1.0 Introduction

This tutorial discusses using Salad software to check your piping system for Acoustically Induced Vibration (AIV). It does not present a comprehensive overview of the phenomenom; for that the reader is referred to References 1 and 2. Two means of checking are available – the D/t method and the Energy Institute Guidelines method.

2.0 Brief Description of Problem

Acoustically induced vibration refers to structural vibration excited by intense pressure fluctuations in a compressible flow stream. Process plants have a number of requirements for abrupt pressure reductions, which invariably generate some amount of acoustic vibration. This is normally accomplished by a throttling valve or orifice such as

Fig. 1 - Relief valves can produce high AIV

- Blowdown valves & restriction orifices
- Relief valves
- Pressure reducing valves
- Compressor recycle valves

The pressure reduction process induces turbulent pressure fluctuations in the flowing medium which in turn excite the downstream pipe wall, causing stresses and potentially fatigue failure. The intensity of vibration tends to increase with mass flowrate, velocity and pressure loss. The accompanying sound radiation is typically broadband in the range of 200Hz to 20kHz with a peak somewhere above 1 kHz.

AIV failures are known to occur preferentially at non-axisymmetric discontinuities in the downstream piping such as small bore branches and welded supports. ('Axisymmetry' means symmetry around the longitudinal axis, such as with a flange or an encirclement sleeve).

3.0 Design Approach

It should be borne in mind that 'Prevention is better than cure', ie sound power reduction at source is the safest way to reduce the likelihood of a failure. Such approaches to the problem include dividing the flow into two or more streams, staging the pressure drop over multiple valves, limiting the flowrate if acceptable and using special noise-reducing valve trims.

3.1 D/t Method

The 'D/t' or Eisinger Method (Reference 1) is perhaps the most common method in use for checking piping against acoustic fatigue, comparing the D/t ratio of piping against design limits empirically derived as a function of Sound Power Level (PWL). Lower D/t ratios can withstand higher PWL's. The PWL is normally calculated using the following semi-empirical relationship , as presented in References 1& 2.

$$PWL = \ 10\log\left(\left(\frac{\Delta P}{P_1}\right)^{3.6} W^2 \left(\frac{T_1}{M}\right)^{1.2}\right) + 126.1$$

Where

PWL is the sound power level in dB (with reference power of 10^{-12} W)
P_1 is the upstream pressure of the source
ΔP is the reduction in pressure, in consistent units to P_1
T_1 is the upstream temperature of the pressure letdown source in Kelvins
W is the gas flow in kg/s
M is the molecular weight in kg/kmol

The Sound Power Level is usually assumed to decay as it travels in the direction of flow at a rate of 3dB per 50 internal diameters of pipe. This implies that after the flow moves from a branch into a larger diameter header, the decay rate with distance reduces. In this manner the decay process might be thought of as being of similar nature to friction head loss. Some companies take this analogy further by assuming that fittings in the line add an 'equivalent length' which further reduces PWL (this option is not currently available in Salad). Evaluation usually stops at the point where the flow enters a large vessel.

The allowable PWL is calculated as per the equation below

$$PWL_{allowed} = 173.6 - 0.125 \ D_i/t$$

The equation includes a 3 decibel safety margin, which is equivalent to a safety factor of 2 on sound power in watts. Note that internal diameter is used in the equation as per the terminology listed in the original paper (Reference 1). It is apparent however from Table 2 of the paper that external diameter was used for most of the D/t ratios, but in any case the difference is very small when compared to the safety margin. The script has been modified as of version 1.20 of Salad to use the internal diameter (previously used external), so that it follows the author's terminology and the recently published non-mandatory Annex A of NORSOK L-002 (Reference 3).

If the high massflow rate occurs downstream of an occasionally used valve such as a PSV or blowdown valve, it may be acceptable to increase the acceptance limit by a number of decibels (5dB is suggested for PSV's in NORSOK, as long as certain 'design improvements' are implemented).   This would not be appropriate for continuous flow because AIV failures can occur within hours or days of operation.

It is up to you to determine whether this assessment method is suitable for your system. For instance, the methodology is based primarily on experience with carbon steel piping as initially researched in

Reference 2. It is not directly applicable for materials with significantly different properties such as titanium or non-metallic piping.

For high massflow rates it may turn out that this design method cannot define a required wall thickness – ie. failure is predicted for all D/t ratios. It may be possible to carry out finite element analysis to prove acceptability in such cases – this involves more specialised work which is beyond the scope of this tutorial.

