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Noise and Vibrations Measurement Techniques

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Abstract: Fast development of technology over the last decades has contributed to the adverse effects that may affect human health (both physical and mental). Such negative effects may include noise and vibration. These phenomena are accompanied by most of the technological processes. The main goal of this paper is to identify the different sources that cause noise and vibrations in the vehicles and identifying the measurement techniques in reducing the noise inside the vehicle body so as to achieve less or zero noise level.

This paper will also cover the instruments being used for measurement of sound, acceleration and vibrations in NVH studies.
Keywords: Design, CAD, FEM, Frequency, Noise, Vibration, Harshness, absorber, vibro-acoustic materials, cabin, Transducer, Vibrometer etc.

I. INTRODUCTION

Noise, vibration, and harshness (NVH), also known as noise and vibration (N&V), is the study and modification of the noise and vibration characteristics of vehicles, particularly cars and trucks. While noise and vibration can be readily measured, harshness is a subjective quality, and is measured either via "jury" evaluations, or with analytical tools that provide results reflecting human subjective impressions.

Both vibrations and noise have negative impact on human safety and health. These effects may cause:

1) Balance disorder (motion sickness),
2) Neck and occiput area pain common among professional drivers.

These factors cannot be underestimated, because the consequences have unquestionable impact on human health and safety. Excessive noise affecting the human body has an influence on human's health, the functions of the organs and systems, in particular the ear. Noise impacts not only the ear, but also other organs by the central nervous system. Influence of noise has an important role on psychological and mental efficiency, and also quality of the work, and of course driving. Low noise level in the cabins is a comfort parameter of high importance. Since all most all places of work are subjected to regulations in the noise area, defining the maximum noise level a worker is allowed to be exposed to, the topic has become interesting.

II. NVH MEASUREMENT TECHNIQUES

Sound changes its frequency and phase when source of them is in move against destination (or both in move). This is set when the source is moving relative to the observer and the observer is moving relative to the source. In the case of light the same phenomenon is observed. Laser Doppler vibrometry allows for direct measurement of vibration velocity and displacement. LDV system is showed on Fig. 1. Laser head is a transceiver device. Inside it there is the source of laser, interferometer and the layout of the lens. In the head, light uncouples into two components. The first one is the reference beam, which going by Bragg cell moves the beam of frequency of (about and generally) 40 MHz It is driven on the photo detector. This process allows for the measurement of the constant component and the direction of movement of object. The second component of the light is set on object. After reflection from our element beam measuring returns to the head of the vibrometer and on the photo detector. This way, we can achieve an accurate measurement of the displacement and the velocity of transverse test object. [1]

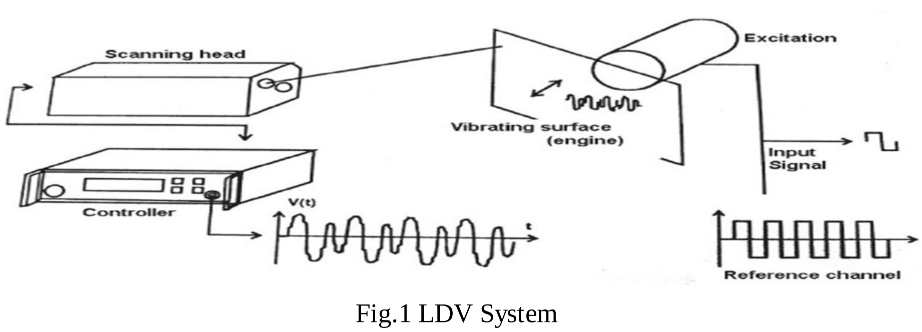

Fig.1 LDV System

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The Fig 2 below gives an idea about single channel measurement system which includes variety of different instruments used in measuring noise and vibrations.

