INSTABILITIES INDUCED BY LEAKAGE FLOWS

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Summary

Many relatively flexible reactor components must be provided sufficient lateral support to maintain acceptable bending vibration levels, while at the same time allowing axial movement to accommodate differential thermal expansion, control functions, and/or component removal. Typically, one end of the component is fixed and lateral support is provided at other axial locations by a channel, the inside of another tube, or the wall of a hole in a plate, all of which have similar but slightly larger cross-sectional shapes. Such supports are referred to as "slip joints" because they must allow axial motion, i.e., the component must be allowed to "slip."

The main coolant flow establishes a pressure drop across the slip joint, allowing fluid to leak through the narrow passages created to accommodate axial motion of the component. Any vibratory motion of the component will modulate the leakage flow. This modulation of the flow can result in fluid forces that are in phase with the structural velocity. In such cases fluidelastic instability will initiate when the energy input to the structure exceeds the energy dissipated by system damping.

Several failures of power reactor components have been attributed to instability induced by leakage flow. This experience motivated a review and evaluation of various CRBR components that had the potential for experiencing such instability. These components included the control rod driveline shroud tubes, flow chimney, and in-vessel transfer machine port plug. In the course of carrying out the evaluation it became obvious that although the basis for instability is simple enough, quantitative analytical predictions are beyond the state of the art. Consequently, testing is required and was performed for the three CRBR components identified above. The difficulty in accurately calculating the motion-dependent fluid forces is the main hindrance to obtaining an analytical solution. Local geometric details and eccentricities can be expected to alter the flow field and are known to significantly influence the instability; thus, they introduce further complexity.





The considerable expense of model testing to evaluate the potential for leakage-flow-induced instability, and of repairs when components in operating reactors fail by this mechanism, can be effectively eliminated if reactor component supports that create leakage flow paths can be limited to a few designs shown by comprehensive study not to lead to instability. With this goal in mind, we embarked on a series of experimental parameter studies of a specific slip joint design - a tube-in-tube design with one tube flexible and one tube rigid. The objective was to develop stability maps and design rules that define conditions for which instability will not occur.

To carry out the study of the tube-in-tube slip joint, a Leakage Flow-Induced Vibration Test Facility was designed and constructed at Argonne. The facility provides for reversing flow directions, variable damping in the fundamental mode, changeable local slip joint geometries, variable engagement length, and monitoring of tube displacements at the slip joint and the second mode antinode. Of these features, the ability to vary the modal damping is especially noteworthy. Damping is one of the more important parameters, since it directly determines the instability threshold; a squeeze-film damper assembly was designed to allow variation of modal damping from ~1 to 8 percent of critical damping in the fundamental mode. Geometric parameters that can be varied in the facility include insertion length, annular gaps, constriction design and dimensions, and eccentricity in initial positioning of the tubes.

The extensive testing that we have performed provides a data base from which comprehensive design rules can be formulated for the avoidance of instabilities caused by leakage flows through tube-in-tube slip joints with an annulus constriction. Two very simple design rules to avoid instability were established as a result of the study:

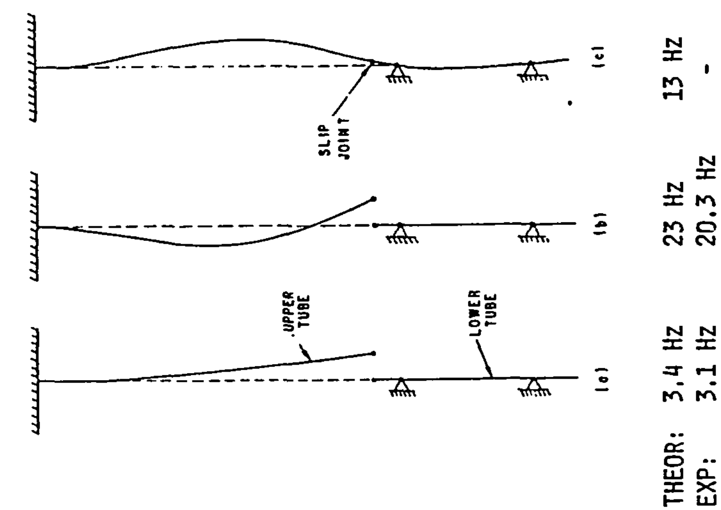
- Use a downstream constriction with an engagement length greater than 20 percent of the annulus diameter, and
- Use an upstream constriction only when the downstream annulus length is less than three times the width of the radial gap between the two tubes.

