

# **Sound Source Localization and Mapping Using Acoustic Intensity Method for Noise Control in Automobiles and Machines**

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**ABSTRACT:** Noise control is gaining a lot of importance now-a-days. We apply various noise control procedures to reduce the noise by controlling either at noise source or by modifying the path followed by it or by using any barrier to restrict noise. The acoustic energy radiated/emitted per unit time from a sound source is known as sound Power to describe the noise characteristic of a source and its measurement can be carried out by different methods such as Sound pressure and Sound Intensity method. Since intensity method is a vector quantity method, a lot of information can be perceived from a spectrum analysis which is more effective to localize the highest noise source than the pressure method. Vibration analysis can also be carried out with the same equipment along with an accelerometer by conducting Run-up and Run-down experiments. The largest scope lies in the automobile firms. The present work carried out on a 2 wheeler automobile so that this idea can be extended to other equipment in noisy environments such as defense and military applications especially in testing of submarine, ship board equipments and also to check the noise levels of engine ship hulls is within the permissible limits. This work covers the aspect that noise measurement acts as an effective tool to carry out analysis before or after making noise control efforts for industries which use mechanical machines need to keep their machines updated and problem free. The work also focuses on complex noise in nature like a diesel generator, compressor, turbine and many multiple noise sources machineries, the sound intensity technique is used by 3-dimensional analysis to pinpoint the hot spots. This work helps automobile sector in providing data to NVH (Noise, Vibration Harshness) team which perform analysis on sub systems of an automobile and also quantifies the aesthetics of the vehicles (luxury cars). Noise pollution is becoming a major issue in the modernized world hence with help of noise analysis; the permissible limits of a safe working environment can be determined to protect flora and fauna of the mother earth.

**KEYWORDS:** Run-Up and Run-Down Experiments, Sound Power, Sound Source Localization, Sound Intensity Method, Vibration Analysis, Microphone Phased Arrays.

## **I. INTRODUCTION**

Noise control is gaining a lot of importance now-a-days [1]. We apply a lot of noise control procedure to reduce noise. It can be controlled either at the noise source or by modifying the path followed by noise or by using any barrier to restrict noise. However to know the changes in noise levels that are obtained after the noise control strategies or procedures have been applied, noise measurements needs to be carried out [2-4]. The acoustic energy radiated/emitted per unit time from a sound source is known as sound power. Sound Power is a better quantity to describe the noise characteristic of a source. Sound power measurement can be carried out by two methods [8]. One is by Sound pressure method and another is Sound Intensity method, the latter being a more accurate and better method.

In a noise environment like a factory floor we can make sound pressure measurements to find out if the workers risk hearing damage. But once we have found this, we may well want to reduce the noise. To do this, we need to know how much noise is being radiated and by what machine. We therefore need to know the sound power of the individual

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machines and rank them in order of highest sound power [2], [4]. Once we have located the machine making most noise we may want to reduce the noise by locating the individual component radiating noise. Sound pressure method cannot be used to determine or locate the exact Noise source [7].

We can do all this with intensity measurements. Previously we could only measure pressure which is dependent on the sound field. Sound power can be related to sound pressure only under carefully controlled conditions where special assumptions are made about the sound field. Specially constructed rooms such as anechoic or reverberant chambers fulfill these requirements [9]. Traditionally, to measure sound power, the noise source had to be placed in these rooms. Sound intensity, however, can be measured in any sound field. No assumptions need to be made. This property allows all the measurements to be done directly. And measurements on individual machines or individual components can be made even when all the others are radiating noise, because steady background noise makes no contribution to the sound power determined when measuring intensity [10].

Sound intensity gives a measure of direction as well as magnitude it is also very useful when locating sources of sound. Using sound intensity techniques accurate localization of noise source can be achieved in multiple noise source equipment. Reducing the noise levels at a source having lower levels of noise would be of no use when the highest noise source is still making some noise unaltered. So it helps in identification of highest noise source in a multiple noise source and rank the sources accordingly, therefore the radiation patterns of complex vibrating machinery can be studied and in our project we have used Sound Intensity method to Identify and Rank the Noise source location in a 2 wheeler which is a best example for multisource machinery [11].

## 1.2. Sound Intensity Mapping

Every sound control problem requires a need for identification of the noise source. There are several ways of carrying out this using the “*Intensity Method*”. These methods are better than the conventional techniques used. A grid is set up to define a surface. Sound intensity measurements normal to the surface are made from a number of equally spaced points on the surface. We can use the same measurements obtained from Sound Intensity to calculate the sound power over the grid. The values are then stored by numbering each grid. The data can also be used to generate 3-D plots which provide easy visualization of the sound field generated by a source. Three-dimensional plots are plots of the intensity level on the vertical axis over the grid. We can plot the positive- or the negative-going intensity. It is, necessary to have some post-processing equipment both to store data and to make the calculations. A contour and 3-D plot for the printer are shown opposite [12].

We can make contour maps and 3-D plots with pressure measurements. But intensity maps can be made in the near field where the relation between the measured intensity levels and the source position is greater. This increases the resolution. Furthermore, both sinks and sources can be identified with intensity and measurements can be made in any acoustic environment.

## 1.3. Sound Field Definitions

In a free field the doubling the distance from the source reduces the sound pressure level by 6 dB.

