

**MASTED**

AN EXPERIMENTAL BENCHMARK FOR PIPING SYSTEM  
DYNAMIC-RESPONSE ANALYSES

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## ABSTRACT

This paper describes the scope and status of a piping system dynamics test program. A 0.20 m (8 in.) nominal diameter test piping specimen is designed to be representative of main heat transport system piping of LMFBR plants. Particular attention is given to representing piping restraints. Applied loadings consider component-induced vibration as well as seismic excitation. The principal objective of the program is to provide a benchmark for verification of piping design methods by correlation of predicted and measured responses. Pre-test analysis results and correlation methods are discussed.

## INTRODUCTION

Dynamic analysis of nuclear power plant piping systems provides assurance of structural integrity by limiting the dynamically-induced response within values set forth in applicable codes. The uncertainty of the predicted response is dependent upon the methods used for creating mathematical models of the system's components and the analytical techniques used in the solution of the dynamic event. For simple systems, the models and techniques are well defined and readily verified with known solutions. For complex systems, i.e. piping systems with nonlinear support trains, a need arises for dynamic testing to provide the required verification.

Of primary importance in the design of piping systems for nuclear power plants is the consideration of dynamic effects attributed to high level, low cycle events such as earthquake disturbances and low level, high cycle events such as mechanical component vibration. The determination of a practical design of piping configuration and restraint arrangement which result in acceptable equipment nozzle loads, support reactions and satisfaction of code stress limits, often poses considerable challenge to the analyst. This is true in the design of Liquid Metal Fast Breeder Reactor (LMFBR) Heat Transport System (HTS) piping where, due to the large and rapid temperature transients in the duty cycle, the piping systems are designed with a relatively thin wall thickness and are routed with large thermal expansion loops. This requires additional restraint to limit the dynamic response to allowable levels when compared to the typical light water reactor (LWR) nuclear steam supply system (NSSS) piping which is relatively thick-walled, short run systems. The use of

a large number of restraints and the flexibility of the thin-walled pipe cross section complicate the analytical effort because the system is sensitive to variations in support arrangement and modeling parameters (1). In light of this, the design of LMFBR piping systems should embody maximum knowledge of dynamic system response to avoid unnecessary conservatism in the application of dynamic restraints. This will be obtained through a comprehensive experimental test and analysis program which will provide understanding of the dynamic response characteristics of breeder reactor piping systems.

This paper describes the scope and status for a development program where restraint effects will be investigated on a piping system representative of large diameter, thin-walled LMFBR piping. Specifically, methods are to be established to account for various characteristics of piping restraints, i.e. mechanical snubbers, in the determination of system response due to dynamic events. The technical approach is to perform systematic tests and analytical investigations and to correlate the measured and predicted responses. The dynamic response characteristics of restraint components will be established independently through analysis and tests prior to system testing. Piping system response will be evaluated for various types of restraint components, configurations and forcing excitations (including earthquake motions and component nozzle vibration). The correlations of analyses and tests will:

- confirm and refine the analytical methods and models currently used in LMFBR Plant piping design practice;
- provide guidelines for the development of design requirements for restraint devices, pipe clamps, support structures and piping insulation.

The results obtained will be most directly applicable to Clinch River Breeder Reactor Plant (CRBRP) piping systems because similar design features and conditions are embodied into the test. However, the test results will be indirectly applicable to other LMFBR (and LWR) piping systems through extrapolation and interpretation.

#### TEST PROGRAM DESCRIPTION

The general test program approach is to independently determine the response characteristics of the individual components prior to investigating their interaction effects with the assembled system. Through this decoupling calibration technique, significant component characteristics will be readily identified. The results of the characterization tests will facilitate separation of the contributions of each component for the investigation of overall system response. System tests will evaluate parametric variations of the component characteristics in addition to actual piping system configurations. As a result, overall response will be identified through the individual participations of the system's components.

