Research Inventy: International Journal of Engineering and Science
Vol.16, Issue 6 (June 2026), PP 16-22
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Design Premises for Flanged Nozzles Connecting Vessel–Piping Systems

Walther Stikvoort
Consultant – Pressure Vessel & Piping Integrity Engineer

Abstract: *This paper presents a comprehensive engineering philosophy for the design of flanged nozzle connections between pressure vessels and piping systems, focusing on the interaction between structural integrity, piping flexibility, thermal loading, and gasket sealing performance. Flanged nozzle interfaces are treated not as simple static pressure-retaining joints, but as deformation-sensitive systems whose reliability is governed by the combined effects of internal pressure, external piping loads, thermal expansion and contraction, bolt preload, and flange rotation.*

A key emphasis is placed on evaluating the full thermal operating envelope, distinguishing between high-temperature expansion and low-temperature contraction conditions, which produce fundamentally different loading mechanisms and failure risks. The study highlights that flange leakage is primarily driven by loss of gasket contact stress due to flange rotation and uneven loading, rather than by pressure-induced structural failure.

The paper advocates a system-level design approach in which piping flexibility is prioritized to prevent excessive nozzle loading, ensuring that vessel nozzles are not used as load-absorbing structural elements. Design guidance is provided for nozzle load allowables, gasket selection, support placement, flange rotation control, and combined load case evaluation, including operating, cold, hydrotest, and occasional conditions.

The overall objective is to ensure leak-tight performance and long-term reliability of flanged nozzle connections by controlling deformation behaviour across the full operating temperature range, integrating principles from established pressure vessel and piping design codes with practical engineering experience.

Keywords: *Flanged nozzle connections; pressure vessels; piping systems; piping flexibility; thermal expansion; thermal contraction; flange rotation; gasket sealing performance; nozzle loads; bolt preload; leakage prevention; pressure vessel design; piping stress analysis; structural integrity; flange joint reliability.*

Date of Submission: 27-05-2026 Date of Acceptance: 06-06-2026

I. Introduction

This paper presents a comprehensive engineering philosophy for the safe and reliable design of flanged nozzle connections between pressure vessels and piping systems. The work addresses one of the most critical interface regions in industrial process equipment: the connection where piping systems meet pressure vessels through flanged nozzles.

The paper emphasizes that nozzle–flange interfaces are not merely static pressure-retaining components, but highly deformation-sensitive systems whose performance depends on the interaction between vessel rigidity, piping flexibility, thermal movement, bolt preload, and gasket sealing behaviour. Rather than treating the flange as a simple structural connection, the author highlights that leakage and integrity problems are often governed by flange rotation, gasket unloading, and externally imposed piping loads rather than by internal pressure alone.

A central theme of the paper is the importance of evaluating the full thermal operating envelope, including both:

- High-temperature expansion conditions, which generate compressive forces and bending moments from pipe growth, and
- Low-temperature contraction conditions, which can induce severe tensile loads, increased bolt stresses, and gasket sealing degradation.

The paper argues that these two thermal conditions produce fundamentally different failure mechanisms and therefore must be analyzed separately during design verification.

Another major contribution of the article is its strong system-level design philosophy. The author stresses that pressure vessel nozzles should not be used as structural anchors to absorb piping deformation. Instead, piping systems must be designed with sufficient flexibility — through loops, offsets, guides, and proper support placement — so that thermal expansion and contraction are accommodated within the piping layout itself. This approach minimizes external nozzle loads and preserves flange sealing integrity.

The document also provides practical engineering guidance regarding:

- Nozzle load allowables,
- Flange leakage mechanisms,
- Gasket behaviour under thermal cycling,
- Support and restraint philosophy,
- Flange rotation control,
- Combined load case evaluation,
- Verification methodologies for piping stress analysis.

Throughout the paper, Walther Stikvoort reinforces the principle that reliable flange performance is primarily a sealing and deformation-control problem rather than a simple strength problem. The work integrates concepts from internationally recognized pressure vessel and piping design codes and aligns them with practical field experience in refinery, petrochemical, and process plant applications.

Overall, this paper serves as a valuable reference for mechanical engineers, piping stress engineers, pressure vessel designers, and integrity specialists involved in the design and assessment of vessel–piping interfaces. Its primary contribution lies in translating complex interaction effects between piping flexibility, thermal loading, and flange sealing mechanics into a clear and systematic engineering design philosophy aimed at preventing leakage, minimizing nozzle overstress, and ensuring long-term operational reliability.

