STUDY OF NOISE GENERATED BY KIRLOSKAR SINGLE CYLINDER FOUR STROKE C.I. ENGINE

A thesis

Submitted in partial fulfillment of the requirement for the award of

Degree of

MASTER OF ENGINEERING

IN

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Submitted By

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, ***"Study Of Noise Generated by Kirloskar Single Cylinder Four Stroke C.I. Engine"*** *in partial fulfillment of the requirement for the award of degree of* ***Master of Engineering in Mechanical Engineering*** *with specialization in* ***CAD/CAM & ROBOTICS*** *in the Mechanical Engineering Department,* ***Thapar University,*** *Patiala, is an authentic record of my own work carried out under the supervision and guidance of* ***Mr. Paras Kumar*** *and refers other researcher's work which are duly listed in the reference section.*

The matter embodied in this thesis has not formed the basis for the award of any other degree of this or any other university.

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This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge.

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In the end, I wish to express my deep sense of gratitude to my family, for supporting and encouraging me at every step of my work. It is the power of their blessings, which has given me the courage, confidence and zeal for hard work.

Date: July 2009 Regards,

Place: PATIALA **(RWINKLE SINGH)**

ABSTRACT

In our modern, rapidly expanding environment one of the developing problems is that of “Noise”. The purpose of this report is to the study the fundamentals of acoustics and analysis of engine noise which causes serious effects on human beings. In India, the transportation sector is growing rapidly and number of vehicles on Indian roads is increasing at very fast rate. This has lead to overcrowded roads and pollution.

Noise from a diesel engine is caused by vibration of the surfaces of the structure. Combustion is a major force which generates pressure and the engine mechanism also generates forces, these forces combine and cause the structure to vibrate.

So, it is necessary to study noise generated by the engine by measuring sound pressure level and calculating sound power and measure the vibrations in which acceleration, velocity and displacement are measured at specific point to understand under which frequency range the vibrations are high. The sound pressure level under 1-1 Octave band Frequency range is also studied. All these studies were done by varying compression ratio and load at all marked locations of the engine.

In the analysis of C.I. Engine noise the maximum sound pressure level comes out at exhaust and the acoustic power increases as load increases for all compression ratios. In the analysis of vibration the acceleration and vibrations are analyzed in which the acceleration is maximum at 1000 Hz and vibration is maximum at 500 Hz. From the analysis, there is more need to concentrate on low frequencies. There is no direct correlation find between sound pressure level analysis and vibrational analysis for the marked location. The analysis for frequency spectrum is also done on engine to find out under which frequency the sound pressure level is high. The regression analysis was also carried out for all locations and for acoustic power to find out the percentage error between measured value and predicted value.

This study will help to optimize compression ratio and load produces lesser or higher noise in which frequency range and at which point.

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NOMENCLATURE

SYMBOLS	DESCRIPTION
TTS	Temporary threshold shift
PTS	Permanent threshold shift
Hz	Hertz
f_{upper}	Frequency of upper limit
f_{lower}	Frequency of lower limit
C_{centre}	Centre frequency
SPL	Sound pressure level
dB	Decibel
Leq	Equivalent continuous sound level
SEL	Sound exposure level
L_{10}	10 percentile exceeded Sound level
L_{90}	90 percentile exceeded sound level
L_{50}	Median value of sound level
Ls	Average SPL in dB(A)
Lw	Acoustic Power in dB(A) (ref. 10^{-12} W)
C.R.	Compression ratio

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CHAPTER 1

INTRODUTION TO NOISE

In our modern world, rapidly expanding environment one of the developing problems is that of noise. Apart from the pure annoyance factor of noise, exposure to an intense sound field over a long period of time presents the risk of permanent damage of hearing. This particular problem is becoming a source of serious concern to industrial corporations, trade unions and companies.

The object of this part is to discuss the concept of noise, problems of noise and its effect on man and environment both as annoyance and as a danger to health.

The noise sources major parts are from:

1. Industrial noise
2. Traffic noise
3. Community noise

Out of above three parameters, the source that affects the most is Traffic noise. In traffic noise, almost 70% of noise is contributing by vehicle noise. Vehicle noise, mainly, arises from two parameters i.e. Engine noise and Tire noise. The major concern is to study the engine noise completely that from where the noise is coming analyze an engine by changing the different parameters.

Some of the basic terms used in noise are:

Noise: Noise is conveniently and concisely defined as “unwanted sound”.

Sound: Sound waves are pressure variations produced as a result of mechanical disturbance in a material medium.

Wavelength: As the sound propagates through the air it creates pressure variations and the distance between succeeding pressure maxima is called the wavelength.

Frequency: Number of cycles per second is known as frequency.

Decibel: Decibel is the logarithm of a ratio of two quantities and therefore has no units. Decibel is defined by expression as $10 \log_{10} (P/P_0)^2$

P is the sound pressure amplitude of the measured sound

P_0 is a reference pressure, 20μPa.

Sound Pressure (N/m^2)	**Sound Pressure Level (dB)**	**Environmental Conditions**
10^2	134 dB	Threshold of pain
10	114 dB	Loud Automobile horn (distance 1m)
1	94 dB	Inside subway train
10^{-1}	74 dB	Average Traffic on street corner
10^{-2}	54 dB	Living room, Typical business office
10^{-3}	34 dB	Library
10^{-4}	14 dB	Broadcasting Studio
$2*10^{-5}$	0 dB	Threshold of Hearing

Fig. 1.1 Environmental conditions at different SPL

1.1. SOUND SOURCES:

A distinction is made between 3 different types of sound sources:

1. Point source
2. Line source
3. Plane source

1.1.1 Point source: A sound source can be considered as a point source, if its dimensions are small in relation to the distance to the receiver and it radiates an equal amount of energy in all directions. Typical point sources are industrial plants, aircraft and individual road vehicles. The sound pressure level decreases 6 dB whenever the distance to a point source is doubled.

1.1.2. Line source: A line source may be continuous radiation, such as from a pipe carrying a turbulent fluid, or may be composed of a large number of point sources so closely spaced that their emission may be considered as emanating from a notional line connecting them. The sound pressure level decreases 3 dB, whenever the distance to a line source is doubled.

1.1.3. Plane source: A plane source can be described as follows. If a piston source is constrained by hard walls to radiate all its power into an elemental tube to produce a plane wave, the tube will contain a quantity of energy numerically equal to the power output of the source. In the ideal situation there will be no attenuation along the tube. Plane sources are very rare and only found in e.g. duct systems.

When 2 sources radiate sound energy, they will both contribute to the sound pressure level a distance away from the sources. If they radiate the same amount of energy and the distance from the point of measurement to the sources is the same, the level will increase by 3 dB compared with the level created by one source alone.

1.2. PHYSICAL PROPERTY OF SOUND

1.2.1 Sound power: When sound is produced, a transfer of energy from the source to the surrounding air molecules takes place. The rate of energy transfer is called Sound Power. The unit of Sound Power is W (Watt).

The audible range of sound power extends from 10^{-9} W to more than 1000 W. 10^{-9} W is the lowest level which can be heard by a listener close to the source, and 1000 W will create immediate hearing damage. Lower levels can also create hearing damage, if the listener is exposed for a long period of time.

1.2.2. Sound intensity: When a source produces sound power (P) it will create a certain Sound Intensity (I) at a distance away from the source. The intensity is a measure for the amount of power through a certain area at this distance.

None of these units can be measured directly. Their values can, however, be calculated after measurement of the sound pressure level, knowing the area over which measurements are being made.

The relationship between Sound Pressure (p), Intensity (I) and Sound Power (P) can be written as

$$p^2 \alpha I \alpha P. \tag{1.1}$$

1.2.3 Sound pressure level: Decibel (dB) is logarithmic ratio which defines the sound pressure level L_p as follows:

$$L_p = 20 \log_{10} P / P_0 \tag{1.2}$$

P is the sound pressure measured

P_o is the reference sound pressure i.e. 20µPa (the threshold of hearing).

This logarithmic scale has several advantages over a linear scale. The most important advantages are:

1. A linear scale would lead to the use of some enormous and unwieldy numbers.

2. The ear responds not linearly, but logarithmically to stimulus.

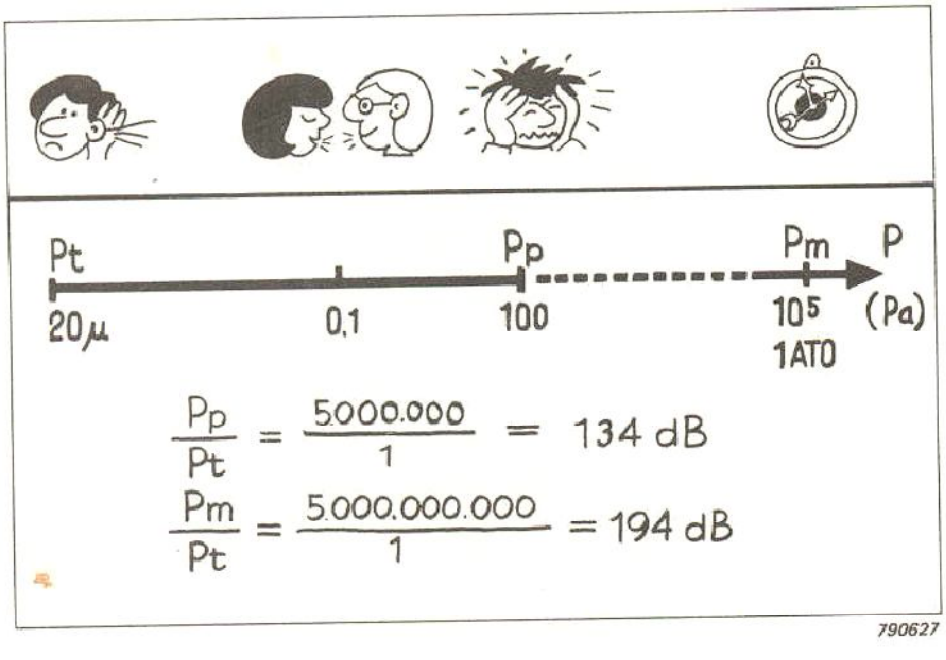

Fig. 1.2 Calculation of SPL

1.3. CHARACTERISTICS OF SOUND

1.3.1. Background noise: When sound measurement on for instance a machine is carried out, it is important that the background noise level is so low, that it does not have any influence on the result. This can be tested in the following manner. Measure the sound at the position where it should be measured with the source (machine) running. Switch off the machine and measure the sound level without the machine running.

If the difference is less then 3dB measurements should be stopped until the background noise has been reduced. If the difference is between 3 and 10 dB use the curve to correct the measured value. If the difference is more than 10 dB, the background noise may be ignored.

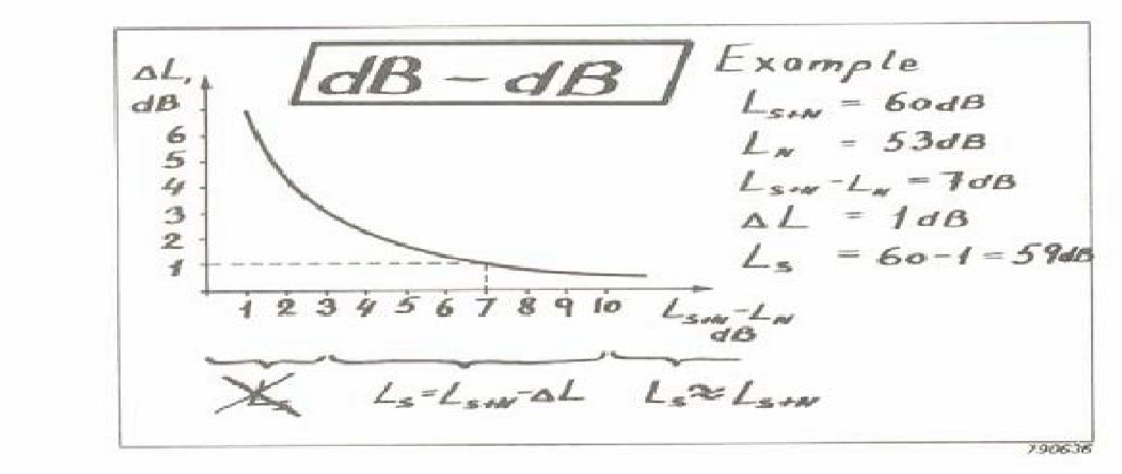

Fig.1.3 Subtraction of background noise in dB

This is the curve for reducing the background noise. In this example, measurement without M/C on is 53dB and with M/C on is 60dB. So there is a difference of 7dB and then from background noise curve, 1 dB of correction value is taken to have a corrected value. So the corrected sound pressure level is 59dB.

1.3.2. Loudness: Loudness is a subjectively perceived attribute of sound which enables a listener to order its magnitude on scale from soft to loud. It is defined as subjective intensity of sound. Based on these curves of equal loudness, the “phon” scale was logically conceived as a measure of loudness level. The loudness level of a sound in phons is the sound pressure level in dB re. $2x10^{-5}$ N/m^{2} of a pure tone.

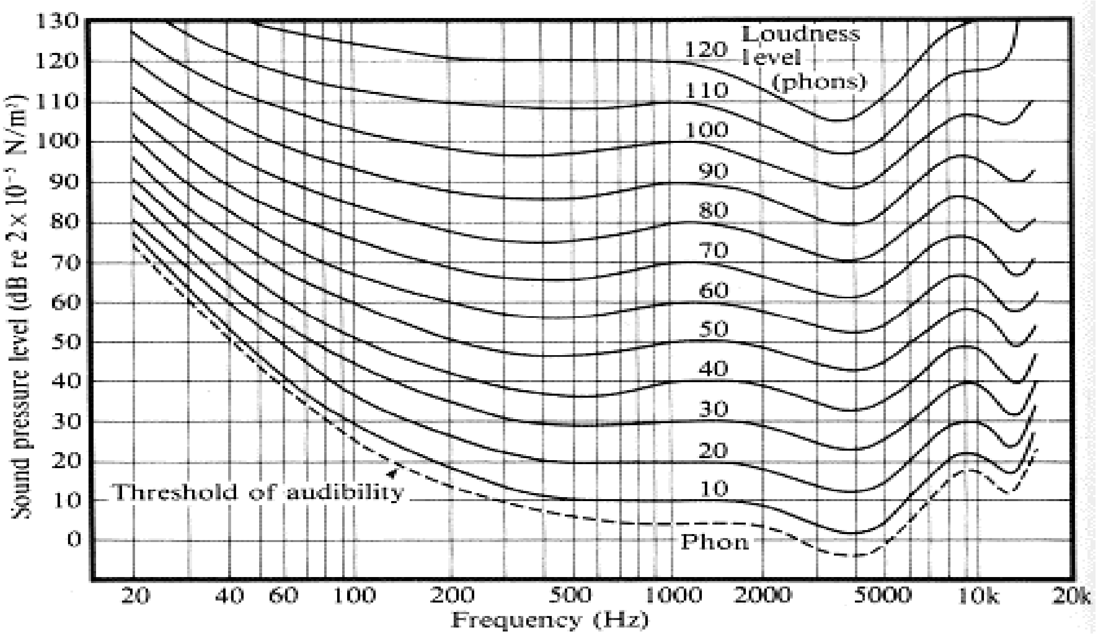

Fig.1.4 Equal loudness contours

Non linear response of the ear:

1. 1000 Hz tone of 40dB (40 phon) is of same loudness as

63 Hz tone of 58dB

or

4000 Hz tone of 31dB

2. Increase in loudness for a corresponding increase in sound level depends upon frequency and on level also.

1.3.3. Weighting curves: The non-linear response of the ear has lead to the introduction of weighting filters, making it possible to carry out measurements, which correlate well with the response of the ear. The most commonly used of these curves is the A-weighting curve, because it gives the best correlation between the measured values and the annoyance and harmfulness of the sound signal. It follows approximately the 40 phons curve in Fig. 4. The B-weighting and C-weighting curve follow more or less the 70 phons and the 100 phons curves. The D-weighting curve follows a contour of perceived noisiness, and is used for aircraft noise measurement. Weighting filters can easily be built into portable Sound Level Meters, and the sound level measured is then given in dB(A) in cases where an A-weighting filter has been used etc.

Some sound level meters also have octave filters built in, or provision for connection of external filters.

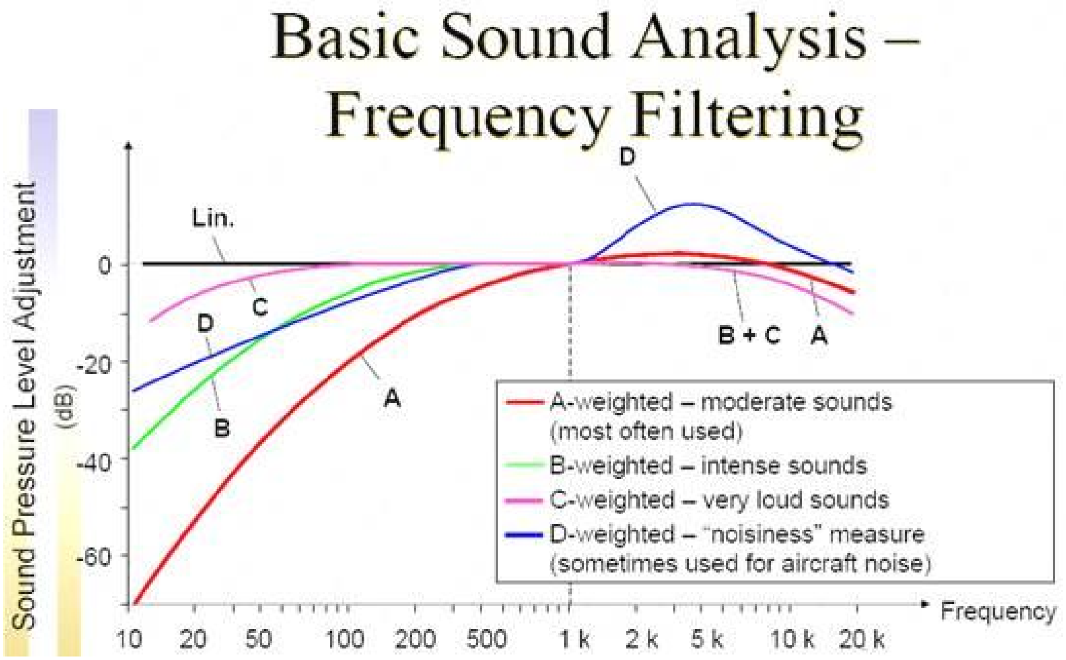

Fig.1.5 weighting curves

1.3.4. Frequency analyzer: All non-sinusoidal signals are composed of 2 or more sinusoidal signals. The non-sinusoidal signal can be represented in either the time domain as a function of time or in the frequency domain, where the individual frequency components are represented on a frequency scale. A noise signal will contain signals of all frequencies, or at least a broad spectrum of frequencies.

When a sound signal is investigated it is often desirable to investigate a limited part of the frequency spectrum. This can be done with the aid of a filter which will allow passage of only that part of the spectrum which lies inside the bandwidth (Δf) of the filter. A practical filter however will not have such a steep cut-off and the usual filter characteristic is that shown in Fig. 3 together with the characteristic for an ideal filter.

The bandwidth (Δf) of the filter can be defined as the frequency range between the points where the filter characteristic shows a reduction of 3dB, or as the frequency range of an ideal filter which would allow the same amount of power of a signal containing all frequencies to pass. The difference between the bandwidth found using these two definitions is for most filters very small. For more details see the literature listed at the end of this note.

It is common to classify a filter according to its bandwidth, and there are 2 classes of filters which may be encountered, constant, bandwidth filters and filters with a constant percentage bandwidth.

The constant bandwidth filters have, as the name indicates, a constant bandwidth filters have a constant ratio between bandwidth and center frequency. A special type of constant percentage bandwidth filters is the octave filters, where the upper limiting frequency is twice the lower limiting frequency $f_2 = 2\ f_1$. Where a narrower constant percentage bandwidth is required 1/3 octave filters are used.

By making the octave filter stepwise or continuously variable, it is possible to sweep over a large frequency range and get individual information about each little part of the frequency band.

1.3.5. Equivalent Continues Sound Level (L_{eq}): L_{eq} is the A-weighted energy mean of the noise level averaged over the measurement period. It can be considered as the continuous noise which would have the same total A-weighted acoustic energy as the real fluctuating noise measured over the same period of time and is defined as

$$L_{eq} = 10 \log_{10} \frac{1}{T}\int_{o}^{T}\left(\frac{p_A(t)}{Po}\right)^2 dt$$

Where T is the total measurement time,

$p_A(t)$ is the A-weighted instantaneous acoustic pressure

and P_O is the reference acoustic pressure of 20 µPa.

1.4. HARMFUL EFFECTS OF NOISE ON HUMAN BEINGS

1. Reduces work efficiency.
2. Affects the speech communication.
3. May cause temporary threshold shift (TTS)/permanent threshold shift (PTS).
4. Induces loss of hearing ability.
5. Causes psychological strain and mental fatigue.

6. May damage the heart.

7. Increases the cholesterol level in the blood.

8. Dilates the blood vessels of the brain.

9. Upsets the chemical balance of the body.

10. Causes headache, nausea and general feeling of uneasiness.

11. Induces errors in ‘motor’ performance, in visual perception and in distance and size evaluations.

12. Induces psychosis and acute mental agony.

1.5. USEFUL APPLICATIONS OF NOISE: Noise is not only has harmful affects but sometimes it is very useful. Some of the examples when noise is useful:

1. Study of heart beats: Noise produced by the heart beats is very useful to diagnose the person’s health accordingly.

2. Masking effects: Sometimes, it is necessary that nobody should hear the conversation between the two persons. For this, masking effect is used. For e.g., In the doctors chamber, doctor wants that nobody should hear his conversation with the patient so Dr. uses masking effect by putting a more noisy exhaust fan which make noise outside the room.

1.6. NOISE MEASURING INSTRUMENT AND TECHNIQUE

1.6.1. NOISE MEASURING INSTRUMENT

Noise measuring devices typically use a sensor to receive the noise signals emanating from a source. The sensor, however, not only detects the noise from the source, but also any ambient background noise. Thus, measuring the value of the detected noise is inaccurate, as it includes the ambient background noise. For this we use Sound Level Meter.

1.6.1.1. Sound Level Meter has:

1. Microphone

2. Amplifier

3. Rectifier

4. Smoothing circuit

5. Meter

Fig.1.6 Sound Level Meter

1.6.2. PRECAUTIONS IN MEASUREMENT

1. Records Prior to Measurement: Record the date and time of measurement, location, weather conditions, personnel names, microphone height, measurement range, frequency compensation of the noise level meter, paper feed speed of the level recorder, and model and manufacturer of equipment.

2. Wind Effect: When measuring noise outdoors, attach a wind prevention screen to the microphone of the noise level meter.

3. Measurement Site: Select a location that is not effected by reverberated sound or subjected to magnetic fields, vibrations, or extreme temperatures or humidity.

4. Measurement Period: Select a time that background noise is stable and there are no other sources possibly effecting measurements. Where the problem source is stable, measurement need last only 2 - 3 min. However, if A-weighted sound pressure level fluctuates greatly, measure for 250 sec or more. If there is background noise from automobile traffic or other source, measure for the aforementioned duration in a period in which those effects are not noticeable. Especially when recording, the longer the recording, the better.

5. Range Setting: Get an idea of A-weighted sound pressure level prior to measurement and then set the full scale with some leeway that accounts for the full measurement time. With shock signals, the peak of the waveform can go off the scale even though the needle reading (measured value) may not, therefore it is necessary to keep an eye on the overload warning lamp that lights when a waveform peaks. This same precaution is needed for the audio recorder and not just the measuring equipment.

6. Keeping Records during Measuring: Using one's own sense of hearing, distinguish between the target sound and other noise and make a record to that effect on the recording paper during measurement. If the measurement environment changes during measurement, record the change in status, the time it occurred and other related information on the recording paper. For example, if a machine stops or someone passes in front of the noise level meter, make a note of the change in status and the time it happened on the recording paper.

7. Instructions to Others: Warn others beforehand not to make sounds while recording noise.

8. Measurement Point Records: Differentiate recording points by numbers or other means and mark them on the prepared documents beforehand. Also include the distance from the source, walls, etc.

Also, in order to verify the measurement point after measurement, take photographs of the site.

9. Communications during Measurement: If the boundary area cannot be seen from the source, station one person at the source to monitor operation and another person at the measurement point, with the two communicating by transceiver. If a large peak or other special event is detected at the measurement point, the person at the measurement should contact the person monitoring the source and record any useful information that can be reported.

1.6.3. STEPS FOR MEASUREMENT OF NOISE

1. Check the Sensitivity (calibration) of the Measurement System: Check the Sensitivity (calibration) of the measuring instrument before and after each measurement.

2. Measure the Acoustical Noise Level

Apply all Necessary Correction to the Observed Measurement.

- Correction for Back Ground Noise.
- Correction for reflection of nearby surfaces.
- Correction for ambient pressure.

3. Out Door Measurement use of Windscreen

Wind can be significant influence on outdoor acoustical measurement.

- Wind effects can be minimized to protect microphone.
- Wind generated noise can be reduced significantly by fitting a wind screen.
- Wind screen is a porous ball of open-cell plastic foam or some other porous material placed over the microphone.

1.7. MEASUREMENT OF SOUND POWER

1.7.1. METHOD TO DETERMINE SOUND POWER LEVEL

1. Sound power level measurement with sound pressure level.

1.7.1.1. Sound power level measurement with sound pressure level

The sound power level of noise sources can be measure with the help of sound pressure level with following steps:

1. Surround the source with hypothetical surface of area S (either a hemisphere or a rectangular parallelepiped).

2. Calculate the area of this hypothetical surface if it is hemisphere, S is given by $2\pi r^2$ where r is radius of the hemisphere.

3. If it is rectangular, S is given by ab + 2(ac + bc), where a, b, c are its length, width and height.

4. Measure the sound pressure level at designated point on the hypothetical surface.

5. Obtain the average Ls of sound pressure level.

6. Finally calculate the sound power level from the equation.

$$Lw = Ls + 10\log_{10}(S/So)$$

Where, So is reference area

S is hypothetical surface area

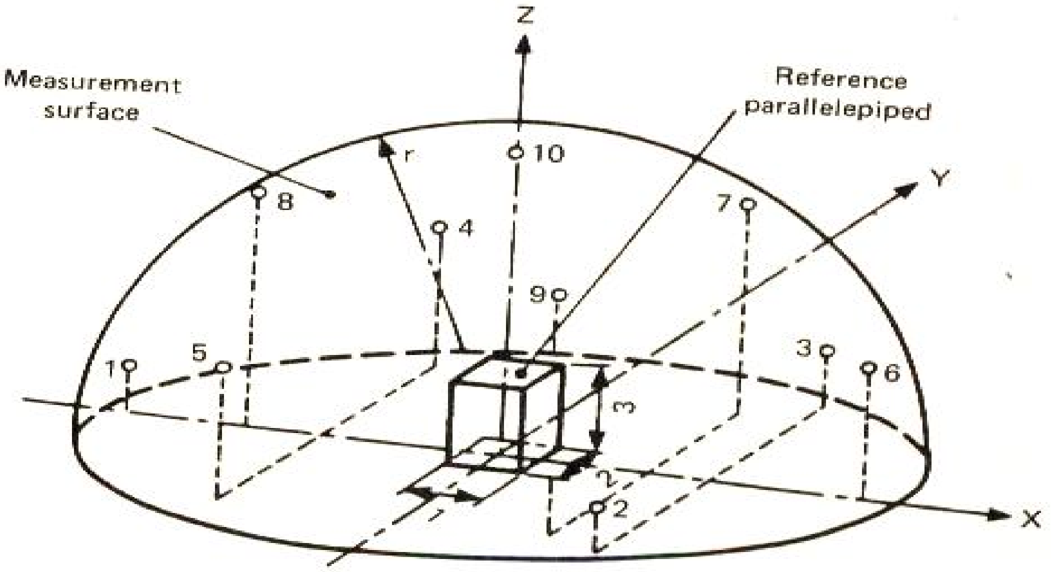

Fig.1.7 Graphical representation of micro phones position on an imaginary hemispherical surface surrounding a source.

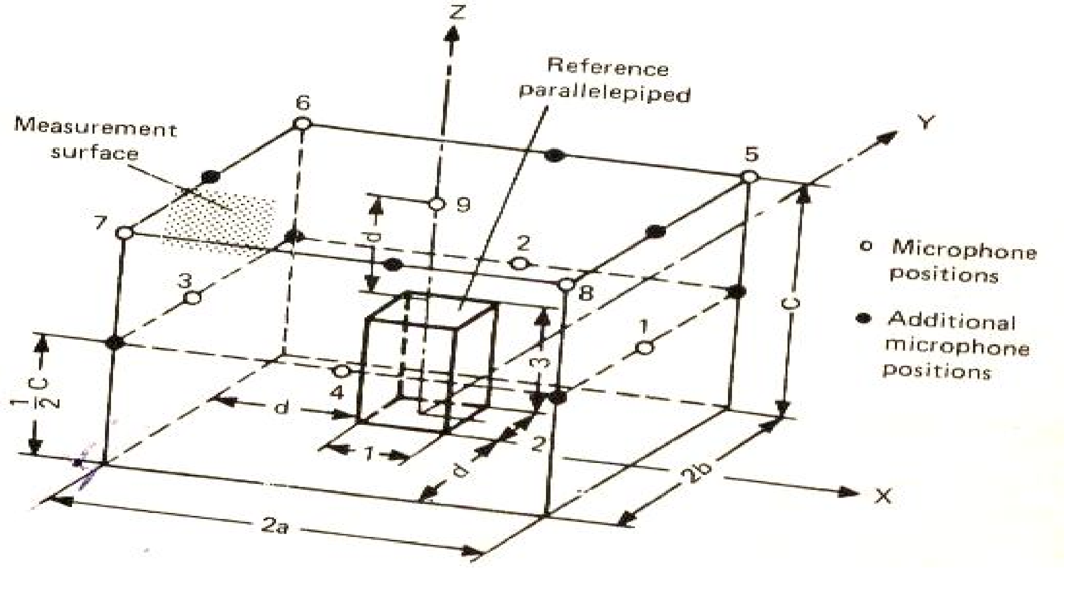

Fig.1.8 Array of microphone positions on an imaginary parallelepiped surface surrounding a source whose sound power is to be measured

1.7.1.2. Additional aspect of measurement which are numbered to correspond to the steps in the above procedure

1. For the small sources those whose largest dimension is significantly less than one meter. It is usually more convenient to se hemisphere the rectangular parallelepiped as a hypothetical measurement surface for large rectangular sources the rectangular parallelepiped surface is usually preferred.

2. The radius of hypothetical hemisphere should be equal to or greater than twice the major source dimension and not less than 1m for the rectangular parallelepiped, the measurement distance “d “, the perpendicular distance between the source and the measurement surface has a preferred value of 1m.

3. For hemisphere the designated point of the microphone locations are shown in Fig. 1.7. The corresponding point for the rectangular parallelepiped is shown in Fig 1.8. The sound pressure level at designated point is measured with A-weighting or in octave or in one-third octave bands.

4. The average sound pressure level over the measurement surface, Ls is calculated from the measured sound pressure level Lsi, after correction for background noise.

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CHAPTER 2

INTRODUCTION TO C.I. ENGINE NOISE

An internal combustion engine operating on a thermodynamic cycle in which the ratio of compression of the air charge is sufficiently high to ignite the fuel subsequently injected into the combustion chamber. Since the combustion of fuel takes place inside the engine cylinder, so these engines are very noisy. C.I. Engine is also known as Diesel engine.

According to the number of strokes per cycle, it is divided into two types:

1. Two stroke cycle engines
2. Four stroke cycle engines

In the two-stroke, or two-cycle, type there is a complete cycle of operation in every two strokes of a piston. This type of engine requires a supply of compressed air for operating and for starting.

In the four-stroke, or four-cycle, type the first downstroke of the piston draws in air, which is compressed on the upstroke to about 500 lb per sq in. (35 kg per sq cm). At the top of the stroke a jet of oil is sprayed in through a fuel injector. The oil is ignited and the rapid expansion of the gas created by the explosion forces the piston down in the working, or firing, stroke. The next upstroke drives the waste gases out through the exhaust valve, and the cycle is complete.

2.1. FACTORS CONTRIBUTING NOISE IN ENGINES

2.1.1. ENGINE NOISE

An **engine** is a mechanical device that produces some form of output from a given input.

The various factors that contribute to the noise in engine are:

2.1.1.1. Combustion noise: Combustion noise is caused by the rapid pressure rise and high peak pressure in the combustion chamber during combustion. This occurs once per revolution per cylinder for two stroke engines and once per two revolutions per cylinder for four stroke engines.

Combustion noise is produced because of unsteady combustion of fluid and is of two types: Turbulent combustion noise and periodic combustion oscillation. The turbulent combustion noise or combustion roar has no specific frequency but is composed of broad-band frequency spectrum. This noise is amplified if the flame is enclosed with the system resonance frequencies dominating. The requirements for reduction of this noise tend to be opposition to those for efficient combustion.

Combustion oscillations involve a feedback cycle that converts chemical energy into oscillatory energy in the gas flow to the combustion region. The mechanism is such that the pressure waves generated are so phased to the velocity fluctuations. The noise spectrum involves one specific frequency and its harmonics and that frequency is related to the resonant modes of the combustion chamber. Some of the possible cures are:

1. Modification of Combustion chamber geometry

2. Change of air-fuel ratio, burner type etc.

3. Change of burning rate

It should be noted that Combustion roar in reciprocating engines which has frequency of the firing rate is not related to the combustion noise, but is due to the gross fluctuation in the flow rate produced by periodic action.

2.1.1.2. Exhaust noise: The engine exhaust noise originates at the exhaust tailpipe openings and is transmitted through the cabin walls, firewall, and nose gear bay. This is the loudest and most objectionable noise heard.

2.1.1.3. Mechanical noise: Mechanical noise is the noise which is generated by various impacts between the engine parts. This noise source is more important in the higher frequency range rather than in lower frequency range where combustion noise is important. There are lots of moving parts, for example, gear, valves, and rocker arms, piston and cylinder liner.
Some are as follows:

1. Engine clicking noise: A clicking or tapping noise that gets louder when you rev the engine is probably "tappet" or upper valve train noise caused by one of several things: low oil pressure, excessive valve lash, or worn or damaged parts.

2. Collapsed lifter noise: Worn, leaky or dirty lifters can also cause valve train noise. If oil delivery is restricted to the lifters (plugged oil galley or low oil pressure), the lifters won't "pump up" to take up the normal slack in the valve train. A "collapsed" lifter will then allow excessive valve lash and noise.

3. Valve lash noise: Too much space between the tips of the rocker arms and valve stems can make the valve train noisy -- and possibly cause accelerated wear of both parts.

4. Damaged engine parts noise: Excessive wear on the ends of the rocker arms, cam followers (overhead cam engines) and/or valve stems can open up the valve lash and cause noise.

5. Rapping or deep knocking engine noise: A deep rapping noise from the engine is usually "rod knock," a condition brought on by extreme bearing wear or damage. If the rod bearings are worn or loose enough to make a dull, hammering noise.

