ENGINEERING STANDARD

FOR

FLEXIBILITY ANALYSIS

ORIGINAL EDITION

JULY 1997

This standard specification is reviewed and updated by the relevant technical committee on Jun. 2006. The approved modifications are included in the present issue of IPS.

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1. SCOPE

This Standard specification covers the basic requirements for the flexibility analysis of piping systems in Oil, Gas and Petrochemical Industries.

The analysis shall consider the effects of temperature, pressure, Vibration, Loads, Fluid, reactions and environmental Factors.

Note:

This standard specification is reviewed and updated by the relevant technical committee on Jun. 2006. The approved modifications by T.C. were sent to IPS users as amendment No. 1 by circular No. 301 on Jun. 2006. These modifications are included in the present issue of IPS.

2. REFERENCES

Throughout this Standard the following dated and undated standards/codes are referred to. These referenced documents shall, to the extent specified herein, form a part of this standard. For dated references, the edition cited applies. The applicability of changes in dated references that occur after the cited date shall be mutually agreed upon by the Company and the Vendor. For undated references, the latest edition of the referenced documents (including any supplements and amendments) applies.

ASME (AMERICAN SOCIETY OF MECHANICAL ENGINEERS)

ASME Section VIII Division I - Edition 2004	"Rules for Construction of Pressure Vessels"
ASME Section III	"Boiler and Pressure Vessel Code"
Part NB-3647.1	
ASME B.31.1	"Power Piping"
ASME B.31.3	"Process Piping"
ASME B.73.1	"Horizontal End Suction Centrifugal Pumps for Chemical Process"

API (AMERICAN PETROLEUM INSTITUTE)

API RP 520	"Sizing, Selection, and Installation of Pressure Relieving Devices in Refineries"
API STD. 610 Edition 1995	"Centrifugal Pumps for Petroleum, Petrochemical and Natural gas Industries"
API STD. 617	"Axial and Centrifugal Compressors and Expander Compressors for Petroleum, Chemical and Gas industry Services"

EJMA (EXPANSION JOINT MANUFACTURERS ASSOCIATION)

IPS (IRANIAN PETROLEUM STANDARDS)

IPS-E-GN-100	"Units"

NEMA (NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION)

NEMA SM 23	"Steam Turbines for Mechanical Drive Service"

3. DEFINITIONS AND TERMINOLOGY

3.1 Creep

Plastic flow of metal, usually occurring at high temperatures, subject to stress appreciably less than its yield strength. Progresses through first, second, and third stage to fracture or results in stress relaxation.

3.2 Flexibility Factor

Flexibility factor is defined as the ratio of the rotation per unit length of the part in question produced by a moment, to the rotation per unit length of a straight pipe of the same nominal size and schedule or weight produced by the same moment.

3.3 Stress Intensification Factor

Will be defined as the ratio of the bending moment producing fatigue failure in a given number of cycles in a straight pipe of nominal dimensions, to that producing failure in the same number of cycles in the part under consideration.

3.4 Section Modulus

The ratio of the moment of inertia of the cross section of a pipe undergoing flexure to the greatest distance of an element of the pipe from the center line.

4. UNITS

This Standard is based on International System of Units (SI) as Specified in IPS-E-GN-100.

5. PIPING STRESS ANALYSIS

Piping systems are subject to a diversity of loadings creating stresses of different types and patterns, of which only the following more significant ones need generally be considered in piping stress analysis:

1) Pressure, internal or external.

2) Weight of pipe, fittings and valves, contained fluid and insulation, wind and earthquake loads, and allowable loads on machinery.

3) Thermal expansion of the line.

5.1 Pressures

5.1.1 Internal pressure

Internal design pressure shall be calculated as per ANSI 31.3.

5.1.2 External pressure

The procedure outlined in the ASME Code Section VIII Division I paragraphs UG-28, 29, 30 shall be followed for determining external pressure.

5.2 Weights and Loads

5.2.1 Weights (w):

Weights shall be per ANSI B 31.3.

5.2.2 Wind loads (W_w):

The wind load shall be calculated by the equation shown below:

$$W_w = 0.7\,Aq$$

Where:

- W_w = wind load
- A = Projected area (outside diameter of the piping including the insulation multiplied by the unit length of the piping)
- q = wind pressure (specific value)

5.2.3 Earthquake load (W_e):

The earthquake load shall be the total weight of the piping system multiplied by the design vertical or lateral earthquake coefficient.

$$W_e = K_e W$$

Where:

- W_e = lateral or vertical earthquake load
- K_e = design lateral or vertical earthquake coefficient (specific value)
- W = weight of the piping system

5.2.4 Impact load

Impact loads caused by pressure relief through a safety valve shall be calculated in accordance with API RP 520.