NOTE: The vibration is not normally considered to travel significantly upstream of branch connections, however we are not aware of any rules addressing this matter. It would seem prudent to exercise caution, for instance by extending thicker walls for several diameters upstream of branches.
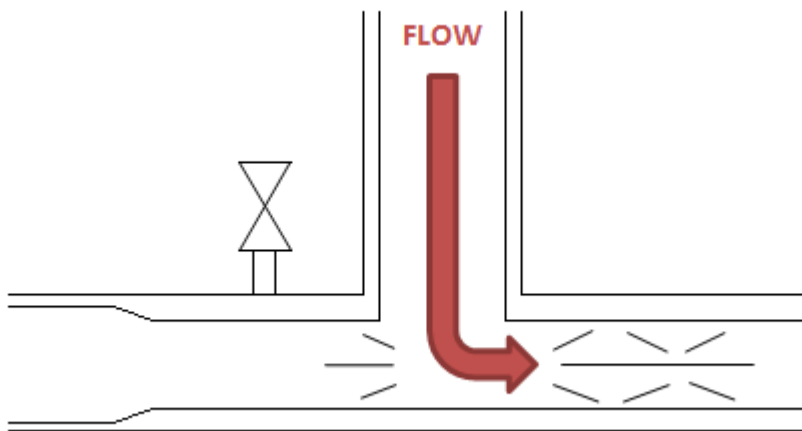

Fig. 2 – Extension of thicker wall upstream of a branch

3.1.1 The "Input Energy" Method
This method is also presented in Reference 1, however it has not gained the popularity of the D/t method. It is based on the pressure drop times the Mach number of the downstream flow, and thus relies on a figure which is not always easy to calculate accurately. It is not readily described in a single formula because the design curve is divided into three regions. We have found the method to be very conservative particularly for high set pressures and moderate massflow rates, and thus do not offer it as an option.

3.2 Energy Institute Guidelines Method
This method is described in section T2.7 of Reference 5. There is an apparent philosophical difference between the methods in that this approach checks only non-axisymmetric locations such as branches and welded attachments (but you could also choose to apply the same logic with the D/t method). There is of course a risk that if branches or attachments were required at some later date this could cause problems or might go unchecked.

The sound power level is calculated in the same manner as the D/t method, however it recommends adding 6dB to the PWL if sonic flow conditions exist. Our interpretation is that this refers to the fluid

velocity downstream of the noise source (not at the throat), although probably not including the reducer which is often immediately downstream of a valve.

The method first calculates a nominal number of cycles which a pipe can safely withstand, based on a detailed formula involving PWL and the D/t ratio (based on external diameter). The number of cycles is then multiplied by 3 reduction factors FLM_1, FLM_2 & FLM_3 which respectively account for branch diameter ratio, use of weldolets and duplex materials.

According to the EI Guidelines, for a given level of acoustic excitement a duplex pipe has a greater likelihood of failure than a 316SS pipe of identical dimensions. It is difficult to see the logic in penalising duplex in this manner. While a duplex pipe may have lower wall thickness than an equivalent carbon steel or 316SS system, it is already 'penalised' by the lower thickness in the EI calculations.

4.0 About the Salad Script

The Salad script 'AIV' takes a stress model of a piping system including one or more letdown valves, and calculates the wall thicknesses required for design against acoustic fatigue using either the 'D/t' or EI Guidelines method. It combines the effects of multiple valves if applicable and allows for decay with distance at a nominal 3dB per 50 diameters.

When using these methods it should be remembered to adhere to good practice for downstream velocity limitations (eg. see Reference 4) , to avoid generating additional intense fluctuations at tees and obstructions. These can become additional AIV sources and are NOT considered by the Salad script.

The stress model which you use for the analysis can omit certain details – you don't need to worry about temperatures and rigid weights for instance. Just ensure that your diameters, wall thicknesses (including corrosion allowances), pressures and dimensions are correct. You also don't need to run the static stress analysis. The EI guidelines method (see section 4.2) requires a little more information to be included in the model.

You define the sections to be analysed by listing 'source' nodes and a single 'sink' node. A pressure letdown valve is a source. You can address 'low noise trim' valves by specifying a number of decibels by which to reduce the calculated PWL.

A sink is where the fluid flows to, which may be the limit of your model or say the inlet to a flare drum. The script will only analyse piping on the paths from sinks to source, ignoring adjacent branches. It is up to you to determine appropriate thicknesses for these by applying some judgement and a little conservatism (eg. see Figure 2).

Note – Salad will only check the 'From' node of reducers. However the 'To' node will effectively be checked on the attached element if it has the same diameter and wall thickness (even if it is 'rigid'). The large end is generally more susceptible to AIV, eg. a 6" Sch 10S pipe has a D/t ratio of 49 compared to 37 for 4" Sch 10S.

4.1 Outline of Algorithm Used

The Salad script employs a simple algorithm to find a path from each source to the sink.

Binding Rules:

- Go from higher pressure to lower or same pressure. If we encounter a higher pressure, go back to the last branch (or source) we came from and go the other way.
- If we encounter the end of a line, a previous branch node or arrive back at the source, go back to the last branch and go the other way.
- If we find the sink, stop

Breakable Rule, for execution speed -

- Go from lower diameter to higher or same diameter if possible.

