Vibrational Analysis of Four Stroke Diesel Engine using FFT Analyzer

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***Abstract*-** **In every diesel engine there is vibration due to reciprocating component, rotating component, unidirectional combustion forces, structural resonance etc. Vibration is an effective tool in detecting and diagnosing some of the incipient failures of machine and equipment. Vibration signature measured on the external surface of the machine or a structure contains a good amount of information, which if properly interpreted, can reveal the running condition of the machine. So, as per standard it is necessary to analyze the vibration and Noise. In this paper vibration testing of single cylinder diesel engine by using FFT (Fast Fourier Transform) is carried out. Numbers of readings to measure mean vibration and noise levels in a single cylinder diesel engine for different cooling water temperatures have been taken. It was seen that a variation in the water temperature affects the mean vibration values. This effect was considered sufficient to require a control of temperature when conducting investigations on other sources or causes of engine vibration. ADASH 4400 – VA4Pro FFT analyzer with Accelerometer is used for vibration testing. Vibration accelerometer is mounted on the cylinder head vertically to record the engine vibrations in RUN-UP mode of FFT Analyzer which directly gives the spectral data.**

Index Terms: Diesel Engine, Vibrations, FFT Analyzer, Cooling Water temperature.

1. INTRODUCTION

A diesel engine (also known as a compression-ignition engine) is an internal combustion engine that uses the heat of compression to initiate ignition to burn the fuel, which is injected into the combustion chamber. This is in contrast to spark-ignition engines such as a petrol engine (gasoline engine) or gas engine (using a gaseous fuel as opposed to gasoline), which uses a spark plug to ignite an air-fuel mixture. The diesel engine has the highest thermal efficiency of any regular internal or external combustion engine due to its very high compression ratio.

The internal combustion (IC) engine is the important part of many machines and if not properly designed, it will cause vibrations and transfers the same to the supporting structures. Vibration analysis is one of the most important conditions monitoring technique that is applied in real life.

W.J.Griffiths and J.Skorecki[1964] [1], investigated that the effect of cooling water temperature on vibrations of diesel engine. Piston slap was investigated by motoring the engine and removing certain sources of the vibration from the engine. They conclude that study of effect of cooling water temperature on vibrations should be considered before analyzing other sources of vibrations. Somashekar V, Dr. K. Satish, Jamuna AB and Ranjitha P, [2013] [2], made an attempt to analyze the vibration signals of the IC engine to detect the existence of any fault utilizing Fast Fourier Transform (FFT),They found that this method may be implemented as a test system for an engine, or as a feedback to an ignition system. A. R.Wargante and Dr. S. S. Gawade, [2013] [3], presented general information of internal combustion engine and measurement of vibration. vibration level of single cylinder diesel engine was investigated and some of the significant factors were examined experimentally. Y.V.V.SatyanarayanaMurthy [2011] [4], the purpose of this paper is to detect the "knock" in Diesel engines which deteriorate the engine performance adversely. The methodology introduced in the present work suggests a newly developed approach towards analyzing the vibration analysis of diesel engines. Knock in diesel engine is detected by measuring the vibration generated by the engine using The DC-11 FFT analyzer with accelerometer. Marcio Santana, Jose Eduardo Mautone Barros and Helder Alves de Almeida Junior [5], Focuses their work to identify and describe the main sources of vibration and noise in internal combustion engine. With test and experimental analysis of frequency spectrum they pinpointed vibrations caused due to different processes. S.S.Bhansali and N.D.Shirgire[6], analyzed the vibration in diesel engine cylinder liner considering combustion gas forces and cylinder liner temperature using finite element software ANSYS. S.H. Cho, S.T. Ahn and Y.H. Kim [2002] [7], presented an analytical model, which can predict the impact forces and vibratory response of engine block surface induced by the Piston Slap of an internal combustion engine. S.D.Haddad and H.L.Pullen [8], explained various methods for estimating some origins of mechanically induced noise caused by various forces acting on the moving parts of the engine. They mainly focused on noise caused due to Piston slap phenomenon. V.L.Maleev [9], states that a lowering of the gas temperature during compression and burning has a beneficial influence in reducing the tendency to knock and ultimately the vibrations of engine. Singiresu S. Rao[10], gives the introductory knowledge of the subject Vibration Engineering right from Fundamentals of vibration to vibration control including vibration measurement techniques and their application.

