ILLINOIS POWER COMPANY

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May 10, 1982

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Mr. J. R. Miller, Branch Chief
Standardization & Special Projects Branch
Division of Licensing
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Miller:

Clinton Power Station Unit 1
Docket No. 50-461

Reference: SER Open Issue 3.9.2, Steady State Piping Vibration Acceptance Criteria

The attached standard, OM-3, has now been approved by the American Society of Mechanical Engineers. It specifies 80% of the endurance limit (Sa) from Appendix I to the ASME Code as the acceptance criteria for the steady state piping vibration stress limit. Illinois Power Company is applying this standard on Clinton Power Station, and on this basis we consider the SER open issue from article 3.9.2 to be closed.

Sincerely,

G. E. Wuller

G. E. Wuller
Supervisor-Licensing
Nuclear Station Engineering

GEW PEW/lt
Attachment
cc: J. H. Williams, NRC Clinton Project Manager
H. H. Livermore, NRC Resident Inspector
Illinois Dept. of Nuclear Safety

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ANSI/ASME OM-3-1982
Draft 5, Rev. 0

DRAFT

CAUTION NOTE: This document is being prepared and reviewed and has not been approved by ANSI. It is subject to revision or withdrawal before issue.

REQUIREMENTS FOR PREOPERATIONAL AND INITIAL STARTUP VIBRATION TESTING OF NUCLEAR POWER PLANT PIPING SYSTEMS

ASME COMMITTEE ON OPERATION & MAINTENANCE OF
NUCLEAR POWER PLANTS

NOTICE

THIS DOCUMENT IS A DRAFT WHICH REPRESENTS WORK BEING DONE BY AN ASME TECHNICAL COMMITTEE AND WHICH IS AIMED AT GENERATING AN ANSI STANDARD. IT IS FURNISHED AS INFORMATIONAL MATERIAL ONLY.

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FOREWORD

Introduction

This standard provides general requirements for the assessment of piping system vibration for nuclear power plants including ASME Section III and applicable ANSI classified systems. It includes steady-state and transient vibration testing and corresponding acceptance criteria, instrumentation and measurement techniques, and recommendations for corrective action when required.

This standard is applicable for vibration qualification and design verification, during preoperational and initial startup testing, of piping systems which require testing by the nuclear power plant Safety Analysis Report, Design Specification, or other governing documents. In addition, this standard may serve as a guide for assessment of vibration levels of applicable piping systems during plant operation.

General

This standard is one of a series of nuclear power plant testing standards; it was developed as a guide for vibration testing and monitoring under the sponsorship of the American Society of Mechanical Engineers (ASME) as an effort by the Nuclear Codes and Standards Operations and Maintenance Committee. This committee has been chartered to identify, develop, maintain, and review Codes and Standards considered necessary for the safe and efficient operation and maintenance of nuclear power plants to assure structural and functional adequacy.

In February, 1976, the ASME Operations and Maintenance Committee established the Subcommittee on Vibration Monitoring under whose jurisdiction this standard was prepared. The Subgroup on Piping Systems responsible for development of this standard was established in March, 1977. The provisions of this standard apply directly to the owners and operators of nuclear power plants.

In documentation pertaining to a specific plant, statements such as "The piping systems are being tested in accordance with ASME Nuclear Vibration Standards" may be made only provided that the mandatory requirements of this standard have been satisfied for each piping system covered by the ASME Standard.

Standard Responsibility

This Piping System Vibration Testing Standard was prepared by a subgroup including the following personnel:

J.S.G. Williams, Chairman

A. J. Ayoob, Westinghouse Electric Corporation
D. A. DesMarais, Stone & Webster Engineering Corporation
K. Khuzaie, General Electric Company
G. T. Kitz, Sargent & Lundy Engineers
L. Memula, Bechtel Power Corporation
J. R. Rajan, U.S. Nuclear Regulatory Commission
H. J. Thailer, Nuclear Service Corporation
J.S.G. Williams, Tennessee Valley Authority
J. C. Wachel, Southwest Research Institute

The ASME Subcommittee on Vibration Monitoring had the following membership at the time of approval of this standard.

G. T. Kitz, Chairman
J. R. Hoffman, Secretary

G. Bohm, Westinghouse Electric Corporation
A. J. Oster, Stone & Webster Engineering Corporation
R. E. Hutchings, General Electric Company
J. R. Hoffman, Yankee Atomic Electric Company
G. T. Kitz, Sargent & Lundy Engineers
R. C. Krytar, Oak Ridge National Laboratories
B. T. Lubin, Combustion Engineering, Incorporated
J. M. McBride, Bechtel Power Corporation
G. C. Millman, NUS Corporation
P. J. Pekrul, Rockwell International
J.S.G. Williams, Tennessee Valley Authority
G. Zigler, Science Applications, Incorporated

The ASME Operation and Maintenance Committee had the following membership at the time of approval of this standard:

W. P. Johnson, Chairman
~~[illegible]~~, Secretary
K. I. Baron
D. Beatty, Catalytic, Incorporated
L. Chockie, General Electric Company
S. L. Daltroff, Philadelphia Electric Company
J. R. Duck, Nuclear Insurance Consultants
T. W. Fitzgerald, NEL-PLA
S. A. Grimes, American Electric Power Service Corporation
W. P. Johnson, Yankee Atomic Electric Company
F. Kelly, EDS Nuclear
G. T. Kitz, Sargent & Lundy Engineers
B. Koh, Westinghouse Electric Corporation
J. M. Kufel, Northeast Utilities Service Company
J. D. Phinney, Babcock & Wilcox
J. Sniezek, Nuclear Regulatory Commission
W. C. Sommer, Burns & Roe
J. Stacey, Yankee Atomic Electric Corporation
R. J. Walker, Combustion Engineering
~~[illegible], ASME~~
L. E. Williamson, Southern Services

Suggestions for improvements as gained in the use of this standard will be welcomed. They should be sent to the Secretary, ASME Vibration Monitoring Subcommittee, The American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, New York, 10017.

This standard was approved by The American Society of Mechanical Engineers Subcommittee on Performance and Committee on Operation Maintenance. It was subsequently approved and designated by The American National Standards Institute on

REQUIREMENTS FOR PREOPERATIONAL
AND INITIAL STARTUP VIBRATION
TESTING OF NUCLEAR POWER PLANT
PIPING SYSTEMS

TITLE

1.0 INTRODUCTION

1.1 Scope

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The standard is applicable for vibration qualification and design verification during preoperational and startup testing of piping systems which require testing by the nuclear power plant safety analysis rep[illegible], design specification, or other governing documents. In addition, this standard may serve as a guide for assessment of vibration levels of applicable piping systems during plant operation.

2.0 DEFINITIONS

2.1 Owner: The organization responsible for the operation, maintenance, safety, and power generation of the nuclear power plant.

2.2 Design specification: The document provided by the owner as required by NCA 3250 of the ASME III for the component/system which contains requirements to provide a complete basis for the construction of the component/system.

2.3 Maintenance/repair/replacement: Actions taken to prevent or correct deficiencies in the system operation.

2.4 System: An assembly of piping subassemblies and components whose limits and functions are defined in its design specifications.

2.5 Record drawing set: The set of drawings which define the systems layout and support configuration at the time the system is placed in service for testing.

2.6 Steady-state vibration: Repetitive vibrations which occur for relatively long periods of time during normal plant operation.

2.7 Transient vibrations: Vibrations which occur during relatively short periods of time. Examples of transient sources of vibration are: pump actuation and pump switching, rapid valve opening or closing, and safety relief valve operation.

2.8 Normal operating conditions: The service conditions the system would experience when performing its intended function.

2.9 Test conditions: The service conditions experienced by the system when undergoing tests to assure its intended functional ability.

2.10 Test specification: The document or documents prepared by the owner or his assignee which meets the requirements set forth in section 3.0.

2.11 Design verification: The process during which the design adequacy of the system is validated. This includes checking the record drawing set against the installed system and evaluating actual system behavior against applicable analyses and/or acceptance criteria.

2.12 Prototype - A system built on the basis of an original design for which there are no previous system test results available.

2.13 Duplicate - A system built on the basis of a previously used and proven design for which test results are available.

2.14 Preoperational Testing - Test activities performed prior to initial fuel loading.

2.15 Initial Startup Testing - Test activity performed during or following initial fuel loading, but prior to commercial operation. These activities include fuel loading, precritical tests, initial criticality, low power tests, and power ascension tests.

2.16 Operational Testing - Test activities performed subsequent to initial startup testing, e.g., testing performed during commercial operation of the plant.

2.17 ASME Code - ASME Boiler and Pressure Vessel Code - Section III.

2.18 Test hold points: System operating conditions for which test information is to be collected; e.g., with the reactor at X% power, with the system at full flow, etc.

2.19 Quality Assurance: All those planned and systematic actions necessary to provide adequate confidence that an item or facility will perform satisfactorily in service.

3.0 GENERAL REQUIREMENTS

The Owner shall determine the portions of piping systems to be tested and shall classify these systems into the vibration monitoring groups defined in the following section. The minimum general requirements for the classification by groups are provided in subsection 3.1; however, the Owner may place a system into a more stringent vibration monitoring group (VMG).

Vibration conditions are classified into steady-state and transient vibration categories. A system may be classified into one vibration monitoring group for steady state vibrations and into another group for transient vibrations. The testing requirements, acceptance criteria, and recommendations for corrective action associated with these categories are provided below. The vibration testing and assessment of vibration levels may be conducted during preoperational and initial startup testing or during plant operation in accordance with the requirements of the test specification.

For preoperational, initial startup, and operational testing, a test specification shall be prepared which will include as a minimum:

Pretest requirements or conditions

Type test (i.e., steady state or transient)

Systems to be tested

Test conditions

Measurements (including visual observation) to be made

Acceptance criteria

Test hold points

Instrumentation to be used (including instruments specifications)

Governing documents and drawings

Data handling and storage

Quality control and assurance

System restoration

Precautions

The test specifications shall be written in a manner to ensure that the objectives of the tests are satisfied and that results obtained are conservative. Prior to testing, an inspection of components and supports shall be made to verify correct installation according to the record drawing set, specifications, and appropriate codes.

When test results are to be correlated to specific analyses, test conditions and measurements should be sufficiently specified to ensure that the parameters and assumptions used in the analyses are not violated. ~~and that~~ The correlation between tests and analysis ~~results~~ should confirms the validity of the analysis and should indicates that the analytical results are conservative. IF the test results indicate that analysis is not adequate or when the measured data from the test indicates that the ~~actual~~ forcing function ~~is~~ not ~~conservatively~~ covered by the forcing functions used in the analysis, the analytic data should be modified or conservatively scaled prior to correlating the test and analysis results.

