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Characterisation of valves as sound sources: Fluid-borne sound

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ABSTRACT

The sound pressure level in receiving rooms, caused by taps at the ends of pipe systems, is considered. The structure-borne sound power, from the pipes to the supporting wall, was obtained from intensity measurement of the fluid-borne sound power of the tap. The fluid-borne sound power is combined with a ratio of structure-borne sound power to fluid-borne sound power, obtained from laboratory measurements of similar pipe assemblies. Alternatively, a reception plate method is proposed, which avoids the necessity for intensity measurements. The structure-borne power into walls, to which the pipe work is attached, provides input to the standard building propagation model, which yields the predicted sound pressure level in the adjacent room.

1. Introduction

In a companion paper [1] the role of structure-borne transmission in the sound emission of water appliances in buildings has been discussed. Methods are proposed for the characterisation of valves and taps as sources of structure-borne sound. The case considered is that of taps on basins, where the running tap generates reactive forces, which energise the basin into vibration. The basin then transmits structure-borne sound into the supporting wall, which radiates sound into the adjacent room.

The focus of this paper is on the fluid-borne emission that forms another component of sound emission from water taps; airborne emission is not considered. Fig. 1 (taken from [1] for completeness) indicates that noise in buildings, resulting from fluid-borne sources, is the result of the following processes: fluid-borne sound emission into the fluid column; fluid–structure interaction, i.e. energy flow from the fluid into the pipe wall; structure-borne transmission from the pipe wall through connectors to building elements; propagation through the building and radiation into the room of interest. These four processes were considered in developing the source characterisation adopted and are described in this paper in the same order.

2. Fluid-borne sound emission

The fluid-borne sound emission, from a tap into a water-filled pipe, is influenced by the impedance of the water column. In order to obtain an independent source characterisation, on a power basis, the effect of pipe material, thickness and diameter, and of pipe length and junction boundary conditions, must be considered. If pipe material, thickness and diameter are fixed, then a source characterisation may be obtained for that particular pipe work, if the effect of resonances in the fluid column and due to the pipe length and junction boundary conditions can be removed or circumvented. Two approaches were considered. The first involved the design of a non-reflective end condition in order to simulate a semi-infinite fluid column. The second involved signal post-processing to eliminate reflection effects. Both approaches were applied to a sound intensity measurement technique.

Sound intensity has been widely used, particularly for airborne-sound sources [2] and has also been applied successfully for fluid-borne sound sources [3] even to the extent of becoming a standardized method [4]. Constant or controllable operating *conditions* are required. This, in turn requires a specified test environment and the knowledge of possible sources of error within the measurement system. These are now discussed, followed by a description of the implementation of sound intensity for water appliances, along with measurement results.

2.1. Operating conditions

Operating conditions, such as flow rate, water pressure and temperature, influence the acoustic emission of taps and valves. In general, it is necessary to control these parameters and keep them at steady levels during acoustical measurements. A water supply system was constructed, shown in Fig. 2, with several operating modes possible: at a constant pressure, volume flow, or

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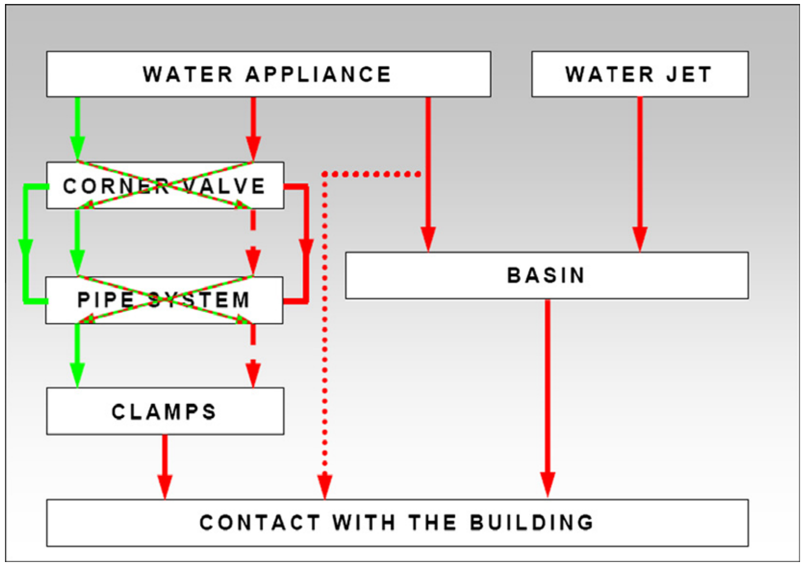