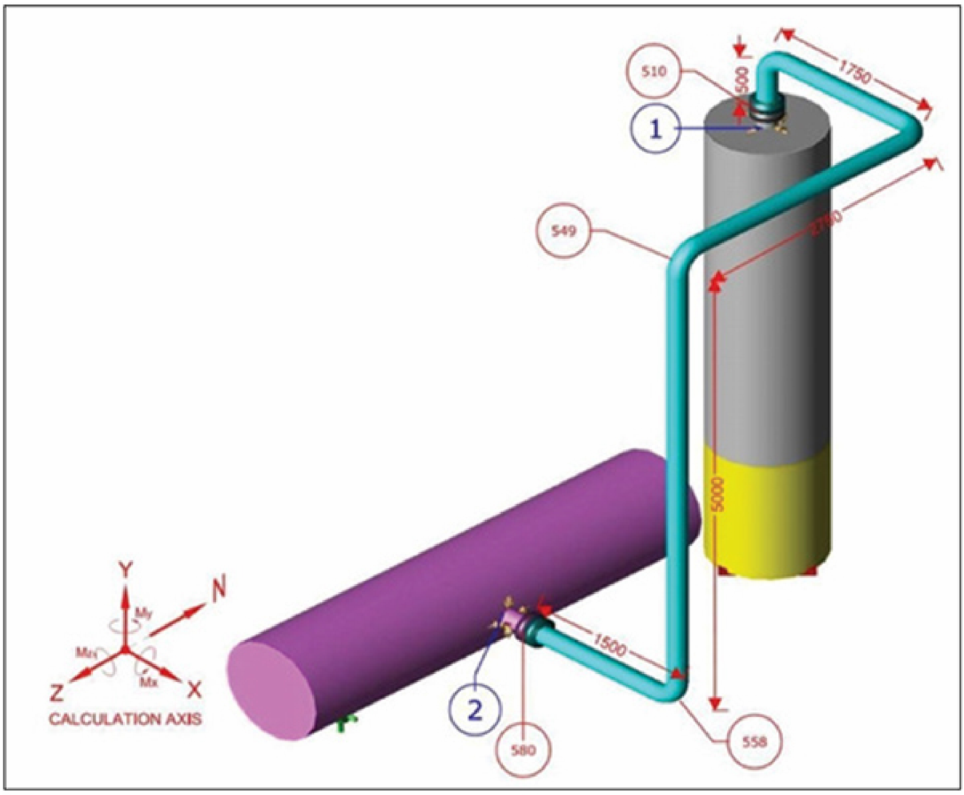

Figure 1. Typical piping configuration showing flanged nozzles connecting piping to vessels.

II. General Design Philosophy

The flange connection at a vessel nozzle shall:

- Maintain pressure boundary integrity
- Maintain leak-tight sealing under all operating conditions
- Withstand combined effects of pressure, thermal movement, and piping loads
- Ensure nozzle loads remain within allowable limits of vessel design

Key principle:

The piping system shall be designed to be flexible enough that vessel nozzle flanges are not used as load-absorbing structural elements.

III. Design Temperature Envelope (Critical Basis)

The interface shall be designed for the full temperature range:

3.1 High-temperature condition

- Thermal expansion of piping system

- Reduction of bolt preload due to relaxation/creep
- Gasket softening or creep (depending on type)
- Increased flange rotation due to pipe growth

3.2 Low-temperature condition

- Thermal contraction of piping system
- Increased tensile loads at nozzle flange
- Bolt stress increase due to differential contraction
- Gasket embrittlement or reduced conformability

Key premise:

Both maximum expansion and maximum contraction cases shall be evaluated independently, as they produce different critical flange loading conditions.

IV. Flanged Nozzle Mechanical Interface Loads

The nozzle flange shall be designed for combined loads:

- Internal pressure (primary load)
- External piping forces:
    - Axial force (tension/compression)
    - Shear forces
    - Bending moments (governing for leakage risk)

Load effects:

- Pressure → gasket compression demand
- Axial force → bolt load variation
- Bending moment → flange rotation (critical for leakage)

V. Flange Leakage and Sealing Premises

Sealing integrity shall be ensured under:

5.1 Assembly condition

- Adequate bolt preload to achieve minimum gasket seating stress
- Uniform gasket compression across sealing surface

5.2 Operating condition (hot case)

- Pressure + thermal expansion loads combined
- Gasket creep and bolt relaxation accounted for
- Flange rotation limited to maintain sealing contact

5.3 Minimum temperature condition (cold case)

- Pipe contraction induces tensile loading on flange
- Bolt stress increases
- Risk of gasket unloading at outer edge
- Potential leakage due to loss of contact stress

Key sealing principle:

Leakage occurs when gasket contact stress falls below minimum required sealing stress, often due to flange rotation rather than bolt failure.

