RELATIONSHIP BETWEEN STRUCTURE-BORNE AND FLUID-BORNE ACOUSTIC POWER OF SMALL CIRCULATION PUMPS

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1. INTRODUCTION

In domestic central heating systems, circulation pumps deliver structure-borne and fluid-borne acoustic power simultaneously and both must be included in a source characterisation. Several important internal noise generating mechanisms that excite the fluid pulsations also will excite the pump housing as a solid mass. A relationship between the structure-borne and fluid-borne sound power, even a relationship between housing acceleration and pulse pressure in the fluid, therefore might be expected.

The acoustic power from pumps into long pipes, which approximate to semi-infinite conditions, of material and cross-section typical of heating systems can be used to characterise the pumps. For the fluid-borne source, the procedure is to measure the power directly by intensimetry in fluid columns where the returning propagating wave has been much reduced. For the structure-borne source, the power is calculated from the measured free velocity and mobility of the pump for each component of vibration and from receiver mobilities of idealised pipe systems.

The ratio of the structure-borne and fluid-borne sound power was obtained for different test conditions. The measured ratios of fluid pressure and pump acceleration are examined and preliminary results indicate a consistent relationship.

The results show an interesting possibility that the combined fluid-borne and structure-borne sound power might be obtained from measurement of a single field variable. This promises simplifications in rating pumps as noise sources.

2. POWER EMISSION

A central heating pump can transmit acoustic power through three paths: airborne, fluid-borne and structure-borne. The structure-borne path is further divided into that which continues along the pipe, suffering reflections and mode conversion at bends, and that transmitted to the supporting structure through the pipe fixings. Characterization of airborne sound sources is a well established procedure [1] and airborne sound, which is directly radiated to the air from the pump casing, often is very low and can be excluded from consideration. For structure-borne sound sources, the source mobility may not be appreciably different from that of the receiver and possibly may match it giving a maximum in power delivered. Therefore the mobilities, which are complex functions of frequency and depend on the position of the contact points on the source and receiver, need to be taken into account. For the fluid-borne sound source, a similar problem exists, except that we usually deal with impedance rather than mobility.

Since the receiving pipe system can not be known in sufficient detail, the approach, proposed in this paper, is to consider the case of the pump connected to a semi-infinite pipe of cross-section typical of the installed condition, for fluid-borne power. For structure-borne power, the wall thickness and material also must be typical.

2.1 Fluid-Borne Sound

For fluid-borne sources, power emission can be directly measured by using intensimetry. Two flexible rubber pipes, 10 metres long, 19 mm bore, with 3.5 mm pipe wall, were used to connect both ends of the pump and water tank. Test results show that the returning propagating waves are much attenuated and the pipes can be considered as semi-infinite. Two spaced pressure sensors were used to measure the time averaged power emission.

2.2 Structure-Borne Sound

For the structure-borne source, the mobilities of the source and receiver must be known. Since the receiving pipe system cannot be known in sufficient detail, the approach was to consider the case of the pump connected to a semi-infinite pipe of cross-section typical of the installed condition. The active power transmitted was obtained from [2]:

$$P = \frac{1}{2}\frac{|v_{sf}|^2}{|Y_s + Y_r|^2}\mathrm{Re}(Y_r)$$

v_{sf} is the rms free velocity of the pump, and Y_s and Y_r are the point mobility of pump and connecting pipe, respectively. Measurement of structure-borne sound transmission from the pumps to the fluid filled pipes included three propagating waves: longitudinal, torsional and bending. The last sub-divides into polarised mutually perpendicular components. The calculated torsional component of the emission was much lower than the other components and could be neglected.

By using measured pump free velocities, pump mobilities and predicted receiver mobilities, all power components of structure-borne power can be calculated [3].

