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Vibration Signature Analysis of IC Engine

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Abstract:
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. It may be regarded as the one of the languages through which the machine tells its ailments.

Each unit of mechanical equipment has a different signature in the frequency spectrum. The vibration spectrum shows the areas of stress and undue energy. Vibration measurements trend changes at different locations along the units to predict problems.

Vibration analysis can determine misalignment, unbalance, mechanical looseness, eccentric shafts, gear wear, broken teeth, bearing wear etc. Using appropriate accelerometer it is possible to get the data which is processed using different methods like FFT, spectrogram, cestrum, and wavelet transform and cyclostationary analysis.

In this work, an attempt has been madeto analyze the vibration signals of the IC engine to detect the existence of any fault utilizing Fast Fourier Transform (FFT), This method depends on the variations in frequency to distinguish different operating conditions of an IC engine and to provide remedies to alleviate the engine from excess of vibrations which also improves the performance of the engine.

Key words: *Fast Fourier Transformation (FFT), Internal Combustion Engine, Monitoring Equipment Uptime, Managing and Scheduling Maintenance Work*

1. Introduction

Rapid automobile industry growth has made engine's maintenance to be of great importance. Therefore, it seems necessary to development accurate condition monitoring and fault detection systems for both reducing maintenance cost and alerting the operator about the engine's operating condition before severe damages occur.

The internal combustion (IC) engine is the concentrated mass in vehicle and if not properly designed, it will cause vibrations and transfer the same to the supporting structures. Ride comfort, driving stability and drivability are important factors in the performance of a vehicle and are affected by the engine vibrations. Because of the environmental considerations, as well as changes in consumer preferences, vibrations induced must be reduced. Vibration behavior of an IC engine depends on unbalanced reciprocating and rotating parts, cyclic variation in gas pressure, shaking forces due to the reciprocating parts and structural characteristics of the mounts. Engine vibrations are caused due to the reciprocating and rotating masses of the engine. The variations of inertial forces are due to the combustion and the compression differences of the piston cylinder arrangement during their operations. The engine inertial forces lead to the unbalanced forces of the engine and they tend to vary with respect to speed, fuel supply and combustion characteristics of the fuel.

Vibration analysis is one of the most important conditions monitoring technique that is applied in real life. Most of the defects encountered in the rotating machinery give rise to a distinct vibration pattern (vibration signature) and hence faults can be identified using vibration signature analysis techniques. 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. It may be regarded as the one of the languages through which the machine conveys its ailments. The information is useful in taking suitable decisions regarding the machine or machine maintenance.

Absolute vibration has been measured related to an inertial (fixed) reference frame. The accelerometers and velocity transducers sensors have been used as sensors for measurement of absolute vibration for absolute vibration measurement the sensors are preferably mounted on the various places on the IC engine to monitor damage.

1.1. Vibration Signature

Vibration signature may be a combination of the various harmonics and they are obtained by processing the signal through a frequency is a potential indicator of machine condition. Spectrum analysis is most powerful for diagnosis study.

Vibration signature as obtained by accelerometer is a time based signal which may be further processed for its overall level, peak, phase, spike energy etc.

The underlying principle is that, each component of the IC engine generates identifiable frequencies. Thus the change in vibration level at any given frequency can relate directly to the concerned engine parts.

1.1.1. Basic Principle Involved

- Any malfunctioning or deterioration in the operation of machine component gives rise to increase in vibration level.
- Vibration emanating from the component consists of certain frequencies depending upon the nature of the operation. This frequency does not get changed or lost during the transmission of vibration. However there vibration level may be attenuated.
- Mixing of different vibration (frequencies) does not cause any loss of individual frequency information.
- Every individual component or a system has its own frequency called natural frequency, which changes only when system parameter affected.

1.2. Vibration Monitoring

It 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 frequencies being analysed.

- Acceleration covers region from 0 up to and beyond 20k Hz
- Velocity covers frequencies typically from 2 Hz to 2k Hz
- A displacement, a measure of absolute position, covers frequencies from 0 up to 200 Hz.

The signals are normally processed and stored using spectrum analysis methods which take incoming signal and break 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 require software to interpret them.

1.2.1. Real Time FFT

The fast Fourier transformer gives the direct representation of signal in frequency domain. The technique computes frequency spectrum and derived results like FRF (Frequency Response Function) from the time domain data acquired by block. Real-time can have two inferences; the first one is that one can see the frequency spectrum in live mode, continuously. This is equivalent to oscilloscope in frequency domain. The second inference is that the computation takes into account all the time domain data to compute the frequency spectrum. The consequence is that the all the computation rate has to be faster than the acquisition time. Any loss in time domain data results in an error in the frequency spectrum. The real time band is then a critical parameter whenever precise measurement is required.

1.3. Vibration Analysis

The frequency of a simple vibration can be calculated from its period. But the vibration signals from most rotating machinery contain harmonics of the fundamental rotational frequencies, so data has to be analyzed by Fourier method which is established for periodic and random vibration using FFT algorithms.

Most of the defects encountered in the rotating machinery give rise to a distinct vibration pattern (vibration signature analysis techniques). But it has been found that the defect developed may not show any indication in time domain unless it deteriorates to an advanced condition. But in frequency domain signal not only registers the problem early in its growth but actually conveys, with certain probability, the nature of impending faults like misalignment, bearing failure, gear faults etc.

1.4. Vibration Signal Acquisition and Conditioning

The first and vital step in vibration monitoring is to capture a recording of vibration levels, normally as time passes. The degree of difficulty in producing a vibration recording increases with the complexity of the instrumentation. The combination of signal conditioner card having simultaneous data acquisition capability at a very high rate provides a DSP (digital signal processor) based real-time analyzer for integration with a dedicated computer for further analysis. A DSP based high speed data acquisition and analysis system is used to analyze the time domain signal (sensor output signal) followed by the frequency analysis of the time domain signal.

Frequency analysis links a problem frequency pattern, the effect to a particular component, its cause. If this can be achieved with confidence, then a diagnosis can be suggested.

1.5. Spectral Analysis

Spectral analysis is the term used to describe the analysis of the frequency domain representation of the signal. Spectral analysis is the most commonly used vibration analysis technique for condition monitoring in geared transmission system and valuable tool for detection and basic diagnosis of faults in simple rotating machinery whereas overall vibration level is measure of vibration produced over a broadband frequency, spectrum is the measure of vibration over a large number of discrete contiguous narrow frequency band.

The fundamental process common to all spectral analysis is the conversion of the component can be estimated therefore a change in vibration level within a particular frequency band can usually be associated with particular machine component. Analysis of the relative vibration level at different frequency band can often give an indication of the nature of fault, providing some diagnostic capabilities.

1.5.1. The Principle Objectives in Analyzing the Vibration Data Are

- Simplify and reduce the vibration data into a more compact easily interpreted form.
- Associate characteristics of the vibration to specific features of the machine vibrating.
- Provide a consistent, repeatable measurement by which to characterize the vibration of a IC engine.
- Identify characteristics that change with time and operating condition, or both.

2. Background

The methodology introduced in this work is based on the vibration signature of the engine. Establishing a connection between the vibration signature and the IC engine is enabled due to the strong relationships between the characteristics of the vibration signature and the unique characteristics of the IC engine.

There are several possible locations to measure the vibration signature of the IC engine. In this work four accelerometer probes are connected for different locations in an IC engine such as cylinder head, crank cover, engine block and engine base by changing the loading condition to predict the vibration levels if any fault exists.

2.1. FFT Analyzer

FFT analyzer also called spectrum analysis, which is defined as the transform of a signal from a time domain representation into a frequency domain representation. The FFT analyzer is a batch-processing device i.e., it samples the input signal for specific time interval collecting the sample in a buffer, after which it performs the FFT calculations on that batch and displays the resulting spectrum. The name of the FFT analyzer used for the experiment is OROS-24.

By using FFT enabled to investigate the degree of chance that occurred at what level of frequency and the frequencies generated from a particular position. Frequency analysis (observing the waveform in the frequency domain) makes detection of even slight anomalies possible.

2.2. Accelerometer

Accelerometer is a Piezo-electric accelerometer and it is considered as the standard vibration transducer for machine vibration measurement. Data capture regarding the vibration emitted by a machine, or other body, begins with the sensor.

The accelerometers shown in Figure 2.1 consist of a piezoelectric crystal which has a mass attached to one of its surfaces. When the mass is subjected to a vibration signal, the mass converts the vibration (acceleration) to a force, this then being converted to an electrical signal. This is the basis of the “accelerometer”. The accelerometer output may then be processed to provide the instantaneous velocity and displacement signals.

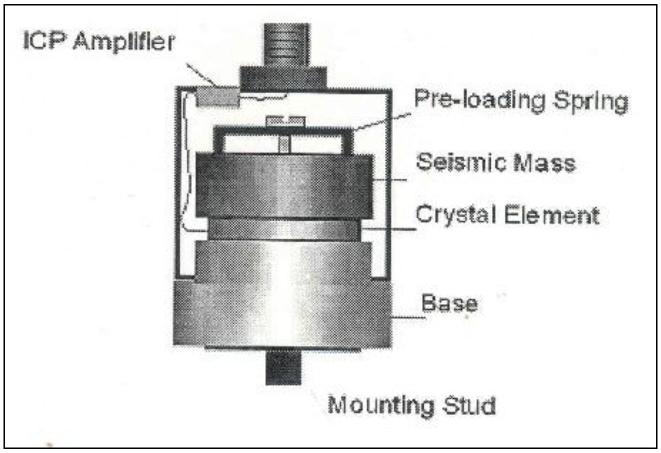


Figure: Piezo- Electric Accelerometer

In this experimental setup using ICP accelerometer which is mounted on the I.C engine at different parts of engine those are called channel 1, 2, 3, 4 respectively.