Tech

The vibration monitoring requirements and acceptance criteria are defined in subsection 3.2. If the test data exceeds the value specified in the hold point section of the test specification, two options are available (1) further testing or evaluation to a more rigorous method or (2) corrective action should be taken as described in section 8.0.

Cognizant engineering personnel shall participate in the development of test specification requirements, selection of instrumentation, establishment of acceptance criteria, review, evaluation, and approval of test results.

Selection of the locations of measuring devices and the type of measurements to be made shall be based upon piping stress analysis, response of a similar system and/or experience gained through testing of the subject system and shall reflect any unique operational characteristics of the system being tested. Evaluation of the test data shall consider characteristics of the measuring devices used.

3.1 Classification

Piping system vibrations are classified into two categories: (1) steady state, and (2) transient, as defined in sections 2.8 and 2.9. Within each applicable category the piping system shall be classified into one of the three vibration monitoring groups according to the criteria presented in subsections 3.1.1 and 3.1.2.

Piping systems which are inaccessible for visual observation or measurement using portable devices, during the conditions listed in the test specification, shall be classified into either VMG 2 or VMG 1.

In addition to the requirements presented in subsections 3.1.1 and 3.1.2, the safety and/or power generation function of the system should also be considered when classifying the system into the vibration monitoring groups.

3.1.1 Steady-State Vibration

3.1.1.1 Vibration Monitoring Group 1

The monitoring program required for systems evaluated in this group typically involves sophisticated monitoring devices and extensive data collection to accurately determine vibratory pipe stresses or other specified component limitation.

When accurate measurement of the system response characteristics are required, the techniques and devices implied by the requirements for this vibration monitoring group shall be employed. Determination of mode shapes, modal response magnitudes and total system response is possible using these evaluation techniques.

All portions of piping systems which experience steady-state vibrations and meet one of the following requirements shall be classified in VMG 1 and shall meet the acceptance criteria of subsection 3.2.1.

3.1.1.1.1 Piping systems which exhibit a response not characterized by simple piping modes (e.g., relatively stiff piping mounted between large softly mounted equipment).

3.1.1.1.2 Piping systems for which the method of VMG 2 and 3 are not applicable based on limitation given in sections 4 and 5.

3.1.1.2 <u>Vibration Monitoring Group 2</u>

The methods and devices employed in the evaluation of vibration monitoring group 2 provide a means of ascertaining whether the piping systems are vibrating, and provide a means for ascertaining the maximum response at a given location.

All portions of piping systems which meet one of the following requirements shall be classified in vibration monitoring group 2 and shall meet the acceptance criteria specified in subsection 3.2.2.

3.1.1.2.1 All piping systems which may exhibit significant vibration response based on past experience with similar systems or similar system operating conditions.

3.1.1.2.2 Piping systems for which the method of VMG 3 are not applicable based on limitation given in section 4.

3.1.1.3 <u>Vibration Monitoring Group 3</u>

The visual method employed in the evaluation of vibration monitoring group 3 is most fundamental and provides the most simplified means for determining whether any significant

vibrations exist in the system. Evaluation of vibration levels using this method is based upon experience and judgment and provide an acceptable basis for assessment. If firm quantitative assessments are required, the methods in vibration monitoring groups 1 or 2 should be employed.

All portions of piping systems which meet one of the following requirements shall be classified in vibration monitoring group 3 and shall meet the acceptance criteria specified in subsection 3.2.3.

3.1.1.3.1 Systems falling in VMG 1 or VMG 2 classification for which measurements or prior test data are available on prototype or duplicate systems and for which the minimum unacceptable vibrations are observable.

3.1.1.3.2 Portions of ASME Class 1, 2, and 3 and ANSI B31 piping systems which are not expected to exhibit significant vibrational response based on past experience with similar systems or system operating conditions.

3.1.2 Transient Vibration

Table 3-1 presents some examples of transient conditions to which systems may be subjected.

3.1.2.1 Vibration Monitoring Group 1

Portions of piping systems which experience transient vibrations and meet the following requirement shall be classified in VMG 1 and shall meet acceptance criteria specified in subsection 3.2.1.

3.1.2.1.1 Systems which from past plant operation experience are known to experience significant dynamic transient conditions due to the inherent nature of component design, system operation, or system design features, for which a transient analysis is not performed.

3.1.2.2 Vibration Monitoring Group 2

Portions of piping systems which experience transient vibrations and meet the following requirement shall be classified in VMG 2 and shall meet acceptance criteria specified in subsection 3.2.2.

3.1.2.2.1 Systems which are designed and analyzed for known anticipated dynamic loading conditions and for which the applied loading (i.e., fluid or mechanical) is based upon methodology which is known to conservatively predict the transient forcing function and corresponding structural response.

3.1.2.3 Vibration Monitoring Group 3

All portions of piping systems which experience transient vibrations and meet the following requirements should be classified in VMG 3 and shall meet the acceptance criteria specified in subsection 3.2.3.

3.1.2.3.1 Systems which undergo transient vibrations during their operating life (e.g., systems subjected to pump startup transients, valve opening or closure) and which by past experience with similar system or systems operating conditions are not expected to exhibit significant vibrational response.

3.2 Monitoring Requirements and Acceptance Criteria

Special attention should be given to the precautions listed in subsection 4.3.

The acceptance criteria presented in this subsection are based upon the following assumptions. The Owner may invoke less stringent criteria provided sufficient justification is given. More stringent criteria shall be invoked if the following assumptions are deemed inappropriate for the system under review.

Assumptions:

a. Vibrations cause maximum stresses within the elastic range, therefore no penalty for plastic cycling is incurred.

b. Thermal transient effects, if they exist during the vibration incident, have already been considered in the piping system evaluation.

c. The membrane stresses caused by pressure fluctuations, alone, are insignificant in comparison to the stresses caused by the vibratory moments.

d. The usage factor from the vibration incident does not significantly affect the cumulative usage factor calculated for other predefined transient conditions.

e. The ASME B&PVC Section III strain controlled fatigue curves represent the S-N fatigue characteristics for the material and loading considered.

3.2.1 Vibration Monitoring Group 1

3.2.1.1 The vibration response of group 1 systems shall be evaluated using the methods and devices listed in section 6.0.

3.2.1.2 For steady-state vibration, the maximum calculated alternating stress intensity, S_{alt}, should be limited as defined below:

a. For ASME Class 1 piping systems,

$$S_{alt} = \frac{C_2 K_2}{Z} M \leq .8\ Sel$$

where:

C_2 = Secondary stress index as defined in the ASME Code

K_2 = Local stress index as defined in the ASME Code

M = Maximum zero to peak dynamic moment loading due to vibration only, or in combination with other loads as required by the system Design Specification

Sel = Endurance limit (Sa) from figure I-9.1 or I-9.2 of the ASME Code, Appendix I. * Tech

* The User shall consider the influence of temperature on the Modulus of Elasticity

Z = Section modulus of the pipe

b. For ASME Class 2 and 3 piping, ANSI B31

$$S_{alt} = \frac{C_2K_2}{Z} M \leq (0.8)\ Sel$$

where

C_2K_2 = 2i

i = stress intensification factor, as defined in the ASME Code, Subsection NC, ND, or B31.

If significant vibration levels are detected during the test program which had not been previously considered in the piping system analysis, consideration should be given to modifying the Design Specification to reverify applicable code conformance.

3.2.1.3 For transient vibrations, the maximum alternating stress intensity should be limited to the value defined below. Before determining the allowable maximum alternating stress intensity, an estimate should be made of the equivalent number of maximum anticipated vibratory load cycles (EVLC).

a. For ASME Class 1 piping systems, the maximum alternating stress intensity shall be limited to the value which will not invalidate the Stress Report, or if the transient event was not previously considered in the Stress Report, the following procedure should be followed: (1) the unused usage factor shall be determined from

$$U_V = 1 - U$$

where

> For transient vibrations which were not previously analyzed and for which it is not appropriate to evaluate the load separately a new fatique analysis may be required in accordance with ASME Section III.

U = Cumulative usage factor from ASME Class 1 analysis, which excluded vibratory load

The maximum allowable equivalent vibratory load cycles shall be calculated from

$$N_V = \frac{EVLC}{U_V}$$

The value of S_a shall be obtained from either figure I-9.1 or I-9.2 using N_V: The maximum alternating stress intensity, S_{alt}, shall be limited to 0.8 S_a

where

S_a = Allowable alternating peak stress value from figure I-9.1 or I-9.2 of the ASME Code, Appendix I

b. For class 2 and 3 and 331 piping, the stresses shall be evaluated in accordance with the requirements of 3.2.1.2(b).

3.2.2 Vibration Monitoring Group 2

3.2.2.1 The vibration response of group 2 systems should be measured using one or more of the vibration monitoring devices specified in section 5.0.

3.2.2.2 The piping vibratory responses of VMG 2 piping shall be evaluated in accordance with the allowable deflection or velocity limits given in section 5.0. These limits are based on meeting the stress requirements of subsection 3.2.1. If adequate quantitative data cannot be obtained or unacceptable vibration response is indicated by the methods and devices listed in section 5, the methods and devices ...

3.2.3 Vibration Monitoring Group 3

3.2.3.1 The vibration response of group 3 systems shall be determined by the methods and devices listed in section 4.0.

3.2.3.2 If an acceptable level of vibration is noted, no further measurement or evaluation is required. The observer shall be responsible for assessing whether the observed vibration level is acceptable. The basis for determining whether the vibration level is acceptable shall be consistent with the limits specified in section 3.2.1.

3.2.3.3 If the level of vibration is too small to be perceived and the possibility of damage is judged to be minimal, the system is acceptable.

The judgment as to acceptability can be made only by evaluation of all the following facts as to their effect on the piping stress:

a. Vibration magnitude and location
b. Proximity to "sensitive equipment"
c. Branch connection behavior
d. Capability of nearby component supports

Any unique operational characteristics of the system shall be considered in the evaluation.

3.2.3.4 If an acceptable assessment of the observed deflections cannot be made, the acceptability of vibration must be based on measured data.

3.2.3.5 If unacceptable vibration levels are indicated by the methods and devices listed in section 4.0, the methods and devices of section 5.0 may be used.

Table - 3-I

EXAMPLES OF TRANSIENT CONDITIONS

Reactor Coolant System	Normal start and stop of Reactor recirculation pumps Flow Control System Changes (BWR)
Main steam line	Turbine bypass system operation Main steam isolation valve closure Turbine stop valve closure Safety valve, relief valve, or safety relief valve operation Atmospheric dump valve operation
Pressurizer	Safety valve, relief valve or safety relief valve operation
Feedwater and condensate systems	Normal start and stop of feedpumps, condensate and condensate booster pumps, and feedwater heater drain pumps. System response to both manual and automatic valve operation. Feedwater control system changes.
Other ASME Class 2 and 3 and B31 water pumping systems, ECCS systems, service water and emergency raw cooling water systems.	Normal startup and shut-down of systems of transfer to other normal modes of operation.