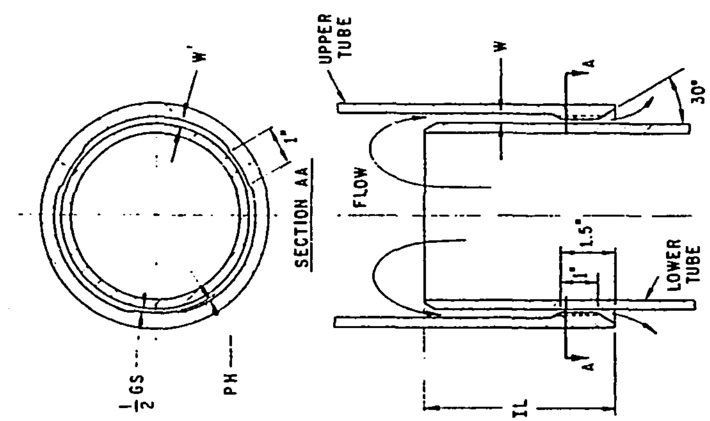
Unconstricted slip joints were also studied. Here, the results demonstrated that instability of essentially unconstricted slip joints occurs only for short engagement lengths and is easily avoided by maintaining engagement lengths greater than 20 percent of the annulus diameter.

INSTABILITIES INDUCED BY LEAKAGE FLOWS

- OBJECTIVES
  - UNDERSTAND/CHARACTERIZE SPECIFIC (TUBE-IN-TUBE) SLIP JOINT DESIGNS
  - DEVELOP DESIGN GUIDELINES

- BACKGROUND/MOTIVATION
  - CLEARANCE OFTEN IS DESIGN REQUIREMENT
  - SEVERAL FAILURES LWR COMPONENTS
  - VARIOUS CRBR COMPONENTS SUSPECT
  - CRBR CRDL SHROUD DEMONSTRATED PROBLEM POTENTIAL
  - DEFINITIVE DESIGN GUIDELINES LACKING




CRBR CRDL SHROUD TUBE DESIGN

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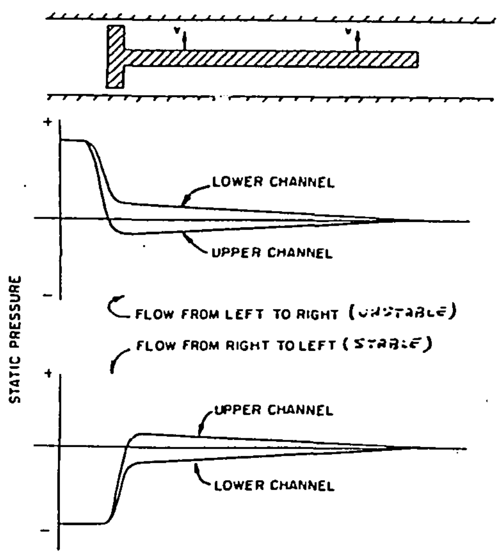
PRELIMINARY STUDY -

- LIMITED PARAMETER STUDY

- GENERAL TEST RESULTS -
  - DESIGN FLOW DIRECTION (DOWNSTREAM CONSTRICTION) STABLE
  - REVERSE FLOW (UPSTREAM CONSTRICTION) UNSTABLE

