Integrity Evaluation of Small Bore Connections (Branch Connections)

by:

Chris B. Harper, P.Eng.
Principal Engineer
Beta Machinery Analysis
Calgary, Canada
charper@betamachinery.com
www.BetaMachinery.com

9th Conference of the EFRC
September 10th - 12th, 2014, Vienna

Abstract:

Evidence shows that vibration induced failure of small bore connections (SBC), also called branch connections or small bore piping, is an ongoing challenge during both the design phase and field testing.

Failure of small bore piping on reciprocating compressor systems is a common industry problem. In fact, many industry experts believe that these failures represent the highest integrity risk and more attention is needed during the design and when conducting vibration surveys.

The Energy Institute and Gas Machinery Research Council provide recommendations and screening guidelines for the evaluation of SBCs in vibratory service. There are other screening guidelines available for vibration-induced fatigue failure that contain stress calculations.

These guidelines and approaches are useful for screening SBCs but they are not as useful for advanced analysis and field vibration surveys. A more comprehensive approach is needed to help industry with this question, “what to do if a SBC fails the EI or GMRC guideline?”

This technical paper will:
- Summarize existing approaches, recommendations and guidelines for SBC;
- Identify gaps and challenges in applying the existing approaches;
- Recommend an approach to address these gaps, and proposed guidelines for new designs; and
- Provide a proposed methodology for evaluating SBC vibration in the field.

SBC vibration guidelines are not currently included in the upcoming EFRC/ISO vibration guidelines. The results and findings from this paper could be a valuable input to addressing SBC integrity risks in this ISO (or other) standards.

1. Introduction

Small bore connections (SBCs) are a major source of failure on piping systems but are infrequently evaluated during the design phase of a project or during the field commissioning phase. Piping vibration and fatigue can account for up to 20% of hydrocarbon releases, and a large portion of those are due to failure of small bore connections [1]. Hydrocarbon emissions can lead to fire, explosions, injuries, property and environmental damage.

The following paper outlines different approaches, standards and guidelines that relate to SBC, both in the design phase, and during field testing.

To address the existing industry challenges, a practical approach is provided to improve the design and integrity of SBCs. The following recommendations are based on years of field testing, research, involvement with API 688/618 and GMRC committees, and involvement with a number of original equipment manufacturers (OEMs) of rotating machinery, packagers of rotating machinery, and end-users/owners.

While the following examples and discussion focus on reciprocating compressor applications, the approaches and recommendations apply to SBC located near reciprocating pumps, as well as centrifugal machines, or nearby piping system.

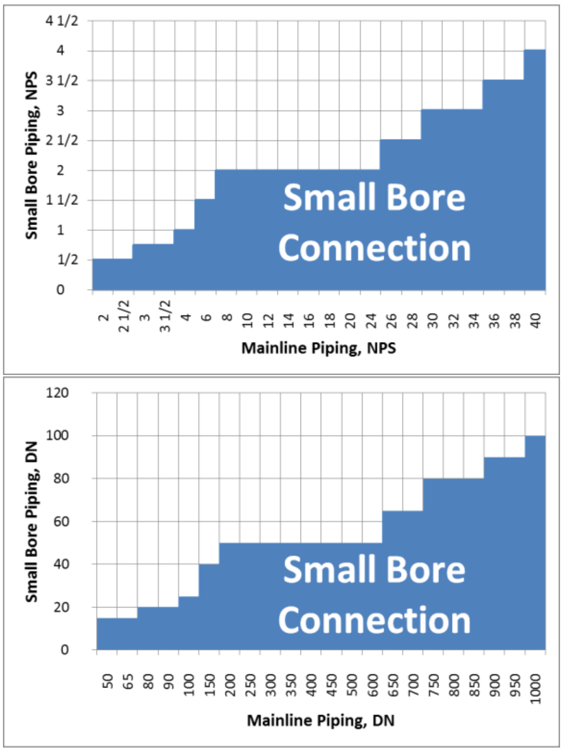


Figure 1. Small bore connection definition chart

1.1. Definitions

A small bore connection (SBC) is defined as a branched connection on mainline piping that is NPS 2” (DN 50) and smaller, including connections that have a branch pipe to mainline pipe ratio (“branch ratio”) of less than 10%, and excluding connections that have a branch ratio greater than 25%. Note that “mainline piping” could also describe equipment like a vessel or cooler to which the SBC is attached. A chart showing the SBC size definition is shown in Figure 1 above.

