Institute of Sound and Vibration Research

Progress Report on the Development of a Transducer to Measure the Volumetric Acceleration of Panel Regions

P. Godano and F.J. Fahy

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UNIVERSITY OF SOUTHAMPTON

INSTITUTE OF SOUND AND VIBRATION RESEARCH

FLUID DYNAMICS AND ACOUSTICS GROUP

Progress Report on the Development of a Transducer to Measure the Volumetric Acceleration of Panel Regions

by

P Godano and F J Fahy

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Authorized for issue by
Professor P A Nelson
Group Chairman

Abstract

The following document describes a new transducer currently under development at ISVR which spatially integrates the normal vibrational acceleration of panel regions. This transducer would be extremely useful for determining the contributions of regions of bodywork in the total noise at the driver's ear inside a car. A survey of the commercial transducers currently available shows that, at low frequency (typically 50 to 400Hz), there is no device which is really practicable for this purpose. As mentioned towards the end of the memorandum, this new device is still at the prototype stage and so, it needs to be improved in term of practicality. Calculations have also to be performed in order to fully understand the way the device works and to quantify the effects of different parameters on its performances.

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1. Introduction

To minimise the noise level inside cavities such as truck or car cabs at low frequencies (50 to 400 Hz) it can be very helpful to determine the contributions of the different components within the enclosure. Individual contributions can be identified by measuring the pressure inside the cavity when all the internal surfaces (except the regions under investigation) of the enclosure are covered by some absorbent material and a heavy sheet. This method has the following shortcomings: at low frequencies the efficiency of the close covers is low, and the process is slow and tedious. Another method to determine individual contributions consists of multiplying the volumetric acceleration of the sources (small regions of the enclosure) by the vibroacoustic transfer function from these sources to the point of interest (for example the driver's ear). This method is best used at low frequencies where the elementary areas are large, otherwise it becomes again very tedious. The most difficult part of this general method is to determine the volumetric acceleration of the source. Indeed the vibroacoustic transfer functions are usually easily measured reciprocally. This determination has to be experimental because of the complexity and uncertainty of modelling a real structure such as car bodywork. The experimental methods can be direct or indirect. Indirect methods require many measurements and the inversion of matrices amplifies measurement uncertainties and errors. Direct methods assume that it is possible to directly measure the volumetric acceleration of the surface source. The next section discusses the practicality of the currently available transducers for use in determining the strength of sources.

2. Currently available transducers

The measurement of vibration levels on structures is currently performed either with accelerometers attached to the vibrating surface or with a laser (Laser Doppler Velocimeter or LDV) which utilises a beam of laser light which is scattered from the surface. Theoretical and experimental studies have demonstrated that these transducers, which measure vibration at individual points, are not entirely suitable for quantifying vibro-acoustic sources because of discrete sampling and spatial (wavenumber) aliasing errors, together with some practical difficulties in application to operating systems.

Accelerometers are contact devices and can only detect vibration at the point where they are attached. They must be removed and reattached at many points in order to make a full surface survey. This can be partly avoided with a multi-channel acquisition system and a large number of accelerometers, but not everybody can afford it and it also requires a lot of discipline and organisation from the operator. Accelerometers cannot be used on surfaces of soft materials such as car floor carpets or on surfaces contaminated by fluids. It is also difficult to attach them to very rough surfaces. In addition, the mass of an accelerometer produces a bias error in the estimated vibration level by inertially loading the surface on which it is attached. This effect is particularly severe in the case of surfaces of light-weight structures such as aircraft skin panels or of surfaces with very low stiffness like a rubber sheet.

LDVs are non-contact devices which are mounted on support constructions and do not load the surface where they are positioned. Unlike accelerometers, they require a motionless support construction which is sometimes extremely difficult to provide, for example in a moving vehicle. LDVs may be scanned over a surface to generate an image of the spatial distribution of the surface vibration but cannot generate a signal proportional to the surface integral of instantaneous vibration velocity. Scanning LDVs are extremely expensive as compared with accelerometers, costing many tens of thousand of pounds. LDVs cannot accurately detect the vibration of very irregular, light-scattering surfaces such as carpets or other highly textured surfaces.