The testing program is structured into three major series, as shown in Figure 1. Within the component characterization tests, the mechanical snubber and pipe hanger devices are calibrated through various loading conditions and configurations. The characterization techniques will yield the static and dynamic parameters required for identification of the components' kinematics. The mechanical snubbers will also be tested with a representative section of 0.20 m (8 in.) piping and pipe clamp as shown in Figure 2. In this way, the response of the overall support train will be determined. The system characterization tests consist of evaluating the structural integrity of the piping system support frame through various techniques and configurations such that dynamic interaction with the piping system, if any, will be identified. The system tests, which culminate the characterization tests, will evaluate the overall response of the assembled system. Variations in component characteristics and piping configurations will be investigated within this test series to further evaluate the overall sensitivity of the system to dynamic excitation. In addition, simulation of component nozzle vibration will be investigated through application of steady state motions

representative of rotating equipment, such as large circulating pump. Dynamic testing will conclude with multi-directional seismic excitation increasing in level until the largest amplitude corresponds to a Safe Shutdown Earthquake (SSE) event. The results of these tests will be compared with analytical predictions to assess the validity of the models and methods currently used in LMFBR piping design practice.

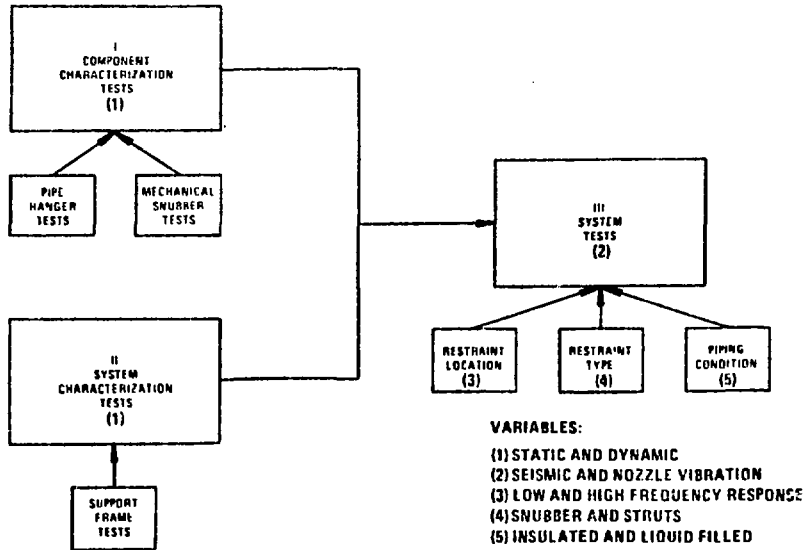


Figure 1. Test Program Progression

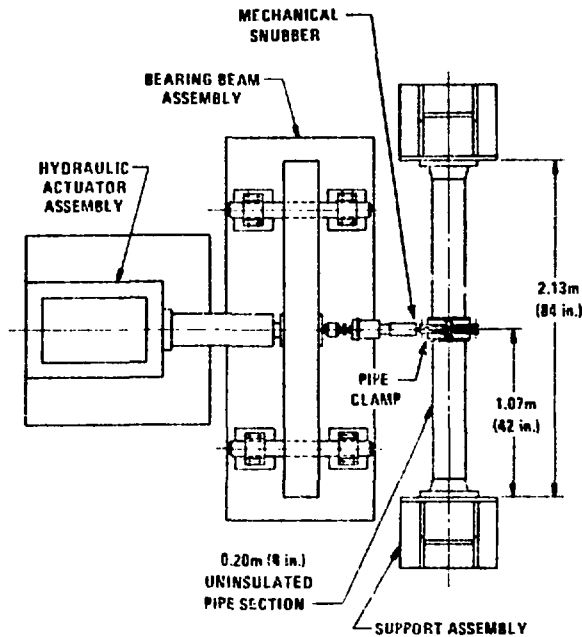


Figure 2. Mechanical Snubber Test Fixture

## DESIGN

The rationale for the component design is to provide a system of piping and restraints representative of large diameter, thin-walled CRBRP heat transport system piping. To accomplish this task, the component designs must be guided by dimensional analysis, as suggested by Ibanez (2). This method uses similar materials in the scale model as in the actual structure, and to scale all geometrical dimensions by a scale factor,  $\lambda$ . With this procedure, the dynamic properties are related as shown in Table 1.

Table 1  
Dynamic Scaling Relationships

Parameter	Actual Structure	Scale Model	Relation
Force	F	f	$F = \lambda^2 f$
Length	L	l	$L = \lambda l$
Time	T	t	$T = \lambda t$
Displacement	D	d	$D = \lambda d$
Velocity	V	v	$V = v$
Acceleration	A	a	$A = a/\lambda$
Frequency	F	f	$F = f/\lambda$
Strain	E	e	$E = e$
Rotation	R	r	$R = r$

This method (referred to as velocity scaling since velocities in the model and actual structure are equal) has its limitations since gravitational and strain rate effects are distorted. However, the approach is judged sufficient for pressure vessel systems.