Assumptions:

- Only one path exists from source to sink. This would be true for the great majority of flare systems.   In any case only one path will be checked if more than one exists.
- Only one sink exists. An obvious exception is that of a flare drum having two inlet nozzles – in this case only one of the inlet nozzles should be chosen as sink and the resulting calculations would prove to be conservative. The thicknesses calculated for one branch would then be applied to the other.

After finding the path from each source to the sink, the script then calculates the PWL for each source and works out the PWL for each leg of the path, based on a decay rate of 3dB per 50 internal diameters (the corroded internal diameter is used).

The script then logarithmically adds the PWL from all sources to calculate a combined figure for each element. Under the D/t method it then computes the allowable PWL for each element based on its D/t ratio. The corroded thickness is used in the calculation but mill tolerance is ignored.

The actual PWL figure is compared to the allowable and where failure is predicted the output text is highlighted in red. The minimum required thickness is calculated if possible (with corrosion allowance added). No pressure checks are made so it is possible that the listed thickness is below the pressure design thickness; of course you must always stay greater than or equal to the Code required thickness.

4.2 Energy Institute Guidelines Method

This section covers the required modelling practices which are specific to the EI Guidelines method. The output of the script is a so-called likelihood of failure (LOF) for each element of the system.

Modelling of branches

 It is common practice in stress analysis not to model small bore branches, however to apply the EI method you must model at least one element of the small bore branch. This is so that Salad can calculate the branch diameter ratio correctly and thus the factor FLM_1.

At weldolet locations you must also model a SIF of type 'weldolet' or 'latrolet' for factor FLM_2 to be applied. Note that at the time of writing (July 2010), there is a bug in the CAESAR II data export for SIFs

– only the first SIF defined on a given element is exported to the XML file. You are therefore advised not to use the second SIF on elements in your model if planning to use the Salad AIV script.
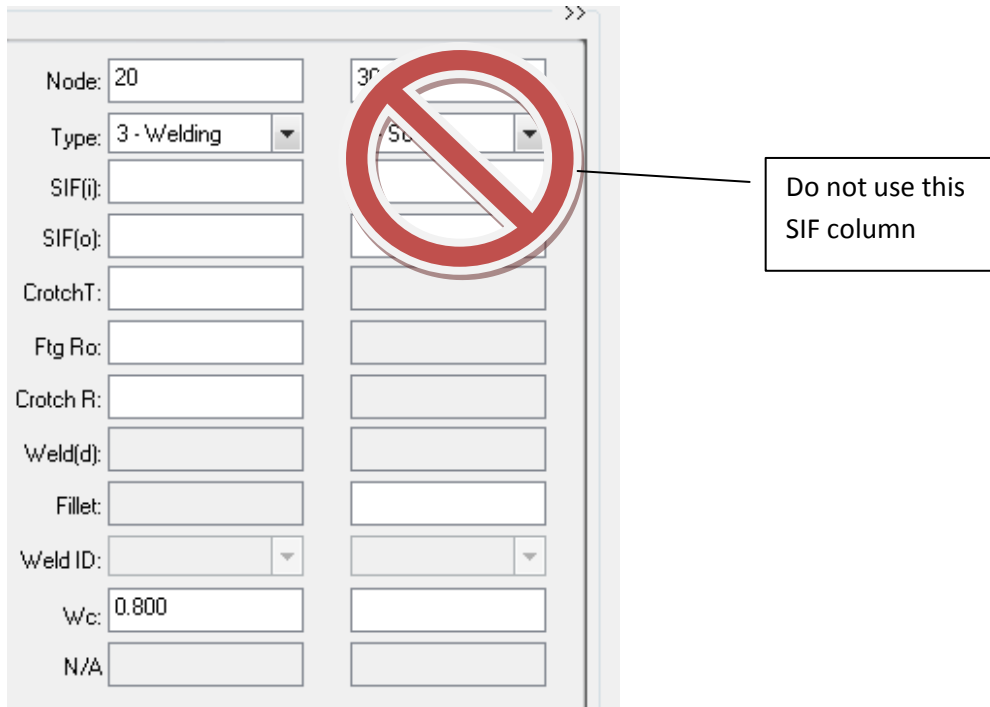

Do not use this SIF column

Fig. 3 – SIF fields in CAESAR II

Welded attachments
Welded attachments may include lugs, pads, pipe shoes and trunnions. There is no particular method or need to denote welded attachments in most stress analysis models. However, for AIV and the EI method these items are potential failure sites which must be investigated. To do this you can tell Salad to check support locations, or you can model attachments as piping branches in your stress model, or you can combine both approaches while modelling only the more critical attachments (ie those which have high LOF after the first pass).