4.0 VISUAL INSPECTION METHOD

4.1 Objective

The acceptability of piping systems in VMG 3 to withstand the effects of steady-state and transient vibration can be evaluated by observation. This section will discuss the different techniques and some of the simple devices that can be employed in the evaluation. Lastly, some of the possible problems that could be encountered during the preoperational and startup of systems will be outlined.

4.2 Evaluation Techniques

The location or locations of maximum deflection can be ascertained by observation. The magnitude of the displacement may be estimated by the use of simple measurement devices; e.g., rules, optical wedge, spring hanger scale, etc. When simple measurement devices are used, the precautions of appendix section A.I shall be observed.

4.2.1 Steady-State Vibration

During the preoperational and startup testing phase of a plant, the piping systems will be observed during its various modes of operation, as defined in the test specification. The acceptability of the observed vibration shall be determined in accordance with section 3.2.3.

4.2.2 Transient Vibration

During the preoperational and startup testing phase of a plant, the piping systems in VMG 3 will be observed during the transient

event as defined in the test specification. The test may be repeated, if necessary, to make the observation at different points. The acceptability of observed response shall be based on section 3.2.3.

4.3 Precautions

There are a few precautions and specific items that should be reviewed, ~~that are listed below.~~

4.3.1 Vents and Drains

Local vents and drains typically have one or two isolation valves that act as concentrated masses. If they have not been braced, careful attention should be given to vibration in this area.

4.3.2 Branch Piping

Minor main line vibration may cause branch piping vibration of significant magnitude remote from the branch connection. These lines shall be reviewed together with the system being qualified.

4.3.3 Multiple Pump Operation

In cases where there are several pumps that operate in parallel, the most significant vibration might occur when some combinations of the pumps are operating.

4.3.4 Sensitive Equipment

Vibrations which can affect the functionality, operability, and structural capability of sensitive equipment such as pumps, valves, and heat exchangers should be closely reviewed. [redacted].

4.3.5 Welded Attachment

Special consideration shall be given to the areas near the welded attachment in the piping system subjected to vibration. If the welded attachment configuration is such that it could cause local moment in the pipe due to vibration, the effects of local stress shall be considered.

5.0 SIMPLIFIED METHOD FOR QUALIFYING PIPING SYSTEMS

5.1 Steady-State Vibration

This section describes simplified methods for the evaluation of steady-state vibration of piping systems which will determine if the vibration exceeds an acceptable level. It is intended for application to systems which are undergoing steady-state vibration and are accessible for a number of vibration measurements at various points in the piping system. Piping systems which are not suitable or adaptable to these methods may be evaluated by procedures defined in section 6.0.

5.1.1 Displacement Method

5.1.1.1 General Requirements

The simplified method requires that displacement should be determined at representative points on the piping system. The piping system shall be subdivided into sufficient subsystems or vibratory (characteristic) spans containing appropriate or conservative boundary conditions, as described in detail in subsection 5.1.1.5.1.

5.1.1.2 Instrumentation

A hand-held or temporarily mounted transducer should be utilized which is suitable for making multiple measurements of displacement.

An accelerometer may be utilized, with velocity and displacement obtained by single and double integration, respectively, of the acceleration signal. The precautions of section 7.0 on measurement techniques should be observed. It is recommended to determine response frequencies and their relative amplitudes as an aid in verifying the appropriateness of subsystem model selected and assist in determining the source of vibration.

5.1.1.3 Deflection Measurement of Process Piping

Measurements are taken along the piping to measure peak deflection points and to establish node points of minimum deflection. The node points establish the characteristic span lengths. Node points (zero deflection points) are generally found at restraint points but could be located between constraints on long runs of piping. The deflection limit can be determined from the curves or nomographs presented in figures 5-1 through 5-9. These nomographs and curves relate limiting deflection with span length and pipe diameter for some typical piping installations.

5.1.1.4 Deflection Measurement of Branch Piping

Branch piping is attached to process piping and has a smaller diameter than the process piping. Three of the potential problems which can exist:

a. Branch piping can be excited at its resonant frequency by motion of the process piping, fluid pulsation, or other source. This problem is characterized by high amplitude vibrations with a clearly defined frequency and mode shape. The amplitude measured on the branch pipe is generally much larger than the process piping. Due to the phasing, the relative motion of the branch pipe to the process pipe is closely approximated by adding the displacement measurement of the process pipe to the motion of the branch pipe. The deflection limits defined in section 5.1.1.5 are applicable.

b. The attachment point of the branch pipe with the process line displaces relative to a branch line support. The deflection limits defined in section 5.1.1.5 are applicable when the deflections measured reflect relative motion between points on the branch piping and can be associated with a deflected shape.

c. The process piping drives the branch piping at a high acceleration level as a rigid body. This problem is generally associated with a cantilevered mass. The peak acceleration at the center of gravity of the branch piping must be measured to establish the inertial force acting at the center of gravity of the branch piping. The cantilever mass and center of gravity of the branch piping must be conservatively estimated and a resultant stress calculated. The resultant stress should be compared with the criteria listed in 3.2.1.2a and 3.2.1.2b.

5.1.1.5 Deflection Limits

The vibrational deflection limit of a piping system depends on a large number of material and geometric considerations with many combinations of the variables. It becomes necessary to classify piping systems into smaller subsystems which can be physically defined and modeled. A deflection measurement can then be conservatively checked against an allowable deflection limit calculated for that subsystem. A breakdown of the piping subsystems for which allowable deflection limits have been computed are given in section 5.1.1.5.1.

Deflection limits are given in nomograph form in figure 5-1 in terms of a characteristic span length, outside pipe diameter, and a configuration coefficient. The characteristic span and the configuration coefficient are established by breaking the piping system into a series of piping subsystems as described in section 5.1.1.5.1. The deflection limit is determined by entering the nomograph of figure 5-1 with the established value of (1) configuration coefficient, K; (2) outside pipe diameter, D_o; and (3) the characteristic span length, L.

The nominal vibrational deflection values determined from the nomograph of figure 5-1 are based on an allowable stress of 10,000 psi with stress indices equal to unity. The allowable deflection limit is determined by:

$$\delta_{allow} = \frac{.8 S_{el}}{10000 \cdot C_2 K_2} \cdot \delta_n$$

where

Sel, C_2, K_2 are defined in section 3.2.1.2

δ_n = Value of deflection obtained, figure 5-1

δ_{allow} = Allowable zero to peak deflection limit

The allowable deflection limit is then compared to the measured value for piping vibration qualification.

5.1.1.5.1 Classification of Piping Subsystems

It is recommended that the measured deflection data be examined to assist in determining the appropriate piping unit used to obtain the allowable deflection limit.

Piping units are broadly classified into two categories by the piping restraints. A single end restraint, with one end free, forms the first category and restraint of both ends of a piping unit forms the second category. The categories are then subdivided into combinations of a single span and two spans joined by a 90-degree elbow. Deflections are measured in the plane of the elbow and out of the plane of the elbow as shown in figure 5-2. The rotational constraint at restraint points is assumed to be fixed for a conservative computation of the allowable deflection limit. An outline of the basic piping units is given below. For any configuration not covered in 5.1.1.5.1 the "K" factor can be established by the user provided equivalent conservatism is maintained.

I. Single end restraint - Cantilever

A. Cantilever single span (figure 5-4)

B. Cantilever span, elbow, span

1. Deflection in plane of elbow--end span free (figure 5-5)

2. Deflection in plane of elbow--guided end span (figure 5-6)

II. Restraint at both ends of piping unit

A. Single span

1. Single span (figure 5-3)

2. Single span with elbow restraint (special case of II.A.1 or limit case of II.B.1)

B. Span, elbow, span

1. Maximum deflection measured out of plane of elbow between restraint point and elbow of long span (characteristic span). Ratio of short span to long span is less than 0.5 (figure 5-7 with configuration coefficient K from figure 5-9).

2. Maximum deflection measured out of plane of elbow at intersection of long span and elbow. Ratio of short span to long span is between 0.5 and 1.0 (figure 5-8 with configuration coefficient K from figure 5-9).

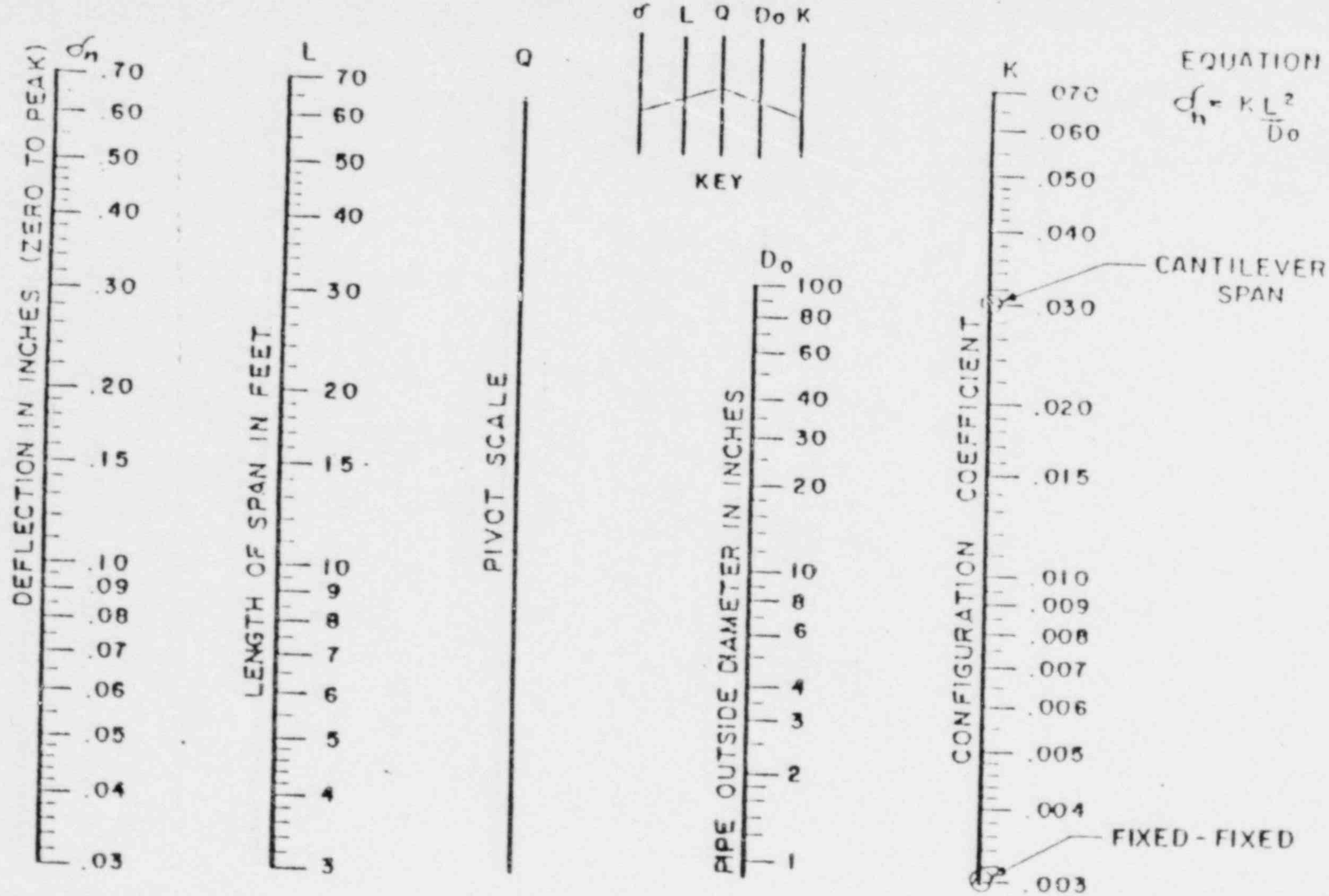

FIG. 5-1 NOMINAL VIBRATIONAL DEFLECTION VALUES 10,000 PSI ($C_2K_2 = 1$)