5.2.5 Allowable loads on machinery

The allowable forces and moments on nozzles of machinery such as pumps, compressors and turbines shall be specified by the Manufacturer.

As a minimum requirement, Manufacturer shall use the following guides in determining the allowable nozzle loads.

5.2.5.1 Pumps

a) API 610 Pumps

The allowable nozzle loads on horizontal centrifugal pumps with steel or alloy casing shall meet the load criteria of API 610, Table 2.

b) ANSI Pumps

The allowable nozzle loads on horizontal centrifugal pumps shall be designed to ANSI B73.1.

c) Vertical Turbine and In-Line Pumps

The combined bending, torsional and thermal stress in the piping attached to the nozzle shall be limited to 25 percent of the allowable stress range as specified in ANSI B31.3. Also, the combined stress due to deadload shall be limited to 25 percent of the allowable hot stress.

d) Reciprocating and Other Type Pumps

The load criteria for these pumps shall follow those of Paragraph (a) above.

5.2.5.2 Compressors

a) API 617 Compressors

The allowable forces and moments acting on the nozzles of centrifugal compressors shall be designed in accordance with API 617.

b) Reciprocating Compressors

The allowable nozzle loads on these compressors shall meet the load criteria of NEMA SM23 for individual nozzles.

5.2.5.3 Thrust loads and moments imposed on mechanical equipment shall not exceed the equipment manufacturer's recommended values.

5.2.6 Allowable loads on equipment

5.2.6.1 Air fin coolers

The allowable nozzle loads on air fin coolers shall be specified by the Manufacturer.

5.2.6.2 Vessels and heat exchangers

Unless detailed calculations are made of the nozzle connection to the equipment, the combined thermal, bending and torsional stress in the piping attached to the nozzle shall be limited to 33 1/3 percent of the allowable stress range as specified in ANSI B31.3.

5.2.6.3 Fired heaters

The allowable nozzle loads and moments on fired heaters shall be specified by the Manufacturer.

Displacement of heater tubes shall be approved by the heater manufacturer and the effect of expansion and or displacement of the tubes shall be reflected in the computer analysis of the piping system.

Any heater designed with a floating coil (all spring or counter weight mounted) shall be provided with fail-safe limit stops in all directions. Computer analysis of piping system connected to floating heater coils shall include the heater coil or an approximate model of the coil as part of the systems and the effects of internal guides and restraints. In floating heater coils the support of the connecting piping system shall be completely and independently balanced so that no dead load is imposed on the coil.

5.2.7 Allowable forces and moments on flanges

To avoid leakage at flanges, the bending moments and forces on the flanges shall be limited by the formula listed in the ASME Code, Section III.

5.2.8 Combination of loads

The combinations of the loads shall conform to the applicable piping code. The wind load and earthquake load shall be regarded as acting separately in two (2) lateral directions 90° apart.

5.3 Stresses Due to Thermal Expansion

Reference shall be made to relevant sections of ANSI B 31.3.

6. FLEXIBILITY REQUIREMENTS

6.1 Piping systems shall be designed to have sufficient flexibility to prevent thermal expansion or contraction from causing excessive stresses in the piping material, excessive bending or unusual loads at joints, or undesirable forces or moments at points of connection to equipment or at anchorage or guide points.

6.2 Startup, shut-down, steam-out where applicable and upset conditions including short-term excursions to higher temperatures or pressures as well as normal operating conditions, shall be considered in flexibility analysis. This is particularly pertinent to loads applied to connecting equipment. The effect of vibration from machinery on connecting piping shall also be assessed.

6.3 The increase in allowable design stress permitted for occasional variations above design conditions shall not be used for flexibility analysis.

6.4 Expansion of piping or associated equipment should be accommodated wherever possible by the inherent flexibility of the pipework. If necessary the route of the piping should be modified, or expansion loops should be incorporated, to obtain sufficient flexibility.

6.5 Sufficient flexibility shall be provided in the piping to enable pressure relief valves, spades, line blinds or bursting discs to be changed.

6.6 Bends, loops, or offsets shall be provided for flexibility in piping system, especially for noxious or hazardous fluids.

6.7 In general, spring hangers shall be used only where vertical expansion limits the use of rigid supports. Spring hangers shall be used to relieve the dead load weight on equipment where rigid supports are not practical. All spring hangers shall be sized according to operating conditions.

6.8 Particular attention should be paid to the design of lines subject to severe temperature changes during start-up or emergency conditions, such as high temperature steam lines.

6.9 Flare system piping shall be designed to take care of expansion, movement or vibration caused by the most severe operating or emergency conditions, and is to be constrained against a tendency to move off its supports. Pipe shoes or saddles shall be furnished on the main flare header at all supports.