- MILLER'S HEURISTIC EXPLANATION -

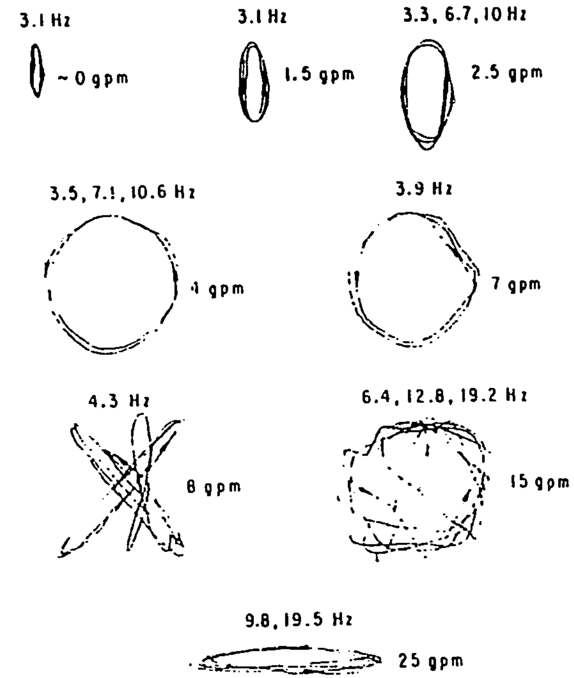


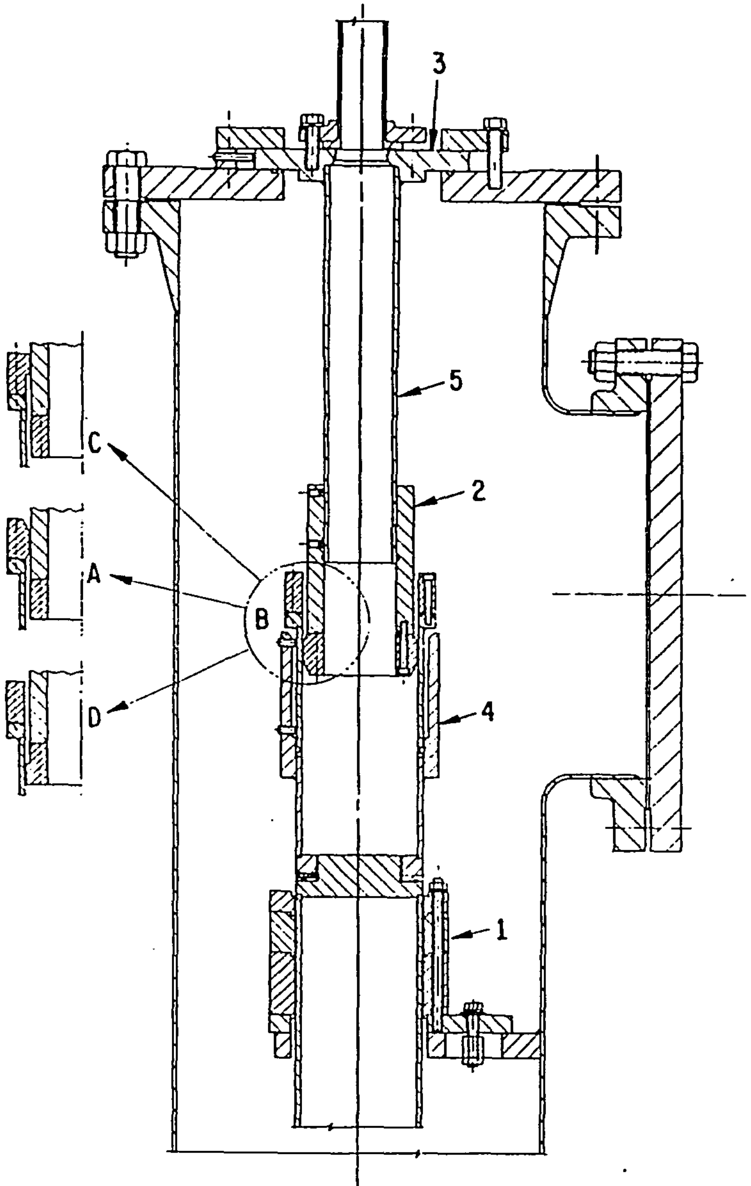

Generation of Positive and Negative Damping

UNSTABLE MOTION PATTERNS -

TEST B-1: IL = 5 IN., 1/2 GS = 0.009 IN., PH = 0.022 IN.,

W' = 0.031 IN., W = 0.271 IN., $\zeta_o$ = 0.3%

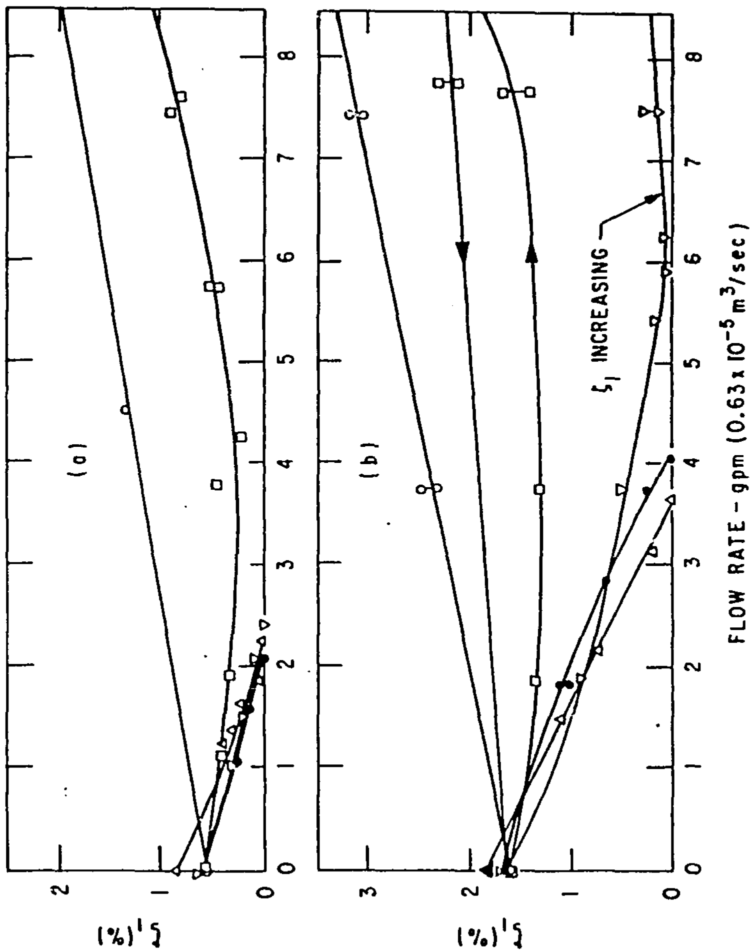




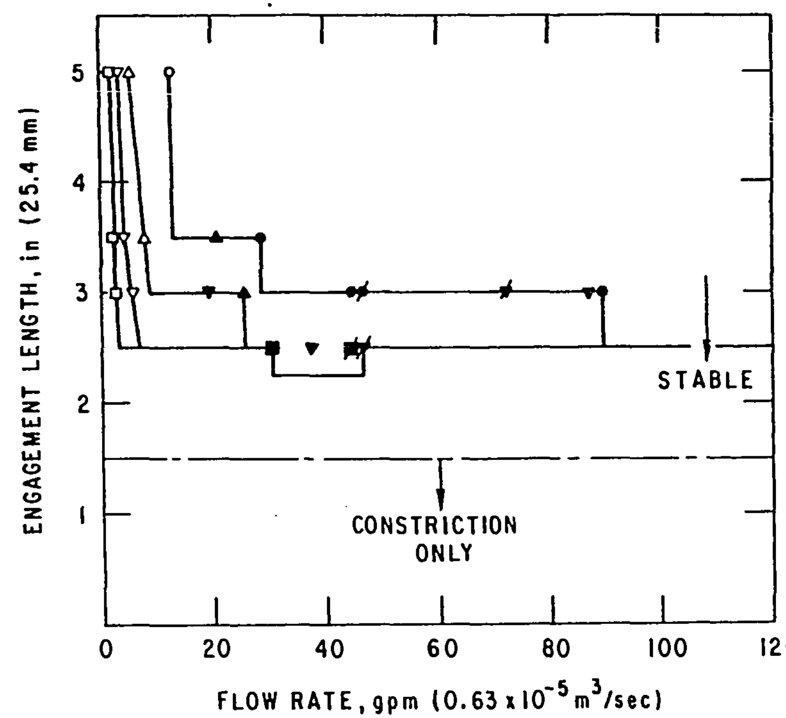
Slip Joint

TEST FACILITY FEATURES -

- REVERSING FLOW DIRECTIONS
- VARIABLE DAMPING IN FUNDAMENTAL MODE
- VARIABLE LOCAL SLIP JOINT GEOMETRIES (CONSTRICTION DESIGN AND DIMENSIONS)
- VARIABLE ENGAGEMENT LENGTH AND ANNULAR GAP
- VARIABLE ECCENTRICITY
- DISPLACEMENT MONITORING
  - SLIP JOINT LOCATION
  - SECOND MODE ANTI-NODE




Variation in First-mode Damping with Top-to-Bottom Flow for (a) H/D = 0.18 and (b) H/D = 0.55 where L/D = 0.28, ○; 0.46, □; 0.55, ▽; 0.64, ●; 0.91, △