MeasurementRange	490 m/s^2
FrequencyRange	0.33 to 10000 Hz (3dB)
TemperatureRange	-540C to + 121 C
Settling Time	10sec
Excitation Voltage	18 to 28 VDC
Constant current excitation	2 to 20 mA
Size (Hex x Height)	22mm x 109mm
Weight (without cable)	94gm
Sensing element	Quartz
Housing material	Stainless steel
Sealing	Welded hermetic
Cable length	3.0 meters
Cable type	Polyurethane

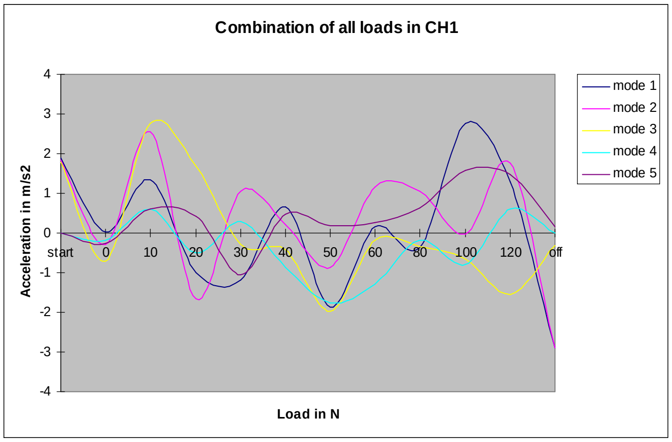
Table 1: Specifications of Accelerometer

3. Methods

The above principles are integrated together to a computer program which with the suitable equipment is capable of testing different vibration levels of an IC engine and the computer program interference between the IC engine and FFT analyser. By using several accelerometers, depending on the size of the engine and different loading conditionit is possible to characterize the vibration levels in the different location of the IC engine.

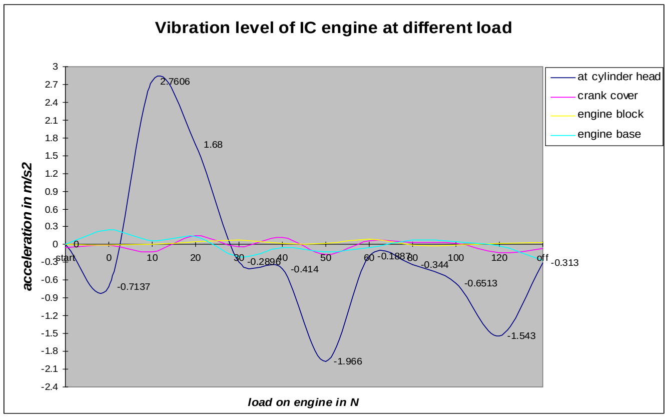
4. Results and Discussion

The IC engine was tested by the above-described method. The results presented are an outcome of a series of experiments that were made on different loading conditions like combinations of all loads and different loads of an IC engine.



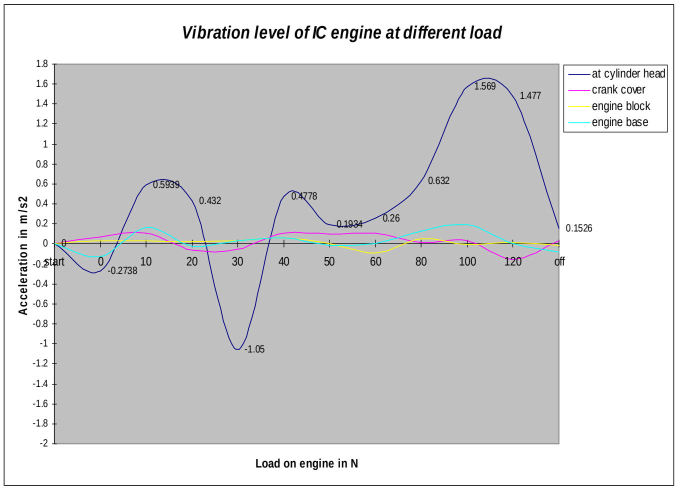
start	1.889	1.855	1.785	0	0
0	0.031	-0.279	-0.7137	-0.1739	-0.2738
10	1.353	2.5617	2.7606	0.5958	0.5939
20	-1	-1.65	1.68	-0.505	0.432
30	-1.1906	1.0588	-0.2896	0.297	-1.05
40	0.658	0.2151	-0.414	-0.8664	0.4778
50	-1.874	-0.858	-1.966	-1.755	0.1934
60	0.1637	1.1618	-0.1887	-1.293	0.26
80	-0.363	1.057	-0.344	-0.186	0.632
100	2.76	-0.027	-0.6513	-0.799	1.569
120	1.298	1.7716	-1.543	0.594	1.477
off	-2.892	-2.892	-0.313	0	0.1526

Figure1: Vibration Level of IC Engine for Mode-1



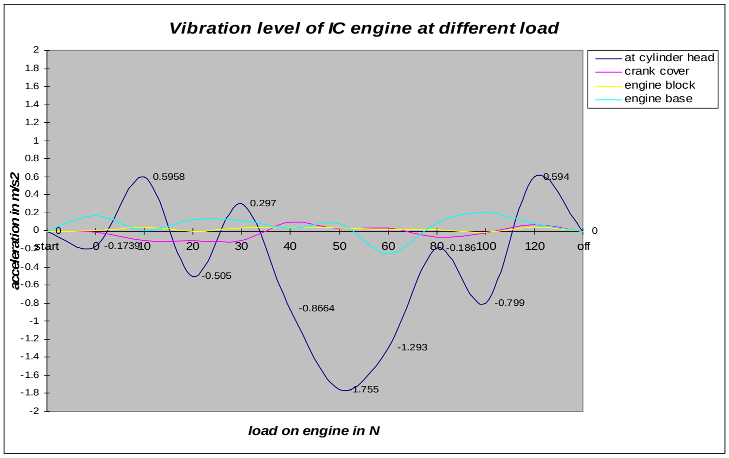
start	1.855	-0.052	0.009	-0.1069
0	-0.279	-0.026	0.003	0.194
10	2.5617	0.014	-0.003	0.2803
20	-1.65	0.141	0.053	0.1007
30	1.0588	-0.32	0.051	-0.0204
40	0.02151	-0.065	0.05	0.1193
50	-0.858	-0.067	0.027	0.25
60	1.1618	-0.107	0.076	0.167
80	1.057	0.058	0.047	0.04866
100	-0.027	-0.003	-0.024	-0.374
120	1.7716	-0.032	-0.012	-0.073
off	-2.892	0.211	0.01	-0.0194

Figure 2: Vibration Level of IC Engine for Mode-2



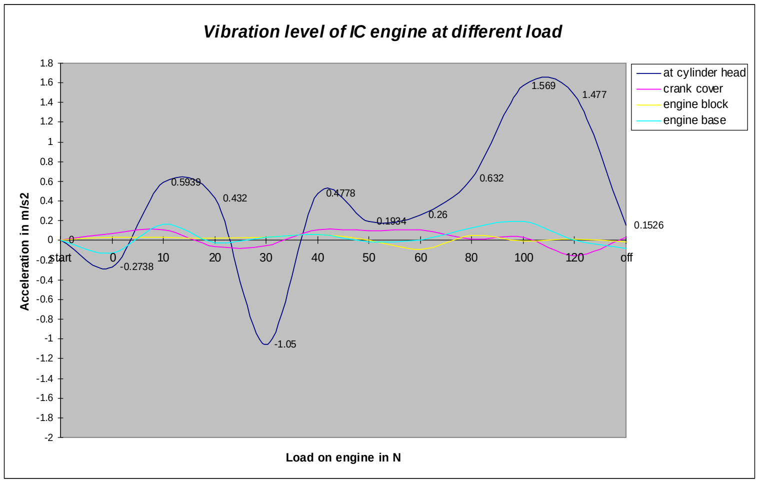
start	1.1.785	-0.057	0	0
0	-0.7137	-0.009	-0.003	0.2438
10	2.7606	-0.12	0.013	0.0666
20	1.68	0.152	0.054	0.136
30	-0.2896	-0.04	0.085	-0.2077
40	-0.414	0.128	0.026	-0.048
50	-1.966	-0.167	0.027	-0.125
60	-0.1887	0.065	0.088	-0.056
80	-0.344	0.035	-0.012	0.0782
100	-0.6513	0.017	-0.008	0.045
120	-1.543	-0.137	0.024	-0.025
off	-0.313	-0.063	0.038	-0.259

Figure 3: Vibration Level of IC Engine for Mode-3



start	0	0	0	0
0	-0.1739	-0.01	0.001	0.1688
10	0.5958	-0.105	0.046	0.0065
20	-0.505	-0.103	-0.004	0.125
30	0.297	-0.111	0.036	0.1138
40	-0.8664	0.101	0.041	0.035
50	-1.755	0.023	0.035	0.078
60	-1.293	0.03	0.015	-0.251
80	-0.186	-0.071	0.01	0.0883
100	-0.799	-0.021	-0.018	0.2082
120	0.594	0.07	0.04	0.0749
off	0	0	0	0

Figure 4: Vibration Level of IC Engine for Mode-4



start	0	0	0	0
0	-0.2738	0.069	0.032	-0.126
10	0.5939	0.107	0.035	0.1684
20	0.432	-0.062	0.022	-0.0213
30	-1.05	-0.054	0.029	0.0305
40	0.4778	0.11	0.064	0.057
50	0.1934	0.101	0.003	-0.0102
60	0.26	0.104	-0.09	0.0074
80	0.632	0.015	0.053	0.127
100	1.569	0.028	-0.004	0.1938
120	1.477	-0.157	0.013	0.0037
off	0.1526	0.035	-0.019	-0.0805