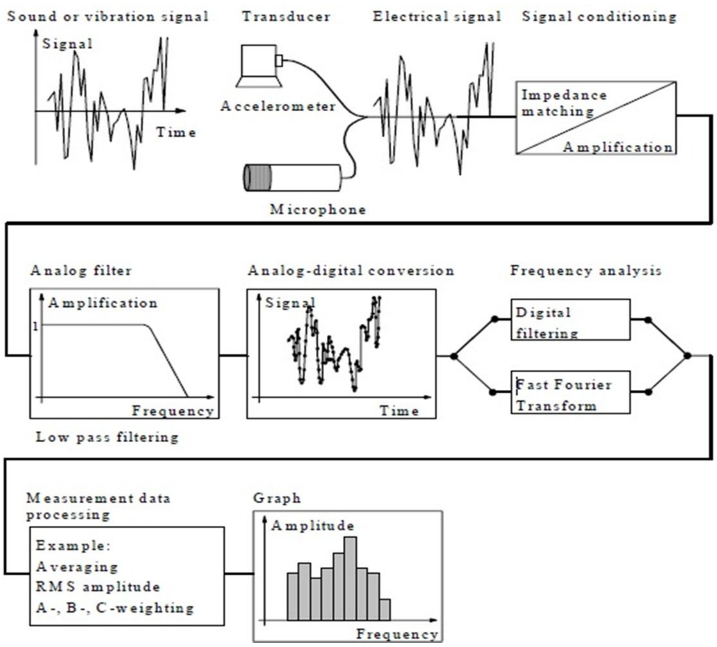

Fig 2. Flow chart of digital single –channel measurement system.

The nature of sound and vibrations to be measured can vary widely. Sound can be "noisy" (roar or hiss-like), like that from a heavily trafficked highway, while vibrations of a machine are often dominated by the rotational frequency and its multiples. A machine under constant loading gives off a stationary noise, while the noise at an airport tends to be intermittent. Moreover, the purpose of measurements varies. The commonly monitored vibration signals are displacement, velocity, and acceleration. The measurement systems that are marketed today are primarily digital, i.e., sound pressure and vibrations are converted into digital values for later treatment in more or less advanced signal processors. While digital technology offers ever more sophisticated possibilities, measurement systems are nevertheless often adapted to be able to compare measurement results with those obtained in the past using analog technology. Digital measurement systems have a more complicated structure than analog ones.[2]

The types of transducers that are most commonly used in vibroacoustics are microphones to measure sound pressure, accelerometers to measure accelerations of solid structures, and force transducers to measure forces on solid structures. Some of the instruments used in measuring noise and vibrations are:

1) Accelerometer
2) Velocity Transducers
3) Displacement Transducers
4) Microphones

Many types of measuring systems can be used for the measurement of sound depending on the purpose of the study, the characteristics of sound and the extent of information that is desired about the sound. Another example is of the sound level meter as shown in fig 3.

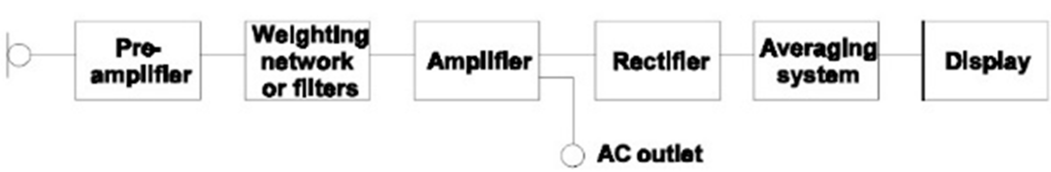

Fig 3. Sound level meter block diagram.

The electrical signal from the transducer is fed to the pre-amplifier of the sound level meter and, if needed, a weighted filter over a specified range of frequencies. Further amplification prepares the signal either for output to other instruments such as a tape recorder or for rectification and direct reading on the meter. The rectifier gives the RMS value of the signal. The RMS signal is then exponentially averaged using a time constant of 0.1 s ("FAST") or 1 s ("SLOW") and the result is displayed digitally or on an analog meter. In some cases, the sound level meter does not include a logarithmic converter. The scale on the indicating device is then exponential so that the linear signal may be read in dB. In this case, the dynamic range of the display is usually restricted to 10 to 16 dB and the precision of the reading is rather poor. In the case of intermittent noise, the user must constantly adjust the amplifier to adapt the output signal to the dynamic range of the display.

When a log converter is used, the display scale is linear in dB and its dynamic range is usually much greater. This type of display has the advantage of providing the same precision at any level and permitting a much better appreciation of the range of fluctuations of the noise to be measured. In this regard, digital displays are less useful. The specifications of sound level meters are given in IEC 60651 for four types 0, 1, 2, 3 differing by the measurement precision. The measurement precision is reduced as the type number increases, affecting manufacturing costs significantly [3]. The instruments used in this method are:

1) Microphones
2) Frequency analyzers
3) Noise dosimeters
4) Recorders
5) Calibrators.