Most of the research in the vibration analysis field has been carried out in processes such as the air intake, exhaust and combustion. It is recognized that a substantial addition to the general level of vibration comes from mechanical impacts of various kinds within the engine.

Prior to investigating such sources as piston slap, valve closure, interaction between gears, cam and follower, fuel pump, etc., certain preliminary work has to be carried out.

In this regard, the most extensive investigation on the effect of the engine cooling water temperature on the acceleration spectrum of vibration at a point on the cylinder head is carried out. These results have an indirect effect on the different investigations carried to find the effect of mechanical impacts on vibration. The temperature of cooling water was controlled by adjusting the rate of recirculation of water.

2. FFT ANALYZER

Fourier transform is a mathematical procedure to obtain the spectrum of a given input signal. A signal which is represented by an equation or a graph or a set of Data points with time as independent variable is transformed into another equation or a graph or a set of data points where frequency is the independent variable by using Fourier transform. Thus the method to obtain the spectrum using computer is called as Fast Fourier Transform (FFT).

The instrument which converts input signal with time as independent variable in to frequency spectrum and displays it in graphical form is called as spectrum analyzer or FFT analyzer.

FFT Analyzer is a unique instrument for machinery vibration diagnostics. FFT analyzer generally includes modules for analyzing, data collecting and the recording of vibration signals. By using a Fourier series representation, the original time signal can be easily transformed in frequency signal and much better understood. Transformations are also performed to represent the same data with significantly less information. Analyzer, RunUp, Recorder, Route, Balancer are the different modes facillated for various condition monitoring process. The FFT spectrum analyzer samples the input signal, computes the magnitude of its sine and cosine components, and displays the spectrum of these measured frequency components. The FFT is simply a clever set of operations which implements Fourier's theorem. The resulting spectrum shows the frequency components of the input signal. The big advantage of this technique is its speed. Because FFT spectrum analyzers measure all frequency components at the same time, the technique offers the possibility of being hundreds of times faster than traditional analogue spectrum analyzers. To measure the signal with higher resolution, the time record is increased. But again, all frequencies are examined simultaneously providing an enormous speed advantage.

3. EXPERIMENTAL SETUP

3.1 Test Rig

Experimental Setup (Fig. 3.1) consists of a single cylinder diesel Engine manufactured by Kirloskar oil Engine Ltd. with power rating of 3.7 KW and compression ratio of 16.5. Engine was coupled to an Eddy Current Dynamometer through universal coupling. The engine and the dynamometer were mounted on a common bed made from Iron C-Channel which was bolted to the cement foundation.

Vibration accelerometer is mounted on cylinder head vertically with the help of magnetic force to record the engine vibrations (as shown in Fig. 3.2)

Fig. 3.1 Test Rig

Fig. 3.2 Accelerometer mounted on Cylinder Head

3.2 Instrumention

3.2.1 FFT Analyzer

By using a Fourier series representation, the original time signal can be easily transformed in frequency signal and much better understood. Transformations are also performed to represent the same data with significantly less information

Fast Fourier Transform Analyzer - Adash VA4-PRO 4400 (fig. 3.2.1) is used for achieving desired graphs and mean values. Engine vibrations are measured using RUN-UP mode of FFT analyzer. The readings and graphs of FFT were analyzed with the DDS software installed in Computer.

Fig. 3.2.1 FFT Analyzer

3.2.2 Accelerometer

An accelerometer is an instrument that measures the acceleration of vibrating body. This device is, perhaps, preferred over the velocity pickup, for a number of reasons. For example, accelerometers have good sensitivity characteristics and a wide useful frequency range; they are small in size and light in weight and thus are capable of measuring the vibration at a specific point without, in general, loading the vibrating structure. In addition, the devices can be used easily with electronic integrating networks to obtain a voltage proportional to velocity or displacement. However, the accelerometer mounting, the interconnection cable, and the instrumentation connections are critical factors in measurements employing an accelerometer.