Small bore piping (SBP) is defined as the piping that is attached to the small bore connection, extending until the effect of the mainline piping vibration is negligible (typically, the nearest support or brace). Refer to Figure 2 for an illustration.

The small bore piping that is of most concern is that which contains production fluid at operating pressure. Auxiliary lines, like pneumatic air, crankcase vents, etc., are not as critical.

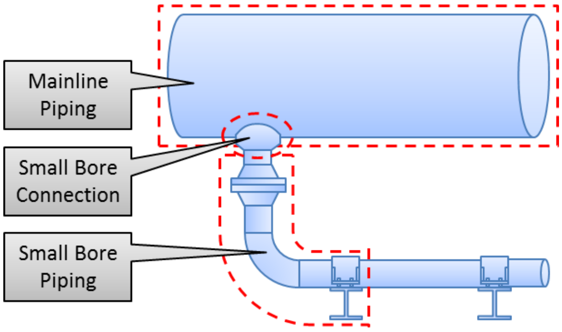


Figure 2. Small bore and mainline piping defintions

1.2. Acronyms

1D	One dimensional
ANSI	American National Standards Institute
DN	Diamètre nominal
EDI	Engineering Dynamics Incorporated
EI	Energy Institute
EPC	Engineering, procurement and construction
ESD	Emergency shutdown
FEA	Finite element analysis
GMRC	Gas Machinery Research Council
LOF	Likelihood of failure
MNF	Mechanical natural frequency
ODS	Operating deflected shape
PSV	Pressure safety (or relief) valve
RFLWN	Raised face long weld neck (flanges)
SBC	Small bore connection
SBP	Small bore piping

2. Challenges and Gaps with Current Practices

A large number of compressor/pump systems are fabricated and installed without a detailed design of SBP weight, geometry, or location, including the SBCs located off-skid or away from the compressor or pump frame.

It is rare that a specification will require a SBP audit at the design stage or during field commissioning. The lack of detailed analysis is due to these reasons:

- The design and layout of small bore piping is not known during the design stage. It is either shop-run or field-run, and there may not be drawings available.

- Even if the drawings are available at the design stage, the mass of non-standard components may be unknown because they have not been selected by the purchasing department, or they will be specified by the EPC. SBP mechanical natural frequencies (MNFs) are more sensitive to uncertainties in concentrated masses because they represent a higher percentage of the total mass of the SBP.

- Field audits may not be specified because of confusion about what piping is classified as SBP, and what vibration guidelines should be used.

- A thorough evaluation of small bore piping requires a shop test or a field evaluation. Different companies (and departments within companies) are involved at different stages, like front-end engineers, design, procurement, testing, commissioning, and operations. Therefore, a complete SBC evaluation involves coordination with many companies and departments.

These practical issues and limitations at the design stage, and during compressor start-up, are significant barriers to resolving SBC integrity risks.

3. Current Design Evaluation Methodology

There are various articles and guidelines on suggested approaches to review SBCs during the design stage of a project. This section briefly outlines these approaches and summarizes their advantages and disadvantages.

At the design stage, there are basically two evaluation methodologies: robustness and mechanical natural frequency (MNF).

- The robustness of a SBC can be judged based on characteristics like piping diameter, thickness, flange rating, and location on the mainline piping. These can be compared to the characteristics of well-designed SBC. This methodology is limited to SBCs that fall into certain predefined groups. Also, there is some risk remaining because of the statistical nature of this method.