- **Free field:** The free field is a region in space where sound may propagate free from any form of obstruction in all directions.
- **Near field:** The near field of a source is the region close to a source where the sound pressure and acoustic particle velocity are not in phase and sound field does not decrease by 6 dB each time the distance from the source is increased (as it does in the far field) which is limited to a distance from the source equal to about a wavelength of sound.
- **Far field:** The far field of a source begins where the near field ends and extends to infinity. The transition from near to far field is gradual in the transition region. In the far field, the direct field radiated by most machinery sources will decay at the rate of 6 dB each time the distance from the source is doubled.
- **Direct field:** The direct field of a sound source is defined as that part of the sound field which has not suffered any reflection from any room surfaces or obstacles.
- **Reverberant field:** The reverberant field of a source is defined as that part of the sound field radiated by a source which has experienced at least one reflection from a boundary of the room or enclosure containing the source.

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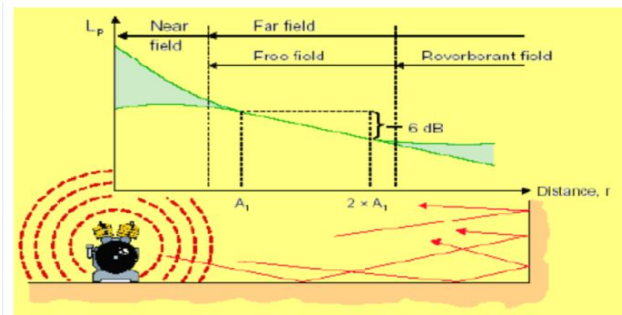


Figure 1: Various fields for noise

## 1.4. Background Noise

Background noise can be regarded as sources outside the measurement box and will have no effect on the measured sound power of the source. In practice this means that sound power can be measured to an accuracy of 1 dB from sources as much as 10 dB lower than the background noise. If background noise is a problem, then choosing a smaller measurement surface will improve the signal-to-noise ratio.

## 1.5. Sound Power by Sound Intensity Measurement

Sound intensity is a well-known application that measures acoustic energy flow and provides information about sound amplitude and direction in the acoustic field. The reference standard for sound power determination of noise source is ISO 9614. It consists of two parts namely, Measurement at discrete points and Measurement by scanning [15].

### 1.5.1. Part 1: Measurement at discrete points (ISO 9614-1)

- Intensity is measured at discrete locations over a surface by placing the intensity probe normal to the surface
- Sound Power is computed by adding the area level of each grid and the corresponding intensity level.
- Total sound power is determined by adding the Sound power of all the five surfaces.
- If measurements are made in 1/1 or 1/3 octave Bands, sound power in each frequency band can be determined.
- This data can also be used for mapping the intensity level which will be helpful in identifying the “HOT SPOT”.

However, this method is time consuming and hence mostly used in investigation for noise control.

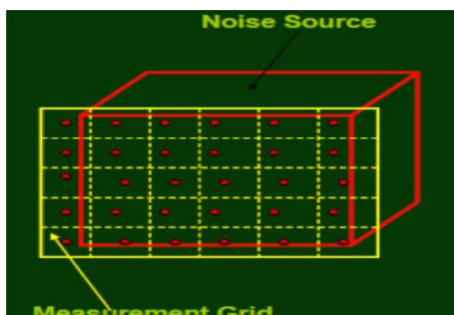


Figure 2: Intensity measurement by grid method

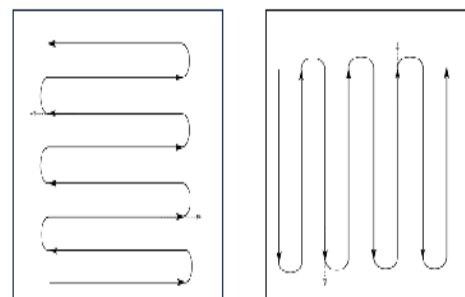


Figure 3: Intensity by scanning method

### 1.5.2. Part 2: Measurement by scanning (ISO 9614-2)

- Instead of measurement at discrete points, the total surface is divided into smaller segments.
- Each segment is scanned with intensity analyzer set to Averaging mode.
- The scanning rate and scan line density is determined as per the guidelines of the standard.

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- At the end of the scanning average intensity level is obtained for each segment.
- Sound power of each segment is determined by adding Intensity level and the corresponding area level of the segment.
- This method is faster than the previous method.
- Sound intensity mapping cannot be obtained by this method.
- HOT SPOT in the area cannot be identified by this method.
- If intensity levels are measured in 1/1 or 1/3 Octave band, sound power in each frequency band can be determined.

## Benefits

- Because sound intensity is a vector quantity, the acoustic field can be represented as amplitude and direction. True measure of acoustic radiation by determination of energy flow.
- Possible determination of sound power from sound intensity measurements.
- Portable technique (can be used with a two channel sound level meter).

## Limitations

- Frequency limitations due to the pressure approximation gradient (determined by the microphone spacing); up to 10 kHz with the smallest spacing.
- Relatively time-consuming.
- Accurate equipment required (accurately phase-matched microphones).
- Sources need to be stationary.

