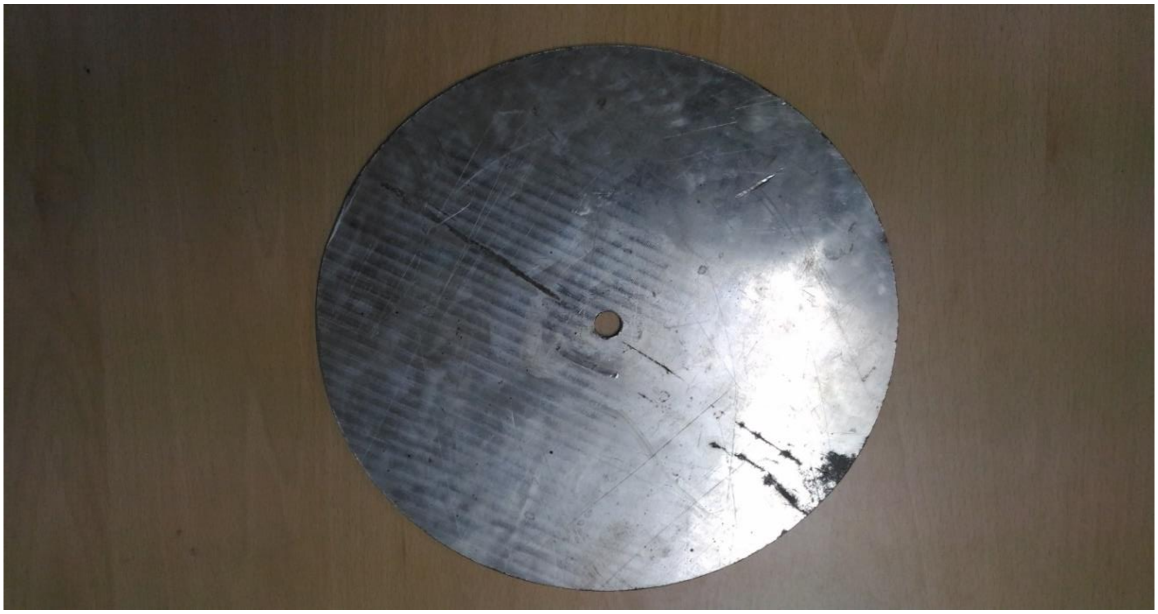


Figure:24: Braking Device

3.6. Gearbox:

A two stage reduction gearbox is used in the experimental setup. It has following specifications:

Number of shafts: 3

Number of gears: 4

Gear1:  50 Teeth

Gear2:  16Teeth

Gear3:  24Teeth

Gear4:  40Teeth

Following Figure shows the detailed view of the gearbox model:

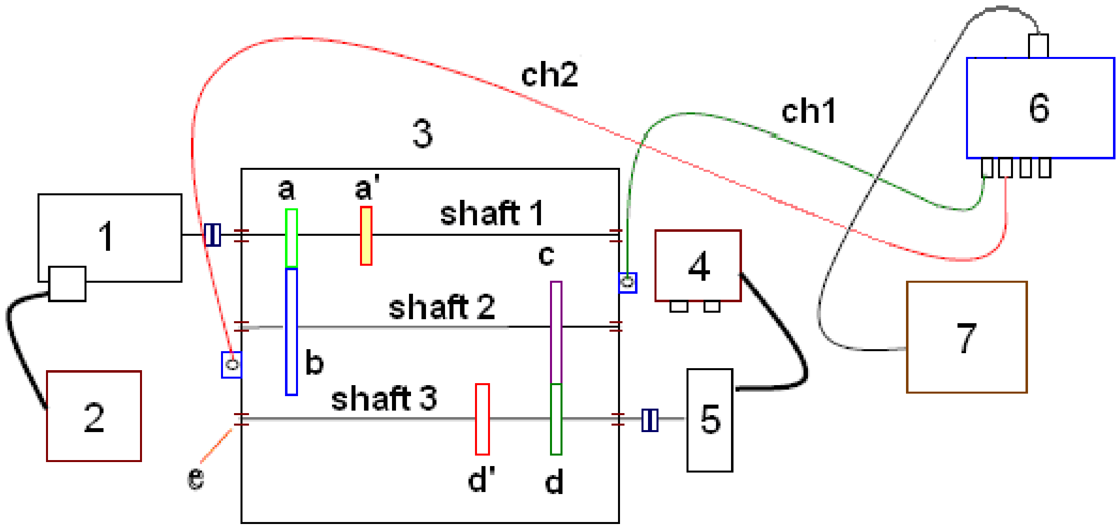


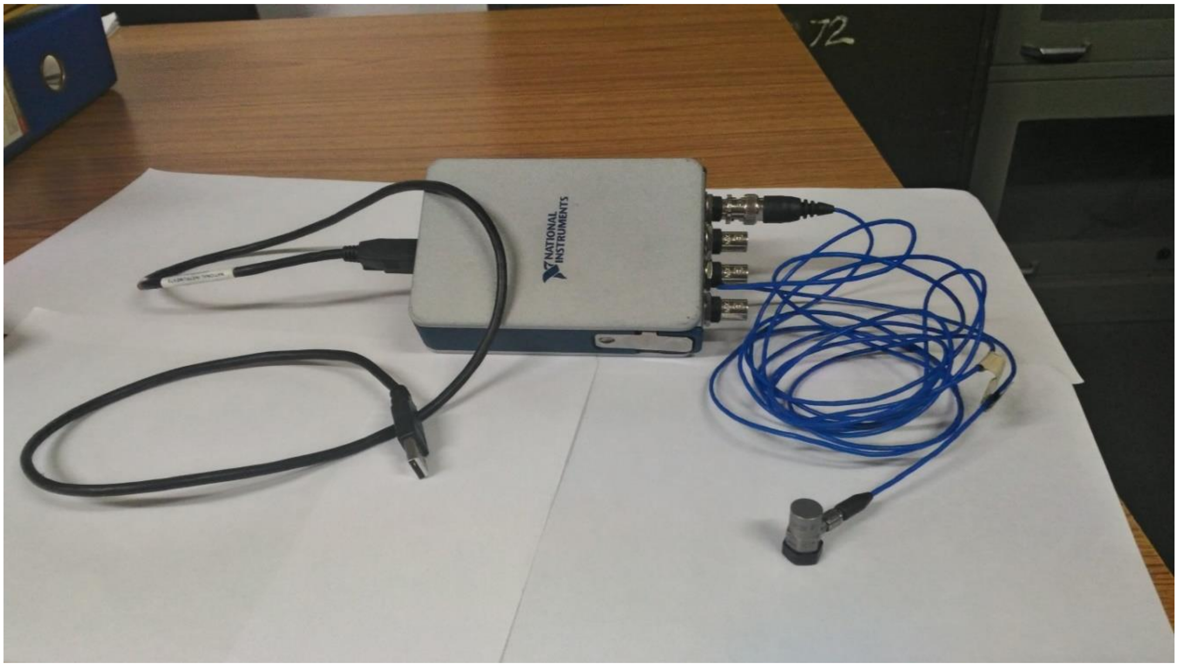

Figure:25: Schematic Diagram of Gearbox

Where,

1. Electric motor
2. Motor Speed Controller or Dimmer stat
3. Frame
4. Brake Pedal
5. Brake
6. Data acquisition unit
7. Computer