Fig. 1. Sound transmission from water appliances: Structure-borne sound transmission shown in red; fluid-borne sound transmission shown in green. Secondary structure-borne sound shown as dashed lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

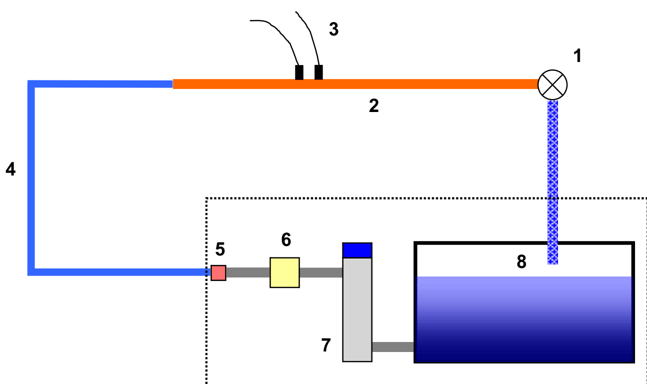

Fig. 2. Measurement rig for fluid-borne sound power: 1 valve/tap under test; 2 copper pipe; 3 pressure transducers; 4 flexible pipe; 5 pressure gauge; 6 flow meter; 7 high-pressure inline pump; 8 water tank.

pump speed. A high-pressure inline pump generated pressures up to 0.6 MPa. The temperature in the water tank was monitored and controlled, so that 25 °C was not exceeded, according to the standard requirement [5]. The flow rate was recorded with a magnetic-inductive flow meter which did not introduce further excitations in the water. The water was pumped from a water tank through a short steel-piping system with flow meter and pressure pick-off, before it is passed into a 5 m flexible rubber pipe. The rubber pipe served to reduce the structure-borne and fluid-borne sound transmission from the pump and the hydraulic measurement devices, to allow the unrestricted measurement of the fluid-borne sound emission of the tested appliance. The appliance under test was attached to a copper pipe with inner diameter 10 mm and 1 mm wall thickness. This allowed measurement under typical installation conditions.

2.2. Sound intensity

The technique of sound intensity measurement can be used for the characterisation of fluid-borne sources, provided that only plane waves propagate in the receiving system [6]. The measurement involves a finite difference approximation to obtain an indirect measure of the particle velocity [7]. The intensity is obtained in terms of the cross-spectrum between two closely spaced pressure transducers, which are mounted flush and at a right angle to the water flow direction. The intensity is given by:

$$I = -\frac{1}{\rho_f \omega \Delta r} \mathrm{Im}[G_{AB}(p_A, p_B, f)] \tag{1}$$

where $\mathrm{Im}[G_{AB}(p_A, p_B, f)]$ is the imaginary part of the cross spectral density between the pressure transducers A and B with a separation distance Δr. The sound power of the valve is the product of the intensity and the inner cross-sectional area of the pipe.

2.3. Measurements errors

Associated with this technique are systematic and random errors. The systematic errors are due to the finite difference approximation and to phase mismatch between transducers. Random errors result from inherent deficiencies in the instrumentation or from limitations in signal processing. The error due to the finite difference approximation sets an upper frequency limit and the normalised error can be estimated according to [2]:

$$e(I) = -(2/3) \cdot (k\Delta r/2)^2 + (2/15) \cdot (k\Delta r/2)^4 \tag{2}$$

For a maximum error of 0.5 dB, and for an upper frequency of 5 kHz, the required separation distance was 30 mm. The phase mismatch error is, again, according to [2]:

$$e_{dB}(I) = 10\log(1 + e(I)) = 10\log(1 + \phi_s/k\Delta r) \tag{3}$$

φ_s is the transducer phase mismatch, which was 0.15°, giving an error less than 1 dB for the frequency range of interest. The random error for the power measurement is:

$$\tilde{s}\{P(f)\} = -\frac{S}{\rho_f \omega \Delta r} \tilde{s}(\mathrm{Im}[G_{AB}]) \tag{4}$$

The error for one measurement, with $N = 5000$ samples, was 2%. Other errors were due to irregularities in the fluid, such as bubbles, which can cause changes in the speed of sound and lead to damping effects in the transmission path [8]. These were reduced by the use of a closed water circuit with venting. The temperature dependent error was of the order of 0.3% increase per 1 °C increase, over the normal operating range.