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Marshall Space Flight Center

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Analytical Failure Determination Of Flow-Induced Fatigue In Bellows

Fatigue failures are experienced in bellows when they carry fluids at high speed. Experience shows that these failures are grouped erratically around Mach 0.3 to Mach 0.4, but the principles governing this behavior are not completely understood. A rigorous treatment of the problem would be very complex and take considerable effort to develop and to follow, but much insight can be obtained by a simple, qualitative analysis.

It can be assumed that flow through a bellows generates sound in the fluid and that the sources of the sound should be repetitive. That is, if the sound is generated by the disturbance in flow past a convolution root, for example, it will be generated at repeating intervals along the bellows corresponding to the convolution spacings. These conditions will amplify certain wavelengths of sound and cancel others, and because the sound travels in both directions, standing waves can be produced. This reasoning applies only to the sound in the fluid and requires no bellows vibration. It would still apply for an infinitely rigid bellows structure. However, the bellows are essentially springs and must be affected to some extent by any varying force such as sound waves. The extent can be expected to range from zero if the natural frequency of the bellows structure opposes and cancels the sound frequency, to a very large magnitude if the natural frequency of the bellows is in phase with and reinforces the sound vibration. The relationship between the sound waves and the spring constants of the bellows can explain the apparently erratic fatigue results.

Using the above assumptions, it is easy to examine the sonic condition in a little more detail. Considering first only a single source of sound (one root), it can be seen that an unknown spectrum of wavelengths will be propagated in all directions with the speed of sound in the fluid. Ignoring all but the axial direction, x, and using a coordinate system fixed to the bellows, it becomes apparent that each wavelength will be greater in the direction of fluid flow than in the opposite direction.

The amplitude of the wave, the sound intensity, will decay in an exponential manner depending on frequency, but if the wave arrives at another source of sound before decay, its residual amplitude will add to the wave from the new source with which it is in phase.

In examining the effects of the sound wave on the bellows structure, the standing wave will tend to cause each root to oscillate back and forth in an opposite direction from each neighboring root. The result will be a flexing of each crest. This mode of vibration explains the metallographic observations in the referenced report which notes that the crests were heavily cold worked in service, while the roots were undisturbed. The natural frequency of the bellows in this type of vibrating notion is therefore critical.

The above analysis was derived rather easily and appears to be qualitatively correct. Greater effort would be required to derive a quantitative expression which would show rate of sound amplification. It is suggested that this analysis be continued to derive such a quantitative description, because one obvious design device to allow high flow rates would be to introduce a half wavelength interruption in the convolutions just prior to the number of convolutions at which the intensity would reach a dangerous level. This would cause destructive interference between the two standing waves and eliminate the vibrations.

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