3.7. Data Acquisition Equipment:

It consists of a data acquisition circuit board in compact format and a biaxial sensor. Schematic diagram and actual diagram of the data acquisition part of the model is as shown below: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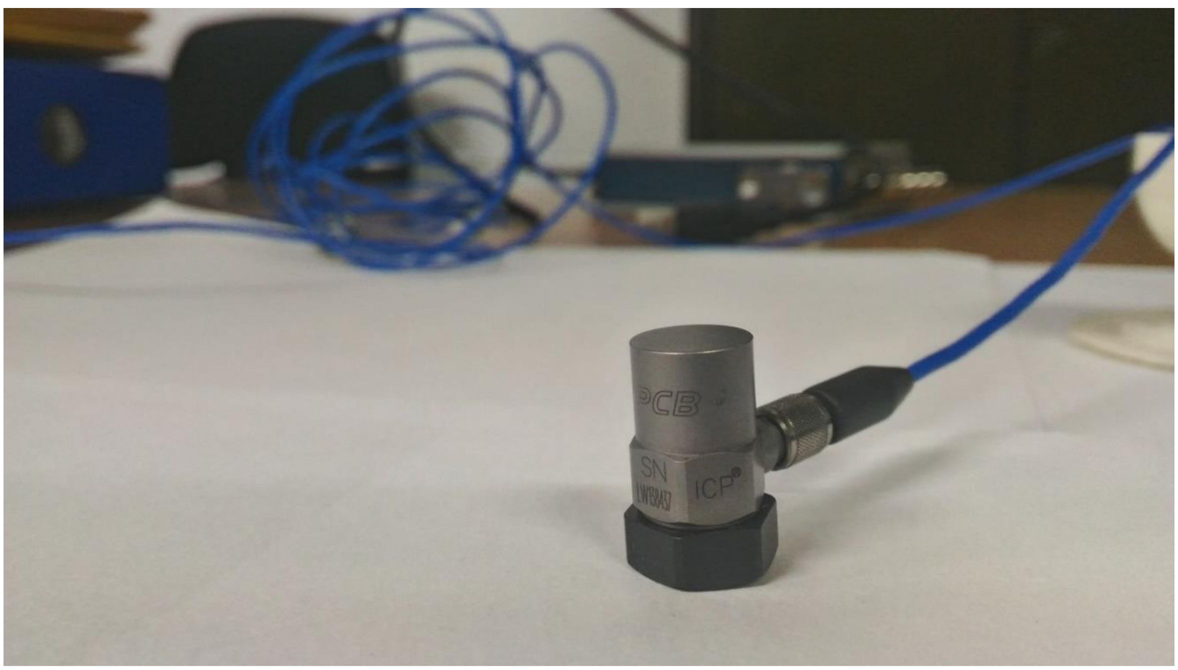

PCB
SN
ICP®


Figure:26: Data Acquisition Equipment

3.8. Bearings:

Shaft ends are mounted in the Ball bearing with housing. The bearings are bolted to a base frame. The bearings used are ball bearings with housing.

Figure:27:Bearing

3.9. Stainless Steel Shafts:

Stainless Steel shafts are used to mount the gears on it. The ends of shaft are fixed in bearing bush.

Figure:28:Shaft

# 5. FABRICATION

The fabrication and assembly was done at mechanical workshop. Frame is prepared by using arc welding, while the other components were bought from market. Hence their assembly was done only in workshop.

The machining of keys for the purpose of gear mounting was done in workshop near Ajmeri Gate (Jaipur, Rajasthan)

The complete gearbox with data acquisition unit looks like somewhat as below:

Figure:29:Experimental Setup

Inventor Modeling of the experimental setup is as following:

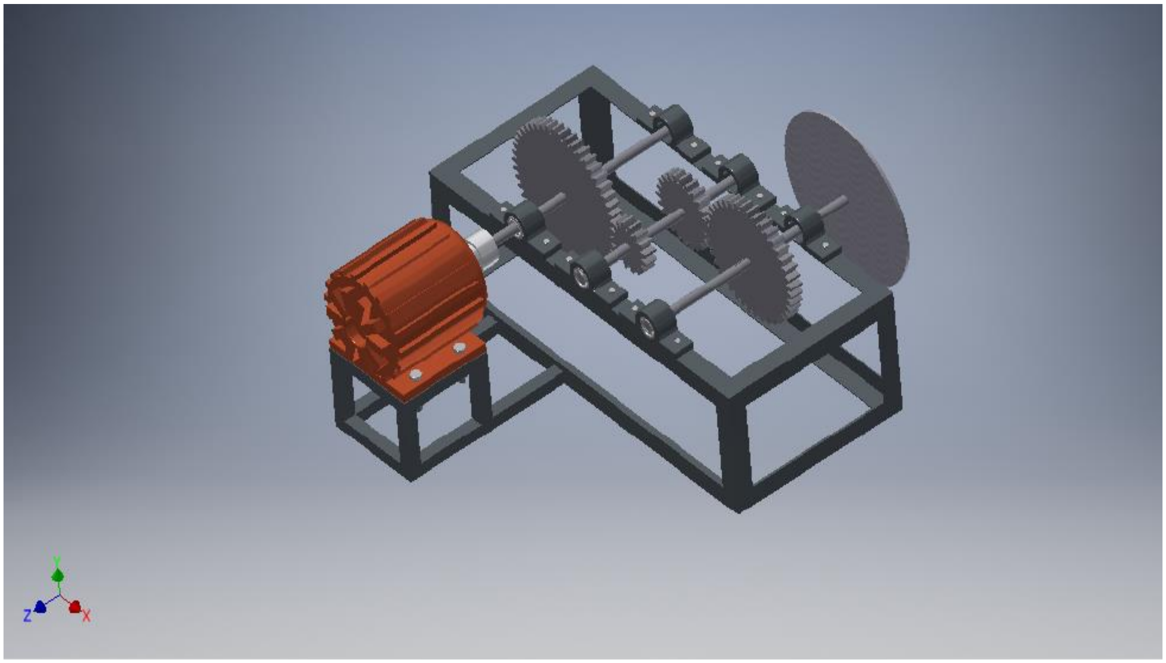



Figure:30: Inventor Model of experimental setup

# 5. RESULTS AND DISCUSSION

The graphs were plotted for different operating conditions of the gearbox, which includes:

1.Gearbox with All Normal Gears
2.Gearbox with One Missing Teeth gear
3.Gearbox with One tooth Chipped
4.Gearbox with chipped and missing tooth altogether

The experimental vibration signals collected from a gearbox using Data Acquisition Unit are used to test the proposed method. When a gear has a local fault such as crack, the vibration signal of the gearbox contains amplitude and phase modulations, which is periodic with the rotational frequency of the gear. The modulation of meshing frequency from the faulty gear generates the sidebands. The sidebands are either the shaft rotational speed or one of its multiples.

The connection diagram for the applied method "Adaptive Time Frequency Representation" in the LabVIEW software is as follows:

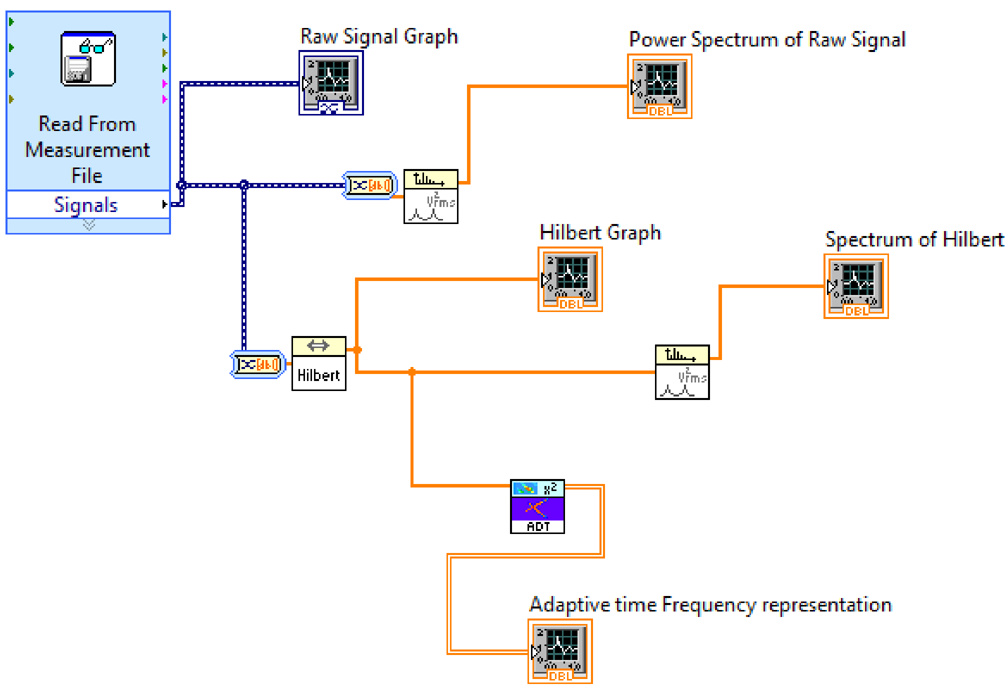
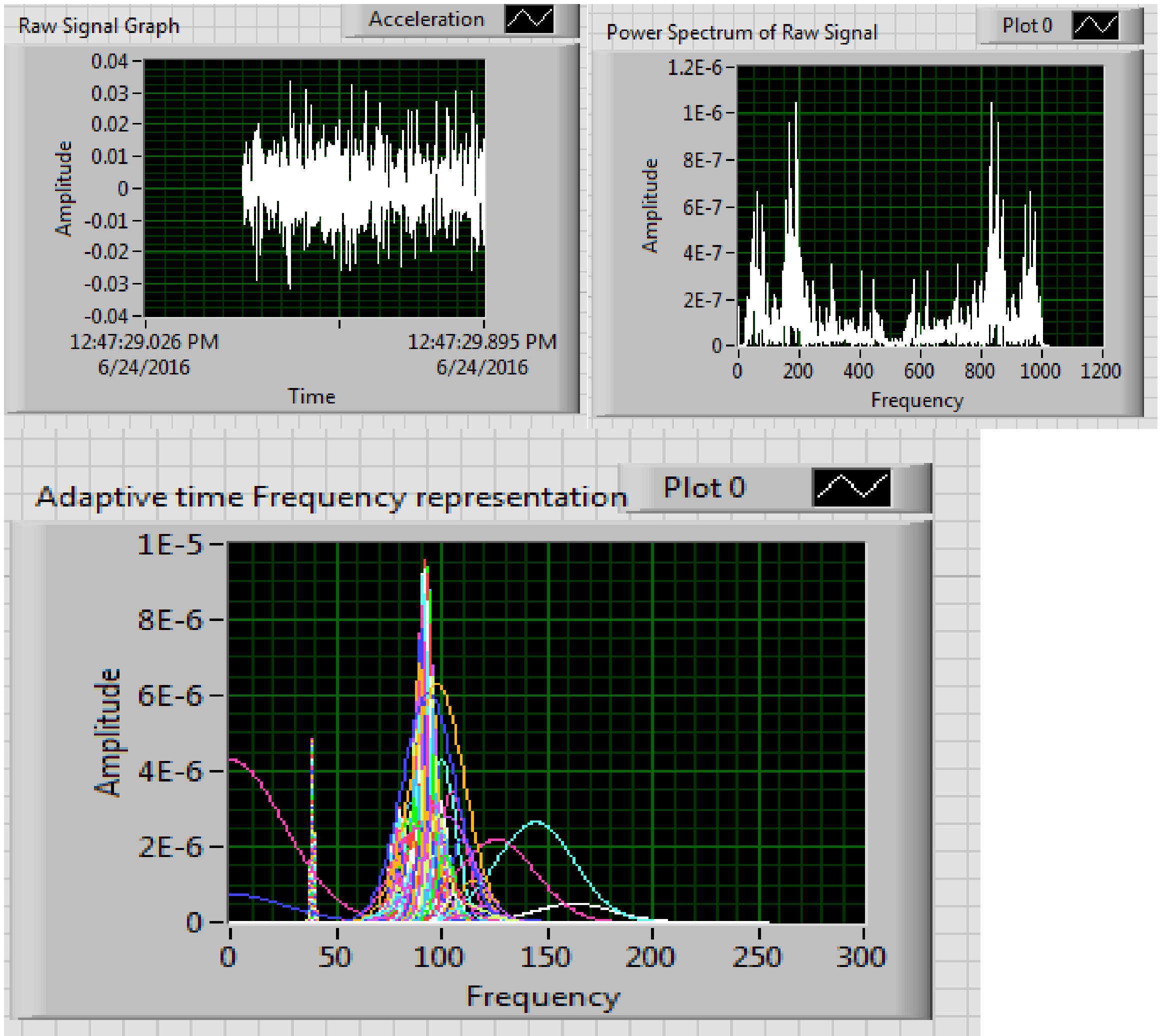


