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INVESTIGATION OF THE PRESSURE AND VIBRATION TRANSMISSIONS IN THE FLUID FILLED PIPEWORK SYSTEMS

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ABSTRACT

In fluid filled pipework systems there is a need to predict and control the vibration transmission to the supports or end termination, arising from both vibration and fluid pressure inputs. This paper describes the parameter studies of the fluid filled pipework system using a validated theoretical model based on transfer matrix method within the framework of the power flow philosophy. The analysis has been carried out for different structural and geometrical parameters. These include the material parameters; the pipe dimensions; and pipeline configurations. These parameter changes have great effect to the structure impedance and the acoustic impedance which determine the transmitted responses.

1 - INTRODUCTION

Vibration control for a pipework system is very complex. The optimized solutions are dependent on the different applications of pipework system and their main problems, for example, noise radiation from a water filled central heating pipework system is probably caused by the pump in which the vibration components in high frequencies may be important. However, to reduce the vibrational 'power input', and the 'power transmission' will reduce the vibration levels in any systems. To investigate how reduction in transmitted pipe pressure and vibration is most easily achieved. The effects of pipework parameters on the dynamic behavior are studied using the theoretical model developed in the Reference [1].

2 - PRINCIPLE OF VIBRATION CONTROL FOR PIPEWORK SYSTEMS

The input power to the system is dependent on the source types: force excitation or velocity excitation. For a pipework system, the pump is likely to be a main source of excitation which acts as both a fluid velocity, or a pressure input to the pipework system and a structural velocity source because the pump is normally heavy and stiff compared to the pipe. For this latter type of pump, or velocity source, pumps with rotating vanes with tend to be a pressure source, i.e., a constant dynamic pressure irrespective of the load impedance. In contrast constant displacement pumps as used in hydraulic systems will be a velocity source, as the internal cavity impedance is much greater than the load impedance. The power input can be reduced by decreasing the input point impedance or increasing the input point mobility.
The transmitted power from input to output is not only dependent on the transfer mobility and the input power, but also the point mobility at output. This can be illustrated using simple two coupled systems as shown in Figure 1.

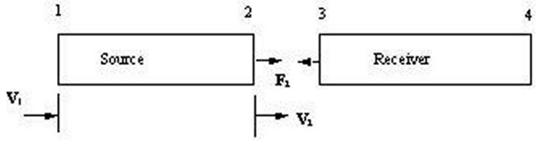

Figure 1: Two coupled sections.

Two sections of pipework system are coupled at point 2 and 3 by a joint which transfers forces from one section to another. The time averaged power transmission to the receiver at point 3, P_{tr}, is

$$P_{tr} = \frac{1}{2}\frac{|\mathbf{V}_1|^2}{|\mathbf{M}_2+\mathbf{M}_3|^2}\frac{|\mathbf{M}_{12}|^2}{|\mathbf{M}_1|^2} Re\left\{\mathbf{M}_3\right\} \tag{1}$$

where $\mathbf{M}_1$, $\mathbf{M}_2$ and $\mathbf{M}_3$ are the point mobility at points 1, 2 and 3, and $\mathbf{M}_{12}$ is the transfer mobility between points 1 and 2. Equation (1) indicates that making $\mathbf{M}_2$ very different from $\mathbf{M}_3$, and decreasing the transfer mobility can reduce the power transmission from source 1 to receiver at point 3.
The ratio between the power transmitted, P_{tr}, through the boundary to the power input, P_{in}, to the beam has been determined from the power flow along the beam at those two points by Pinnington [2] and is given as

$$P_{tr}/P_{in} = \alpha\left(1-r^2\right)/\left(1-\alpha^2 r^2\right) \tag{2}$$

where $\alpha = e^{-\eta kl/2}$ is the attenuation due to damping of a wave travelling a distance $2l$, and

$$r=(Z_2-Z_1)/(Z_2+Z_1)=1-2Z_1/(Z_2+Z_1),$$

is the reflection coefficient of the reflected wave to incident wave. Here Z_1 and Z_2 are impedances of two sides respectively at the reflection boundary. Z_1 and Z_2 are the reciprocals of the mobilities. The attenuation term, a, is dependent on the damping loss factor and the non-dimensional wavenumber *kl*. *k* is wavenumber, and *l* is the pipe length. The vibration attenuation can be increased by increasing damping loss factor or non-dimensional wavenumber. The reflection coefficient is dependent on the boundary properties, i.e., the impedance, ρc, and their difference of two coupling sections. ρ is density, and $c = \omega/k$ the wave speed. For a fluid filled pipe, the fluid wave speed is affected by the pipe wall. The softer pipe wall, the slower the wave speed of fluid. The minimum power is transmitted with minimum attenuation and maximum reflection.
For the acoustic wave, if the transmitted fluid pressure is expected to be reduced a large reflection is required at the boundary between pipe elements. The reflection coefficient will be increased if the pipe walls across the interface are changed from hard to soft, i.e.