Figure 5: Vibration Level of IC Engine for Mode-5

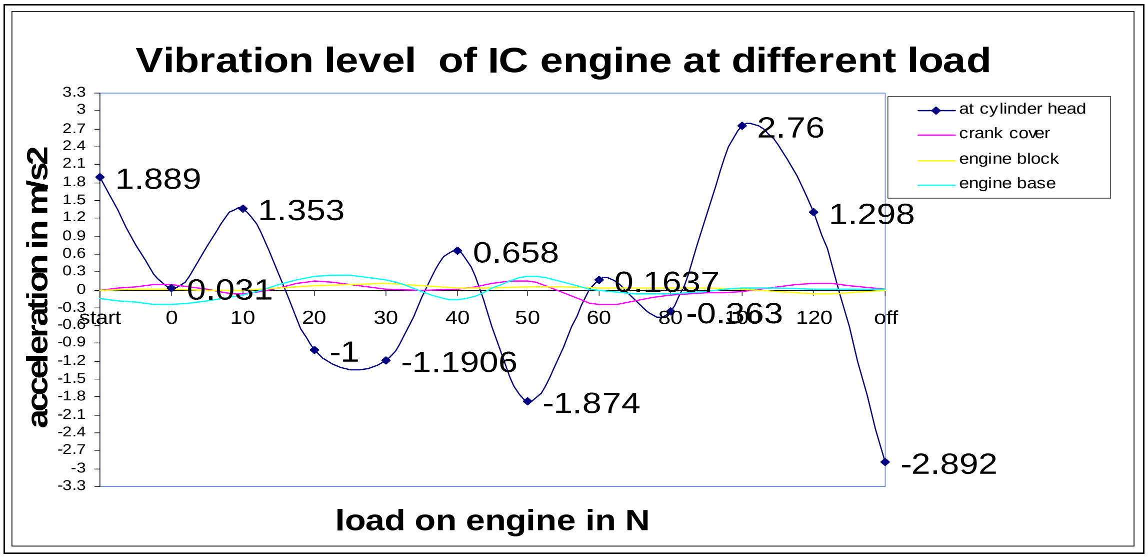


Figure 6: Vibration Level of IC Engine for Mode -1

start	1.889	0	0	-0.1402
0	0.031	0.092	0.001	-0.241
10	1.353	-0.075	-0.004	-0.095
20	-1	0.14	0.067	0.227
30	-1.1906	0.012	0.101	0.1712
40	0.658	0.005	0.032	-0.1739
50	-1.874	0.155	0.056	0.2188
60	0.1637	-0.236	0.032	-0.0014
80	-0.363	-0.089	0.021	-0.0749
100	2.76	-0.039	0.017	0.0268
120	1.298	0.104	-0.059	0.0194
off	-2.892	0.001	0	0.0116

Table 2

4.1 Trigger Windows at Initial Start (Ignition) of IC Engine

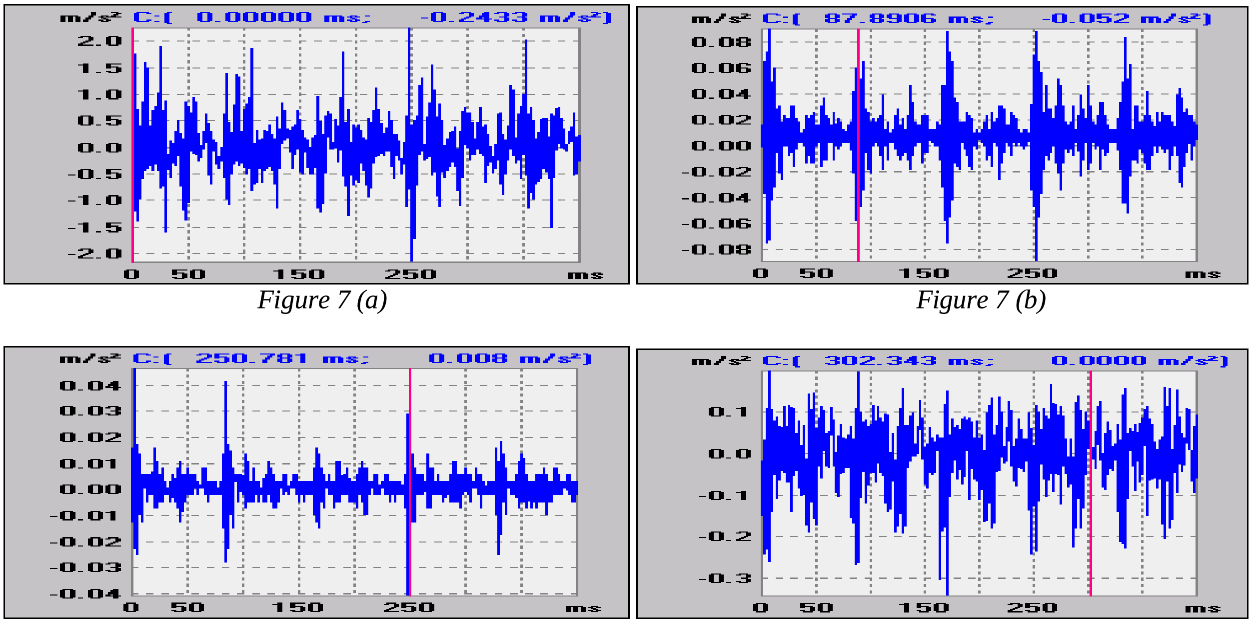
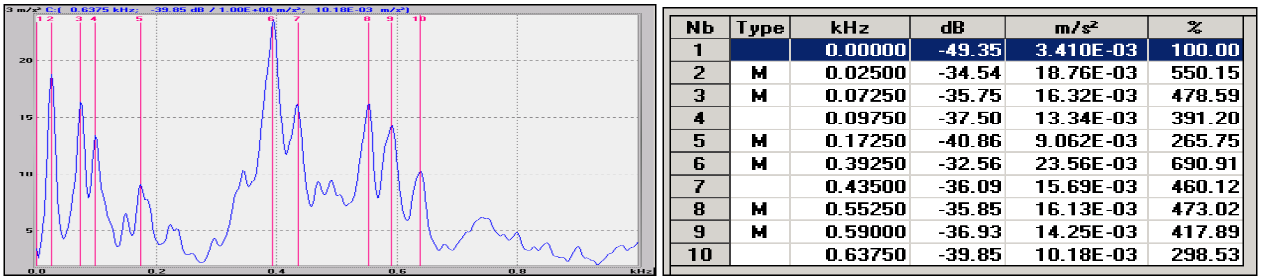


Figure 7 (a) *Figure 7 (b)*

Figure 7 (c) *Figure 7 (d)*

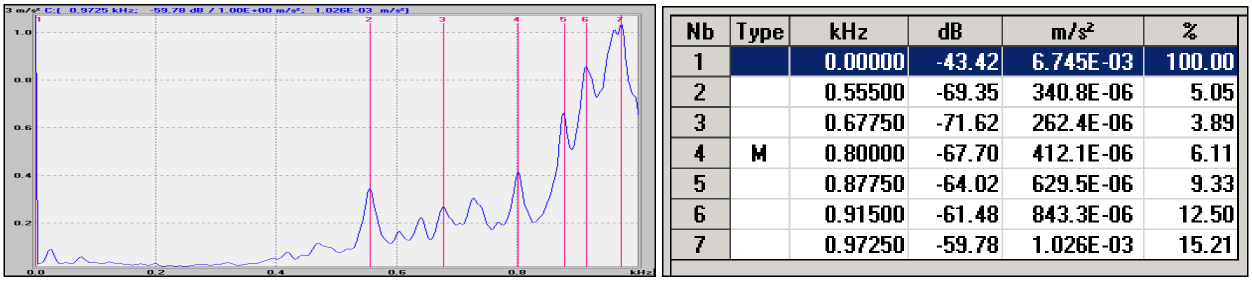
Figure 7 (A) To (D): Graphs of Time and Frequency Domain of IC Engine at Initial Start

4.2. Spectrum Graphs at Initial Start (Ignition) of IC Engine



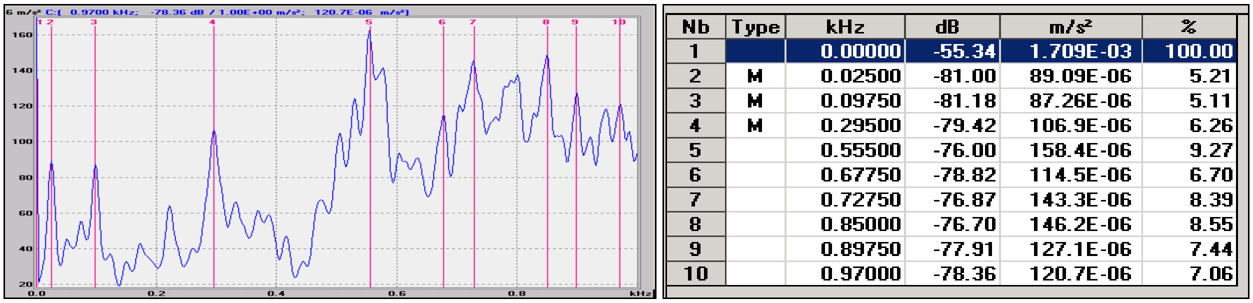
Nb	Type	kHz	dB	m/s²	%
1		0.00000	-49.35	3.410E-03	100.00
2	M	0.02500	-34.54	18.76E-03	550.15
3	M	0.07250	-35.75	16.32E-03	478.59
4		0.09750	-37.50	13.34E-03	391.20
5	M	0.17250	-40.86	9.062E-03	265.75
6	M	0.39250	-32.56	23.56E-03	690.91
7		0.43500	-36.09	15.69E-03	460.12
8	M	0.55250	-35.85	16.13E-03	473.02
9	M	0.59000	-36.93	14.25E-03	417.89
10		0.63750	-39.85	10.18E-03	298.53

