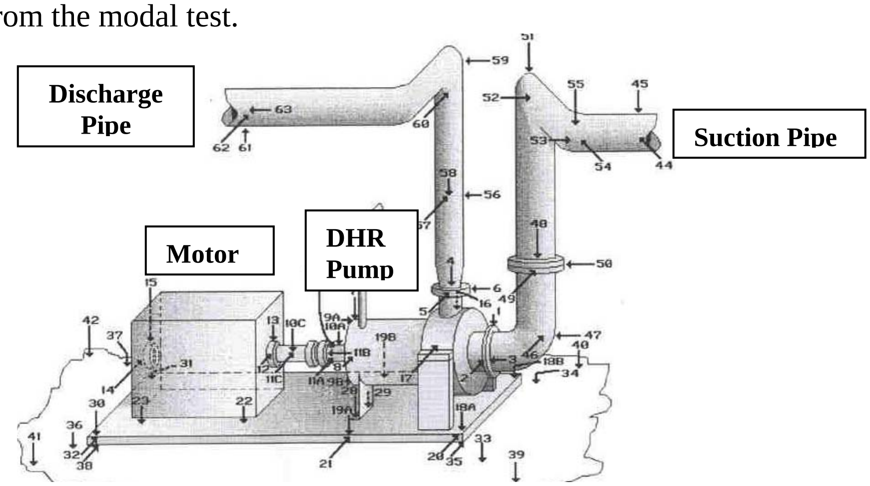
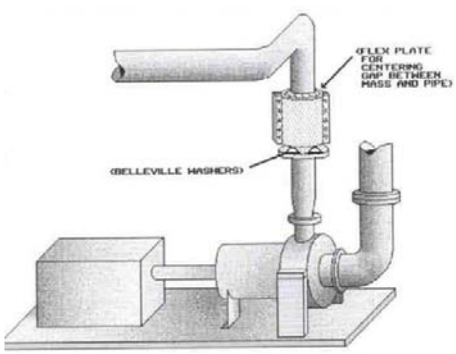
Case History: Impeller Vane Pass Acoustic Excitation of Pipe Resonance in a Nuclear Power Plant

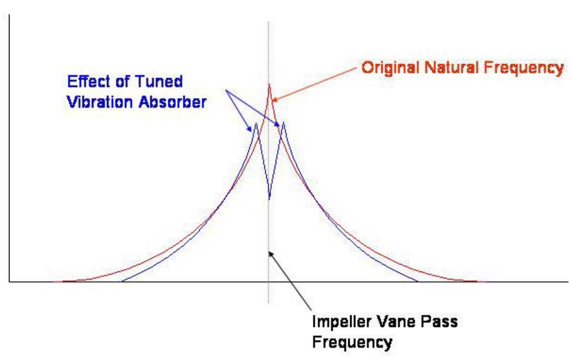
MSI engineers investigated and suggest practical solutions for premature failure of bearings and seals in a safety-related Decay Heat Removal Pump, a single-stage end-suction volute pump. Operating Deflection Shape (ODS) testing demonstrated that the direct reason for the reliability problems was that the pump casing was badly distorting dynamically, with a dominant frequency of impeller vane pass versus the casing's single volute tongue. The motion of the system at this frequency involved a vertical "bouncing" of the oversize discharge pipe, which tended to "jam" the pump casing through the dynamic force it imparted to the pump discharge nozzle. An impulse modal test was performed and determined that a structural natural frequency dominated by vertical motion of the discharge pipe was nearly coincident with the first harmonic of the vane pass frequency, thereby causing a resonance. This resonance was relatively poorly damped, based on the "half power" width of the resonant response peak of the Frequency Response Function for this mode, as obtained from the modal test.



MSI was requested by the regulatory agency and plant to verify that the resonance issue was the only reason for the increased vibration, and if so to determine how best to eliminate the excessive vibration response, and end the chronic failures. This was problematic, since there were no piping taps near the pump discharge, and if the piping was violated by installing a tap, it would need to be re-qualified for system operation in a safety-related situation. The cost of this re-qualification would be high, and the plant might be required to shut down until analysis was completed. On the other hand, the plant might be required to shut down because of the DHR pump chromic failures, until there was quantitative assurance that the source of the failures had been successfully addressed. MSI applied a technique that it had used successfully in other plants where pressure pulsation measurements were required in pump or compressor systems where many axial pressure readings were needed to evaluate acoustic natural frequency mode shapes, but where pressure taps were sparse and/ or unwelcome. The method consists of using a minimum of 4 uniaxial accelerometers, attached perpendicular to the pipe wall at 90 degree intervals around the periphery of the pipe at each location where pulsation readings are needed. Away from stiffening components such as flanges or piping supports, this technique allows the pressure pulsation (which makes the pipe radially expand) to be separated from the piping gross structural vibration, which merely translates the pipe as a relatively rigid body, unless shell modes are suspected. The latter occur at high frequencies (order of 1 kHz and higher, depending upon pipe thickness divided by diameter squared), and if they are a possibility at the frequency of interest, can be sorted out by a larger number of measurements around the periphery of the pipe. MSI measured the pressure pulsation one pipe diameter downstream of the discharge nozzle, and then demonstrated with both manual and finite element analysis (FEA) that the pulsation level was close to that required to drive the discharge piping resonant response at the vibration level that had been detected, verifying it as the "problem source".

MSI then used the cross-confirmed FEA model to perform some "what if" analyses of possible alternative solutions. Adding mass to the pipe, use of a piping damper (shock absorber), stiffening of the pipe supports, and lengthening of the pipe were all explored, and found viable. However, each of these solutions would require piping re-qualification. MSI then designed a low weight dynamic absorber, in the form of a low-mass thin-walled pipe "clamshell" surrounding the discharge pipe vertical leg, able to move vertically separately from the discharge pipe, attached to the discharge pipe through clamping plates that had tuned and adjustable stiffness in the vertical direction. The assembly was shown analytically, and by test, to quench the resonance at the vane pass acoustic frequency. Because the assembly was of sufficiently low mass, and did not penetrate the discharge pipe, only the absorber needed analysis and review/ approval.





Design concept of tuned vibration absorber, & its effect on vibration response. The net result was a 25x reduction in vibration amplitude at the vane pass frequency.

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