If you tell Salad to check all supports, you would need to model a restraint at each welded attachment and remove any non-welded supports from your model (or ignore those in the script output). Although welded attachments are not treated any differently to branches in the EI Guidelines, the definition of diameter ratio for a non-circular attachment is not discussed in the document. The Salad script assumes that attachments have a diameter ratio of D/d >=10, ie $FLM_1=0.5$.

If you model attachments as branches in your stress model you can specify an equivalent diameter for the attachment. For a rectangular attachment you might select a branch diameter which gives the same area, or more conservatively you might adopt the minimum side dimension as the diameter.

Treatment of duplex stainless steels
The Salad script provides the option to ignore this added penalty (factor FLM_3). If you choose to include the factor, material numbers 337 to 342, 425 and 436 will be treated as duplex by the Salad script.

Example Analysis – Flare System

NOTE: This tutorial focuses on a simple example flare system incorporating only two blowdown valves. A typical flare system would incorporate many pressure relief and blowdown valves. When analysing your flare system you should work with your Process department if applicable to consider various relief and blowdown scenarios, in order to determine the worst case for each section of piping. Different system back-pressures, different valves relieving simultaneously and differing blowdown sequences may all impact on the analysis. The Salad script considers only one scenario at a time – to keep a record of all scenarios considered you would save a new '.sal' file for each one.
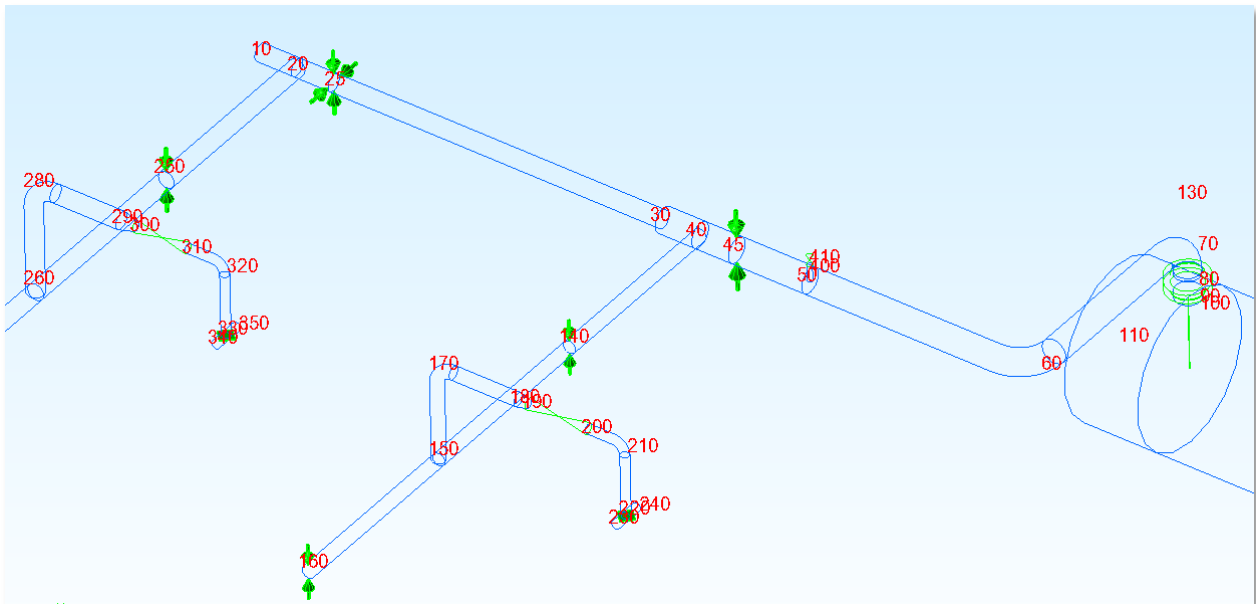
Fig. 4 – Flare System Example

Blowdown valves are modelled at elements 300-310 and 190-200, discharging via subheaders to the main header and into the flare drum at node 100.

The steps that you would need to go through to analyse a piping system such as this will first be demonstrated here. To get started you would invoke the CAESAR II Data Export Wizard and export the model input data to an XML file.

You must be using CAESAR II Build 080207 or later.
The Build number is displayed in the bottom right of the parent window, as well as in the 'About' box, and is in format YYMMDD.