More recently a new transducer, developed at ISVR by Dr. K. Holland and Prof. F. Fahy, has been introduced. This device, known as a Volumetric Velocity Transducer (V.V.T.), consists of a tube with an anechoic termination. Below the lowest cut-off frequency of the tube, the signal given by the microphone inside the tube is directly related to the spatial integration of the vibration velocity of the source located close to the opening of the tube. This device is best used in the mid frequency range where its dimensions are not too large.

So, at the moment there is no cheap, rugged, compact, portable, non-contact transducer which acts as a spatial integrator and wavenumber filter of surface vibration at low frequency.

3. General description of the new transducer

The new transducer is based on the Euler equation which states that the nearfield pressure gradient normal to a vibrating surface is proportional to the vibration acceleration of the structure (it is called the Volumetric Acceleration Transducer or V.A.T.). This equation is fundamental in acoustics and is extensively used in modelling. This has already been used in the past for experimental purposes, sometimes with the two-microphone technique (Forsen and Crocker[1] and Pascal[2]) and sometimes with the three-microphone technique (Loyau[3] and recently Le Louarn and Barbeau[4]). These methods have failed to become popular because of a lack of practicality and the inherent problems due to the distance between the surface and the centre point of the probe; there is a systematic error and an error due to extraneous noise.

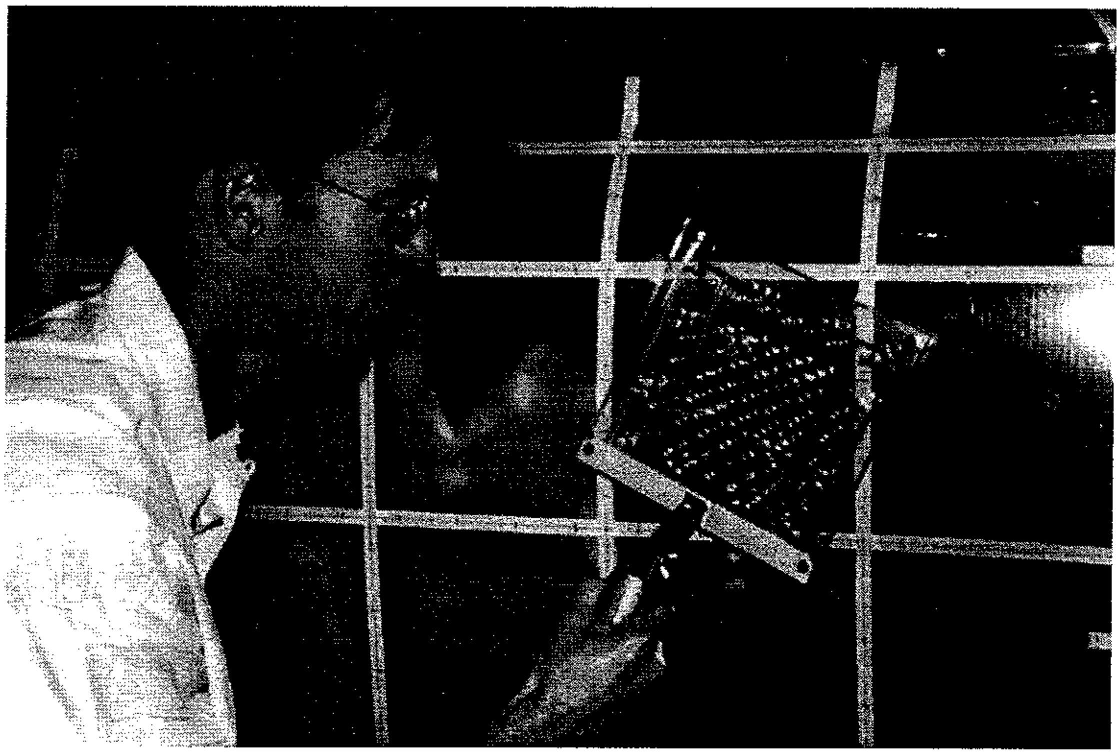

Fig. 1 *General view of the transducer*

Unlike the previous probe, either with two or three microphones, the V.A.T. spatially integrates the vibration of the source by the use of an array of miniature microphones embedded in a perforated sheet (see Fig. 1). The perforated sheet rigidly supports the microphones and amplifies the difference of pressure between the two layers of microphones by controlled diffraction and so increases considerably the sensitivity of the device (this amplification is very directional: it is maximum for a wave normal to the device and minimum for a wave parallel to the sheet). Then, the distance between the two layers of microphones can be minimised to decrease the stand-off distance and to give a light and compact device. The errors described above are reduced by the small stand-off distance and by the fact that the large wavenumber waves contribute less in the total value of the volumetric acceleration than the small wavenumber waves for which the error stays small (see Fahy[5]).