VI. Flange–Pipe Compatibility Requirements

The flange interface shall ensure:

- Matching pressure class and flange standard geometry
- Compatible facing type (RF, RTJ, etc.)
- Gasket selection appropriate for:
    - Temperature extremes
    - Chemical compatibility
    - Cyclic loading conditions

Material compatibility shall consider:

- Differential thermal expansion between vessel nozzle and piping
- Strength reduction at elevated temperatures
- Brittle behaviour at low temperatures

VII. Nozzle Load Allowables and Flexibility Requirement

The piping system shall be designed such that:

- Nozzle loads remain within vessel allowable limits
- Vendor flange load limits (if applicable) are not exceeded
- Piping flexibility absorbs thermal movement

Design premise:
Vessel nozzles are rigid boundary points; piping must accommodate thermal expansion and contraction without imposing excessive loads.

VIII. Thermal Expansion and Contraction Behaviour

8.1 High temperature

- Pipe expansion pushes against nozzle
- Induces bending moment at flange
- May cause flange opening on tension side

8.2 Low temperature (critical addition)

- Pipe contraction pulls on nozzle
- Creates axial tensile load
- Increases bolt stress
- Reduces gasket compression margin

Key requirement:
Both expansion and contraction cases must be evaluated separately, as they govern different failure modes.

IX. Flange Rotation Control (Critical Design Driver)

Flange rotation is the primary cause of leakage.
Design shall ensure:

- External piping moments minimized
- Short stiff spools near nozzle avoided
- Supports placed to reduce eccentric loading
- Nozzle reinforcement sufficient to limit local deformation

Acceptance concept:

- Low rotation → uniform gasket stress
- High rotation → gasket edge unloading → leakage risk

X. Support and Flexibility Philosophy

Piping system shall incorporate:

- Expansion loops or offsets where required
- Sliding supports to accommodate contraction
- Proper anchor placement away from nozzle
- Guide supports to control lateral instability without restraining axial movement

Key rule:
Restraints shall control movement direction, not eliminate thermal movement.

XI. Load Cases for Design Verification

The following cases shall be evaluated:

(A) Operating high temperature case

- Maximum expansion
- Pressure + thermal + sustained loads

(B) Minimum temperature case

- Maximum contraction
- Maximum tensile loading at flange/nozzle
- Reduced gasket flexibility

(C) Hydrotest case

- Maximum pressure
- Minimal thermal effects
- Check structural strength of flange and bolts

(D) Occasional loads

- Wind
- Seismic

- Vibration (pulsation, rotating equipment)

XII. Design Principle Summary

The governing design philosophy for flanged nozzle interfaces is:
The flange connection shall remain leak-tight under the combined effects of pressure, piping-induced mechanical loads, and thermal expansion/contraction across the full operating temperature range, without relying on the nozzle flange to absorb piping system deformation.

XIII. Conclusions and Recommended Practice

13.1 Conclusions

1. **Flanged nozzle interfaces are deformation-sensitive systems**
   Leakage and mechanical failure are governed more by **flange rotation and gasket unloading** than by pure pressure containment strength.
2. **Thermal effects dominate interface behaviour**
   Both:
   - High-temperature expansion (compressive/misalignment effects)
   - Low-temperature contraction (tensile pull-out effects)
     can govern nozzle and flange design.
     These must always be treated as **separate critical load cases**.
3. **Piping loads are often the controlling design driver**
   External piping-induced:
   - Bending moments (most critical for leakage)
   - Axial forces (critical in cold service)

   frequently govern flange integrity rather than internal pressure.
4. **Nozzle integrity depends on system flexibility, not local strength alone**
   Vessel nozzles are relatively rigid; therefore:
   > System-level piping flexibility is the primary protection mechanism for nozzle and flange integrity.
5. **Flange leakage is primarily a sealing performance problem**
   Not a structural failure problem. Leakage is driven by:
   - Loss of gasket contact stress
   - Uneven gasket loading due to flange rotation
   - Thermal cycling and bolt relaxation
6. **Cold service introduces additional critical risks**
   Low-temperature contraction can:
   - Increase bolt tensile loads
   - Reduce gasket compliance
   - Amplify sensitivity to misalignment and stiffness imbalance