Since laboratory testing of a full scale, large diameter piping system is both cost and test facility prohibitive, a scale model test specimen has been designed. However, a pure scale model is impractical; therefore, certain assumptions are required. Departures exist when the scale model design becomes impractical. The dynamic relationships between the full and scale models were preserved where possible.

The test piping specimen has been designed to be similar to the 0.61 m (24 in.) primary hot leg located in the containment building of the CRBRP (3). This system transports liquid sodium from the primary sodium pump (PSP) to the intermediate heat exchanger (IHX). The system consists of stainless steel piping interconnecting the two major components via a typical U-shaped thermal expansion loop. This arrangement provides flexibility to limit the thermally-induced stresses and reactions to within allowable limits when operating at elevated temperatures, 546 C (1015 F). Due to the relatively low operating pressure, 1.16 MPa (168 psi) and the large thermal transients that occur during operating conditions, the piping wall thickness is designed as a minimum, 12.7 mm (0.50 in.). The test piping system design reflects these two major design features of the primary hot leg, i.e. a U-shaped configuration and a thin-walled pipe cross section. A 0.20 m (8 in.) nominal diameter pipe was judged appropriate for laboratory testing and results in approximately a one-third scale model ( $\lambda = 3$ ). The diameter to thickness ratio of the test specimen was maintained to preserve the thin-walled characteristics of the large diameter piping. Also, the materials for both plant and model systems are similar.

The test pipe clamp design reflects the same basic considerations embodied into the large diameter pipe clamps and is presented in Figure 3. The clamp has been scaled geometrically from the 0.61 m (24 in.) design to ensure dynamic similarity and is constructed of similar materials. The two semi-circular steel rings (with attachment gussets) are held together by a system of Belleville springs which accommodate variations in pipe diameter due to temperature changes. The Belleville springs are preloaded which prevent the clamp from lifting off the pipe when loads are applied at the attachment points. The load-bearing insulation is sandwiched between the inner clamp ring and the outer pipe wall which minimizes thermal transient stresses in the piping. The insulation bands contain segmented sections of the load-bearing insulation and are encased by stainless steel sheathing. These insulation bands surround the pipe wall over the width of the clamp (axial to the pipe centerline) to provide a positive compressive load area.

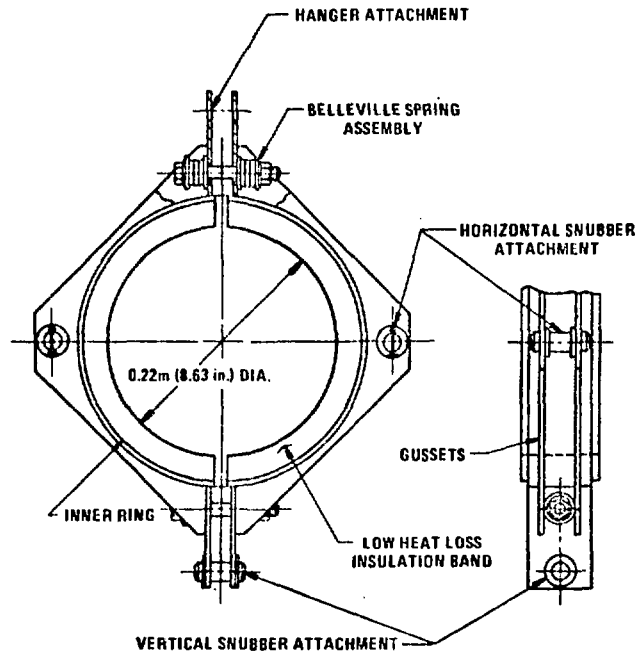


Figure 3. Test Pipe Clamp Assembly

The piping support frame consists of an assemblage of structural steel beams and plates which provide deadweight support for the piping system and also to facilitate transmission of vibratory motions from a shaker table to the piping loop. In order to ensure that excessive dynamic interaction does not occur between the support frame and piping system, the fundamental resonant frequency of the support frame is designed to be sufficiently greater than that of the maximum testing frequency expected. Accomplishment of this requirement provides a sound and rigid frame which will not reinforce the dynamic response of the piping system. Structural integrity of the support frame is ensured as well as dynamic de-coupling of the frame and piping. The support frame is designed with horizontal sides equal to 4.9 m (16 ft) and a maximum vertical height of 2.7 m (8.9 ft), as shown in Figure 4. The total mass of the assembled structure, including the piping system, is approximately 9072 kg (20 000 lb). The entire assembly will be mounted on a shaker table capable of accommodating the spatial dimensions and total mass.