2.1.1.4. Piston slap: Piston slap noise is generated by the sudden impact of the piston to the cylinder wall is considered to be predominant due to the higher amount of energy released.

In the compression stroke, the connecting rod pushes the piston upwards overcoming the gas force. The force acting on the piston has a lateral component and the piston slides upwards on the minor thrust side of the cylinder wall. As the piston moves through T.D.C. the gas forces dominate the internal forces and keep the connecting rod in compression. Thus, as the crank pin passes through the cylinder center line, the lateral component of force on the piston pin changes direction, causing the piston to accelerate through the clearance and slap against the major thrust side of the cylinder wall. There at least two piston slaps per revolution, but the major impact occurs at T.D.C. before the power stroke.

These simple models do not take into account others factors which may affect the piston motion such as:

1. Piston pin offset

2. Rocking motion of piston

3. Frictions at piston pin as well as piston’s outer surface

4. Piston configuration, especially under operation

5. Pressure distribution around piston due to the squeezing motion of oil film

6. Compliance of cylinder liner wall

7. Cylinder liner deformation

2.1.1.5. Bearing noise: Crankshaft bearings are always replaced when rebuilding an engine because they are a wear component. Heat, pressure, chemical attack, abrasion and loss of lubrication can all contribute to deterioration of the bearings. The above features give rise to the noise.

Some of the factors that cause bearing noise are as follows:

1. Dirt: Dirt contamination often causes premature bearing failure. When dirt or other abrasives find their way between the crankshaft journal and bearing, it can become embedded in the soft bearing material. The softer the bearing material, the greater the embed ability, which may or may not be a good thing depending on the size of the abrasive particles and the thickness of the bearing material.

2. Heat: Heat is another factor that accelerates bearing wear and may lead to failure if the bearings get hot enough. Bearings are primarily cooled by oil flow between the bearing and journal. Anything that disrupts or reduces the flow of oil not only raises bearing temperatures but also increases the risk of scoring or wiping the bearing.

3. Misalignment: Misalignment is another condition that can accelerate bearing wear. If the center main bearings are worn more than the ones towards either end of the crankshaft, the crankshaft may be bent or the main bores may be out of alignment.

4. Disassembly: Disassembly can be another cause of premature bearing failure. Common mistakes include installing the wrong sized bearings, installing the wrong half of a split bearing as an upper, getting too much or not enough crush because main and/or rod caps are too tight or loose, forgetting to tighten a main cap or rod bolt to specs, failing to clean parts thoroughly and getting dirt behind the bearing shell when the bearing is installed.

5. Corrosion: Corrosion can also play a role in bearing failure. Corrosion results when acids accumulate in the crankcase and attack the bearings causing pitting in the bearing surface. This is more of a problem with heavy-duty diesel engines that use high sulfur fuel rather than gasoline engines, but it can also happen in gasoline engines if the oil is not changed often enough and acids are allowed to accumulate in the crankcase.

2.1.1.6. Knocking: The injection of fuel in C.I. engines takes place for a certain interval of time. This means, that as the first droplets to be injected are passing through the ignition delay period, additional droplets are being injected into the combustion chamber. In case of shorter delay period, the first droplets of fuel being injected will commence actual burning phase in a relatively short time after injection, and small amount of fuel will be accumulated in the chamber when the actual burning commences. Consequently the mass burning of the mixture will produce a smooth pressure rise and the combustion will be normal. If, the ignition delay is longer, the actual burning of first droplets is delayed and greater quantities of fuel droplet are accumulated in the combustion chamber. When the actual burning starts, the ignition of the large amount of accumulated fuel causes a violent and instantaneous rise of pressure. Under such conditions extreme pressure differentials are produced and violent gas vibrations known as detonation or knock occurs.

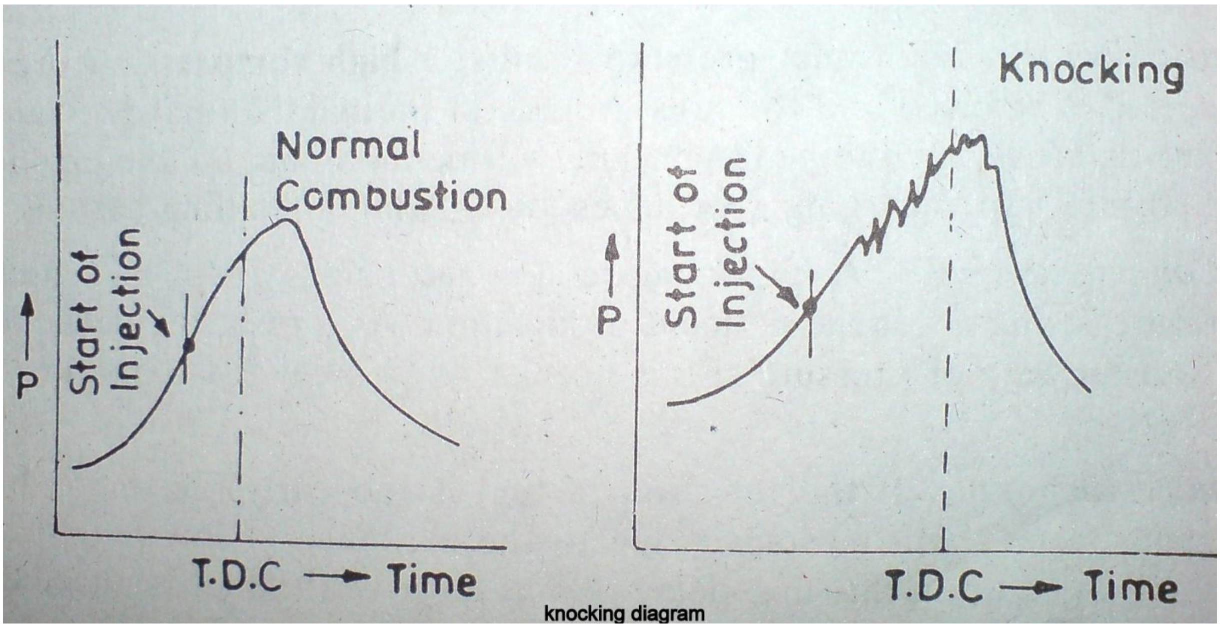

Fig.2.1 Knocking

The following operating variables affect the delay period and cause diesel knock:

1. **Inlet temperature:** A higher inlet air temperature increase the cylinder air temperature at the moment of injection. This decrease the delay period.
2. **Inlet pressure:** High inlet pressure results in high compression pressure. The delay period is reduced and the pressure rise is normal. Normal pressure rise eliminates knock.
3. **Compression ratio:** A high compression ratio brings about high pressure and temperature in the air at the moment of injection. As a result, the delay period is reduced.
4. **Injection timing:** If the injection of the fuel is too early. The delay period will be longer due to the existence of low pressure and temperature of air. During this long delay period most of the fuel is injected and the mixing is relatively through. This results in an abnormal pressure rise.

5. **Engine speed:** The amount of fuel injected in the engine depends upon the engine speed because the fuel pump is driven by the engine crankshaft. At high speed more fuel will be injected during the delay period, and the mixing of air and fuel will also be better, both of which cause a high rate of pressure rise giving rise to knock.
6. **Engine size:** A large engine runs at low speed and hence the quantity of fuel injected during delay period is less. Moreover in large engines, the compression temperature is higher. Both these effects have the tendency to reduce knocking.
7. **Jacket water temperature:** Increase in jacket water temperature decreases the delay period.
8. **Injection pressure:** Increase in injection pressure gradually decreases the delay period.
9. **Type of combustion chamber:** In general, a precombustion gives a shorter delay period compared to an open type combustion chamber.
10. **Turbulence:** The effect of turbulence is to strip the fuel from the injected spray and, therefore, promote a homogeneous mixture. A high turbulence thus decreases the delay period.
11. **Fuel volatility:** Highly volatile fuels with low viscosity are usually desirable in order to promote a homogeneous mixture quickly and so reduce physical delay. On the other hand, a highly volatile fuel may knock badly because a longer supply of combustion mixture is furnished during delay period. In general, however, a low volatile fuel increases the probability of knock.
12. **Chemical composition of fuel:** Fuels having high self-ignition temperatures give longer delay periods.
13. **Additives:** some additives such as amylnitrate, reduce the ignition delay and hence the tendency of knock.

2.2. GENERAL CONSIDERATIONS OF THE MECHANISM OF ENGINE NOISE

The engine can be considered to consist of two basic structural elements.

1. The internal load-carrying structure, i.e. piston-connecting rod-crank-shaft system.

2. Outer load carrying cylinder block structure.

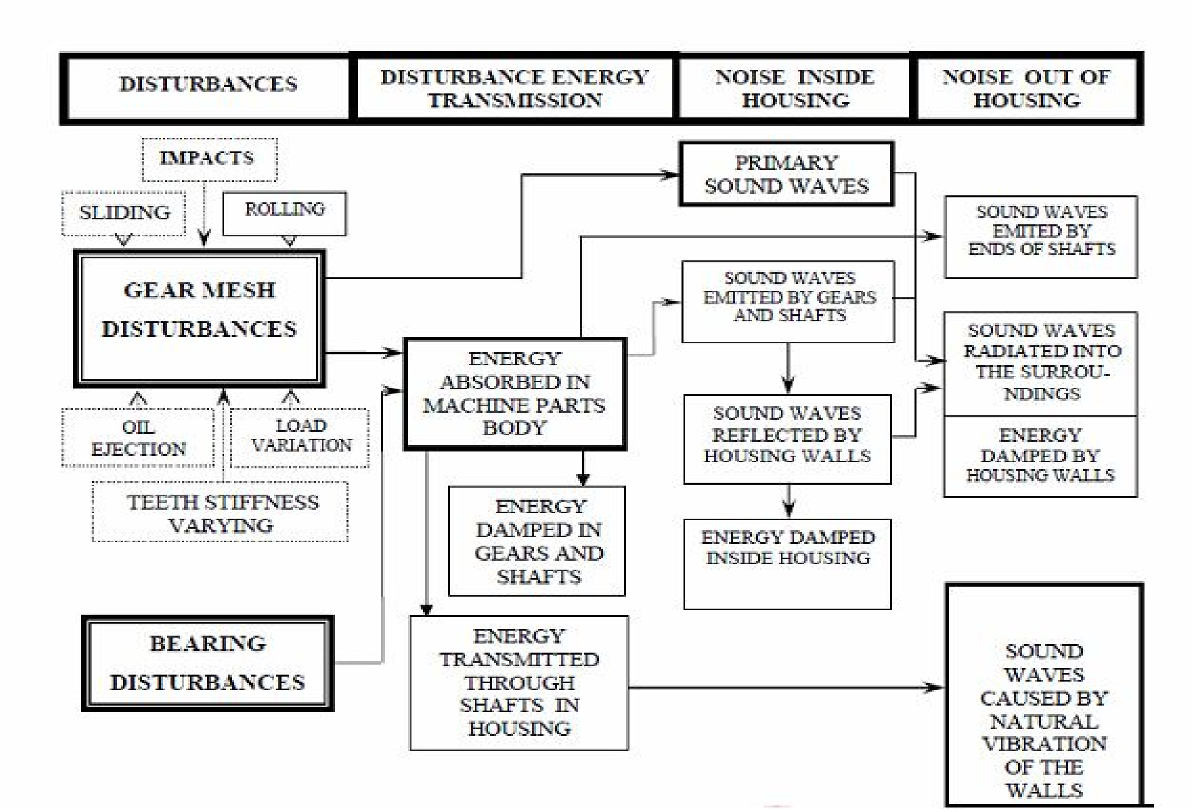

Fig.2.2 Diagram showing process of disturbance energy transformation which cause noise

The internal load-carrying structure is mechanically separated from the main outer load – carrying structure by running clearance. A simple equivalent system of the engine thus can be developed. The principle existing forces which are responsible of vibration and noise. The outer elastic load-carrying structure provides location for the piston and crankshaft represented as two masses joined together by a spring.

There are two major forces which are responsible for the engine structure vibration and the emitted noise, namely unidirectional forces and reversible forces.

2.2.1. Combustion-induced noise – unidirectional force excitation

Unidirectional forces are only important in the vicinity of TDC on the compression stroke and are produced from compression and subsequent pressure rise resulting from combustion. The clearances in the vertical direction for the equivalent mass of piston, connecting rod, and crankshaft are taken up by these forces, and a linear vibratory system results. Since during this period the force does not change its direction any appreciable vibration can only be produced if there is a rapid change in the magnitude of the force. The rapid change in magnitude is produced by the onset of combustion in the engine cylinder and thus can be defined as combustion-induced noise. The gas forces excites the top part of the engine structure (i.e. cylinder head) while the lower part of the structure is excited by the combined gas forces and the inertia force.

2.2.2. Mechanically-induced noise - reversible force excitation

Reversible forces which change direction are produced by the engine crank mechanism and associated inertia forces. Although these forces change in magnitude, the rate of change is too low to induce any appreciable vibration amplitudes in the comparatively stiff (high natural frequency) engine structure. These forces, however, accelerate the various elements of the internal load-carrying structure across the clearances and thus cause impact which effectively induces structure vibration and noise.

2.2.3. Relation between Noise, Engine design and operating parameters

Despite the numerous exciting forces which almost simultaneously excite the engine structure there is some justification to look at the problem in a simpler way. Since the gas force resulting from combustion tends to be the predominant force in most of the engines, the relationship between the gas force characteristics and emitted noise can be used to establish a basic model to identify the effects of fundamental engine design and operating parameters.

The three basic parameters of an engine are

1. Speed
2. Size
3. Load

1. **Engine speed**

The engine structure characteristics can be defined by use of electro-dynamic vibration generators, and the broad response readily established as shown by the solid envelop line. It will be seen that when the structure is subjected to a constant sinusoidal force it exhibits maximum response in the high – frequency range from 800-2000 Hz.

Electronic analysis show is some detail the existence of numerous natural frequencies at which the structure can vibrate. It also indicates that it is reasonably heavily damped and thus any better resolution of various modes of vibration by any instrument is impossible.

The gas force which again in it is very complex can be subjected to frequency analyses to quantify its exciting propensities. Comparing this force spectrum with the response of the structure one can see that only the high order harmonics (frequency range 800 – 2000 Hz) are responsible for the predominant noise of the engine.

If the engine speed is doubled, the engine structure is now excited with lower order harmonics which have higher amplitudes. Since the general slope of the force spectrum is about 30 dB/decade an increase of excitation by 9 dB will be obtained with further speed the same pattern is followed.

It can be concluded that the characteristics of force determine the rate of increase with engine speed which in this instance, for a naturally aspirated diesel engine, is 30 dB per tenfold increase of speed.

- **Effect of combustion system on noise**

It will be seen that the combustion system determines the rate of increase of noise with engine speed the exponent for petrol engine is 5, while for the most viscous diesel engine about 2.5. It can be seen that at low speeds there is a possibility of reducing noise by as much as 25 dB(A) by smoothing the development of the gas force.

2. **Engine size**

Measurement carried out on a large number of engines with engine size is considerably less. An increase of size to ten times gives an increase of noise of 17.5 dB(A). The detailed investigations now indicate that vibration levels of the engine surfaces are about the same irrespective of their size, thus the increase of noise with size is simply due to larger radiating surface area.

3. **Engine load**

Engine load has no effect on noise, which is in agreement with the findings that noise is simply due to the initial ignition of the fuel. This occurs at the same intensity whether the engine is running at no load at all or full load. It can be concluded that:

- The form of the exciting gas force determines the rate of increase of noise with engine speed.
- At high engine speeds the form of the gas force has a less significant effect on noise.

Engine noise is independent of the horsepower produced

CHAPTER 3

LITERATURE REVIEW

A wealth of literature exists in the area of Engine Noise and a lot of time and effort has been devoted to measure noise in different working conditions of Engine. From a long time, work is continued in this field. Some important literatures are as below:

Mills C.H.G. and Aspinall D.T. [1] discussed the various sources of the noise in I.C. engine commercial vehicle and methods of noise reduction by the use of high transmission-loss enclosures and sound-absorbent and panel-damping materials are described.

Examples are given on the practical applications of acoustical treatments to the reduction of the noise within and emitted by typical road haulage vehicles. Useful reductions can achieve by palliative treatments but attention is drawn to the practical and economic difficulties associated with incorporation of sound reducing treatments in production vehicles.

Wonnacott E.J. [2] uses the recommendations and established theory to analyze and build a series of efficient silencers for general vehicle and stationary engine use. The recommended design procedure has generally been found to be flexible in its application and the silencers thus designed appear to have distinct advantages over their current counter parts in relation to design simplicity, ease of manufacture and consistent attenuation performance throughout their useful life. The results of these trials are described together with details of manufacturing and testing problems that has been experienced in building such units.

Jenkins S. H. [3] Noise from a diesel engine is caused by vibration of the surfaces of the structure, the accessories attached to the structure and covers such as valve covers and oil pan. Two basic forces cause the system to vibrate. Combustion is a major force which generates pressure in the acoustically important frequency range of 500-5000 Hz. The engine mechanism also generates forces which can be important in the same critical frequency range. These forces combine and cause the structure to vibrate in its preferred modes. Every harmonic of cylinder-firing frequency is generated and, since the fundamental is generally below 25 Hz for a four cycle diesel engine at rated speed, the forcing may be regarded as continuous over the entire acoustical frequency range. All modes of engine vibration are therefore continuously excited. Noise reduction can be achieved by lowering any of the forcing functions, couplings or responses. Partial or complete shielding of external surface is also effective. External surfaces are the least difficult to treat, although truck application problems are often encountered with the present size of engines. Because of this, partial treatment is preferred to engine-mounted complete enclosures. It is important, therefore, to analyze external noise sources prior to any treatment.

Priede T. [4] a road vehicle is continuously subjected to varying operating conditions and it is very seldom that steady-state running occurs over a period of any length. The main operating parameters are speed, load and acceleration and deceleration, with associated gear changes. Even on a motorway, where a steady speed can be maintained, the load factor of the prime mover will vary according to the road gradient.

The noise of the road vehicle constitutes a number of individual sources of diverse origin and characteristic. Each of these noise sources has a different speed-load relationship and also a different transient relationship. The resultant noise therefore may have very complex characteristics. In the assessment and control of vehicle noise, and also in the determination of general traffic noise, it is essential that the effects of various operating parameters are clearly understood. These include the influence of prevailing climatic conditions which particularly affect the rolling noise. An understanding of these parameters can help to optimize road traffic environmental planning. The introduction of new products, such as turbocharged diesel engines for commercial vehicles, with different characteristics, can change considerably the characteristics of traffic noise and therefore need to be fully understood and evaluated. Throughout the paper the vehicle noise and its individual sources, with particular reference to basic engine noise, are described in overall dB(A) values.

Bryce W. D. and Stevens R. C. K. [5] identified and understand the noise sources that contribute to the exhaust noise of aircraft gas turbine engines, controlled experiments have been carried out to study the noise characteristics of a model turbo-jet exhaust system. The noise data have been related to measurements of the aerodynamic conditions in the model and, with the aid of specific diagnostic tests, the predominant noise mechanisms are considered to have been recognized. The noise radiation, above that of the jet, is attributed primarily to dipole sources generated by the turbine outlet struts, the transmission of this noise being modified by duct propagation and nozzle impedance effects.

Jha S.K. [6] studied the characteristics of noise and vibration in a motor car. The predominant frequency regions in which noise levels are high are established. It is shown that the major part of the sound energy lies within the frequency region below 20 Hz and is caused mainly by road excitation being transmitted through the wheel and suspension system. The predominant noise in the audible range lies within 30-300 Hz frequency band and is produced primarily by body resonances excited by various engine harmonics. The vibrational and acoustical behavior of the car body at some of these critical frequencies is also discussed. Finally it is shown that by structural modification a substantial noise reduction can be obtained

Mugridge B. D. [7] concerned with the reduction of noise from automotive cooling systems. A comparison is made between the use of axial flow and centrifugal fans and formulae presented for obtaining the octave sound power for each type of fan. The disadvantages of centrifugal fan installations are highlighted and axial fan design configurations are examined with the object of providing optimized systems. Experimental results are presented for different axial fans and comparisons made of the noise measurements with the ingested flow distortions measured by means of a hot wire anemometer. The results indicate the limits of maximum noise reduction which manufacturers may expect using existing fan designs and also indicate the methods for achieving maximum noise reduction for these configurations.

Stephenson J. and Hassan H A. [8] calculated the energy release rate resulting from the combustion of propane-air mixtures is presented and the result is used to calculate the far field noise spectrum for an open flame by using appropriate Fourier transform techniques. The results illustrate the broad band nature of combustion noise and show that, for the range of parameters indicated, the peak frequency in the f octave band is in the range 400-l 000 Hz. The results also indicate that the shape of spectrum is influenced by the time history of the heat release rate and the turbulence intensity and length scales; on the other hand, the peak frequency is a function of the heat release per unit mass of fuel which is essentially the same for hydrocarbon fuels.

Andrian David Jones [9] experimental study of radiated exhaust noise from a single cylinder, piston ported 2- stroke engine. Part 2 consists of a study of noise sources on a rotary 2-stroke lawnmower.

In part 1, a detailed study of the gas dynamics of the exhausting process in a 2-stroke and the associated sound power radiated by the exhaust of the engine has been made. The exhaust systems considered include straight pipes of lengths 0.4m and 1.3m and a tuned expansion chamber of length 1.38m. Measurements show the significance of non-linear behavior which results in wave steeping and shock wave formation. A series of measurements of far field SPL and associated pressure at several locations in the exhaust pipe for a different exhaust systems. These results then compared with theoretical predictions obtained by calculating, using the method of characteristics, the detailed unsteady flow in the exhaust pipe matched to the flow out of the engine cylinder, for several engine cylinders. The calculations include entropy characteristics and therefore allows for the significant variations in the entropy, arising mainly from the variable shock strength at the exhaust port, which occur in the system. Of particular interest is the close agreement between the calculated third-octave radiated sound pressure spectra and the measured spectra, for both the straight pipes and the tuned expansion chamber exhaust systems.

In part 2, the problem of rotary 2-stroke lawnmower noise is initially considered in terms of the four components parts: inlet, exhaust and mechanical and blade noise. Of these, all but inlet noise are found to be significant at moderate engine speeds, with blade noise dominating at high speeds. Detailed investigations, experimental and theoretical, into the nature of exhaust, mechanical and blade noise are then described. In particular the mechanical noise is investigated quite thoroughly with the analysis made of piston slap. Finally, recommendations are made for design changes which would lead t the reduction of the major components of the total noise.

Tetsuru Oguchi [10] studied the piston slap noise, which is generated by the sudden impact of the piston on the cylinder wall, is the most predominant mechanical noise emitted from the engine. It is studied here in terms of its transmission paths through the engine elements. Two engines with different cylinder liners types are tested in a non-running condition. The transmission paths are measured and evaluated in terms of the mechanical mobility, the ratio of the velocity response on the cylinder wall to the force applied to the external surface of the engine, which represents, by reciprocity, the ratio of the velocity response on the external surface of the engine to the force applied to the cylinder wall. The work concentrates on the major transmission paths of the piston slap noise and the factors which affect that transfer mobility in the frequency range of 1.5 to 4 kHz.

The major transmission path of the piston slap noise is experimentally determined to be the path through the cylinder wall and the upper deck of the cylinder block to the external surface of the cylinder block.

Richards E. J., Westcitt M. E. and Jeyapalan R. K. [11] studied the noise generation by impacting bodies due to the high surface accelerations during the contact period. An account is presented of the theoretical development and experimental validation of curves for the prediction of peak sound pressure and radiated energy for collisions of compact bodies which are incapable of flexural motions It is shown that acceleration noise energy is of the same order of magnitude as that due 10 ringing, that it cannot be greater than 1.5 x 10e4 times the kinetic energy input at impact and that it falls off rapidly as the normalized contact time increases above a critical value.

James W. Slack [12] studied the piston slap, is typically the major source of noise and vibration in the I.C. Engine. An investigation of piston slap noise in an I.C. Engine is carried out. Vibration measurements are carried out at connecting rod, cylinder wall and block surface while monitoring. Drive point and transfer mobility measurements were made on non-running engine. The measured mobility’s are used to construct a model of piston-cylinder wall interaction which predicts the excitation due to the piston slap. The measured transfer mobility’s are used to predict vibration transfer to the block surface. Bending of the connecting rod is to play an important role in both the excitation and vibration and the transmission of vibration energy to the block surface.

Jones A.D. and Brown G.L. [13] used a computational technique for the method of the characteristics solution of 1-D compressible, unsteady flow in the duct to the wave action in engine exhaust system. By using the method it was possible to compute the detailed flow in both straight pipe and tuned expansion chamber exhaust system as matched to flow the cylinder of a small two stroke engine. The radiated exhaust noise was then determined by assuming monopole radiation from tailpipe outlet. Experiment on an operating engine has been achieved with the calculation of both the third octave radiated noise and associated pressure cycles at several locations in the different exhaust systems. Its essential feature is the computation of the precise paths on the x-t plane of a finite number of C+, C- and P characteristics, to provide high accuracy in determining the tailpipe outlet velocity and hence radiated noise.

Cuschierit J.M. and Richards E.J. [14] studied the noise radiated from I.C. engine due to combustion and piston slap excitation is investigated by considering single impacts. From the results obtained, possible method of noise control are studied, and the expected results due to changes in the liner mounting to the engine frame, and the bearings of the camshaft for an injected engine, are compared to measured noise levels. This proves to be very successful and radical modifications in the engine for noise control can be investigated in this way prior to full development of the prototype engine

Kantarelis C. [15] the study reported in this paper examines the sources of diesel locomotive noise that give rise to annoyance. It is shown that the amplitude modulation present in diesel engine noise has importance in determining annoyance. The frequency and depth of the modulation are related to the fundamental firing frequency, the firing frequency of the engine and exhaust manifold design. Changes in the manifold design could reduce the adverse subjective response.

Tandara V. [16] studied the radiator fan noise. The combustion engine is only one of many vehicle noise sources. Every combustion engine has inner and external noise sources. The cooling fans can be important noise sources. They are installed to cool the engine, encasement and the inside of the car. The influence of fans is great in case of high ambient temperature, low traveling speed and frequent stoppages.

Schachner P., Reisinger W. [17] studied the concept of exhaust gas emissions. The design and development of modern internal combustion engines is marked by a reduction in exhaust gas emissions and increase in specific power and torque. Correspondingly, combustion noise excitation and fuel consumption also have to be reduced. These objectives can be achieved through the development of advanced combustion systems, the increased flexibility of fuel injection systems. However, development of modern combustion systems and vehicle applications has become increasingly complex. Creating an exact, yet straightforward description of combustion noise is a very important task. The customer's subjective impression of the entire vehicle, regarding items such as diesel knock sensitivity, provides evidence to support its value.

Desmons L., Hardy J. and Auregan Y. [18] applied a least squares method to characterize an internal combustion engine considered as a noise source. It is shown that, although extremely severe conditions exist (high sound pressure level, high temperatures, turbulent flow, etc.), a linear theory can predict the noise level at the output of the exhaust systems with a surprisingly good accuracy when the transfer matrix is known. The measurements avoid the use of calibrated internal microphones; only one external microphone and a set of calibrated loads are needed. An indirect validation of the linearity hypothesis is achieved and the predicted exhaust noise level is compared with experimental results in the case of a tube and in the case of a silencer composed of three expansion chambers.

Orjan Johansson [19] the lower front end of a diesel engine is a major noise source. Describing the source mechanisms of this area is problematic as it consists of a rotating torsional vibration damper in front of the timing transmission cover and the oil sump. This experimental study focuses on the acoustic interaction phenomena between the damper and the structure behind it. To describe the source mechanisms a test series of different modifications by conventional lead wrapping technique is performed. The vibration behaviour of each substructure is determined by operational deflection shape measurements and the source strength for each modification is determined by near-field sound intensity measurements. The results show the contributions from different substructures and describe the interference effects due to coherent radiation. It is concluded that the radiation is dominated by the timing transmission cover structure behind the damper. At some frequencies though, the torsional vibration damper in combination with the timing transmission cover behind it, causes the high radiation. This effect is mainly due to coherent vibrations and a resonance phenomenon in the cavity between the structures.

Torben Astrup [20] gives an overview of observations from almost I.5 years of practical experience with acoustic intensity measurements. The often difficult working conditions of acoustic consultants mean that we tend to make demands on the measuring methods and the instrumentation that presently cannot easily be met. Therefore the instrumentation should be improved in order to increase both the dynamic and the frequency range. Further development of ‘real-time’ control of measurement quality is also desirable, i.e. the possibility of surveying the quality of the result during or immediately after the measurement is performed.

Davies P.O.A.L. and Holland K.R. [21] studied the intake and exhaust noise from piston engines in the context of intake and exhaust system acoustic design. The objectives combine the achievement of sound emission targets with the maintenance of optimum engine performance and fuel efficiency throughout a specified range of operating conditions. Practical experience demonstrates that the relevant technology includes a quantitative evaluation of those factors directly concerned with engine operation and breathing, those factors influencing the excitation and propagation of pressure waves through the relevant system and those factors controlling the emission of sound to the surrounding environment. A summary is provided of previous and current developments in appropriate existing numerical codes for performing the detailed calculations and associated performance assessments with increasing realism.

KIM Y. S. AND LEE D. J. [22] intake noise from internal combustion engine has not received much attention compared to exhaust noise. But nowadays, the intake noise is a major contributing factor to automotive passenger compartment noise levels. The main objective of this paper is to identify the mechanism of generation, propagation and radiation of the intake noise. With a simple geometric model, it is found that one of the main noise sources for the intake stroke is the pressure surge, which is a compression wave due to the compressed air near the intake valve after closing. The pressure surge, which has the non-linear acoustic behavior, propagates and radiates with relatively large amplitude. In this paper, unsteady compressible Navier-Stokes equations are employed for the intake stroke of axis-symmetric model having a single moving piston and a single moving intake valve. To simulate the periodic motion of the piston and the valve, unsteady deforming mesh algorithm is employed. For the purpose of perfect closing of the intake valve, the numbers of mesh are changed using a Lagrange interpolation. In order to resolve the small amplitude waves at the radiation field, essentially non-oscillatory (ENO) schemes are used. The source of the intake noise can be identified through the visualization of propagation in a finite duct and radiation to the far fields. Comparison with measured data is given for in-duct pressure showing a better agreement than the one-dimensional calculation data.

HE yong, BAO Yi-dan [23] studied a single cylinder S195 (8.8 kw) single cylinder was used in this study to determine the effect of four operational parameters, i.e. intake valve close angle, exhaust valve open angle, fuel delivery angle and fuel injection pressure on noise. Single factor and multi factor quadratic regressive orthogonal methods were adopted in the experiment to find the relationship between the four parameters and noise. By means of optimization technique, the operational parameters for two working conditions of the engine were selected and the test result showed that optimum adjustment could reduce noise by 2-4 dB.

O M I Nwafor [24] studied the combustion knock characteristics of diesel engines running on natural gas using pilot injection as means of initiating combustion. The diesel engines knock under normal operating conditions but the knock referred to in this paper is an objectionable one. In the dual-fuel combustion process we have the ignition stage followed by the combustion stage. There are three types of knock: diesel knock, spark knock and knock due to secondary ignition delay of the primary fuel (erratic knock). Several factors have been noted to feature in defining knock characteristics of dual-fuel engines that include ignition delay, pilot quantity, engine load and speed, turbulence and gas flow rate

Cho S.H., Ahn S.T. and Kim Y.H. [25] studied the concept of piston slap and model or estimate the impact forces using FEM. One of the major sources of noise and vibration in an internal combustion engine is the impact between piston and cylinder wall. The crank-slider mechanism of an internal combustion engine has very small clearance between piston and cylinder inner wall. The clearance is very small but large enough to induce the piston's secondary motion periodically and finally generates unwanted sound and vibration. This secondary motion across the clearance between piston and cylinder inner wall is caused by the side thrust force that changes its direction depending on its position. This side thrust force is induced by the connecting rod. As a result, the piston moves from one side to opposite side in the cylinder. Then eventually, the piston collides against the cylinder inner wall. These impact phenomena are called “piston slap".

There have been many attempts to model or estimate the impact forces and the side thrust force. These are a function of inertia force of piston and connecting rod and explosive force in internal combustion engine. There are also studies on the dynamics of planar crank-slider mechanism in order to investigate the influence of the clearance gap size, bearing friction, and crank speed on the response of the system. Finite Element Method (FEM) has been also applied in order to analyze the impact force. However, the models as well as FEM are not satisfactory to estimate the impact forces. This is because the basic mechanism associated with the piston slap is complicatedly related to the mechanical elements of engine block.

Philip Scarth, Diego Ortiz [26] studied the idling noise of medium and heavy I.C. engines have become an important noise assessment criterion in the commercial vehicle sector. Starting and low idle noise is often the first impression a potential customer gains of the vehicle. A quiet and pleasant low idle noise is critical in giving the desired impression. In urban environments, with heavy traffic and consequently large amounts of non-moving vehicles, high levels of idle noise are a disturbance to the general public.

This paper deals with the systematic approach to the reduction of idle noise in light, medium and heavy-duty I.C. engines. Actual examples are given of recent developments made in idle noise reduction on current production engines.

Kaminski T. and Wendeker M. [27] studied cycle to cycle variation of internal cylinder pressure. Combustion process in spark ignition engines is widely known as a nonlinear and noisy process. Instabilities, which are occurring as cycle-to-cycle variations of internal cylinder pressure, affect directly the power output.

Examination of these variations can lead to better understanding of their sources and help in their elimination in a future engine control procedure. Improving engine efficiency requires achieving better combustion conditions without introducing additional disturbances. In the present paper we analyze the dynamics of a combustion process and we estimate the noise level based on experimental time series of internal pressure and calculated from them heat release. In the following analysis we apply the nonlinear multidimensional methods which can distinguish random variations from a deterministic behavior.

Norbert Alt, Hans-Dieter Sonntag, Stefan Heuer, Rainer Thiele [28] studied the cold start noise behavior of modern I.C. engines. The overall improved noise and vibration behavior of modern I.C. engines has also contributed to this trend. Despite overall improvements in I.C. engine noise and vibration, certain aspects of I.C. engines continue to present significant challenges. One such issue is the presence of I.C. knocking that is prevalent during cold start and warm-up conditions. This paper discusses a technique used to optimize the cold start noise behavior of modern I.C. engines. The methods used in this study are based on optimizing the engine calibration to improve the vehicle interior and exterior (engine) noise, even at low ambient temperatures. Initially, the engine's combustion noise behavior is characterized by measuring the cylinder pressure (under various operating conditions) and developing appropriate transfer functions. Various engine calibration iterations are carried out using a structured Design of Experiments (DOE) and for each iteration, the measured cylinder pressure is used to calculate the combustion noise influence (based on existing transfer functions). At the end of this study, the influence of key calibration parameters on improving the cold start noise characteristics is demonstrated. The acoustic optimization achieved in this way has no detrimental effects on the engine’s ability to start, combustion stability, visible black or white smoke and emissions.