13.2 Recommended Practice

A. Piping system design (primary recommendation)

- Design piping to be **highly flexible near vessel nozzles**
- Avoid rigid restraint close to nozzle connections
- Use:
  - Expansion loops
  - Offsets and bends
  - Properly located guides and anchors
- Ensure thermal movement is absorbed by piping geometry, not vessel nozzles

B. Nozzle load control philosophy

- Treat vessel nozzles as **fixed boundary constraints**
- Ensure piping stress analysis explicitly verifies:
  - Code allowable nozzle loads
  - Vendor equipment limits (if applicable)
- Do not rely on local nozzle reinforcement to “absorb” poor piping design

C. Flange integrity and leakage prevention

- Perform combined checks for:
  - Pressure
  - External piping loads
  - Thermal expansion and contraction
- Limit flange rotation as a primary design target

- Ensure gasket selection is suitable for:
    - Full temperature range
    - Cyclic loading
    - Long-term relaxation behaviour

D. Low-temperature (contraction) design practice

- Explicitly check cold case as a governing scenario
- Ensure:
    - Axial tensile loads at nozzles are controlled
    - Bolt stress increase remains acceptable
    - Gasket sealing margin is maintained
- Avoid over-constrained piping layouts that "trap" thermal contraction

E. High-temperature (expansion) design practice

- Control piping growth away from vessel nozzles
- Prevent:
    - Excessive bending moments
    - Flange opening on tension side
- Ensure supports do not unintentionally increase stiffness near nozzles

F. Support system design

- Supports shall:
    - Allow controlled axial movement
    - Prevent lateral instability
    - Avoid introducing unintended restraint forces
- Anchors shall be located to define movement domains, not restrict them excessively

G. Engineering verification approach

A robust design requires:

- Piping stress analysis including hot and cold cases
- Nozzle load verification against allowable limits
- Flange integrity evaluation considering rotation effects
- Iterative redesign of routing/supports when limits are exceeded

13.3 Final Engineering Statement

Reliable flanged nozzle performance is achieved not by strengthening the flange alone, but by controlling the interaction between piping flexibility, thermal movement, and gasket sealing behaviour across the full operating temperature range.

XIV. Recommended Further Reading

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• **Stikvoort, W.J.** "Proper Interface Design for Pressure Vessels." Chemical Engineering, June 1994, pp. 133–134, McGraw-Hill. (Directly relevant to flange and nozzle interface design philosophy.)

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• **Stikvoort, W.** "Load Capacity Limits of Flanged Pressure Vessel Nozzles." Petroleum & Petrochemical Engineering Journal, Vol. 2, Issue 3, 2018. (Highly relevant discussion of flange load allowables and nozzle integrity limits.)

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- **Stikvoort, W.** "Yardstick for the Evaluation of Nozzle Loads." American Journal of Engineering Research (AJER), Vol. 8, Issue 3, 2019, pp. 293–298. (Useful practical guidance for nozzle load assessment and verification.)
- **Stikvoort, W.** "Awareness of Crucial Design Aspects for Pressure Vessels." The International Journal of Engineering and Science (IJES), Vol. 8, Issue 4, 2019, pp. 58–64. (General pressure vessel integrity and design philosophy relevant to the present work.)

Author Biography

Walther Stikvoort is an independent consultant specializing in pressure vessel engineering, piping integrity, nozzle load evaluation, and vessel–piping interface design. With extensive experience in refinery, petrochemical, and industrial process systems, he has contributed significantly to the practical understanding of piping-induced nozzle loading, flange integrity, thermal flexibility, and pressure vessel reliability.

Over several decades, Mr. Stikvoort has published numerous technical papers and engineering articles addressing pressure vessel nozzles, piping reactions, flange load capacity, thermal expansion effects, and mechanical interface behaviour between vessels and piping systems. His work combines code-based engineering principles with practical field experience, emphasizing deformation control, leak prevention, and system-level mechanical integrity.

His publications have appeared in recognized engineering journals and technical references including *Chemical Engineering*, the *ASME Pressure Vessels and Piping Conference Proceedings*, the *International Journal of Pressure Vessels and Piping*, and several engineering research journals. His contributions are widely focused on translating complex interaction effects between piping flexibility, thermal loading, and structural behaviour into practical engineering design methodologies.

Mr. Stikvoort's engineering philosophy emphasizes that reliable pressure equipment performance is achieved through integrated system design, where piping flexibility, nozzle load control, flange sealing behaviour, and thermal movement management are treated as interdependent aspects of overall mechanical integrity.