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THE EXPERIMENTAL BASIS FOR PARAMETERS CONTRIBUTING TO ENERGY DISSIPATION IN PIPING SYSTEMS

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Abstract

The paper reviews several pipe testing programs to suggest the phenomena causing energy dissipation in piping systems. Such phenomena include material damping, plasticity, collision in gaps and between pipes, water dynamics, insulation straining, coupling slippage, restraints (snubbers, struts, etc.), and pipe/structure interaction. These observations are supported by a large experimental data base. Data are available from in-situ and laboratory tests (pipe diameters up to about 20 inches, response levels from milli-g's to responses causing yielding, and from excitation wave forms including sinusoid, snapback, random, and seismic). A variety of pipe configurations have been tested, including simple, bare, straight sections and complex lines with bends, snubbers, struts, and insulation. Tests have been performed with and without water and at zero to operating pressure. Both light water reactor and LMFBR piping have been tested.

1. Introduction

A number of full-scale and separate effect experiments have been conducted to determine the parameters contributing to energy dissipation in piping systems. Some of the earlier U.S. experiments identified amplitude level as a primary contributor [3,4,5], and the Japanese Seismic Damping Ratio Evaluation Program expanded the data base to explore other parameters [13-16]. Further efforts were made to integrate the experimentally determined damping and draw overall conclusions based on the collected data as a whole [26,27]. In this paper, the piping system damping data base is reviewed in order to assess those phenomena contributing to energy dissipation.

2. Material Damping/Plasticity

The majority of damping tests have been conducted at low stress levels where it appears the material damping is low and where most of the energy is dissipated due to other effects. In the few tests in which yield stresses were reached or exceeded, the damping increased considerably. This may in part be attributed to increased exercising and impacting of supports, but the major contributor at high levels is plasticity.

In tests of a 6-foot long, fixed-end, 1/2-in. OD pipe at the Westinghouse Astronuclear Laboratories [4], damping increased from about 1% of critical at 50% of yield stress to approximately 14% of critical at 110% of yield stress. Damping started to increase rapidly at stresses greater than 70% yield, which was considered by Morrone to be typical of material (hysterestic) damping. These results were obtained using a sinusoidal input motion, and the damping values were calculated from the magnification factor at resonance.

In tests performed by Ware and Thinnes at the Idaho National Engineering Laboratory (INEL) straight sections of 3-inch and 8-inch pipes approximately 33 feet in length were excited using the snapback method into the plastic range [28,29]. Damping was calculated using the logarithmic decrement method. For the 3-inch pipe, damping increased from 1% of critical at 900$\mu\varepsilon$ to 6% at 1,500$\mu\varepsilon$. For the 8-inch pipe, damping increased from 2% at 600$\mu\varepsilon$ to 14% at 1,300$\mu\varepsilon$.

Scavuzzo [38] used a 1-1/2 inch, simply supported pipe excited by an impact method to reach strains of 7,000$\mu\varepsilon$. The logarithmic decrement method was used to compute damping. In the elastic range (< 1,000$\mu\varepsilon$), the damping averaged about 1% and increased almost linearly to as high as 26% at 7,000$\mu\varepsilon$. At comparable levels, these tests and the INEL 3-inch pipe results were similar. In both the Scavuzzo and INEL tests, plastic energy absorbed at the center of the span resulted in high damping at all locations; and almost all plastic energy was absorbed in the first half cycle, i.e., the pipe did not cycle plastically.

In tests conducted in Germany, damping was also found to increase in the plastic range [32]. The measured damping values (up to 4,000$\mu\varepsilon$) were nearly a quadratic function of the bending stress. At yield stress, damping was 15% in these tests.

Since the data base is very sparse for vibrations in the plastic range, a quantitative evaluation of damping as a function of strain cannot yet be formulated. However, for piping to fail due to inertial loads, it must first deform plastically; and thus, decreasing the data base of high amplitude damping response would be highly desirable.

3. Impact Damping

Collisions between gaps in piping supports and between pipes can cause increased energy dissipation. This phenomenon is sometimes referred to as impact damping. Energy is lost by transfer to adjacent structures and by metal deformation.

In Japanese studies by Shibata [14], it was noted that energy dissipation due to impact and sliding was greatest at the amplitude in the range of the support gap (0.8-1.0 mm). At lower amplitudes, impact and sliding behavior is weak, and the damping values are low and scattered. At amplitudes higher than the range of the gap, damping effects gradually decreased with amplitude.

In INEL tests by Ware and Thinnes [28,29], a straight pipe was fixed at both ends and supported with a rod hanger with a gap at midspan. For the first (antisymmetric) mode, the support was at a modal point, and the damping remained the same as for the base case with no center support. For the second (symmetric) mode, however, there was considerable impacting at the center support; and the damping was significantly higher than for the base case.

