Table E.4: Method of calculating F_v (continued)

Support arrangement	Range of outside diameter	F_v	α	β
Flexible	60 mm to 219 mm	$\exp[\alpha(D_{ext}/T)^{\beta}]$	$1{,}32*10^{-5} D_{ext}^2 - 4{,}42*10^{-3} D_{ext} + 12{,}22$	$2{,}84*10^{-4} D_{ext} - 4{,}62*10^{-7} D_{ext}^2 - 0{,}164$

Note: $\exp[z] = e^z$

E.2.3.5 Calculation of likelihood of failure (LoF)

The LoF for flow-induced turbulence is then determined by the equation:

$$\text{Flow induced turbulence LoF} = \frac{\rho v^2}{F_V}\text{FVF} \tag{8}$$

Where ρv^2 is determined in E.2.3.1, fluid viscosity factor (FVF) is defined in E.2.3.2. The flow-induced vibration factor F_v is defined in E.2.3.4.

An additional check which can be undertaken on each control valve in the system is to assess the level of fluid kinetic energy at the trim exit. This should be 480 kPa or less for continuous service single-phase fluids, and 275 kPa or less for multi-phase fluids (where the kinetic energy in kPa is given by $\rho v^2/2\,000$, ρ is the fluid density in kg/m^3, and v is the velocity of the fluid exiting the valve trim in m/s).

E.2.4 ADDITIONAL CORRECTION FOR FLEXIBLE PIPING

E.2.4.1 Overview

This advanced screening approach is only relevant for pipes having a natural frequency greater than 1 Hz and less than or equal to 3 Hz. This is particularly relevant where the LoF from flow-induced turbulence is greater than or equal to 1,0, as calculated using the standard assessment method described in E.2.3.5. This is necessary because the flow-induced turbulence LoF for flexible pipes is very sensitive to the fundamental natural frequency.

The method detailed in E.2.3 for pipework with a flexible support arrangement, assumes a fundamental natural frequency of the pipe span of 1 Hz. In a number of cases, the actual fundamental natural frequency of a flexible pipe span may be significantly higher, and in such a situation the method given in E.2.3 may be too conservative.

In certain situations, depending on the local configuration of the pipe and its support arrangement, the method may not be conservative. If there is any uncertainty regarding the application of this method then specialist advice should be sought.

E.2.4.2 Calculation method

Determining flow-induced-vibration factor, F_v:

F_v is a flow-induced vibration factor dependent on the actual outside diameter of the pipe D_{ext} (mm), the wall thickness T (mm) and the fundamental natural frequency f_n.

The following is valid for flexible pipe spans with structural natural frequencies (f_n) ranging from 1 Hz to 3 Hz.

For pipework with nominal bore between 273 mm to 762 mm (i.e. greater than or equal to 10 inch nominal):

$$F_v = \alpha\left(\frac{D_{ext}}{T}\right)^{\beta} \tag{9}$$

where:

$\alpha = (41{,}21D_{ext} + 49\ 397)(f_n^{\ 0{,}0001665D_{ext} + 0{,}84615})$

$\beta = 0{,}0815\ln(D_{ext}) - 1{,}3842 + 0{,}0191(f_n - 1)$

For pipework with nominal bore less than 219 mm (i.e. between 2 to 8 inch nominal):

$$F_v = \exp\left[\alpha\left(\frac{D_{ext}}{T}\right)^{\beta}\right] \tag{10}$$

where:

$\alpha = (1{,}3175*10^{-5}D_{ext}^{\ 2} - 4{,}4213*10^{-3}D_{ext} + 12{,}217)(0{,}0529\ln(f_n) + 1)$

$\beta = (-4{,}622*10^{-7}D_{ext}^{\ 2} + 2{,}835*10^{-4}D_{ext} - 0{,}164)(-0{,}1407\ln(f_n) + 1)$

The fundamental natural frequency f_n of the pipe can be determined via site measurements on existing plant or calculated once detailed isometric drawings are available on a new design.