- The SBP MNF can be estimated (using empirical calculations or finite element analysis) and compared to industry guidelines. Currently, there is not industry-wide consensus on the MNF guidelines to use.

3.1. Best Practices

Many owners, EPCs, and machinery packagers have best practices on SBC design. These include guidelines on what type of connection to use (e.g., weldolet, sweepolet, or welded tee), welding procedures on SBCs, whether bracing is required, where small bore connections should be located, etc. In many cases, these are specified due to pressure requirements, and not specifically for reducing vibration-induced fatigue failure, but are useful nonetheless in avoiding some problems.

Below is a list of good practices in SBC design [2]:

1. Avoid locating SBCs near within about 20’ (6m) of rotating machinery, including pulsation bottles and scrubbers on reciprocating compressor manifolds.

2. Avoid mounting SBCs within 10 mainline pipe diameters of pressure reducing devices (e.g., recycle valves, control valves, relief valves, or tight orifice plates) and fittings (e.g., elbows, tees, and reducers).

3. SBCs should be located within 2 mainline pipe diameters of pipe clamps and not on long unsupported piping spans. SBCs should be schedule 80 thickness, as a minimum.

4. Heavy valves (including isolation valves, double block and bleed, and gate valves) should not be used on SBCs. Use low profile valves instead, like monoflange valves. If large valves are required, use gussets on the SBC or brace the valve back to the mainline pipe. Other alternatives are to use robust connections like RFLWN or studding outlet connections.

5. Cantilever-type SBP should be as short as possible, and should avoid heavy valves, elbows, and tees.

Best practices are useful in reducing poor SBC design, but still leave some risk of vibration and fatigue failure.

3.2. Energy Institute Guideline

The Energy Institute (EI) has published a guideline for evaluating the failure risk of mainline and SBP [1]. The SBP can be evaluated either in conjunction with a mainline piping evaluation, or separately.

The EI assessment of SBP is a robustness methodology that calculates a likelihood of failure (LOF) for the connection. The SBP LOF calculation is based on the mainline dynamic forces (optional), the SBP geometry, and the location of the SBC on the mainline piping. If the LOF is greater than 0.7, then the SBP should be redesigned or braced.

The EI guideline considers the SBC fitting type (e.g., weldolet, threadolet, sockolet), SBP length and thickness, and presence of heavy valves. However, it does not estimate the SBP MNF.

3.3. GMRC Design Guideline

The Gas Machinery Research Council (GMRC) assessment of SBP is based on simple finite element analysis (FEA) models, which estimate the MNF and quasi-static stress (due to horizontal 1.5 G load) [3]. The MNF is compared to the appropriate MNF guideline (Table 1), and the maximum predicted stress is compared to a 3000 psi (20.7 MPa) 0-peak ("peak") stress guideline. From this, a chart of SBP lengths versus weights can be referenced for guidance on selecting and designing SBP. The three main variables used for evaluation are the SBP configuration, length, and mass.

In the chart (Table 1), "Near" means within 20-25 feet (6.1-7.6 m) of the machinery and "N" means number of plungers.

While the GMRC assessment is more accurate than the EI assessment, it is still deficient in some respects. Although many layouts are covered by the GMRC guideline, the list is not exhaustive. The recommended simple 1D FEA method does not predict the stress and flexibility at the connection accurately. In some cases, the highest stress in a SBC is not in the SBP but in the mainline pipe (which is not modelled).

Table 1: GMRC Natural Frequency Guideline

Machinery	**Natural Frequency Guideline**	
	(Near)	**(Far)**
Reciprocating Compressor	> 4.8 * maximum runspeed	> 2.4 * maximum runspeed
Centrifugal Compressor	Detailed analysis recommended	> 15 Hz
Reciprocating Pump	> N * 2.4 * maximum runspeed	> N * 1.2 * maximum runspeed
Centrifugal Pump	> 2.4 * maximum runspeed	> 15 Hz

4. Current Field Evaluation Methodology

Currently, most companies treat SBP the same as mainline piping, when screening vibrations. Some companies will use more accurate vibration guidelines, which consider the small bore geometry, like those described in ASME OM-S/G-2003 [4], by Woodside Energy [5], or by EDI [6]. A few companies also use finite element analysis (FEA) to determine an allowable vibration guideline; a detailed discussion of FEA strategies will be presented in Section 5.1.