6.10 An ant sloshing baffle shall be installed in the flare stack water seal.

6.11 Cold spring shall be used as much as practical to reduce forces on equipment, and to prevent interferences from expanding lines.

6.12 Horizontal piping expansion loops in pipe tracks or on pipe bridges shall have vertical offset to stay clear of adjacent piping.

6.13 Thermally expanding piping shall be anchored at the plot limit.

6.14 The use of cold spring for piping systems which connect to rotating equipment is prohibited.

7. FLEXIBILITY ANALYSIS

7.1 Flexibility analysis shall be made in accordance with requirements of ANSI B31.1 and B 31.3.

7.2 Extent of Analysis

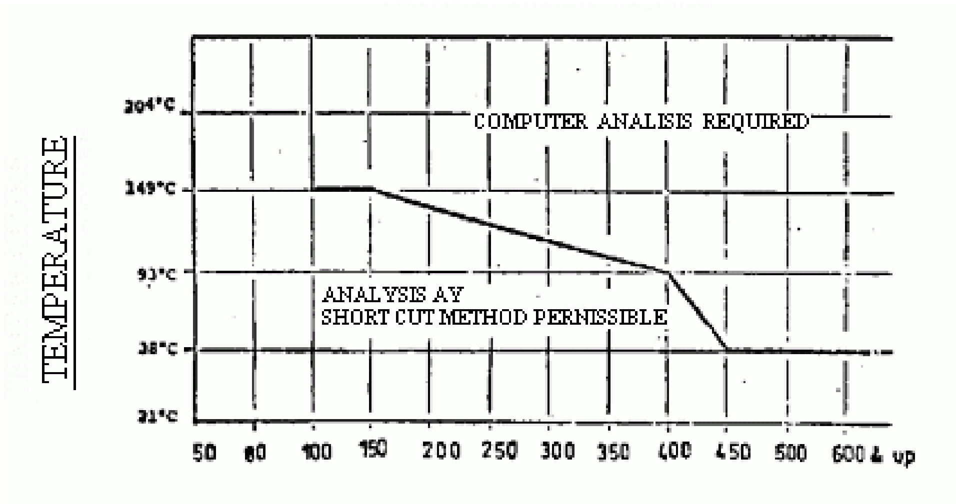
Formal computer analysis shall be required on all of the following lines:

7.2.1 All process, regeneration and decoking lines to and from fired heaters, and steam generators.

7.2.2 All process lines to and from centrifugal compressors and blowers.

7.2.3 All steam lines to and from turbines.

7.2.4 All pump lines that fall above the curve on the chart, shown below:



PIPE MANIFOLD SIZE DN

7.2.5 All lines over 427°C.

7.3 Analysis by visual inspection of mechanical layout, configuration anchoring etc. and/or manual calculation is required on all of the following lines not listed in Section 7.2.

7.3.1 Lines DN80 and larger connected to rotating equipment such as pumps, turbines, compressors, and blowers.

7.3.2 Lines DN100 and larger to air coolers.

7.3.3 All Lines DN 300 and Larger.

7.3.4 Line to vessels which can not be disconnected for purging.

7.3.5 Lines DN150 and larger at operating temperatures over 260°C.

7.3.6 All relief systems. (Must include analysis for dynamic load from the worst possible flow conditions including slugs if there is a possibility that one could occur.)

7.3.7 Vacuum lines.

7.3.8 All nonmetallic piping.

7.3.9 Lines subject to excessive settlement.

7.3.10 Lines to and from reciprocating pumps and compressors.

7.4 All analysis shall include the effects of thermal expansion and or contraction, wind, earthquake Vibration, operating and test dead loads, guides, anchors, restraints, settlement, branches, supports and terminal displacements as described in the codes and specifications listed herein.

7.5 Lines to be analyzed shall be marked on the line list.

7.6 Basic Assumption and Requirements

Reference shall be made to ANSI B 31.1.

7.7 Movements

Reference shall be made to ANSI B 31.3 or B 31.1.

7.8 Cold Spring

Reference shall be made to ANSI B 31.3 or B 31.1.

APPENDICES

APPENDIX A
EXTERNAL FORCES AND MOMENTS

Piping force and moment limitations shall be per the following:

a) Nozzle force limitation (imposed at the nozzle flange from external piping) shall not exceed the following :

1) For forces parallel to the nozzle axis:

$F \leq 200$ lbf per in. of nominal nozzle diameter

2) For forces perpendicular to the nozzle axis:

$F \leq 100$ lbf per in. of nominal nozzle diameter.