Determining the LoF:

The LoF due to flow-induced turbulence for main pipe is calculated using:

$$\text{Advanced Screening Flow Induced Turbulence LoF} = \frac{\rho v^2}{F_v}\text{FVF} \tag{11}$$

where ρv^2 is determined in E.2.3.1, FVF is defined in E.2.3.2. The flow-induced vibration factor F_v is defined in E.2.4.2.

The resulting LoF value may then be substituted for the standard assessment LoF.

E.2.4.3 Limitations of the advanced screening method

Extreme care needs to be taken with such an assessment because the method relies heavily on knowing the fundamental natural frequency of the pipe. Once detailed isometric drawings are available then an initial assessment of the fundamental natural frequency of the line can be undertaken.

E.2.5 MODIFICATION FOR SOURCE TYPE (SINGLE PHASE FLUIDS ONLY)

E.2.5.1 Introduction

The previous methodology for flow-induced turbulence (FIT) screening, in E.2.3 as taken from EI *Guidelines for avoiding vibration-induced fatigue failure in process pipework*, is for a 'worst case' turbulent source located mid span, irrespective of the true situation. For instances where the only turbulent sources in a piping system are well separated, long radius (i.e. bend radius/pipe diameter ≥1,5) 90 degree bends, which is representative of a number of subsea piping systems as found on PLEMs and FTAs, this methodology is overly conservative and the use of a correction factor can be justified. Note that this correction only applies to single phase gas (defined here as a gas where the no-slip liquid hold up <0,01) or liquid systems; it does not apply to multi-phase fluids.

E.2.5.2 Derivation of correction factor

Based on the data given in Norton and Bull (1984), a correction factor has been derived for a long radius bend. This correction factor is found to vary between 0,129 and 0,416 depending on Strouhal number, but an approximate value can be determined as follows:

Correction factor (CF) = aΩ + b (12)

where:

$$\Omega = (2\pi f r_i) / U$$

U = mean flow velocity (m/s)

f = pipe fundamental natural frequency (Hz)

r_i = internal radius of pipe (m)

a and b are defined in Table E.5.

Table E.5: Coefficients

Ω	a	b
$0,1 < \Omega \leq 4,0$	0,07359	0,12164
$4,0 < \Omega \leq 10,0$	−0,01383	0,47133

Note that if $\Omega < 0,1$ then CF = 0,129, and if $\Omega > 10$ then CF = 0,333.

The corrected LoF score is then obtained using:

$$LoF_{LR\ bend} = LoF \times CF \tag{13}$$

Note that this correction applies to piping which has no other turbulent sources other than long radius bends, where the bends are separated by at least 10 pipe diameters. Note also that the correction factor will vary between 0,129 to a maximum of 0,416 depending on Strouhal number.

E.3 PULSATION: FLOW-INDUCED EXCITATION

E.3.1 Extent of excitation

The mechanism considered is that due to gas flow past a branch with a closed end (a dead leg branch off the main line). It can occur in gas systems where the void fraction (gas volumetric flow rate/mixture volumetric flow rate at actual conditions) ≥0,95. The pulsations caused can propagate upstream and downstream from the side branch to the first major change in main pipe diameter.

Note: A major change is defined as a pipe diameter change by a factor of 2 or more (e.g. a vessel or significant expansion/reduction).

The excitation characteristics can change under certain operations (e.g. flow rate), and the acoustic modes are affected by changes in pressure, temperatures and molecular weight. Therefore, the anticipated range of operating conditions should be considered as part of the assessment.

E.3.2 Input

Table E.6: Information requirements

Input	Symbol	Units	Comment
Speed of sound in gas	c	m/s	
Internal diameter of branch	d_{int}	mm	
Internal diameter of main line	D_{int}	mm	
Length of side branch	L_{branch}	m	
Reynolds Number	R_e		Refer to Annex I for definition of characteristic dimension and calculation method
Mean fluid velocity in main pipe	v	m/s	
Gas density	ρ	kg/m^3	

E.3.3 Calculation of likelihood of failure (LoF)

The assessment method allocates a main line LoF score for each side branch on the main line. The highest LoF score from all the side branches on the main line should then be used as the representative LoF score for the main line itself.