Figure 8: Vibration Level of IC Engine at Initial Start Condition for Channel-1



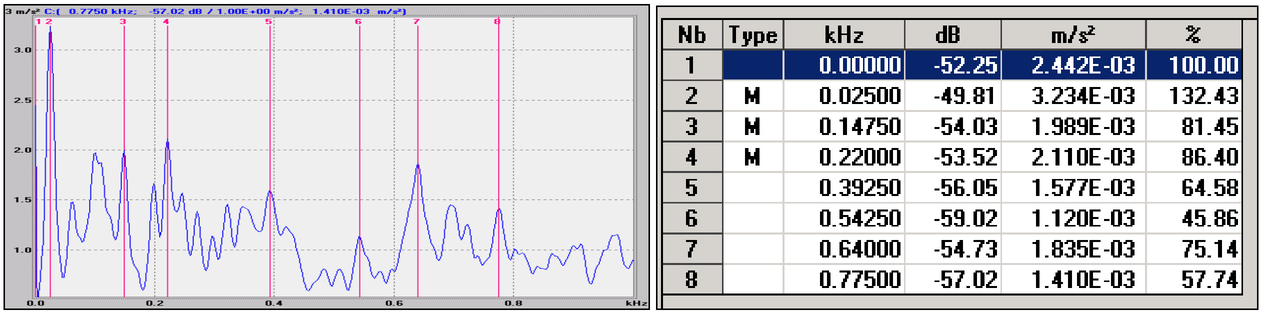
Nb	Type	kHz	dB	m/s²	%
1		0.00000	-43.42	6.745E-03	100.00
2		0.55500	-69.35	340.8E-06	5.05
3		0.67750	-71.62	262.4E-06	3.89
4	M	0.80000	-67.70	412.1E-06	6.11
5		0.87750	-64.02	629.5E-06	9.33
6		0.91500	-61.48	843.3E-06	12.50
7		0.97250	-59.78	1.026E-03	15.21

Figure 9: Vibration Level of IC Engine at Initial Start Condition for Channel-2



Nb	Type	kHz	dB	m/s²	%
1		0.00000	-55.34	1.709E-03	100.00
2	M	0.02500	-81.00	89.09E-06	5.21
3	M	0.09750	-81.18	87.26E-06	5.11
4	M	0.29500	-79.42	106.9E-06	6.26
5		0.55500	-76.00	158.4E-06	9.27
6		0.67750	-78.82	114.5E-06	6.70
7		0.72750	-76.87	143.3E-06	8.39
8		0.85000	-76.70	146.2E-06	8.55
9		0.89750	-77.91	127.1E-06	7.44
10		0.97000	-78.36	120.7E-06	7.06

Figure 10: Vibration Level of IC Engine at Initial Start Condition for Channel-3



Nb	Type	kHz	dB	m/s²	%
1		0.00000	-52.25	2.442E-03	100.00
2	M	0.02500	-49.81	3.234E-03	132.43
3	M	0.14750	-54.03	1.989E-03	81.45
4	M	0.22000	-53.52	2.110E-03	86.40
5		0.39250	-56.05	1.577E-03	64.58
6		0.54250	-59.02	1.120E-03	45.86
7		0.64000	-54.73	1.835E-03	75.14
8		0.77500	-57.02	1.410E-03	57.74

Figure 11: Vibration Level of IC Engine at Initial Start Condition for Channel-4

4.3. Trigger Windows at 40 N

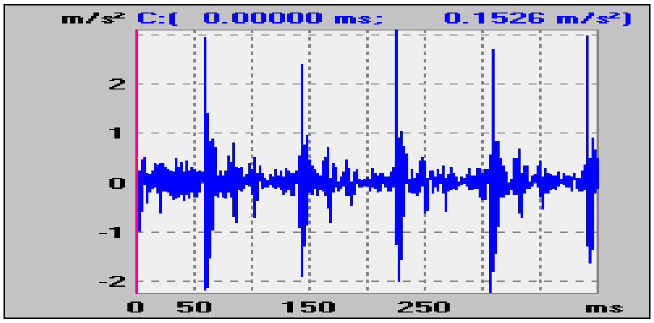


Figure: 12 (a)

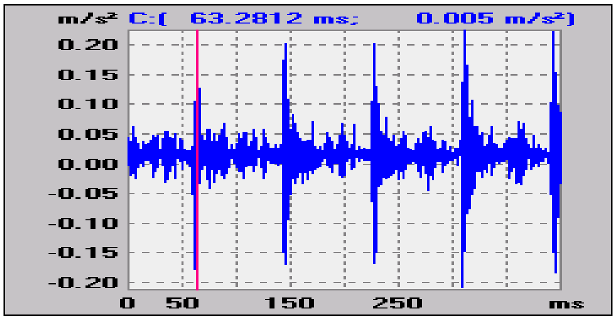


Figure: 12 (b)

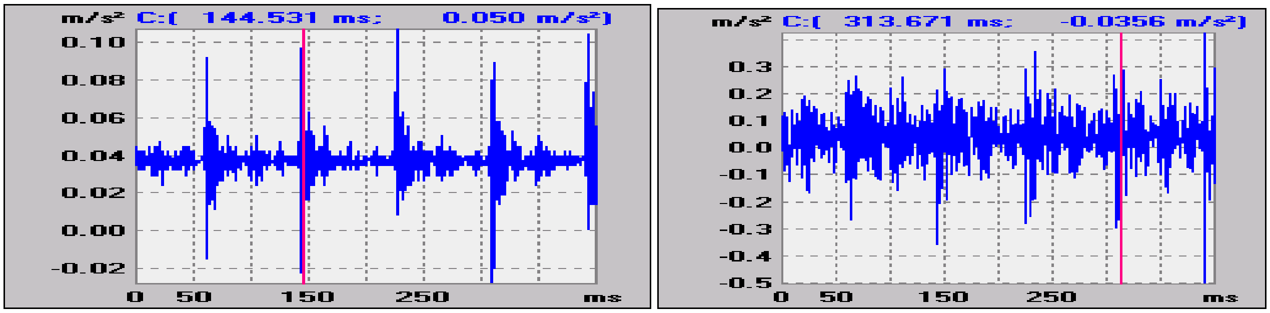
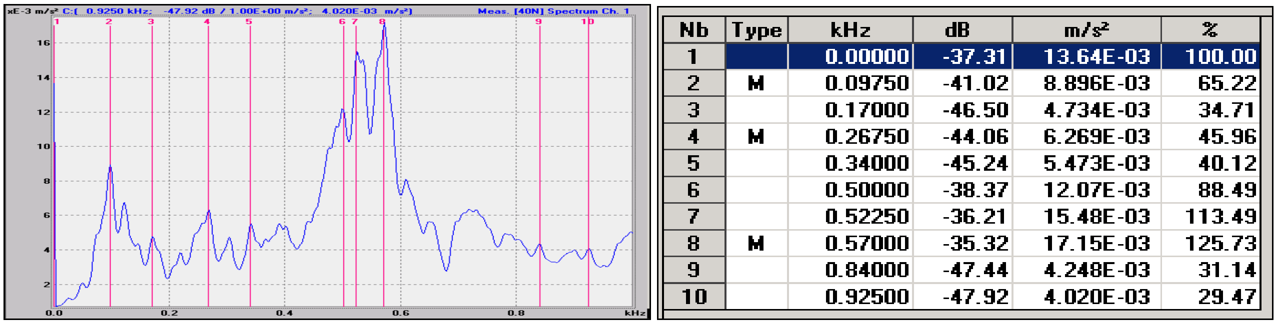


Figure: 12 (c

Figures: 12 (d)

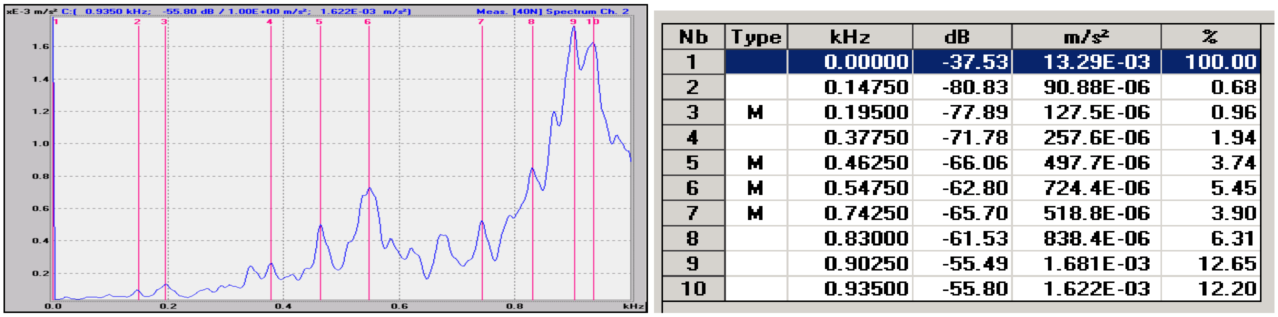
Figure 12: (A) To (D): Graphs of Time and Frequency Domain of IC Engine at Load 40N