## 1.6. Noise Source Ranking

A complicated structure may radiate sound from several Sources and absorb sound in other places. To evaluate the effectiveness of noise reduction methods, we need to know how much noise is being radiated by the individual components of machines. This means finding the sound power from the components of a machine. This is simple with sound intensity measurements because we can define a measurement surface which can enclose single components. All the other noise radiating components can be treated as background noise -provided the noise is stationary. Furthermore, the total sound power can be found simply by adding the partial sound powers from all the noise radiating components.

## 1.7. Octave Bands

Human Ear cannot differentiate small variations in frequency. Octaves are the minimum frequency shift necessary for human being to perceive the difference of tones. Octave bands are standardized bands starting from 1.25 Hz to 20 kHz for acoustic measurements. Each octave band is referred by its “center frequency”. The human ear also responds more to frequency ratios than to frequency differences, so the frequency ranges generally have terminal frequencies such as upper and lower frequencies of the range that are related by the same ratio. The frequency interval over which measurements are made is called the “bandwidth”. It is described by lower frequency ( $f_1$ ) and upper frequency ( $f_2$ ). In acoustics, bandwidths are often specified in terms of *octaves*, where octaves have upper frequency which is twice the lower frequency. For an octave,

$$f_2 = 2 \times f_1$$

In some cases, a more refined division of the frequency range is used in measurement, such as 1/3 octave bands, in which

$$\frac{f_1}{f_2} = 2^{1/3} = 1.26$$

Octave band filter sets are often included as a feature of sound level meters. If the filters were “perfect” all energy outside the octave band frequency range would be attenuated or cancelled out. For a more detailed analysis of the frequency distribution of the acoustic energy, 1/3 octave band filters may be used. The ratio of upper and lower frequency for a 1/3 octave band is  $2^{1/3} = 1.260$ . The lower frequency ( $f_1$ ) in the 1/3 octave band is related to the center frequency ( $f_o$ )

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$$f_1 = 2^{-\frac{1}{6}} f_0 = 0.8909 f_0.$$

The upper frequency ( $f_2$ ) in the 1/3 octave band is related to the center frequency by

$$f_2 = 2^{\frac{1}{6}} f_0 = 1.1225 f_0.$$

## II. EXPERIMENTAL METHODOLOGY

### S2.1. Preliminary Preparation

We have chosen a two wheeler bike as a noise source for our present study, since it consists of several noise sources such as engine, transmission/gear box, air intake system, exhaust and tire noise can also be accounted while the bike is in motion. A lot of noise contributed to the environment in metros is because of two wheelers which are used by the common man. Identification of the noise source by sound intensity method in a two wheeler gives us an idea of what exactly contributes to the environmental noise and it could help the manufacturers to work on it and come out with better designs of automobiles that will have reduced levels of noise.



Fig.4. Experimental specimen 4 Stroke-petrol engine

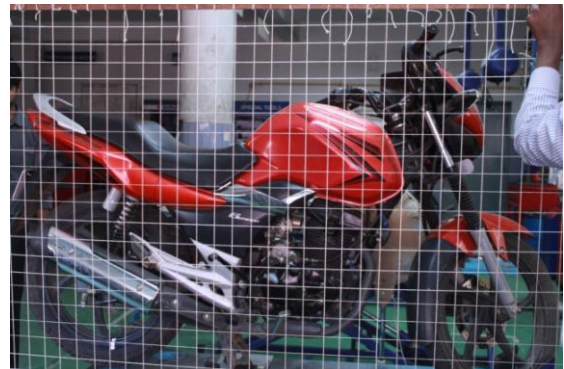


Fig.5. Grid setup dimensions: 5x5 and the No. of grids: 1056

The environment in which the Sound Intensity is measured also plays an important role for accurate measurement. We chose a two wheeler service station which was located in an isolated place and the surrounding environment was calm with no reflections to contribute to the measured quantity. Though sound intensity method can be used even if there are external sources contributing to the measurement, random interruption should be avoided. Therefore, it was carried out on a holiday under steady noise environment which causes no harm to the measurement when the method used is Sound Intensity.

The gear conditions used for the measurement and analysis were the common gear shifts used in the cities and highways i.e., the 2<sup>nd</sup> and 4<sup>th</sup> gear respectively. The vibration analysis was done on 2<sup>nd</sup> and 4<sup>th</sup> gear whereas the acoustic measurements were done at steady state condition and 2<sup>nd</sup> gear shift. Since intensity method is a time dependant one we cannot run the engine for a longer duration continuously and a peddler fan was used intermittently to cool down the engine or reduce the increased temperature of the engine as the bike was made to operate under stationary conditions.

To determine and locate the exact noise source, the right hand side plane of the bike was divided into a number of segments using a grid. The length and width of the grid was equal to the bike dimensions and the overall grid was divide into 1056 segments each of area of 25 square cm .This grid is made of thread and it looks like a net as shown below. The probe is held at each segment of the grid for a few seconds and the intensity data is recorded in the system software via analyzer. The bike was elevated about half a meter above the ground using a servo lift used in service stations and accordingly the grid was made out of a wooden frame was plugged into two mud pots placed laterally in front of the bike.



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## 2.2. Experimental Procedure

- 1) Configuring the analyzer and NV GATE<sup>®</sup> software with the laptop.
- 2) Enabling the OROS<sup>®</sup> sound intensity software in the laptop via analyzer.
- 3) Connecting the elements of the sound intensity probe.
- 4) Connecting the sound intensity probe to the module.
- 5) Enabling the analyzer to the module.
- 6) Calibrating the each microphone of probe with acoustic calibrator.
- 7) Reconnecting the probe and initializing the measurement.