Sensitivity of Accelerometer – 100 mV/g. (g= 9.81 m/s^2)

Fig. 3.2.2 Accelerometer

3.3.3 Noise Sensor – Microphone

Many types of measuring systems can be used for the measurement of sound depending on the purpose of the study, the characteristics of sound and the extent of information that is desired about the sound.

The microphone is the interface between the acoustic field and the measuring system. It responds to sound pressure and transforms it into an electric signal which can be interpreted by the measuring instrument (e.g. the sound level meter).

Sensitivity of Microphone – 46.17 mV/Pa.

Fig. 3.2.3 Microphone

4. RESULTS AND DISCUSSION

With the help of FFT analyzer mean values of different parameters are obtained at different temperatures and are presented in the form of graphs. Also spectrums of Displacement, Velocity and Acceleration response of engine are obtained for different cooling water temperatures. Different RMS values obtained for different cooling water temperature are as shown below in Table 4.1.

Table 4.1 RMS values for different temperatures

Sr. No	Cooling Water Temp. (^{0}C.)	RMS Acceleration(mm/s^2)	RMS Velocity (mm/s.)	RMS Displacement (µm.)	RMS Noise (Pa.)
1	26	23.5	28.7	151	3.29
2	30	23.4	29.7	165	3.46
3	35	22.8	29.9	169	3.36
4	40	22.5	29.9	165	3.39
5	44	21.8	28.9	163	3.23

At the 26^{0}C of cooling water temperature, Mean displacement (RMS) is 151 µm. Also RMS values of velocity and acceleration found to be 28.7 mm/s and 23.5mm/s^2 respectively. Mean noise level is measured and is equal to 3.29 Pa.

Mean values of similar parameters are obtained for different cooling water temperatures. They are presented in table 4.1.

With the help of these mean values obtained from FFT analyzer, individual graphs for different parameters are plotted against cooling water temperature.

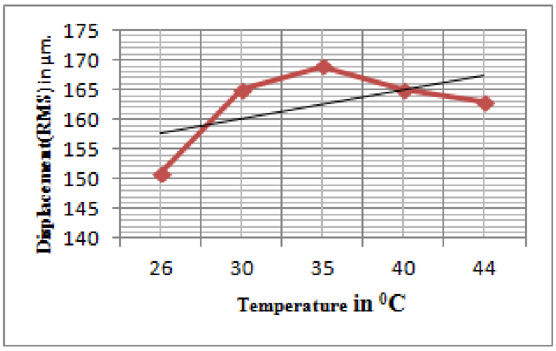

Fig. 4.1 Graph of RMS Values of Displacement vs. Temperature

Fig. 4.1 shows the graph of RMS values of displacement versus cooling water temperature, in which temperature (in ^{0}C.) is plotted on abscissa and RMS values of displacement (in µm.) are plotted on its ordinate.

From graph, RMS values of displacement are seen to be increasing as temperature is increasing from 26^{0}C to 35^{0}C. While some reverse effect is seen above 35^{0}C of cooling water temperature. Overall general linear relationship is shown with the help of straight line as shown. It indicates the fact that, as cooling water temperature increase, the mean values of displacement are increasing and ultimately vibrations of Engine are increasing.

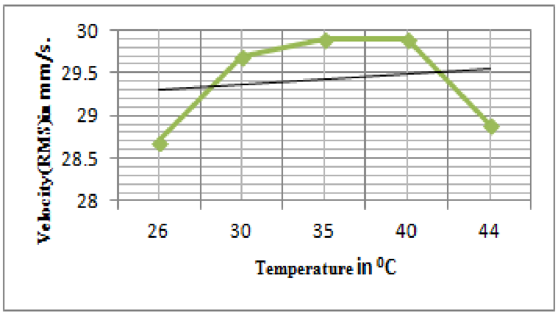

Fig. 4.2 Graph of RMS Values of Velocity vs. Temperature

Fig. 4.2 shows the graph of RMS values of velocity versus cooling water temperature in which temperature is plotted along X-axis and mean values of velocity are plotted along Y-axis.

From the graph shown in Fig. 4.2, RMS values of Velocity are found to be increasing as temperature is increasing, while again some reverse effect is seen above 40^{0}C of cooling water. Overall general relationship is shown with the help of straight line. It also ultimately indicates that vibrations of Engine are increasing with increase in cooling water temperature.