4.4. Spectrum Graphs of I.C. Engine at 40 N



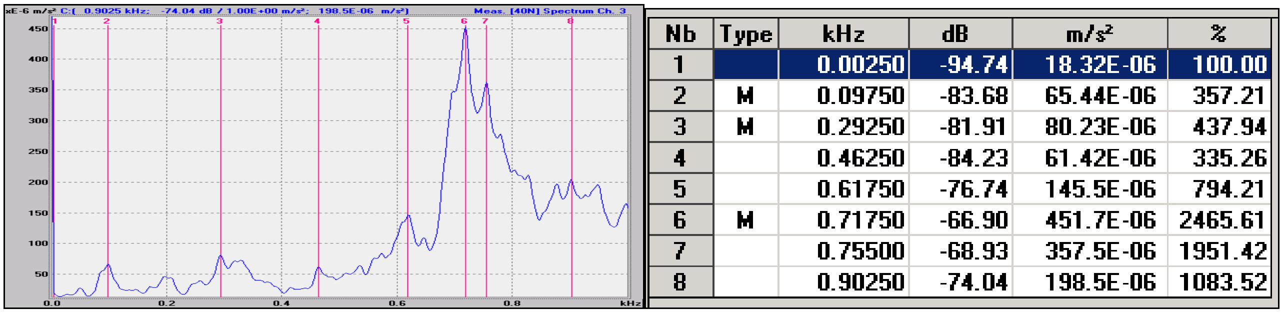
Nb	Type	kHz	dB	m/s²	%
1		0.00000	-37.31	13.64E-03	100.00
2	M	0.09750	-41.02	8.896E-03	65.22
3		0.17000	-46.50	4.734E-03	34.71
4	M	0.26750	-44.06	6.269E-03	45.96
5		0.34000	-45.24	5.473E-03	40.12
6		0.50000	-38.37	12.07E-03	88.49
7		0.52250	-36.21	15.48E-03	113.49
8	M	0.57000	-35.32	17.15E-03	125.73
9		0.84000	-47.44	4.248E-03	31.14
10		0.92500	-47.92	4.020E-03	29.47

Figure 13: Vibration Level of IC Engine at 40N for Channel-1



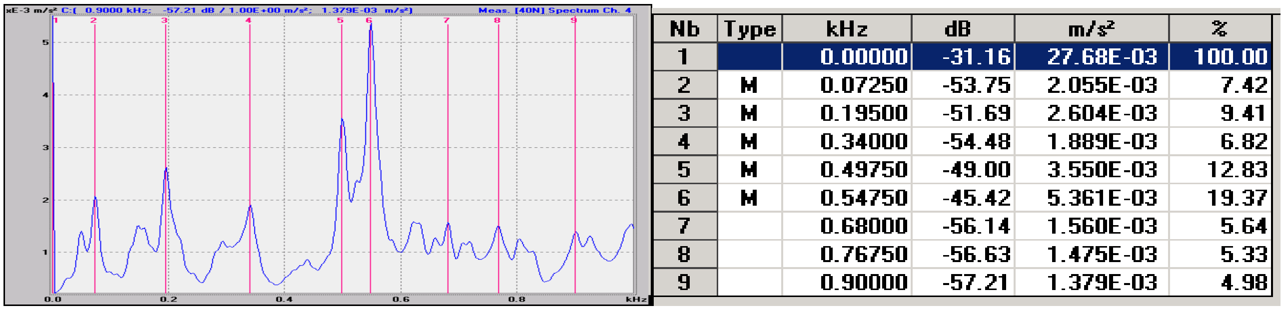
Nb	Type	kHz	dB	m/s²	%
1		0.00000	-37.53	13.29E-03	100.00
2		0.14750	-80.83	90.88E-06	0.68
3	M	0.19500	-77.89	127.5E-06	0.96
4		0.37750	-71.78	257.6E-06	1.94
5	M	0.46250	-66.06	497.7E-06	3.74
6	M	0.54750	-62.80	724.4E-06	5.45
7	M	0.74250	-65.70	518.8E-06	3.90
8		0.83000	-61.53	838.4E-06	6.31
9		0.90250	-55.49	1.681E-03	12.65
10		0.93500	-55.80	1.622E-03	12.20

Figure 14: Vibration Level of IC Engine At40n for Channel-2



Nb	Type	kHz	dB	m/s²	%
1		0.00250	-94.74	18.32E-06	100.00
2	M	0.09750	-83.68	65.44E-06	357.21
3	M	0.29250	-81.91	80.23E-06	437.94
4		0.46250	-84.23	61.42E-06	335.26
5		0.61750	-76.74	145.5E-06	794.21
6	M	0.71750	-66.90	451.7E-06	2465.61
7		0.75500	-68.93	357.5E-06	1951.42
8		0.90250	-74.04	198.5E-06	1083.52

Figure 15: Vibration Level of IC Engine at 40N for Channel-3



Nb	Type	kHz	dB	m/s²	%
1		0.00000	-31.16	27.68E-03	100.00
2	M	0.07250	-53.75	2.055E-03	7.42
3	M	0.19500	-51.69	2.604E-03	9.41
4	M	0.34000	-54.48	1.889E-03	6.82
5	M	0.49750	-49.00	3.550E-03	12.83
6	M	0.54750	-45.42	5.361E-03	19.37
7		0.68000	-56.14	1.560E-03	5.64
8		0.76750	-56.63	1.475E-03	5.33
9		0.90000	-57.21	1.379E-03	4.98

Figure 16: Vibration Level of IC Engine at 40N for Channel-4

4.5. Trigger Windows at 80 N

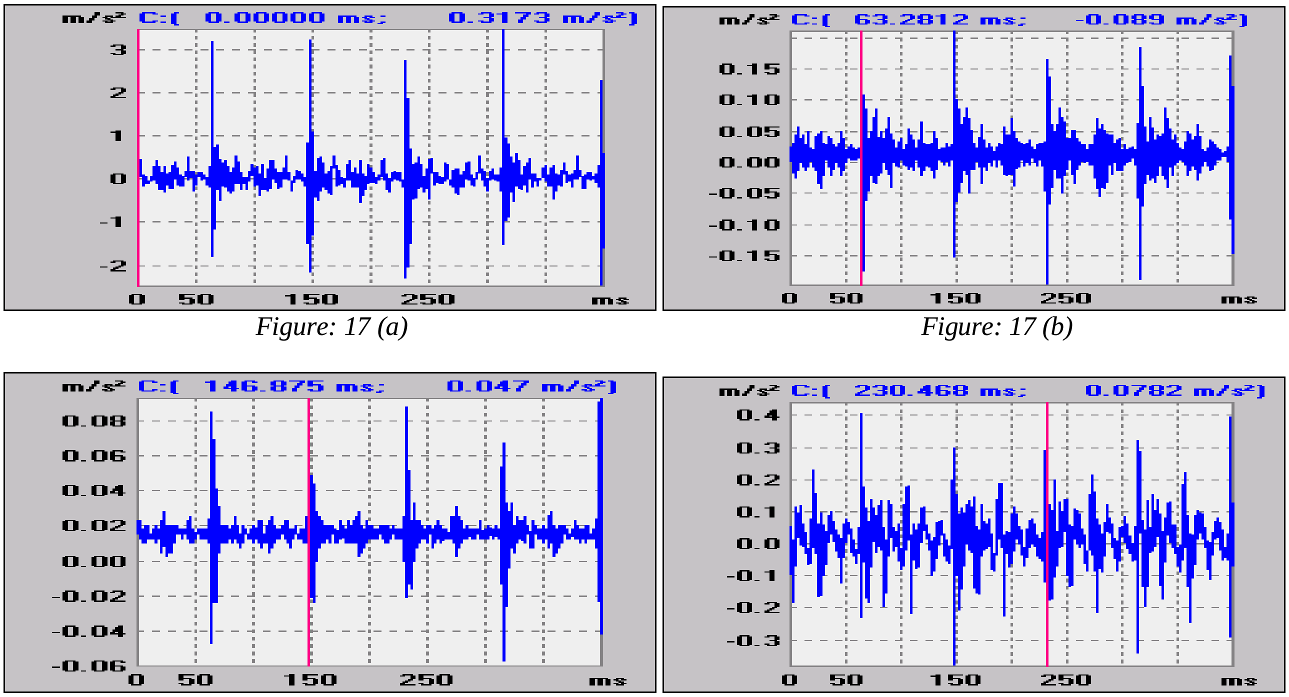
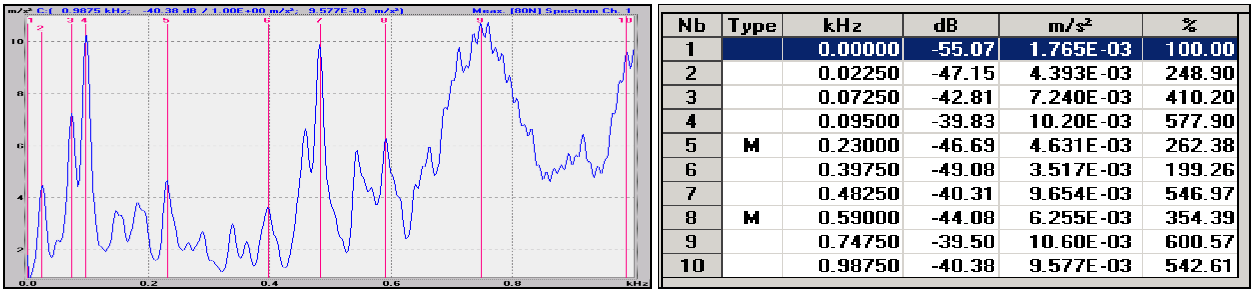