## 2.3. Experimental Aspects:

Experiments are carried out when the bike is engaged at a particular gear. The bike is made to operate at that gear (2<sup>nd</sup> and 4<sup>th</sup>) in parked condition. During the operation, the following measurements are conducted:

### 1) Run-up and Run-down Measurement:

The bike is gradually accelerated to its maximum engine speed and was made to gradually run down to its minimum speed, by manual deceleration. During this period, noise and vibration levels are measured by tracking the wheel speed to assess the noise and vibration levels of the rotating parts of bike when the engine is made to run from maximum speed to minimum speed at a particular transmission ratio and to identify resonance frequencies of rotating and/or stationary parts of the bike within the operating speed of the engine. They are measured by noise (sound pressure) in Pascal at a location near to the engine in a plane parallel to the right hand side of the bike, vibration levels (in velocity) on the engine casing in three orthogonal directions (transverse, longitudinal and vertical) and rear wheel speed in revolutions per minute is tracked. Run down measurements are carried out for two gearing arrangements at 2<sup>nd</sup> gear and at 4<sup>th</sup> gear.



Fig.6. Rear wheel speed tracking by Laser Taco probe



Fig.7. Engine Casing vibration measurement by Tri-axial accelerometer

### 2) Steady State Noise Measurements:

**Measurement Method:** sound intensity probe was held at a location normal to a plane on the right hand side of the bike. The distance of the microphone from the bike is maintained at 0.25 m and the height of the microphone is maintained at 1 m. The bike is made to operate at a speed of ~4000 rpm of engine speed with the 2<sup>nd</sup> gear in engaged mode. The noise levels are observed for a period of 20 to 25 seconds to assess the frequencies at which the noise levels are higher, to correlate the obtained frequencies with the kinematics of the bike and to know the octave bands in which those found frequencies will fall for measuring noise (sound pressure) level from the bike at 2<sup>nd</sup> gear with the engine operating at 4000 rpm.

### 3) Sound intensity measurements:

**Measurement Method:** The bike is made to operate at 4000 rpm of the engine speed with the 2<sup>nd</sup> gear in engaged mode. Intensity measurements are made in a vertical plane covering the right hand side of the bike. The vertical plain

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arrangement was made by placing a grid structure made of threads parallel to the right hand side plane of the bike. The whole grid area is divided into small equal segmental areas. Intensity probe is held at the centre of each segment in the grid. The orientation of the probe is maintained normal to the grid plan to measure sound intensity levels & sound pressure levels from the bike on the plane, to map or to assess the distribution of the noise by intensity method & pressure method, to calculate the sound power emitting from the bike on the RHS plane and to assess the contribution of parts of bike (i.e., combustion chamber, exhaust pipe etc.) to the total sound power “noise ranking” in order to measure Sound intensity level and sound pressure level in dB in a 1/3<sup>rd</sup> octave frequency band from 50 Hz to 10 kHz.

## III. RESULTS AND DISCUSSION

### 3.1. Run-up and Run-down Measurements:

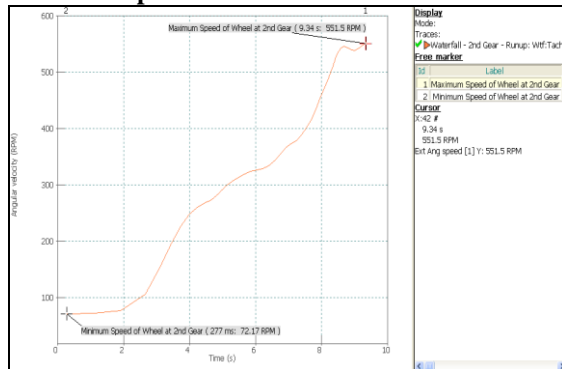


Fig. 8. Run Up plot showing the wheel speed from min to max rpm at 2<sup>nd</sup> Gear.

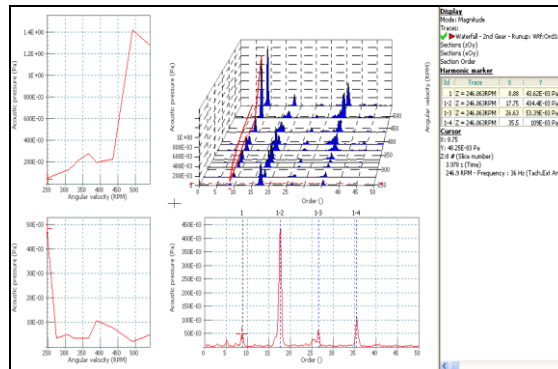


Fig. 9. Waterfall spectra of noise from the bike during RUN UP at 2<sup>nd</sup> Gear

From the Noise water fall spectra (table 1) and the waterfall spectra of vibration (table 2), the peaks are observed at the following orders

Table 1: Order representation for noise of RUN UP at 2<sup>nd</sup> Gear

Table 2: Order representation for vibration of RUN UP at 2<sup>nd</sup> Gear

Peak number	Order Number	Remarks
1	5.25	Drive wheel speed
2	8.75	Firing order of the engine
3	17.75	Engine speed
4	26.5	3 <sup>rd</sup> harmonic of Firing order
5	35.5	2 <sup>nd</sup> Harmonic of Engine speed