The simplified screening analysis given in Figure E.3.1 does not strictly apply if the side branch geometry is complex (i.e. the side branch itself is not a single line from the main line to the closed end). A typical example would be a relief line that divides to feed two or more relief valves. In such cases, a detailed analysis, 3.3.4, should be conducted to accurately determine the acoustic natural frequencies of the side branch (i.e. F_s).

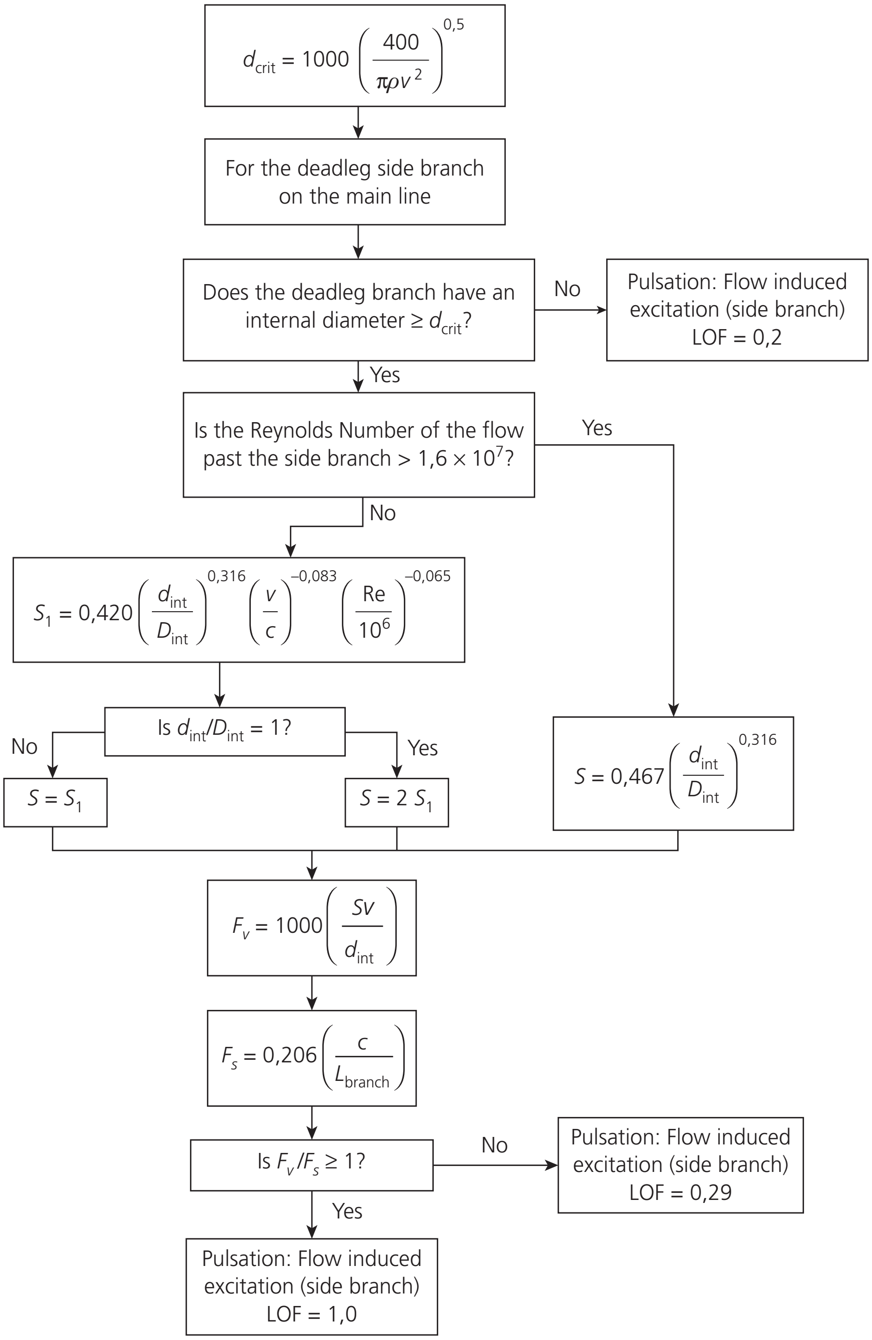

Figure E.3.1: Pulsation: Flow-induced excitation assessment

Note: For each side branch that scores an LoF = 1,0 it is recommended that a more detailed analysis as described in section 3.3.4 is undertaken.