CAESAR II is a registered trademark of COADE, Inc. (part of Intergraph Corporation).
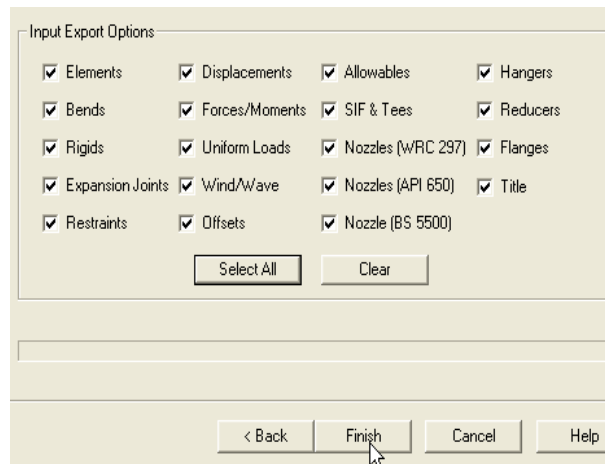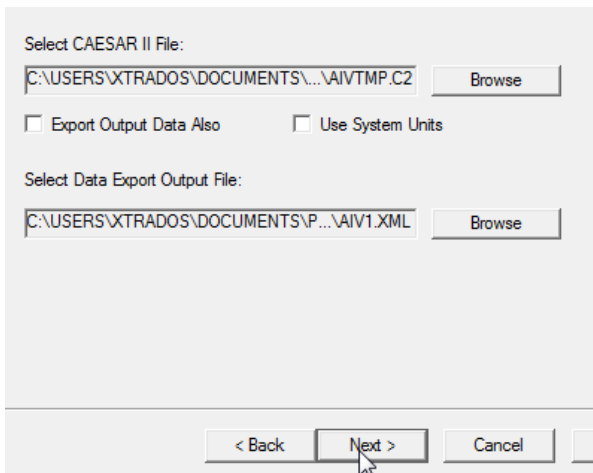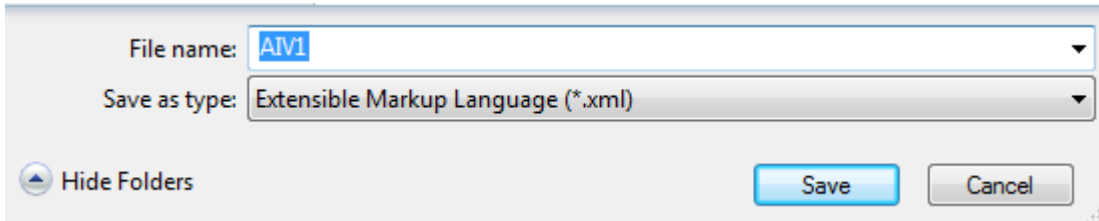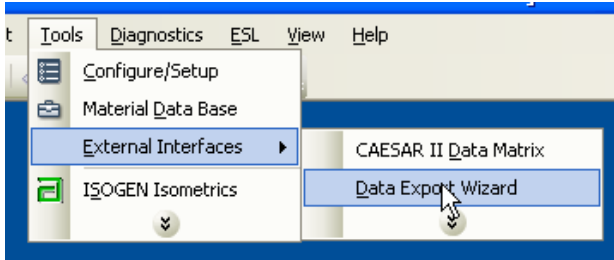
Give the file a slightly different name to the '.C2' file, if you are exporting only the input data. Otherwise CAESAR II zips the exported '.XML' file back into the '.C2' file.

Next click on Salad's 'Load XML files' shortcut button and browse to the XML file to import it:

Now start a new script from the script template 'AIV':
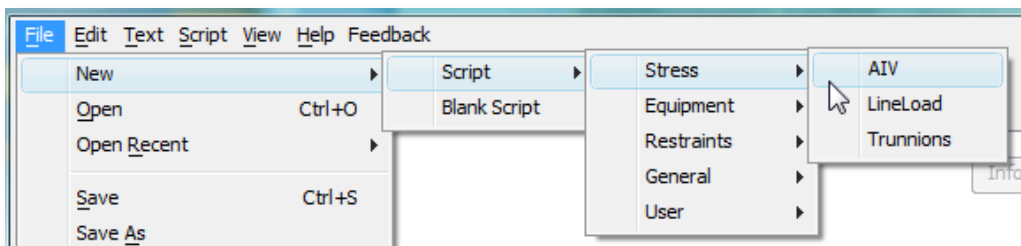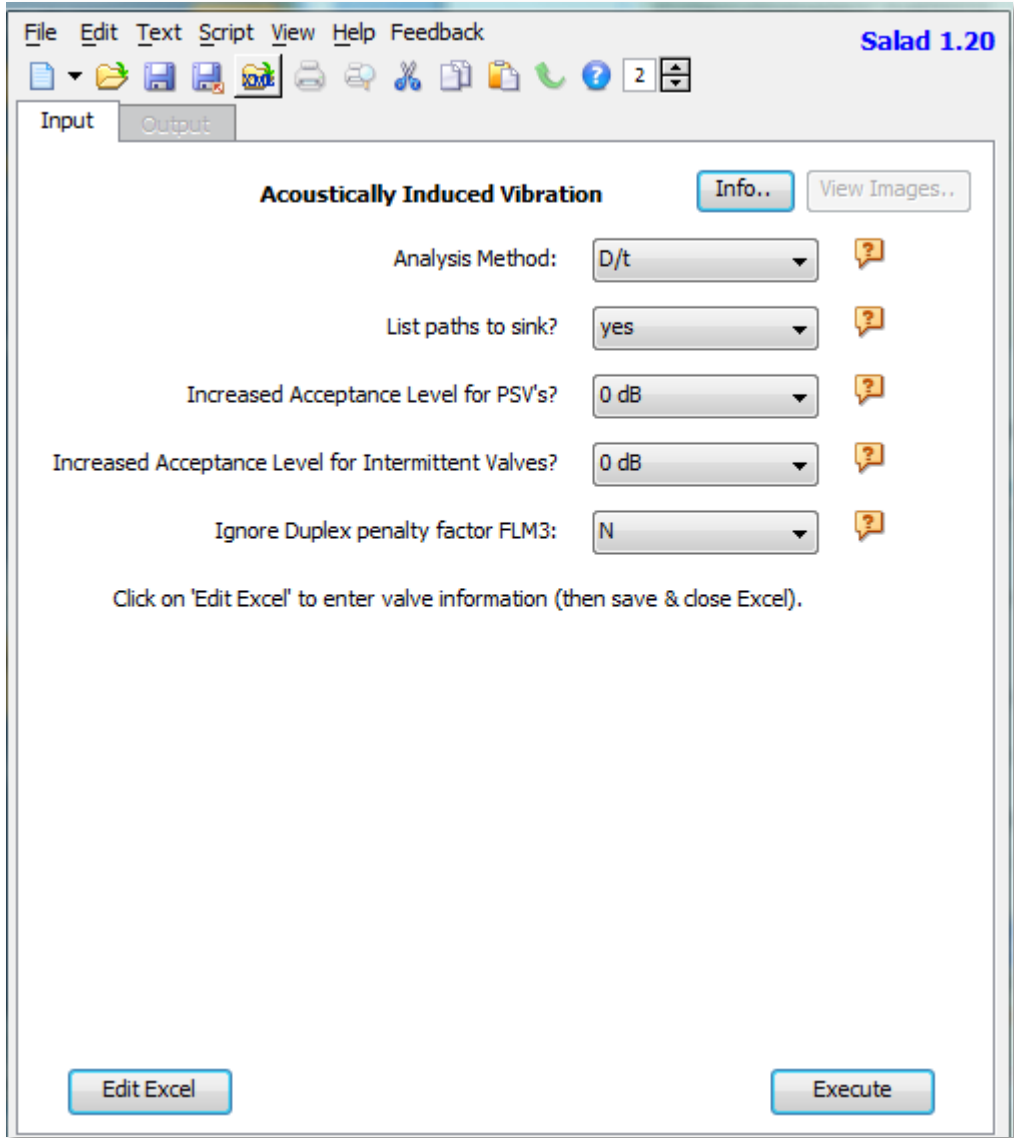
A number of options are presented such as analysis method, increased acceptance levels etc. After selecting your options you need to enter the data for your valves. Click on 'Edit Excel' to launch Excel and enter the data into the predefined spreadsheet:


A few notes about the Excel file:

- The type of valve is either 'Control', 'Intermittent', 'Modulating PSV' or 'Conventional PSV'. A 'control' valve is considered continuously operating.
- 'Area Calculated' and 'Area Selected' are used for conventional relief valves only to pro-rata the required flowrate to estimate an actual flowrate.
- The 'Valve in use' column is used to toggle valves on or off for evaluating different scenarios.
- You must of course enter the correct node numbers for your Sources and your Sink.

The Excel sheet should be saved and closed when you are finished. Excel may be left open or closed.

Now click on the 'Execute' button to run the script.