The performance characteristics of sound measurement instruments are quantified by:

Frequency Response - Range of frequencies over which an instrument reproduces the correct amplitudes of the variable being measured (within acceptable limits).

Typical Limits over a specified frequency range:

Microphones ± 2dB

Tape Recorders ± 1 or ± 3 dB

Loudspeakers ± 5 dB

a) *Dynamic Range*: Amplitude ratio between the maximum input level and the instrument’s internal “noise floor” (or self noise). All measurements should be at least 10 dB greater than the noise floor. The typical dynamic range of meters is 60 dB, more is better.
b) *Response Time*: The time interval required for an instrument to respond to a full scale input, (limited typically by output devices like meters, plotters)
c) *White Noise*: Is defined as having the same amplitude at all frequencies (radio static, or a jet of compressed air are pretty good approximations). It is often used as a known input to a system, in order to determine the system’s frequency response.
d) *Pink Noise*: Is specifically designed to yield constant amplitude across all octave bands. On a linear scale, it decreases in amplitude as frequency increases in just the right amount (-3 dB/octave) to compensate for the increasing widths of the octave filters [4].

An environment that spreads sound sensation from quivering body to ear, it is mostly air. Vacuum is the only environment that cannot spread noise. The unit bel (B) is used to express sound intensity level, but mostly its tenth – decibel (dB) [5].

Examples of sound intensity:

20 dB – whisper,

50 dB – conversation,

60 dB – rush street

90 dB – motorcycle,

110 dB – rock concert

120 dB – jet aeroplane

Measuring devices

i) *Sound Level Meter:* This digital device is used to record sound between 30 – 130 dB to ± 1.4.
ii) *Video Car Recorder*: It is used to record the position, acceleration in 3 axles and instantaneous velocity.

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Piezoelectric accelerometers commonly used for vibration measurement are not well suited for the analysed frequency range. Hence, other sensors capable of measuring accelerations down to the sub-Hertz region have to be used. MEMS acceleration sensors are particularly suitable for such purposes.

The compact vibration measuring system consists of the following parts [6].

Two identical three-axial MEMS accelerometers;

An analogue acquisition unit with a USB output;

A standard laptop with an acquisition program.

A. Selection Of Accelerometer

An accelerometer is an electromechanical transducer which produces at its output terminals, a voltage or charge that is proportional to the acceleration to which it is subjected. Piezoelectric accelerometers exhibit better all-round characteristics than any other type of vibration transducer and are more-or less universally preferred for measurements covering a wide frequency range.

The heart of the accelerometer is its piezoelectric elements which are usually made from an artificially polarized ferroelectric ceramic. These piezoelectric elements have the property of producing an electrical charge which is directly proportional to strain and thus the applied force when loaded either in tension, compression or shear! In practical accelerometer designs the piezoelectric elements are arranged so that they are loaded by a mass or masses and a preloading spring or ring. When subjected to vibration the masses exert a varying force on the piezoelectric elements which is directly proportional to the vibratory acceleration. For frequencies lying well under the resonant frequency of the assembly, the acceleration of the masses will be the same as the acceleration of the base, and the output signal level will be proportional to the acceleration to which the accelerometer is subjected.

Two accelerometer configurations are in common use, the compression and the shear types which are shown in the schematic drawings in Fig.4

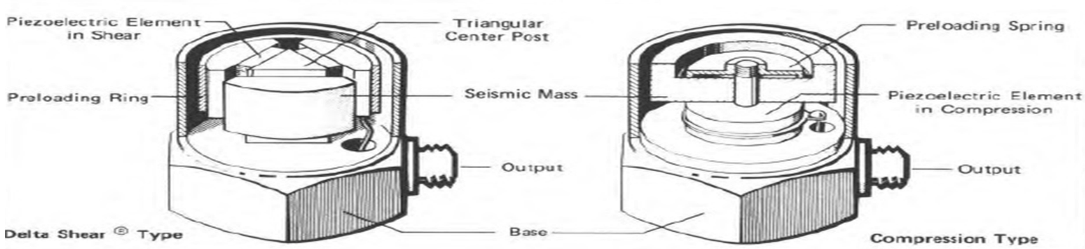

Fig. 4 The two accelerometer configurations

Following table in Fig.5 indicates the application and main characteristics of the B & K accelerometer range [7].