3. EXPERIMENTAL INVESTIGATION

The fact that the pump includes three generation mechanisms air-borne, structure-borne and fluid-borne makes for a rather complicated picture that it would be preferable to simplify if possible. One possible simplification is to find a link between the various mechanisms. This is expected because forces on the impeller that excite the pump housing as a solid mass will also excite pressure pulsations in the fluid.

To find the links between fluid-borne and structure-borne mechanisms, the fluid-borne power and the total structure-borne power (the sum of quasi-longitudinal and two polarised bending powers) were obtained for four test conditions:

1) The pump operating at 2373 rpm with flow rate 27.3 L/min.
2) The pump operating at 2707 rpm with flow rate 3.6 L/min. By clipping the flexible pipe, the load of the pump was increased.
3) The pump operated in the same condition as test 1, but at a speed of 2020 rpm and flow rate 23.1 L/min.
4) The pump operated as test 1 and test 3, but at a speed of 1520 rpm with flow rate 18.8 L/min.

In Figure 1 are shown the fluid-borne powers for the four tests. In Figure 2 are shown the total structure-borne powers for the corresponding conditions. The following conclusions can be obtained from both figures:

1) The frequency corresponding to rotational speed can be identified for each case by the peaks between 20 Hz and 50 Hz. Both figures show that speed order from high to low is Test 2, Test 1, Test 3, Test 4, this can be seen as a frequency shift of the first peak for each case.
2) The pump blade passing frequencies for 4 test conditions are in same order as that of rotational frequencies.
3) The peak at 100 Hz does not shift when the test condition is changed. This peak corresponds to the magnetostriction of the armature stampings in the single-phase induction motor of the pump; this frequency is only dependent on frequency of the mains. Therefore, for different test conditions, the amplitude of this peak may change but it will remain at 100 Hz.
4) Fluid-borne power is about 10 dB higher than structure-borne power for each case.
5) The fluid-borne power spectra have the same general slope as for the structure-borne power spectra.

3.1 The Ratio of The Structure-Borne and Fluid-Borne Sound Power

From preliminary comparisons of the structure-borne and fluid-borne powers of pumps under the same operating conditions, it can be seen that early indications are that a simple relationship exists between the fluid power and the axial component of vibration. The ratios of fluid-borne power to structure-borne power for the four tests are shown in Figure 3. Up to 400 Hz the four ratios are similar, but with large deviations above 400 Hz. For example, in test 4 the pump delivers more fluid-borne power than structure-borne power.

In Figure 4 are shown the ratios in Figure 3 but against the Strouhal number instead of frequency. The Strouhal number St , is defined as the ratio of the frequency and the blade passage frequency of the impeller [4]. It can be used to characterize fluid dynamic phenomena and usually leads to a coincidence of the peaks in power spectra for different loading conditions or operating speeds. When plotted against Strouhal number, the relationship is preserved independently of operating speed. This might be expected for compact pumps that display rigid-bodied motion over significant parts of the frequency range of interest.

The agreement between the results for the four operating conditions is promising, up to the blade passage frequency. A repeatable relationship between the fluid-borne and structure-borne emission is obtained, independent of operating condition.

3.2 Ratios of Fluid Pressure and Pump Acceleration

Internal noise generating mechanisms that excite the fluid pulsations also will excite the pump housing as a solid mass. A relationship between the acceleration of housing and the pulse pressure might therefore be expected. The ratios of fluid pressure and pump acceleration for three tests are shown in Figure 5. The agreement is again promising but now for the region above the blade passage frequency as well as below. Note that the scale on this plot has been reduced and that the variance is significantly less than defore

All the above results were measured on pumps from one manufacturer. To confirm that the result in Figure 5 is common for this type of pumps, some measurements were carried out on two further units from a different manufacturer. One of the results is shown in Figure 6. The agreement is also promising and the curve shape of result is same as that in Figure 5. This indicates that the result in this study could be suitable for circulation pumps made by other manufacturers.

These results allow the speculation that a simple measure of the free velocity might yield the fluid-borne power as well as the structure-borne power. The practical implications of such a data-reduction are clear. The measurement systems and methods required for rating the pumps would be in the range of many small and medium-sized manufacturers.