Leclere Q. [29] we are interested in the low frequency amplitude modulation of the noise generated by an engine operating at idle. This phenomenon, perceived inside the car, is particularly annoying. Modulated vibrations are transmitted to the frame mainly by one of the three engine mounts. The combustion is the first potential source to be inspected, but pragmatic observations on consecutive measurements show that it is not the cause of the amplitude modulation. Spectral analysis tools are applied on multi-channel measurements to identify the source of the phenomenon. A sensor is placed on each potential noise and vibration source. A virtual source analysis shows that several uncorrelated sources are contributing to the operating response, particularly on frequencies for which a high amplitude modulation is observed. The computation of residual spectra obtained by means of conditioned spectral analysis proves that the diesel pump is involved in the amplitude modulation. Experiments are carried out to validate this diagnosis. Added masses appropriately placed on the injection circuit strongly attenuate the phenomenon.

Shrivastava A., Dang M. [30] studied a novel setup for measuring sound power emitted by an automobile engine has been designed and fabricated in this study. Sound pressure levels have been measured to compute sound power level as per ISO Standard 3744. A microphone traversing system has been designed and fabricated to measure sound pressure at various points on a spatial grid. Sound pressure level and spectra have been measured at these points for various operating conditions of throttle opening and speed The setup seems to be a cost effective option for automobile engine industry for power level certification and for online silencer design

Nicklas Frenne [31] an experiment on a diesel engine provides for validation of a method that retrieves source strength spectra, source strength time histories and sound pressure time histories of the engines complex partial sources. The method is based on empirical transfer function measurements and inverse matrix calculations briefly described in the article. Different simplifying source models were selected by comparison of calculated and measured auto spectra. The results show: (1) indication of time efficient measurements of source strength spectra, (2) the importance of correct source models in the case of separated source strength time histories, and (3) spectra of separated sound pressure time histories. Listening tests reported that it is possible to detect well differentiated sounds of the partial sources as a result of the method.

Hao Zhi Yong, Jin Yan, Yang Chen [32] studied the total noise emission using continuous wavelet transform. Noise emission from engine is a complicated acoustic signal with many different components mainly caused by combustion and mechanism operations. The rapid rise of pressure in the cylinder caused by combustion of fuel near the top dead center (TDC) transmits to the engine structure surface and forms an important part of the total noise emission. The combustion can also cause the vibration of cylinder head, connection rods and crankshaft, with the vibration being also an important source of engine noise. All the air-borne noise emission induced by combustion in cylinders is usually called combustion-induced noise. Otherwise, the movements of engine mechanical systems including the rotation of the crankshaft, the operation of valves, the injection of fuel, and the piston slap, are also main factors contributing to the noise radiation of the engine. It is very important to separate the different sources of noise from the engine for the purpose of diagnosis and main noise source identification. Continuous wavelet transform (CWT) was applied to analyze the acoustic signals from Petrol engine for the purpose of noise source identification.

Benjamin Higgs, Ryan Rupke [33] designed the muffler. The primary goal of this project is to develop a muffler system to meet the demanding needs of a Formula SAE prototype race car. This development must adhere to the FSAE standards as they relate to noise control.

In order to fully understand the problem definition, a comprehensive study of sound properties is completed. This research elaborates on sound waves and how they may be reflected, diffracted or absorbed or actively cancelled using constructive interference. Reflection and diffraction properties represent destructive interference and depend on the angles at which they hit an object. Absorption, also a form of destructive interference, relates to the material that the sound wave comes in contact with. Constructive interference occurs when a second sound source is placed 180° out of phase from the first source.

The source of noise that a muffler must attenuate is the result of combustion from the engine.

Therefore, it is seen that various researchers have devoted a lot of time to develop different methods to detect noise. The important parameters of engine noise are identified and there causes are found.

CHAPTER 4

EXPERIMENTAL SETUP

4.1. ENGINE DETAIL

The engine used in the study is kirloskar single cylinder, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. These signals are interfaced to computer. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The compression ratio is varied from 12 to 18 and the load is varied from 0 Kg to 8 Kg. The set up has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator

Fig.4.1 VCR engine set up

Specification of Engine:

Type	Kirloskar
No. Of cylinders	1
No. Of strokes	4
Bore	87.5mm
Stroke length	110mm
Rated power	5.2 kw
Speed	1500 rpm
Cooling system	Water cooled
Compression ratio range	12 to 18
Load	0 Kg to 8 Kg

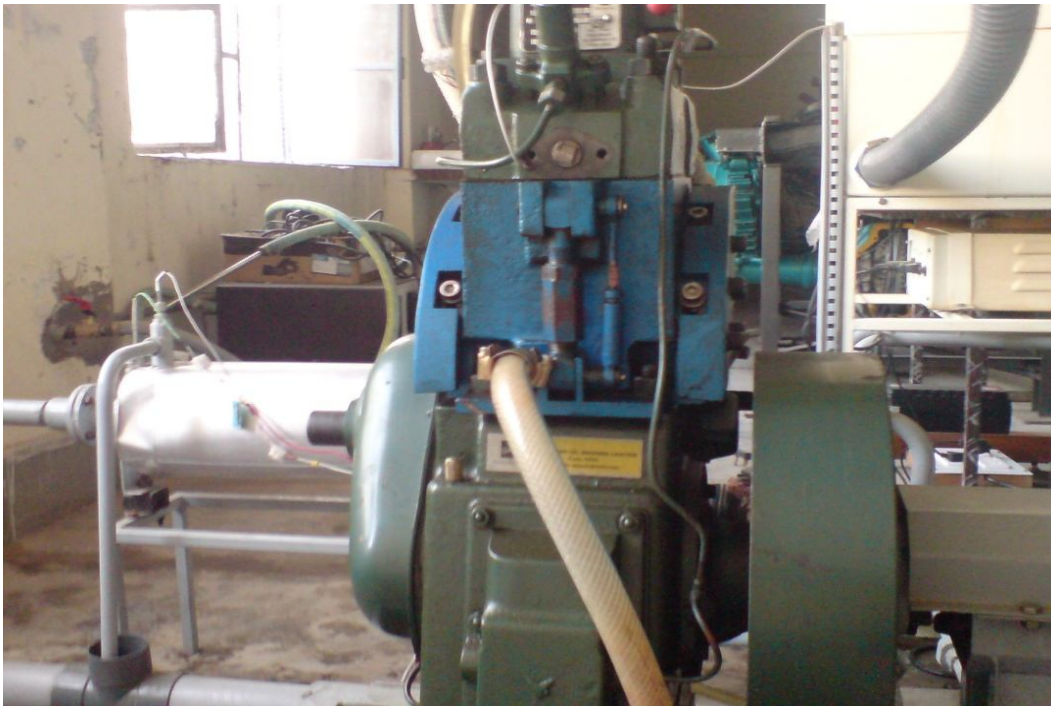

Fig.4.2 Kirloskar engine

4.2. PROCEDURE

1. First of all measure the engine size i.e. length, breadth, height. and then calculate the area for the Acoustic power measurement.

2. Mark the A, B, C, D points at the 0.5 m distance from the engine boundary. To study the noise completely it is required to take the SPL at various points as close as engine. So the points are taken at a distance of 0.5 m from each side of an engine. The four points A, B, C and D at centre of each side of an engine and fifth point is at the Exhaust.

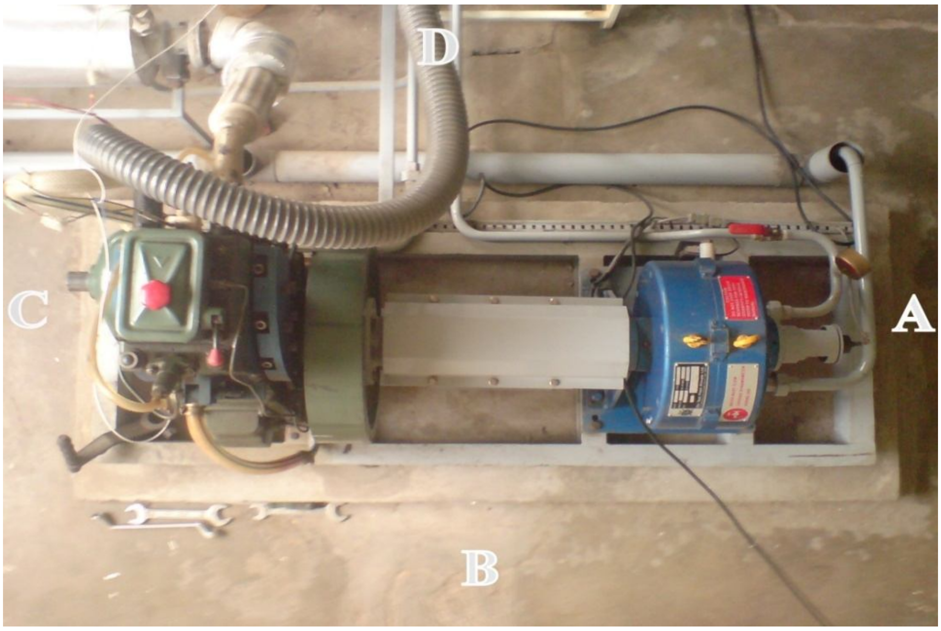

Fig.4.3 Four points at 0.5 m from engine boundary

3. Mark the EXHAUST point of the engine which is going outside the wall to open environment.

Fig.4.4 Exhaust going outside

4.2.1. Sound Pressure level measurement: It is measured by using SLM (Sound level meter), SLM used in the experiment is manufactured by CESVA (a Spanish company) model no. SC310:

Fig.4.5 SLM

1. **Sound Pressure level** is measured by this method:

➢ Calibrate the SLM (Sound level meter). Find out the calculating error. It must be checked before and after the measurement.

➢ Measure the SPL with the help of SLM.

➢ Apply necessary corrections:

  ✓ Correction for background noise.

2. Measurement of **Sound Power Level:**

➢ Determination of hypothetical surface area acc. to reference area.

➢ According to ISO-3741, Rectangular parallelepiped method will be used as described in article 1.7.

➢ Create the grid with the help of threads.

Fig.4.6 Grid formation

- Arrange the microphones on the first specified point and measure the SPL and then do the same for other specified points.
- Above step will be repeated for different Loads and varying Compression ratios.
- Calculate the **Ls** for all the points by taking mean of all seventeen grid points.
- Calculate the sound power level from

  $L_w = L_s + 10\log_{10}(S/S_o)$

  Where, So is reference area

  S is hypothetical surface area

- Use the above data of sound power level for graphical representation of frequency spectrum.

4.2.2. Measurement of vibrations:

The measurement of vibrations is done with the help of vibrations measuring instrument manufactured by DATACONE. In this instrument the probe is attached at the point where vibrations are to be measured. This instrument can measure Acceleration, Velocity & Displacement. All the parameters can be measured by placing vibration knob at point "C" at the foundation of engine. The vibration is measured at point "C" because it has maximum SPL. The data of vibrations is taken for 1-1 octave band frequency and by changing frequencies from 31.5 Hz to 2000 Hz.

Fig.4.7 Vibration instrument

All the procedure is repeated again and again at different C.R. and by varying loads at all C.R. After that the graphical representation of varying frequency at different C.R. and loads takes place.

4.2.3. Measurement of SPL in frequency spectrum

The value of SPL at 1-1 octave band frequency gives an idea of the maximum and minimum value at what frequency. In this the point selected where frequency spectrum is formed is that point where SPL is more. Take the readings at that point by changing the parameters. This instrument gives the data of all frequencies in software "CESVA CAPTURE STUDIO".

The measurements are taken at point "C" by changing Compression ratios and loads.

CHAPTER 5

RESULTS AND DISCUSSIONS

After all the measurements has been taken, it is required to analyze the sound pressure level by varying compression ratio and loads. The measurement of Sound Pressure Level at different points near Engine is taken. The data for Sound Pressure Level for five locations i.e. A, B, C, D and at EXHAUST. A, B, C and D are those four points which is 0.5m from the Engine boundary and EXHAUST is going outside. At every point the graph is plotted between sound pressure level and compression ratio keeping compression ratio fixed and then the graph between sound pressure level and load is plotted keeping loads fixed.

All the data for article 5.1 & 5.2 are shown in APPENDIX-A, from Table no.7 to Table no.19 for compression ratio 12 to compression ratio 18 at loads 0 Kg to 8 Kg.

5.1. GRAPH BETWEEN SOUND PRESSURE LEVEL V/S COMPRESSION RATIO FOR DIFFERENT VALUES OF LOAD

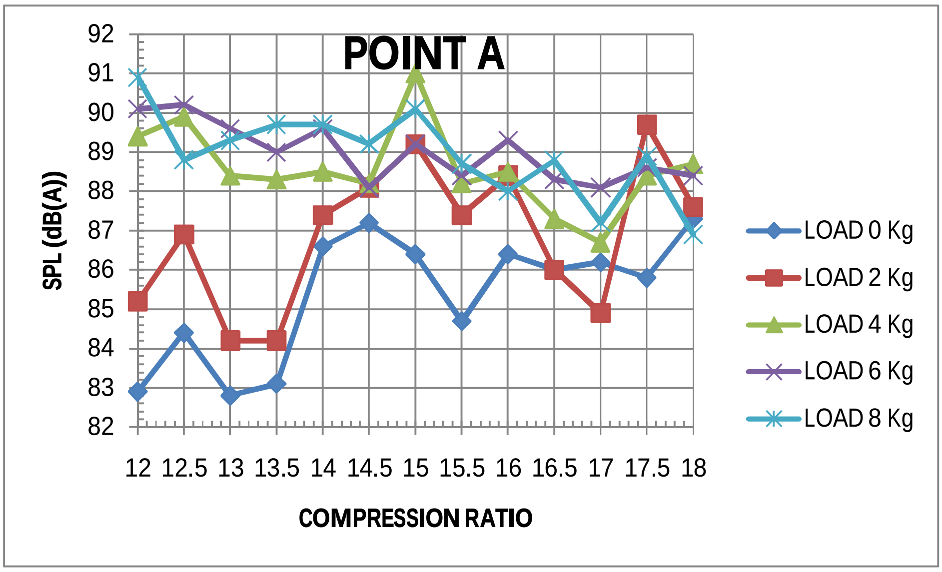

Fig.5.1 at point A

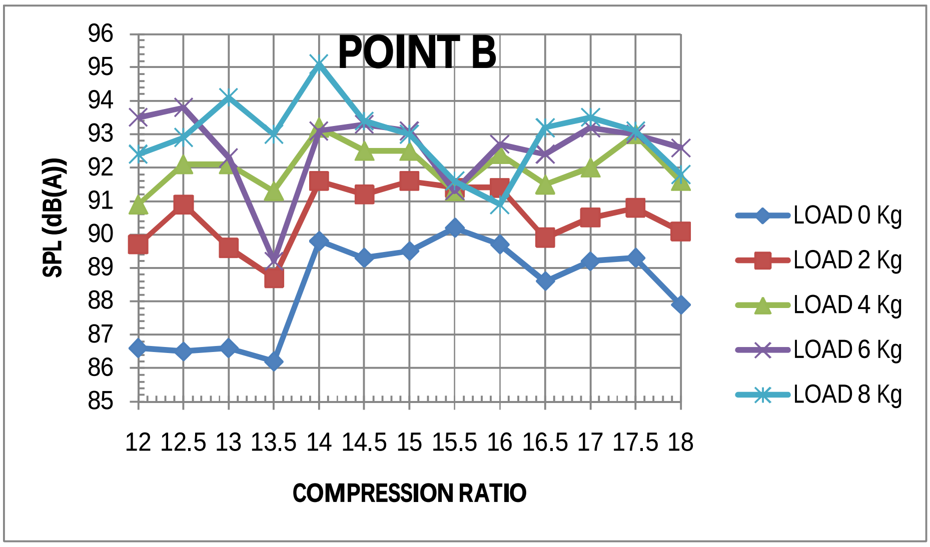

Fig.5.2 at point B

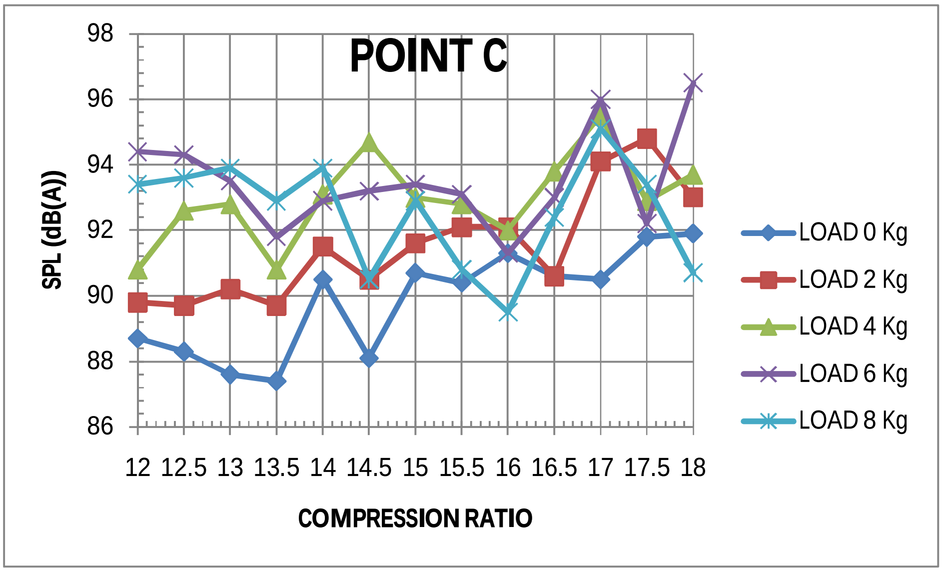

Fig.5.3 at point C

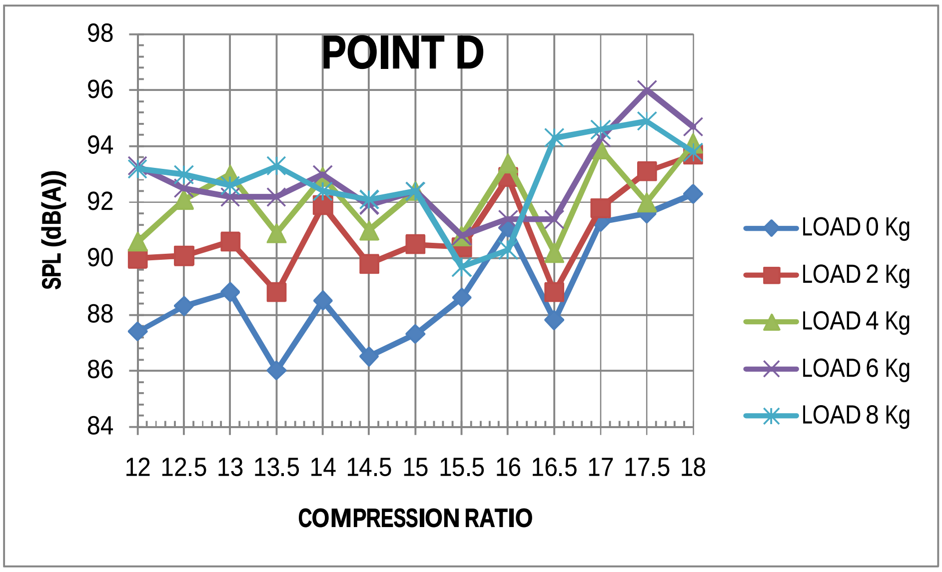

Fig.5.4 at point D

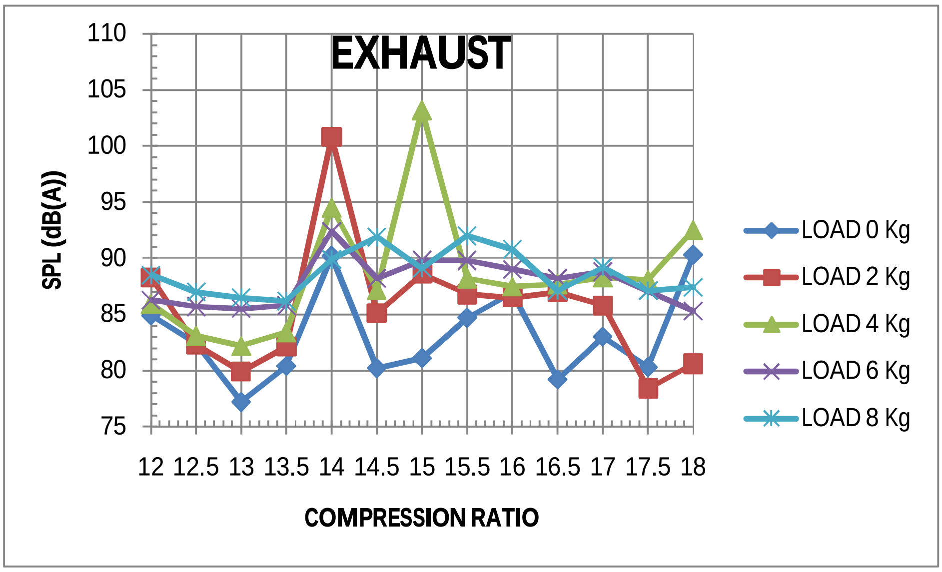

Fig.5.5 at EXHAUST

As shown in Fig.5.1 for point “A” the noise level increases not continuously but there are certain variations in the pattern, it goes up and down as the compression ratio increases. The maximum noise level is at load 4 Kg and C.R.15. There is decreasing noise level pattern for load 6 Kg and 8 Kg.

In Fig.5.2 for point “B” the pattern is mainly the same for all loads. The noise level has less variation in the start but after that the variations are high. The maximum noise level is for load 8 Kg and C.R.14. There is maximum dip in noise level at load 6 Kg.

In Fig.5.3 for point “C” the noise goes increasing in the same pattern for load 0 Kg and 2 Kg. the maximum noise is at load 6 Kg at C.R. 18. The variations at load 8 Kg is very high.

In Fig.5.4 for point “D” the variations are mostly the same as in Fig. 3 for point “C” the pattern generation is same but the noise level is generally less in this point. The maximum level of noise is again at load 6 Kg.

In Fig.5.5 for “EXHAUST” the noise level is less in the start at low loads, but as the C.R. increases at low loads i.e. at 2 Kg and 4 Kg. the noise level crosses 100 dB (A) mark. The noise level of load 6 Kg and 8 Kg is less at exhaust.

Therefore, the low loads i.e. 0 Kg and 2 Kg have high variations in pattern but at high loads the pattern form by all graphs is mainly forms the constant pattern.

5.2. GRAPH BETWEEN SOUND PRESSURE LEVEL V/S LOAD FOR DIFFERENT VALUES OF COMPRESSION RATIO

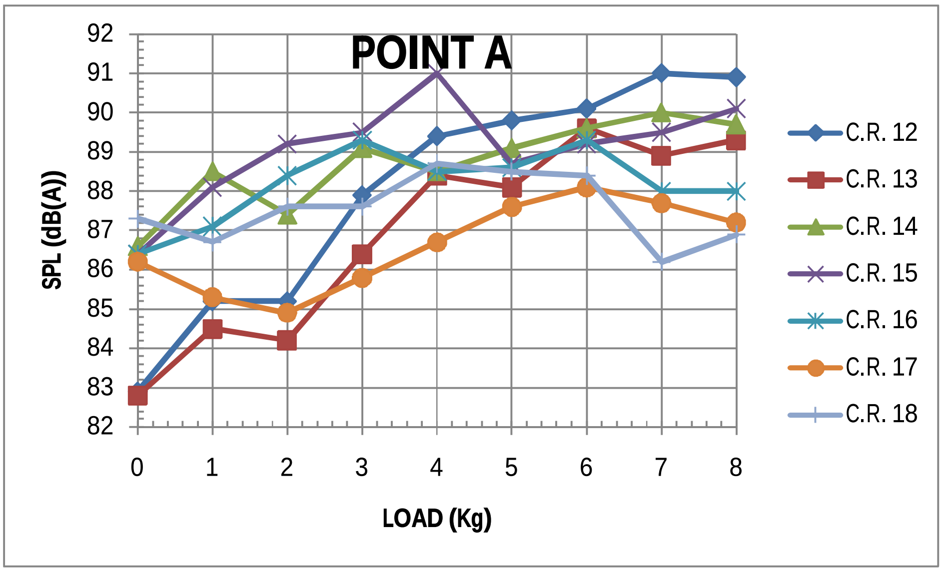

Fig.5.6 at point A

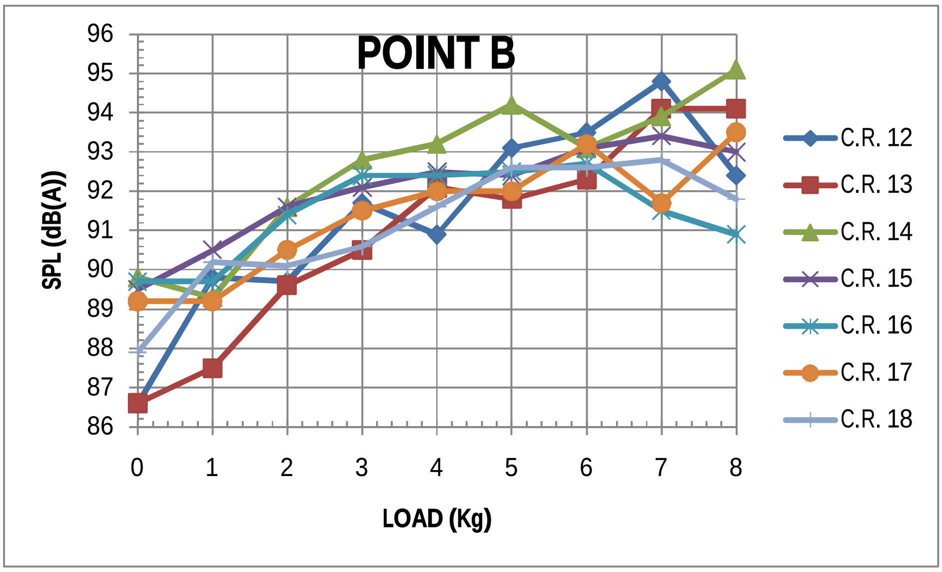

Fig.5.7 at point B

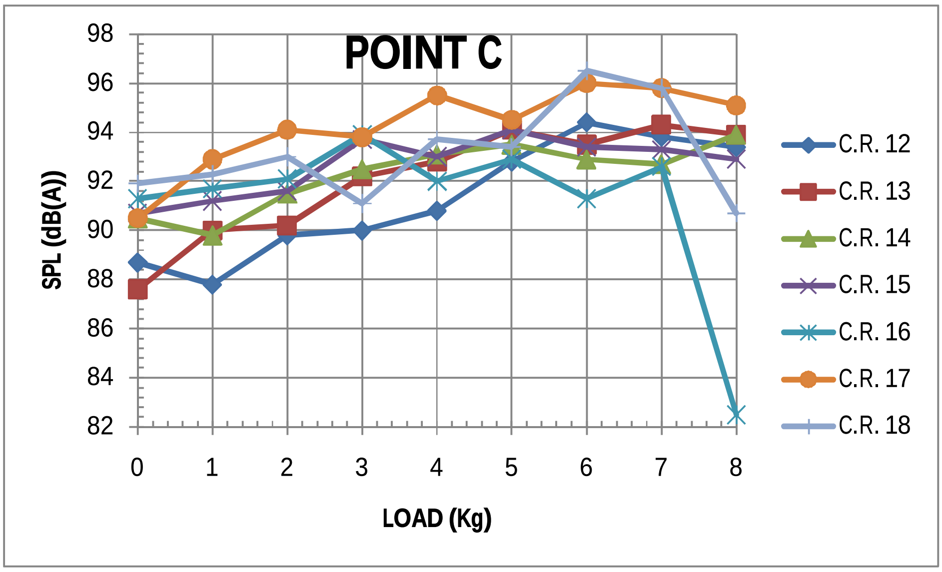

Fig.5.8 at point C

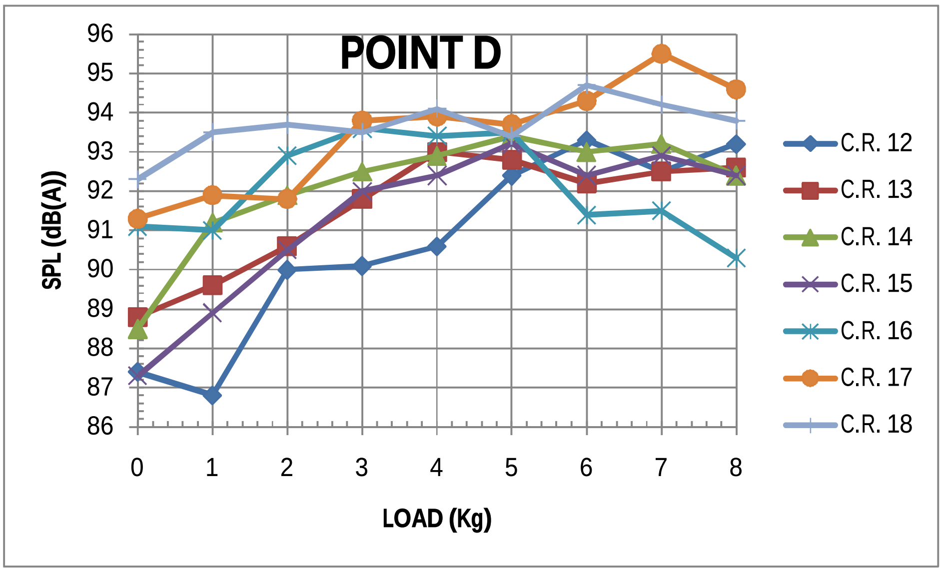

Fig.5.9 at point D

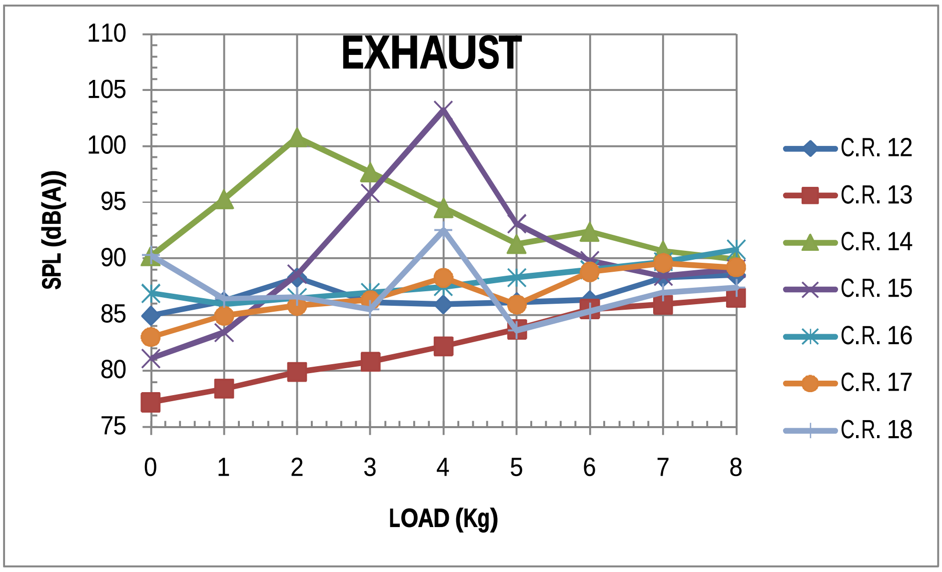

Fig.5.10 at EXHAUST

In Fig.5.6 for point "A" the pattern is in the increasing manner. As the loads increases with increasing C.R. noise level increases. It is maximum for C.R. 12 at load 8 Kg. The noise level decreases at C.R. 18 as the load increases.

In Fig.5.7 for point "B" the noise level at point B is generally high at point than at point A. The noise level has same way of proceeding upwards for all C.R. with increasing loads.

In Fig.5.8 for point "C" the noise level increase the same way. At C.R.16 the noise level goes up and down, at last at 8 Kg it goes straight down. It also goes on increasing as the load increases the noise level increases.

In Fig.5.9 for point "D" the noise level is maximum at C.R.17and load 7 Kg. The noise level first increases and then in the same pattern it decreases at C.R.16. Except C.R.16 the noise level increases as load increases.

In Fig.5.10 for "EXHAUST" the pattern is straight for all loads at C.R.12, 13 & 16. There are two peaks at C.R. 14 & 15 and then it comes in the same decreasing range.

5.3 MEASUREMENT OF ACOUSTIC POWER

The value of Acoustic power is calculated in APPENDIX-B by putting values of Ls of different compression ratios and at different loads in "equ.1" shown in APPENDIX-B. All observations of Acoustic power are shown in Table no.20.

5.3.1. SOUND PRESSURE LEVEL GRAPHS FOR ACOUSTIC POWER KEEPING COMPRESSION RATIO FIXED

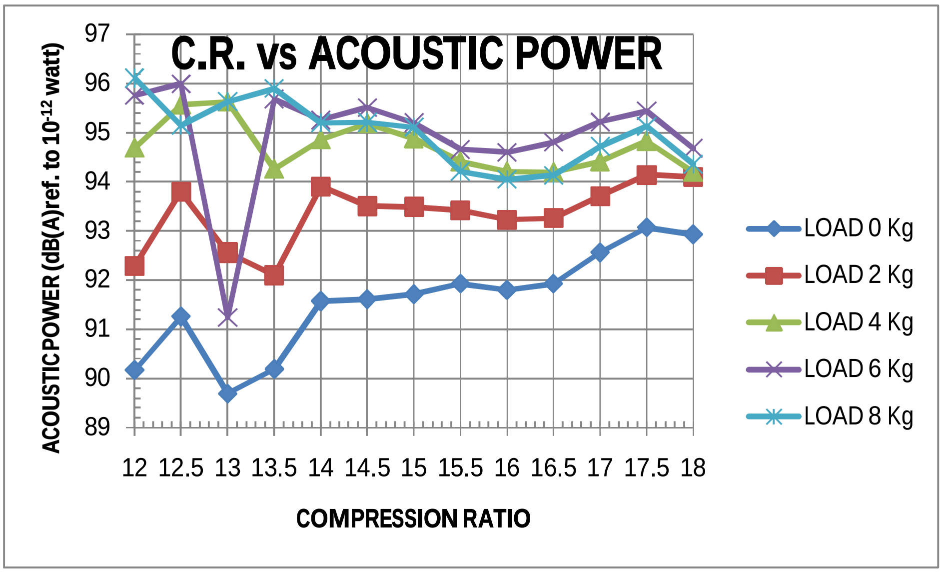

Fig.5.11 for Acoustic power

In Fig.5.11 for "ACOUSTIC POWER" the acoustic power at loads 0 Kg, 2 Kg, 4 Kg, has same way of proceeding. There is very high decrease in acoustic power at load 6 Kg for compression ratio13. The noise level is increasing at C.R. 14 and 15 and then it comes in the same constant range. For low loads there is variations till compression ratio14 after that the the pattern is constant.