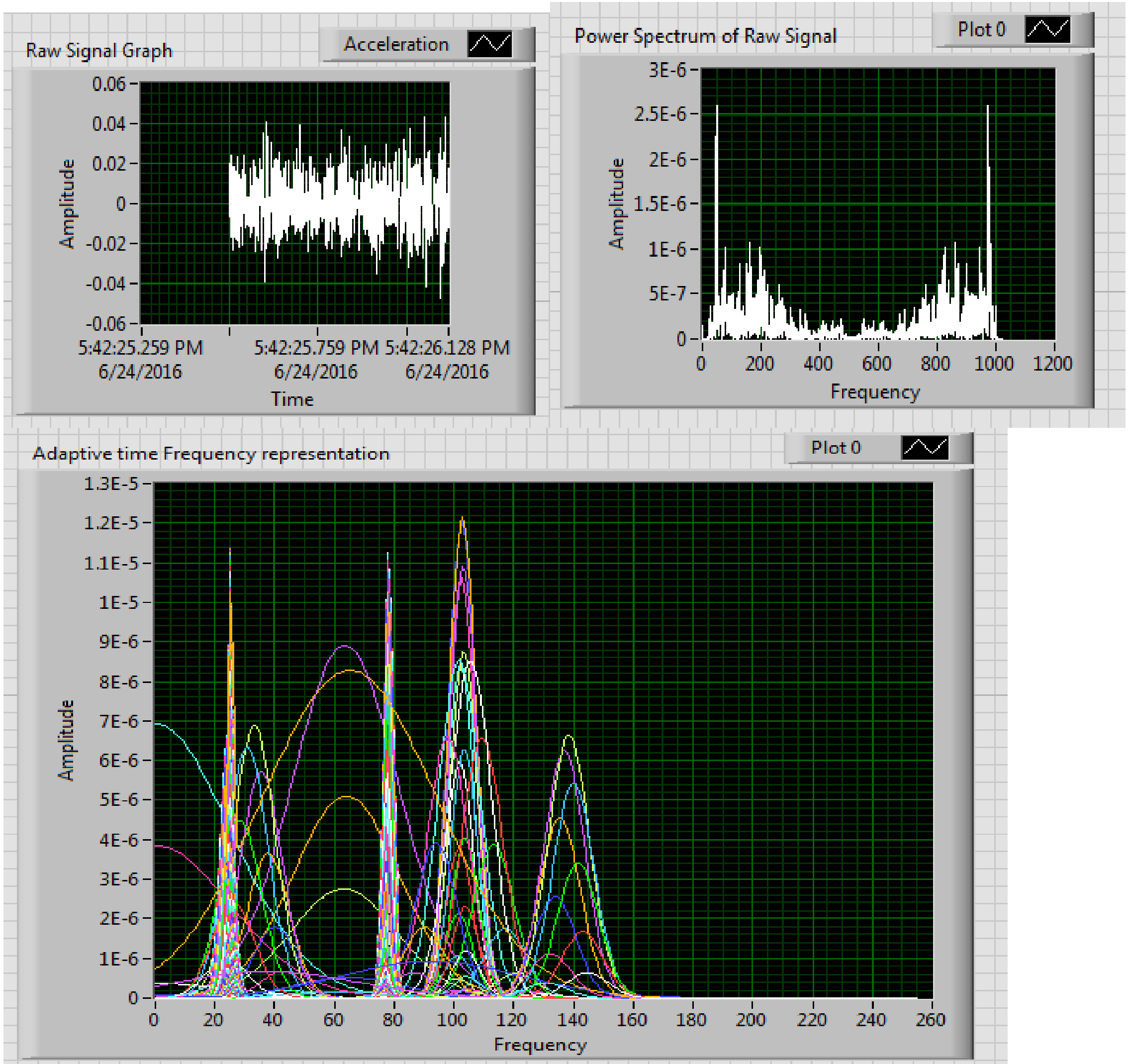

Figure:31:Connection Diagram in LabVIEW software

Graphs plotted for normal condition of gearbox are as follows:



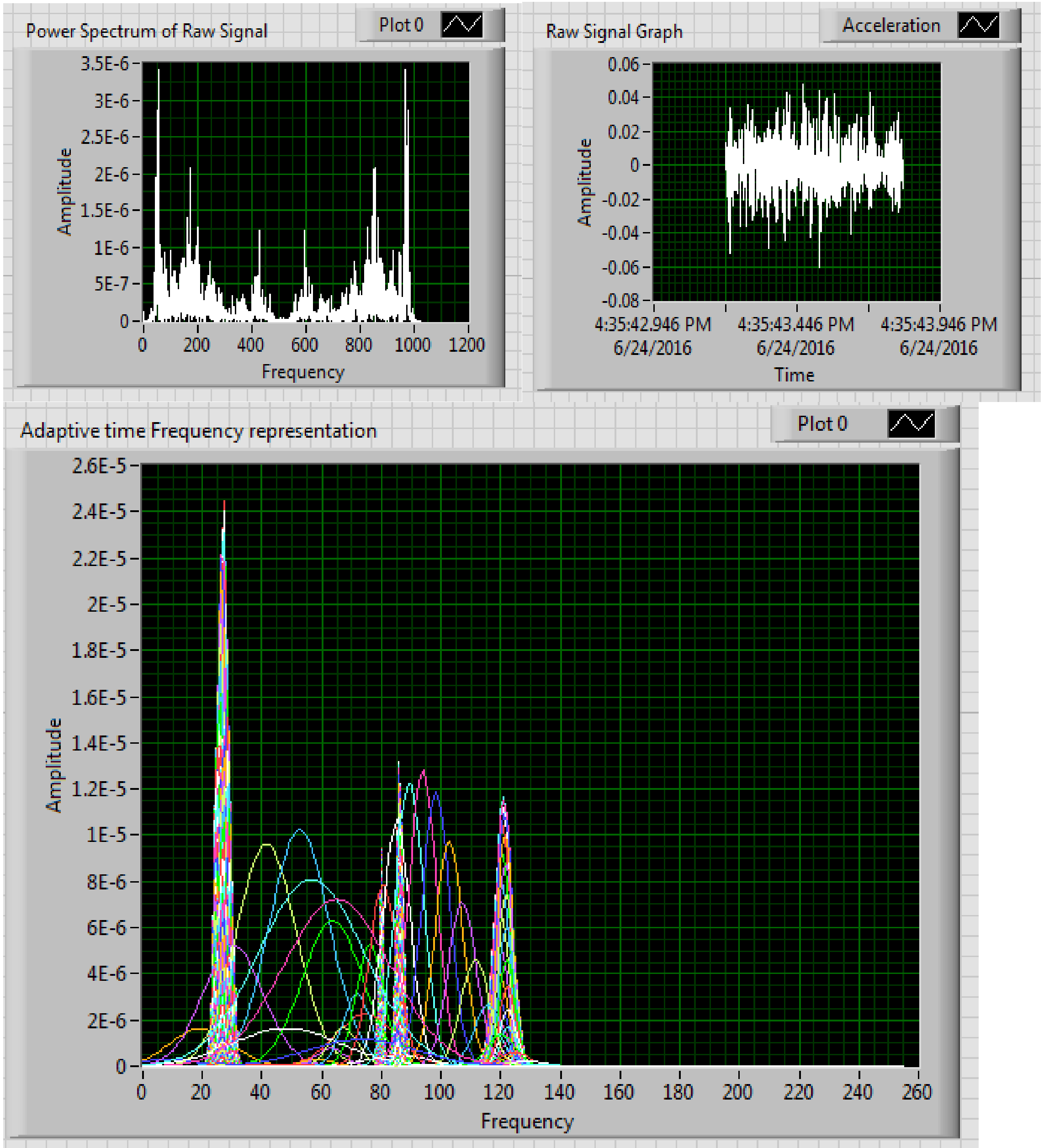

Graph:1: Normal condition Plots

The graphs plotted for missing tooth condition of a gearbox are as follows:



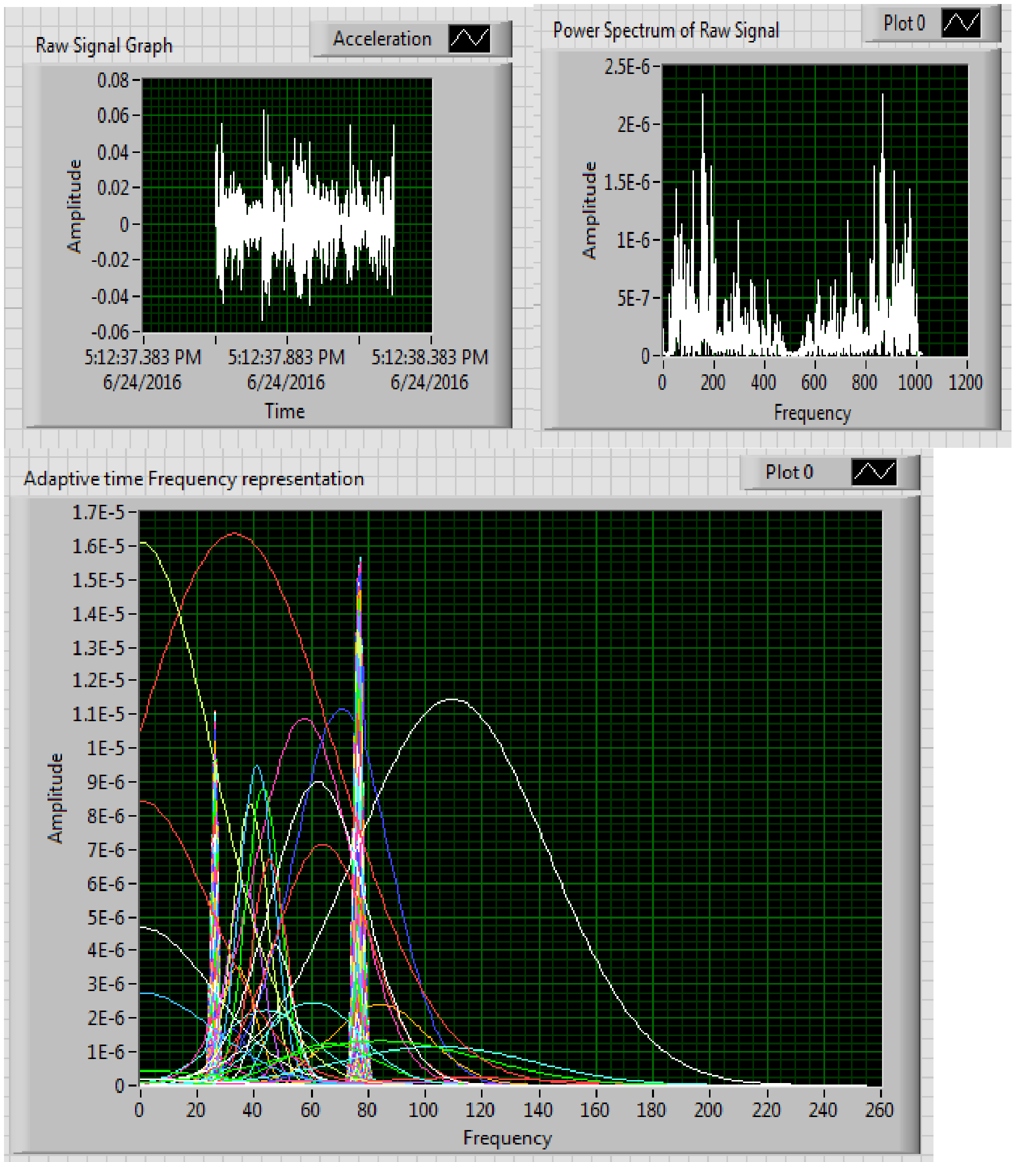

Graph:2: Missing Tooth condition Plots

The graphs plotted for cracked tooth condition of a gearbox are as follows:




Graph:3: Cracked tooth condition Plots

The graphs plotted for missing tooth and cracked tooth together condition of a gearbox are as follows:




Graph:4: Cracked plus Missing tooth condition Plots

Following table shows the rotational speeds of various shafts:

Table:4: Shaft Rotational Speeds

| | | | |
|---|---|---|---|
| Shaft 1 | 150rpm | 240rpm | 360rpm |
| Shaft 2 | 468.75rpm | 750rpm | **(1125rpm=18.75Hz)** |
| Shaft 3 | 281.25rpm | 450rpm | 675rpm |

Following table shows the gear meshing frequency:
{Note: Gear meshing frequency is the multiplication of No. of teeth and Rotational Frequency (Hz) }

Table:5: Gear meshing frequency

| | | | |
|---|---|---|---|
| F12 | 120Hz | 200Hz | 300Hz |
| F23 | 187.2Hz | 300Hz | 450Hz |

In the graphs, It is clearly visible that there is increase in amplitude at the rotational frequency, which is **18.75Hz** of faulty gear (ex. Missing and cracked gears).
And hence the method is verified.
It also understood that method is such a versatile that is can detect faults as minor as tooth crack to the tooth missing case.

# 6. CONCLUSION

The method proposed "Adaptive Time Frequency Representation" is a good method to detect the faults in any rotating machineries.

It is also verified by comparing the plots of normal condition gearbox with a faulty one.

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