However, these are preliminary measurements and observations, an additional detailed measurement survey is required to confirm these results.

4. CONCLUDING REMARKS

A brief study has been carried out to investigate the relation of fluid-borne and structure-borne excitation in pump. The results produced a rather convincing collapse of experimental data indicating that the fluid and structure excitations vary in constant proportion as the speed of the impeller varies. The constant relation appears to hold for hydro dynamic excitation mechanisms, but as might be expected, breaks down for electrical excitation. This offers the interesting possibility that only the fluid-borne power is required to estimate the structure-borne power or *vice-versa*.

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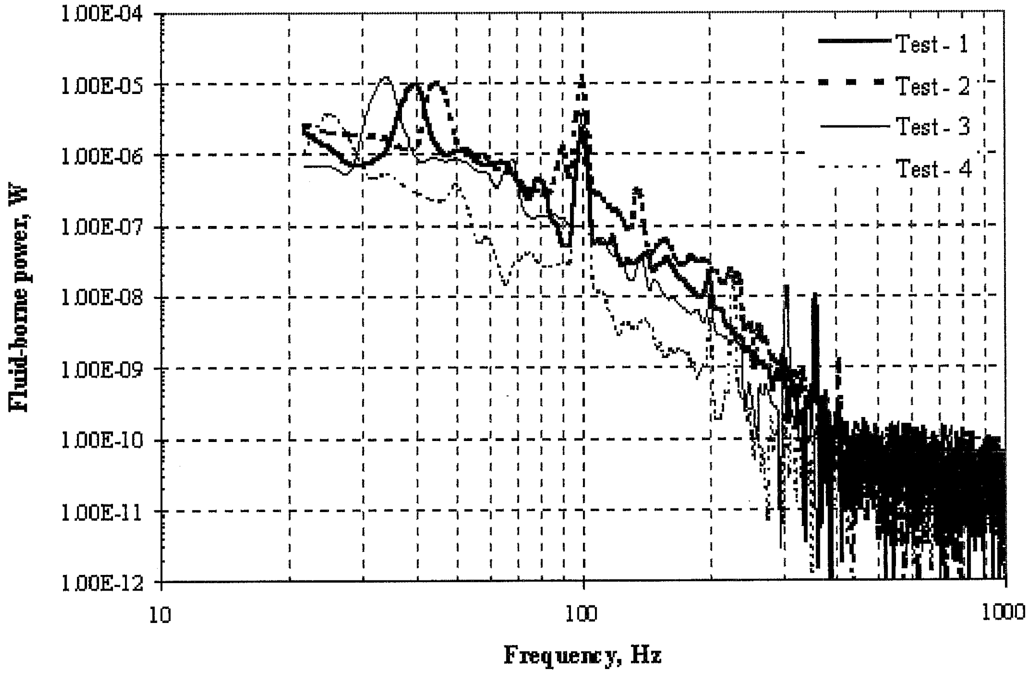