5.3.2. SOUND PRESSURE LEVEL GRAPHS FOR ACOUSTIC POWER KEEPING LOADS FIXED

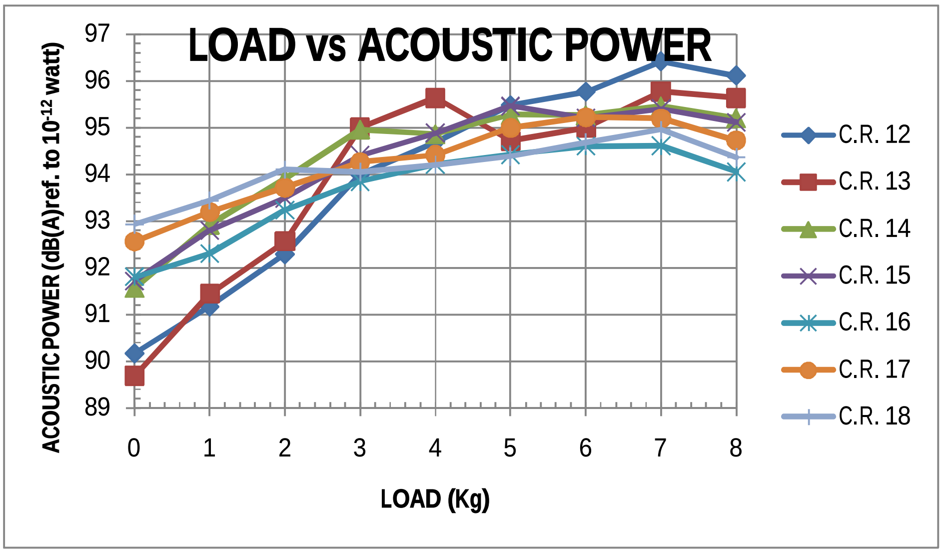

Fig.5.12 for Acoustic power

In Fig.5.12 for "ACOUSTIC POWER" shows that the acoustic power of all compression ratio increases as the load increases and it comes in the same mark between 94 dB(A) to 96 dB(A).

5.4. MEASUREMENTS OF VIBRATIONS

Vibration analysis is required as there is a close relation between Noise and Vibration. In this 1-1 octave band frequency analysis has been carried out for Acceleration and Velocity at point where the SPL is high. In this case, point "C" has more sound pressure level so vibration analysis is to be done at point C at foundation of the engine. This analysis is done for frequency at 1-1 octave band. All the observations for vibrations are shown in APPENDIX-C from Table no.21 to Table no.27.

5.4.1. VIBRATIONS GRAPHS FOR ACCELERATION (ms^{-2}) KEEPING C.R. FIXED

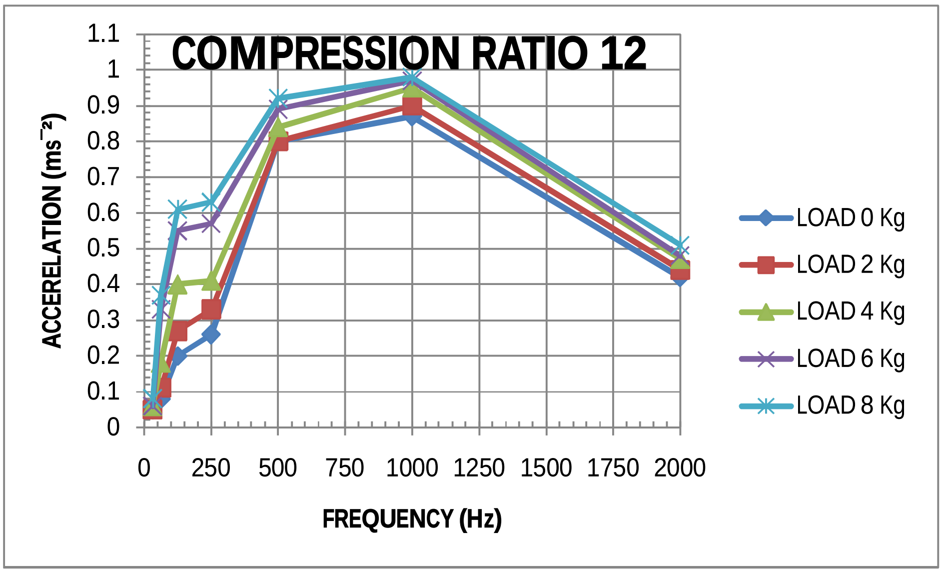

Fig.5.13 for Acceleration at C.R. 12

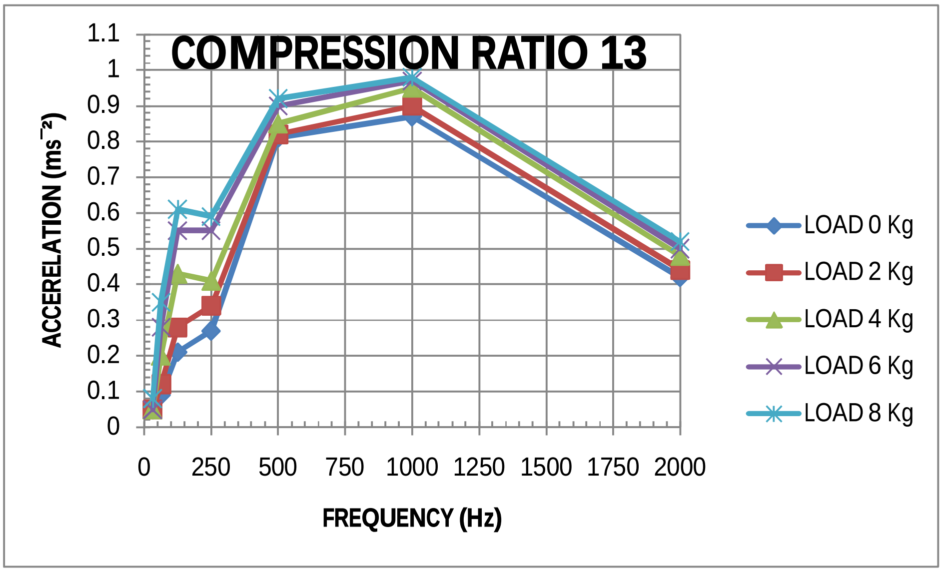

Fig.5.14 for Acceleration at C.R. 13

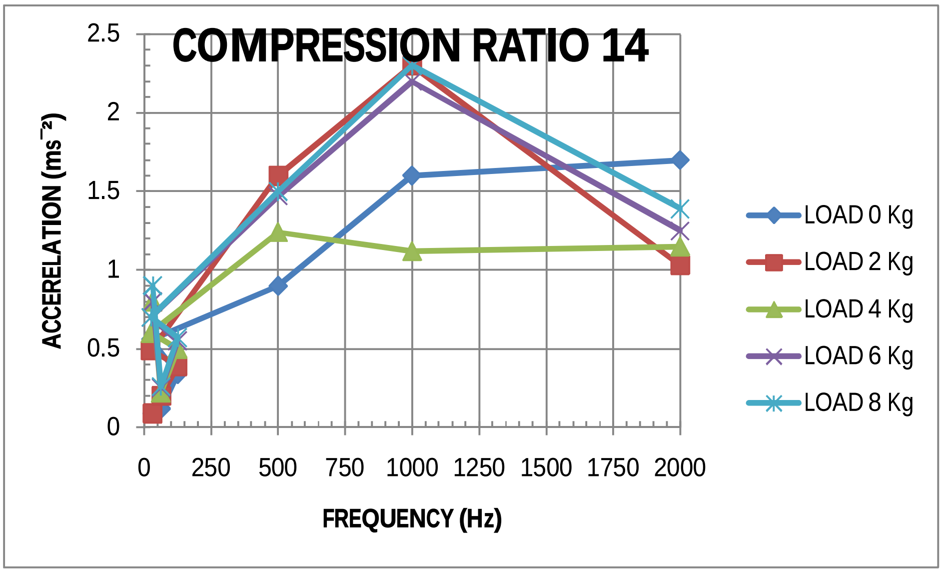

Fig.5.15 for Acceleration at C.R. 14

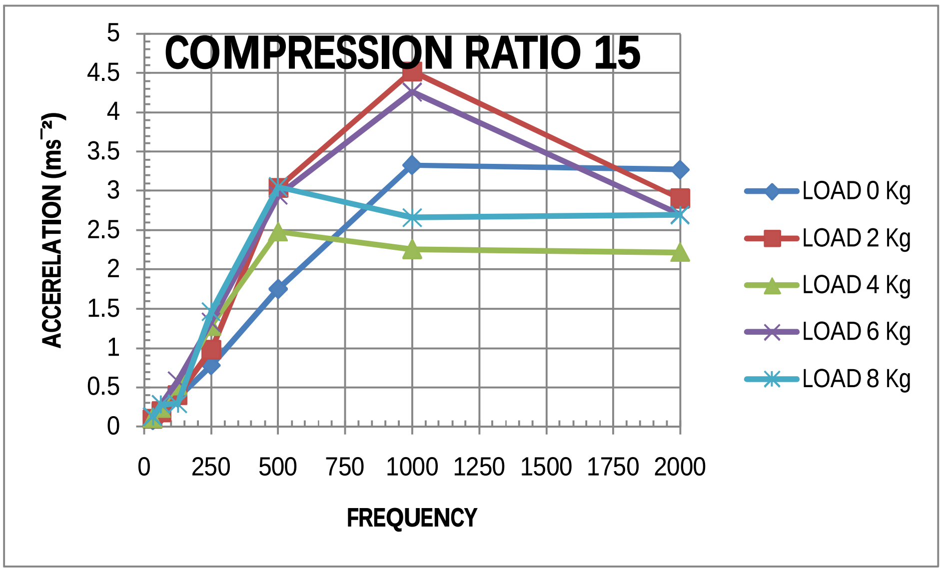

Fig.5.16 for Acceleration at C.R. 15

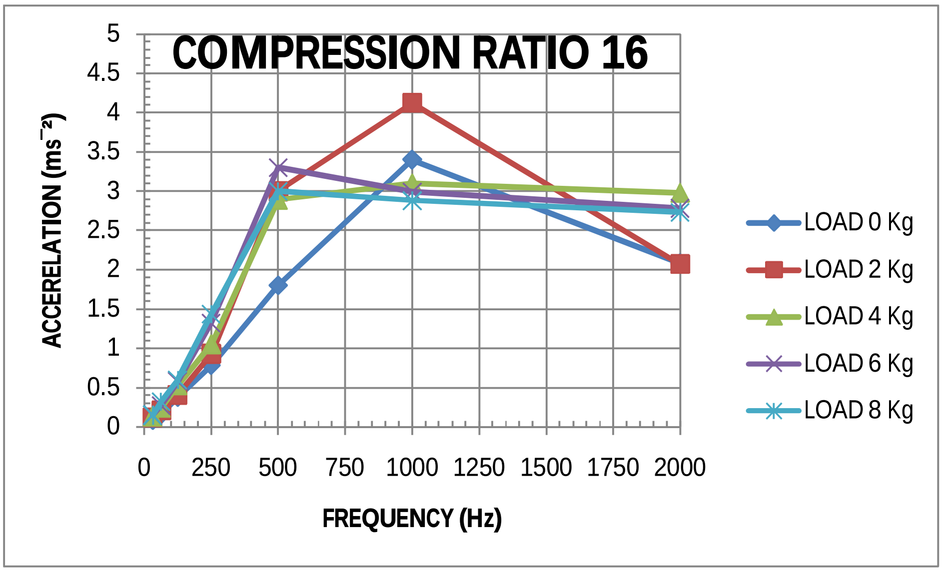

Fig.5.17 for Acceleration at C.R. 16

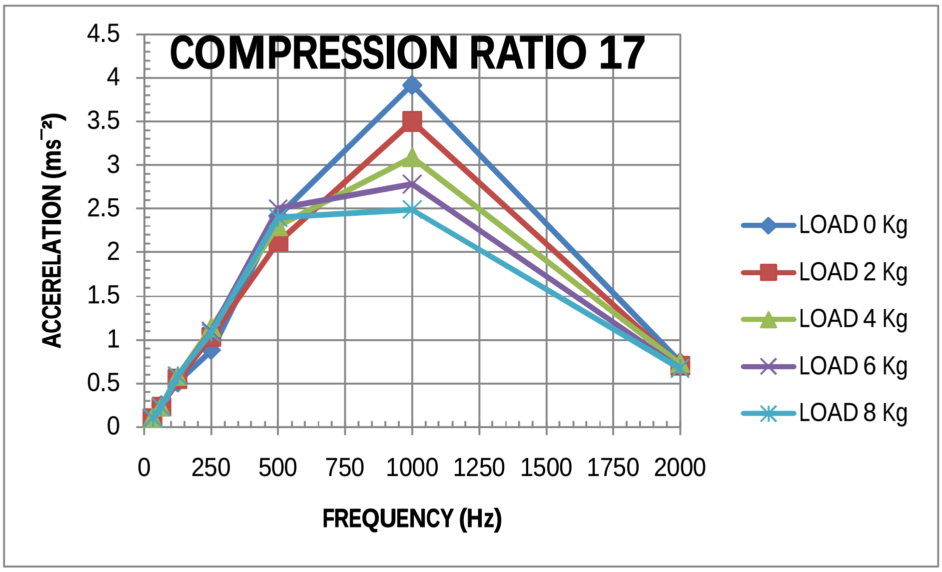

Fig.5.18 for Acceleration at C.R. 17

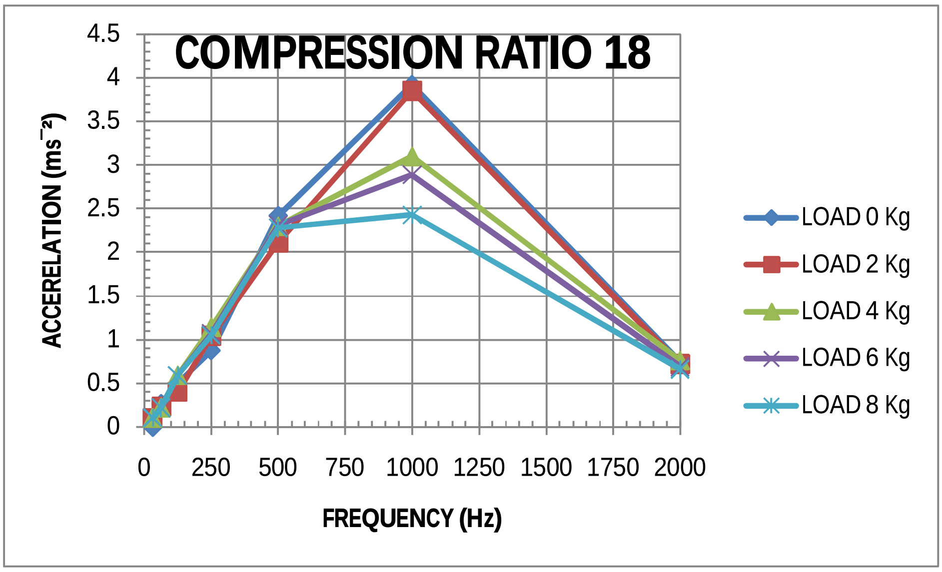

Fig.5.19 for Acceleration at C.R. 18

In Fig.5.13 & 5.14 for C.R.12 & 13 respectively, the pattern of these two graphs is same. The acceleration increase till 1000 Hz frequency and then it comes down at 2000 Hz. The maximum acceleration is 0.9 ms^{-2} at 1000 Hz frequency and at 6 Kg load.

In Fig.5.15 for C.R.14 there are variations in the acceleration from 31.5 Hz to 63 Hz, after that as the frequency increases the acceleration crosses 2 ms^{-2} mark at 1000 Hz frequency and then the acc. comes down at 2000 Hz. for load 0 Kg, 4 Kg the acceleration increases till 1000Hz frequency after that acceleration is constant.

In Fig.5.16 for C.R. 15 the pattern is same as for Fig.5.15, but the acc. level increases to 4.5 ms^{-2} at 1000 Hz frequency. In this the load 0 Kg, 4 Kg, 8 Kg comes to constant range after 1000 Hz.

In Fig.5.17 for C.R. 16 there are constant pattern till 63 Hz, after that the acc. increases. The maximum acc. is at 1000 Hz frequency which is at load 2 Kg and then it comes down. The load 4 Kg, 6 Kg, 8 Kg forms constant path after 1000 Hz frequency.

In Fig.5.18 & 5.19 for C.R.18 & 19 resp. there is same pattern for all loads as the frequency increases till 1000 Hz, the acc. increases and it comes down to one same point at 2000 Hz.

5.4.2. VIBRATIONS GRAPHS FOR ACCELERATION (ms^{-2}) KEEPING LOADS FIXED

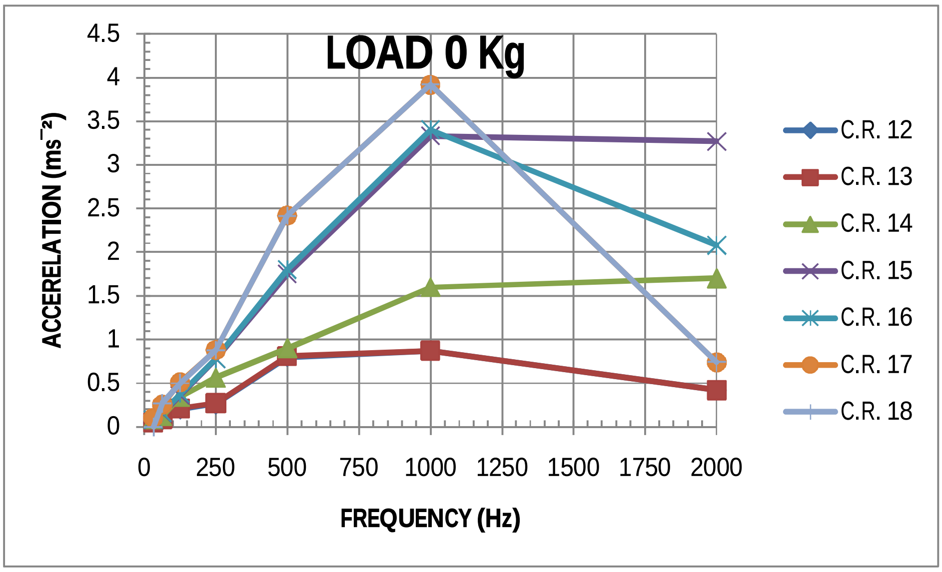

Fig.5.20 for Acceleration at LOAD 0 Kg

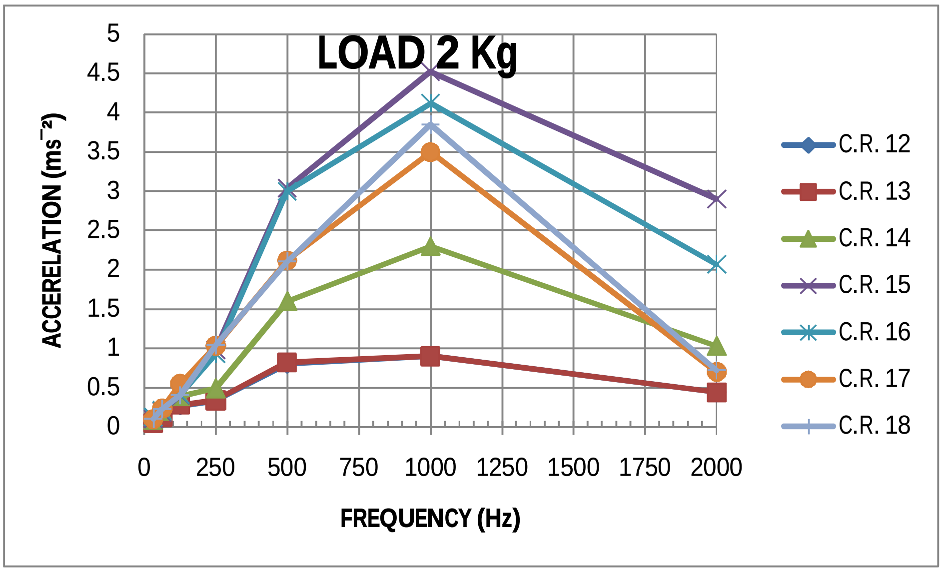

Fig.5.21 for Acceleration at LOAD 2 Kg

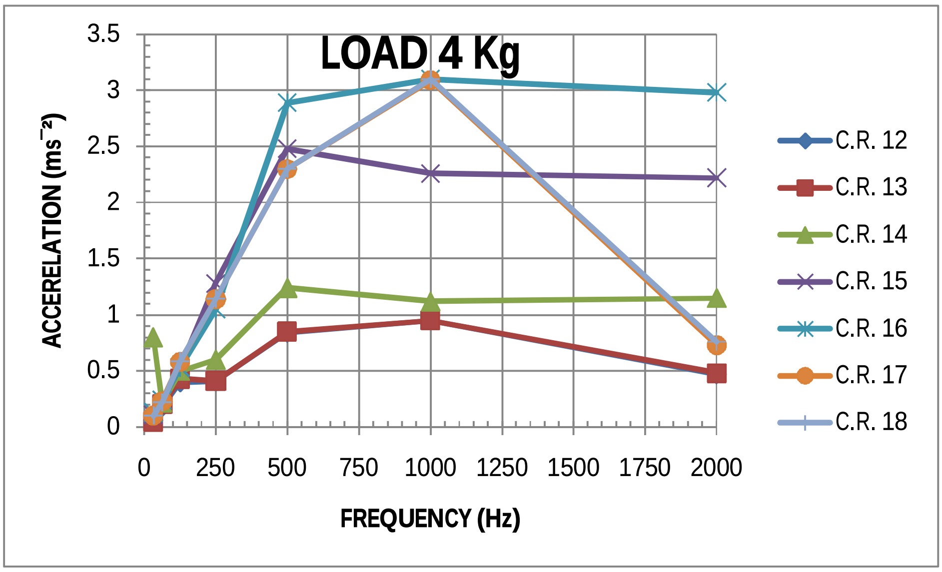

Fig.5.22 for Acceleration at LOAD 4 Kg

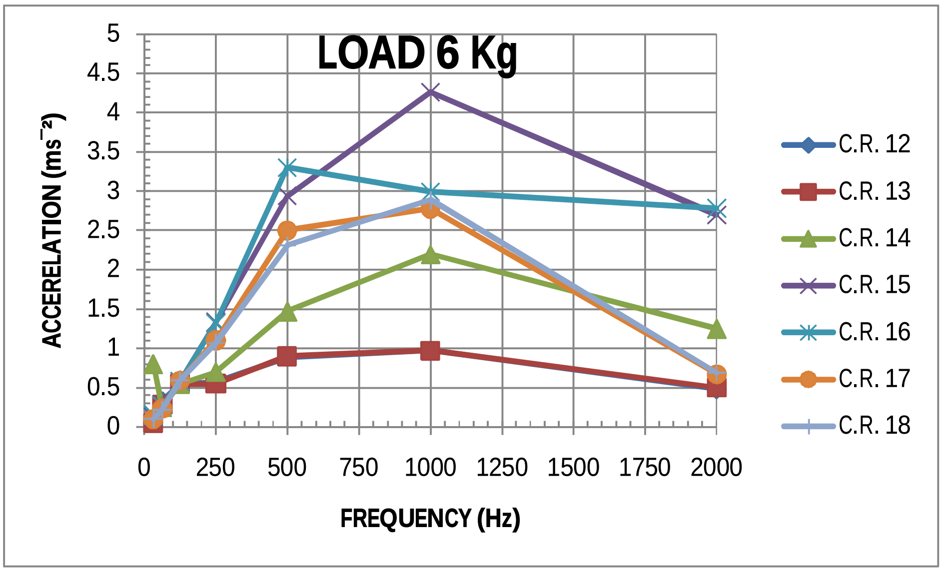

Fig.5.23 for Acceleration at LOAD 6 Kg

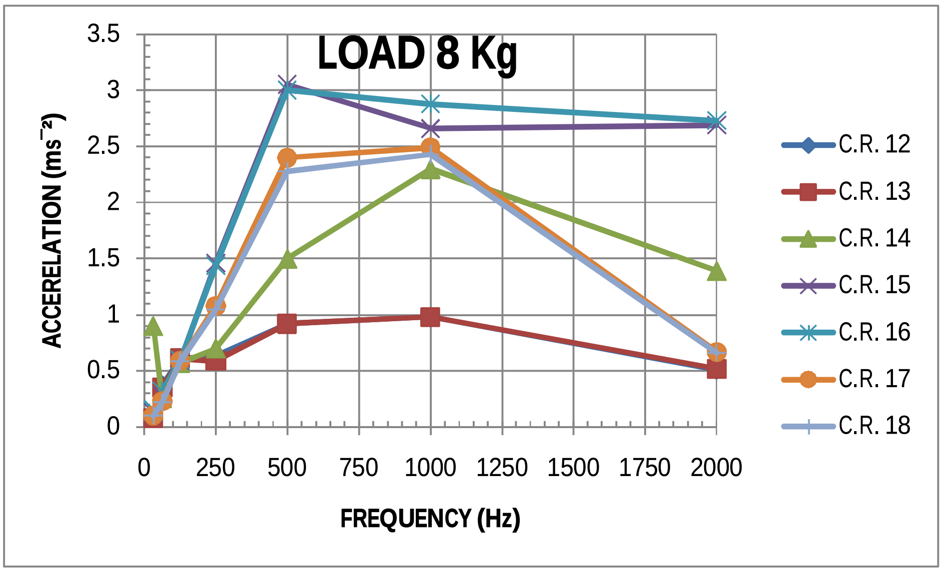

Fig.5.24 for Acceleration at LOAD 8 Kg

In Fig.5.20 for acc. at load 0 Kg, there are certain variations at 31.5 Hz to 63 Hz. As the frequency increases, the acc. increases. There is same peak point for C.R.17 & C.R.18, which is at 1000 Hz frequency and then the entire acc. for all C.R. decreases at 2000Hz.

In Fig.5.21 for acc. at load 2 Kg, there are increase in acc. at 1000 Hz frequency. The maximum acc. is 4.5 ms^{-2}, which is at C.R.15.

In Fig.5.22 for acc. at load 4 Kg, the C.R.12 & C.R.13 has same graphic display, C.R.14 values first increases and then comes down on same scale and then again increases little bit. C.R.16 values increase the most and take path of straight line, but the values of acc. goes down from 1000 Hz frequency for C.R.16, C.R.17 & C.R.18.

In Fig.5.23 for acc. at load 6 Kg, the trend of the graph is same as in Fig.5.22, the values increases till the frequency 1000 Hz and then all acc. decreases down to 2000 Hz.

In Fig.5.24 for acc. at load 8 Kg, the C.R.15 & C.R.16 has highest acc., there is certain increase in acc. after 1000 Hz at C.R.15. The other acc. decreases after 1000 Hz.

5.4.3. VIBRATIONS GRAPHS FOR VELOCITY (ms^{-1}) KEEPING C.R. FIXED

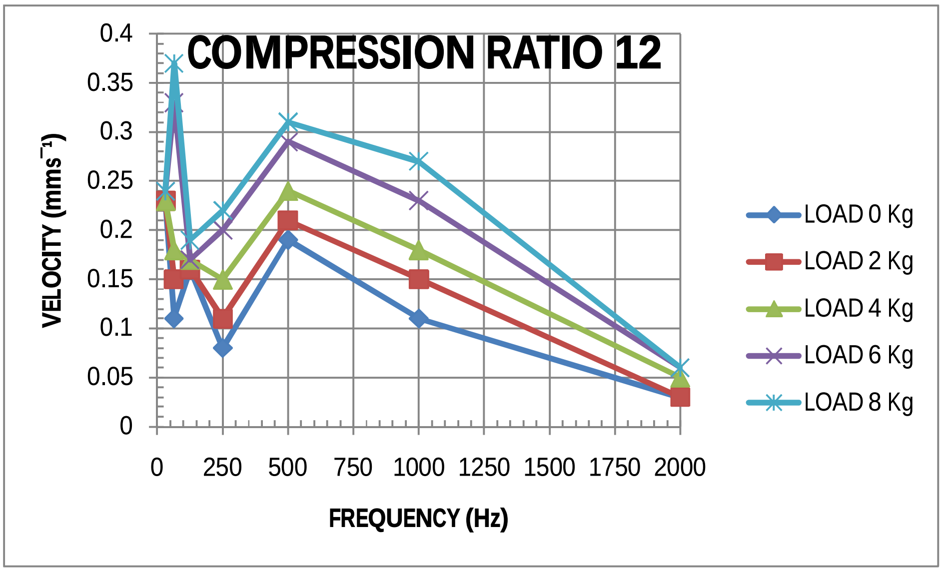

Fig.5.25 for Velocity at C.R.12

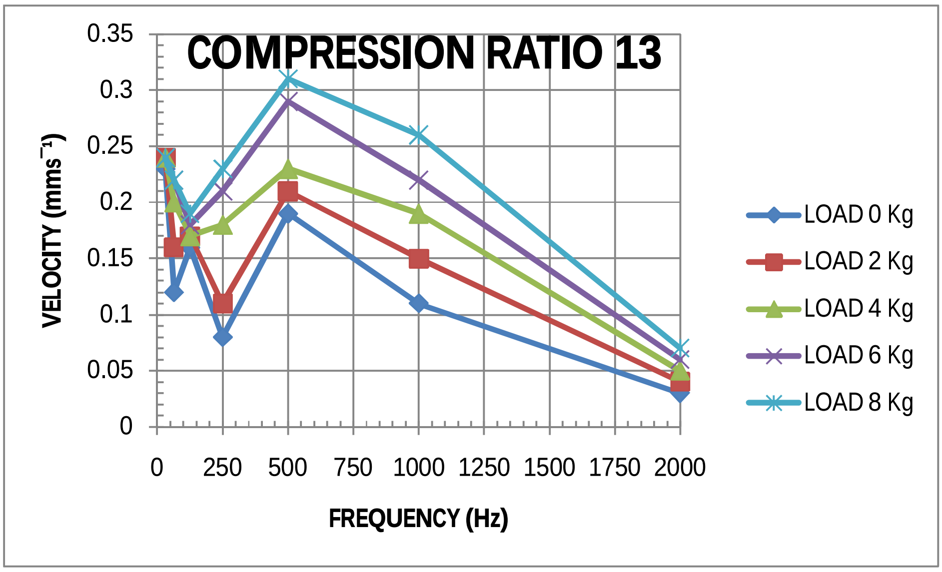

Fig.5.26 for Velocity at C.R.13

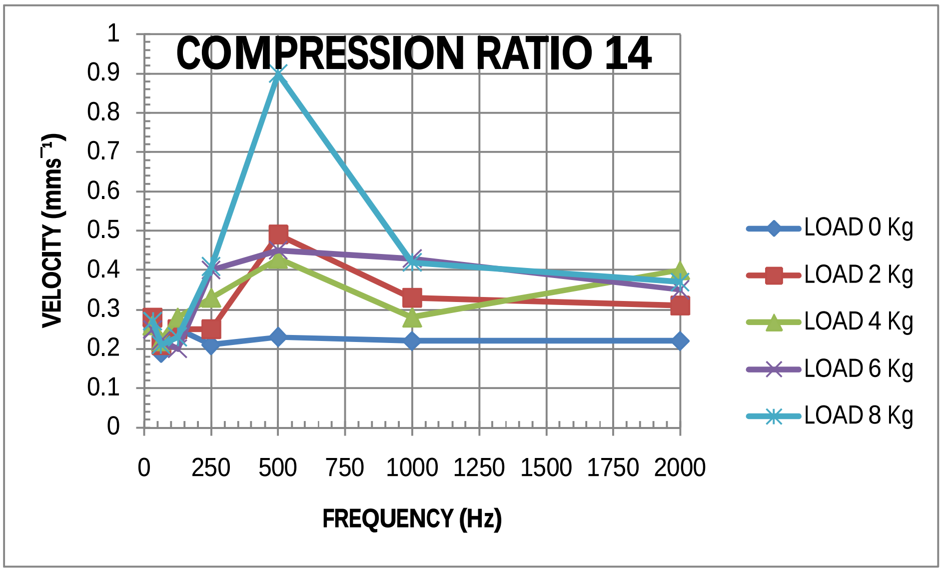

Fig.5.27 for Velocity at C.R.14

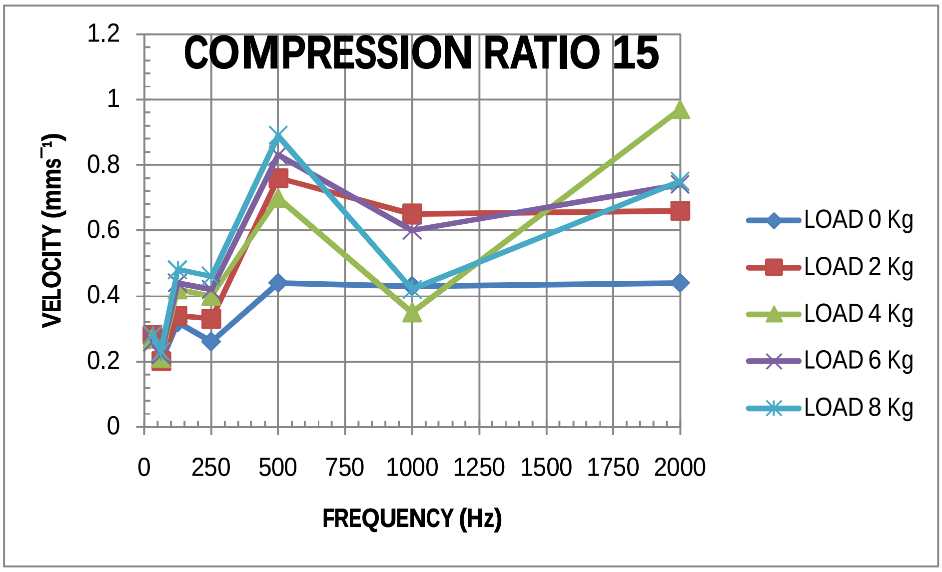

Fig.5.28 for Velocity at C.R.15

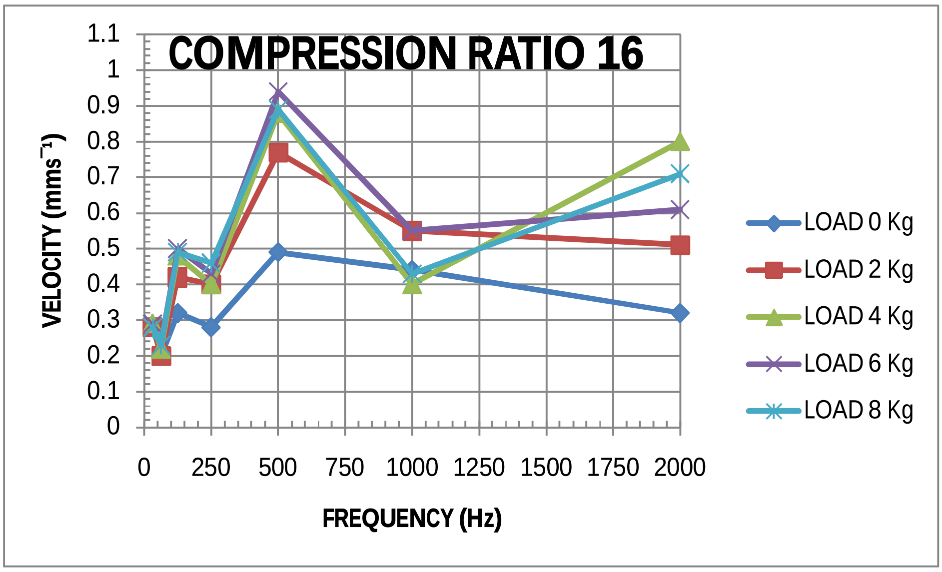

Fig.5.29 for Velocity at C.R.16

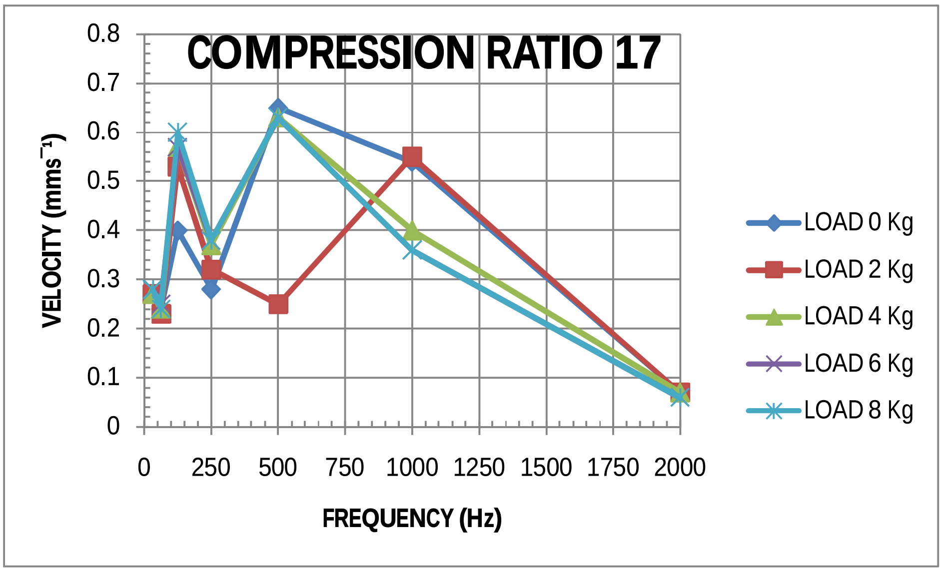

Fig.5.30 for Velocity at C.R.17

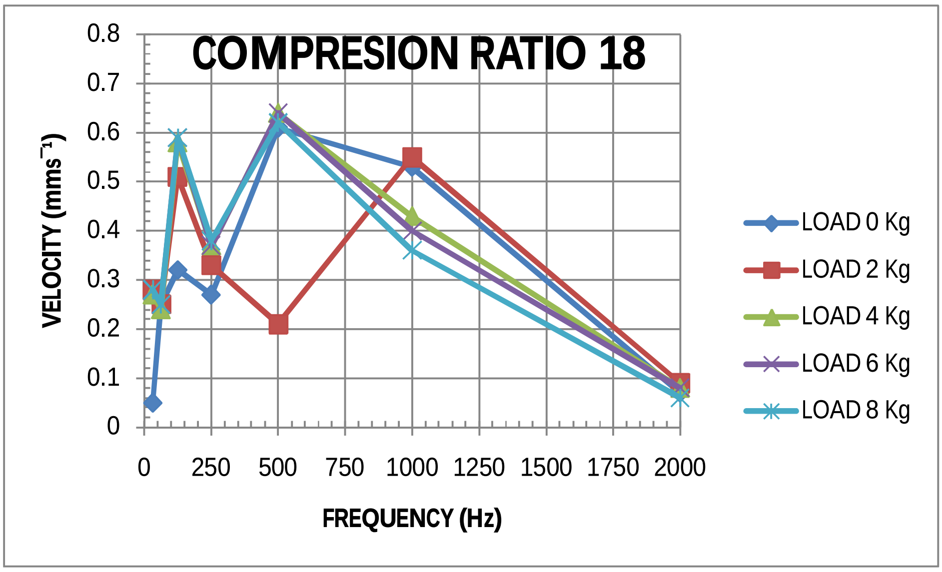

Fig.5.31 for Velocity at C.R.18

In Fig.5.25 & 5.26 for C.R.12 & 13 resp. there are certain variations at the start till 250 Hz**.** As the load increases the velocity increases till 500 Hz and after that the velocity comes to decline mode, comes in the range 0.06 ms^{-1} at 2000 Hz.