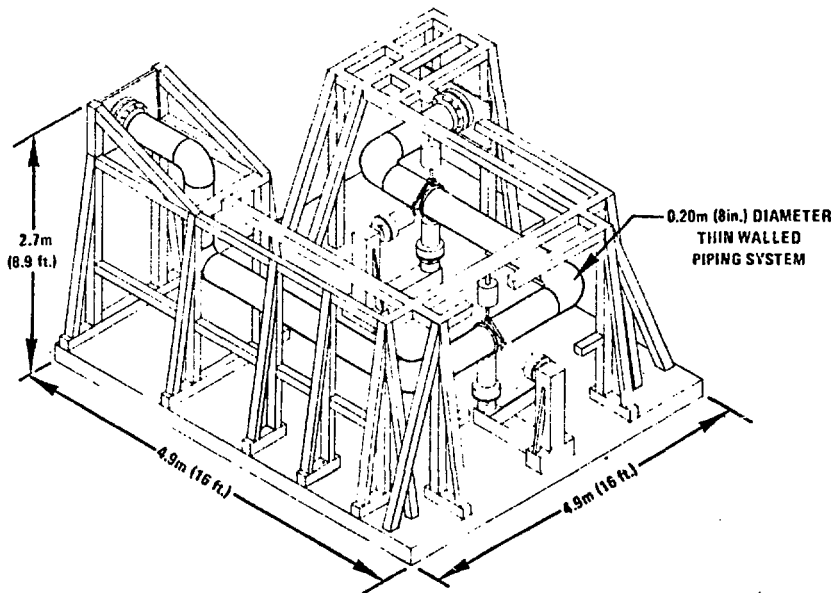


Figure 4. Test Piping Specimen and Support Frame Assembly

The design of the insulation system for the test piping loop includes components representative of large diameter HTS piping. A typical section of insulated straight piping, detailing the individual hardware, is shown in Figure 5. The stand-off assembly, which provides an annulus for the location of trace heaters and leak detection equipment, is attached directly to the pipe wall by means of a locking device. The inner jacketing, supported by the stand-off assembly, encloses the annulus and is secured with the inner banding strap. The insulating material is layered in specified thicknesses and individually secured with tie wires. The outer jacketing completes the assembly and is fastened and locked with an outer banding strap. For the elbows, the typical inner jacketing is replaced by pre-formed, split sheathing which provides a smooth contoured jacket ensuring a uniform annulus. The insulation is layered as in the straight piping, but glass cloth tape secures the final layer at the outer boundary in lieu of the outer jacketing and banding straps. The design is prototypic, since geometric and material similarities are maintained.

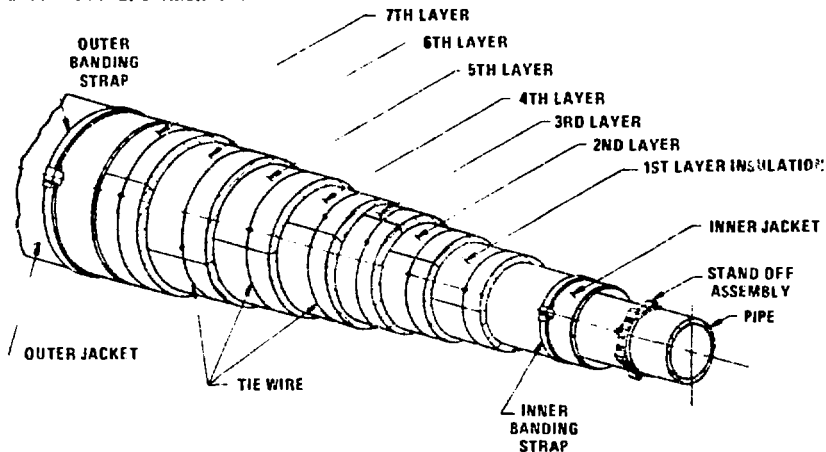


Figure 5. Test Pipe Insulation System

The specification of the mechanical snubbers for the test piping system considered various characteristics and similarities to the large diameter HTS restraint devices. As a result, the equivalent support train consisting of the mechanical snubber, pipe clamp, piping cross section and civil structure are dynamically similar. Variable spring hangers are chosen in lieu of constant support hangers, since testing will be performed at room temperature and vertical thermal expansion effects are negligible. Also, the predicted piping movements due to vibration will not significantly vary the supporting force of the variable spring hangers. A typical test restraint arrangement is presented in Figure 6.