Peak number	Order number	Remarks
1	8.9	Firing order of engine
2	17.75	Engine speed
3	26.75	2 <sup>nd</sup> harmonic of firing order
4	35.5	2 <sup>nd</sup> harmonic of engine speed

Table 3: Interferences made from noise and vibration data during RUN UP at 2<sup>nd</sup> Gear

Inferences from Noise data	Inferences from vibration data
Noise levels observed at the tabulated peaks are related to engine kinematics.	The vibration levels observed at the tabulated peaks are related to engine kinematics
The maximum noise level is observed at 17.75 <sup>th</sup> Order, which is related to the engine shaft speed (1X of the engine)	The maximum vibration levels are observed at 35th Order which is related to the 2X of the engine speed (i.e., the piston moves from TDC to BDC & from BDC to TDC , for each revolution of the engine crank shaft)

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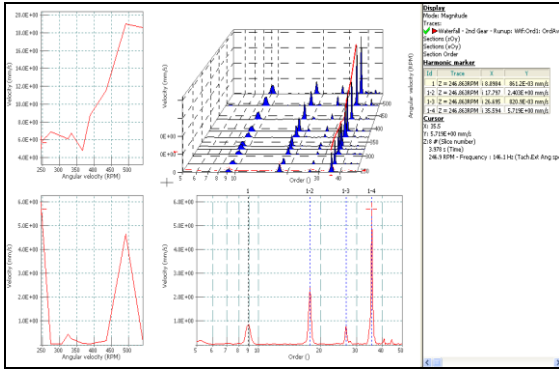


Fig.10. Waterfall spectra of vibration at engine body in vertical RUN UP at 2<sup>nd</sup> Gear.

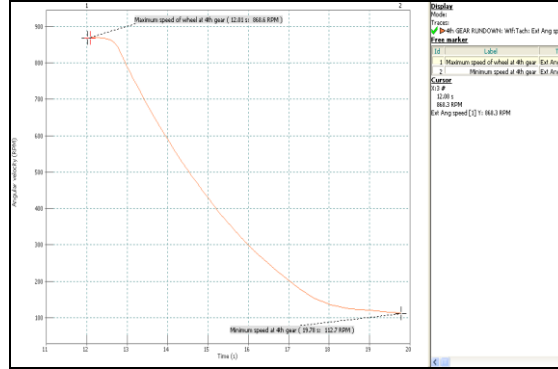


Fig.11. RUN DOWN plot showing the wheel speed from max direction during to min rpm at 4<sup>th</sup> Gear.

Table 4: Interferences made from Noise and Vibration data during Run Up.

Inferences from Noise data	Inferences from vibration data
Noise levels observed at the tabulated peaks are related to engine kinematics.	The vibration levels observed at the tabulated peaks are related to engine kinematics
The maximum noise level is observed at 16.75th Order, which is related to 3rd harmonic of firing order.	The maximum vibration levels are observed at 22.25th Order which is related to the 2X of the engine speed (i.e., the piston moves from TDC to BDC & from BDC to TDC , for each revolution of the engine crank shaft)vibration levels.

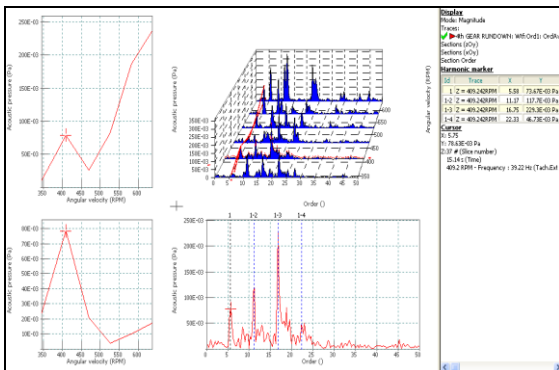


Fig.12. Waterfall spectra of noise from the bike during RUN DOWN at 4<sup>th</sup> Gear

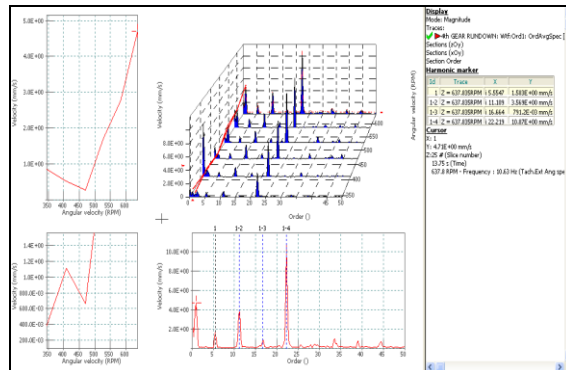


Fig.13. Waterfall spectra of vibration from the bike during RUN DOWN at 4<sup>th</sup> Gear

From the Noise water fall spectra (Table1.5) and waterfall spectra of vibration (Table 1.6), peaks are observed at the following orders

Table 5: Order representation for noise of RUN DOWN at 4<sup>th</sup> gear

Peak order	Order number	Remarks
1	5.75	Firing order of engine
2	11.25	Engine speed
3	16.75	3 <sup>rd</sup> harmonic of firing order