$$1-2Z_{\text{acoustic}}(\text{hard})/[Z_{\text{acoustic}}(\text{hard})+Z_{\text{acoustic}}(\text{soft})]$$

decreased. This implies a low ratio of the acoustic impedances, $Z_{\text{acoustic}}(\text{soft})/Z_{\text{acoustic}}$ (hard).
For the structural flexural waves, the lower vibration responses are expected so that the high reflection coefficient and high impedance are required. The reflection coefficient will also be increased if the pipe wall are changed from soft to hard, i.e.

$$1-2Z_{\text{structure}}(\text{soft})/[Z_{\text{structure}}(\text{hard})+Z_{\text{structure}}(\text{soft})]$$

increased.
As above, it is indicated that the insertion of a soft pipe section in the system should minimize both fluid pressure and structural flexural responses and their power transmissions.
For a straight pipe the fluid pressure wave is coupled with pipe wall in the radial direction, but this coupling from fluid wave does not affect the pipe wall flexural waves. However, when the direction of the pipeline is changed via a pipe bend or a joint, there is strong coupling between the fluid wave and pipe wall waves, and also between the different wall wave types. Therefore the number of bends may affect the power transmission if the main source is the fluid wave.

3 - EFFECTS OF THE PIPEWORK PARAMETERS

3.1 - Pipework parameters

The attenuation of flexural vibration waves in the pipe is dependent on in term $e^{-\eta kl/4}$. This indicates that the damping loss factor η and the non-dimensional parameter *kl* affect the vibration power flow. Non-dimensional parameter, *kl*, can be changed by the wave number, *k*, and pipe length, *l*. The wave number of the flexural wave is defined as $k = \omega^{\frac{1}{2}}\sqrt{\frac{\rho A}{EI}}$ which is affected by the pipe material and the geometry. There are three main areas in the parameters, pipe wall material, pipe geometry and the pipeline configuration. These parameter changes have great effect to the structure impedance ($\rho_s c_s A_s$) and the acoustic impedance ($\rho_f c_f A_f$) which determine the transmitted responses. The details of the individual parameters had been studied and presented in Reference [3]. These included the structural wave, fluid wave and the structure-fluid coupling. The system impedance can be also changed in other methods, for example, pipe support, additive concentrated mass, dynamic absorber and so on, also alter the system dynamic behavior.

3.2 - The effects of the materials combination in the pipework system

The parameter studies of the pipework system have shown that changes in material or geometry of the pipework influence its vibration behavior. A change in impedance causes wave reflection at the junction between two pipes carrying a fluid wave and can thereby increase the energy absorption in the system. For the pipe wall waves, increasing the impedance of the pipe wall can reduce the wall response. However, for the fluid wave, pipe wall material and the geometry parameters strongly affect the fluid wave impedance via the fluid loading term. For the m = 0 wave a decrease in pipe wall stiffness decreases the wall impedance and hence decreases the fluid wave speed and associated wave impedance. In this paper, the transfer mobilities of three "U" shaped pipe systems, with different materials for the middle section, are studied in order to investigate above effects. Three "U" shaped pipe systems are: copper-copper-copper (cc1); copper-Nylon-copper (cn1); and copper-rubber-copper (cr1). These correspond to the reflection coefficients of 0, 0.910, and 0.996 respectively. Here, the fluid wave speed is 1219 m/s with copper pipe, 365 m/s with Nylon pipe, and 21.8 m/s with rubber pipe.

Figure 2, Figure 3 show the transfer mobilities of the pipe wall flexural wave and the fluid wave respectively between the inlet and outlet for three different systems filled with water. This indicates that the transfer mobilities are significantly changed by the pipe wall material in the middle section of the system. The responses with soft pipe section are not only reduced on the pipe wall but also on the fluid, particularly in the high frequencies. For example with rubber pipe section in the system, the mobility amplitudes are reduced by more than 60 dB for the frequencies over 40 Hz on flexural wave, and over 100 Hz on fluid pressure wave. Generally, this effect on frequencies for flexural wave is approximately about over that corresponded frequency of a half fluid wavelength in the soft pipe section. This method may be very efficiency to control the transmitted power in the pipe system. Inserting a soft pipe section in the system can significantly control the responses for both pipe wall and fluid waves. The softer the pipe section is, the lower the start frequency of effective reduction will be.