4.1. Screening Vibration Guideline

1.0 inch/sec peak (25.4 mm/sec peak) is a good screening guideline for SBP vibration. This guideline can be compared to spectrum (frequency domain) or, if base motion is subtracted out, to time domain waveforms.

To evaluate this screening guideline, a simple one dimensional (1D) FEA model was created (similar to the procedure described in Ref. [3]) to test different cantilevered SBP configurations. (Cantilever SBP is very common on mainline piping and vessels, as shown in Figure 3.) The SBP ranged from NPS 0.5" to 2" (DN 15 to 50), the flange ratings varied from ANSI 150 to 600, and some included gate valves. The stresses were compared to a 3000 psi (20.7 MPa) peak-to-peak allowable stress range. While there was no clear trend, the results do show that cantilevered SBP has an allowable vibration that varies between about 1.0 in/s peak to 3 in/s peak (25 mm/s peak to 76 mm/s peak) (Figure 3). This suggests that a vibration screening guideline of 1.0 inch/sec peak (25.4 mm/sec peak) is reasonable.

Vibration guidelines can be in displacement, velocity or acceleration. Velocity is a good screening guideline because for pipe with no concentrated mass, the peak stress at resonance is related to velocity only, not geometry. Vibration guidelines will be discussed in more detail in section 4.4.

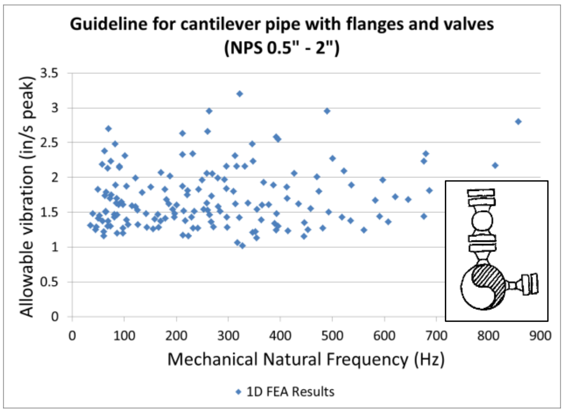


Figure 3. Allowable vibration for cantilever-type SBP

4.2. Woodside Energy Guideline

A paper by Woodside Energy describes a procedure to calculate stress due to measured acceleration in cantilevered SBP with concentrated masses [5]. A vibration velocity screening guideline is also provided, along with a robustness classification (Table 2).

Table 2. Woodside Energy vibration screening guideline

Small Bore Piping Type	Robustness Classification	Screening Velocity	
		mm/s peak	in/s peak
Cantilevered	Weak	15	0.6
	Moderate	30	1.2
	Robust	50	2.0
Continuous or supported	Weak	40	1.6
	Robust	60	2.4

While this method is more accurate than other methods, it has some limitations:

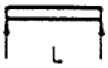
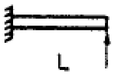
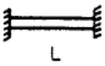
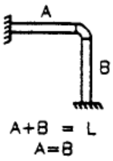
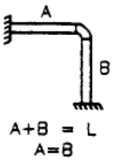
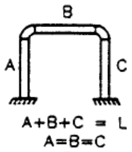
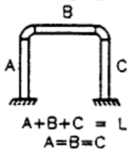
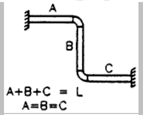
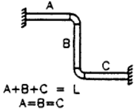
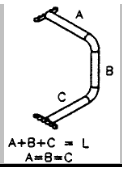
- It is more common to measure piping vibration in velocity or displacement, not acceleration.
- The method is applicable to the first mode of vibration of cantilevered SBP only. Therefore the acceleration measurements must be filtered in a band around the first MNF.
- The vibration measurement must be taken at the center of mass of the concentrated mass.