Table 6: Order representation for vibration of RUN DOWN at 4<sup>th</sup> Gear

Peak order	Order number	Remarks
1	1	Wheel speed
2	5.5	Firing order
3	11.25	Engine speed( 1x)
4	22.25	2 <sup>nd</sup> harmonic of engine speed



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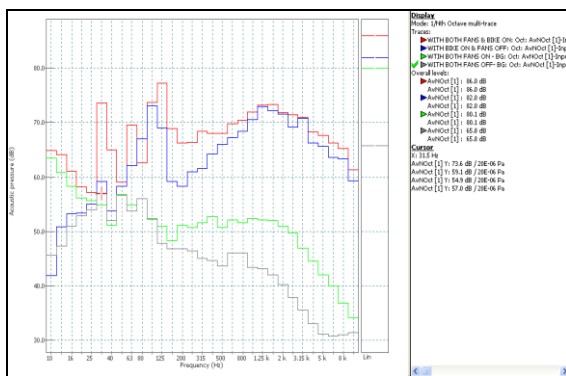
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Table 7: Interferences from noise and vibration data during run down at 4<sup>th</sup> gear

Inferences from Noise data	Inferences from vibration data
Noise levels observed at the tabulated peaks are related to engine kinematics.	The vibration levels observed at the tabulated peaks are related to engine kinematics
The maximum noise level is observed at 16.75th Order, which is related to 3rd harmonic of firing order.	The maximum vibration levels are observed at 22.25th Order which is related to the 2X of the engine speed (i.e., the piston moves from TDC to BDC & from BDC to TDC , for each revolution of the engine crank shaft).

## 3.2. Steady State Noise Measurement:



Legend:

**Black** – Background Noise level  
**Green** - Background noise with Fans ON  
**Blue** – Bike ON with Fans OFF  
**Red** – Bike ON with Fans ON

Fig.14. 1/3<sup>rd</sup> Octave noise spectra measured near the bike at 2<sup>nd</sup> Gear & at 4000 rpm

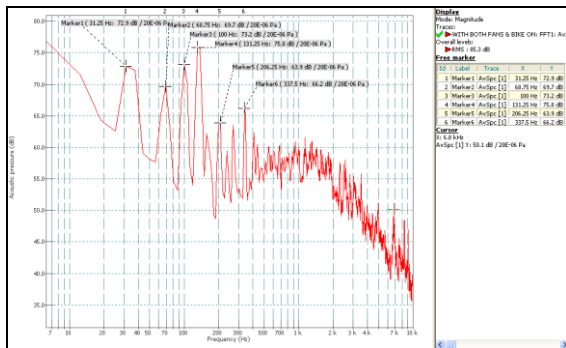


Fig.15. FFT Spectra at a location near **RHS** plan of the bike  
(X – Axis is given in Log scale from 0 to 10 kHz)

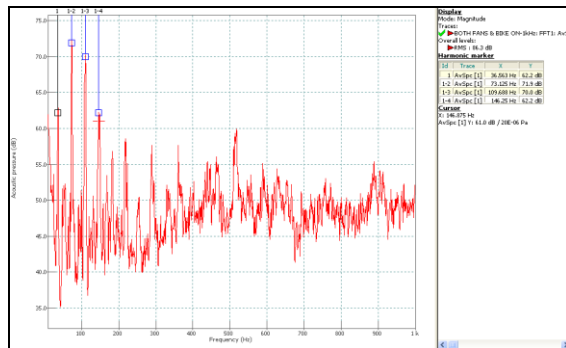


Fig.16. FFT **Zoomed Spectra** at the same location near RHS plan of the bike(X – Axis is given in linear scale from 0 to 1 kHz)

Table 8: Major Frequencies observed in the FFT spectra of Bike operating at 2<sup>nd</sup> Gear at 4000 rpm

Peak number	Frequency in Hz	1/3 <sup>rd</sup> Octave band	Remarks
1	36.563	30 Hz	Firing Frequency (Half of the Engine Frequency)
2	73.125	80 Hz	Engine Fundamental Frequency
3	109.688	100 Hz	Related to the third harmonic of the Firing frequency
4	146.25	160 Hz	Related to the 2 <sup>nd</sup> Harmonic of engine fundamental frequency & 4 <sup>th</sup> Harmonic of Firing frequency

Table 9: Interferences made from Fft spectra of bike at 2<sup>nd</sup> Gear at 4000 rpm.

Inferences from Noise data
Major noise levels are observed at the frequencies which are related to the engine kinematics.
Maximum noise level is observed at 73.125 Hz. This frequency corresponds to 4387.5 rpm, which is approximately equal to the engine throttling speed (fundamental frequency)
The noise levels are also observed at the harmonics of engine fundamental frequency beyond 200 Hz. Since the noise levels at these harmonics are lower .than the tabulated frequencies, they are not tabulated.

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### 3.3. Sound Intensity Measurements:

Inferences from overall sound intensity mapping & overall sound pressure mapping:

- From the sound pressure mapping spectrum (see Figure 1), it is found that the distribution of noise is scattered. This is because; the sound pressure is a scalar quantity as it considers the noise coming from all the direction and also the sound pressure depends not only on the noise source but also on the environment (reflection & background noise effects).
- From the sound intensity mapping spectrum, it is found that the distribution of noise is concentrated as the sound intensity is a vector quantity (depends on the direction of sound normal to the probe only).
- Acoustic hot spots can be pin pointed in sound intensity mapping spectrum than in the sound pressure mapping spectrum.