As shown in Fig. 1, the transducer is portable. It is a non-contact transducer and because the high wavenumber waves do not radiate and generate acoustic evanescent waves, it behaves like a low-pass filter in the wavenumber domain (no aliasing).

4. At what stage is the development of the transducer?

The transducer held by the operator in Fig. 1 is the second prototype built since the beginning of the PhD. The first prototype was the culmination of the first part of the study which aimed to show the feasibility of the idea. This first part was sponsored by Renault trucks. Later a second prototype was ordered by Daimler-Benz and is currently used by Mercedes to determine the contributions of the windows of their cars to the total noise at the driver's ear. This device has been tested on a 1 mm steel plate excited mechanically (square panel region of 200 mm by 200 mm). Comparison between the measurement with the new transducer and the sum of 100 measurements given by an LDV shows excellent agreement (see Fig. 2). The idea of using a perforated sheet, which constitutes the originality of the concept, has been patented.

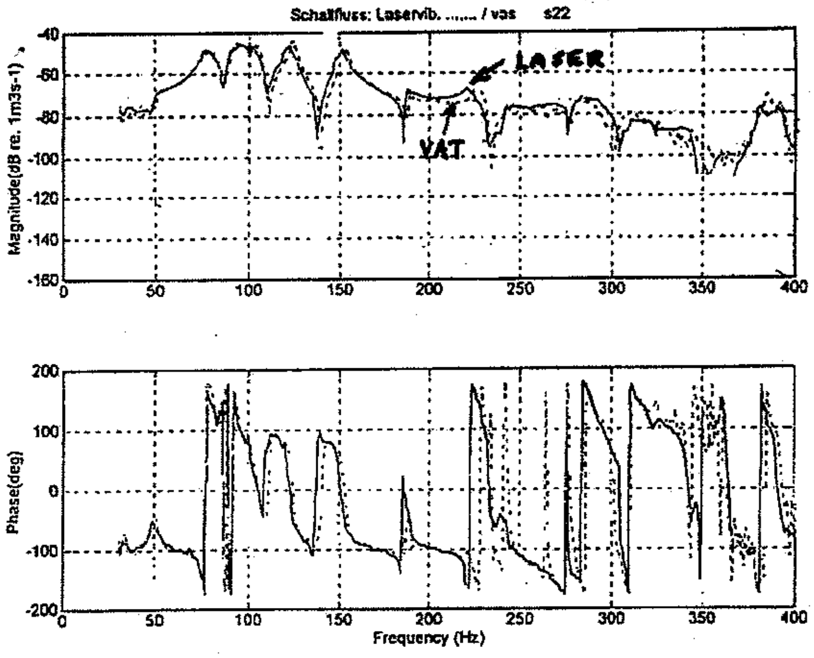

Fig. 2 *Comparison between spatially-integrated multi-point laser measurement and single V.A.T. measurement on vibrating panel (courtesy of Daimler-Benz)*

5. Future work

Most of the work has already been done: the concept has been validated. There is now a need to "optimise" the device and to quantify the sensitivity and the effect of a number of parameters (what happens if the thickness of the sheet is increased or if the diameter of the holes is decreased?). To answer these questions a boundary element model of the perforated sheet has been started. With the model, different configurations are going to be tested with different vibration fields. In order to simplify the electronic, pressure gradient microphone are tested instead of the usual two-microphone configuration to reduce costs, weight and improve the reliability. At the moment an optical sensor is also being tested, which could help the operator to locate the device at the proper distance of the source. To summarise, we want a better understanding, more simplicity in the design of the transducer and even more practicality.

6. References

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