Figure: 17 (a) *Figure: 17 (b)*

Figure: 17 (c) *Figures: 17 (d)*

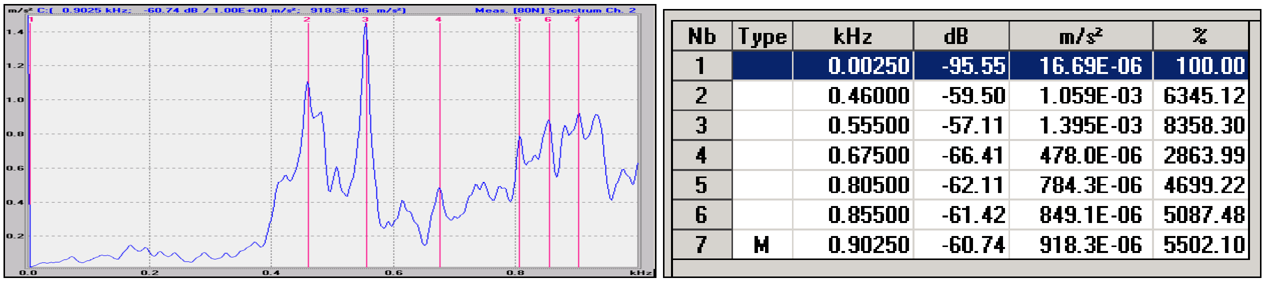
Figure 17: (A) To (D): Graphs of Time and Frequency Domain of IC Engine at Load 80N

4.6. Spectrum Graphs of I.C. Engine at 80 N



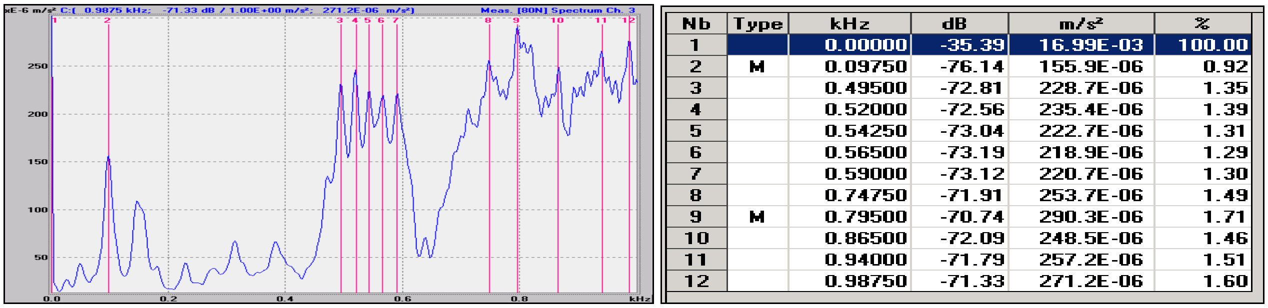
Nb	Type	kHz	dB	m/s²	%
1		0.00000	-55.07	1.765E-03	100.00
2		0.02250	-47.15	4.393E-03	248.90
3		0.07250	-42.81	7.240E-03	410.20
4		0.09500	-39.83	10.20E-03	577.90
5	M	0.23000	-46.69	4.631E-03	262.38
6		0.39750	-49.08	3.517E-03	199.26
7		0.48250	-40.31	9.654E-03	546.97
8	M	0.59000	-44.08	6.255E-03	354.39
9		0.74750	-39.50	10.60E-03	600.57
10		0.98750	-40.38	9.577E-03	542.61

Figure 18: Vibration Level of IC Engine at 80N for Channel-1



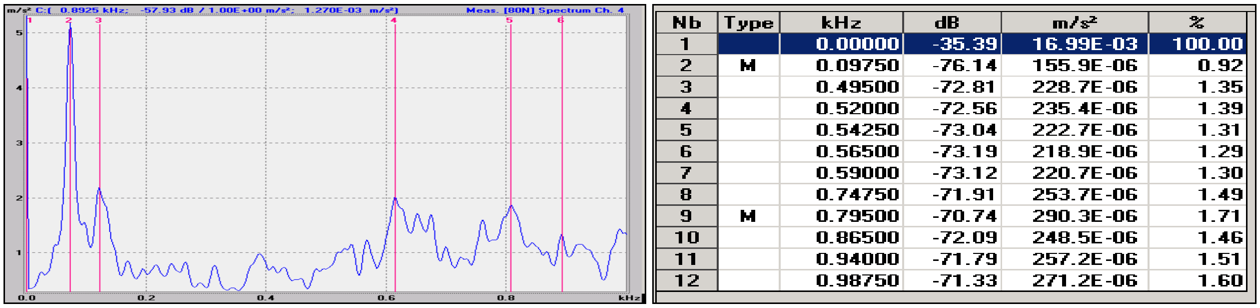
Nb	Type	kHz	dB	m/s²	%
1		0.00250	-95.55	16.69E-06	100.00
2		0.46000	-59.50	1.059E-03	6345.12
3		0.55500	-57.11	1.395E-03	8358.30
4		0.67500	-66.41	478.0E-06	2863.99
5		0.80500	-62.11	784.3E-06	4699.22
6		0.85500	-61.42	849.1E-06	5087.48
7	M	0.90250	-60.74	918.3E-06	5502.10

Figure 19: Vibration Level of IC Engine at 80N for Channel-2



Nb	Type	kHz	dB	m/s²	%
1		0.00000	-35.39	16.99E-03	100.00
2	M	0.09750	-76.14	155.9E-06	0.92
3		0.49500	-72.81	228.7E-06	1.35
4		0.52000	-72.56	235.4E-06	1.39
5		0.54250	-73.04	222.7E-06	1.31
6		0.56500	-73.19	218.9E-06	1.29
7		0.59000	-73.12	220.7E-06	1.30
8		0.74750	-71.91	253.7E-06	1.49
9	M	0.79500	-70.74	290.3E-06	1.71
10		0.86500	-72.09	248.5E-06	1.46
11		0.94000	-71.79	257.2E-06	1.51
12		0.98750	-71.33	271.2E-06	1.60

Figure 20: Vibration Level of IC Engine at 80N for Channel-3



Nb	Type	kHz	dB	m/s²	%
1		0.00000	-35.39	16.99E-03	100.00
2	M	0.09750	-76.14	155.9E-06	0.92
3		0.49500	-72.81	228.7E-06	1.35
4		0.52000	-72.56	235.4E-06	1.39
5		0.54250	-73.04	222.7E-06	1.31
6		0.56500	-73.19	218.9E-06	1.29
7		0.59000	-73.12	220.7E-06	1.30
8		0.74750	-71.91	253.7E-06	1.49
9	M	0.79500	-70.74	290.3E-06	1.71
10		0.86500	-72.09	248.5E-06	1.46
11		0.94000	-71.79	257.2E-06	1.51
12		0.98750	-71.33	271.2E-06	1.60

Figure 21: Vibration level of IC engine at 80N for channel-4

4.7. Trigger Windows at 120 N

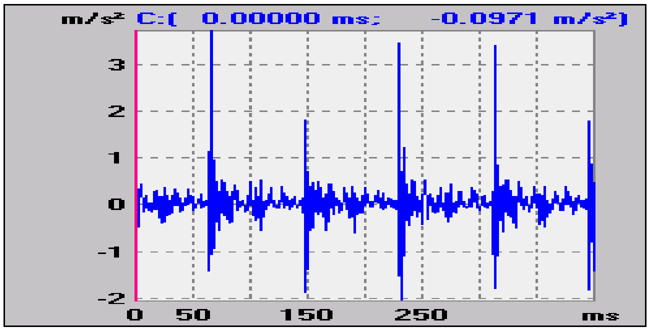


Figure 22 (a)

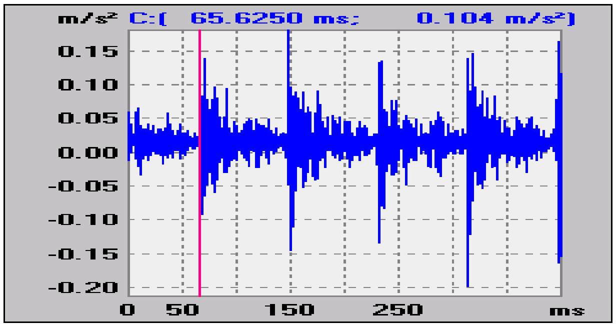


Figure 22 (b)

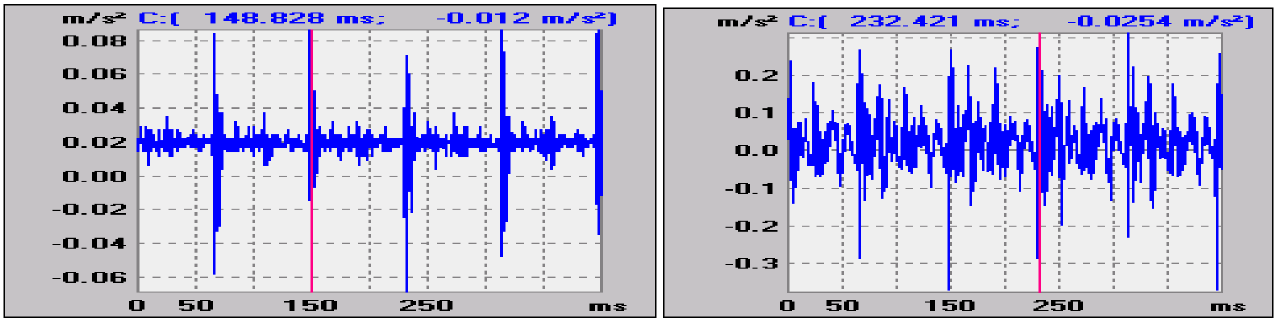
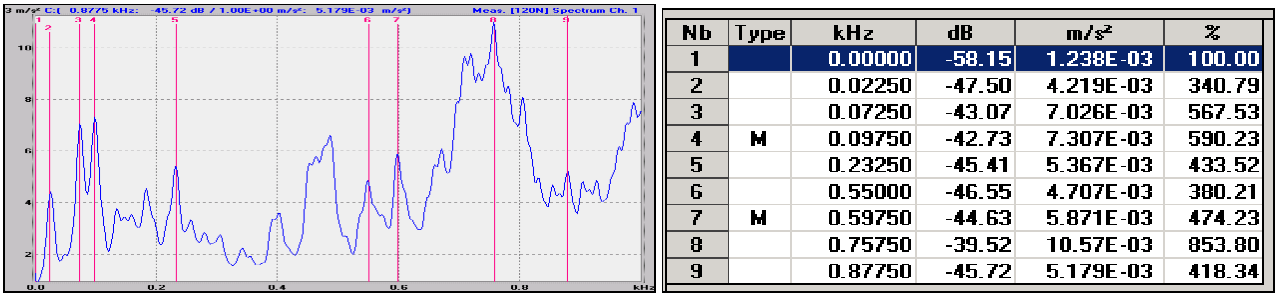