In Fig.5.27 for C.R.14, after 125 Hz the velocity increases instantaneously for load 8 Kg and reached at 0.9 ms^{-1} then it comes to normal range and form the constant path of velocity like other loads.

In Fig.5.28 for C.R.15, all the loads has increasing velocities till 500 Hz and after that there is dip in velocity at 1000 Hz and then there is sudden increase in velocity for loads 4 Kg, 6 Kg, 8 Kg at 2000 Hz.

In Fig.5.29 for C.R.16, as in Fig.5.28 for C.R.15 the load 4 Kg, 6 Kg, 8 Kg follows the same path but load 0 & 2 Kg has decreasing velocity after 1000 Hz.

In Fig.5.30 & 5.31 for C.R.17 & 18, the velocity again increases till 63 Hz and then decreases at 250 Hz. After that loads 0 Kg, 6 Kg, 8 Kg increases above 0.6 ms^{-1} and then instantaneously comes down below 0.1 ms^{-1} at 2000 Hz. There is decrease in velocity for load 2 Kg after 125 Hz till 500 Hz and then it increases.

5.4.4. VIBRATIONS GRAPHS FOR VELOCITY (ms^{-1}) KEEPING LOADS FIXED

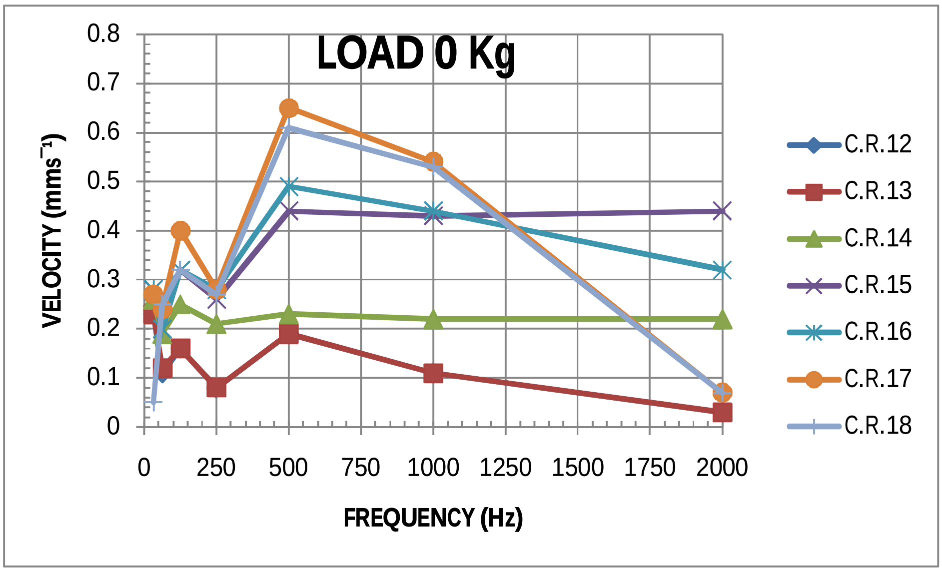

Fig.5.32 for Velocity at LOAD 0 Kg

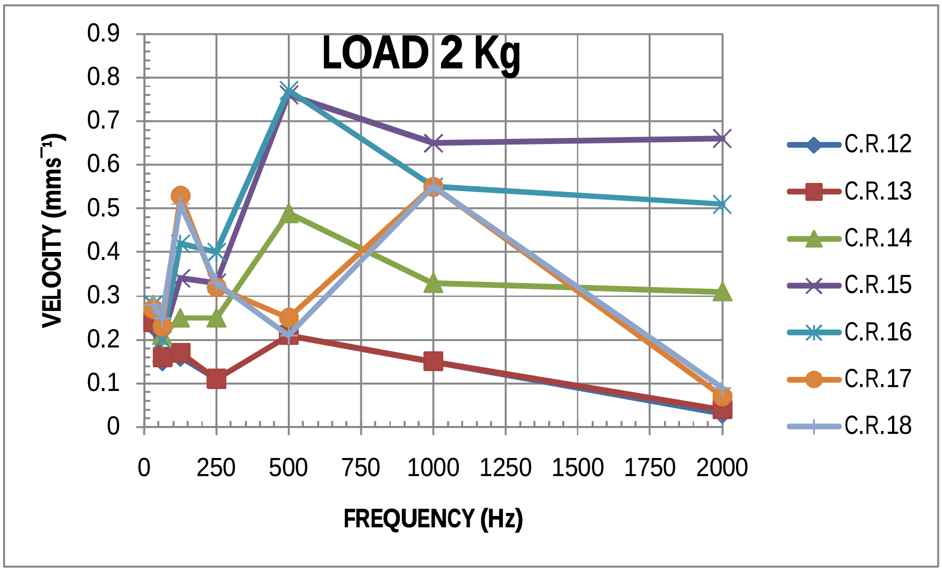

Fig.5.33 for Velocity at LOAD 2 Kg

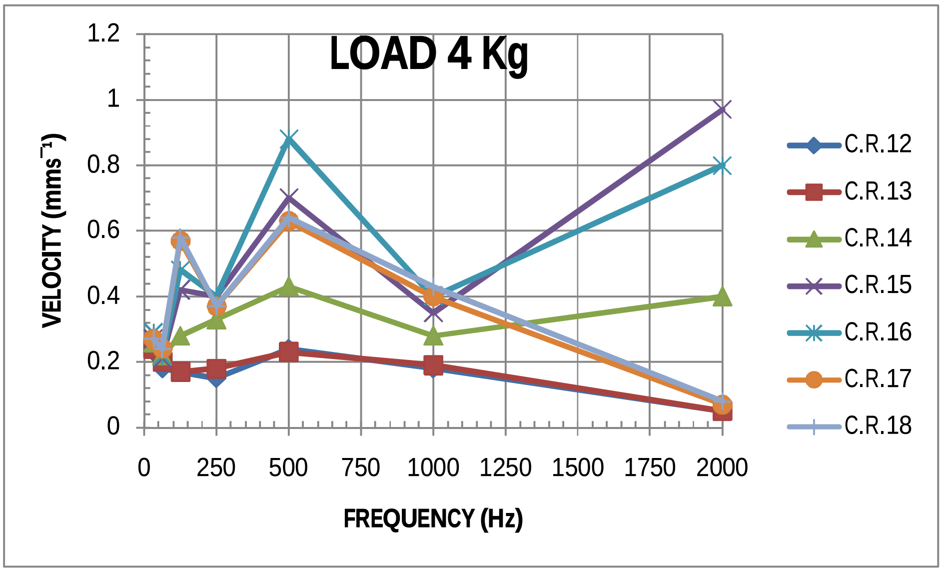

Fig.5.34 for Velocity at LOAD 4 Kg

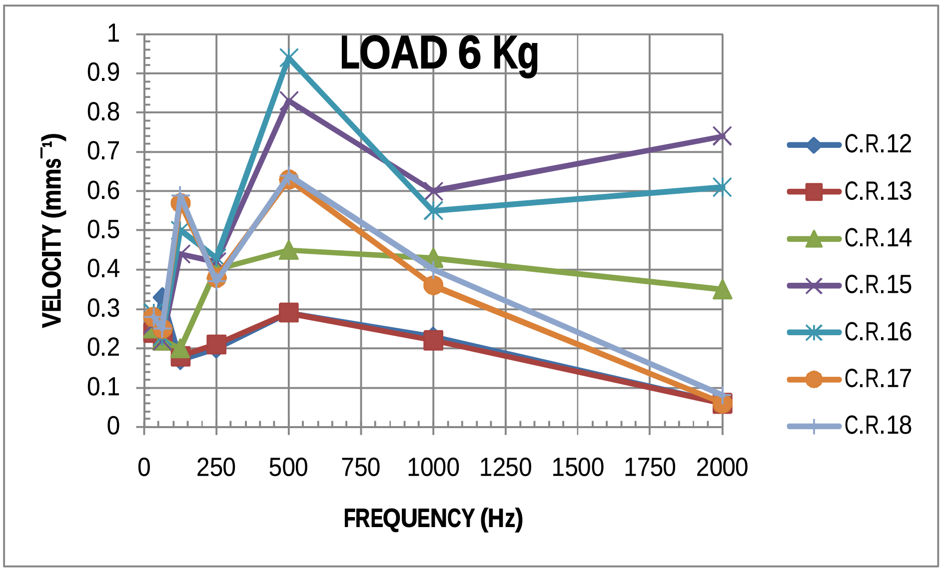

Fig.5.35 for Velocity at LOAD 6 Kg

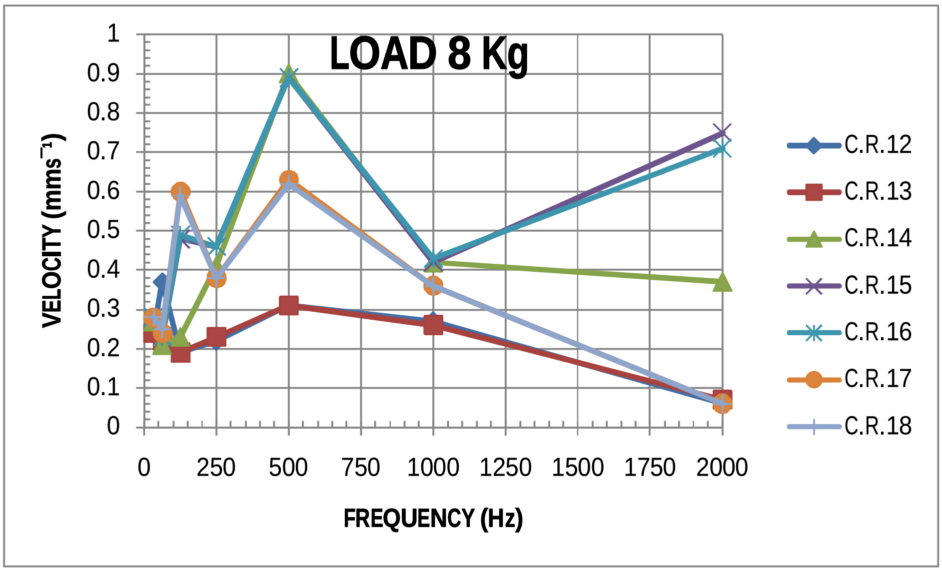

Fig.5.36 for Velocity at LOAD 8 Kg

In Fig.5.32 & 5.33 for load 0 Kg & 2 Kg, they follow the almost same pattern. There is increase in velocity of all C.R. till 500 Hz, after that it comes to decline mode. As velocity decreases with increase in frequency. The maximum velocity is at C.R.17. The C.R.14 & C.R.15 forms a constant path after 500 Hz.

In Fig.5.34 for load 4 Kg, the velocity increase till 500 Hz after that there is decrease in velocity at 1000 Hz. The velocity increases after 1000 Hz for C.R. 14, 15 & 16. The maximum velocity is at C.R.15.

In Fig.5.35 & 5.36 for load 6 Kg & 8 Kg, the both graphs follow the same pattern. The velocity increases till 500 Hz and there are increases in velocity for C.R.15 & 16 at 1000 Hz. But in Fig.5.36, C.R.14 increases the most and reaches the maximum value of velocity near 0.9 ms^{-1}.

5.5. MEASUREMENT OF SPL FOR FREQUENCY SPECTRUM IN 1-1 OCTAVE BAND

The value of SOUND PRESSURE LEVEL at 1-1 octave band frequency gives an idea of the maximum and minimum value at particular frequency. Frequency spectrum is formed at that point where SPL is maximum. Take the readings at that point by changing the different compression ratio and load. This instrument gives the data for all frequencies of 1-1 octave band in software “CESVA CAPTURE STUDIO. The observations for frequency spectrum are shown in APPENDIX-D from Table no.28 to Table no.34.

5.5.1. GRAPHS SHOWING FREQUENCY SPECTRUM KEEPING C.R. FIXED

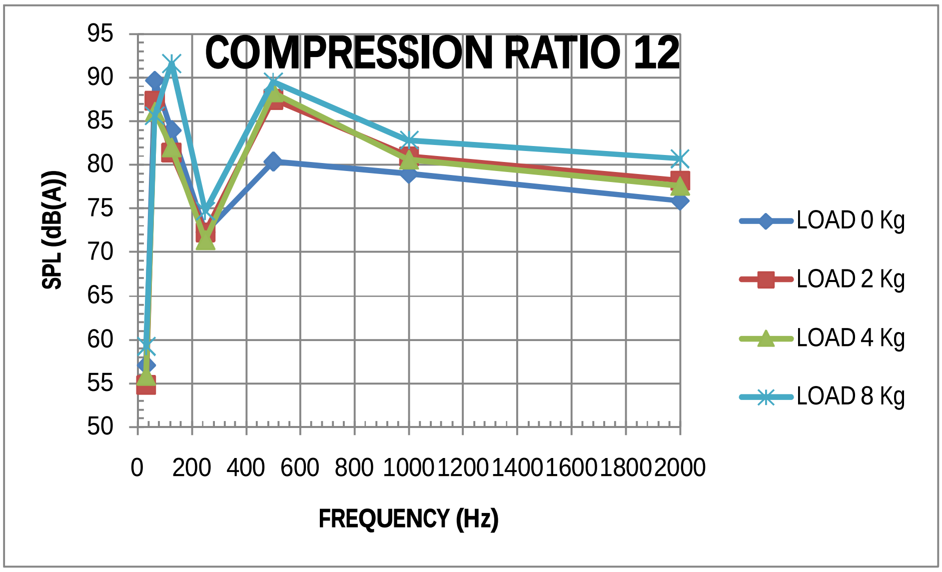

Fig.5.37 at C.R.12

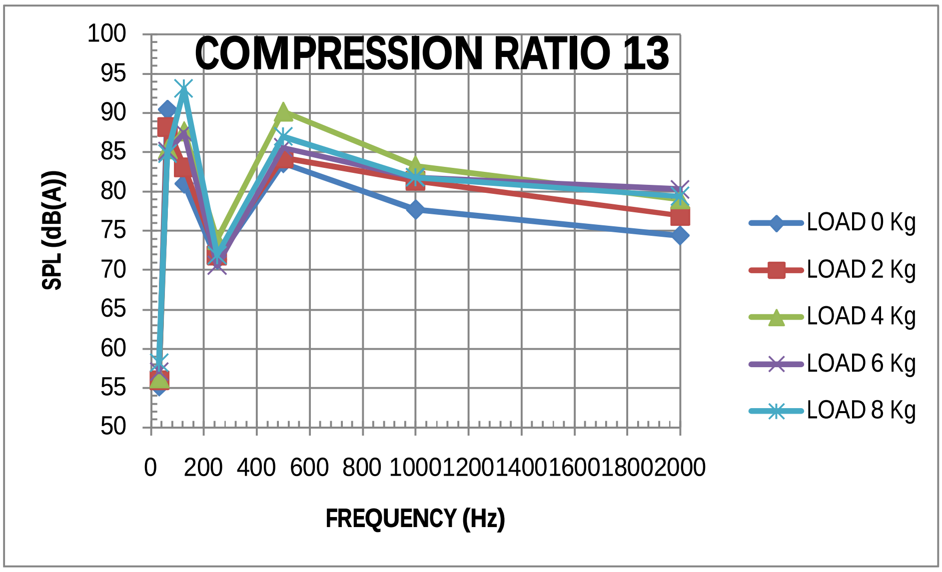

Fig.5.38 at C.R.13

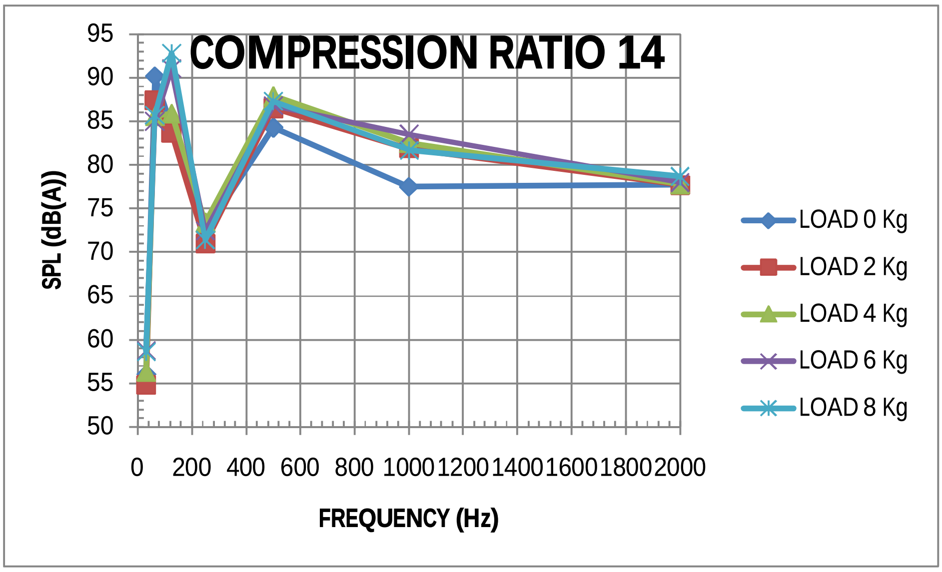

Fig.5.39 at C.R.14

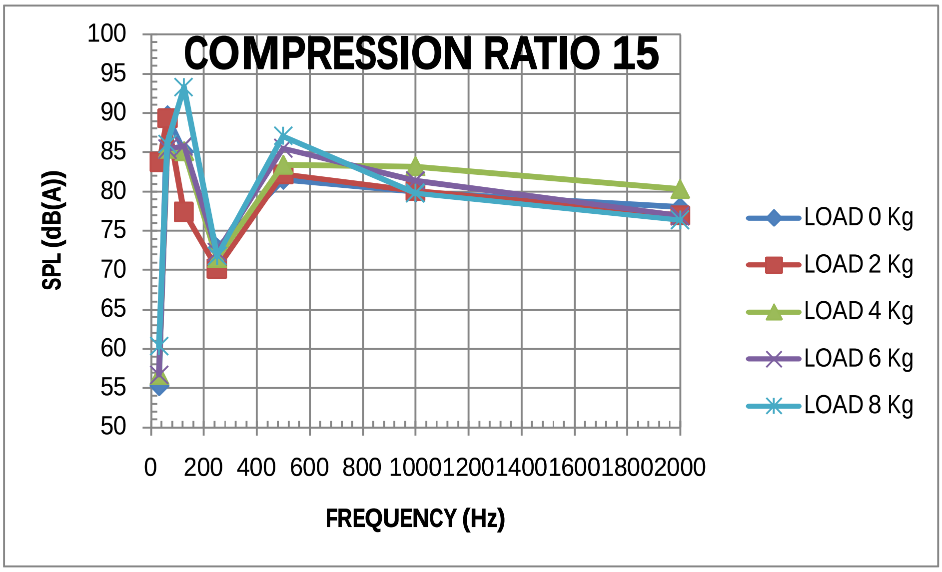

Fig.5.40 at C.R.15

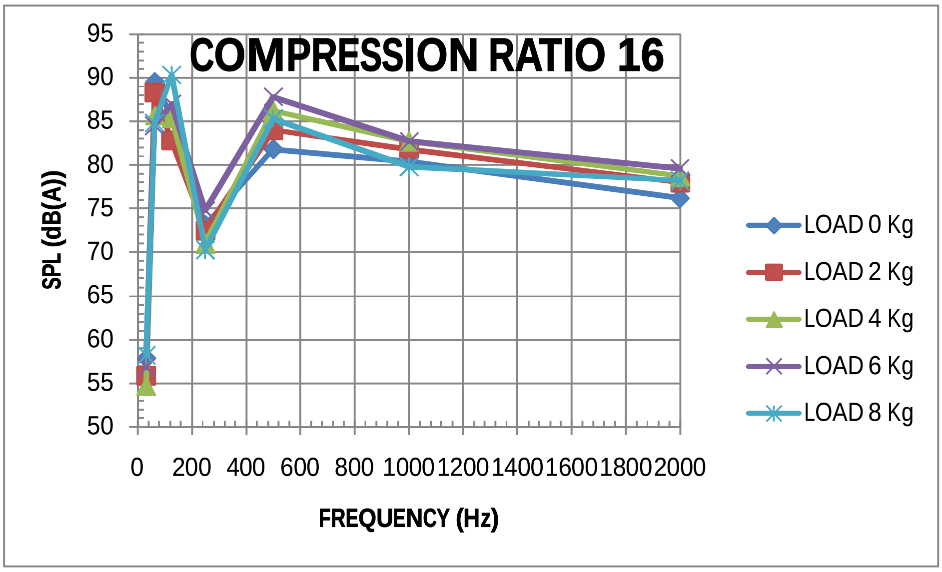

Fig.5.41 at C.R.16

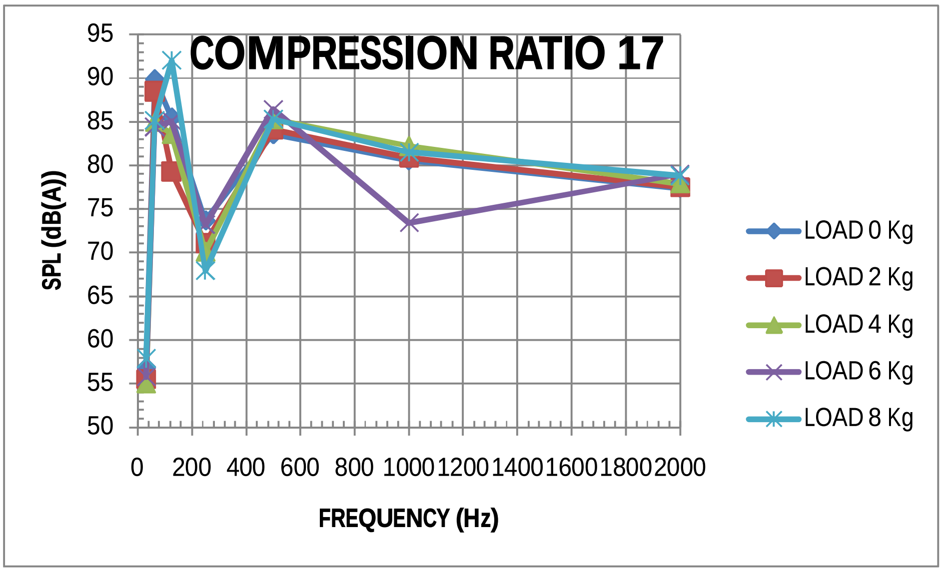

Fig.5.42 at C.R.17

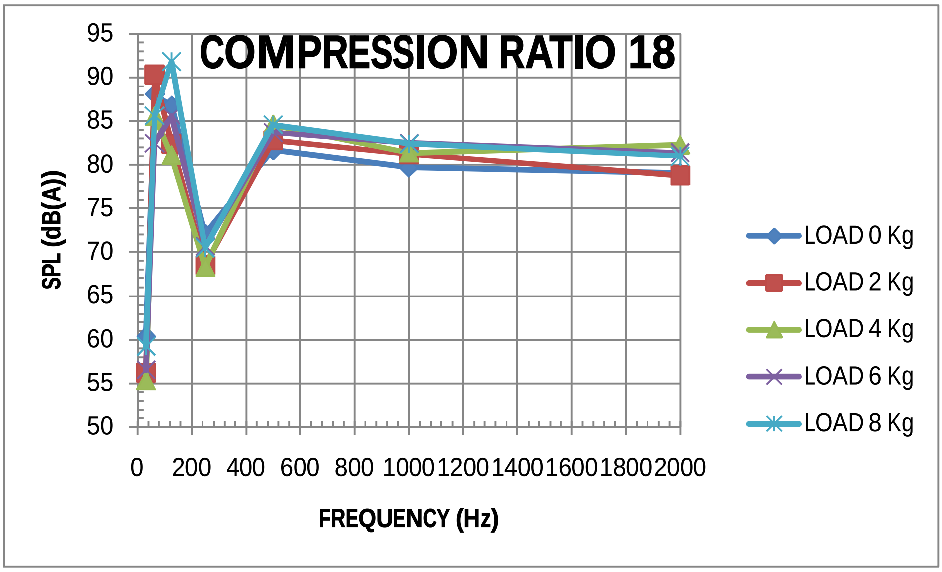

Fig.5.43 at C.R.18

In all Figures from 5.37 to 5.43, the SPL increases with increasing frequency range till 125 Hz , at 125 Hz the SPL is maximum for all C.R. at load 8 Kg. the SPL decreases at 250 Hz and increases for 500 Hz, the SPL again decreases after 500 Hz to 1000 Hz and continue till 2000 Hz. The maximum SPL is 93.3 dB (A) at load 8 Kg for C.R.15.

5.5.2. GRAPHS SHOWING FREQUENCY SPECTRUM KEEPING LOADS FIXED

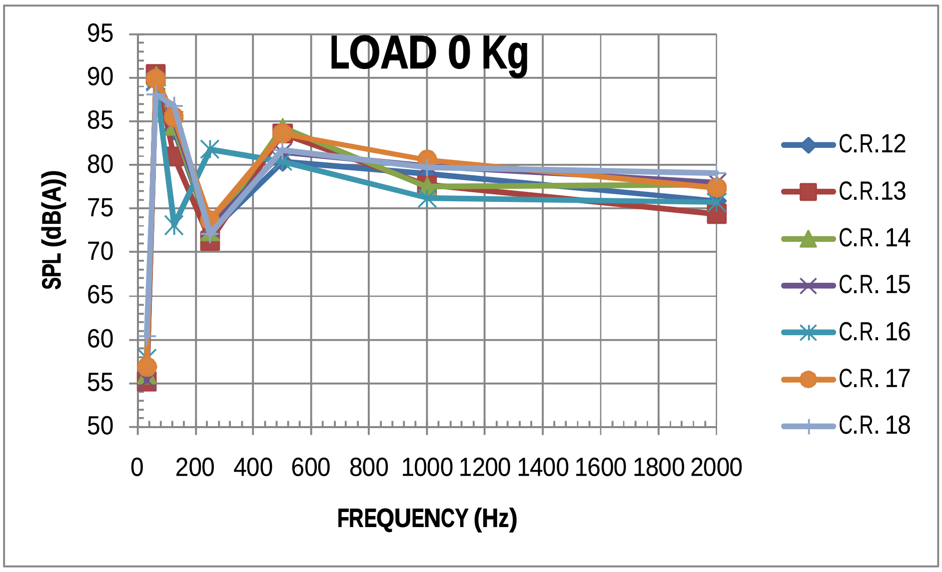

Fig.5.44 at LOAD 0 Kg

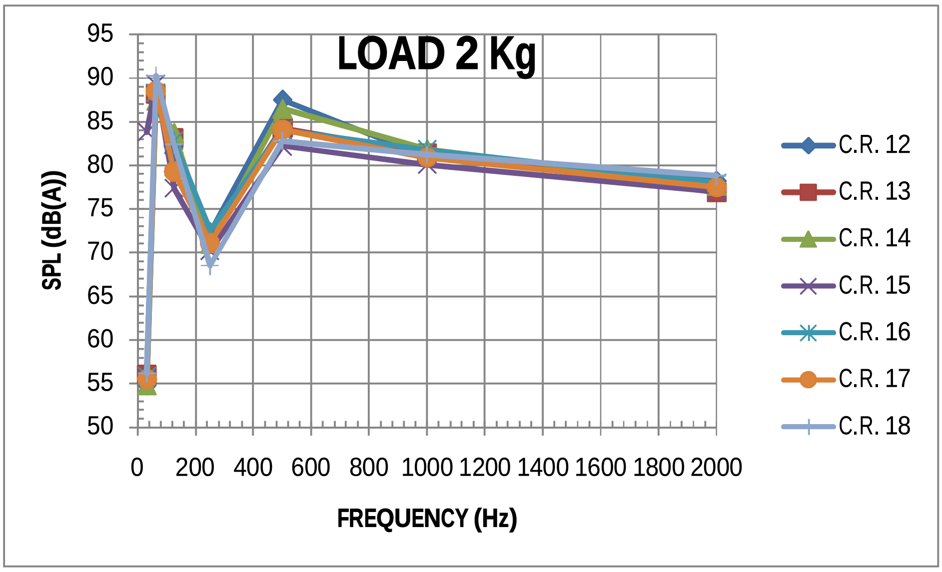

Fig.5.45 at LOAD 2 Kg

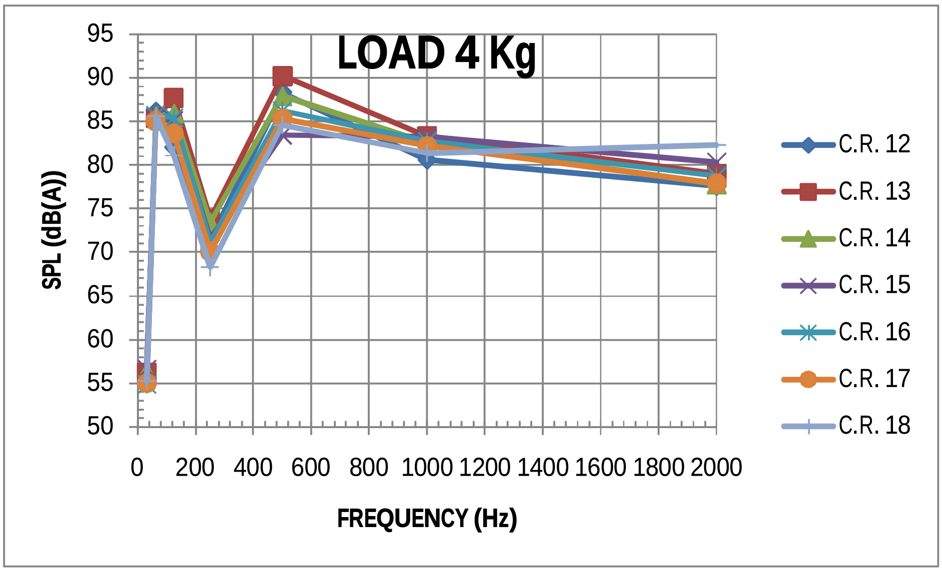

Fig.5.46 at LOAD 4 Kg

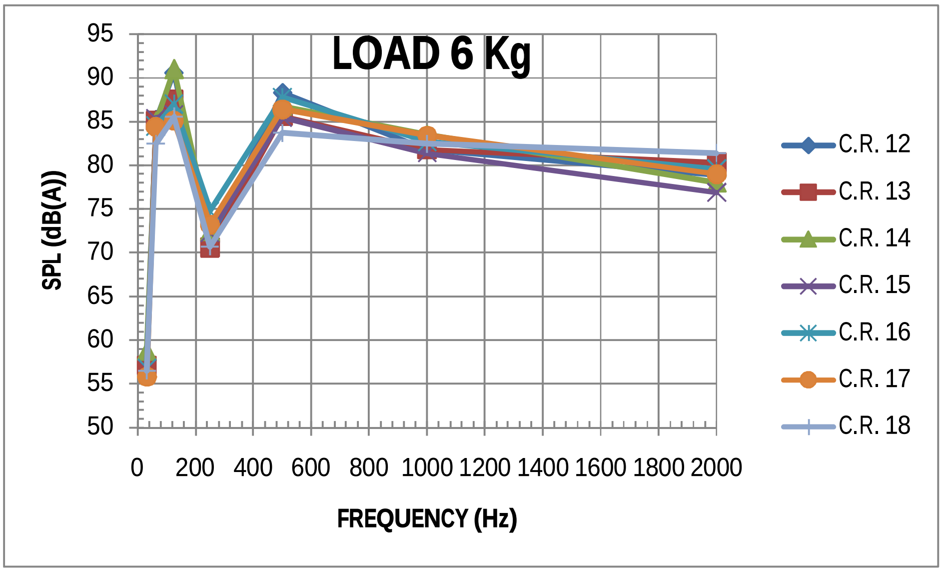

Fig.5.47 at LOAD 6 Kg

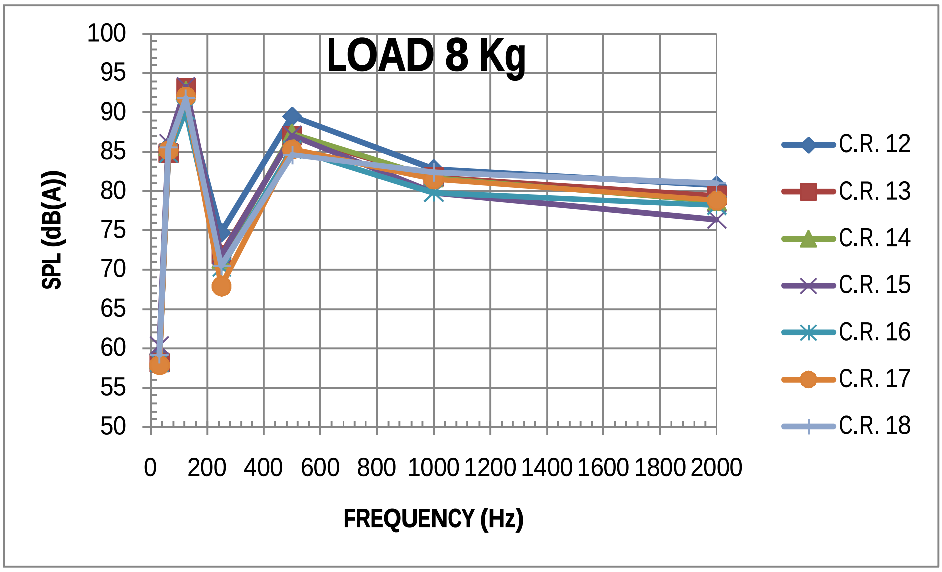

Fig.5.48 at LOAD 8 Kg

In all these Figures from 5.44 to 5.48, the pattern is same as increase in SPL till 125 Hz, at 125 Hz SPL is maximum and there is decrease in SPL at 250 Hz. At 500 Hz the SPL again increases, after that SPL goes down in decline manner for 1000 Hz and 2000 Hz.