Figure 1. **Results of fluid-borne power for four tests.**

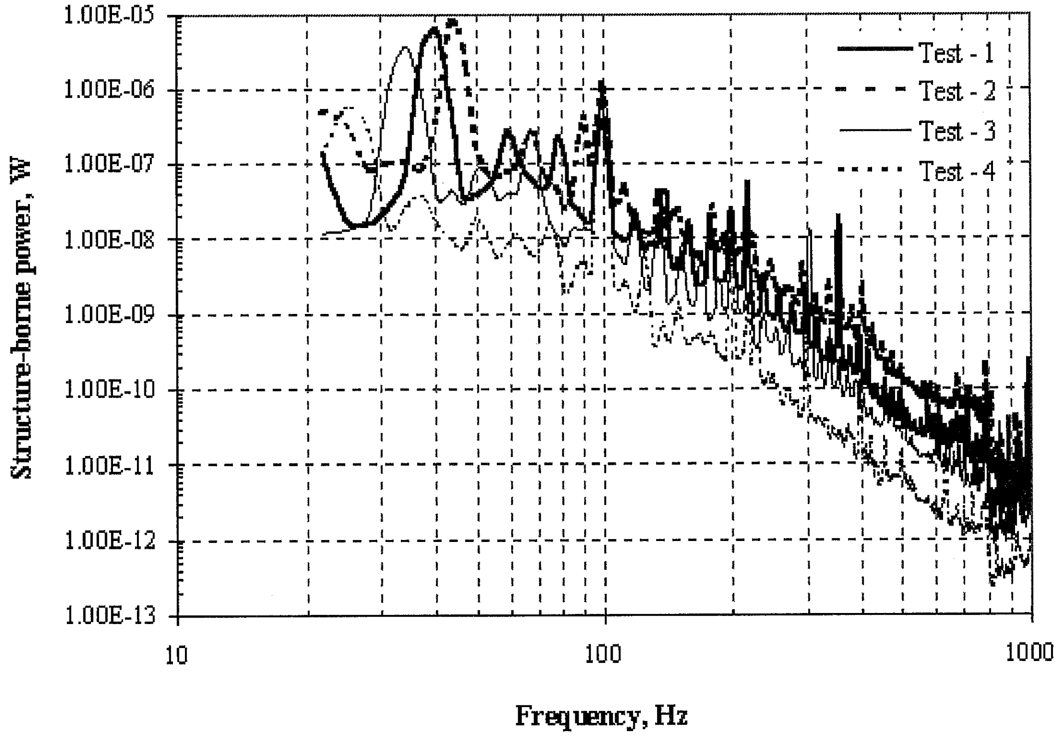

Figure 2. **Results of structure-borne power for four tests.**

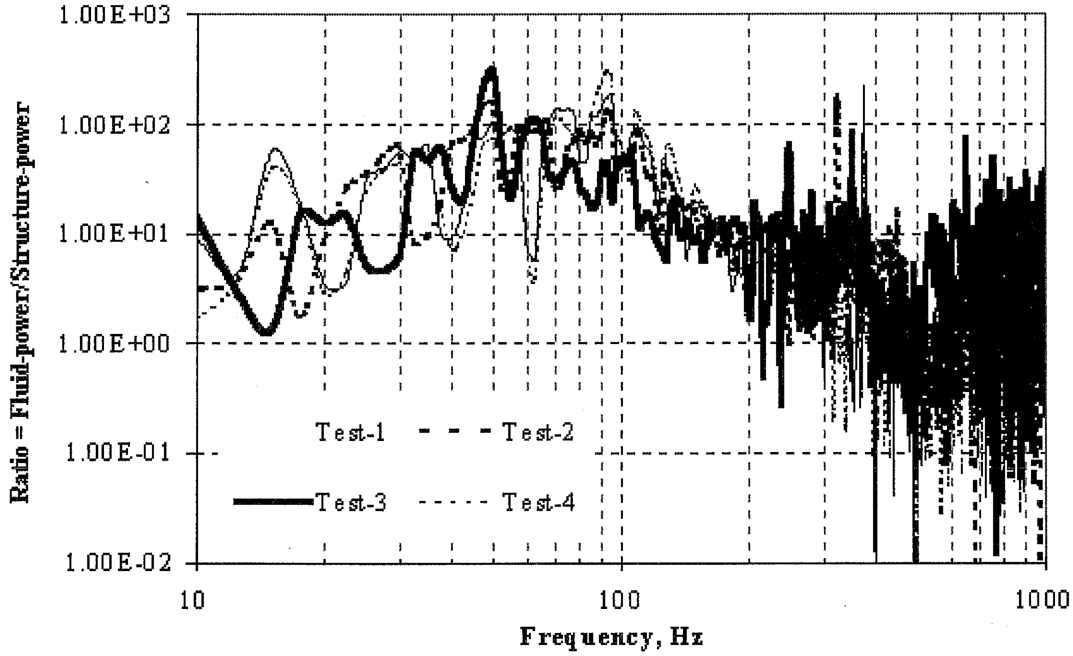