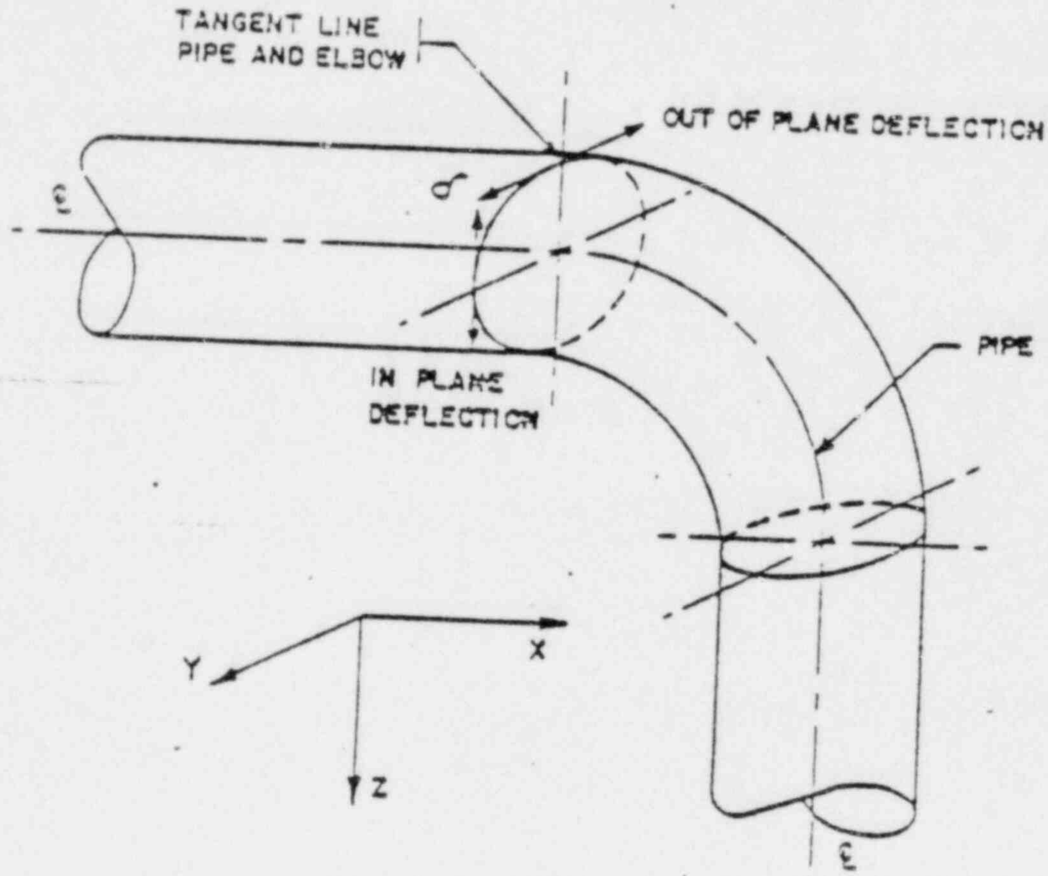

FIG. 5-2 DEFLECTION MEASUREMENT AT INTERSECTION OF PIPE AND ELBOW

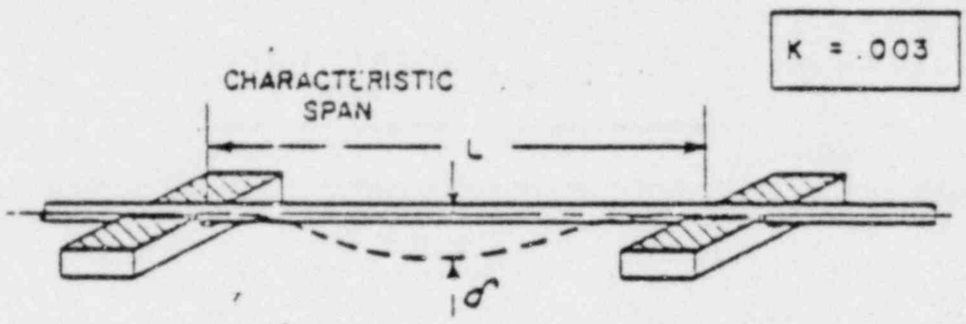

FIG. 5-3 SINGLE SPAN
DEFLECTION MEASUREMENT

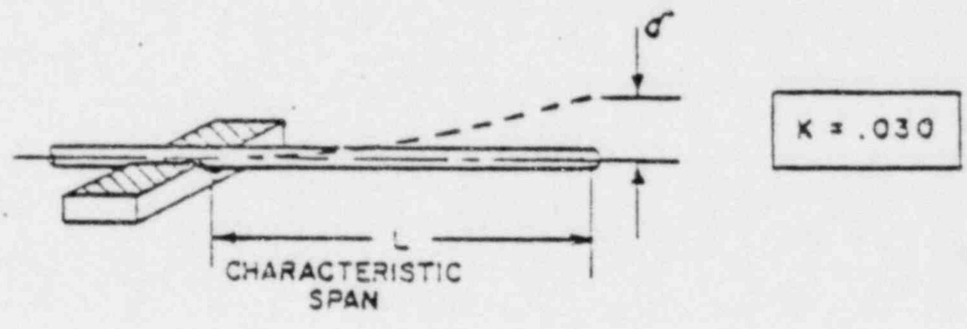

FIG. 5-4 CANTILEVER SPAN
DEFLECTION MEASUREMENT

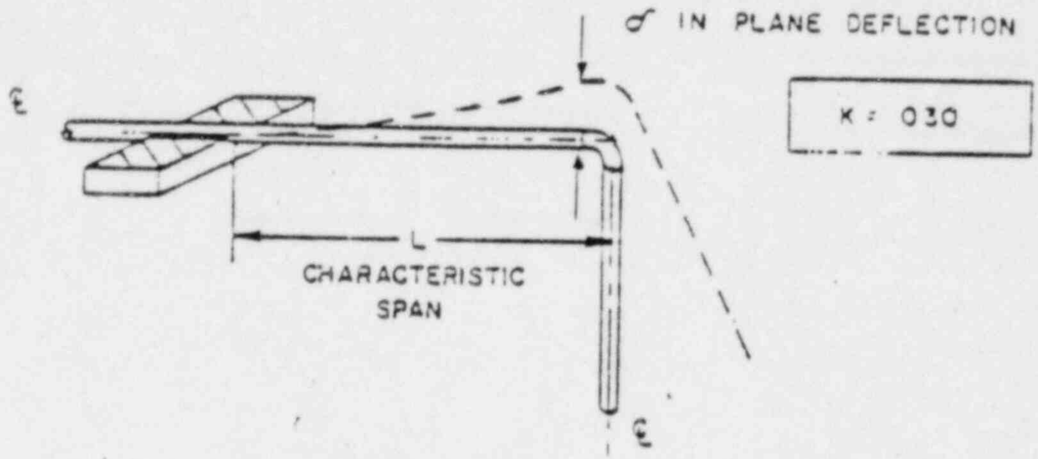

FIG. 5-5 CANTILEVER SPAN-ELBOW-SPAN IN PLANE DEFLECTION MEASUREMENT

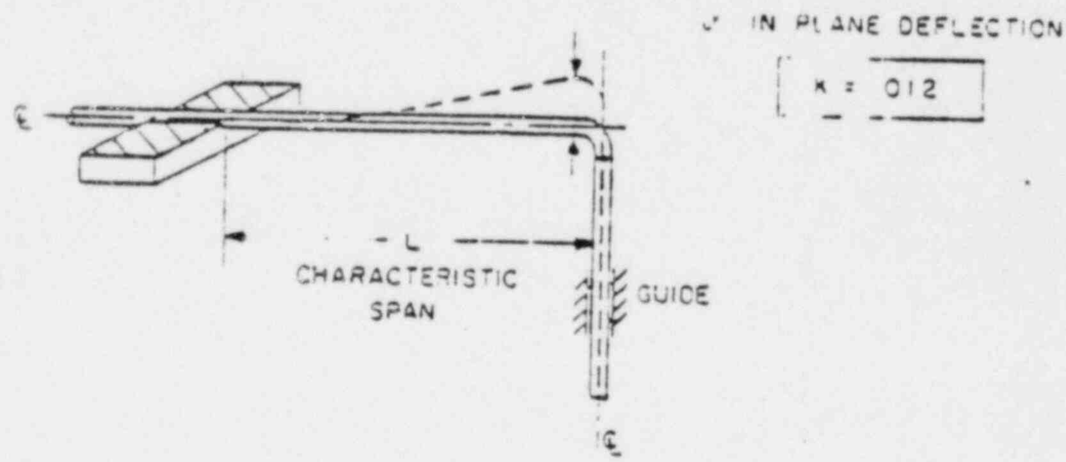

FIG. 5-6 CANTILEVER SPAN-ELBOW-GUIDED SPAN IN PLANE DEFLECTION MEASUREMENT

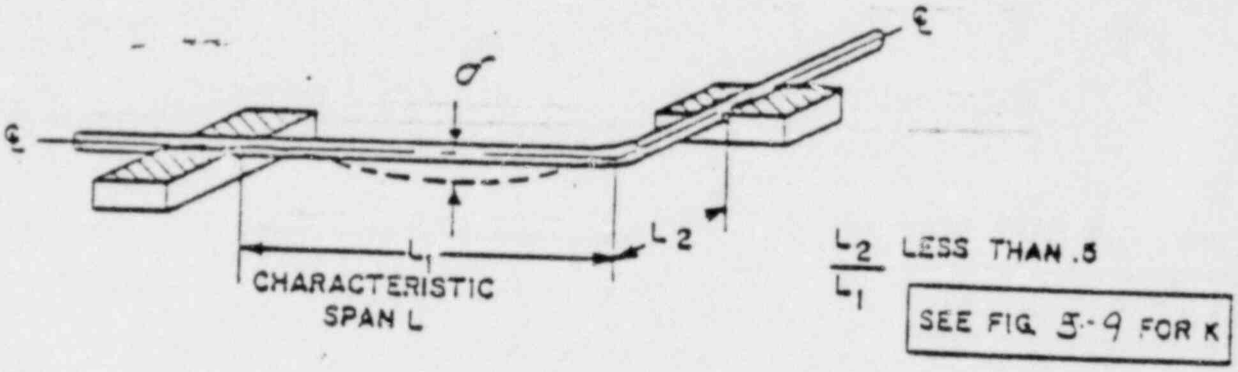

FIG. 5-7 SPAN-ELBOW-SPAN OUT OF PLANE DEFLECTION MEASUREMENT SPAN RATIO LESS THAN .5

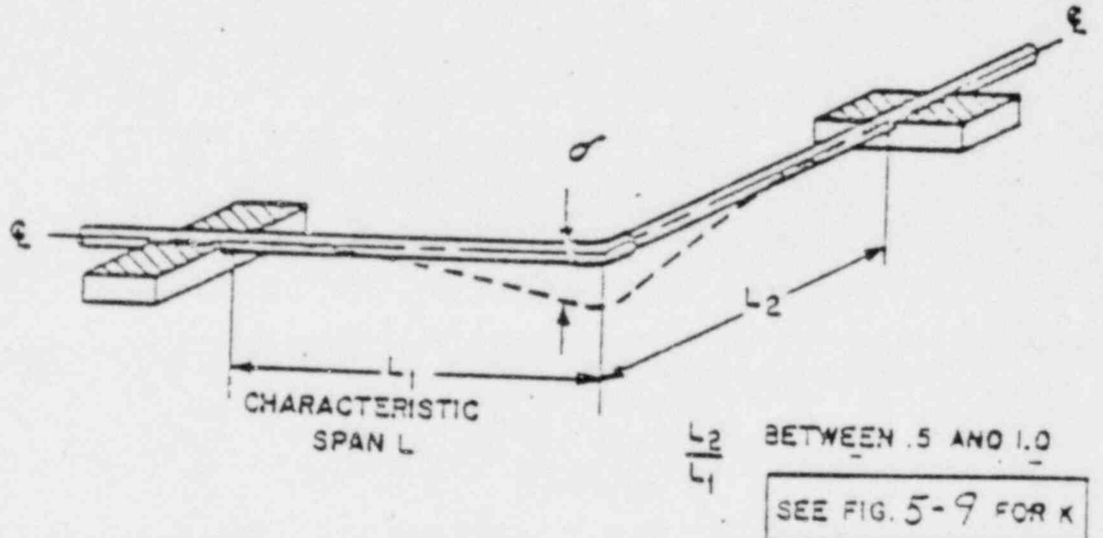

FIG. 5-8 SPAN-ELBOW-SPAN OUT OF PLANE DEFLECTION MEASUREMENT SPAN RATIO GREATER THAN .5

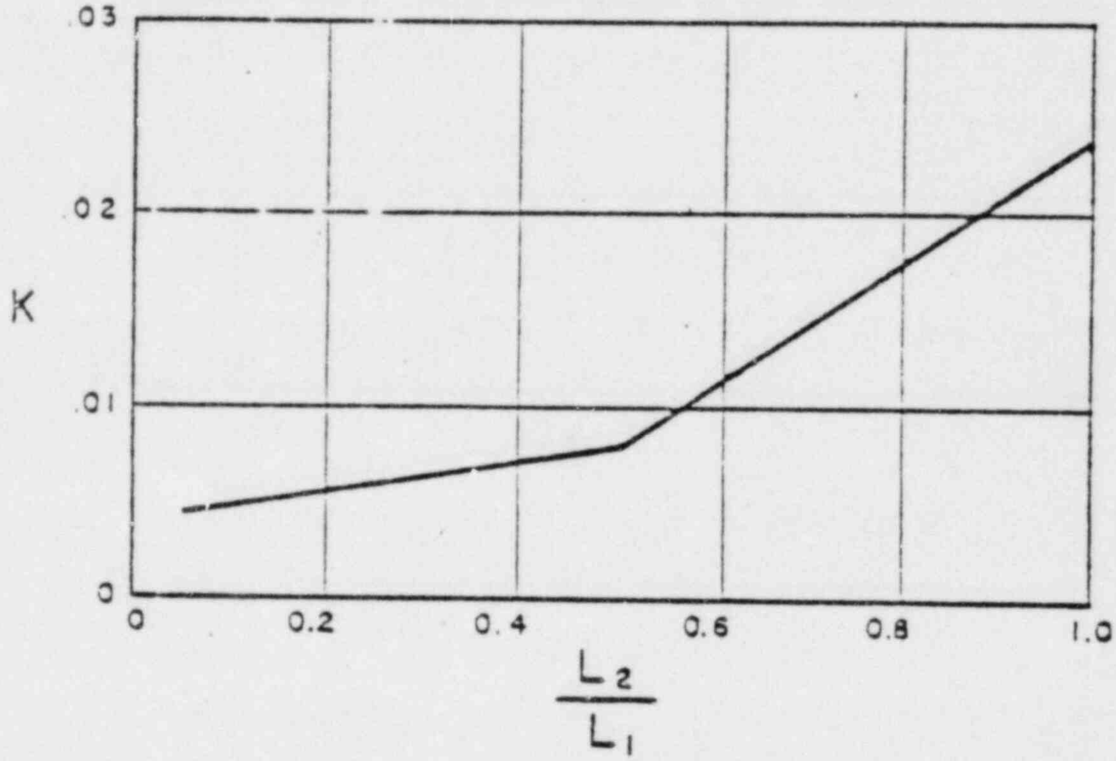

FIG. 5-9 SPAN-ELBOW-SPAN OUT OF PLANE CONFIGURATION COEFFICIENT VERSUS RATIO OF SPANS

$$\sigma_n = \frac{KL_1^2}{D_o}$$

5.1.2 Velocity Method

5.1.2.1 General Requirements

The method requires consecutive measurements of velocity at various points on the piping system in order to locate the point which is exhibiting the maximum vibratory velocity. Once this point is located, a final measurement of the maximum velocity (V_{max}) at that point is made and compared with an allowable peak velocity (V_{all}) as given in paragraph 5.1.2.4. The criteria for acceptability is that

$$V_{max} \leq V_{all}$$

5.1.2.2 Instrumentation

The instrument used should be portable and capable of making a number of consecutive velocity measurements at various points on the piping. The instrument should be capable of indicating a trace of the actual velocity-time signal from which the maximum velocity can be read. This may be achieved by readout devices such as a cathode ray tube or a paper chart recorder. Alternatively, the instrument could have a holding circuit which would result in a meter reading of the maximum velocity.

5.1.2.3 Procedure