Hence, sound intensity mapping is preferred for further analysis. Further graphs show the sound intensity mapping spectrum at certain 1/3<sup>rd</sup> octave frequency bands. These are the bands in which, the engine kinematic frequencies are observed when the bike is operated at 4000 rpm & at 2<sup>nd</sup> gear. (Black spots indicate negative intensity).

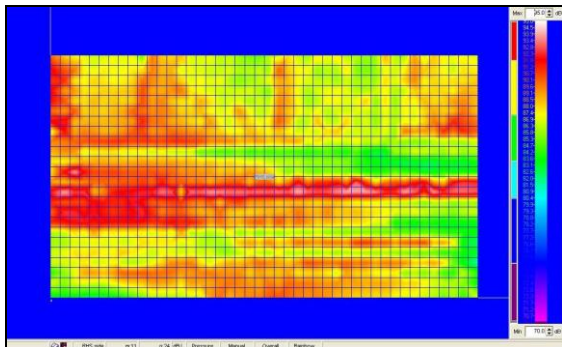


Fig. 17: Sound Pressure mapping – Overall sound pressure distribution

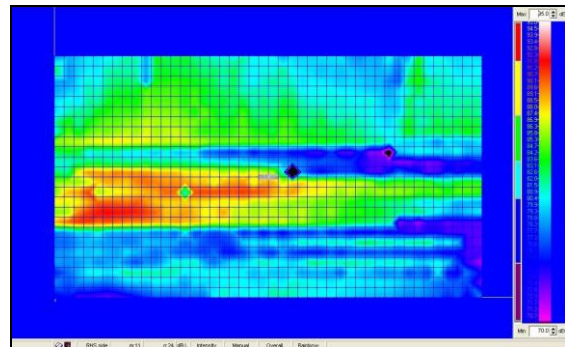


Fig.18. Sound Intensity mapping - Overall sound intensity on RHS plain

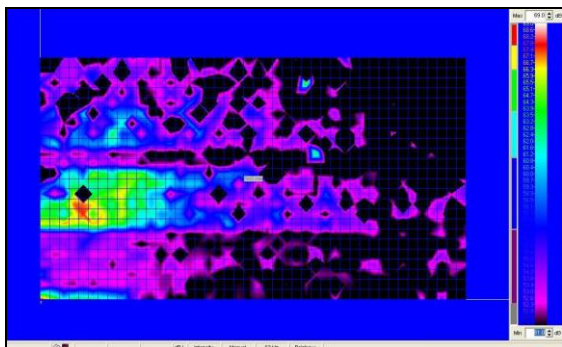


Fig. 19. Sound intensity mapping spectrum at 50 Hz band

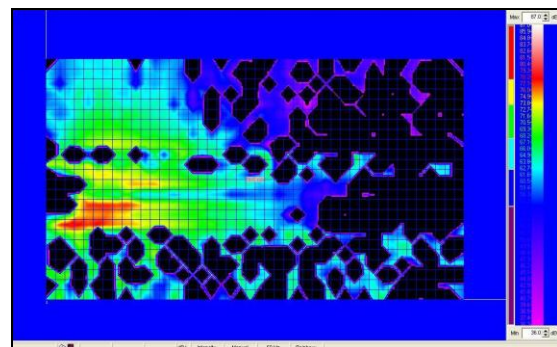


Fig. 20. Sound intensity mapping spectrum at 63 Hz band

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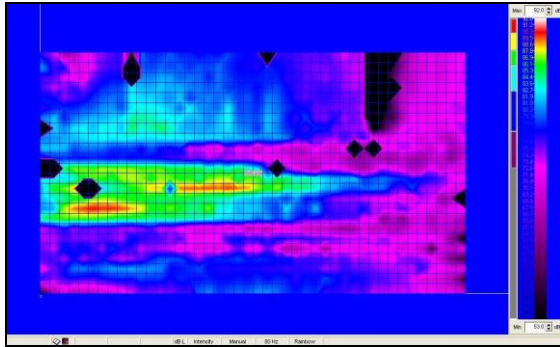