Figure 22 (c) Figure 22 (d)

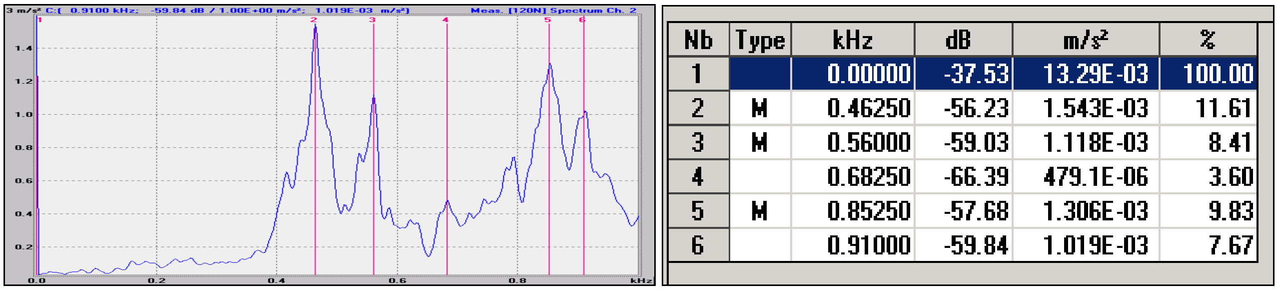
Figure 22: (a) to (d): Graphs of time and frequency domain of IC engine at load 120N

4.8. Spectrum Graphs of I.C Engine at 120 N



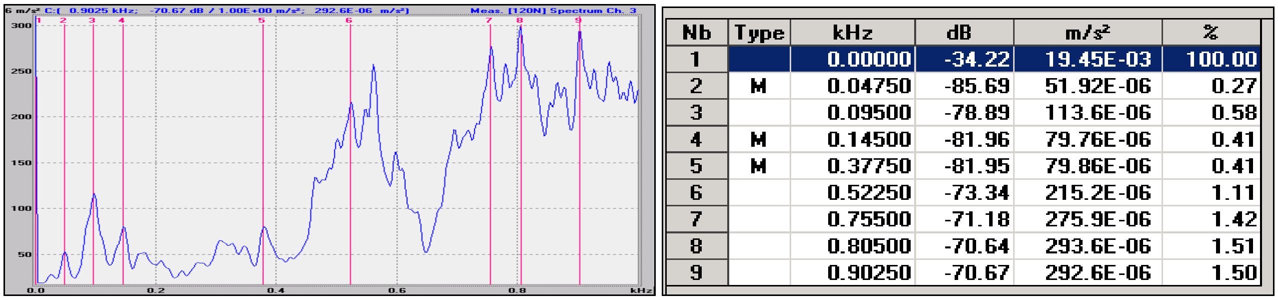
Nb	Type	kHz	dB	m/s²	%
1		0.00000	-58.15	1.238E-03	100.00
2		0.02250	-47.50	4.219E-03	340.79
3		0.07250	-43.07	7.026E-03	567.53
4	M	0.09750	-42.73	7.307E-03	590.23
5		0.23250	-45.41	5.367E-03	433.52
6		0.55000	-46.55	4.707E-03	380.21
7	M	0.59750	-44.63	5.871E-03	474.23
8		0.75750	-39.52	10.57E-03	853.80
9		0.87750	-45.72	5.179E-03	418.34

Figure 23: Vibration Level of IC Engine at 120N for Channel-1



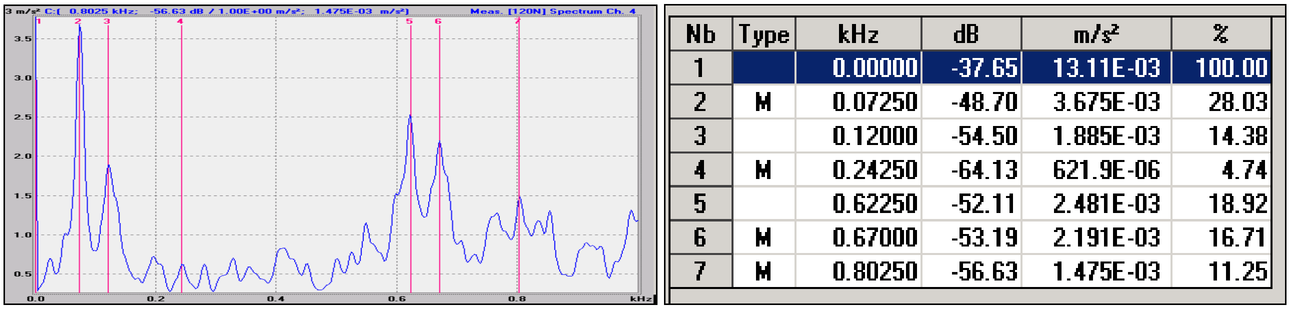
Nb	Type	kHz	dB	m/s²	%
1		0.00000	-37.53	13.29E-03	100.00
2	M	0.46250	-56.23	1.543E-03	11.61
3	M	0.56000	-59.03	1.118E-03	8.41
4		0.68250	-66.39	479.1E-06	3.60
5	M	0.85250	-57.68	1.306E-03	9.83
6		0.91000	-59.84	1.019E-03	7.67

Figure 24: Vibration Level of IC Engine at 120N for Channel-2



Nb	Type	kHz	dB	m/s²	%
1		0.00000	-34.22	19.45E-03	100.00
2	M	0.04750	-85.69	51.92E-06	0.27
3		0.09500	-78.89	113.6E-06	0.58
4	M	0.14500	-81.96	79.76E-06	0.41
5	M	0.37750	-81.95	79.86E-06	0.41
6		0.52250	-73.34	215.2E-06	1.11
7		0.75500	-71.18	275.9E-06	1.42
8		0.80500	-70.64	293.6E-06	1.51
9		0.90250	-70.67	292.6E-06	1.50

Figure 25: Vibration Level of IC Engine at 120N for Channel-3



Nb	Type	kHz	dB	m/s²	%
1		0.00000	-37.65	13.11E-03	100.00
2	M	0.07250	-48.70	3.675E-03	28.03
3		0.12000	-54.50	1.885E-03	14.38
4	M	0.24250	-64.13	621.9E-06	4.74
5		0.62250	-52.11	2.481E-03	18.92
6	M	0.67000	-53.19	2.191E-03	16.71
7	M	0.80250	-56.63	1.475E-03	11.25

Figure 26: Vibration Level of IC Engine at 120N for Channel-4

4.9. Trigger Windows at off Condition

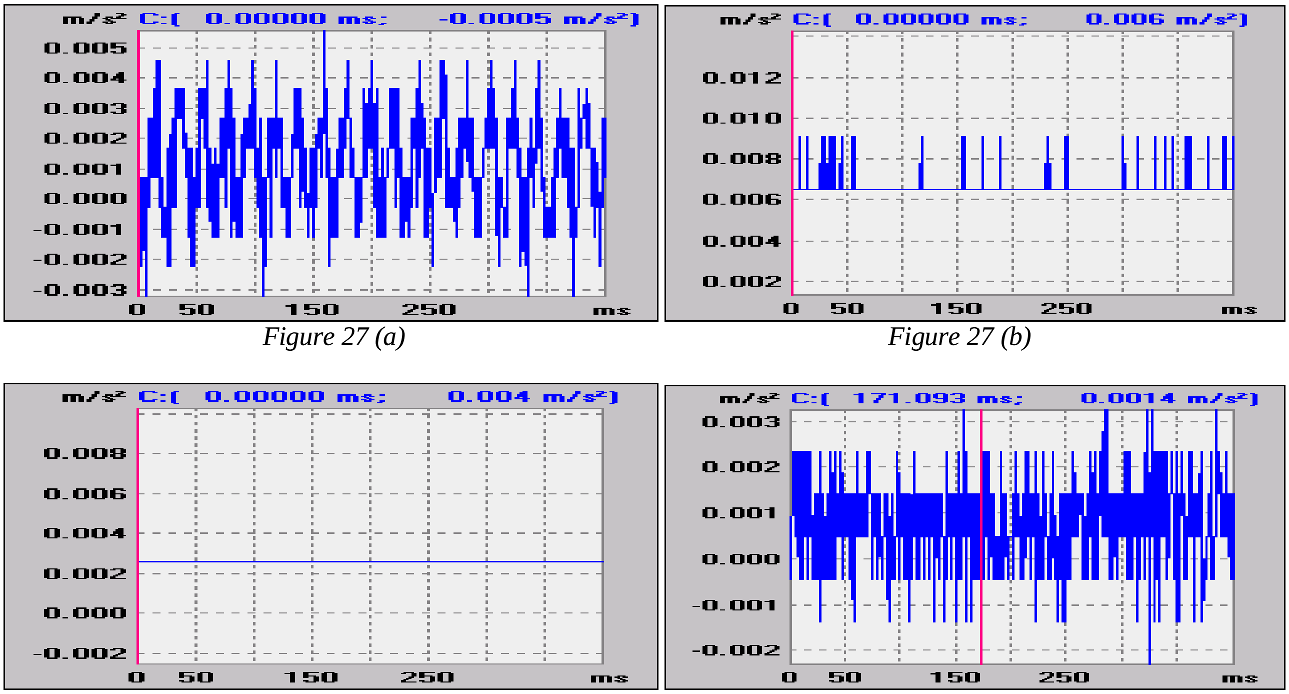


Figure 27 (a)