Instability Map for Top-to-Bottom Flow where First Mode $\zeta_1$ (%) = 0.5, □; 2.2, ▽; 3.3, △; 6.6 ○ (The solid symbols indicate instability in the second mode: $f_2 \cong 21$ Hz, $\zeta_2 = 0.3$. The solid line (——) bounds stable regions.)

GENERAL TEST RESULTS -

- INSTABILITY CAN OCCUR IN BOTH FIRST AND SECOND MODES
- INSTABILITY IS MORE LIKELY TO OCCUR FOR
  - LARGER FLOW RATES
  - LONGER ENGAGEMENT LENGTH
  - SMALLER FIRST MODE DAMPING
- THRESHOLD VALUES EXIST FOR THE ABOVE PARAMETERS
- ECCENTRICITY TENDS TO STABILIZE THE SLIP JOINT
- INSTABILITY OF "UNCONSTRICTED" SLIP JOINTS CAN OCCUR FOR SHORT ENGAGEMENT LENGTHS

DESIGN RULES TO AVOID INSTABILITY -

- USE A DOWNSTREAM CONSTRICTION WITH AN ENGAGEMENT LENGTH GREATER THAN 20 PERCENT OF THE ANNULUS DIAMETER
- USE AN UPSTREAM CONSTRICTION ONLY WHEN THE DOWNSTREAM ANNULUS LENGTH IS LESS THAN THREE TIMES THE WIDTH OF THE RADIAL GAP BETWEEN THE TWO TUBES