In other tests [22,28,29], it has been shown that supports with gaps such as snubbers can increase damping for those modes that cause impacting in the gap. Interchanging supports with similar gap sizes does not seem to vary the damping. This has been demonstrated in References 30 and 36 in which rigid struts and various type snubbers were exchanged at a given location.

Since gaps induce nonlinear response behavior, it is difficult to derive empirical formulas to describe impact damping. Here again considerable effort remains before impact damping can be adequately characterized.

4. Water Dynamics

Most of the damping tests conducted to date have been conducted for seismic purposes and, consequently, have focused on frequencies in the 0-33 Hz range. This has left a considerable gap in our knowledge of the effects of damping due to water-dynamics-induced loadings (33-100 Hz).

The General Electric (GE) Company has reported several damping tests in which the motion was induced by water dynamics [21]. These include safety relief valve (SRV) tests at the Caroso, Monticello, and Hatch nuclear plants and Wyle Laboratories. GE concluded that the test data show no strong dependency of damping on either frequency or pipe size, but damping did tend to increase with nominal pipe bending stress. Damping in these LWR piping systems was at least 5% for measured stresses considerably less than ASME Code Service Levels A and B limits. It is not clear at this time how much water dynamics contributes to damping in pipes excited by seismic motion.

5. Insulation

One of the major factors potentially contributing to piping system damping is the presence and type of insulation. Energy is dissipated by sliding and impacting between the insulation and pipe.

A number of tests on piping with and without thermal insulation have been conducted in Japan by Shibata. For small displacements (1 mm), the damping of piping with 75-mm thermal insulation increases by 2 to 3 over a bare pipe. With gaps and friction included, this increases to 5-7%. As response displacement becomes larger, the damping decreased. For calcium silicate insulation, the damping increased as the insulation became thicker and the pipe became larger. The damping for a reflective metal insulator was observed to be considerably lower than that of calcium silicate insulation.

Tests on two 275-mm piping systems at the German Kernkraftwerk Krummel plant [31] showed a marked increase in damping with the presence of insulation. In Reference 32, it was reported that in experiments conducted on several full-scale German systems, a large reduction in damping could be observed when the measurement was repeated with removed insulation.

In testing by ANCO of the Indian Point feedwater line [34], it was concluded that the insulation probably increases damping. It could not be exactly determined to what extent the insulation affected damping because of the small differences in test damping values. Impact and scraping of pipes with insulation had a very large damping effect.

The Westinghouse Hanford Company has conducted a considerable number of tests of one- to three-inch LMFBR piping with standoff insulation with an annulus. Reference 35 presents a good summary of these experiments. In this type system, the insulation/pipe weight is greater than for LWR systems, and it was observed that the insulation made a significant contribution to damping. Values from 5% of critical to 25% were reported. The test data also indicate a decrease in damping values as pipe size increases.

Tests on an 8-inch scale model LMFBR piping system have been conducted by Westinghouse Advanced Reactors Division [35]. This system had an insulation/pipe weight ratio more typical of LWR systems than LMFBR systems. An increase in damping of about 1 to 2% of critical due to insulation was reported for systems supported by snubbers and rigid struts, while the unrestrained system damping essentially did not change with insulation.

Insulation appears to be a definite contributor to damping, especially for heavily insulated systems.

6. Coupling Slippage

Friction between joints and in supports is another source of energy dissipation in piping systems. The effect seems to be more pronounced at low amplitude vibrations when Coulomb friction is predominant. At higher levels of vibration, the frictional force is overcome, and damping due to slippage decreases.

In tests by Shibata [15], the effects of friction due to spring hangers were demonstrated. For the unrestrained system in which damping was 0.1% of critical, the addition of a spring hanger caused damping of 5% at very small displacements decreasing to 0.5% at approximately 0.75 mm. Tests by Ware and Thinnes further demonstrated this phenomenon. For small displacements (less than 0.1 inch) of a straight piping system supported by a spring hanger, the damping could be attributed to almost pure Coulomb damping. At higher vibration levels, the effect could not longer be seen.

7. Restraints/Structure Interaction

As discussed somewhat in the previous paragraphs, the restraints are one of the major contributors to damping. Through the restraints, energy is radiated away from the piping system and is dissipated through slippage and impacting in the supports. At low levels, Coulomb friction dominates especially for spring hangers, sway braces, and constant force hangers where friction between the spring and housing occurs. At higher levels, impacting due to gaps in snubbers, struts, and rod hangers occurs after sufficient excitation is supplied to cause "lift-off" overcoming the weight of the pipe. Compared to friction and impacting, radiation damping of piping appears to be low. Hydraulic and mechanical snubbers do contribute to damping as shown in the comparative Indian Point tests [20].

8. Conclusion

The most significant contributors to energy dissipation in piping systems appear to be friction between supports at low amplitude levels, impacting of supports at intermediate and high amplitude levels, while material damping dominates at high stress levels. The amount and type of insulation also causes energy dissipation. On the other hand, the effects of pressure, temperature, fluid condition, and pipe shape have not been demonstrated to be major contributors to energy dissipation.

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