5.6. REGRESSION ANALYSIS

A multi-parameter regression analysis is carried out and mathematical expressions are predicted at all points i.e. A, B, C, D, Exhaust and also for Acoustic power.

5.6.1. REGRESSION OUTPUT FOR POINT "A"

R-Square = 0.4284

Std. error = 1.3390

Constant = 86.6672

Equation: SPL at point "A" (dB (A)) = 86.6672 -0.038 * C.R. + 0.4423 * LOAD

Table no.1 Regression output for point "A"

C.R.	LOAD	Measured SPL at point "A"	Predicted SPL at "A"(dB(A))	ERROR (dB(A))	% ERROR

		(dB(A))			
12	0	82.9	86.21	-3.31	-3.99276
12	1	85.2	86.6523	-1.4523	-1.70458
12	2	85.2	87.0946	-1.8946	-2.22371
12	3	87.9	87.5369	0.3631	0.413083
12	4	89.4	87.9792	1.4208	1.589262
12	5	89.8	88.4215	1.3785	1.535078
12	6	90.1	88.8638	1.2362	1.372031
12	7	91	89.3061	1.6939	1.861429
12	8	90.9	89.7484	1.1516	1.266887
12.5	0	84.4	86.19095	-1.79095	-2.12198
12.5	1	85.8	86.63325	-0.83325	-0.97115
12.5	2	86.9	87.07555	-0.17555	-0.20201
12.5	3	88.5	87.51785	0.98215	1.109774
12.5	4	89.9	87.96015	1.93985	2.157786
12.5	5	90.5	88.40245	2.09755	2.317735
12.5	6	90.2	88.84475	1.35525	1.502494
12.5	7	89.3	89.28705	0.01295	0.014502
12.5	8	88.8	89.72935	-0.92935	-1.04657
13	0	82.8	86.1719	-3.3719	-4.07234
13	1	84.5	86.6142	-2.1142	-2.50201
13	2	84.2	87.0565	-2.8565	-3.39252
13	3	86.4	87.4988	-1.0988	-1.27176
13	4	88.4	87.9411	0.4589	0.519118
13	5	88.1	88.3834	-0.2834	-0.32168
13	6	89.6	88.8257	0.7743	0.864174
13	7	88.9	89.268	-0.368	-0.41395
13	8	89.3	89.7103	-0.4103	-0.45946
13.5	0	83.1	86.15285	-3.05285	-3.67371
13.5	1	84.1	86.59515	-2.49515	-2.96688
13.5	2	84.2	87.03745	-2.83745	-3.36989
13.5	3	86.1	87.47975	-1.37975	-1.6025
13.5	4	88.3	87.92205	0.37795	0.428029
13.5	5	88.6	88.36435	0.23565	0.265971
13.5	6	89	88.80665	0.19335	0.217247
13.5	7	89.7	89.24895	0.45105	0.502843
13.5	8	89.7	89.69125	0.00875	0.009755
14	0	86.6	86.1338	0.4662	0.538337
14	1	88.5	86.5761	1.9239	2.173898
14	2	87.4	87.0184	0.3816	0.436613
14	3	89.1	87.4607	1.6393	1.839843

14	4	88.5	87.903	0.597	0.674576
14	5	89.1	88.3453	0.7547	0.847026
14	6	89.6	88.7876	0.8124	0.906696
14	7	90	89.2299	0.7701	0.855667
14	8	89.7	89.6722	0.0278	0.030992
14.5	0	87.2	86.11475	1.08525	1.244553
14.5	1	86.7	86.55705	0.14295	0.164879
14.5	2	88.1	86.99935	1.10065	1.249319
14.5	3	89.3	87.44165	1.85835	2.081019
14.5	4	88.2	87.88395	0.31605	0.358333
14.5	5	88.3	88.32625	-0.02625	-0.02973
14.5	6	88.1	88.76855	-0.66855	-0.75885
14.5	7	89.3	89.21085	0.08915	0.099832
14.5	8	89.2	89.65315	-0.45315	-0.50802
15	0	86.4	86.0957	0.3043	0.352199
15	1	88.1	86.538	1.562	1.772985
15	2	89.2	86.9803	2.2197	2.488453
15	3	89.5	87.4226	2.0774	2.321117
15	4	91	87.8649	3.1351	3.445165
15	5	88.7	88.3072	0.3928	0.442841
15	6	89.2	88.7495	0.4505	0.505045
15	7	89.5	89.1918	0.3082	0.344358
15	8	90.1	89.6341	0.4659	0.517092
15.5	0	84.7	86.07665	-1.37665	-1.62532
15.5	1	87.5	86.51895	0.98105	1.1212
15.5	2	87.4	86.96125	0.43875	0.502002
15.5	3	87.7	87.40355	0.29645	0.338027
15.5	4	88.2	87.84585	0.35415	0.401531
15.5	5	89.2	88.28815	0.91185	1.022253
15.5	6	88.4	88.73045	-0.33045	-0.37381
15.5	7	88.7	89.17275	-0.47275	-0.53298
15.5	8	88.7	89.61505	-0.91505	-1.03162
16	0	86.4	86.0576	0.3424	0.396296
16	1	87.1	86.4999	0.6001	0.688978
16	2	88.4	86.9422	1.4578	1.649095
16	3	89.3	87.3845	1.9155	2.145017
16	4	88.5	87.8268	0.6732	0.760678
16	5	88.6	88.2691	0.3309	0.373476
16	6	89.3	88.7114	0.5886	0.659127
16	7	88	89.1537	-1.1537	-1.31102
16	8	88	89.596	-1.596	-1.81364

16.5	0	86	86.03855	-0.03855	-0.04483
16.5	1	87.1	86.48085	0.61915	0.71085
16.5	2	86	86.92315	-0.92315	-1.07343
16.5	3	86.7	87.36545	-0.66545	-0.76753
16.5	4	87.3	87.80775	-0.50775	-0.58162
16.5	5	87.3	88.25005	-0.95005	-1.08826
16.5	6	88.3	88.69235	-0.39235	-0.44434
16.5	7	88.4	89.13465	-0.73465	-0.83105
16.5	8	88.8	89.57695	-0.77695	-0.87494
17	0	86.2	86.0195	0.1805	0.209397
17	1	85.3	86.4618	-1.1618	-1.36202
17	2	84.9	86.9041	-2.0041	-2.36054
17	3	85.8	87.3464	-1.5464	-1.80233
17	4	86.7	87.7887	-1.0887	-1.25571
17	5	87.6	88.231	-0.631	-0.72032
17	6	88.1	88.6733	-0.5733	-0.65074
17	7	87.7	89.1156	-1.4156	-1.61414
17	8	87.2	89.5579	-2.3579	-2.70401
17.5	0	85.8	86.00045	-0.20045	-0.23362
17.5	1	88.1	86.44275	1.65725	1.881101
17.5	2	89.7	86.88505	2.81495	3.138183
17.5	3	89.3	87.32735	1.97265	2.209015
17.5	4	88.4	87.76965	0.63035	0.713066
17.5	5	88.1	88.21195	-0.11195	-0.12707
17.5	6	88.6	88.65425	-0.05425	-0.06123
17.5	7	89.6	89.09655	0.50345	0.561886
17.5	8	88.9	89.53885	-0.63885	-0.71862
18	0	87.3	85.9814	1.3186	1.510424
18	1	86.7	86.4237	0.2763	0.318685
18	2	87.6	86.866	0.734	0.8379
18	3	87.6	87.3083	0.2917	0.332991
18	4	88.7	87.7506	0.9494	1.070349
18	5	88.5	88.1929	0.3071	0.347006
18	6	88.4	88.6352	-0.2352	-0.26606
18	7	86.2	89.0775	-2.8775	-3.33817
18	8	86.9	89.5198	-2.6198	-3.01473

5.6.2. REGRESSION OUTPUT FOR POINT "B"

R-Square = 0.5800

Std. error = 1.2337

Constant = 88.0054

Equation: SPL at point “B” (dB (A)) = 88.0054 +0.0806 * C.R. + 0.5512 * LOAD

Table no.2 Regression output for point “B”

C.R.	LOAD	Measured SPL at point “B” (dB(A))	Predicted SPL at point “B” (dB(A))	ERROR (dB(A))	% ERROR
12	0	86.6	88.9726	-2.3726	-2.73972
12	1	89.8	89.5238	0.2762	0.307572
12	2	89.7	90.075	-0.375	-0.41806
12	3	91.7	90.6262	1.0738	1.170992
12	4	90.9	91.1774	-0.2774	-0.30517
12	5	93.1	91.7286	1.3714	1.47304
12	6	93.5	92.2798	1.2202	1.305027
12	7	94.8	92.831	1.969	2.077004
12	8	92.4	93.3822	-0.9822	-1.06299
12.5	0	86.5	89.0129	-2.5129	-2.90509
12.5	1	88.4	89.5641	-1.1641	-1.31686
12.5	2	90.9	90.1153	0.7847	0.863256
12.5	3	91.9	90.6665	1.2335	1.34222
12.5	4	92.1	91.2177	0.8823	0.95798
12.5	5	94.2	91.7689	2.4311	2.580786
12.5	6	93.8	92.3201	1.4799	1.577719
12.5	7	91.5	92.8713	-1.3713	-1.49869
12.5	8	92.9	93.4225	-0.5225	-0.56243
13	0	86.6	89.0532	-2.4532	-2.83279
13	1	87.5	89.6044	-2.1044	-2.40503
13	2	89.6	90.1556	-0.5556	-0.62009
13	3	90.5	90.7068	-0.2068	-0.22851
13	4	92.1	91.258	0.842	0.914224
13	5	91.8	91.8092	-0.0092	-0.01002

13	6	92.3	92.3604	-0.0604	-0.06544
13	7	94.1	92.9116	1.1884	1.262912
13	8	94.1	93.4628	0.6372	0.677152
13.5	0	86.2	89.0935	-2.8935	-3.35673
13.5	1	87.6	89.6447	-2.0447	-2.33413
13.5	2	88.7	90.1959	-1.4959	-1.68647
13.5	3	88.3	90.7471	-2.4471	-2.77135
13.5	4	91.3	91.2983	0.0017	0.001862
13.5	5	89	91.8495	-2.8495	-3.20169
13.5	6	89.2	92.4007	-3.2007	-3.58823
13.5	7	91	92.9519	-1.9519	-2.14495
13.5	8	93	93.5031	-0.5031	-0.54097
14	0	89.8	89.1338	0.6662	0.741871
14	1	89.3	89.685	-0.385	-0.43113
14	2	91.6	90.2362	1.3638	1.488865
14	3	92.8	90.7874	2.0126	2.16875
14	4	93.2	91.3386	1.8614	1.99721
14	5	94.2	91.8898	2.3102	2.452442
14	6	93.1	92.441	0.659	0.707841
14	7	93.9	92.9922	0.9078	0.966773
14	8	95.1	93.5434	1.5566	1.636803
14.5	0	89.3	89.1741	0.1259	0.140985
14.5	1	90.1	89.7253	0.3747	0.415871
14.5	2	91.2	90.2765	0.9235	1.01261
14.5	3	92.4	90.8277	1.5723	1.701623
14.5	4	92.5	91.3789	1.1211	1.212
14.5	5	93.2	91.9301	1.2699	1.362554
14.5	6	93.3	92.4813	0.8187	0.877492
14.5	7	93.7	93.0325	0.6675	0.71238
14.5	8	93.4	93.5837	-0.1837	-0.19668
15	0	89.5	89.2144	0.2856	0.319106
15	1	90.5	89.7656	0.7344	0.811492
15	2	91.6	90.3168	1.2832	1.400873
15	3	92.1	90.868	1.232	1.337676
15	4	92.5	91.4192	1.0808	1.168432
15	5	92.4	91.9704	0.4296	0.464935
15	6	93.1	92.5216	0.5784	0.621267
15	7	93.4	93.0728	0.3272	0.350321
15	8	93	93.624	-0.624	-0.67097
15.5	0	90.2	89.2547	0.9453	1.048004
15.5	1	89.4	89.8059	-0.4059	-0.45403

15.5	2	91.4	90.3571	1.0429	1.141028
15.5	3	91.3	90.9083	0.3917	0.429025
15.5	4	91.3	91.4595	-0.1595	-0.1747
15.5	5	92.3	92.0107	0.2893	0.313434
15.5	6	91.3	92.5619	-1.2619	-1.38215
15.5	7	91.5	93.1131	-1.6131	-1.76295
15.5	8	91.6	93.6643	-2.0643	-2.2536
16	0	89.7	89.295	0.405	0.451505
16	1	89.7	89.8462	-0.1462	-0.16299
16	2	91.4	90.3974	1.0026	1.096937
16	3	92.4	90.9486	1.4514	1.570779
16	4	92.4	91.4998	0.9002	0.974242
16	5	92.5	92.051	0.449	0.485405
16	6	92.7	92.6022	0.0978	0.105502
16	7	91.5	93.1534	-1.6534	-1.80699
16	8	90.9	93.7046	-2.8046	-3.08537
16.5	0	88.6	89.3353	-0.7353	-0.82991
16.5	1	89.5	89.8865	-0.3865	-0.43184
16.5	2	89.9	90.4377	-0.5377	-0.59811
16.5	3	90.9	90.9889	-0.0889	-0.0978
16.5	4	91.5	91.5401	-0.0401	-0.04383
16.5	5	92.7	92.0913	0.6087	0.656634
16.5	6	92.4	92.6425	-0.2425	-0.26245
16.5	7	92.9	93.1937	-0.2937	-0.31615
16.5	8	93.2	93.7449	-0.5449	-0.58466
17	0	89.2	89.3756	-0.1756	-0.19686
17	1	89.2	89.9268	-0.7268	-0.8148
17	2	90.5	90.478	0.022	0.024309
17	3	91.5	91.0292	0.4708	0.514536
17	4	92	91.5804	0.4196	0.456087
17	5	92	92.1316	-0.1316	-0.14304
17	6	93.2	92.6828	0.5172	0.554936
17	7	91.7	93.234	-1.534	-1.67285
17	8	93.5	93.7852	-0.2852	-0.30503
17.5	0	89.3	89.4159	-0.1159	-0.12979
17.5	1	92.2	89.9671	2.2329	2.4218
17.5	2	90.8	90.5183	0.2817	0.310242
17.5	3	92.2	91.0695	1.1305	1.226139
17.5	4	93	91.6207	1.3793	1.483118
17.5	5	92.9	92.1719	0.7281	0.783746
17.5	6	93	92.7231	0.2769	0.297742

17.5	7	93.6	93.2743	0.3257	0.34797
17.5	8	93.1	93.8255	-0.7255	-0.77927
18	0	87.9	89.4562	-1.5562	-1.77042
18	1	90.2	90.0074	0.1926	0.213525
18	2	90.1	90.5586	-0.4586	-0.50899
18	3	90.6	91.1098	-0.5098	-0.56269
18	4	91.6	91.661	-0.061	-0.06659
18	5	92.6	92.2122	0.3878	0.41879
18	6	92.6	92.7634	-0.1634	-0.17646
18	7	92.8	93.3146	-0.5146	-0.55453
18	8	91.8	93.8658	-2.0658	-2.25033

5.6.3. REGRESSION OUTPUT FOR POINT “C”

R-Square = 0.3093

Std. error = 1.7835

Constant = 85.7070

Equation: SPL at point “C” (dB (A)) = 85.7070 + 0.3289 * C.R. + 0.3891 * LOAD

Table no.3 Regression output for point “C”

C.R.	LOAD	Measured SPL at point “C” (dB(A))	Predicted SPL at point “C”(dB(A))	ERROR (dB(A))	% ERROR
12	0	88.7	89.6538	-0.9538	-1.07531
12	1	87.8	90.0429	-2.2429	-2.55456
12	2	89.8	90.432	-0.632	-0.70379
12	3	90	90.8211	-0.8211	-0.91233
12	4	90.8	91.2102	-0.4102	-0.45176
12	5	92.8	91.5993	1.2007	1.293858
12	6	94.4	91.9884	2.4116	2.554661
12	7	93.8	92.3775	1.4225	1.516525
12	8	93.4	92.7666	0.6334	0.678158
12.5	0	88.3	89.81825	-1.51825	-1.71942
12.5	1	89.6	90.20735	-0.60735	-0.67785
12.5	2	89.7	90.59645	-0.89645	-0.99939
12.5	3	92.8	90.98555	1.81445	1.955226

12.5	4	92.6	91.37465	1.22535	1.323272
12.5	5	93.8	91.76375	2.03625	2.170842
12.5	6	94.3	92.15285	2.14715	2.276935
12.5	7	94.4	92.54195	1.85805	1.968273
12.5	8	93.6	92.93105	0.66895	0.71469
13	0	87.6	89.9827	-2.3827	-2.71998
13	1	90	90.3718	-0.3718	-0.41311
13	2	90.2	90.7609	-0.5609	-0.62184
13	3	92.2	91.15	1.05	1.138829
13	4	92.8	91.5391	1.2609	1.358728
13	5	94.1	91.9282	2.1718	2.30797
13	6	93.5	92.3173	1.1827	1.26492
13	7	94.3	92.7064	1.5936	1.689926
13	8	93.9	93.0955	0.8045	0.856763
13.5	0	87.4	90.14715	-2.74715	-3.14319
13.5	1	88.6	90.53625	-1.93625	-2.18538
13.5	2	89.7	90.92535	-1.22535	-1.36605
13.5	3	90.5	91.31445	-0.81445	-0.89994
13.5	4	90.8	91.70355	-0.90355	-0.9951
13.5	5	92.1	92.09265	0.00735	0.00798
13.5	6	91.8	92.48175	-0.68175	-0.74265
13.5	7	93.1	92.87085	0.22915	0.246133
13.5	8	92.9	93.25995	-0.35995	-0.38746
14	0	90.5	90.3116	0.1884	0.208177
14	1	89.8	90.7007	-0.9007	-1.00301
14	2	91.5	91.0898	0.4102	0.448306
14	3	92.5	91.4789	1.0211	1.103892
14	4	93.1	91.868	1.232	1.323308
14	5	93.5	92.2571	1.2429	1.329305
14	6	92.9	92.6462	0.2538	0.273197
14	7	92.7	93.0353	-0.3353	-0.3617
14	8	93.9	93.4244	0.4756	0.506496
14.5	0	88.1	90.47605	-2.37605	-2.69699
14.5	1	90.4	90.86515	-0.46515	-0.51455
14.5	2	90.5	91.25425	-0.75425	-0.83343
14.5	3	91.6	91.64335	-0.04335	-0.04733
14.5	4	94.7	92.03245	2.66755	2.816843
14.5	5	91.8	92.42155	-0.62155	-0.67707
14.5	6	93.2	92.81065	0.38935	0.417758
14.5	7	91.8	93.19975	-1.39975	-1.52478
14.5	8	90.5	93.58885	-3.08885	-3.41309

15	0	90.7	90.6405	0.0595	0.065601
15	1	91.2	91.0296	0.1704	0.186842
15	2	91.6	91.4187	0.1813	0.197926
15	3	93.7	91.8078	1.8922	2.019424
15	4	93	92.1969	0.8031	0.863548
15	5	94.1	92.586	1.514	1.608927
15	6	93.4	92.9751	0.4249	0.454925
15	7	93.3	93.3642	-0.0642	-0.06881
15	8	92.9	93.7533	-0.8533	-0.91851
15.5	0	90.4	90.80495	-0.40495	-0.44795
15.5	1	90.4	91.19405	-0.79405	-0.87837
15.5	2	92.1	91.58315	0.51685	0.561183
15.5	3	92.2	91.97225	0.22775	0.247017
15.5	4	92.8	92.36135	0.43865	0.472683
15.5	5	92.5	92.75045	-0.25045	-0.27076
15.5	6	93.1	93.13955	-0.03955	-0.04248
15.5	7	91.4	93.52865	-2.12865	-2.32894
15.5	8	90.8	93.91775	-3.11775	-3.43365
16	0	91.3	90.9694	0.3306	0.362103
16	1	91.7	91.3585	0.3415	0.37241
16	2	92.1	91.7476	0.3524	0.382628
16	3	93.9	92.1367	1.7633	1.877849
16	4	92	92.5258	-0.5258	-0.57152
16	5	92.9	92.9149	-0.0149	-0.01604
16	6	91.3	93.304	-2.004	-2.19496
16	7	92.6	93.6931	-1.0931	-1.18045
16	8	82.5	94.0822	-11.5822	-14.039
16.5	0	90.6	91.13385	-0.53385	-0.58924
16.5	1	90.1	91.52295	-1.42295	-1.5793
16.5	2	90.6	91.91205	-1.31205	-1.44818
16.5	3	91.3	92.30115	-1.00115	-1.09655
16.5	4	93.8	92.69025	1.10975	1.183102
16.5	5	91.7	93.07935	-1.37935	-1.5042
16.5	6	93	93.46845	-0.46845	-0.50371
16.5	7	93.8	93.85755	-0.05755	-0.06135
16.5	8	92.4	94.24665	-1.84665	-1.99854
17	0	90.5	91.2983	-0.7983	-0.8821
17	1	92.9	91.6874	1.2126	1.305274
17	2	94.1	92.0765	2.0235	2.150372
17	3	93.8	92.4656	1.3344	1.422601
17	4	95.5	92.8547	2.6453	2.769948

17	5	94.5	93.2438	1.2562	1.329312
17	6	96	93.6329	2.3671	2.465729
17	7	95.8	94.022	1.778	1.85595
17	8	95.1	94.4111	0.6889	0.724395
17.5	0	91.8	91.46275	0.33725	0.367375
17.5	1	93.8	91.85185	1.94815	2.076919
17.5	2	94.8	92.24095	2.55905	2.69942
17.5	3	92.5	92.63005	-0.13005	-0.14059
17.5	4	92.9	93.01915	-0.11915	-0.12826
17.5	5	95.6	93.40825	2.19175	2.292626
17.5	6	92.2	93.79735	-1.59735	-1.73248
17.5	7	97.2	94.18645	3.01355	3.10036
17.5	8	93.4	94.57555	-1.17555	-1.25862
18	0	91.9	91.6272	0.2728	0.296844
18	1	92.3	92.0163	0.2837	0.307367
18	2	93	92.4054	0.5946	0.639355
18	3	91.1	92.7945	-1.6945	-1.86004
18	4	93.7	93.1836	0.5164	0.551121
18	5	93.4	93.5727	-0.1727	-0.1849
18	6	96.5	93.9618	2.5382	2.630259
18	7	95.8	94.3509	1.4491	1.51263
18	8	90.7	94.74	-4.04	-4.45424

5.6.4. REGRESSION OUTPUT FOR POINT “D”

R-Square = 0.5217

Std. error = 1.4737

Constant = 83.2169

Equation: SPL at point “D” (dB (A)) = 83.2169 + 0.4328 * C.R. + 0.4978 * LOAD

Table no.4 Regression output for point “D”

C.R.	LOAD	Measured SPL at point “D” (dB(A))	Predicted SPL at point “D”(dB(A))	ERROR (dB(A))	% ERROR
12	0	87.4	88.4105	-1.0105	-1.15618
12	1	86.8	88.9083	-2.1083	-2.42892
12	2	90	89.4061	0.5939	0.659889
12	3	90.1	89.9039	0.1961	0.217647
12	4	90.6	90.4017	0.1983	0.218874
12	5	92.4	90.8995	1.5005	1.623918
12	6	93.3	91.3973	1.9027	2.039335
12	7	92.5	91.8951	0.6049	0.653946
12	8	93.2	92.3929	0.8071	0.865987
12.5	0	88.3	88.6269	-0.3269	-0.37022
12.5	1	90.2	89.1247	1.0753	1.192129
12.5	2	90.1	89.6225	0.4775	0.529967
12.5	3	91.6	90.1203	1.4797	1.615393
12.5	4	92.1	90.6181	1.4819	1.609012
12.5	5	92.9	91.1159	1.7841	1.920452
12.5	6	92.5	91.6137	0.8863	0.958162
12.5	7	92.6	92.1115	0.4885	0.527538
12.5	8	93	92.6093	0.3907	0.420108
13	0	88.8	88.8433	-0.0433	-0.04876
13	1	89.6	89.3411	0.2589	0.288951
13	2	90.6	89.8389	0.7611	0.840066
13	3	91.8	90.3367	1.4633	1.594009
13	4	93	90.8345	2.1655	2.328495
13	5	92.8	91.3323	1.4677	1.581573
13	6	92.2	91.8301	0.3699	0.401193
13	7	92.5	92.3279	0.1721	0.186054
13	8	92.6	92.8257	-0.2257	-0.24374
13.5	0	86	89.0597	-3.0597	-3.55779
13.5	1	87.4	89.5575	-2.1575	-2.46854
13.5	2	88.8	90.0553	-1.2553	-1.41363
13.5	3	90.1	90.5531	-0.4531	-0.50289
13.5	4	90.9	91.0509	-0.1509	-0.16601
13.5	5	91	91.5487	-0.5487	-0.60297
13.5	6	92.2	92.0465	0.1535	0.166486
13.5	7	92.7	92.5443	0.1557	0.167961
13.5	8	93.3	93.0421	0.2579	0.27642
14	0	88.5	89.2761	-0.7761	-0.87695
14	1	91.2	89.7739	1.4261	1.563706

14	2	91.9	90.2717	1.6283	1.771817
14	3	92.5	90.7695	1.7305	1.870811
14	4	92.9	91.2673	1.6327	1.757481
14	5	93.4	91.7651	1.6349	1.750428
14	6	93	92.2629	0.7371	0.792581
14	7	93.2	92.7607	0.4393	0.471352
14	8	92.4	93.2585	-0.8585	-0.92911
14.5	0	86.5	89.4925	-2.9925	-3.45954
14.5	1	88.9	89.9903	-1.0903	-1.22643
14.5	2	89.8	90.4881	-0.6881	-0.76626
14.5	3	91.3	90.9859	0.3141	0.344031
14.5	4	91	91.4837	-0.4837	-0.53154
14.5	5	91.1	91.9815	-0.8815	-0.96762
14.5	6	91.9	92.4793	-0.5793	-0.63036
14.5	7	92.4	92.9771	-0.5771	-0.62457
14.5	8	92.1	93.4749	-1.3749	-1.49283
15	0	87.3	89.7089	-2.4089	-2.75934
15	1	88.9	90.2067	-1.3067	-1.46985
15	2	90.5	90.7045	-0.2045	-0.22597
15	3	92	91.2023	0.7977	0.867065
15	4	92.4	91.7001	0.6999	0.757468
15	5	93.2	92.1979	1.0021	1.075215
15	6	92.4	92.6957	-0.2957	-0.32002
15	7	92.9	93.1935	-0.2935	-0.31593
15	8	92.4	93.6913	-1.2913	-1.39751
15.5	0	88.6	89.9253	-1.3253	-1.49582
15.5	1	88.6	90.4231	-1.8231	-2.05767
15.5	2	90.4	90.9209	-0.5209	-0.57622
15.5	3	90.9	91.4187	-0.5187	-0.57063
15.5	4	90.8	91.9165	-1.1165	-1.22963
15.5	5	90.2	92.4143	-2.2143	-2.45488
15.5	6	90.8	92.9121	-2.1121	-2.3261
15.5	7	90.9	93.4099	-2.5099	-2.76117
15.5	8	89.7	93.9077	-4.2077	-4.69086
16	0	91.1	90.1417	0.9583	1.051921
16	1	91	90.6395	0.3605	0.396154
16	2	92.9	91.1373	1.7627	1.897417
16	3	93.6	91.6351	1.9649	2.099252
16	4	93.4	92.1329	1.2671	1.356638
16	5	93.5	92.6307	0.8693	0.929733
16	6	91.4	93.1285	-1.7285	-1.89114

16	7	91.5	93.6263	-2.1263	-2.32383
16	8	90.3	94.1241	-3.8241	-4.23488
16.5	0	87.8	90.3581	-2.5581	-2.91355
16.5	1	88.1	90.8559	-2.7559	-3.12815
16.5	2	88.8	91.3537	-2.5537	-2.87579
16.5	3	90	91.8515	-1.8515	-2.05722
16.5	4	90.2	92.3493	-2.1493	-2.38282
16.5	5	90.9	92.8471	-1.9471	-2.14202
16.5	6	91.4	93.3449	-1.9449	-2.1279
16.5	7	95.3	93.8427	1.4573	1.529171
16.5	8	94.3	94.3405	-0.0405	-0.04295
17	0	91.3	90.5745	0.7255	0.794633
17	1	91.9	91.0723	0.8277	0.900653
17	2	91.8	91.5701	0.2299	0.250436
17	3	93.8	92.0679	1.7321	1.846588
17	4	93.9	92.5657	1.3343	1.42098
17	5	93.7	93.0635	0.6365	0.679296
17	6	94.3	93.5613	0.7387	0.783351
17	7	95.5	94.0591	1.4409	1.508796
17	8	94.6	94.5569	0.0431	0.04556
17.5	0	91.6	90.7909	0.8091	0.883297
17.5	1	93.7	91.2887	2.4113	2.573426
17.5	2	93.1	91.7865	1.3135	1.410849
17.5	3	93.7	92.2843	1.4157	1.510886
17.5	4	92	92.7821	-0.7821	-0.85011
17.5	5	95.7	93.2799	2.4201	2.52884
17.5	6	96	93.7777	2.2223	2.314896
17.5	7	96	94.2755	1.7245	1.796354
17.5	8	94.9	94.7733	0.1267	0.133509
18	0	92.3	91.0073	1.2927	1.400542
18	1	93.5	91.5051	1.9949	2.133583
18	2	93.7	92.0029	1.6971	1.811206
18	3	93.5	92.5007	0.9993	1.06877
18	4	94.1	92.9985	1.1015	1.170563
18	5	93.4	93.4963	-0.0963	-0.1031
18	6	94.7	93.9941	0.7059	0.745407
18	7	94.2	94.4919	-0.2919	-0.30987
18	8	93.8	94.9897	-1.1897	-1.26834

5.6.5. REGRESSION OUTPUT FOR “EXHAUST”

R-Square = 0.372

Std. error = 4.1754

Constant = 82.1850

Equation: SPL at “EXHAUST” (dB (A)) = 82.1850 + 0.2297 * C.R. + 0.2658 * LOAD

Table no.5 Regression output for “EXHAUST”

C.R.	**LOAD**	**Measured SPL at “EXHAUST” (dB(A))**	**Predicted SPL at "EXHAUST" (dB(A))**	**ERROR (dB(A))**	% ERROR
12	0	84.9	84.9414	-0.0414	-0.04876
12	1	86.2	85.2072	0.9928	1.15174
12	2	88.3	85.473	2.827	3.201586
12	3	86.1	85.7388	0.3612	0.419512
12	4	85.9	86.0046	-0.1046	-0.12177
12	5	86.1	86.2704	-0.1704	-0.19791
12	6	86.3	86.5362	-0.2362	-0.2737
12	7	88.3	86.802	1.498	1.696489
12	8	88.5	87.0678	1.4322	1.618305
12.5	0	82.4	85.05625	-2.65625	-3.2236
12.5	1	82.2	85.32205	-3.12205	-3.79811
12.5	2	82.3	85.58785	-3.28785	-3.99496
12.5	3	82.7	85.85365	-3.15365	-3.81336
12.5	4	83.1	86.11945	-3.01945	-3.63351
12.5	5	84.4	86.38525	-1.98525	-2.35219
12.5	6	85.7	86.65105	-0.95105	-1.10974
12.5	7	86.2	86.91685	-0.71685	-0.83161
12.5	8	87	87.18265	-0.18265	-0.20994
13	0	77.2	85.1711	-7.9711	-10.3253
13	1	78.4	85.4369	-7.0369	-8.97564
13	2	79.9	85.7027	-5.8027	-7.26245
13	3	80.8	85.9685	-5.1685	-6.39666
13	4	82.2	86.2343	-4.0343	-4.90791
13	5	83.7	86.5001	-2.8001	-3.3454
13	6	85.5	86.7659	-1.2659	-1.48058
13	7	85.9	87.0317	-1.1317	-1.31746
13	8	86.5	87.2975	-0.7975	-0.92197