Initial measurements are to be taken at points on the piping which appear to be undergoing the largest displacements. These will normally correspond to points of highest velocity. At each such point, measurements can be taken around the circumference of the pipe to find the magnitude of the maximum velocity. Measurements may be confined to directions perpendicular to the axis of the pipe at that point.

The maximum velocity should be obtained only from the actual velocity-time signal. The readout of the signal should be of sufficient duration to ensure a high probability that the maximum velocity has in fact been obtained for that point in that direction.

5.1.2.4 Allowable Peak Velocity

The expression for allowable velocity is:

$$V_{all} = \frac{C_1 C_4}{C_3} \quad \frac{3.64 \times 10^{-3} \, (0.8 S_{el})}{C_2 \, K_2}$$

V_{all} = Allowable velocity, inches per second

S_{el}, C_2, K_2 are defined in section 3.2.1.2. The secondary stress index, C_2, and the local stress index, K_2, are associated with the point of maximum stress, and not necessarily with the point of maximum velocity.

This velocity criterion is consistent with the deflection criterion for a fixed end beam.

C_1 = a correction factor to compensate for the effect of concentrated weights along the characteristic span of the pipe. See figure 5-10.

C_3 = a correction factor accounting for pipe contents and insulation.

$$= \left(1.0 + \frac{W_F}{W} + \frac{W_{INS}}{W}\right)^{1/2}$$

where W = weight of the pipe per unit length (lb/ft)

W_F = weight of the pipe contents per unit length (lb/ft)

W_{INS} = the weight of the insulation per unit length (lb/ft)

C_3 = 1.0 for pipe without insulation and either empty or containing steam.

C_4 = Correction factor for end conditions different from fixed ends and for configurations different from straight spans.

C_4 = 1.0 for a straight span fixed at both ends, but conservative for any practical end conditions for straight spans of pipe.

C_4 = 1.33 for cantilever and simply supported pipe span.

C_4 = 0.74 for equal leg Z bend.

C_4 = 0.83 for equal leg U bend.

Nonmandatory appendix D presents examples of correction factors C_1 and C_4 for typical piping spans along with a combination of these factors to provide an initial screening method.