E.4 FLIP FROM ROUGH BORE RISERS/JUMPERS

E.4.1 Extent of excitation

The mechanism considered is that due to dry gas flow over the internal corrugations of a rough bore flexible riser or jumper. Vorticity in the boundary layer generates small pressure pulsations. These can be amplified if the pulsation frequency is close to an acoustic natural frequency of the connected pipework system and lock-on occurs.

Research (Swindell et al 2007 and Belfroid and Swindell 2009) and experience have shown that pressure pulsations are only excited when gas velocity in the flexible exceeds a minimum value called the 'onset velocity'. There are usually so many acoustic natural frequencies associated with a 'typical' process system that, as long as the gas velocity is above the onset velocity, noise will continue to be generated, no matter how high the gas velocity. This phenomenon only occurs with dry gas and FLIP is typically suppressed if the ratio of liquid volume to actual gas volume is greater than 0,1 %.

E.4.2 Input

Table E.7: Information requirements

Input	Symbol	Units	Comment
Speed of sound in gas	c	m/s	
Upstream acoustic reflection coefficient	*R1*	m	At end of flexible – if unknown then a conservative value of 1,0 should be used
Downstream acoustic reflection coefficient	*R2*	m	
Gap width	*W*	m	See Figure E.4.1
Downstream edge radius	r_2	m	Relative to gap, see Figure E.4.1
Length of plateau	*L*	m	See Figure E.4.1
Gas dynamic viscosity	μ	Pa.s	
Gas density	ρ	kg/m³	

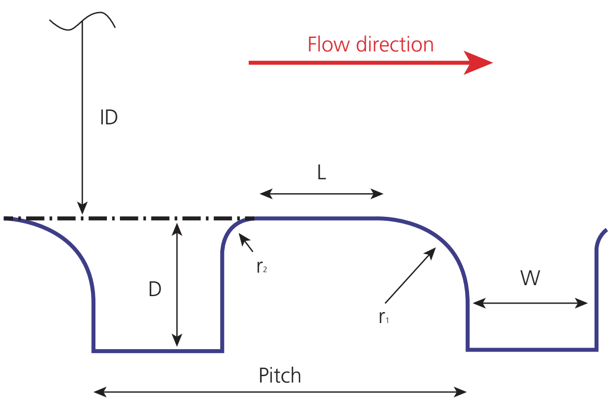

Figure E.4.1: Carcass geometry

E.4.3 Methodology

E.4.3.1 Screening assessment

Flow-induced pulsation may be an issue if all of these aspects are true:

- Rough bore flexibles are used (including flowlines, risers, subsea and topsides jumpers).
- The flexible is carrying dry gas (where the liquid content <0,1 % by volume, defined as the liquid volumetric flow rate/gas volumetric flow rate at actual conditions).
- The expected (maximum) gas velocity through the flexible is above the onset velocity.

E.4.3.2 Calculation of onset velocity

The onset velocity is calculated using the equation:

$$\text{onset velocity (m/s)} = \frac{8c \quad C1}{[|R1| + |R2|]} \tag{13}$$

where:

$$C1 = 1{,}54 \quad 10^{-3} \left[\frac{2 \quad 10^{-3}}{1{,}15W}\right]^2 \frac{\mu/\rho}{1{,}15 \quad 10^{-7}} \frac{[0{,}85(L + 0{,}1 \quad 2\pi \quad r_2)]}{15{,}56 \quad 10^{-3}} \tag{14}$$

If the orientation of the carcass is unknown then the onset velocity should be calculated for both directions and the lowest value taken.

Note: The prediction of onset velocity incorporates a conservative factor (0,85) to account for uncertainty associated with the true carcass geometry.