4.3. ASME OM-S/G-2003 Guideline

This standard for nuclear power plants describes a method for determining an allowable displacement limit, for steady-state vibrations, based on SBP configuration, length, and diameter [4]. It also has a non-mandatory Appendices for determining allowable velocity levels, and describes a method for determining an allowable acceleration limit for cantilevered small bore piping, which is similar to the method described by Woodside Energy.

While this standard does go into some detail about how to calculate the allowable displacement limit, the paper "Displacement Method for Determining Acceptable Piping Vibration Amplitudes" [6] presents a simpler and more comprehensive method for determining an acceptable vibration limit, based on ASME OM-S/G-1991. This older version of the standard is still substantially the same, for the purpose of calculating an allowable displacement limit.

Table 3: Allowable vibration factor

Configuration	Diagram	K_a
Fixed-Free		0.0569
Simply Supported		0.0203
Fixed-Supported		0.00979
Fixed-Fixed		0.00710
L-Bend, Out-of-Plane, Equal Leg Length		0.0110
L-Bend, In-Plane, Equal Leg Length		0.00267
U-Bend, Out-of-Plane, Equal Leg Length		0.00746
U-Bend, In-Plane, Equal Leg Length		0.00555
Z-Bend, Out-of-Plane, Equal Leg Length		0.00592
Z-Bend, In-Plane, Equal Leg Length		0.00591
3D-Bend, Equal Leg Length		0.00523

4.4. ASME OM-S/G-1991 (EDI Paper)

This method [6] is recommended by the author for calculating an allowable displacement limit for piping, including SBP. The allowable vibration amplitude, Y_{all} (mil peak-to-peak or micron peak-to-peak), for different configurations of pipe is defined by:

$$Y_{all} = K_a \frac{L^2}{D}$$

L is the pipe length (in or mm), D is the pipe actual outer diameter (in or mm), and K_a is a factor based on the pipe configuration for the first vibration mode shape (Table 3 above). K_a is calculated by dividing the maximum allowable un-intensified dynamic stress range of 3000 psi peak-to-peak (20.7 MPa peak-to-peak) by the deflection stress factor, K_d, found in Ref. [6]. Y_{all} can be compared to vibration measurements, presented as either spectrum or time domain waveforms (the latter, as long as relative motion is measured; refer to section 6.3).

To convert this allowable deflection limit into an allowable velocity limit, V_{all} (in/s peak or mm/s peak), use the following formula:

$$V_{all} = Y_{all} \frac{f_{meas}}{318.31}$$

f_{meas} is the measured MNF of the first vibration mode shape of the small bore piping (Hz).

4.5. Multiple Vibration Modes

In the case where multiple mode shapes are excited by the mainline piping (i.e., the operating deflected shape (ODS) is a combination of k different modes), the allowable vibration is defined by:

$$\sum_{i=1}^{k} \frac{Y_i}{Y_{iall}} \le 1$$

Y_i is the measured vibration amplitude for mode i, and Y_{iall} is the allowable vibration amplitude for mode i (mil peak-to-peak or mm peak-to-peak). This assumes:

- The frequency of vibration of a mode is not an integer multiple of any another mode.
- The location of highest vibration amplitude occurs at the same point for all modes.
- The location of highest stress occurs at the same point for all modes.

The example of two modes being excited is shown in Figure 4. In this example, there is low frequency vibration that is in-phase with the mainline piping and has the same amplitude. This vibration can be ignored, because it does not cause significant stress.