5.2 Transient Vibration

This section defines a method for evaluation of vibration of the piping systems subjected to transient loads for which the expected

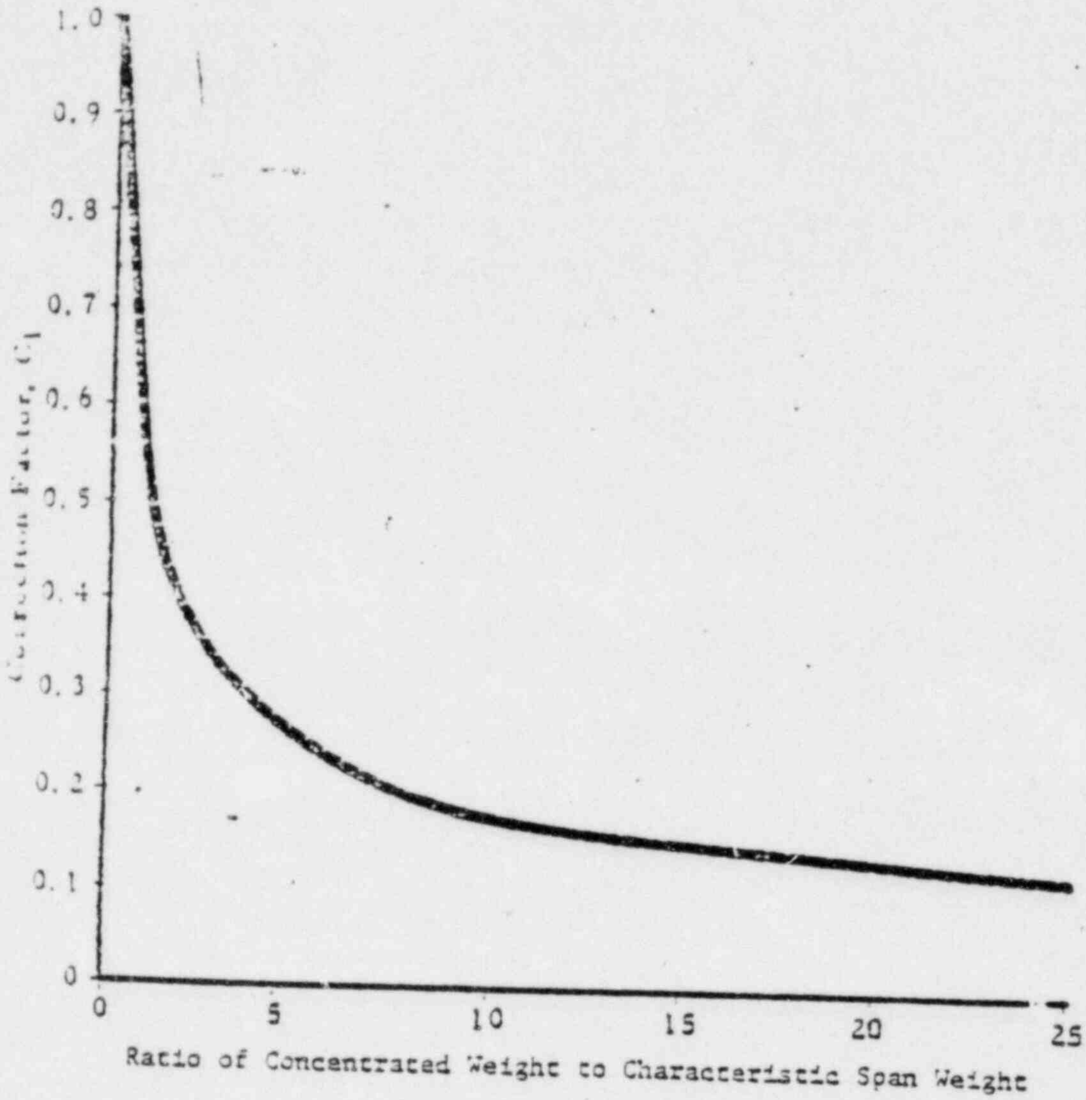

FIGURE 5-10

CORRECTION FACTOR, C_1

response under the anticipated transient loads is determined by analysis. Piping systems that are not suitable or adaptable to these methods shall be evaluated by the methods of section 6.0.

5.2.1 General Requirements

This method requires that a dynamic analysis of the piping system subjected to the expected transient loads has been performed yielding the system dynamic responses. Furthermore, the analytical responses must be shown to be conservative through comparison of the analytical responses with those measured during testing. The measured response can be piping displacements and/or restraint forces. The simplified method requires that dynamic response of piping, at selected locations, be measured. A minimum of two separate remote locations selected for the data points should be based on the analysis performed. In addition fluid pressure may be measured. The necessary parameters to be measured and their locations shall be included in the test specification.

The criteria for acceptability of the measured data is given in 5.2.3. If the criterion specified in 5.2.3 is not met, additional evaluation of the piping systems based on the measured data shall be made to justify the acceptance. This may include reanalysis of the piping system based on measured data.

5.2.2 Instrumentation

Appropriate instruments as recommended in section 7.0 shall be utilized for obtaining the piping system responses.

5.2.3 Measurements and Criteria for Acceptance

The measured responses

shall be compared to the analytically obtained response of the system. If the analysis indicates larger responses than those measured and the general requirements of section 3.0 concerning analysis versus test conditions have been met, then the vibratory response of the system is acceptable.

5.3 Inaccessible Piping (Both Steady-State and Transient)

For inaccessible piping systems requiring monitoring, the search procedure for maximum response location is not required. The locations of anticipated maximum response at which measurement devices are to be applied shall be defined. Adequate precautions shall be taken to verify that the assumptions used for the selection of anticipated maximum response locations are consistent with in-situ system response.

The portion of the system is evaluated in VHC-1, or when

6.0 RIGOROUS VERIFICATION METHOD FOR STEADY-STATE AND TRANSIENT VIBRATION

The method described in this section is required when the methods of the sections 4.0 and 5.0 are not applicable or overly conservative. It is also intended for application to systems where the dynamic characteristics indicate that the system modes are primarily a result of rocking of massive equipment (such as pumps, heat exchangers, etc.). The primary objective of this verification method is to obtain an accurate assessment of the vibrational stresses in the piping system from the measured vibrational behavior.

Two acceptable techniques for implementing this method are given in sections 6.1 and 6.2 along with corresponding requirements. Section 6.1 is supplemented by nonmandatory appendixes B and C which describe several methods of implementing this technique.

6.1 Modal Response Technique

6.1.1 General Requirements

This method requires that the modal displacements and natural frequencies of the system be identified via the test data.

The method also requires that a modal analysis of the system be performed yielding analytically determined natural frequencies and mode shapes and modal stress vectors (or bending moments) corresponding to the mode shape vectors. The analysis and test natural frequencies and modeshapes of the piping system shall be correlated and the analytical stress vectors shall then be used to determine the actual state of stress in the piping due to the measured modal displacements.

6.1.2 Test Requirements

The piping system shall be instrumented sufficiently to enable identification of the natural frequencies and modal displacements. It is not necessary to ensure that the measurements are taken at the location of maximum vibration. The instrumentation may be capable of measuring acceleration, displacement, or velocity according to the guidelines of section 7.0. Locations of instruments shall correspond closely to points included in the analytical model of the system.

The system shall be exercised through the conditions defined in test specifications. A sufficient amount of data shall be recorded to allow appropriate data processing as described in section 6.1.3.

6.1.3 Data Processing

Steady-state vibration data shall be reduced to obtain the zero-to-peak displacement in each of the predominant vibrational modes of the system. Several methods of determining the modal displacements are available and two of these are discussed in the nonmandatory appendix 3. When using either of the two methods described in appendix 3, special attention should be given to separately identify closely spaced modes which may exist in the system.

6.1.4 Test/Analysis Correlation

The measured modal frequencies and modal displacements of the piping system shall be correlated to analytically obtained

modal frequencies and modeshapes for all major contributing modes. As a minimum, the test and analytical modeshapes shall correlate with respect to the predominant modal direction; the relative magnitudes of the modal components need not be in exact agreement. In addition, the corresponding modal frequencies of the test and analysis shall be in reasonable agreement.

6.1.5 Evaluation of the Measured Responses

The measured modal displacements of the piping and the correlated analytical results shall be used to obtain an accurate assessment of the vibrational stresses (or moments) in the piping system. A method for obtaining the vibrational stress in the piping using the measured piping displacements and the information from the modal analysis of the system is given in nonmandatory appendix C. The resulting vibrational stresses shall be evaluated according to the acceptance criteria of section 3.2.1.2.

6.2 Measured Stress Technique

Strain gages can be used to directly determine stresses in the piping system during steady-state or transient vibration. This section outlines the general requirements in the use of strain gages. Several precautions associated with the use of strain gages are presented in section 7.0. These precautions should be considered prior to defining the test program.

6.2.1 General Requirements

The piping system shall be instrumented on straight pipe with sufficient number of gages near points where maximum stresses in the piping system are expected to occur. Strain gages shall be located remote from points of stress concentration.

6.2.2 Evaluation of the Measured Responses

The experimentally obtained strains at the instrumented points in the piping system shall be converted to a 3-component moment set and evaluated using the acceptance criteria of subsection 3.2.1.2.

7.0 INSTRUMENTATION AND MEASUREMENT TECHNIQUES

Instrumentation and measurement technique guidelines and suggestions are contained in nonmandatory appendix A. Note that this section is not intended to be all-inclusive and the most up-to-date instrumentation and measurement techniques appropriate to the vibration amplitudes and frequencies of the piping system may be used. All instrumentation shall be reviewed against the expected test environment (pressure, temperature, humidity, etc.) and against the expected range of system responses (frequency, displacement, velocity, etc.) to determine its capability of functioning as required.

The acceptance criteria in this Standard is based on zero to peak piping deflections, therefore the instrumentation used must result in actual zero to peak measurements. If the instrumentation used yields rms measurements, then conservative methods must be used to convert the rms measurements to zero to peak values.

NMANDATORY APPENDIXES

APPENDIX A

ION AND MEASUREMENT TECHNIQUES

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8.0 CORRECTIVE ACTION

Should the piping vibra
3.2, further evaluation
necessary to make the sy
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modifications, addition
changes in operating pro
conditions.

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After corrective action i
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If corrective restraints
make the piping system ac
shall be reviewed and rev

temperature operation, physical durability and reliability, ease and stability of calibration, intrinsic low noise, linearity over a wide dynamic range, small mass, and ease of application for absolute measurement.

Of the two types of piezoelectric accelerometers in wide use, shear-mode accelerometers with high sensitivities (10 PC/g) are the preferred type for low-frequency measurements (below 5 Hz), because compression-mode accelerometers tend to produce spurious outputs (from case deformation and thermal shock) at low frequencies. Accelerometers that have their signal return lead electrically isolated from the metal case facilitate control of unwanted ground loops, but are considerably more expensive than the grounded case variety. Other methods for controlling ground loops are treated in section A.2.1.3.7.

Accelerometer characteristics of particular importance for piping measurements are:

a. Variation of sensitivity with temperature. If the change in sensitivity from room temperature to operating temperature exceeds 10%, a correction factor determined from the manufacturer's data sheet should be applied.

b. Variation of sensitivity with frequency. This variation depends on the type of accelerometer, the mounting technique used, and whether its output signal is fed into a charge-sensitive amplifier or a voltage-sensitive amplifier. Variation of sensitivity may be as high as 3% per decade in

NONMANDATORY APPENDIXES

APPENDIX A

INSTRUMENTATION AND MEASUREMENT TECHNIQUES

A.1 Visual Inspection Method (VMG 3)

The simple aids suggested in section 4.2 for estimating the amplitude of displacement are not required to yield precise results. Even so, the user should be cautioned against attempting to use these simple aids under circumstances where erroneous estimates will almost surely be obtained. For example, low-amplitude (<30 mils) vibrations at relatively high frequencies (>20 Hz) would be difficult to quantify with a spring hanger scale. Likewise, low-frequency (<5 Hz) vibrations are usually difficult to read with an optical wedge because the eye's persistence of vision is inadequate to yield a distinct intersection between the dark and light regions of the wedge.