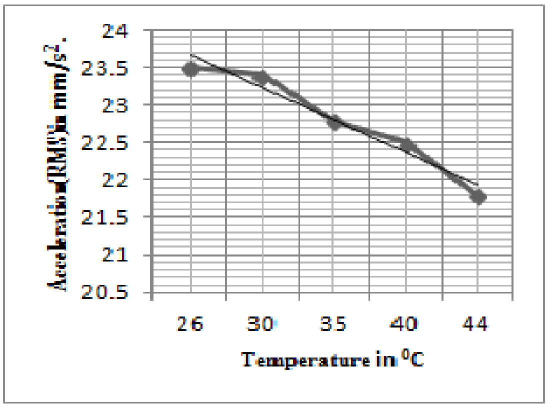

Fig. 4.3 Graph of RMS Values of Acceleration vs. Temperature

Fig. 4.3 is the graph of RMS values of acceleration versus cooling water temperature in which temperature is plotted along X-axis and RMS values of Acceleration are plotted along Y-axis.

From this graph it is seen that mean acceleration levels are decreasing exceptionally, when cooling water temperature is increasing.

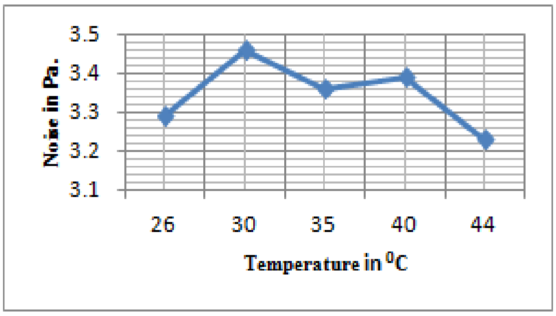

Fig. 4.4 Graph of RMS Values of Noise vs. Temperature

Fig. 4.4 is the plot of RMS values of noise measured against cooling water temperature, in which temperature is plotted along X-axis and RMS values of acceleration are plotted along Y-axis.

It was expected that mean noise readings will increase as the cooling water temperature increases. But actually, as noise sensor (microphone) used for noise measurement was held manually approximately 5 cm. above the cylinder head, so because of certain human errors, some varying nature of graph is seen (as shown in Fig. 4.4).

By studying graphs of Mean Displacement, Velocity, Acceleration and Noise plotted against different cooling water temperatures, it would be advisable to keep the cooling water temperature within such limits where mean values of those parameters are minimum; when investigating studies related to different sources of vibrations.

With the help of FFT analyzer different spectrums for acceleration, velocity and displacement are obtained at different temperatures of cooling water and are discussed below.

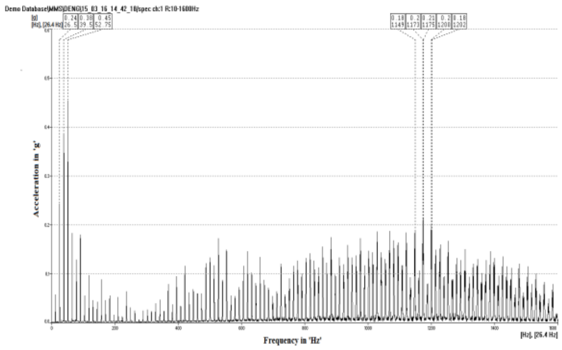

Fig. 4.5 Acceleration spectrum obtained from FFT at 26^{0}C.

Fig. 4.5 shows the actual spectrum obtained from FFT analyzer for acceleration of Engine, when cooling water temperature is 26^{0}C. This spectrum is like a conventional graph having acceleration (in terms of ‘g’) on abscissa and frequency (in ‘Hz’) on ordinate. Frequency range from 10 Hz to 1600 Hz. is considered. The top eight peaks obtained in the spectrum are marked seperately. Similar acceleration spectrums for different cooling water temperatures are obtained.

Acceleration spectrums obtained from FFT analyzer for different cooling water temperature shows repetitive responses in particular frequency ranges. Maximum peaks are seen in the low frequency region of 10 Hz to 150 Hz. Acceleration variations are seen quiet low in the middle frequency range in 150 Hz to 400 Hz. In high frequency region above 400 Hz., a set of repetitive higher acceleration peaks are observed.