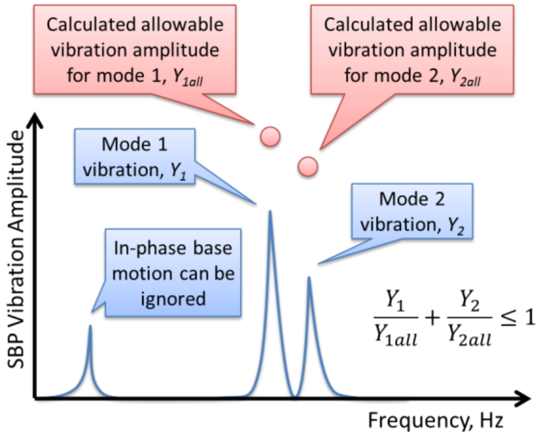


Figure 4. Multiple vibration mode example

5. Recommended Design Approach

The recommended design approach for evaluating SBP is to use one of the design guidelines described by the EI (section 3.2) or GMRC (section 3.3). For small bore connections that appear high risk, a detailed FEA can be conducted.

5.1. Finite Element Analysis

The goal of a detailed FEA at the design stage is to estimate the MNF of the SBP and calculate an allowable deflection limit, for use during field evaluations. Note that it is not possible to estimate the stress in the small bore piping at the design stage because the base motion of the mainline piping is typically not known. However, the stress (at the connection) per deflection (on the SBP) can be calculated.

5.1.1. Scope of Model

Some of the mainline piping is required to accurately model the SBC. As a start, at least one diameter of mainline piping should be used, upstream and downstream of the connection. In some cases, significant shell vibration occurs with the small bore vibration, especially for thin-walled mainline piping.

The FEA model must be accurate enough to calculate the MNF of the SBP (typically within +/-10%) and to estimate the stress near the SBC. There are several methods available for estimating the stress near a weld using the hot spot stress technique; one is described in Ref. [7].

5.1.2. Damping

The damping on SBP is typically only material damping. The critical damping ratio is usually between 0.5% and 2%, and can be measured during an impact (bump) test.

Damping is an important consideration because most SBP are excited at their resonant frequencies.

5.1.3. Stress per Deflection Evaluation

Most failures on SBP occur near the connection point to the mainline piping. The crack can occur in the mainline piping or in the SBP, but typically the latter. Estimating the stress at the connection is required to calculate the allowable deflection limit.

The relationship between the deflection of the SBP and the stress at the connection depends on the actual field-measured operating deflected shape (ODS). While the actual ODS can be simulated using FEA (using base excitation), there are some alternative methods for determining a relationship between deflection and stress:

1. **Base excitation**. This is when the mainline piping in the FEA model is excited at a certain frequency or with broadband vibration. This method most closely resembles the ODS of the SBP, but it is also the most computationally intensive. Additionally, base motion of the mainline piping is rarely known at the design stage.

2. **Mode shape**. This method makes the assumption that the ODS resembles the vibration mode shape (eigenvector) of the SBP. It is the method used in Ref. [4], [5] and [6]. This method is very quick and accurate, except in the case where multiple SBP modes are excited by the mainline piping vibration. In that case, the procedure described in section 4.5 can be used.

3. **Acceleration load**. This method applies an acceleration load (e.g., gravity) to the SBP to get a deflected shape. This method is not recommended, except when considering vibration due to transient motion of the mainline piping, or deflection due to quasi-static loads like seismic.

4. **Point load**. This method applies a load or deflection at a location (typically at the anti-node, or point of highest deflection) to get a deflected shape. This method is not recommended (because it can be non-conservative when compared to base excitation). It can be used to model static loads due to thermal expansion, for example.

5.1.4. Allowable Deflection Calculation

Once the stress per deflection is calculated, the allowable deflection can be calculated by using an allowable stress (typically the endurance strength which is based on weld type). The MNF of SBP is high enough that failure usually occurs in hours or days. Therefore, the SBC must be designed for infinite life, except in the case of transient vibrations (section 6.6).

6. Recommended Field Approach

The recommended field approach for evaluating SBP is the following:

1. Take velocity measurement on SBP at the anti-node location (i.e., location of highest vibration) and compare it to a screening guideline. Use relative vibrations (Section 6.3), if possible, or else simply add the SBP vibration and mainline piping vibration. If under guideline, the vibration is acceptable. If over guideline, go to step 2.