13.5	0	80.4	85.28595	-4.88595	-6.07705
13.5	1	82	85.55175	-3.55175	-4.3314
13.5	2	82.1	85.81755	-3.71755	-4.52808
13.5	3	82.8	86.08335	-3.28335	-3.9654
13.5	4	83.4	86.34915	-2.94915	-3.53615
13.5	5	85.1	86.61495	-1.51495	-1.7802
13.5	6	85.8	86.88075	-1.08075	-1.25962
13.5	7	86.7	87.14655	-0.44655	-0.51505
13.5	8	86.2	87.41235	-1.21235	-1.40644
14	0	90.2	85.4008	4.7992	5.320621
14	1	95.3	85.6666	9.6334	10.1085
14	2	100.8	85.9324	14.8676	14.7496
14	3	97.7	86.1982	11.5018	11.77257
14	4	94.5	86.464	8.036	8.503704
14	5	91.3	86.7298	4.5702	5.005696
14	6	92.4	86.9956	5.4044	5.848918
14	7	90.7	87.2614	3.4386	3.79118
14	8	89.9	87.5272	2.3728	2.639377
14.5	0	80.2	85.51565	-5.31565	-6.62799
14.5	1	84	85.78145	-1.78145	-2.12077
14.5	2	85.1	86.04725	-0.94725	-1.1131
14.5	3	86.6	86.31305	0.28695	0.331351
14.5	4	87.2	86.57885	0.62115	0.712328
14.5	5	86.2	86.84465	-0.64465	-0.74785
14.5	6	88.2	87.11045	1.08955	1.235317
14.5	7	89.3	87.37625	1.92375	2.154255
14.5	8	81.1	87.64205	-6.54205	-8.06665
15	0	83.4	85.6305	-2.2305	-2.67446
15	1	88.6	85.8963	2.7037	3.05158
15	2	95.8	86.1621	9.6379	10.06044
15	3	103.2	86.4279	16.7721	16.25203
15	4	93.1	86.6937	6.4063	6.881096
15	5	89.8	86.9595	2.8405	3.16314
15	6	88.4	87.2253	1.1747	1.328846
15	7	89.1	87.4911	1.6089	1.805724
15	8	84.7	87.7569	-3.0569	-3.60909
15.5	0	86	85.74535	0.25465	0.296105
15.5	1	86.8	86.01115	0.78885	0.908813
15.5	2	87.6	86.27695	1.32305	1.510331
15.5	3	88.2	86.54275	1.65725	1.878968
15.5	4	89.7	86.80855	2.89145	3.223467

15.5	5	89.8	87.07435	2.72565	3.035245
15.5	6	90.7	87.34015	3.35985	3.704355
15.5	7	92	87.60595	4.39405	4.776141
15.5	8	86.9	87.87175	-0.97175	-1.11824
16	0	85.9	85.8602	0.0398	0.046333
16	1	86.5	86.126	0.374	0.43237
16	2	87	86.3918	0.6082	0.69908
16	3	87.5	86.6576	0.8424	0.962743
16	4	88.3	86.9234	1.3766	1.559003
16	5	89	87.1892	1.8108	2.034607
16	6	89.7	87.455	2.245	2.502787
16	7	90.8	87.7208	3.0792	3.391189
16	8	79.2	87.9866	-8.7866	-11.0942
16.5	0	86.7	85.97505	0.72495	0.836159
16.5	1	87	86.24085	0.75915	0.872586
16.5	2	85.2	86.50665	-1.30665	-1.53363
16.5	3	87.7	86.77245	0.92755	1.05764
16.5	4	87.8	87.03825	0.76175	0.867597
16.5	5	88.2	87.30405	0.89595	1.015816
16.5	6	87	87.56985	-0.56985	-0.655
16.5	7	87.1	87.83565	-0.73565	-0.8446
16.5	8	83	88.10145	-5.10145	-6.14633
17	0	84.9	86.0899	-1.1899	-1.40153
17	1	85.8	86.3557	-0.5557	-0.64767
17	2	86.3	86.6215	-0.3215	-0.37254
17	3	88.3	86.8873	1.4127	1.599887
17	4	85.9	87.1531	-1.2531	-1.45879
17	5	88.8	87.4189	1.3811	1.555293
17	6	89.6	87.6847	1.9153	2.137612
17	7	89.2	87.9505	1.2495	1.400785
17	8	80.3	88.2163	-7.9163	-9.85841
17.5	0	80.3	86.20475	-5.90475	-7.35336
17.5	1	80.9	86.47055	-5.57055	-6.88572
17.5	2	78.4	86.73635	-8.33635	-10.6331
17.5	3	81	87.00215	-6.00215	-7.41006
17.5	4	88.1	87.26795	0.83205	0.944438
17.5	5	90.7	87.53375	3.16625	3.490904
17.5	6	87.1	87.79955	-0.69955	-0.80316
17.5	7	86.5	88.06535	-1.56535	-1.80965
17.5	8	87.1	88.33115	-1.23115	-1.41349
18	0	90.3	86.3196	3.9804	4.407973

18	1	86.4	86.5854	-0.1854	-0.21458
18	2	86.6	86.8512	-0.2512	-0.29007
18	3	85.5	87.117	-1.617	-1.89123
18	4	92.5	87.3828	5.1172	5.532108
18	5	83.6	87.6486	-4.0486	-4.84282
18	6	85.3	87.9144	-2.6144	-3.06495
18	7	87	88.1802	-1.1802	-1.35655
18	8	87.4	88.446	-1.046	-1.1968

5.6.6. REGRESSION OUTPUT FOR “ACOUSTIC POWER”

R-Square = 0.5325

Std. error = 1.0455

Constant = 92.1148

Equation: SPL of “ACOUSTIC POWER” (dB (A) ref. to 10^{-12} watt)

= 92.1148 + 0.0143 * C.R. + 0.4264 * LOAD

Table no.6 Regression output for “ACOUSTIC POWER”

C.R.	LOAD	Measured SPL “ACOUSTIC POWER”	Predicted SPL of "ACOUSTIC POWER"	ERROR (dB (A) ref. to 10^{-12} watt)	% ERROR
12	0	90.17	92.2864	-2.1164	-2.34712
12	1	91.17	92.7128	-1.5428	-1.69222
12	2	92.29	93.1392	-0.8492	-0.92014
12	3	93.99	93.5656	0.4244	0.451537
12	4	94.69	93.992	0.698	0.737142
12	5	95.47	94.4184	1.0516	1.101498
12	6	95.76	94.8448	0.9152	0.955723
12	7	96.41	95.2712	1.1388	1.181205
12	8	96.11	95.6976	0.4124	0.429092

12.5	0	91.26	92.29355	-1.03355	-1.13253
12.5	1	92.13	92.71995	-0.58995	-0.64035
12.5	2	93.8	93.14635	0.65365	0.696855
12.5	3	95	93.57275	1.42725	1.502368
12.5	4	95.57	93.99915	1.57085	1.643664
12.5	5	95.96	94.42555	1.53445	1.599052
12.5	6	95.99	94.85195	1.13805	1.185592
12.5	7	96.29	95.27835	1.01165	1.050628
12.5	8	96.15	95.70475	0.44525	0.463079
13	0	89.69	92.3007	-2.6107	-2.9108
13	1	91.44	92.7271	-1.2871	-1.40759
13	2	92.56	93.1535	-0.5935	-0.64121
13	3	95	93.5799	1.4201	1.494842
13	4	95.63	94.0063	1.6237	1.697898
13	5	94.71	94.4327	0.2773	0.292789
13	6	91.24	94.8591	-3.6191	-3.96657
13	7	95.77	95.2855	0.4845	0.5059
13	8	95.63	95.7119	-0.0819	-0.08564
13.5	0	90.19	92.30785	-2.11785	-2.34821
13.5	1	90.67	92.73425	-2.06425	-2.27666
13.5	2	92.1	93.16065	-1.06065	-1.15163
13.5	3	93.33	93.58705	-0.25705	-0.27542
13.5	4	94.26	94.01345	0.24655	0.261564
13.5	5	94.99	94.43985	0.55015	0.579166
13.5	6	95.68	94.86625	0.81375	0.850491
13.5	7	95.82	95.29265	0.52735	0.550355
13.5	8	95.9	95.71905	0.18095	0.188686
14	0	91.57	92.315	-0.745	-0.81359
14	1	92.92	92.7414	0.1786	0.192208
14	2	93.9	93.1678	0.7322	0.779766
14	3	94.96	93.5942	1.3658	1.43829
14	4	94.86	94.0206	0.8394	0.884883
14	5	95.27	94.447	0.823	0.863861
14	6	95.26	94.8734	0.3866	0.405837
14	7	95.46	95.2998	0.1602	0.167819
14	8	95.2	95.7262	-0.5262	-0.55273
14.5	0	91.61	92.32215	-0.71215	-0.77737
14.5	1	92.8	92.74855	0.05145	0.055442
14.5	2	93.51	93.17495	0.33505	0.358304
14.5	3	94.54	93.60135	0.93865	0.99286
14.5	4	95.19	94.02775	1.16225	1.220979

14.5	5	95.33	94.45415	0.87585	0.918756
14.5	6	95.51	94.88055	0.62945	0.659041
14.5	7	95.64	95.30695	0.33305	0.348233
14.5	8	95.21	95.73335	-0.52335	-0.54968
15	0	91.71	92.3293	-0.6193	-0.67528
15	1	92.79	92.7557	0.0343	0.036965
15	2	93.49	93.1821	0.3079	0.32934
15	3	94.4	93.6085	0.7915	0.838453
15	4	94.88	94.0349	0.8451	0.890704
15	5	95.46	94.4613	0.9987	1.046197
15	6	95.2	94.8877	0.3123	0.328046
15	7	89.88	95.3141	-5.4341	-6.04595
15	8	95.11	95.7405	-0.6305	-0.66292
15.5	0	91.93	92.33645	-0.40645	-0.44213
15.5	1	92.63	92.76285	-0.13285	-0.14342
15.5	2	93.42	93.18925	0.23075	0.247003
15.5	3	93.82	93.61565	0.20435	0.217811
15.5	4	94.41	94.04205	0.36795	0.389736
15.5	5	94.66	94.46845	0.19155	0.202356
15.5	6	94.66	94.89485	-0.23485	-0.2481
15.5	7	94.58	95.32125	-0.74125	-0.78373
15.5	8	94.21	95.74765	-1.53765	-1.63215
16	0	91.8	92.3436	-0.5436	-0.59216
16	1	92.3	92.77	-0.47	-0.50921
16	2	93.23	93.1964	0.0336	0.03604
16	3	93.85	93.6228	0.2272	0.242088
16	4	94.21	94.0492	0.1608	0.170683
16	5	94.42	94.4756	-0.0556	-0.05889
16	6	94.6	94.902	-0.302	-0.31924
16	7	94.61	95.3284	-0.7184	-0.75933
16	8	94.05	95.7548	-1.7048	-1.81265
16.5	0	91.93	92.35075	-0.42075	-0.45769
16.5	1	92.44	92.77715	-0.33715	-0.36472
16.5	2	93.26	93.20355	0.05645	0.06053
16.5	3	93.81	93.62995	0.18005	0.19193
16.5	4	94.2	94.05635	0.14365	0.152495
16.5	5	94.78	94.48275	0.29725	0.313621
16.5	6	94.81	94.90915	-0.09915	-0.10458
16.5	7	94.7	95.33555	-0.63555	-0.67112
16.5	8	94.13	95.76195	-1.63195	-1.73372
17	0	92.56	92.3579	0.2021	0.218345

17	1	93.19	92.7843	0.4057	0.435347
17	2	93.71	93.2107	0.4993	0.532814
17	3	94.26	93.6371	0.6229	0.660832
17	4	94.41	94.0635	0.3465	0.367016
17	5	94.99	94.4899	0.5001	0.526476
17	6	95.22	94.9163	0.3037	0.318946
17	7	95.19	95.3427	-0.1527	-0.16042
17	8	94.72	95.7691	-1.0491	-1.10758
17.5	0	93.07	92.36505	0.70495	0.757441
17.5	1	93.44	92.79145	0.64855	0.694082
17.5	2	94.14	93.21785	0.92215	0.979552
17.5	3	94.48	93.64425	0.83575	0.884579
17.5	4	94.83	94.07065	0.75935	0.800749
17.5	5	95.09	94.49705	0.59295	0.623567
17.5	6	95.44	94.92345	0.51655	0.54123
17.5	7	95.24	95.34985	-0.10985	-0.11534
17.5	8	95.13	95.77625	-0.64625	-0.67933
18	0	92.93	92.3722	0.5578	0.600237
18	1	93.44	92.7986	0.6414	0.68643
18	2	94.1	93.225	0.875	0.929862
18	3	94.05	93.6514	0.3986	0.423817
18	4	94.2	94.0778	0.1222	0.129724
18	5	94.38	94.5042	-0.1242	-0.1316
18	6	94.68	94.9306	-0.2506	-0.26468
18	7	94.95	95.357	-0.407	-0.42865
18	8	94.36	95.7834	-1.4234	-1.50848

5.7. RESULTS AND DISCUSSIONS

An analysis of the collected data indicates the following:

1. It is found that the maximum sound pressure level is for point C as compared to A, B and D. SPL is maximum at point C, which is 96.5 dB (A) at load 6 Kg and C.R.18. shown in Fig.5.8
2. Maximum SPL is at EXHAUST, which is 103.2 dB (A) at load 4 Kg and C.R.15.SPL is maximum at exhaust because the exhaust is going outside the wall to the open area. As the silencer is inside and there is a long pipe of small diameter to get the smoke out

of the laboratory, due to contraction of diameter of exhaust pipe, the sound pressure level is high.

3. It is found that the maximum sound pressure level for point A is 90.9 dB (A) for compression ratio 12 and at load 8 Kg and the minimum sound pressure is 82.8 dB (A) for compression ratio 13 and at load 0 Kg, shown in Fig.5.1.
4. It is found that the maximum sound pressure level for point B is 95.1 dB (A) for compression ratio 14 and at load 8 Kg and the minimum sound pressure is 86.2 dB (A) for compression ratio 13.5 and at load 0 Kg, shown in Fig.5.2.
5. The maximum sound pressure level for point D is 96 dB (A) for compression ratio 17.5 and at load 6 Kg & load 7 Kg and the minimum sound pressure is 86 dB (A) for compression ratio 13.5 and at load 0 Kg, shown in Fig.5.4.
6. It is found that the minimum sound pressure level is for point A as compared to B, C and D. This is because the point A is farthest point as compared to points B, C & D.
7. Acoustic power is maximum at load 7 Kg, C.R.12, which is 96.41 dB (A). It is minimum at load 0 Kg, C.R.13 i.e. 89.69 dB (A) shown in Fig.5.11 & Fig.5.12.
8. Acoustic power increases as load increases for all Compression ratios. This is due to as the load varies the rpm of the engine decreases and the value of sound pressure level increases at all grid points.
9. The value of Acceleration varies from 0 to 4.52 ms^{-2}. Its value is maximum at load 2 Kg, C.R.15 at 1000 Hz shown in Fig.5.21 and minimum at load 0 Kg, C.R.18 at 31.5 Hz frequency shown in Fig.5.20.
10. The value of Velocity varies from 0.03 to 0.94 mms^{-1}. Its value is maximum at load 6 Kg, C.R.16 at 500 Hz frequency shown in Fig.5.29 & Fig.5.35 and minimum at load 0 Kg, C.R.12 at 2000 Hz frequency shown in Fig.5.25 & Fig.5.32.
11. The value of Displacement varies from 0 to 1.1 µm. Its value is maximum at load 8 Kg, C.R.18 at 31.5 Hz frequency and minimum above 250 Hz at all compression ratios.
12. The value of SPL in frequency spectrum is maximum at load 8 Kg, C.R.15 is 93.3 dB(A) at 125 Hz frequency shown in Fig.5.40 and minimum at load 4 Kg, C.R.16 is 54.7 dB(A) at 31.5 Hz frequency shown in Fig.5.41.

13. The regression analysis done at point A,B,C,D, EXHAUST & for the ACOUSTIC POWER of the engine. The equations are generated for these points are as follows:

- ✓ SPL at point "A" (dB (A)) = 86.6672 - 0.038 * C.R. + 0.4423 * LOAD
- ✓ SPL at point "B" (dB (A)) = 88.0054 + 0.0806 * C.R. + 0.5512 * LOAD
- ✓ SPL at point "C" (dB (A)) = 85.7070 + 0.3289 * C.R. + 0.3891 * LOAD
- ✓ SPL at point "D" (dB (A)) = 83.2169 + 0.4328 * C.R. + 0.4978 * LOAD
- ✓ SPL at "EXHAUST" (dB (A)) = 82.1850 + 0.2297 * C.R. + 0.2658 * LOAD
- ✓ SPL of "ACOUSTIC POWER" (dB (A) ref. to 10^{-12} watt)

  = 92.1148 + 0.0143 * C.R. + 0.4264 * LOAD

14. From the regression analysis there is calculation of error calculated between measured value and predicted value is lying in range is as follows:

- ✓ For point A = The error lies in the range -3.3719 dB (A) for load 0 Kg at compression ratio 13 to 3.1315 for dB (A) for load 4 Kg at compression ratio 15.
- ✓ For point B = The error lies in the range -3.2007 dB (A) for load 6 Kg at compression ratio 13.5 to 2.4311 for dB (A) for load 5 Kg at compression ratio 12.5.
- ✓ For point C = The error lies in the range -11.5822 dB (A) for load 8 Kg at compression ratio 16 to 3.01355 for dB (A) for load 7 Kg at compression ratio 17.5.
- ✓ For point D = The error lies in the range -4.2077 dB (A) for load 8 Kg at compression ratio 15.5 to 2.4201 for dB (A) for load 5 Kg at compression ratio 17.5.
- ✓ For Exhaust = The error lies in the range -8.7866 dB (A) for load 8 Kg at compression ratio 16 to 16.7721 for dB (A) for load 3 Kg at compression ratio 15.
- ✓ For Acoustic power = The error lies in the range -5.4341 dB (A) for load 7 Kg at compression ratio 15 to 1.6237 for dB (A) for load 4 Kg at compression ratio 13.

15. The percentage error of measured value and predicted value for point A lies in the range -4.07% to 3.44%.

16. The percentage error of measured value and predicted value for point B lies in the range -3.58% to 2.58%.
17. The percentage error of measured value and predicted value for point C lies in the range -14.03% to 3.1%.
18. The percentage error of measured value and predicted value for point D lies in the range -4.69% to 2.52%.
19. The percentage error of measured value and predicted value for EXHAUST lies in the range -11.09% to 0.0016%.
20. The percentage error of measured value and predicted value for ACOUSTIC POWER lies in the range -6.04% to 1.69%.
21. The value of R^2 for Exhaust is very low. Its value is 0.372.

CHAPTER 6

CONCLUSION AND SCOPE FOR FUTURE WORK

6.1. CONCLUSION

The object of the present work is to collect the data based on two parameters i.e. compression ratio and load.

From the present study following conclusions are drawn:

a) The maximum sound pressure level near the engine is at point "C" is 96.5 dB (A) at load 6 Kg and C.R.18 shown in fig.5.8 and the maximum sound pressure level is at EXHAUST is 103.2 dB (A) at load 4 Kg and C.R.15.

b) Acoustic power increases as load increases for all Compression ratios.

c) Maximum acceleration is 4.52 ms^{-2} at 1000 Hz. After 1000 Hz the acceleration starts decreasing so there is need to concentrate on low frequencies.

d) Maximum velocity is 0.94 mms^{-1} at 500 Hz. There is also need to concentrate on low frequencies

e) The value of SPL in frequency spectrum is maximum at point C at load 8 Kg, C.R.15 is 93.3 dB(A) at 125 Hz shown in Fig.5.40.to get the more clearer picture of frequency spectrum consider more on low frequencies as there are variations at low frequencies.

f) R^2 value ranges from 0.3723 to 0.58 for different equations of point A, B, C, D and Exhaust and for Acoustic power. As the R^2 value of 0.7 – 1 indicate a very good correlation between the observed and estimated data sets. The value of R^2 can be improved by incorporating variations by taking number of different compression ratios and taking variations in loads for more number of sets.

g) The more the data is finer the results are plotted.

6.2. SCOPE FOR FUTURE WORK

The present work may be extended in one of the following direction:

a) All the measurements can be repeated at least 2-3 times to cover more variations for varying parameters and to get better results.

b) Result can be identified better by using Intensity probe. By this identify the point from which part of the engine the most sound pressure level is generated and identify the cause make certain changes and see the effect on sound pressure level.

c) There are different fuels in the use today, use the different fuels like Biofuels etc. and verify the results.

d) To get the proper results, the foundation of the engine should be properly designed.

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APPENDIX-A

1. OBSERVATIONS IN SPL (dB(A)) FOR VARYING COMPRESSION RATIOS AND LOADS

Table no.7 for C.R. 12

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 12									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	82.9	85.2	85.2	87.9	89.4	89.8	90.1	91	90.9
B	86.6	89.8	89.7	91.7	90.9	93.1	93.5	94.8	92.4
C	88.7	87.8	89.8	90	90.8	92.8	94.4	93.8	93.4
D	87.4	86.8	90	90.1	90.6	92.4	93.3	92.5	93.2
EXHAUST	84.9	86.2	88.3	86.1	85.9	86.1	86.3	88.3	88.5
GRID POINTS									
1	80.5	80.9	82.2	84.7	85.5	86.6	86.8	87	87.2
2	80.7	81.7	83.5	84.2	85.3	86.7	86.8	87.5	87.5
3	79.9	81.3	84.1	85.4	86.1	86.3	86.4	86.7	87.2
4	84	83.7	85.1	86.2	86.7	87.6	88.1	87.7	88.1
5	82.7	84.3	85	87.3	88.1	87.9	88.1	88.6	82.4
6	84	84.8	85.9	87.6	88.5	88.5	88.3	89.9	89.9
7	82.6	84.7	84.5	86.2	87.5	88.7	88.7	88.4	89.6
8	82.2	83.1	84.3	86.5	87	87.6	88.6	88.7	88.9
9	83.6	84.5	85.5	87.6	87.7	88	88.8	90.1	90.7
10	79.8	81.6	83.2	84.3	85.2	85.8	85.8	86.1	87.2
11	80.9	82.9	84	85.3	85.2	87.1	87	87.7	87.5
12	80	80.7	82	84.2	84.9	86	86.1	88.9	86.3

13	84.5	84.8	85.6	86.6	86.9	87.8	89.1	89.6	89.2
14	83.4	83.4	84.7	86.2	87.8	89.4	89.1	91.3	89.7
15	82.9	84.4	84.8	88.5	88.9	88.9	88.5	87.8	90.2
16	82.8	84	85.3	86.7	87.4	87.1	87.6	87.6	87.9
17	86.1	86.8	81.6	89.3	89.6	90.6	91.8	91.4	92.1
Ls	**82.38**	**83.38**	**84.5**	**86.2**	**86.9**	**87.68**	**87.97**	**88.62**	**88.32**

Table no.8 for C.R. 12.5

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 12.5									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	84.4	85.8	86.9	88.5	89.9	90.5	90.2	89.3	88.8
B	86.5	88.4	90.9	91.9	92.1	94.2	93.8	91.5	92.6
C	88.3	89.6	89.7	92.8	92.6	93.8	94.3	94.4	93.6
D	88.3	90.2	90.1	91.5	92.1	92.9	92.5	92.6	93
EXHAUST	82.4	82.2	82.3	82.7	83.1	84.4	85.7	86.2	87
GRID POINTS									
1	81.8	83.7	85.2	85.1	88.5	87.2	87.3	87.4	88.1
2	82.7	82.2	83.9	85	86.6	87.5	87.3	87.8	86.4
3	82.3	83.9	85.3	85.9	86.7	87.6	86.3	87	87
4	83.7	84.8	86.6	86.7	88.2	88.6	88.7	88.7	89.2
5	84.3	85.5	86.7	87.9	88.8	89	89.1	89.3	88.2
6	84.5	85.1	86.8	88.7	88.7	90.6	89.3	89.9	89.1
7	84	85.2	87.8	87.8	88.5	88.5	89	89.9	89.5
8	83	84.3	86.6	87.1	87.6	87.7	87.7	87.8	87.8
9	84.7	85.7	86.8	88.7	88.8	90	89.5	86.8	89.7
10	81.4	82.4	84.5	84.9	86	86.6	86.8	90.1	87.6
11	83.4	84.2	85.5	86.6	86.9	87.5	86.9	88	86.8
12	81.4	82.3	83.4	85.3	85.7	86.6	86.1	86.6	85.3
13	84.5	85.6	86.5	87.8	88.4	88.7	88.6	88.5	88.6
14	83.5	85	86.6	87.5	89.4	87.8	88.1	88	87.7
15	83.9	85.7	86.3	89.1	88.6	88.4	88.8	88.8	89.2
16	83.5	84.3	86.9	88.7	87.3	88	88.8	89.6	87.2
17	86.5	84	86.9	88.9	88.6	89.3	91.2	91.9	91.8
Ls	**83.47**	**84.34**	**86.01**	**87.21**	**87.78**	**88.17**	**88.2**	**88.5**	**88.36**

Table no.9 for C.R. 13

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 13									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	82.8	84.5	84.2	86.4	88.4	88.1	89.6	88.9	89.3
B	86.6	87.5	89.6	90.5	92.1	91.8	92.3	94.1	94.1
C	87.6	90	90.2	92.2	92.8	94.1	93.5	94.3	93.9
D	88.8	89.6	90.6	91.8	93	92.8	92.2	92.5	92.6
EXHAUST	77.2	78.4	79.9	80.8	82.2	83.7	85.5	85.9	86.5
GRID POINTS									
1	80.5	81.7	82.1	83.6	85.3	85.6	86.1	86.5	85.6
2	80.6	81.7	83	84.4	85.4	85.5	86.8	87.7	86.1
3	80.9	81.8	83.2	84.7	87.7	86.4	86.8	85.9	86.1
4	82.8	84.1	85	86.8	86.9	87.4	88	88.2	87.8
5	82.6	84.8	84.7	85.6	87.2	86.7	88.9	88.4	88.6
6	83.8	84.8	86.4	87.5	88.5	88.1	88.9	89.7	90.4
7	82.6	84.2	84.8	86.3	87.5	87.1	89.1	88.6	88.8
8	81.7	82.8	85.2	85.2	85.5	86.4	87.8	87.6	89.3
9	83.6	85	85.9	86.4	88	88.8	89.5	89.1	89.6
10	74.2	80.8	82.7	83.1	85.1	84.5	85.9	85.5	86.7
11	81	82.2	83.6	84.8	85.5	86.1	87.3	86.7	86.7
12	80.1	81.2	82.7	83.8	85.3	84.7	88.1	85.9	85.4
13	84.3	84.9	86.4	87	87.8	88.5	89.4	88.8	88.8
14	82.1	84	84.9	86.2	87	87	87.6	87.4	87.3
15	82.6	84.1	86	86.4	86.4	86.7	89.4	89	87.5
16	83.7	84.5	85.4	85.9	86.2	86.6	87.8	88.1	87.6
17	85.3	88.4	89.1	89.2	91	91	91.3	92.7	91.1
Ls	**81.9**	**83.65**	**84.77**	**87.21**	**87.84**	**86.92**	**83.45**	**87.98**	**87.84**

Table no.10 for C.R. 13.5

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 13.5									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	83.1	84.1	84.2	86.1	88.3	88.6	89	89.7	89.7
B	86.2	87.6	88.7	88.3	91.3	89	89.2	91	93
C	87.4	88.6	89.7	90.5	90.8	92.1	91.8	93.1	92.9
D	86	87.4	88.8	90.1	90.9	91	92.2	92.7	93.3
EXHAUST	80.4	82	82.1	82.8	83.4	85.1	85.8	86.7	86.2
GRID POINTS									
1	82.3	80.9	84.5	85	85.9	85.6	87.6	87.1	88.1
2	81.3	82	82.8	83.8	85.5	85.3	87.1	86.6	87.1
3	80.3	81.5	83.1	84.6	86.4	85.6	86.9	87.1	87.3
4	82.4	82.7	84	87.4	86.6	87.1	87.8	87.7	88
5	83.1	83.3	84.9	85.7	86.9	87.9	88.6	89.7	88.8
6	86.3	84.2	84.9	85.9	87.9	87.8	88.1	89.1	89.8
7	82.7	83.7	85	85.9	86.6	87.7	88.5	88.6	88
8	81.8	82.8	84.8	85.3	85.6	86.4	87.4	87.4	87.4
9	84.1	83.6	85.5	86.4	87.8	88.4	89.1	89.5	89.7
10	83.2	81.2	82.3	83.9	84.7	85.3	85.5	86.6	86.4
11	80.6	82.6	83.7	85.4	86.6	86.9	88	87.5	88.6
12	79.6	80.9	82.5	84.2	84.3	85.2	86.6	86.7	86
13	82.7	84.2	84.7	86.2	87.2	87.7	87.9	88.7	88.7
14	82.8	82.9	84.4	85	86.7	87.3	87.9	88.4	87.8
15	82.7	83.4	84.8	86	87.3	87.5	89.6	89	89.2
16	82.6	83.3	85.1	86.5	86.6	87.4	87.9	87.9	87.8
17	82.3	85.9	86.3	87	87.4	90.3	89.7	89	89.3
Ls	**82.4**	**82.88**	**84.31**	**85.54**	**86.47**	**87.2**	**87.89**	**88.03**	**88.11**

Table no.11 for C.R. 14

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 14									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	86.6	88.5	87.4	89.1	88.5	89.1	89.6	90	89.7
B	89.8	89.3	91.6	92.8	93.2	94.2	93.1	93.9	95.1
C	90.5	89.8	91.5	92.5	93.1	93.5	92.9	92.7	93.9
D	88.5	91.2	91.9	92.5	92.9	93.4	93	93.2	92.4
EXHAUST	90.2	95.3	100.8	97.7	94.5	91.3	92.4	90.7	89.9
GRID POINTS									
1	81.5	82.5	83.8	84.9	84.9	85.1	85.6	85.6	85.2
2	82.6	84.4	84.8	85.9	85.7	86.8	86.4	86.1	85.5
3	82.2	85.6	85.7	85.9	86.1	86	86.3	87.2	85.7
4	82.9	85.1	86	87.7	87.8	87	87	88.1	87.4
5	84.5	85.3	85.9	87.3	88.6	87.9	87.8	87.4	88.2
6	85.3	84.6	87.3	88.7	87.7	88.1	88.8	88.1	89.4
7	84	84.4	85.7	87.8	87.9	87.8	88.9	88.7	89.5
8	83.3	85.4	86.3	86.6	86.7	87.5	86.8	87.9	86.7
9	84.5	86	86.9	87.5	87.4	88.2	88	87.9	88.2
10	82.2	82.4	84.5	85.6	85.6	85.7	85.9	86	84.7
11	83.5	85.9	86.3	86.9	86.7	87.5	86.9	87.3	86.9
12	81.9	82.8	84.3	85.1	84.7	86.2	85.9	86	85.6
13	85.1	86.5	86.9	88.3	88.5	88.6	88.4	88.2	88.6
14	84.7	86.1	86.5	87.5	87.4	87.6	88	88.9	87.4
15	84.5	86.6	86.3	87.6	87.8	87.6	88.2	88	88.1
16	84.3	85.1	86.6	87.4	87.7	87.6	87.2	87.9	87.4
17	87.4	88.6	90.1	91.2	89.1	92	90.9	91.1	91.6
Ls	**83.78**	**85.13**	**86.11**	**87.17**	**87.07**	**87.48**	**87.47**	**87.67**	**87.41**

Table no.12 for C.R. 14.5

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 14.5									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	87.2	86.7	88.1	89.3	88.2	88.3	88.1	89.3	89.2

B	89.3	90.1	91.2	92.4	92.5	93.2	93.3	93.7	93.4
C	88.1	90.4	90.5	91.6	94.7	91.8	93.2	91.8	90.5
D	86.5	88.9	89.8	91.3	91.2	91.1	91.9	92.4	92.1
EXHAUST	80.2	84	85.1	86.6	87.2	86.2	88.2	89.3	91.9
GRID POINTS									
1	89.1	84	84.7	85.4	85.8	85.7	86.2	86.9	85.5
2	82.6	83.6	84.8	85.2	86.2	86.9	86.8	86.2	86.3
3	83.2	84	85.2	86.3	86.8	85.8	87.6	86.6	86.4
4	83.2	85.4	86.3	87.4	87.6	87.9	87.5	87.5	87.8
5	84.3	84.4	85.9	87.1	87.1	87.7	88.1	88.9	88.1
6	84.5	84.7	86.3	88.2	89.1	89.3	88.1	88.7	89.8
7	84.5	84.8	85.7	87.8	88.8	87.5	89.1	88.2	88.9
8	83.4	89.8	88.1	86.1	86.6	88.6	87.2	87.8	86.4
9	85.3	84.5	87.1	88.5	89.4	89.5	90	88.6	89.7
10	81.7	83.2	83.9	85.2	87.7	88.4	86.3	86.9	85.8
11	83.4	84.7	85.2	86.1	86.3	88.3	87.7	87.2	85.7
12	81.1	82.5	83.1	85.3	85.5	85.5	85.8	87.2	85.5
13	84.6	85.7	86.3	87.4	87.5	85.9	88	88.6	85.5
14	84.5	84.9	85.2	86.6	86.9	88.1	87.6	88.1	89.1
15	84.5	85.8	86.1	86.9	87.5	87.7	88.2	88.2	88.6
16	83.7	84.6	85.3	86.3	87.2	86.6	86.7	87.1	87.1
17	86.5	87.6	88.1	89.1	89.8	89.9	90.5	90.8	90.1
Ls	**83.82**	**85.01**	**85.72**	**86.75**	**87.4**	**87.54**	**87.72**	**87.85**	**87.42**

Table no.13 for C.R. 15

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 15									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	86.4	88.1	89.2	89.5	91	88.7	89.2	89.5	90.1
B	89.5	90.5	91.6	92.1	92.5	92.4	93.1	93.4	93
C	90.7	91.2	91.6	93.7	93	94.1	93.4	93.3	92.9
D	87.3	88.9	90.5	92	92.4	93.2	92.4	92.9	92.4

EXHAUST	81.1	83.4	88.6	95.8	103.2	93.1	89.8	88.4	89.1
GRID POINTS									
1	80.7	83.1	84	84.4	85.2	85.7	85.4	84.8	84.5
2	83.1	85.8	84.2	84.6	86	86.8	86.4	86.2	87.3
3	85.1	85	85.8	85.5	85.7	86.1	85.6	85.8	86.4
4	84	84.2	85.9	85.9	86.3	86.4	86.2	85.7	86
5	84.7	84.7	86.2	87.2	89.7	90.4	88.8	89	89.3
6	83.7	84.8	85.6	87.6	88	89	88.8	89.1	88.6
7	83.8	85.4	86.3	87.3	87.3	88.8	88.8	88.5	88.4
8	82.8	86.4	85.3	86.4	86.7	87.5	87.3	86.6	87.2
9	84.7	86.5	87	87.8	88.3	88.6	88.2	88.6	89.1
10	81.2	82.5	83.2	85.4	85.4	85.4	85.1	85.5	85.1
11	82.7	84.2	85.7	86.3	86.3	87.5	86.7	87	86.3
12	85.1	85.5	86.2	85.3	85.2	85.5	86.4	85.7	85.2
13	86	85.8	87	87.3	87.6	87.5	87.8	87.7	87.6
14	84.3	84.8	86.3	86.1	87.7	88.1	86.8	87.1	87.5
15	83.6	84.7	86.3	86.7	87.9	88	88.3	87.9	87.3
16	83.7	85	85.9	87.6	87.2	87.4	87.5	87.5	87.5
17	87.5	81.3	86.1	91.1	90.1	91.8	91.9	91.5	91.2
Ls	**83.92**	**85**	**85.7**	**86.61**	**87.09**	**87.67**	**87.41**	**82.09**	**87.32**