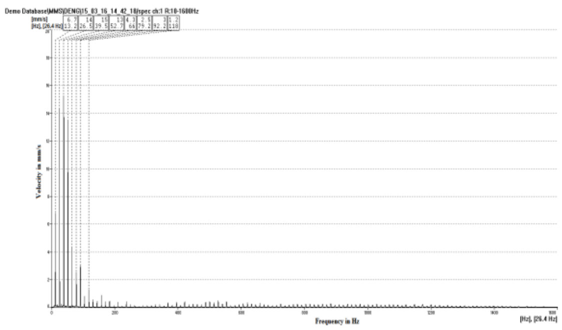

Fig. 4.6 Velocity spectrum obtained from FFT at 26^{0}C.

Fig. 4.6 shows the velocity spectrum obtained from FFT analyzer at 26^{0}C of cooling water temperature. This spectrum is a graph of velocity drawn verses frequency responses, in which velocity (in mm/s.) is plotted along Y-axis and frequency (in Hz.) along X-axis.

The top 8 peaks obtained are marked separately and shown in the spectrum. By considering all the spectrums obtained at different cooling water temperatures, maximum value of Displacement is always seen in the initial frequency range of 20 to 50 Hz.

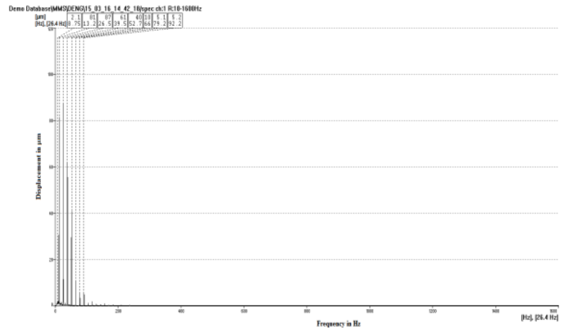

Fig. 4.7 Displacement spectrum obtained from FFT at 26^{0}C.

Fig. 4.7 shows displacement spectrum obtained from FFT analyzer, when cooling water temperature is 26^{0}C. This spectrum is in the form of graph having displacement (in µm.) on abscissa and frequency (in Hz.) on ordinate. Frequency range up to 1600 Hz. is considered.

The top 8 peaks found in displacement spectrum are marked separately and shown.

With the help of FFT analyzer different spectrums for noise are obtained at different temperatures and one (for 26^{0}C) is presented below.

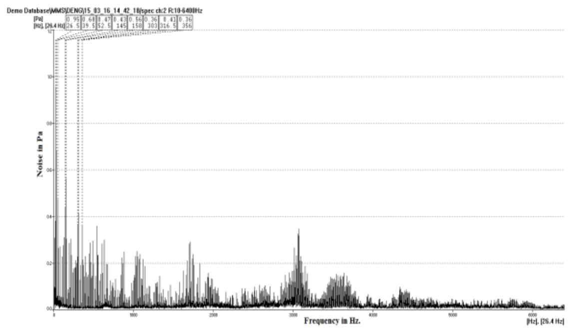

Fig. 4.8 Displacement spectrum obtained from FFT at 26^{0}C.

Fig. 4.8 shows Noise spectrum obtained from FFT analyzer, when cooling water temperature is 26^{0}C. This spectrum is also like a conventional graph having Noise (in Pa.) on Y- axis and frequency (in Hz.) on X-axis.

CONCLUSIONS

From the Experimentation and Analysis of Diesel Engine carried out it is observed that as cooling water temperature increases, mean values of velocity and displacement are increasing. This ultimately indicates that vibration levels are increasing with increase in temperature of cooling water. On an exceptional note, mean values of acceleration are found to be decreasing with increase in cooling water temperature. This effect of increase in mean vibration levels of engine with respect to increasing cooling water temperature is considered sufficient to require a control of water temperature when conducting investigations related to the other causes of engine vibrations and their effects on engine vibration levels. Also, from respective spectrums of displacement, velocity and acceleration obtained at different cooling water temperatures it is found that most of the top peaks are seen in the initial frequency range of 10 Hz to 150 Hz, indicating maximum vibrations of engine in that range.

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