E.4.4 Determination of likelihood of failure (LoF)

The LoF score is obtained as follows:

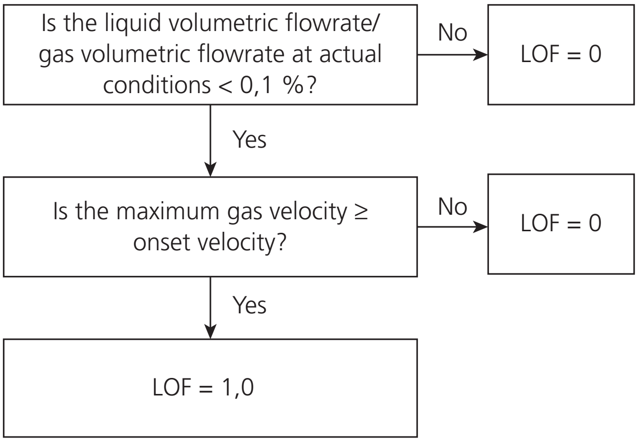

Figure E.4.2: Determination of LoF

E.5 HIGH-FREQUENCY ACOUSTIC EXCITATION

E.5.1 Extent of excitation

The response caused by high-frequency acoustic excitation affects the pipework downstream of the source to the first major vessel, e.g. separator, KO drum.

The assessment generates a main line LoF value at each welded discontinuity, e.g. SBC, welded tee, welded support. It is at the discontinuities with an LoF equal to one where corrective actions are required.

The sources of high-frequency acoustic excitation are pressure-reducing devices such as control/relief valves, restriction orifices, or branch connections.

E.5.2 Input

Table E.8: Information requirements

Input	Symbol	Units	Comment
External diameter of the main line	D_{ext}	mm	
External diameter of the branch	d_{ext}	mm	
Internal diameter of the main line	D_{int}	mm	
Distance between source and the welded discontinuity	L_{dis}	m	
Molecular weight of gas	Mw	grams/mol	Refer to Annex I for typical values
Pressure upstream of pressure-reducing device	P_1	Pa absolute	
Pressure downstream of pressure-reducing device	P_2	Pa absolute	
Wall thickness of the main line	T	mm	
Wall thickness of the branch	t	mm	
Upstream temperature	Te	K	
Mass flow rate	W	kg/s	

E.5.3 Calculation of likelihood of failure (LoF)