The first part of the output is the calculated sound power for each source. The path determined by Salad from each source to sink is listed (if you select this option) to demonstrate proper script operation.
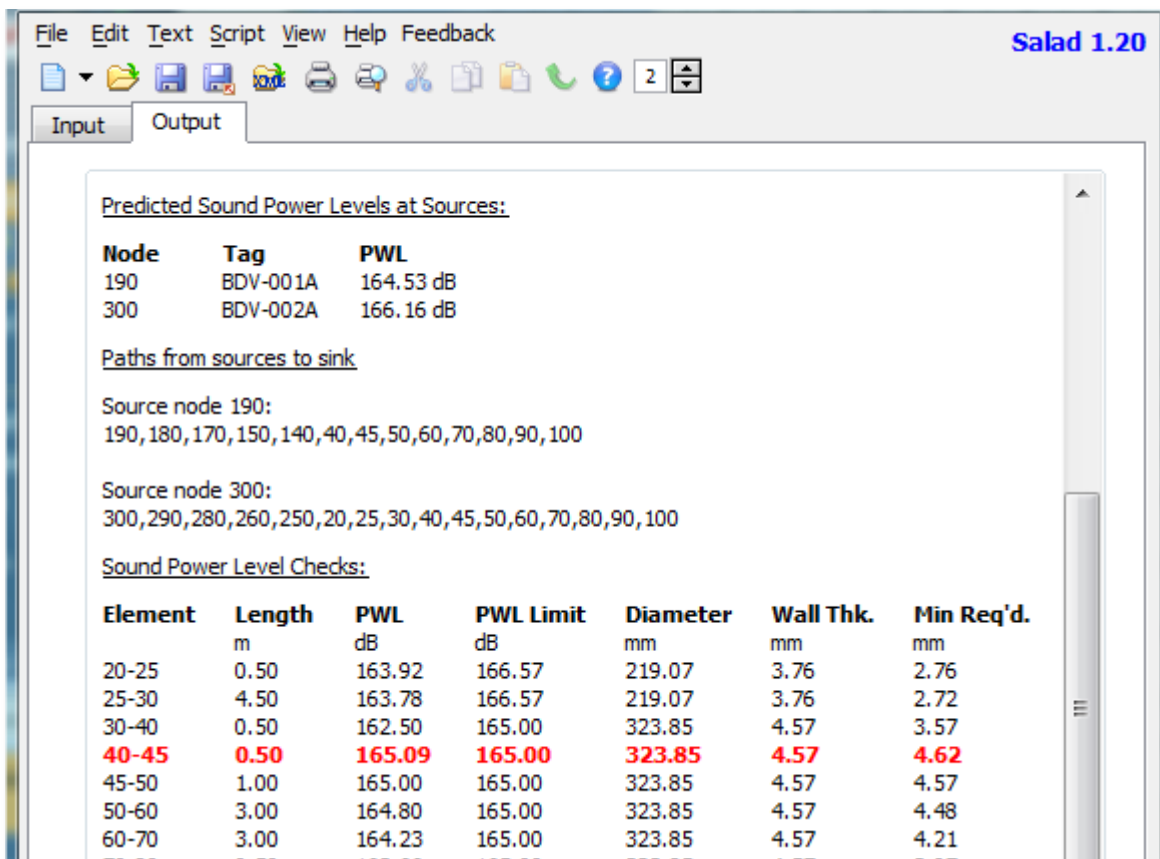
It can be observed above that the stretch of piping from 40-45 is failing the design criterion under the combined vibration from both valves. It is expected that the current wall thickness would be adequate if the valve at node 190 could be moved further back from the header, thus giving more distance for decay of sound power. Of course if such a change were to be made it must be coordinated with your design department.
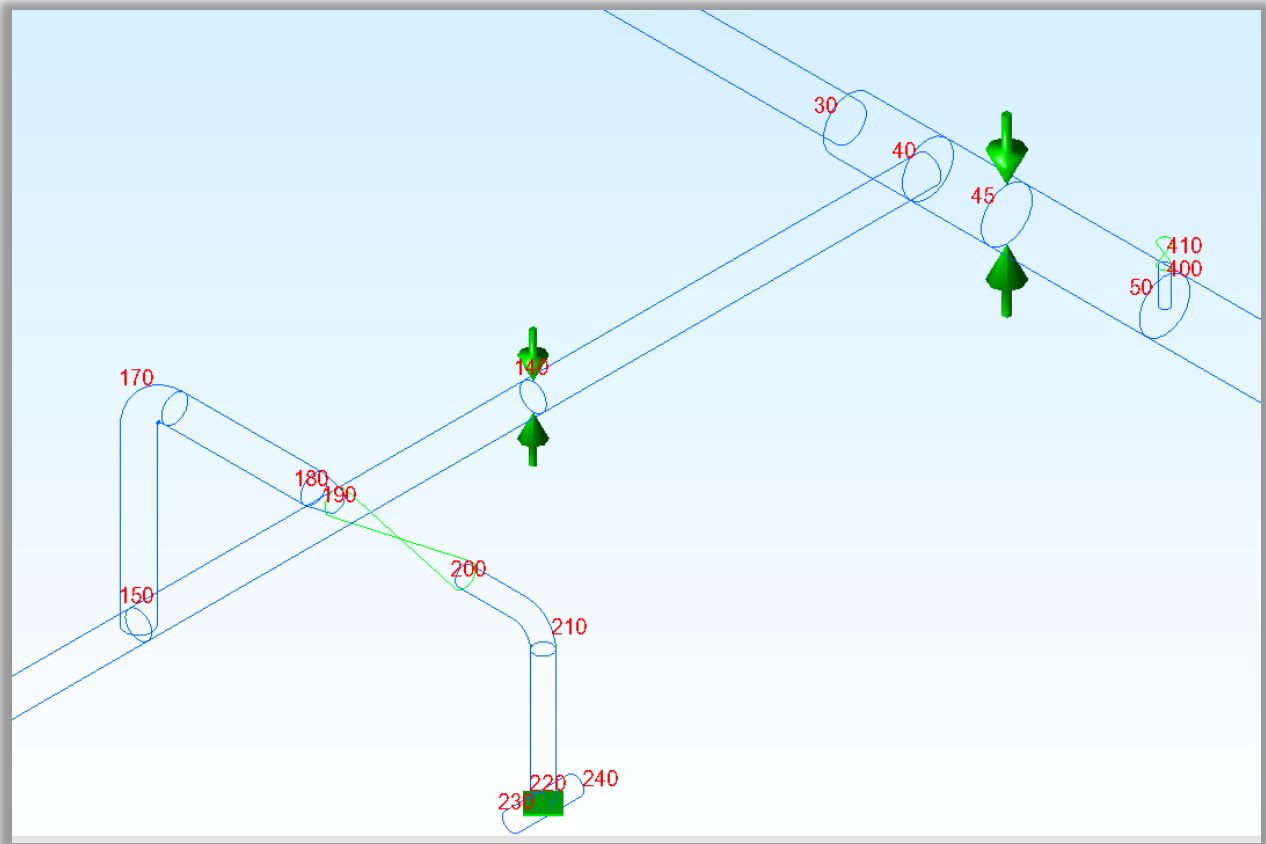
Fig. 5– By moving the tee at node 150 further away from the main header, the combined Sound Power Level in element 40-45 should be reduced.