Accelerometer Type		Weight (gram)	Charge Sensitivity (pC/ms^{-2})*	Mounted Resonance Frequency (kHz)	Important Characteristics	Application Areas
4366	△	28	~ 4,5	27	Delta Shear® Construction having good all-round characteristics and particularly low sensitivity to temperature transients and base strains	General shock and vibration measurements. Vibration testing and control.
4367	△	13	~ 2	32		
4368	△	30	~ 4,5	27		
4369	△	14	~ 2	32		
4371	△	11	1 ± 2%	35	Delta Shear® types as above. Also have Uni-Gain® sensitivity for simple system calibration and Interchangeability	
4370	△	54	10 ± 2%	18		General vibration measurements. High sensitivity for low-level measurements
4375	△	2 excl. cable	~ 0,3	60	Miniature size, low weight Delta Shear® type. High resonance frequency	High level and high freq. vibr. measurements. Ideal for delicate structures, panels etc. and in confined spaces
4374	△	0,7 excl. cable	~ 0,1	75	Submiature size, low weight shear type. Very high resonant frequency	
8309	□	3 excl. cable	~ 0,004	180	Miniature size. Integral fixing stud. Integral cable.	Shock measurements up to 1 million ms^{-2} High frequency vibr. measurements
4321	△	55	1 ± 2%	40	Three Delta Shear® Uni-Gain® accelerometers combined in one unit	Vibration measurements in three mutually perpendicular directions
8305	□	40	~ 0,12	30	Quartz element for high stability. Laser calibrated to ± 0,5% accuracy	Reference standard for comparison calibration of accelerometers
8306	□	500	1000	1 kHz LP filter built in	Very High Uni-Gain® sensitivity. Built-in Preamp and LP filter. Requires 28V 2mA DC power supply	Ultra low-level (down to 0,000 002 g) and low freq. vibration measurements on large structures
8308	□	100	1 ± 2%	30	Robust-construction. Balanced Uni-Gain® output. Max. Temp. 400°C	Permanent vibration monitoring. High temp. vibr. measurements. Aeronautical, industrial and nuclear use. Used with preamp. Type 2634
8310	□	100 excl. cable	1 ± 20%	30	As Type 8308 but with integral high temp (800°C) cable	

Fig. 5 Main characteristics and application areas for B & K accelerometers

B. Frequency-Measuring Instruments

Most frequency-measuring instruments are of the mechanical type and are based on the principle of resonance. Two kinds are discussed in the following paragraphs: the Fullarton tachometer and the Frahm tachometer.

Single-Reed Instrument or Fullarton Tachometer:. This instrument consists of a variable length cantilever strip with a mass attached at one of its ends. The other end of the strip is clamped, and its free length can be changed by means of a screw mechanism as shown in fig 6(a).

1) *Multireed-Instrument or Frahm Tachometer*: This instrument consists of a number of cantilevered reeds carrying small masses at their free ends (see Fig. 6(b)). Each reed has a different natural frequency and is marked accordingly. Using a number of reeds makes it possible to cover a wide frequency range.

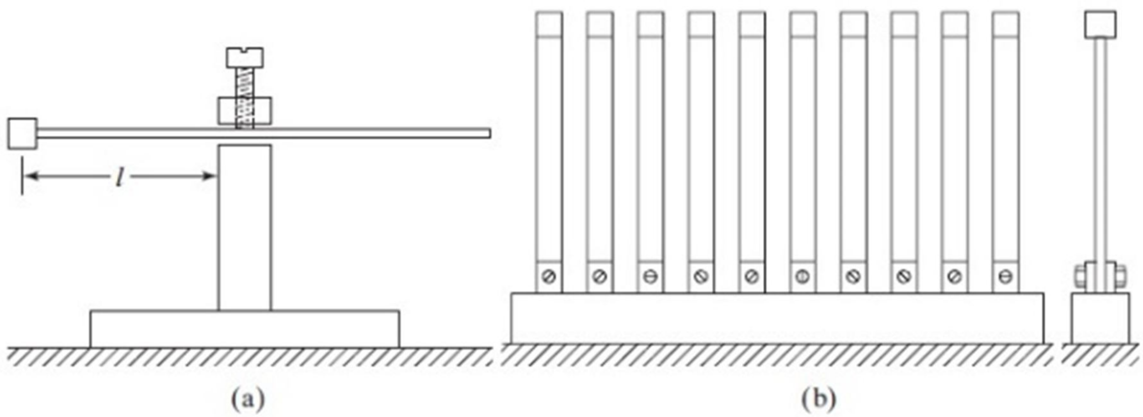

Fig 6. Frequency Measuring Instruments

C. Vibration Exciters

The vibration exciters or shakers can be used in several applications such as determination of the dynamic characteristics of machines and structures and fatigue testing of materials. The vibration exciters can be mechanical, electromagnetic, electrodynamic, or hydraulic type. The working principles of mechanical and electromagnetic exciters.