Fig. 21. Sound intensity mapping spectrum at 80 Hz band

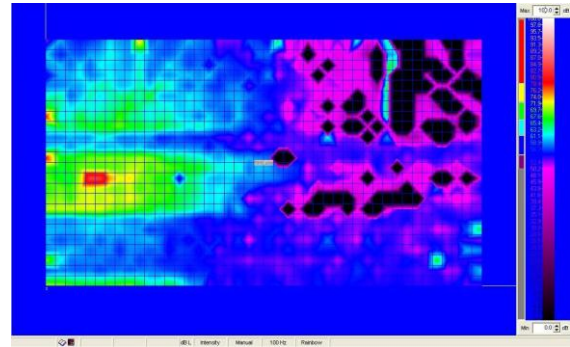


Fig. 22. Sound intensity mapping spectrum at 100 Hz band

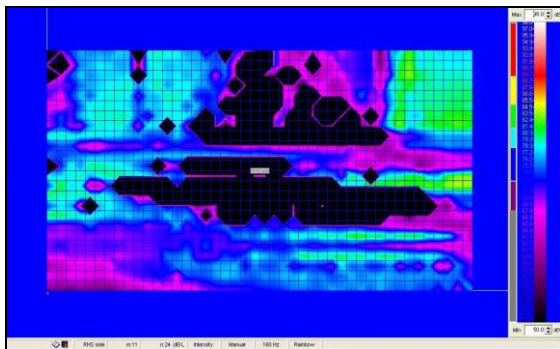


Fig. 23. Sound intensity mapping spectrum at 125 Hz band

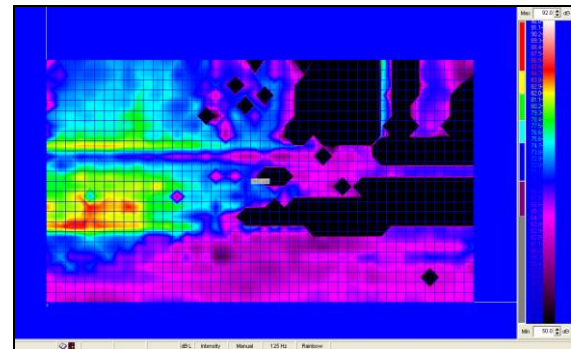


Fig. 24. Sound intensity mapping spectrum at 160 Hz band

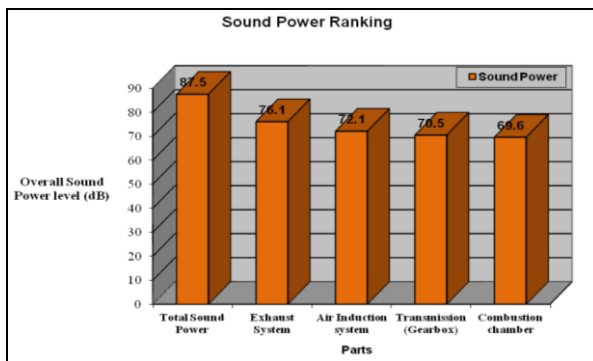


Fig.25. above bar chart signifies sound power of components in bike

S. No.	Part	Overall Sound Power Level (dB)
1	Combustion Chamber	69.6
2	Transmission (Gearbox)	70.5
3	Air Induction System	72.1
4	Exhaust System	76.1
Total		87.5

Table 10: Overall sound power of each component

Table 11: Total sound pressure and sound power level for 1/3<sup>rd</sup> octave band frequencies

1/3 <sup>rd</sup> Octave Frequency (Hz)	Total Sound Pressure Level in dB	Total Sound Power Level in dB
50	67.4	68.1
63	60.0	59.2
80	83.3	84.1
100	66.5	66.9
125	77.0	77.1

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160	82.6	78.5
200	67.0	65.4
250	67.6	66.1
315	70.5	67.2
400	70.2	68.3
500	74.4	72.1
630	71.9	69.3
800	73.7	71.9
1000	73.6	72.1
1250	74.2	72.7
1600	74.8	73.5
2000	73.3	71.8
2500	72.7	71.4
3150	71.8	70.5
4000	68.0	66.0
5000	68.3	66.7
6300	67.2	65.6
8000	64.9	63.4
10000	61.0	58.8
<b>Overall</b>	<b>88.5</b>	<b>87.5</b>



Fig.26. Profile of noise source component

## IV. CONCLUSIONS

It is concluded that the “*sound intensity technique*” is the best technique to obtain “*noise measurement*” results, when compared pressure method. The process can be used to carry out noise measurement in any field such as multiple noise source machinery or any environment and to assess the noise control measurement effectively. So that, if the efforts carried out to control noise are good enough to reduce undesired noise level can be decided by carrying out the noise measurement using sound intensity technique followed by the noise control measurement. Sound power calculations revealed to rank multiple noise sources based on their levels of sound power. The output is directly obtained from the software (NV Gate) when sound intensity technique is used avoiding the tedious calculations manually. It was found that the exhaust system had highest sound power whereas the combustion chamber had the least. The intensity spectrum also reveals that the hot spots are concentrated around the exhaust system which matches with the sound power ranking data. This is a proof to the fact that sound intensity technique is valid method to carry out noise measurement.



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From the Run-up and Run-down measurements we infer that noise levels observed at tabulated peaks are related to engine kinematics. The maximum level noise level observed is related to the engine shaft speed. These results are also obtained from the waterfall spectra and we can correlate the noise levels to the engine. There was no resonant frequency found corresponding to the vibration calculations. Major noise levels are observed at frequencies which are related to engine kinematics.

From the steady state noise measurements we infer that the background noise in the environment if steady, the noise measurement can be carried out by using the sound intensity technique. The steady state results are obtained thus the effect of background noise can be obtained and comparison can be made by eliminating the effect of background noise. Steady state measurements also reveal that the major levels of noise are generated at the frequencies related to the engine kinematics. Hence, maximum noise level generated corresponds to the engine throttling speed. Acoustic hot spots are pin pointed in sound intensity mapping spectrum than in the sound pressure mapping spectrum.

Its results are very useful in the automobile firms to NVH (Noise, Vibration Harshness) team which perform analysis on sub systems of an automobile and also quantify the aesthetics of the vehicle (Luxury Cars). Finally, noise analysis can also be useful in determining the permissible limits of a safe working environment to protect the flora and fauna of the mother earth.

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