A.2 Simplified Method for Qualifying Piping Systems (VMG 2)

Many of the following discussions regarding hardware selection and methodology for VMG 2 are also applicable to the Rigorous Verification Method (VMG 1).

A.2.1 Hardware

A.2.1.1 Sensor

One sensor for VMG 2 measurements is the piezoelectric accelerometer. Its advantages include a capability for high

frequency. If the variation in sensitivity exceeds 10% over the frequency band being measured, data should be corrected in accordance with the manufacturer's data sheet.

c. Maximum temperature of operation. Under no circumstances should the maximum operating temperature specified by the manufacturer be exceeded. However, direct attachment to the pipe surface is usually feasible because accelerometers with maximum temperature ratings of at least 650° F (345° C) are readily available. Thermally insulated mounts may also be used, if necessary, to reduce the temperature at the accelerometer.

d. High-frequency resonances. In addition to the relatively small variation of accelerometer sensitivity that may occur over the device's working frequency band (item b above), almost all accelerometers exhibit greatly increased responses in a range of higher frequencies (usually 5 kHz or greater) where the accelerometer internals resonate. To the extent possible this frequency region should be avoided, since response correction factors will be large and imprecisely known.

A.2.1.2 Cables

Low-noise flexible coaxial cable is strongly recommended for use between the accelerometer and the signal conditioner (or remote preamplifier, if one is required). Such cable is available for continuous operation of 500° F (260° C). A few types may be used for short times at higher temperatures, and some exposed-braid cable can be used continuously at higher temperatures.

Hardline (non-flexible), mineral-insulated cable is not recommended for temporary installation of sensors because of its high cost, susceptibility to fatigue failure, and difficulty in installation.

If possible, the cable should be continuous (connectionless) from the sensor to the signal conditioning unit. If connectors must be used, then precautions should be taken to avoid the introduction of moisture at these locations, since both system sensitivity and reliability may be adversely affected.

In general, long cable runs (> 100 ft (35 m)) between the sensor and the signal conditioning unit will produce high noise pickup or signal attenuation, and a remote preamplifier (or remote charge converter) will be required to avoid these difficulties. Consult the accelerometer and cable manufacturers' data sheets for details. The connection between the remote charge converter and the signal conditioner may be made with inexpensive coaxial cable or with a shielded twisted pair cable.

A.2.1.3 Signal Conditioner

A.2.1.3.1 General Requirements

A signal conditioner with a charge converter input (commonly called a charge amplifier) is recommended because the accelerometer sensitivity does not vary with cable length when used in the charge mode, whereas accelerometer sensitivity varies with cable length when it is connected to a voltage-sensitive amplifier.

Integrating circuits yielding velocity and displacement outputs from the acceleration signal must be included in the signal conditioner. Gain normalization for direct incorporation of accelerometer sensitivity (as supplied by the manufacturer) is an important feature because all outputs can then be designed to read out directly in absolute velocity and displacement units. This gain normalization would typically be required to accommodate accelerometers with sensitivities ranging from ~10 to 250 pC/g.

A.2.1.3.2 Frequency Range

A working range from 1 to 1000 Hz will cover practically all piping applications.

A.2.1.3.3 Vibration Scale Range

The signal conditioner should typically be able to measure velocities over the range 10^{-2} to 10^{2} in./sec rms, and displacements from 10^{-3} to 10 in. rms. It should be realized that these measurement ranges are necessarily frequency dependent, i.e., due to physical limitations of background noise and instrumentation noise, the lowest levels of vibration cannot be measured reliably at the low end of the frequency band and, conversely, the highest measurement ranges would represent unrealistically high accelerations at the high end of the frequency band. For further guidance, see section A.2.3.

To provide accurate measurements over the wide amplitude ranges specified above, the signal conditioner may provide several fixed-gain adjustments or intermediate full-scale ranges.

A.2.1.3.4 High-Pass Filtering

At least two switch-selected low-frequency cutoff limits (typically 0.3 and 3 Hz) should be provided to eliminate extremely low-frequency signals and unwanted noise. The filter complexity should be at least two-pole (12 dB/octive) for velocity signals and at least three-pole (18 dB/octave) for displacement signals.

A.2.1.3.5 Low-Pass Filtering

Low-pass filtering of at least two-pole complexity should be applied at the upper end of the vibration band to eliminate unwanted high-frequency noise. The cutoff frequency is not critical, but would typically be ~1000 Hz.

[Note: We may want to supply frequency response accuracy (say ±1 dB) specifications for A.2.1.3.4 and A.2.1.3.5, in addition to the approximate -3 dB cutoff frequencies.]

A.2.1.3.6 Band-Pass Filtering

Further filtering of the velocity and displacement signals may often be desirable to reduce interference among closely spaced frequency components, to enhance the signal-to-noise ratio, and to help isolate vibration modes. To these ends, a switch should be available to provide either wide-band (limited only by the settings selected under A.2.1.3.4 and A.2.1.3.5) or narrow-band signals. For the latter, the band center frequency should be continuously adjustable from the front panel over three, one-decade ranges from 1 to 1000 Hz. A recommended bandwidth

between -3 dB response frequencies is 10-20% of the center frequency, i.e., a "Q" between 5 and 10. The complexity of the filter should be at least two-pole (12 dB/octave). Calibrated front-panel indication of center frequency is desirable. An alternative method for achieving the same ends is to employ a spectrum analyzer.

A.2.1.3.7 Control of Ground Loops

The signal conditioner should have a front-panel switch that provides separation of the signal references for the input circuits and the output circuits. This allows an internal differential circuit to remove common-mode ground voltages caused by having the transducer case grounded at the point of measurement. The switch and differential amplifier prevent large ground-circuit currents from flowing through the accelerometer cable shield, and thus help to minimize the appearance of line-frequency components at the output terminals of the signal conditioner.

A.2.1.4 Output Signals and Readout

The AC outputs for velocity and displacement should have a convenient, round-number voltage associated with full-scale output (e.g., 1.0 V rms). These outputs are for viewing the signal waveforms with an optional oscilloscope. Peak output capability of ±10 V at 10 mA with 50-ohm output impedance is sufficient.

A.2.1.4.1 Visual Indication

In addition to an oscilloscope, a suitably damped analog meter is strongly recommended to indicate the true rms value of both

displacement and velocity. Due to the typical time-varying amplitude of the signals being monitored, digital indicators are generally unsatisfactory for quantifying vibration signals. Furthermore, a true rms indication (rather than an average or peak value) is preferred because vibration signals typically encountered may be almost random in character with near-gaussian amplitude distributions, or quasi-periodic with sinusoidal amplitude distributions, or pulse-like with high crest factors, and sometimes mixtures of all three. If rms measurements are obtained, the requirements of section 7.0 are to be used.

A.2.1.4.2 Averaging

Averaging the output of the true rms circuitry is required to achieve a stable meter indication. The low-pass cutoff frequency required is related to the minimum measurement frequency selected by the user's choice of high-pass filter in section A.2.1.3.4. If two-pole low-pass filtering of the true rms output is used to achieve this averaging, a cutoff frequency of no more than 1/2 the minimum frequency of measurement is recommended. This choice will yield a peak-to-peak ripple no greater than 6% of the indicated rms value for sine waves throughout the measurement bandwidth selected. The settling time for such a filter is approximately $1/f_o$ seconds, where f_o is the lowest measurement frequency, expressed in Hz.

A.2.1.5 Auxiliary Equipment

An oscilloscope for viewing the waveforms of the velocity and displacement outputs from the signal conditioner is optional but

quite helpful under many circumstances. A real-time frequency analyzer (for modal separation) and an analog FM tape recorder (for data preservation and/or additional off-line study and processing) are also useful, but optional, equipment. The averaged outputs from the true rms circuitry described in section A.2.1.4.2 might also be made available to an optional strip chart recorder, thereby providing a permanent record of the analog meter indication.

A.2.2 Alternatives

A.2.2.1 Accelerometer Limitations

All transducers have limitations and some alternative sensors may give superior performance under certain circumstances. Two intrinsic shortcomings of piezoelectric accelerometers that may cause difficulties in plant piping applications are (1) low-level, high-impedance output, and (2) poor signal-to-noise (S/N) ratio at low frequencies, particularly following the double integration required to obtain displacement.

In all but the most severe electrical interference environments, the accelerometer's low-level output can nevertheless be made to yield an acceptably high S/N ratio by placing a preamplifier (with or without charge converter) close to the sensor and by using one of the recommended low-noise cable types described in section A.2.1.2. Should these measures fail, the user may be able to achieve better performance with the high-output, low-impedance devices described in sections A.2.3.2 and A.2.3.3.

Difficulties in inferring displacements at low frequencies from accelerometer signals often arise because the sensor responds inherently to acceleration, not velocity or displacement. The latter required outputs must therefore be derived by single- and double-integrations with respect to time, and these operations produce a magnification of any low-frequency extraneous noise that may be present. This difficulty can be overcome by employing alternative sensing devices that respond inherently to velocity and displacement, as follows.

A.2.2.2 Velocity Sensors

Velocimeters (or "velocity pickups") are sensors designed to respond to this variable directly. They usually consist of a moving coil or moving magnet arranged so that the electrical output generated is proportional to the rate at which the magnetic field lines are cut by the moving element, and hence its velocity. The main advantage of these electrodynamic transducers over piezoelectric accelerometers is their high-level, low-impedance output, thereby making their signals relatively immune to electromagnetic noise pickup. Their chief disadvantages are their larger size and their somewhat restricted useful linear bandwidth. Like accelerometers, they suffer from resonant responses at high frequencies and contamination from background at low frequencies. The latter shortcoming limits their usefulness in providing displacement indications at low frequencies, since the necessary integration tends to amplify low-frequency noise selectively.

A.2.2.3 Displacement Sensors

Types of direct sensing displacement transducers applicable to piping vibration measurements are the eddy current sensor (or "proximity probe"), the linearly-variable differential transformer (LVDT) and the lanyard gage potentiometer. All sense absolute displacement relative to a fixed reference, and therefore have frequency response and S/N curves that are uniform all the way to zero frequency (DC). This is their chief advantage, along with high electrical output and hence immunity to extraneous noise. An attendant disadvantage, however, is that they must be mounted firmly to some structure that is stationary relative to the vibrating system whose displacement is to be measured, and this is often difficult to accomplish in an operating plant environment. Other disadvantages of these sensors are (1) generally poor high-frequency response, (2) limited range of displacement over which the transducer responds linearly and without hysteresis, (3) need for special accompanying electronics (oscillator/demodulator) and cabling, and (4) in some cases, high noise, offset errors, and limited (quantized) displacement resolution.