2. Compare vibration measurement to a geometry-based guideline, like ASME OM-S/G. This will require either converting vibration measurements to displacement or measuring the MNF of the SBP (to convert the guideline to velocity). If under guideline, the vibration is acceptable. If over guideline, go to step 3.

3. Compare vibration measurement to a guideline based on FEA using either the base excitation or mode shape method. If under guideline, the vibration is acceptable. If over guideline, go to step 4. If the transient vibration is over guideline and the steady-state vibration is under guideline, then do a fatigue life calculation (Section 6.6).

4. Modify the SBP by either bracing, reinforcing the connection (e.g., gusseting), removing or moving the SBP, or replacing concentrated masses like valves with shorter and lighter styles.

6.1. Impact Test

If the vibrations cannot be measured because the unit is not running (e.g., during a shop inspection), then the MNF can be measured using an impact (bump) test, and compared to the GMRC guideline (Table 1). The SBP MNFs should be kept at least 10% away from known significant excitation forces. Additionally, it is recommended that the MNF of SBP that can be excited by horizontal vibrations of the reciprocating compressor cylinders (or pump plungers) are above the horizontal natural frequency of the cylinders, which is typically 300 Hz and below.

6.2. Worst Case Operating Conditions

It is unlikely that the operating conditions present during the vibration audit are the worst case the piping system will see. To compensate for this, take measurements at several operating conditions (e.g., rotating machinery speed, loading, pressure, flow rates). If this is not possible, then pro-rate the vibration measurements based on the expected worst case operating conditions. This can be done by calculating the ratio of pulsation-induced shaking forces at the as-found condition and the worst case condition, for example.

6.3. Relative Vibration

The vibration of the SBP relative to the mainline piping is the only vibration of interest, as it is the vibration that causes stress. In most cases, this relative vibration is highest at the SBP MNF. If the SBP is moving at the same amplitude and in-phase with the mainline piping, then the stress on the connection will be very low. The mainline piping vibration can be subtracted out from the vibration of the small bore piping (either using software or hardware). In some cases, the effect of the rotational vibration of the mainline piping must be subtracted out, also.

If the mainline piping vibration is low compared to the SBP vibration (i.e., 10% of the SBP vibration, or 0.1 in/s peak, whichever is lower) then it can be ignored. If the phase between the SBP and mainline piping vibration cannot be determined, they can be added together, as a conservative estimation of the SBP vibration. (At resonance, the phase between the mainline piping and the SBP vibration is 90°).

6.4. Coordinate Systems

The naming convention for SBP coordinate systems is a smaller issue, but can be important when many connections are being audited. One useful system is shown in Figure 5, which references SBP directions relative to the mainline piping it is connected to. These direction names (T/R/P) are different from the standard Horizontal/Vertical/Axial or X/Y/Z, and therefore help reduce confusion.

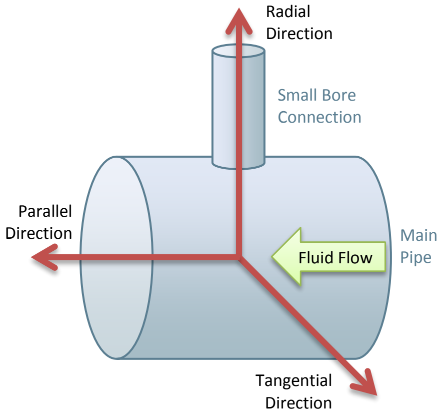


Figure 5. Small bore connection coordinate system

6.5. Pipe Strain

Pipe strain is strain introduced into piping systems due to misalignment and static deflections. It can be seen when pipe clamps are loosened and piping moves away from the clamped position, revealing gaps. It cannot be totally eliminated because piping is deflected during normal operation due to temperature and pressure. However, it is recommended that all pipe strain be removed at the installation (ambient) temperature by shimming with metal (or compliant) shims and comparing flange misalignment to standards such as ASME B31.3.