3) For tensile forces parallel to the nozzle axis in top discharge and top suction nozzles $\leq$ 4 in. NPS (100 mm):

$F \leq 100$ lbf per in. of nominal nozzle diameter.

b) Nozzle bending moment limitation (imposed at the nozzle flange from external piping) shall not exceed the value determined per the following formula:

$$M = S \times Z$$

Where:

M = Nozzle bending moment limitation, lbf-in. (N.m)

S = Nozzle bending stress limitation, psi, equivalent to the lesser of:

1) Carbon or alloy steel pumps: 0.75 S_h or $\frac{1.5}{D}$ S_h psi (bar)

2) Cast iron pumps: 0.75 S_h or, $\frac{18000}{D}$ psi (bar)

S_h = Allowable hot stress for the pump casing material, psi (stresses per ANSI B31.3 Appendix A, Table 1)

D = Nominal nozzle size, in. (mm)

Z = Section modulus of pipe, $in.^3$; (mm^3) for pipe of Diameter D, and thickness equivalent to:

1) ANSI Class 400 or lower rating flanges: Schd standard.

2) ANSI Class 600 or higher rating flanges: Schd extra strong.

Note:
In calculations using SI terms for Nozzle Force (F) and Nozzle Moment (M). Per sub-par. a) and b) above:

Specified Term	**Acceptable Metric Equivalent**
$F \leq 200$, lbf/in.	**$F \leq 35.6$, N/mm**
$F \leq 100$, lbf/in.	**$F \leq 17.8$, N/mm**
M. lbf in	**M. N.m**
$\frac{1.5}{D}$ **S_h. psi**	$\frac{0.26}{D}$ **S_h.N/mm^2**
$\frac{18000}{D}$**, psi**	$\frac{3100}{D}$ **,N/mm^2**
S_h. psi	**No change Use ANSI B 31.3 values, psi**
D. in	**(25) × in. = mm**
Z. in^3	**$(1.65 \times 10^{-5}) \times in^3 = m^3$**

(to be continued)

APPENDIX A (continued)

c) Combined moment limitation. For the orientation shown below, the combined moments from external piping reactions on nozzles for horizontal pumps shall not exceed the following:

	For calculation in SI Units:
$\sum$ **M_x** = 3.0 W ft-lb	$\sum$ **M_x** = 8.9 W N.m
$\sum$ **M_y** = 2.0 W ft-lb	$\sum$ **M_y** = 6.0 W N.m
$\sum$ **M_Z** = 1.5 W ft-lb	$\sum$ **M_Z** = 3.0 W N.m

Where: **Where:**

M_x = moment in Y-Z plane Minimum W is 454 kg

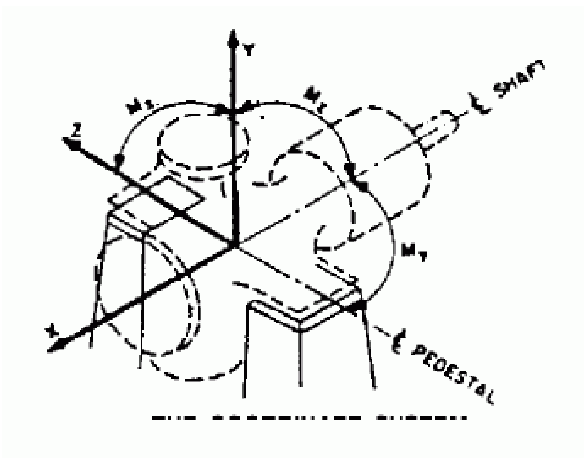
M_y = moment in X-Z plane

M_Z = moment in X-Y plane

W = weight of pump only, lb

Minimum W is 1.000 lb in these computations.

In each coordinate direction, the combined moments shall include the piping moment reactions in that direction from all pump nozzles as well as the moments resulting from piping forces resolved about the center of the pump casing.



THE COORDINATE SYSTEM

Fig. 2

Deviations permitting higher loads require approval of Owner's Engineer. Such approval will be based on proof submitted by pump vendor that the specified pump coupling deflection will not be exceeded.

Piping force and moment limitations may be increased by 50% for reactions which occur only when a pump is not operating: e.g., the case of an idle pump (installed spare) or a condition during equipment steam out.

Use of a more rigid baseplate and support assembly for horizontal pumps shall be evaluated as an alternative to revised piping layout when computations indicate that the combined piping moment limitations would be exceeded.

The more rigid support assemblies shall have the characteristic of limiting shaft displacement, measured at the coupling, to 0.005 in. (0.13 mm) for:

2X (designation):	twice allowable combined moments
4X (designation):	four times allowable combined moments

For in-line pumps, piping forces shall be determined with the pump considered as a rigid, but unanchored segment of the piping system.

The effects of piping weight and friction force due to thermal expansion shall be included in the evaluation of loads on pump nozzles.