A.2.2.4 Special Situations

More exotic instrumentation (e.g., laser vibrometers that detect the Doppler shift accompanying motion of the target) is commercially available for those special situations requiring unusually high measurement accuracy or where physical access to the vibrating structure prohibits use of the sensors already described, but such devices are too specialized to warrant further description in this document.

A.3 Rigorous Method for Qualifying Piping Systems (VMG 1)

In addition to the instrumentation discussed for VMG 2 the following instrumentation is applicable to VMG 1.

A.3.1 Strain Gages Method

The method of strain gages is a method of measurement of strain (μ in/in) at selected points in the piping system which can, in turn, be related to stress. Test instrumentation system typically consists of three major items: Electrical strain gages, signal conditioning, and data recording systems. The type of gages normally used on the piping systems are either the weldable or the bondable type. Evaluation of the temperature and radiation level will limit the use of bondable gages. Weldable gages are available which will operate for all temperature and radiation levels typical of nuclear power plant piping systems. The usual requirement is that the state of stress at points on the piping system can be determined from strain-gage readings. This implies the use of an appropriate theory relating strains to stresses. The validity of the final results depends upon the validity of any relationships used in reducing the data.

A.3.1.1 Problems Encountered in the Use of Resistance Strain Gages

The user of strain gages must be aware of some problems encountered by the use of these devices. Some of these problems are:

(a) Temperature Compensation: If strain gages were to be used for a long period of time, temperature may vary over a long period of time; it is extremely important that temperature compensation be as perfect as possible. If temperature compensation is imperfect, then readings interpreted as varying strain may only represent a variation in temperature. Due to this variation in temperature, the strain gages are not recommended for static piping stress measurements.

(b) Bond Stability: Any shrinkage, swelling, or creep of the bond or any change in the conductivity of the bond may produce a signal which is unrecognized from the strain-gage signal. Adequate curing of strain-gage bond for long-term tests is important.

(c) Instrument Stability: Many factors acting on the strain-gage circuit and signal device may produce signals that are unrelated to strain. Check for resistance, supply voltage variation, and to correct for any drift in the indicators prior to start of the test.

(d) Moistureproofing Strain Gages: Moisture acts to reduce the gage-to-surface resistance or partially to short circuit the leads or sections of the gage itself. This may produce a change in resistance which is equivalent to strain. Moistureproofing is necessary for indoor and outdoor testing. Some moistureproofing techniques are: Curing the bond, insulating, or use moistureproofing agents, or cover the entire assembly with Epoxylite or comparable material.

A.3.1.2 Strain Gages Subjected to Nuclear Radiation

The use of bonded resistance strain gages in radiation environments is a suspect. Any organic material (most strain-gage bonds) are affected by modest amounts of radiation; the radiation produces dimensional changes as well as change in the mechanical and electrical properties. Short-time tests can be made during irradiation until gage-to-specimen resistance breakdowns. Some semiconductor devices are affected by radiation damage; however, silicon semiconductor gages will tolerate radiation flux of at least 10^{14} particles/cm^2 with energies greater than 1 Mev before changes in resistance of gage factor occur. Special attention should be paid to soldered strain gages joints and lead wires, since they are also affected by radiation. Welded connections are recommended.

A.3.1.3 Strain Measurements at High Temperatures

Many techniques are available to use strain gages at low or high temperature (350° F (177°C) - 1200° F (650°C)). Metallurgical changes that produce sudden and/or irreversible resistance changes are not encountered at temperatures below 350° F (177°C). Strain-gage manufacturer recommendations are to be followed when using strain gages above 350° F (177°C).

A.3.1.4 Data Processing

Steady-state and transient vibration data of piping systems should be reduced to obtain maximum strain (μ in/in) (μcm/cm) at points where

maximum stresses are predicted by analysis due to vibration. Evaluation of data shall be made where the material on which the gages are mounted behaves in accordance with the linear theory of elasticity throughout the range of strain being investigated. Evaluation of stresses from measured strains beyond the elastic limit is uncertain due to the lack of practical method for relating stresses to strains in this region. During data processing, attention must be paid to "gage factor" value for uniaxial stress field.

NONMANDATORY APPENDIX B

This appendix describes two methods of obtaining modal displacements of the piping system from the measured total displacement time history. It is recommended to be used in conjunction with mandatory section 6.1.

B-1 Fourier Transform Method[1]

The recorded acceleration, velocity, or displacement time histories can be converted to a spectral density function using Fast Fourier Transform techniques. The spectral density should be computed in the frequency range which contains the expected predominant system response. A sufficient number of spectral averages should be made to ensure that the density function has converged. Integration of the density function over discrete frequency bands around the predominant modal responses yields the RMS modal response. These can readily be converted to peak-to-peak response through consideration of the statistical properties of the response.

In addition to the modal responses, the spectral density function will indicate system response at deterministic frequencies associated with shaft and blade passing frequencies of rotating equipment which feed the piping system.

The piping displacements at these frequencies should be determined. The piping displacements at these frequencies should be absolutely summed with the modal displacement of the piping system mode which is nearest to the deterministic frequency or which closely resembles the displaced configuration at the deterministic frequency.

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[1] The user of this method is referred to the latest revision of ANSI S210 entitled "Methods for Analysis and Presentation of Shock and Vibration Data."

B-2 Other Methods

Alternative methods may be employed, such as modal superposition, provided that the method used is demonstrably conservative and the test analysis correlation requirements of section 6.1.4 are met.

NONMANDATORY APPENDIX C

This appendix presents a method for converting measured modal displacements of the piping system to bending stress (or bending moments) through utilization of analytically obtained modal characteristics. It is recommended to be used in conjunction with mandatory section 6.1.

C-1 Test/Analysis Correlation

The modal displacements, at each measurement point, obtained in section 6.1.3 should be tabulated and normalized to an appropriate value (such as the maximum displacement) in the mode. The relative sign of each displacement can be obtained by computing the phase between measurement points using Fourier Transform techniques. This yields a normalized modeshape and modal frequency obtained by test that can be compared to analytically obtained normalized modeshapes and frequencies. The test and analytical results should be correlated according to the mandatory requirements of section 6.1.4.

C-2 Evaluation of the Measured Responses

Having achieved a correlation of test/analysis results, the analytically obtained modal moments or stresses in the system piping can be determined using the actual modal responses obtained from the test data. This can be done in the following way.

The measured modal displacement at point j in mode i (denoted by D^T_{ij}) is divided by the corresponding analytical displacement (D^A_{ij}), yielding the modal response factor K_{ij}.

i.e., $$K_{ij} = \frac{D^T_{ij}}{D^A_{ij}}$$

Theoretically, all K_{ij} within a mode should be the same if perfect correlation of test and analytical mode shapes has been achieved. Realistically, however, the K_{ij} will vary. Therefore, for each mode the maximum K_{ij} is chosen as the modal response factor for mode i (denote as K_i). The maximum K_{ij} should be chosen from among those K_{ij} in the direction of predominant modal motion, to reduce unnecessary conservatisms. Having obtained the modal response factors (K_i) for each mode, the test stress vector (S^T_j) for each mode should be calculated by premultiplying the analytical stress vector* $(S^A_j)_i$ by the modal response factor.

i.e., $$(S^T_j)_i = K_i \, (S^A_j)_i$$

The modal stress vectors thus obtained should be combined by an appropriate conservative method to obtain the total stress in the piping.

*It is assumed in this method that the stress vector includes the stress indices as defined in subsection 3.2.1.2. Alternatively, the modal bending moments in the piping (obtained from the modal analysis of the piping) can be converted to stress using the equation for S_{alt} defined in subsection 3.2.1.2.

NONMANDATORY APPENDIX D

This appendix describes a method for establishing a velocity criterion for screening piping systems. Using these procedures, piping systems requiring further analysis can be determined. This appendix is to be used in conjunction with section 5.1.2.4.

D-1 Velocity Criterion

The expression for allowable peak velocity from 5.1.2.4 is

$$V_{all} = \frac{C_1 C_4}{C_3} \frac{3.64 \times 10^{-3} (0.8 S_{al})}{C_2 K_2}$$

C_1 = Correction factor that compensates for the effect of concentrated weights. If concentrated weight is less than 20 times the weight of the span for straight beams, L bends, U bends, and Z bends, a conservative value of 0.12 can be used for screening purposes.

C_4 = Correction factor for end conditions different from fixed ends and for configurations different from straight spans.

As examples:

C_4 = 1.33 for cantilever and simply supported beam

C_4 = 0.74 for equal leg Z bend

C_4 = 0.83 for equal leg U bend

C_4 = 0.7 as conservative value for screening purposes.

C_3 = A correction factor accounting for pipe contents and insulation. For contents and insulation equal to the weight of the pipe, the value would be 1.414. In most cases it is less than 1.5.

C_2K_2 = Stress indices as defined in B31.7, Appendix D, Table D-201.

$C_2K_2 \leq 4$ for most piping systems.

D-2 Screening Velocity Criterion

If conservative values of the correction factors are combined. a criterion can be derived which should indicate safe levels of vibration for any type of piping configuration. Using this criterion, piping systems can be checked and those with vibration velocity levels lower than the screening value would require no further analysis. Piping systems that have vibration velocity levels higher than the screening value do not necessarily have excessive stresses, but further analysis is necessary to establish its acceptability.

The following correction factors are considered to be conservative values and should be applicable to most piping configurations; however, the conservatism for extremely complex piping configurations cannot be attested.

$C_1 = 0.12$

$C_2K_2 = 4$

$C_3 = 1.5$

$C_4 = 0.7$

$0.8\ S_{el} = 10{,}000$ psi

$$V_{all} = \frac{(0.12)(0.7)(.00364)(10000)}{(1.5)(4)}$$

$V_{all} = 0.5$ in/sec Screening vibration velocity value.

D-3 Use of Screening Vibration Velocity Value

A screening vibration velocity value of 0.5 ips has been established which can be used in conjunction with 5.1.2.4. Piping systems with peak velocities less than 0.5 ips are considered to be safe from a dynamic stress standpoint and require no further analysis. If vibrational velocities greater than 0.5 ips are measured, then further analyses are required to determine acceptability.

The first step to take if vibration velocities are greater than 0.5 ips is to determine more accurate values of the correction factors C_1, C_3, and C_4 and the stress indices C_2K_2 so that the applicable velocity criteria for the piping system in question can be established.