To check this without going back to CAESAR II, you can go to the Excel tab and once again click on 'Edit' to launch the Excel spreadsheet. This time the 'Length Tweaks' sheet is selected and an increased length is entered for element 150-140 (the order of Element Node 1 and Node 2 does not matter).

	A	B	C	D	E
1	Changes to Element Lengths in the CAESAR II Model				
2					
3	No.	Element Node 1	Element Node 2	Revised Length (m)	
4	1	140	150	3.5	
5	2				
6	3				
7	4				

The Excel sheet should again be saved and closed before rerunning the script, giving the following results:

Sound Power Level Checks:

Element	Length m	PWL dB	PWL Limit dB	Diameter mm	Wall Thk. mm	Min Req'd. mm
20-25	0.50	163.92	166.57	219.07	3.76	2.76
25-30	4.50	163.78	166.57	219.07	3.76	2.72
30-40	0.50	162.50	165.00	323.85	4.57	3.57
40-45	0.50	164.92	165.00	323.85	4.57	4.53
45-50	1.00	164.83	165.00	323.85	4.57	4.49
50-60	3.00	164.64	165.00	323.85	4.57	4.39
60-70	3.00	164.07	165.00	323.85	4.57	4.14

The modification shows a favourable result. The Salad script would then then saved as a record of the analysis.

For comparison the EI Guidelines result for the same system is shown below (without any tweaking to lengths). Table 3-1 of the guidelines recommends redesign if the LOF is greater than 0.5.

Sound Power Level Checks:

Node	PWL dB	Type	Header D mm	Branch D mm	Header Thk. mm	Corrosion mm	LOF
20	163.92	Branch	219.07	219.07	3.76	0.00	0.29
25	163.78	Attach.	219.07		3.76	0.00	0.51
30	162.50	Run					0.29
40	165.09	Branch	323.85	168.27	4.57	0.00	0.57
45	165.00	Attach.	323.85		4.57	0.00	0.69
50	164.80	Branch	323.85	60.33	4.57	0.00	0.81
60	164.23	Run					0.29
70	163.66	Run					0.29
80	163.57	Run					0.29
90	163.52	Run					0.29
140	162.65	Attach.	168.27		3.40	0.00	0.29
150	163.58	Branch	168.27	168.27	3.40	0.00	0.29
170	164.07	Run					0.29
180	164.48	Run					0.29
190	164.53	Run					0.29
250	164.63	Attach.	219.07		3.76	0.00	0.56
260	165.34	Branch	219.07	219.07	3.76	0.00	0.29
280	165.77	Run					0.29
290	166.11	Run					0.29
300	166.16	Run					0.29

Overall System Result: Redesign/ detailed analysis recommended
Max LOF: 0.81 at Node 50

References

1. Designing Piping Systems Against Acoustically Induced Structural Fatigue, F L Eisinger, Journal of Pressure Vessel Technology, Aug. 1997 Vol 119 pp. 379-383
2. Acoustically Induced Piping Vibration in High Capacity Pressure Reducing Systems, V A Carucci & R T Mueller, ASME 82-WA / PVP-8
3. NORSOK Standard L-002 (2009), Piping System Layout, Design and Structural Analysis
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