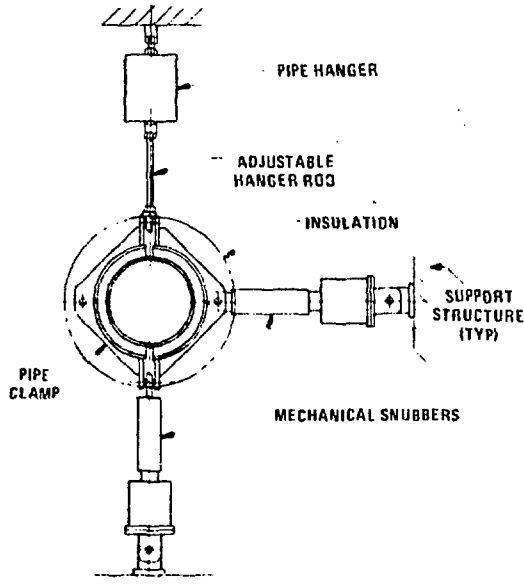


Figure 6. Test Restraint Arrangement

#### ANALYSIS

Pre-test analyses were performed to verify the static and dynamic characteristics of the test system and also to serve as pre-test predictions for evaluation of the test results. The preliminary mathematical models utilized will provide the basis for future analyses. The actual test results will be correlated with analytical predictions, and the models will be modified until test response can be simulated by analysis. Therefore, a close interaction between the test program and analytical effort will be maintained.

The test piping system was analyzed both uncoupled and coupled with the piping support frame. Various piping mass conditions were investigated to determine the effects on system response. Two restraint arrangements were simulated; (1) a low frequency system characteristic of typical piping, and (2) a dynamically scaled system where resonant conditions are increased due to the scale factor (as shown in Table 1).

The restraint configurations were determined using static and modal analysis techniques to achieve the required responses. The low frequency system consisted of five mechanical snubbers and five variable spring hangers. This restraint configuration approximates a conventional 0.20 m (8 in.) piping system design. The dynamically scaled system consisted of twelve mechanical snubbers and five variable spring hangers (equivalent to the CBRP primary hot leg). The resulting fundamental resonant frequencies for the insulated and liquid filled piping conditions were:

Low Frequency System

$f = 10.9 \text{ Hz}$

Dynamically Scaled System

$f = 20.1 \text{ Hz}$

The results of the piping system and support frame interaction analysis indicated that a total of eight piping system vibrational modes can be simulated without resonating the support frame. The response from subsequent modes (above 50 Hz) included interaction effects from both subsystems.

Response spectrum analyses were performed to determine the response of the piping and restraint components for planned seismic simulation tests. The test excitation was constructed from actual time history motions used in the design of the CRBRP large diameter piping. However, for the dynamically scaled system, frequency and acceleration parameters were scaled (as shown in Table 1) to preserve dynamic similarity. The results obtained from these analyses (reaction forces, displacements and stresses) will be used as pre-test predictions for actual test conditions.

#### CORRELATION

The primary objective of this development program is to provide a benchmark for piping design methods and analytical techniques. Comparisons of the predicted and measured responses will be made at several levels including as-designed, as-built and post-test. Both simplified and detailed models will be used. The data obtained from preliminary characterization tests will reinforce assumptions made in the analytical models, i.e. restraint stiffness, free play and damping characteristics.

Linear and nonlinear time history analyses will be used for correlation with the test data. Conventional analyses using the response spectrum method will also be performed. Additional post-test analyses will be conducted using data obtained from the control accelerometer mounted on the shaker table platform.

The analytical data obtained from the various models and methods will be compared with the measured responses. The degree of deviation will provide the basis to verify and refine the piping design methods. As a result, the integrity of the design methodology will be established.

#### STATUS

This development program was initiated in January 1980. Final assembly and testing began in March 1981.

#### CONCLUSIONS

The development program described in this paper will confirm and refine the mathematical models and analytical methods currently used in the design of LMFBR piping systems. Design and practical performance requirements for restraint devices, pipe clamps, support structures and piping insulation will also be developed. In addition, the payoff of improved dynamic analysis models will be established.

#### ACKNOWLEDGEMENTS

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