Figure 3. **Ratio of fluid-borne power and structure-borne power.**

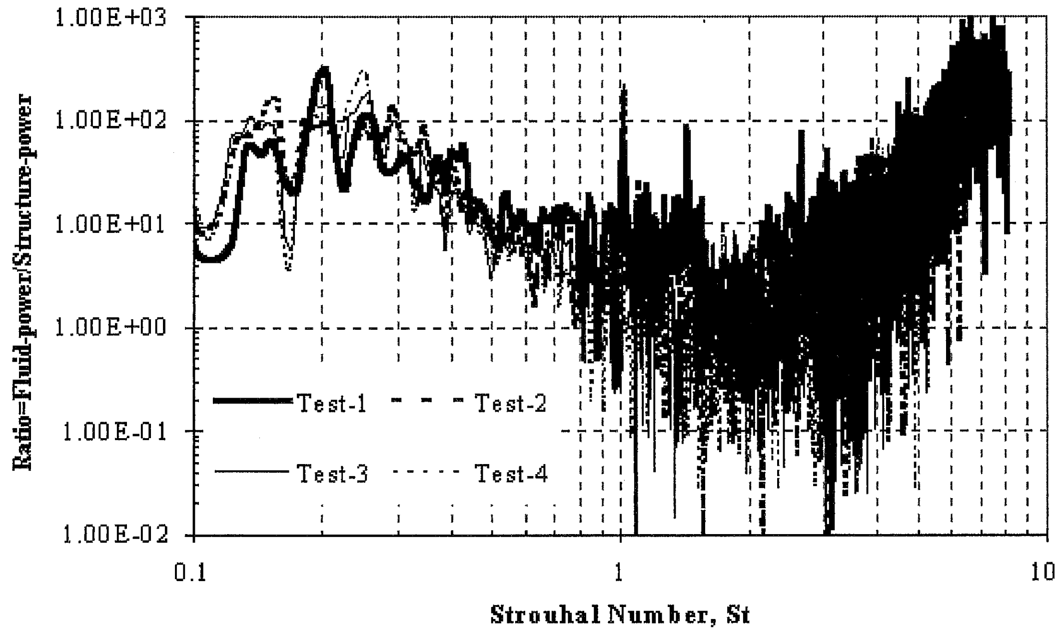

Figure 4. **Ratio of fluid-borne power and structure-borne power.**

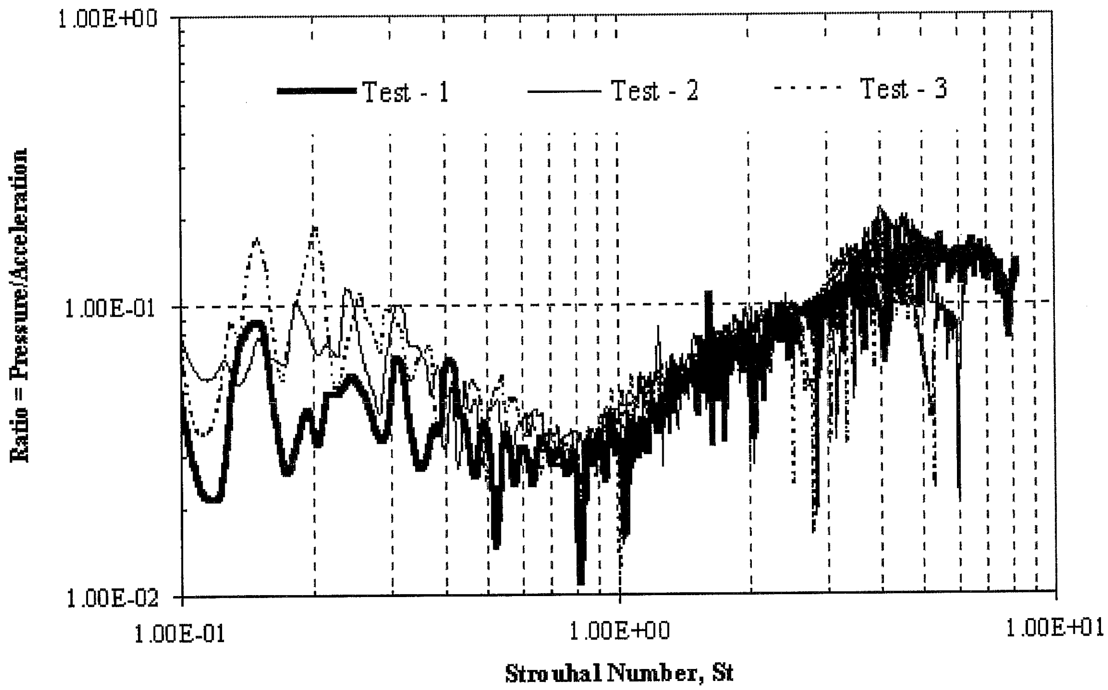