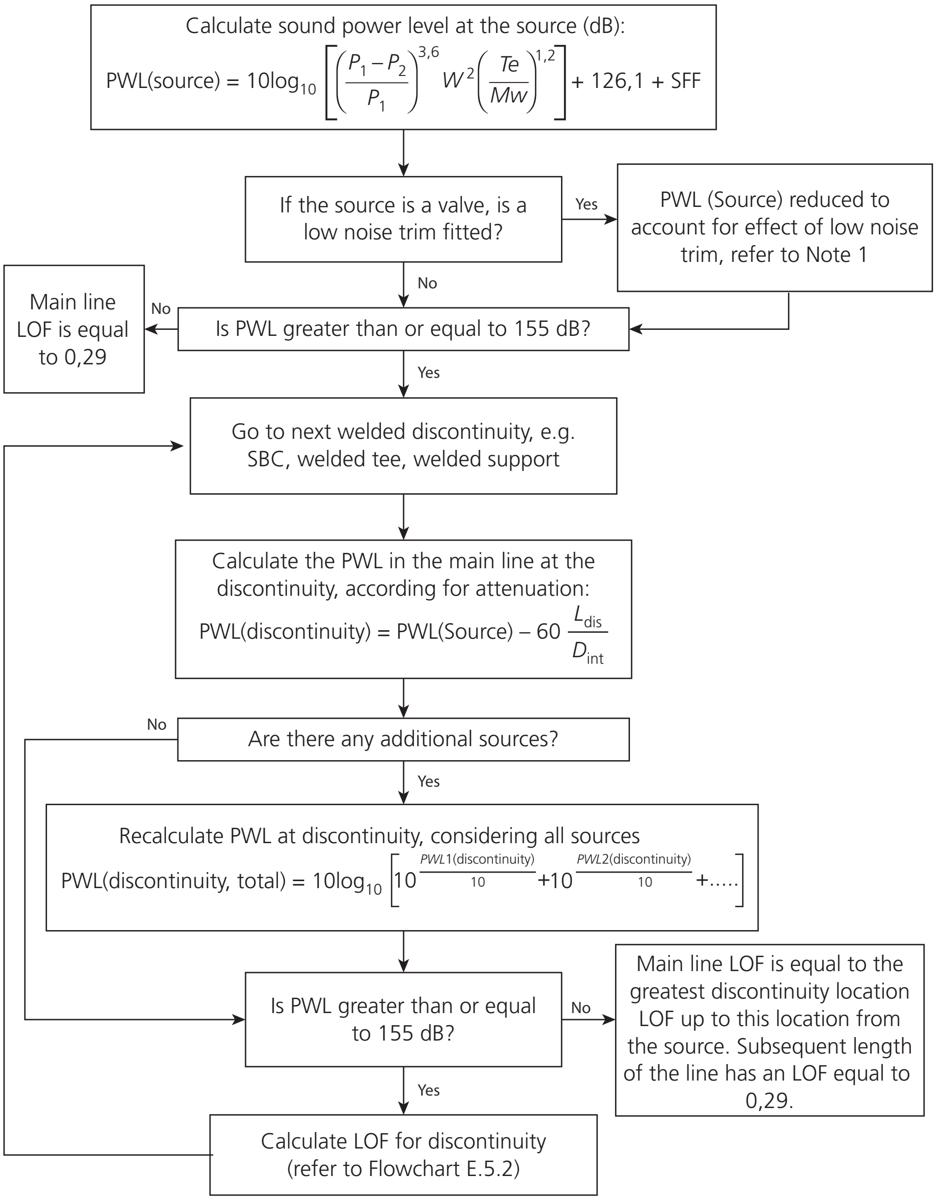

Figure E.5.1: High-frequency acoustic fatigue assessment

Where PWL is the sound power level:

PWL1 (discontinuity) = PWL at the discontinuity due to source 1

PWL2 (discontinuity) = PWL at the discontinuity due to source 2

SFF is a correction factor to account for sonic flow. If sonic conditions exist then SFF = 6; otherwise SFF = 0.

Note 1: If the source is a valve and a low noise trim is fitted then the PWL (source) should be reduced in line with data supplied by the valve manufacturer. For example, if the low noise trim reduces the sound power level by 15 dB, then this value should be subtracted from the calculated sound power level. When using this method, the source sound power level (PWL) supplied by the valve manufacturer must not be used.