The schematic diagram of an electrodynamic shaker, also known as the electromagnetic exciter, is shown in Fig. 7.

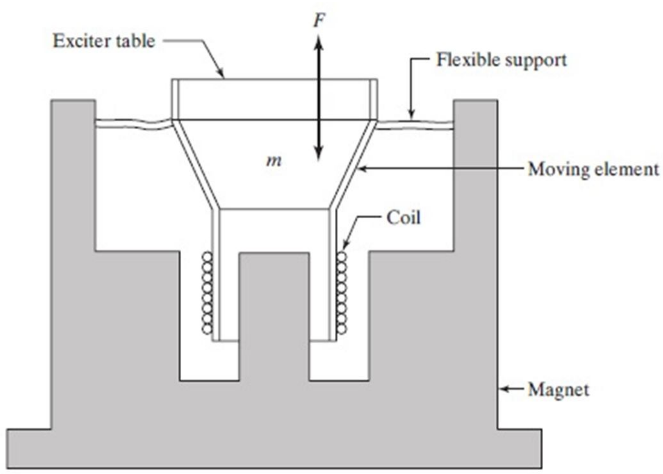

Fig 7. Electrodynamic Shaker

The electrodynamic shaker can be considered as the reverse of an electrodynamic transducer. When current passes through a coil placed in a magnetic field, a force F (in Newtons) proportional to the current I (in amperes) and the magnetic flux intensity D (in teslas) is produced which accelerates the component placed on the shaker table [8].

$$F = DIL$$

where L is the length of the coil (in meters).

III. CONCLUSIONS

A. Frequency may have an implications for the health and comfort of vehicle travellers. The maximum vibration velocities are higher in case of the vehicle equipped with diesel engine.

B. In order to maintain high standard of measurement quality, test of measurement system should be *calibrated* regularly.

C. Measuring instruments should not be exposed to vibration for obvious reasons. This implies that they should always be stored, handled and transported in their original box with damping materials such as plastic foam around them. Measuring instruments should be protected against dust. Portable instruments such as sound level meters, and dosimeters, when not used, must be stored in their box.

D. The manual of each instrument might give special instructions concerning its handling, the storage and the maintenance. Needless to say that this must not be overlooked but must be practised during the entire life of the instrument.

E. Commercial vehicles give more noise compared to family cars which have separate luggage compartment. This will help to reduce the noise in the vehicle and then increases driving comfort.

F. For the three-axial vibration measurement an apparatus from commercially available MEMS acceleration sensors was developed to have instrumentation for field measurements of vibrations at a reasonable cost without the need of specialised equipment.

G. It is good policy always to check the "*back ground noise*" level of a vibration measurement system. This can be done by mounting the accelerometers on a non-vibrating object and measuring the "apparent vibration level of this arrangement.

H. To obtain reasonably good accuracy in the actual vibration measurements the “*apparent*" vibrations should be less than one third of the measured vibrations. Or said in other words: The noise "floor" of the installation should be at least 10 dB below the vibration levels to be measured.

IV. SCOPE FOR FUTURE WORK

Present research is focussing on development of user-friendly commercial vehicle cabin which must have less or zero noise inside the cabin. For this a structural acoustic model have to be established and the response of the sound pressure in frequency domain is obtained by using finite element method. A suitable noise and vibration measurement technique and instruments are used. The frequency generated at all panels inside the cabin are measured and highest sound pressure is considered for the optimization studies. The baseline FE model will be used for further design iterations and virtual testing is performed. By performing this virtual test, the final design configuration can be achieved and the final physical test is carried out to verify the deign performance. Hence, for study of any noise and vibration aspects experimentally, a suitable measuring technique is necessary and the corresponding instruments are to be calibrated before use to get better accuracy.

V. ACKNOLODGEMENT

The study is for improving commercial vehicle cabin interiors to reduce noise and improve driver health and performance. The authors would like to thank all the staff for their support and guidance in making this work and paper.

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