Pipe strain affects piping in several ways. It increases the MNF of the piping. It increases the vibration response of the SBP (speculated due to a reduction in damping). It also introduces mean stresses into the SBC which lowers the remaining allowable endurance strength. This can be quantified using a Goodman or Soderberg diagram.

It is recommended to post-weld heat treat critical SBCs to reduce the residual weld stress. This will tend to increase the allowable vibration of the SBP before fatigue failure occurs.

6.6. Transient Vibrations

Transient vibrations on SBP typically occur during events like changing operating conditions, other units coming online, normal start-up and shutdown, emergency shutdown, and valve operation (e.g., control valves or pressure relief valves). It is challenging to measure vibrations during these events without specialized equipment and using many vibration sensors. However, these short term events are important since they can affect the fatigue life of the SPC. If transient vibrations are significant, compared to steady-state vibrations, it is recommended fatigue life calculations be done, using Miner’s rule.

7. Mitigation

The simplest method for dealing with high risk SBCs is to remove the connection altogether. Redundant connections and connections that can be isolated (e.g., double block and bleed valves) are typically installed to increase the reliability of a piping system, but can actual decrease the reliability if they become a high fatigue-failure risk.

High risk SBP can be moved to a location with lower base excitation. An example would be to move a pressure safety valve (PSV) from the top of a suction pulsation bottle to the shell of the scrubber (and brace the PSV back to the scrubber shell) or on to the piping upstream of the scrubber.

If detailed information is known about the small bore connection MNF and the excitation frequency, the SBP can be detuned by adding mass. This will lower vibrations of the SBP by separating the SBP MNF from the excitation frequency by at least 10%.

High risk SBP that cannot be removed, moved, or redesigned can be braced. A brace is most effective when the brace is parallel to the direction of vibration. The brace stiffness is significantly affected by the stiffness of the weakest (i.e., most flexible) part, therefore, good connection and fit is required for a brace.

8. Summary

SBP can be a significant integrity risk on a piping system. A methodology is required to evaluate SBP during the design, fabrication, and commissioning of machinery and piping systems. The recommended evaluation procedure, outlined in this paper, is shown in Table 4 .

9. References

1. Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework, 2nd Edition, Energy Institute, January 2008.

2. Vibration Related Failures of Small-Bore Attachments, B. C. Howes & C. B. Harper, Gas Machinery Conference, October 2003.

3. Design Guideline for Small Diameter Branch Connections, Releases 1.0, Gas Machinery Research Council, March 2011.

4. Standards and Guides for Operation and Maintenance of Nuclear Power Plants, ASME OM-S/G-2003, January 2004.

5. Fatigue of Cantilevered Pipe Fittings Subjected to Vibration, M. Hamblin, Woodside Energy, April 2003.

6. Displacement Method for Determining Acceptable Piping Vibration Amplitudes, J. C. Wachel, Engineering Dynamics Incorporated, 1995.

7. Unfired Pressure Vessels - Part 3: Design, BS EN 13445-3:2009, July 2009.

Table 4. Small bore piping evaluation procedure

DESIGN STAGE

- Evaluate SBP using EI robustness evaluation or GMRC MNF calculation
- Use FEA to evaluate high risk SBP
- Remove, relocate, redesign (or brace) high-risk SBP (same for Fabrication and Operation stage)

FABRICATION STAGE

- Inspect SBP for adherance to best practices, welding procedures, and appropriate fitting selection
- Measure SBP MNFs using shop impact (bump) test and compare to industry guidelines (same for Operation stage)

OPERATION STAGE

- Measure SBP vibrations and MNFs and compare to screening or other industry guidelines
- Measure vibration of SBP relative to mainline piping vibration
- Consider worst case operating conditions by varying speed, loading, pressures, flow rates or pro-rate measurements
- Consider transient vibrations and effect on fatigue life
- Consider effect of pipe strain on vibration measurements