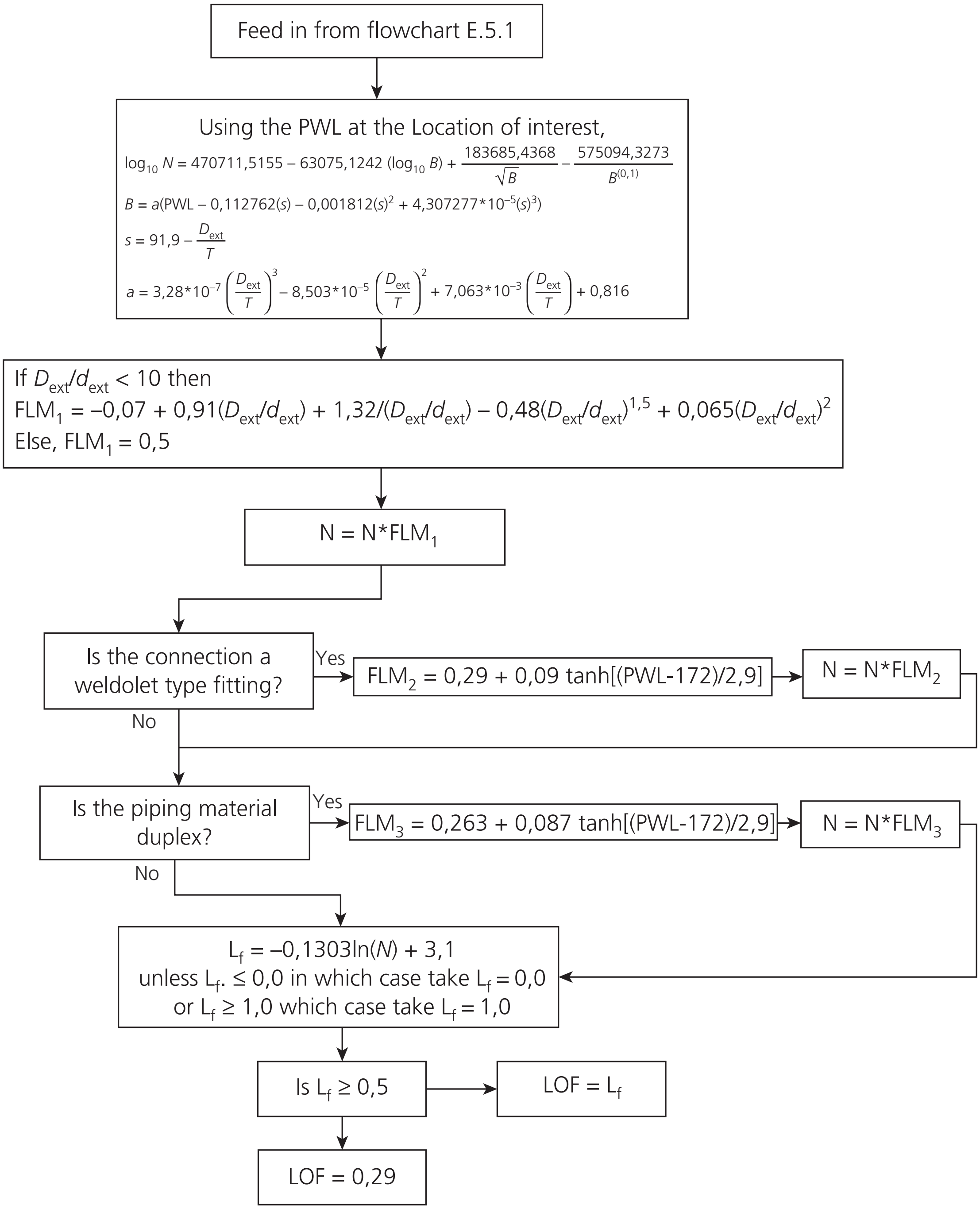

Figure E.5.2: High-frequency acoustic fatigue assessment (determining individual welded discontinuity LoF)

where:

N is the number of cycles to failure,

FLM is the fatigue life multiplier for stage *i*

PWL is $PWL_{(discontinuity,\ total)}$ calculated in Figure E.5.1

E.6 SURGE/MOMENTUM CHANGES DUE TO VALVE OPERATION

E.6.1 Overview

The first step in the assessment process involves identifying all the significant valves on a particular line. Excitation due to surge and momentum changes is only considered for fast-acting valves, which excludes all manually operated valves. Typical automatic valves that need to be considered in the assessment include:

- emergency shut down valves (ESD);
- flow control valves (FCV);
- pressure control valve (PCV);
- blow down valves (BDV), and
- relief valves (RV).

The assessment of excitation due to surge and momentum changes can be split into the three operational cases:

- dry gas valve opening;
- liquid or multi-phase valve closure, and
- liquid or multi-phase valve opening.

For a dry gas, any potential surge pressure due to a rapid valve closure is taken up via compression of the gas; hence, the LoF due to a gas valve closing is considered negligible. Therefore, the LoF for this operation is zero. The assumption is made that the line is adequately supported for any reaction loads and that any anchors have significant strength.

E.6.1.1 Extent of excitation: liquid or multi-phase valve closure

The main line LoF value predicted in section E.6.3 should be applied to the entire main line length upstream of the valve, up to the next major vessel or significant pipe diameter change ('L' in Table E.9) and up to two partial or full pipe supports downstream of the valve (not spring hangers or constant load supports).

E.6.1.2 Extent of excitation: liquid or multi-phase valve opening

The main line LoF value predicted below should be applied to up to two partial or full pipe supports both upstream and downstream of the valve (not spring hangers or constant load supports). During this type of valve operation, there is a likelihood of cavitation and flashing and assessments detailed in Annex E.7 are required.