

Piping-Flexibility Analysis

By A. R. C. MARKL,¹ LOUISVILLE, KY.

A steadily expanding literature bears testimony to the growing recognition of the importance of the problem of providing flexibility in piping and to the many difficulties besetting efforts at establishing a simple rational approach for its solution. This paper aims to outline the various phases of the problem, with particular emphasis on the phenomena of plastic flow and fatigue which distinguish the behavior of piping systems under thermal expansion from the ordinary room-temperature steady-state structural problems and lead to the concept of a limiting-stress range rather than an allowable stress as the criterion of the adequacy of a layout. In treating his subject, the author has sought to present the consensus of the Task Force on Flexibility charged with reformulating Chapter 3 of Section 6 of the Code for Pressure Piping. Their Proposed Rules are included as a focal point on which it is hoped broad discussion will center.

INTRODUCTION

IN the course of a general review and revision of the Code for Pressure Piping, initiated in 1951, a Task Force on Flexibility² was appointed by ASME Sectional Committee B31.1 to study and report on the adequacy of the current provisions of the chapter on "Expansion and Flexibility" included in Section 6 of the Code. Two subgroups³ were formed, one to deal with stresses and their allowable limits, and the second to digest available information on physical properties entering into piping-flexibility analysis.

The former group, with the findings of which this paper is solely concerned, came to the conclusion that a complete reformulation of this chapter was desirable to improve its clarity and, more importantly, to bring its clauses into accord with advanced theoretical concepts, new research results, and accumulated experience. A working group⁴ was charged with the task of devising rules which would reduce this objective and still be readily understandable and easy to apply. A draft effecting a satisfactory compromise between scientific truth and the simplicity so essential to any body of rules destined for wide application was produced and accepted by the Sectional Committee.

However, since the Proposed Rules depart appreciably from past practice in several respects, primarily by their open recognition of the concept of stress range, it was thought desirable to publish them first in nonmandatory form as a Task Force Report (TRF) to permit piping engineers at large to familiarize themselves with them, test their suitability by application to their

individual problems, and assist in arriving at a final formulation assuring uniform interpretation and intelligent enforcement. At the same time, the author was invited to prepare a paper to explain the basic philosophy and scientific background underlying the Proposed Rules.

Task Function

The objective of piping-flexibility analysis is to assure safety against failure of the piping material or another structure from overstress, against leakage at joints, and against overstrain of connected equipment, without waste of material. While expansion joints of various types in some instances prove useful for this purpose, by far the more common and generally preferable practice is to provide for thermal expansion by utilizing the inherent flexibility of the pipe run itself acting as a spring in bending or torsion.

Piping-flexibility analysis resolves itself into the following:

- 1 The calculation of the forces, moments, and stresses (and desirably also, displacements) at all significant locations in a tubular structural frame under the influence of thermal expansion.
- 2 Their comparison with allowable limits.

The frame may be in one or more planes. The number of redundants will vary with the number of branch lines or intermediate restraints (guides, braces, and so on). For a space system, there will be six unknown reaction components (three forces and three moments, or three forces and their lever arms) for each anchor point in excess of one; intermediate restraints introduce a lesser number of unknowns.

As compared with the parallel structural problems, the evaluation of the reactions, stresses, and deformations in a piping system under thermal expansion involves a number of additional considerations, of which the following are the most important:

- 1 Piping components other than straight pipe, notably elbows and bends, exhibit peculiar stress-and-strain behavior under bending which generally reflects itself in increased flexibility, usually accompanied by intensification of stresses.
- 2 Piping systems are not intended to behave elastically in their entirety. As a result of local creep (at high temperatures) or local yielding (even at ordinary temperatures) relaxation may take place whereby the reactions and stresses in the operating condition are lowered and substantially equivalent reactions and stresses are made to appear in the cold or off-stream condition. This process can be anticipated by cold springing.
- 3 Owing to the cyclic nature of the operation of all piping systems, fatigue becomes a factor requiring consideration, particularly where the fluid carried is corrosive to any degree.

Task General Practice or Sequence

In the flexibility analysis of any system of given line size, configuration, and material, with a predetermined amplitude and number of temperature cycles, the following steps are involved:

- 1 The significant physical properties of the material, such as expansion coefficient, modulus of elasticity, Poisson's ratio, yield stress, creep and relaxation stress, and endurance strength have to be determined. This paper will not concern itself with the

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors and not those of the Society. Manuscript received at ASME Headquarters, July 27, 1953. Paper No. 53-A-11.

¹ Chief Research Engineer, Tube Works.

² For membership, see source (121). Numbers in parentheses refer to the Bibliography at the end of the paper.

³ Under the chairmanship of H. C. K. Meyer and R. Michael, respectively.

⁴ With R. W. Spalding as chairman, and N. Blais, H. V. Walstrom, and the author as members.

⁵ The original formulation by Subgroup 1 is transcribed in Appendix 1; alternate clauses introduced later in discussion to a dissenting viewpoint are given separately in Appendix 2.

Contributed by the Power Division and presented at a joint session of the Power, Applied Mechanics, Heat Transfer, Safety, Metals Engineering, and Petroleum Divisions, Joint ASME-ASME Research Committee on Effect of Temperature on the Properties of Metals, and Research Committee on High-Temperature Steam Generation, at the Annual Meeting, New York, N. Y., November 29-December 4, 1953, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

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