Table no.14 for C.R. 15.5

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 15.5									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	84.7	87.5	87.4	87.7	88.2	89.2	88.4	88.7	88.7
B	90.2	89.4	91.4	91.3	91.3	92.3	91.3	91.5	91.6
C	90.4	90.4	92.1	92.2	92.8	92.5	93.1	91.4	90.8
D	88.6	88.6	90.4	90.9	90.8	91.2	90.8	90.9	89.7
EXHAUST	84.7	86	86.8	87.6	88.2	89.7	89.8	90.7	92
GRID POINTS									

1	83.5	83.1	84.1	84.3	85.8	84.6	84.9	85.3	85.6
2	83.5	83.9	84	85.1	85.8	86.1	85.7	86.2	85.3
3	83.8	84.1	84.5	84.9	85.1	85.4	85.1	84.9	84.8
4	84.2	84.4	85.2	85.5	86.8	87.1	87.2	86.2	86.1
5	84.2	85.9	87.5	86.7	86.6	86.7	86.9	89.2	86.5
6	84.3	85.3	86.7	86.8	87.1	87.7	88.1	87.9	87
7	84.2	84.8	86.2	86.6	87.3	7.2	88.4	88	87.5
8	83.9	83.9	85	85.2	86.4	86.5	86.3	86.3	86.4
9	86	86.6	87.4	87.6	87.8	88.8	88.7	87.8	88
10	82.7	83.3	84.6	85.2	85.4	85.2	86.3	84.9	84.9
11	83.8	85	85.6	85.7	86.8	86.6	86.7	86.6	86.5
12	81.8	83	84.3	84.5	85.2	85.2	84.6	84.7	84.8
13	84.4	86	85.8	86.7	87.3	87.8	87.4	87.8	87.4
14	84.6	85.3	86.5	86	86.7	87.4	86.6	86.4	87.2
15	84.8	86.2	85.9	86.8	86.8	86.9	87.6	87.6	86.4
16	84.1	84.8	85.2	86.3	86	86.8	86.2	85.8	86
17	86.7	86.7	87.3	88.7	89.8	90.8	90.2	89.9	88.9
Ls	**84.14**	**84.84**	**85.63**	**86.03**	**86.62**	**86.87**	**86.87**	**86.79**	**86.42**

Table no.15 for C.R. 16

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 16									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	86.4	87.1	88.4	89.3	88.5	88.6	89.3	88	88
B	89.7	89.7	91.4	92.4	92.4	92.5	92.7	91.5	90.9
C	91.3	91.7	92.1	93.9	92	92.9	91.3	92.6	89.5
D	91.1	91	92.9	93.6	93.4	93.5	91.4	91.5	90.3
EXHAUST	86.9	85.9	86.5	87	87.5	88.3	89	89.7	90.8
GRID POINTS									
1	81.5	83.1	84.1	84.9	87.1	84.4	84.5	85.8	84.3
2	83.1	83.8	84.5	85.1	85.8	85.9	85.5	86.3	85.4
3	82.4	83	84.5	86.8	85	85.7	85.1	84.7	84.6
4	85	84.3	84.9	85.8	86.7	86.5	86.4	86.2	84.7
5	84.7	84.5	86	86.1	86.8	86.6	87.3	89	86.9

6	84.7	85.9	87	86.3	87.6	86.7	88.1	87.9	87.7
7	84.6	85.5	85.9	86.5	86.2	87.2	88	88.1	88.1
8	83.2	83.6	84.7	84.5	85.1	85.9	85.9	86.4	86.6
9	85.6	86	86.5	86.5	87.5	88.5	89.1	89	87.9
10	81.8	81.5	85.3	84.8	84.3	84.8	85.4	84.5	84.9
11	82.9	84.4	85.9	85.6	86.7	87.1	87.3	86.5	86.3
12	84.1	83.8	85.2	86.2	85.1	85.3	85	84.9	84.4
13	84.9	85.5	86.4	86.4	87	86.7	87.1	87.3	86.8
14	85.4	85	85.4	86.4	86.9	86.6	87.3	86.5	86.5
15	84.9	85.3	86.4	86.5	87	87.1	87.5	86.7	86.6
16	84	84.4	84.9	85.8	85.7	86.1	86.7	86.6	85.5
17	85.4	87.2	86.9	88.9	88.7	89.7	89.7	89.7	89.3
Ls	**84.01**	**84.51**	**85.44**	**86.06**	**86.42**	**86.63**	**86.81**	**86.82**	**86.26**

Table no.16 for C.R. 16.5

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 16.5									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	86	87.1	86	86.7	87.3	87.3	88.3	88.4	88.8
B	88.6	89.5	89.9	90.9	91.5	92.7	92.4	92.9	93.2
C	90.6	90.1	90.6	91.3	93.8	91.7	93	93.8	92.4
D	87.8	88.1	88.8	90	90.2	90.9	91.4	95.3	94.3
EXHAUST	79.2	86.7	87	85.2	87.7	87.8	88.2	87	87.1
GRID POINTS									
1	82.1	82.2	83.7	85.2	84.5	85.7	85.1	84.5	84.2
2	84.1	84.7	85	85.6	86	85.8	87	85.9	85.1
3	83.5	83.1	84.2	85.2	85.2	85.2	85.2	85.4	85.4
4	83.7	83.8	85	85.9	86.2	86	86.5	86.1	85.9
5	84.9	84.9	85.4	86.4	86.9	87.7	88.8	88.9	87.2
6	85.2	85.9	87.1	87.7	87.5	87.4	88.4	90	87
7	84.7	86.2	87.1	86.7	87.6	88.8	89.2	88.1	88.7
8	83.4	84.2	84.5	84.9	86.1	86.3	86	86.1	85.2

9	85.5	86.3	87.5	87.3	86.9	88.4	88.6	88.3	87.8
10	81.6	83.1	83.9	84.8	84.3	85	84.8	83.6	83.9
11	83.5	83.9	84.9	85.2	85.8	85.9	84.6	85.9	85.4
12	82.1	83.5	83.7	83.9	84.4	86	85.6	86.6	87
13	85	84.9	86.9	86.6	87.5	87.7	88.3	87	86.6
14	85.1	85.3	85.8	86	86.5	87.2	87.7	87.5	87.6
15	85.6	85	86.3	87.2	87.2	88.1	87.6	87.6	86.8
16	84.7	84.3	85	86	86.3	86.9	86.4	86.8	85.9
17	85.8	87.8	87.4	87.9	90.2	90.8	89.7	89.3	88.2
Ls	**84.14**	**84.65**	**85.47**	**86.02**	**86.41**	**86.99**	**87.02**	**86.91**	**96.34**

Table no.17 for C.R. 17

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 17									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	86.2	85.3	84.9	85.8	86.7	87.6	88.1	87.7	87.2
B	89.2	89.2	90.5	91.5	92	92	93.2	91.7	93.5
C	90.5	92.9	94.1	93.8	95.5	94.3	96	95.8	95.1
D	91.3	91.9	91.8	93.8	93.9	93.7	94.3	95.5	94.6
EXHAUST	83	84.9	85.8	86.3	88.3	85.9	88.8	89.6	89.2
GRID POINTS									
1	83.4	82.7	83.4	83	84.1	84.6	84.3	85.5	83.5
2	83.3	84.7	84.8	84.6	85.4	84.7	86.1	86.4	85.5
3	83	84.9	84.8	86.6	86.6	87.9	86.9	86.2	86.2
4	84.7	85.9	86.1	87.1	86.1	87.1	87.1	87.8	86.4
5	85.7	84.8	86.7	87	86.6	87.6	88.1	89	87.2
6	85.9	86.1	87	87.1	88.3	88.4	88.9	88.5	88.9
7	85.1	86.8	86.9	87.9	88.5	89.4	90.3	88.8	89
8	84	84.8	84.9	85.4	85.6	86.2	86.6	85.9	85.5
9	85.7	86.5	87.1	86.9	87.9	88.6	88.6	89	88.3
10	82.3	82.1	83.3	83.9	84.6	84.2	85.3	83.5	83.8
11	83.5	84	85.3	85.4	86.1	86	86.3	86.3	86.3

12	84.7	85.3	85.2	85.7	85.1	86.3	87	87	87.1
13	85.4	86.1	86.7	86.9	87	88.2	87.9	87.6	86.6
14	85.3	85.9	86.9	86.6	87.2	87.2	87.8	88.2	88.4
15	85.3	85.8	86.6	87.4	87.6	88.8	88.4	89	88.7
16	85.3	85.8	86.2	86.4	86.5	86.3	87	87	86.6
17	88.6	89.7	88.8	90.1	89.4	90.9	89.8	90.2	89.9
Ls	**84.77**	**85.4**	**85.92**	**86.47**	**86.62**	**87.2**	**87.43**	**87.4**	**86.93**

Table no.18 for C.R. 17.5

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 17.5									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	85.8	88.1	89.7	89.3	88.4	88.1	88.6	89.6	88.9
B	89.3	92.2	90.8	92.2	93	92.9	93	93.6	93.1
C	91.8	93.8	94.8	92.5	92.9	95.6	92.2	97.2	93.4
D	91.6	93.7	93.1	93.7	92	95.7	96	96	94.9
EXHAUST	80.3	80.9	78.4	81	88.1	90.7	87.1	86.5	87.1
GRID POINTS									
1	83.7	83.1	84.9	84.5	84.8	84.5	85	85.2	84.7
2	84.6	84.8	85	85.9	85.4	85.5	86.5	85.8	85.9
3	84.6	86.5	87.7	87.5	87.1	87.1	86.3	86.4	86.8
4	86	86.2	86.8	87.9	87.4	87.2	86.8	87.1	81.5
5	86.1	85.7	87.5	87.5	88.2	88.4	89.5	89.4	88.1
6	85.4	87.2	86.1	87.2	88.3	88.7	90	89.3	89.9
7	87	85.9	87.5	86.2	87.9	89.2	89.3	89.8	88.8
8	84.2	84.7	85.2	86.4	85.9	86.4	86.4	86.4	86.2
9	86.7	87.4	88.2	87.2	88.7	88.2	88.8	89.1	88.3
10	83.7	83.6	84.2	84.1	85	84.9	85.4	84.5	85.4
11	83.9	85	85.1	85.4	86.3	86.8	86.5	87	86.3
12	83.9	85.5	86.4	87.2	86.8	88	87.8	87.2	86.7
13	85.5	86.4	86.7	87.7	87.4	87.9	88.3	87.7	87.7
14	86.2	86.5	86.8	87.9	88.3	88.4	88.2	88.5	88.6
15	85.7	86.1	87.3	86.8	87.4	88.8	88.9	88.5	89
16	85.4	85.5	86.4	86.4	86.8	86.2	87.2	87.1	87.6

17	87.3	86	86.3	88	88.1	88	89.3	87.8	87.4
Ls	**85.28**	**85.65**	**86.35**	**86.69**	**87.04**	**87.3**	**87.65**	**87.45**	**87.34**

Table no.19 for C.R. 18

OBSERVATIONS IN SPL (dB(A)) FOR COMPRESSION RATIO 18									
LOADS (Kg)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
POINTS									
A	87.3	86.7	87.6	87.6	88.7	88.5	88.4	86.2	86.9
B	87.9	90.2	90.1	90.6	91.6	92.6	92.6	92.8	91.8
C	91.9	92.3	93	91.1	93.7	93.4	96.5	95.8	90.7
D	92.3	93.5	93.7	93.5	94.1	93.4	94.7	94.2	93.8
EXHAUST	90.3	86.4	80.6	85.5	92.5	83.6	85.3	87	87.4
GRID POINTS									
1	82.3	83.1	83.9	84.4	84.4	84.2	84.8	84.6	84.6
2	84	85.1	85	85.7	86	85.8	85.9	86.3	85.8
3	85.6	85.9	85.3	85.6	84.9	85.3	86.7	85.3	85.5
4	84.9	85.6	86.1	86.4	86.6	87.2	86.8	86.8	86.9
5	85.5	85.7	87.4	87	86.9	86.8	87.8	88.7	88.8
6	85.7	86.8	86.4	86.1	87.5	87.7	87.6	87.9	87
7	85.3	85.9	86.7	87	86.7	87.4	88.1	89.3	87.9
8	84.4	84.8	85.9	85.8	85.8	85.9	85.7	87.2	85.8
9	86.6	87.9	88.4	88.5	88.3	88.1	87.8	88.1	88.7
10	82.2	83.2	83.6	83.8	84	84.3	84.1	84.4	83.9
11	83.7	84.3	85.6	85.6	85.5	85.7	86.3	85.9	86.3
12	85.7	84.2	86.5	86.2	84.6	86.2	87.7	88.2	84
13	86.6	86.1	87.1	87.7	87.7	87.7	87.4	87.6	87.8
14	85.8	86.9	87.2	86.9	87.4	87.7	88.1	88.6	87.3
15	85.6	85.8	86.1	86.4	87.6	87.8	88.6	88.6	86.9
16	85.7	86.2	86.7	86.4	86.9	87.1	86.8	87.3	86.6
17	87.8	88.6	89.4	87	88.3	87.2	87	87.2	88
Ls	**85.14**	**85.65**	**86.31**	**86.26**	**86.41**	**86.59**	**86.89**	**87.16**	**86.57**

APPENDIX-B

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1. MEASUREMENT OF ACOUSTIC POWER

To measure acoustic power identify the length, breadth and height of the sound source (i.e. engine) and then calculate the area by the given formula

Area = ab + 2(bc + ca)

Where, "a" is Length =1.71 m

"b" is Breadth =0.7 m

"c" is Height =1m

Area =1.71*0.7+2(0.7*1+1*1.71)

= 6.017 m^2

For calculation of Acoustic power (Lw):

Lw = Ls +10$\log_{10}(S/S_0)$

Where, Lw = Acoustic power, (dB (A) ref. to 10^{-12} watt)

Ls = Sound pressure level, dB (A)

S = Hypothetical surface area

S_0 =Reference area, 1m^2

Lw = Ls +10$\log_{10}(6.017/1)$

Lw = Ls +7.79 ……………………………………………………………………… [equ. (1)]

Put all the values of Ls for different compression ratios and at different loads from the table no.7 to table no.19 from appendix A in equation no. (1).

2. OBSERVATIONS FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt)

Table no.20 for all C.R

OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 12									
Lw	90.17	91.17	92.29	93.99	94.69	95.47	95.76	96.41	96.11
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 12.5									
Lw	91.26	92.13	93.8	95	95.57	95.96	95.99	96.29	96.15
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 13									
Lw	89.69	91.44	92.56	95	95.63	94.71	91.24	95.77	95.63
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 13.5									
Lw	90.19	90.67	92.1	93.33	94.26	94.99	95.68	95.82	95.9
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 14									
Lw	91.57	92.92	93.9	94.96	94.86	95.27	95.26	95.46	95.2
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 14.5									
Lw	91.57	92.92	93.9	94.96	94.86	95.27	95.26	95.46	95.2
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 15									
Lw	91.71	92.79	93.49	94.4	94.88	95.46	95.2	89.88	95.11
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 15.5									
Lw	91.93	92.63	93.42	93.82	94.41	94.66	94.66	94.58	94.21
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 16									
Lw	91.8	92.3	93.23	93.85	94.21	94.22	94.6	94.61	94.05
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 16.5									
Lw	91.93	92.44	93.26	93.81	94.2	94.78	94.81	94.7	94.13
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 17									
Lw	92.56	93.19	93.71	94.26	94.41	94.99	95.22	95.19	94.72
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 17.5									
Lw	93.07	93.44	94.14	94.48	94.83	95.09	95.44	95.24	95.13
OBSERVATION FOR ACOUSTIC POWER (dB(A)ref. to 10^{-12} watt) FOR COMPRESSION RATIO 18									
Lw	92.93	93.44	94.1	94.05	94.2	94.38	94.68	94.95	94.36

APPENDIX-C

1. OBSERVATIONS FOR VIBRATIONS

Table no.21 for C.R. 12

OBSERVATION FOR ACCERELATION (ms^{-2}) AT COMPRESSION RATIO 12							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.05	0.08	0.2	0.26	0.8	0.87	0.42
1	0.05	0.09	0.22	0.29	0.8	0.88	0.43
2	0.05	0.11	0.27	0.33	0.8	0.9	0.44
3	0.05	0.13	0.33	0.38	0.82	0.92	0.45
4	0.06	0.18	0.4	0.41	0.84	0.95	0.47
5	0.06	0.28	0.49	0.49	0.87	0.96	0.48
6	0.06	0.33	0.55	0.57	0.89	0.97	0.48
7	0.08	0.36	0.59	0.61	0.91	0.97	0.5
8	0.08	0.37	0.61	0.63	0.92	0.98	0.51
OBSERVATION FOR DISPLACEMENT (μm) AT COMPRESSION RATIO 12							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.9	0.1	0	0	0	0	0
1	0.9	0.1	0	0	0	0	0
2	0.9	0.1	0	0	0	0	0
3	0.9	0.1	0	0	0	0	0
4	0.8	0.1	0	0	0	0	0
5	0.9	0.1	0	0	0	0	0
6	0.9	0.1	0	0	0	0	0
7	0.9	0.1	0	0	0	0	0
8	0.8	0.1	0	0	0	0	0
OBSERVATION FOR VELOCITY (mm/s) AT COMPRESSION RATIO 12							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (kg)							
0	0.23	0.11	0.16	0.08	0.19	0.11	0.03
1	0.23	0.12	0.16	0.08	0.2	0.11	0.03
2	0.23	0.15	0.16	0.11	0.21	0.15	0.03

3	0.23	0.16	0.16	0.12	0.23	0.16	0.04
4	0.23	0.18	0.17	0.15	0.24	0.18	0.05
5	0.23	0.28	0.17	0.17	0.27	0.2	0.05
6	0.24	0.33	0.17	0.2	0.29	0.23	0.06
7	0.24	0.36	0.18	0.21	0.3	0.27	0.06
8	0.24	0.37	0.19	0.22	0.31	0.27	0.06

Table no.22 for C.R. 13

OBSERVATION FOR ACCERELATION (ms^{-2}) AT COMPRESSION RATIO 13							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (kg)							
0	0.05	0.09	0.21	0.27	0.81	0.87	0.42
1	0.05	0.09	0.23	0.29	0.81	0.88	0.42
2	0.05	0.12	0.28	0.34	0.82	0.9	0.44
3	0.05	0.13	0.34	0.39	0.83	0.91	0.45
4	0.05	0.2	0.43	0.41	0.85	0.95	0.48
5	0.05	0.25	0.51	0.5	0.87	0.96	0.49
6	0.05	0.28	0.55	0.55	0.9	0.97	0.5
7	0.06	0.3	0.59	0.59	0.91	0.98	0.51
8	0.08	0.35	0.61	0.59	0.92	0.98	0.52
OBSERVATION FOR DISPLACEMENT (μm) AT COMPRESSION RATIO 13							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.9	0.1	0	0	0	0	0
1	0.9	0.1	0	0	0	0	0
2	0.9	0.1	0	0	0	0	0
3	0.9	0.1	0	0	0	0	0
4	0.9	0.1	0	0	0	0	0
5	0.9	0.1	0	0	0	0	0
6	0.9	0.1	0	0	0	0	0
7	0.9	0.1	0	0	0	0	0
8	0.9	0.1	0	0	0	0	0
OBSERVATION FOR VELOCITY (mm/s) AT COMPRESSION RATIO 13							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (kg)							
0	0.23	0.12	0.16	0.08	0.19	0.11	0.03
1	0.23	0.14	0.17	0.08	0.2	0.12	0.03
2	0.24	0.16	0.17	0.11	0.21	0.15	0.04
3	0.24	0.18	0.17	0.15	0.23	0.18	0.05
4	0.24	0.2	0.17	0.18	0.23	0.19	0.05

5	0.24	0.22	0.16	0.21	0.27	0.2	0.06
6	0.24	0.22	0.18	0.21	0.29	0.22	0.06
7	0.24	0.22	0.18	0.22	0.31	0.23	0.07
8	0.24	0.22	0.19	0.23	0.31	0.26	0.07

Table no.23 for C.R. 14

OBSERVATION FOR ACCERELATION (ms⁻²) AT COMPRESSION RATIO 14							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (kg)							
0	0.09	0.12	0.34	0.56	0.9	1.6	1.7
1	0.09	0.13	0.34	0.49	1.57	1.7	1.02
2	0.09	0.2	0.39	0.49	1.6	2.3	1.03
3	0.1	0.21	0.41	0.59	1.2	1.33	1.1
4	0.8	0.22	0.5	0.6	1.24	1.12	1.15
5	0.8	0.23	0.48	0.7	1.43	1.45	1.13
6	0.8	0.25	0.55	0.7	1.47	2.2	1.25
7	0.9	0.25	0.56	0.71	1.7	2.2	1.36
8	0.9	0.26	0.57	0.7	1.5	2.3	1.39
OBSERVATION FOR DISPLACEMENT (µm) AT COMPRESSION RATIO 14							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	1	0.4	0.2	0	0	0	0
1	1	0.4	0.2	0	0	0	0
2	1	0.4	0.2	0	0	0	0
3	1	0.4	0.2	0	0	0	0
4	1	0.4	0.1	0	0	0	0
5	1	0.4	0.2	0	0	0	0
6	1	0.4	0.3	0	0	0	0
7	1	0.4	0.2	0	0	0	0
8	1	0.4	0.2	0	0	0	0
OBSERVATION FOR VELOCITY (mm/s) AT COMPRESSION RATIO 14							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.26	0.19	0.25	0.21	0.23	0.22	0.22
1	0.27	0.2	0.26	0.25	0.5	0.25	0.25
2	0.28	0.21	0.25	0.25	0.49	0.33	0.31
3	0.27	0.22	0.27	0.33	0.4	0.19	0.3
4	0.26	0.22	0.28	0.33	0.43	0.28	0.4
5	0.25	0.23	0.29	0.39	0.49	0.31	0.45

6	0.25	0.22	0.2	0.4	0.45	0.43	0.35
7	0.26	0.21	0.23	0.4	0.89	0.42	0.36
8	0.27	0.21	0.23	0.41	0.9	0.42	0.37

Table no.24 for C.R. 15

OBSERVATION FOR ACCERELATION (ms^{-2}) AT COMPRESSION RATIO 15							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (kg)							
0	0.08	0.15	0.36	0.78	1.75	3.33	3.27
1	0.09	0.18	0.38	0.97	2.93	3.57	2.08
2	0.1	0.19	0.4	0.98	3.04	4.52	2.9
3	0.11	0.22	0.47	1.07	2.4	2.66	2.06
4	0.11	0.24	0.53	1.28	2.48	2.26	2.22
5	0.13	0.27	0.56	1.32	2.85	2.96	3.3
6	0.13	0.28	0.58	1.33	2.94	4.26	2.7
7	0.13	0.33	0.62	1.45	3.38	4.5	2.72
8	0.13	0.28	0.59	1.46	3.05	2.66	2.69
OBSERVATION FOR DISPLACEMENT (μm) AT COMPRESSION RATIO 15							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	1.1	0.5	0.3	0.2	0	0	0
1	1	0.5	0.3	0.2	0	0	0
2	1	0.4	0.4	0.2	0	0	0
3	1	0.5	0.4	0.2	0	0	0
4	1	0.5	0.5	0	0	0	0
5	0.9	0.4	0.4	0	0	0	0
6	1	0.4	0.4	0	0	0	0
7	1	0.5	0.4	0	0	0	0
8	1	0.5	0.5	0	0	0	0
OBSERVATION FOR VELOCITY (mm/s) AT COMPRESSION RATIO 15							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.28	0.2	0.32	0.26	0.44	0.43	0.44
1	0.26	0.19	0.31	0.31	0.73	0.5	0.52
2	0.28	0.2	0.34	0.33	0.76	0.65	0.66
3	0.26	0.2	0.36	0.33	0.67	0.39	0.57
4	0.27	0.21	0.42	0.4	0.7	0.35	0.97
5	0.26	0.22	0.43	0.4	0.77	0.57	0.92
6	0.26	0.22	0.44	0.42	0.83	0.6	0.74

7	0.26	0.23	0.47	0.46	0.94	0.85	0.74
8	0.28	0.23	0.48	0.46	0.89	0.42	0.75

Table no.25 for C.R. 16

OBSERVATION FOR ACCERELATION (ms^{-2}) AT COMPRESSION RATIO 16							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.08	0.16	0.38	0.78	1.8	3.4	2.08
1	0.1	0.2	0.38	0.8	2.9	3.59	2.9
2	0.12	0.21	0.41	0.93	3	4.12	2.07
3	0.13	0.22	0.48	0.96	2.5	4.1	2.11
4	0.13	0.24	0.53	1.05	2.89	3.1	2.98
5	0.15	0.26	0.57	1.3	2.95	2.77	3.3
6	0.15	0.27	0.58	1.32	3.3	2.99	2.78
7	0.15	0.3	0.59	1.44	3.4	4.1	2.72
8	0.15	0.32	0.6	1.44	3	2.88	2.73
OBSERVATION FOR DISPLACEMENT (µm) AT COMPRESSION RATIO 16							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	1	0.5	0.3	0	0	0	0
1	1	0.5	0.3	0	0	0	0
2	1	0.5	0.4	0	0	0	0
3	1	0.4	0.4	0	0	0	0
4	1	0.5	0.5	0	0	0	0
5	1	0.5	0.4	0	0	0	0
6	1	0.5	0.4	0	0	0	0
7	1	0.5	0.5	0	0	0	0
8	1	0.5	0.4	0	0	0	0
OBSERVATION FOR VELOCITY (mm/s) AT COMPRESSION RATIO 16							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.28	0.2	0.32	0.28	0.49	0.44	0.32
1	0.28	0.2	0.36	0.28	0.77	0.52	0.31
2	0.28	0.2	0.42	0.4	0.77	0.55	0.51
3	0.28	0.21	0.44	0.4	0.76	0.62	0.58
4	0.29	0.22	0.48	0.4	0.88	0.4	0.8
5	0.28	0.23	0.48	0.43	0.93	0.37	0.63
6	0.29	0.23	0.5	0.43	0.94	0.55	0.61
7	0.28	0.23	0.48	0.46	0.94	0.79	0.7

8	0.28	0.23	0.49	0.46	0.89	0.43	0.71

Table no.26 for C.R. 17

OBSERVATION FOR ACCERELATION (ms^{-2}) AT COMPRESSION RATIO 17							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.1	0.25	0.51	0.88	2.42	3.92	0.74
1	0.1	0.23	0.53	0.97	2.43	3.9	0.7
2	0.1	0.23	0.55	1.03	2.12	3.5	0.7
3	0.1	0.23	0.58	1.12	1.99	3.33	0.73
4	0.1	0.23	0.58	1.14	2.3	3.09	0.73
5	0.1	0.23	0.58	1.14	2.89	2.8	0.68
6	0.1	0.23	0.59	1.1	2.5	2.78	0.67
7	0.1	0.23	0.59	1.08	2.4	2.5	0.67
8	0.1	0.23	0.59	1.08	2.4	2.49	0.67
OBSERVATION FOR DISPLACEMENT (µm) AT COMPRESSION RATIO 17							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	1	0.5	0.3	0	0	0	0
1	1	0.6	0.3	0	0	0	0
2	1	0.5	0.5	0	0	0	0
3	1	0.5	0.6	0	0	0	0
4	1	0.5	0.5	0	0	0	0
5	1	0.5	0.6	0	0	0	0
6	1	0.6	0.5	0	0	0	0
7	1	0.5	0.5	0	0	0	0
8	1	0.4	0.6	0	0	0	0
OBSERVATION FOR VELOCITY (mm/s) AT COMPRESSION RATIO 17							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.27	0.24	0.4	0.28	0.65	0.54	0.07
1	0.27	0.25	0.52	0.3	0.66	0.55	0.08
2	0.27	0.23	0.53	0.32	0.25	0.55	0.07
3	0.28	0.25	0.54	0.38	0.44	0.46	0.09
4	0.27	0.24	0.57	0.37	0.63	0.4	0.07
5	0.27	0.24	0.57	0.38	0.63	0.39	0.07
6	0.28	0.25	0.57	0.38	0.63	0.36	0.06
7	0.28	0.24	0.59	0.38	0.4	0.36	0.06
8	0.28	0.24	0.6	0.38	0.63	0.36	0.06

Table no.27 for C.R. 18

OBSERVATION FOR ACCERELATION (ms^{-2}) AT COMPRESSION RATIO 18							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0	0.27	0.5	0.88	2.42	3.92	0.74
1	0.1	0.2	0.48	0.97	2.46	3.95	0.66
2	0.1	0.23	0.4	1.04	2.11	3.85	0.72
3	0.1	0.22	0.54	1.13	1.73	3.21	0.72
4	0.1	0.22	0.59	1.14	2.3	3.1	0.76
5	0.1	0.22	0.58	1.12	2.8	2.72	0.76
6	0.1	0.22	0.59	1.07	2.31	2.89	0.69
7	0.1	0.22	0.59	1.08	2.28	2.46	0.88
8	0.1	0.22	0.59	1.05	2.28	2.43	0.66
OBSERVATION FOR DISPLACEMENT (µm) AT COMPRESSION RATIO 18							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.3	0.3	0.2	0	0	0	0
1	1	0.6	0.5	0	0	0	0
2	1	0.6	0.4	0	0	0	0
3	1	0.5	0.4	0	0	0	0
4	1	0.4	0.5	0	0	0	0
5	1	0.4	0.5	0	0	0	0
6	1	0.5	0.6	0	0	0	0
7	1.1	0.5	0.6	0	0	0	0
8	1.1	0.5	0.7	0	0	0	0
OBSERVATION FOR VELOCITY (mm/s) AT COMPRESSION RATIO 18							
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**
LOAD (Kg)							
0	0.05	0.25	0.32	0.27	0.61	0.53	0.07
1	0.27	0.24	0.51	0.31	0.65	0.56	0.09
2	0.28	0.25	0.51	0.33	0.21	0.55	0.09
3	0.27	0.25	0.49	0.39	0.43	0.46	0.07
4	0.27	0.24	0.58	0.37	0.64	0.43	0.08
5	0.28	0.24	0.58	0.38	0.33	0.42	0.08
6	0.28	0.25	0.59	0.37	0.64	0.4	0.08
7	0.29	0.24	0.59	0.37	0.64	0.36	0.09
8	0.28	0.25	0.59	0.38	0.62	0.36	0.06

1. OBSERVATION OF SOUND PRESSURE LEVEL FOR FREQUENCY SPECTRUM IN 1-1 OCTAVE BAND

Table no.28 for C.R. 12

OBSERVATION FOR FREQUENCY SPECTRUM IN 1-1 OCTAVE BAND AT COMPRESSION RATIO 12									
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
LOAD (Kg)									
0	57.1	89.7	84	72.3	80.4	79	75.9	75.2	66.1
2	54.8	87.3	81.4	72.3	87.5	81	78.2	76	69.2
4	55.9	86.1	82	71.4	88.3	80.6	77.6	75.9	67
6	57.7	85.2	90.6	71.3	88.3	81.8	78.9	76	68.7
8	59.2	85.6	91.6	74.7	89.5	82.8	80.7	78.4	70.8

Table no.29 for C.R. 13

OBSERVATION FOR FREQUENCY SPECTRUM IN 1-1 OCTAVE BAND AT COMPRESSION RATIO 13									
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
LOAD (Kg)									
0	55.2	90.4	81	71.3	83.6	77.7	74.4	73.4	68.1
2	56	88.2	83.1	71.9	84.3	81.4	76.9	75.8	68.9
4	56.2	85.4	87.7	73.8	90.2	83.3	79	78.7	69.3
6	57.1	85.1	87.5	70.6	85.6	81.8	80.3	74.6	68.8
8	58.2	84.8	93.1	71.9	87	81.8	79.4	76.5	69.7

Table no.30 for C.R. 14

OBSERVATION FOR FREQUENCY SPECTRUM IN 1-1 OCTAVE BAND AT COMPRESSION RATIO 14									
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
LOAD (Kg)									
0	56	90.2	84.5	72.4	84.3	77.5	77.7	74.6	67.6
2	54.8	87.4	83.7	71	86.5	81.9	77.7	76.3	68.2
4	56.3	85.6	85.9	73.4	87.9	82.5	77.8	78.5	67.8

6	58.7	85	91	72.4	86.8	83.5	78	75.3	69.1
8	58.6	85.7	92.8	71.4	87.3	81.7	78.7	75.6	69.3

Table no.31 for C.R. 15

OBSERVATION FOR FREQUENCY SPECTRUM IN 1-1 OCTAVE BAND AT COMPRESSION RATIO 15									
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
LOAD (Kg)									
0	55.3	89.7	85.1	72.8	81.5	79.9	78	74.2	68.8
2	83.8	89.3	77.4	70.2	82.2	80.1	77	74.5	67
4	56.6	85.4	85.1	71.5	83.4	83.2	80.3	76.5	69.4
6	56.7	85.4	85.8	72.3	85.5	81.4	76.9	74.7	68.7
8	60.3	86.1	93.3	71.8	87.1	79.8	76.4	75.1	68.1

Table no.32 for C.R. 16

OBSERVATION FOR FREQUENCY SPECTRUM IN 1-1 OCTAVE BAND AT COMPRESSION RATIO 16									
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
LOAD (Kg)									
0	57.9	89.5	85.6	73.1	81.8	80.4	76.2	75.7	68.5
2	55.9	88.3	82.8	72.5	84	81.8	78	76.6	69.4
4	54.7	85.7	85.4	71	86.2	82.7	78.7	77.1	68.6
6	56.8	84.5	87	74.8	87.8	82.7	79.6	76.1	68.3
8	58.2	84.8	90.3	70.3	85.3	79.8	78.2	75.2	69.6

Table no.33 for C.R. 17

OBSERVATION FOR FREQUENCY SPECTRUM IN 1-1 OCTAVE BAND AT COMPRESSION RATIO 17									
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
LOAD (Kg)									
0	56.9	89.9	85.5	73.7	83.6	80.6	77.4	75	68.2
2	55.5	88.5	79.3	71.1	84.1	80.9	77.5	74.1	69
4	55	85	83.6	70.1	85.3	82.2	77.9	76.8	69.3
6	55.8	84.4	85.1	73.2	86.4	73.4	79	75.6	69.8
8	57.9	85.2	92	67.9	85.3	81.5	78.8	76.1	69.2

Table no.34 for C.R. 18

OBSERVATION FOR FREQUENCY SPECTRUM IN 1-1 OCTAVE BAND AT COMPRESSION RATIO 18									
FREQUENCY (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
LOAD (Kg)									

0	60.4	88.1	86.8	72.1	81.7	79.7	79.1	74.1	67.9
2	56.2	90.3	82.4	68.5	82.8	81.2	78.8	77.6	69.8
4	55.3	85.6	81.1	68.3	84.6	81.4	82.3	79	72.3
6	56.5	82.5	85.6	70.7	83.7	82.5	81.4	77.4	71.8
8	59.2	85.6	91.8	70.5	84.6	82.4	81	77	73.2