PIPE RUPTURE AND STEAM/WATER HAMMER DESIGN LOADS FOR DYNAMIC ANALYSIS OF PIPING SYSTEMS

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SUMMARY

Design of restraints and protection devices for many nuclear Class I and Class II piping systems for survival during severe pipe rupture and steam/water hammer loadings makes the accurate generation of these loadings important. Methods are currently available for such fluid transient load development, but each method is severely restricted as to the complexity of the piping system and/or the range of fluid state excursions which can be simulated. In addition, these methods do not specifically evaluate transient force imbalances experienced in the piping system and so are not oriented towards piping support or restraint design.

This paper presents general technique for generation of pipe rupture and steam/water hammer design loads which does not have the limitations of the existing techniques. Blowdown thrust loadings and unbalanced piping acceleration loads for restraint design of all nuclear piping systems may be found using this method. The technique also dramatically increases the types of steam/water phenomena which may be dynamically simulated by including non-linear two-phase distributed friction and choking, liquid flashing and condensation, with the effects of heat exchangers, pumps and other surrounding thermal and mechanical equipment.

A new form of the unsteady momentum equation is derived which incorporates computer generated fluid acceleration histories as:

$$-F = \frac{\partial}{\partial t} \iiint_V \frac{q}{A g_c} \bar{m} dV - [F_P + F_M]_{\text{Blowdown}} = \left(\frac{I}{g_c} \frac{\partial \omega}{\partial t} \right) \text{FEA} \bar{m} - [F_P + F_M]_{\text{Blowdown}}$$

which describes the acceleration (closed system) force and the pressure and momentum (open system or blowdown) forces. The acceleration force term is composed of the fluid acceleration term and two integral geometry descriptors—the geometric “inertia” I and the FEA or “Force Equivalent Area”, both of which are required to reduce the initial three-dimensional momentum equation to the one-dimensional form shown. Within the parentheses is a term which is calculated by the RELAP4 computer program which is termed the acceleration pressure. The FEA, which makes possible the coupling of the RELAP4 program and the piping dynamics programs, is a volume integral of the inverse area which summarizes the local geometry.

Verification is presented which compares both blowdown thrust and acceleration load histories developed by this technique with load histories developed by F. Moody and others. Good agreement is found throughout the load histories for the severe condition of pipe rupture. A typical application of the method to steam line rupture restraint design is also presented which illustrates the development of both blowdown thrust and acceleration force histories.

To summarize, a general technique has been developed which allows the generation of blowdown thrust and piping acceleration loads for restraint design of arbitrary nuclear piping systems. To accomplish this, a new form of the fluid momentum equation has been derived which incorporates computer generated fluid acceleration histories by inclusion of a volume integral which summarizes the local three-dimensional geometry. Agreement of the technique with existing methods has been established.