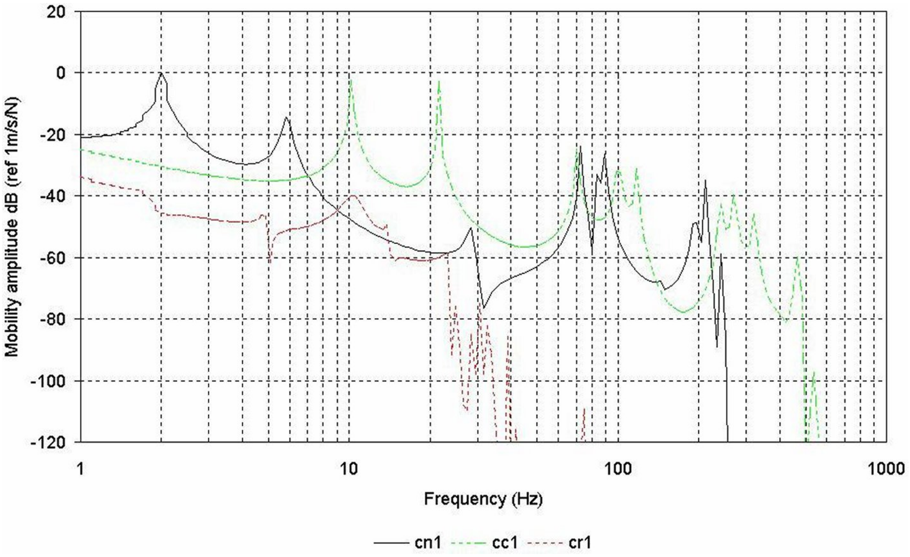

Figure 2: Effect of pipe material in middle section on transfer mobility of the pipe wall flexural wave.

4 - CONCLUSIONS

The effects of parameters of pipework system to its performance were studied with a straight pipe and a pipe configuration of a three-element system. The analysis has been carried out for different structural and geometrical parameters, and the results were compared. The fluid wave velocity has a large effect on system mobilities for both pipe wall and fluid waves, particularly at high frequencies. More pipe bends may reduce the vibrational power in the fluid. Inserting a soft pipe section in the system can significantly minimize both fluid pressure and structural responses and their power transmission. The softer the pipe section, the lower the start frequency of effective reduction.

REFERENCES

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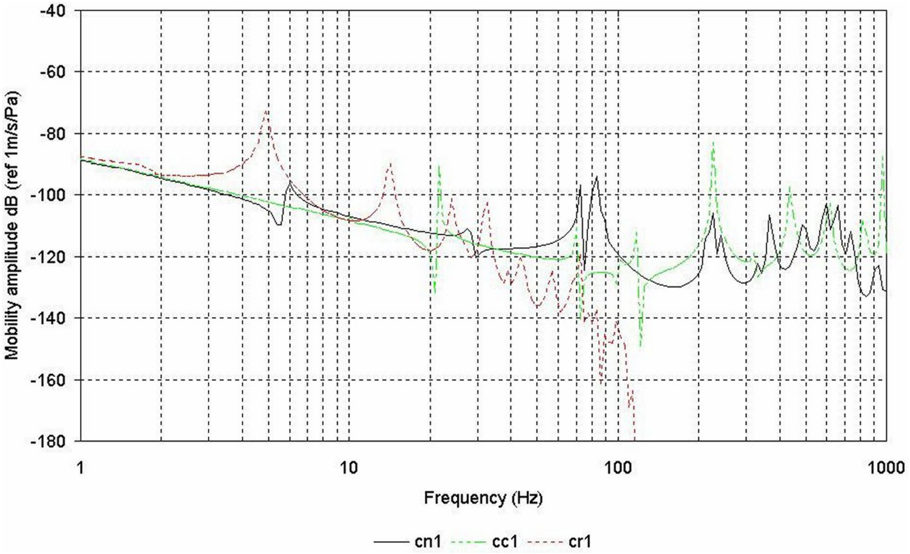

Figure 3: Effect of pipe wall material in central section on transfer mobility of the fluid wave.

2. **R.J. Pinnington**, *Vibration power transmission between sources and substructures*, PhD thesis, The University of Southampton

3. **A. Wang**, *Vibration analysis of fluid filled pipework systems*, PhD thesis, The University of Southampton.