Figure 5. Ratio of fluid pressure and pump acceleration.

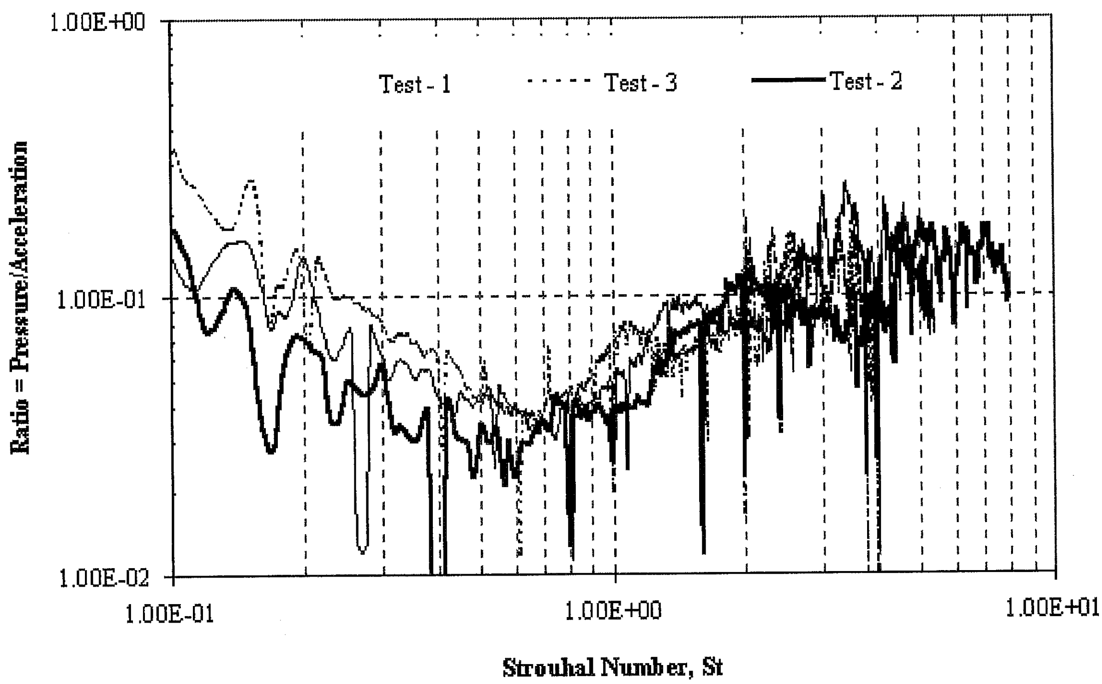

Figure 6. Ratio of fluid pressure and pump acceleration for the pump from different manufacturer.