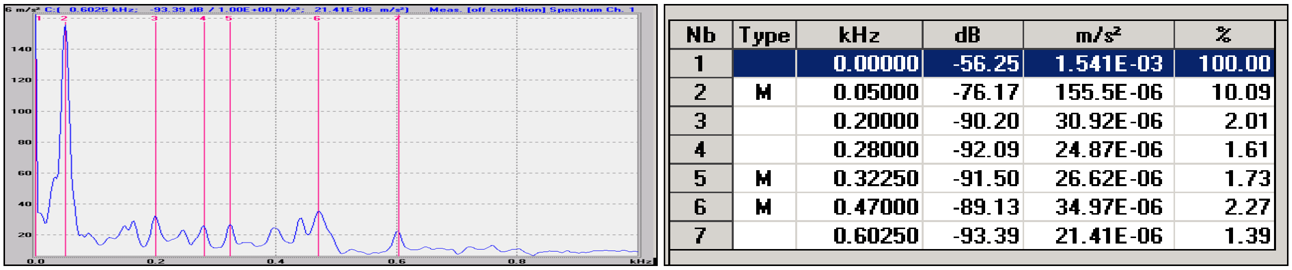
Figure 27 (b)

Figure 27 (c)

Figure 27 (d)

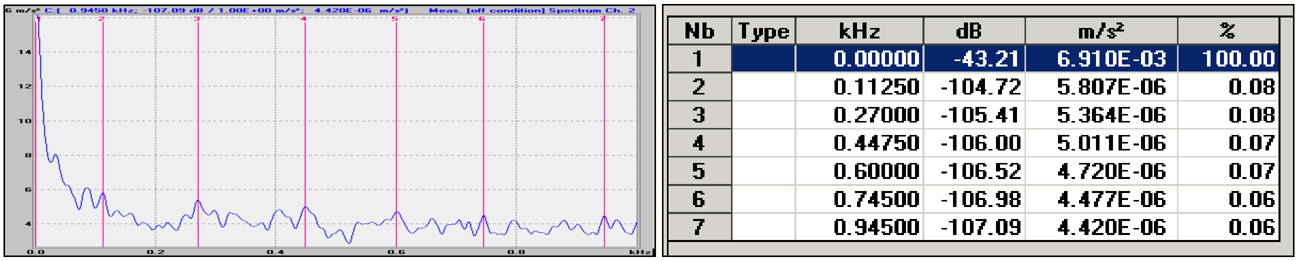
Figure 27 (A) To (D): Graphs of Time and Frequency Domain of IC Engine at Off Condition

4.10. Spectrum Graphs at off Condition



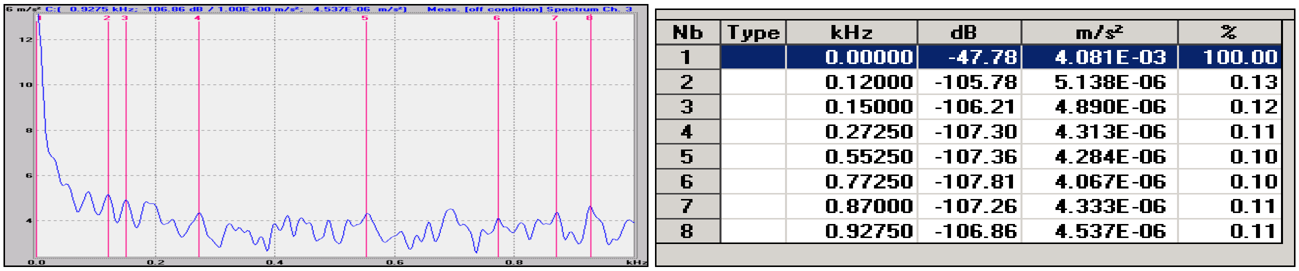
Nb	Type	kHz	dB	m/s²	%
1		0.00000	-56.25	1.541E-03	100.00
2	M	0.05000	-76.17	155.5E-06	10.09
3		0.20000	-90.20	30.92E-06	2.01
4		0.28000	-92.09	24.87E-06	1.61
5	M	0.32250	-91.50	26.62E-06	1.73
6	M	0.47000	-89.13	34.97E-06	2.27
7		0.60250	-93.39	21.41E-06	1.39

Figure 28: Vibration Level of IC Engine at Off Condition for Channel-1



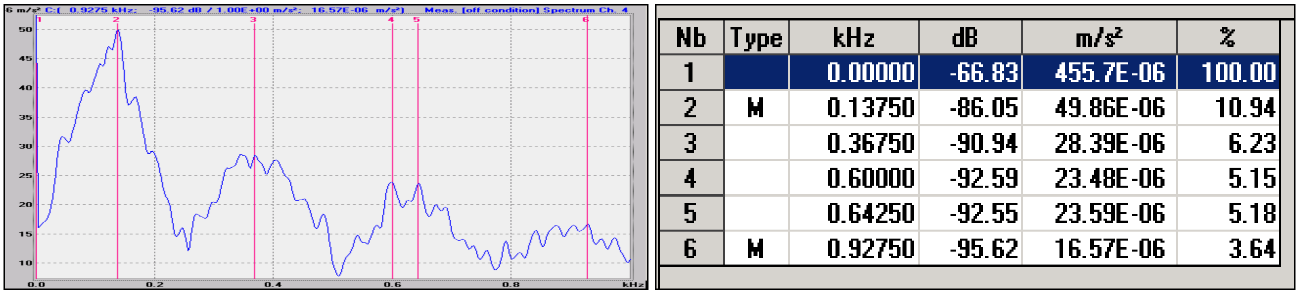
Nb	Type	kHz	dB	m/s²	%
1		0.00000	-43.21	6.910E-03	100.00
2		0.11250	-104.72	5.807E-06	0.08
3		0.27000	-105.41	5.364E-06	0.08
4		0.44750	-106.00	5.011E-06	0.07
5		0.60000	-106.52	4.720E-06	0.07
6		0.74500	-106.98	4.477E-06	0.06
7		0.94500	-107.09	4.420E-06	0.06

Figure 29: Vibration Level of IC Engine at Off Condition for Channel-2



Nb	Type	kHz	dB	m/s²	%
1		0.00000	-47.78	4.081E-03	100.00
2		0.12000	-105.78	5.138E-06	0.13
3		0.15000	-106.21	4.890E-06	0.12
4		0.27250	-107.30	4.313E-06	0.11
5		0.55250	-107.36	4.284E-06	0.10
6		0.77250	-107.81	4.067E-06	0.10
7		0.87000	-107.26	4.333E-06	0.11
8		0.92750	-106.86	4.537E-06	0.11

Figure 30: Vibration Level of IC Engine at Off Condition for Channel-3



Nb	Type	kHz	dB	m/s²	%
1		0.00000	-66.83	455.7E-06	100.00
2	M	0.13750	-86.05	49.86E-06	10.94
3		0.36750	-90.94	28.39E-06	6.23
4		0.60000	-92.59	23.48E-06	5.15
5		0.64250	-92.55	23.59E-06	5.18
6	M	0.92750	-95.62	16.57E-06	3.64

Figure 31: Vibration Level of IC Engine at Off Condition for Channel-4

5. Discussion

Form the graphs of time and frequency domain of the internal combustion(IC) engine we can see that the vibration levels at the starting of the engine are very high as shown clearly in the Figures 8 to 12 and the vibration reduces as engine starts running at constant speed without any load. Then we can conclude that the vibration levels will be very high at the time of ignition of the engine.

As we increase the load gradually like starts from 40N, 80N, and 120N on the engine, the vibration levels are getting changed as shown in Figures 13 to 27 clearly the trigger and spectrum graphs of all the four channels mounted on the engine at various parts from base to head of the engine.

In this work the vibration levels of an IC engine is very high at the very start of an engine. That means at the ignition level of the engine there is more vibration occurs that shown in the graphs of time and frequency domain. The above Figures show the vibration levels of an IC engine.

As the vibrations are more at the beginning are at the time of ignition that may cause the "maximum vibration amplitude" is connected to the rate of pressure change and the maximum pressure in the cylinder during ignition. The typical ticking noise of diesel engines comes from the ignition. When the rate of pressure change in the cylinder increases the "maximum vibration amplitude" increases. We may refer to the "maximum vibration amplitude" by means of ignition smoothness. When the "maximum vibration amplitude" is smaller the ignition is smoother and the engine noise is moderate.

6. Conclusion

The chosen measurement technique was based on vibration signature analysis. The sensors are attached to the engine by a magnet without an intrusive approach. The experiments that were done showed that there is a more vibration at the starting of engine and that may the vibrations in whole body of the vehicle and that may cause to discomfort of the passengers.

The results show that the system is capable of identifying fault engine operation and can direct the user to the source of the problem. The results presented in this paper are for engine working without load under steady engine speed and also under various load and speed conditions. But this technique works for a variety of engines speeds and loads, under steady operation conditions or under varying operation conditions. This method may be implemented as a test system for an engine, or as a feedback to an ignition system.

7. References

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