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# Managing vibration related fatigue failures in process pipework

## Case Study: NGT's Pressure Reduction Stations

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# Scope of presentation

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- Advantica have team dedicated to tackling vibration issues in process pipework.
- Have undertaken a substantial amount of work for NGT, including:
  - Project to tackle vibration of small-bore attachments at all NGT compressor stations
  - Project to reduce the likelihood of vibration failures at NGT pressure reduction stations.

# Background

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- NGT operate over 1500 pressure reduction stations (>7bar)
- Fatigue failures have occurred at rate of a ‘few per year’. (Most sites have no problems)
- Failures lead to a release of gas, which causes environmental damage as well as safety concerns.

# Issues

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1. What is causing the failures?
2. How to find the needles in the hay stack? (and establish confidence that other sites are at acceptable low risk?)
3. How to define allowable vibration levels, and deal with vibration that occurs only intermittently.
4. How can problems be resolved and failures be avoided in new design?

# Overview of presentation

- Causes of vibration failures at pressure reduction stations
- Examples
- Advantica/NGT approach to tackling the problem
  - Desk and site based screening and case specific problem solving
  - Development of design guidance
- Progress to date and lessons learned

# Causes of vibration failures

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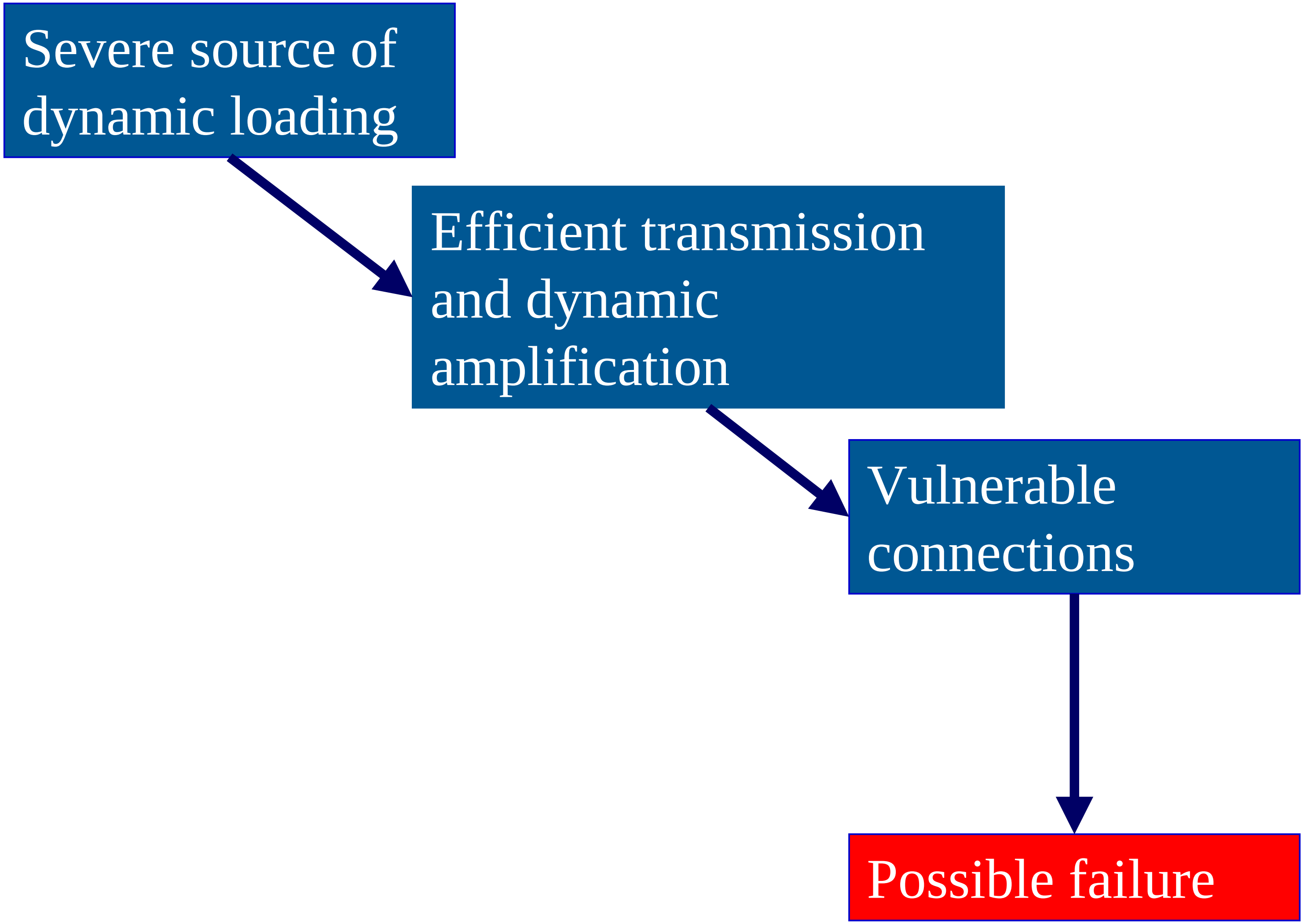

# Sources of vibration

- Pressure regulator
- Turbulence
- Vortex shedding
  - Flow induced vibration
  - Flow induced pulsations

These are subset of sources present in most process pipework. Other common sources are pressure pulsations associated with compression, and mechanical vibration associated with rotating machinery.

# Sources of vibration

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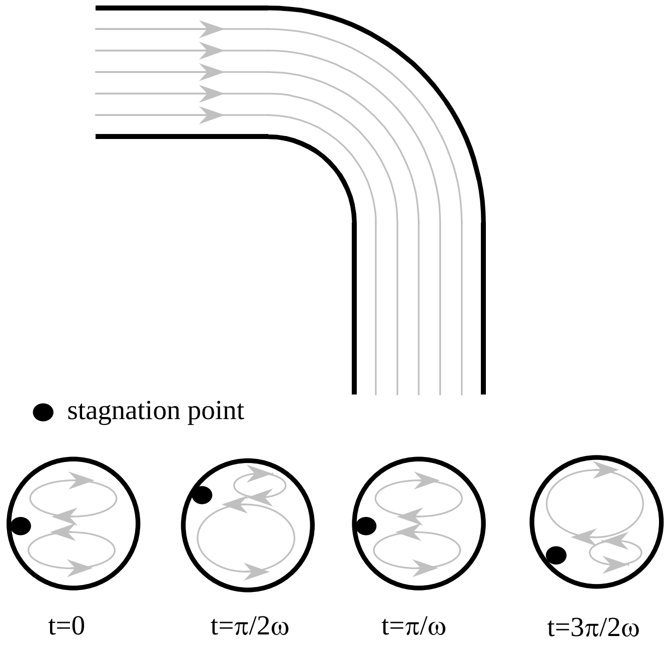
## *Pressure regulator*

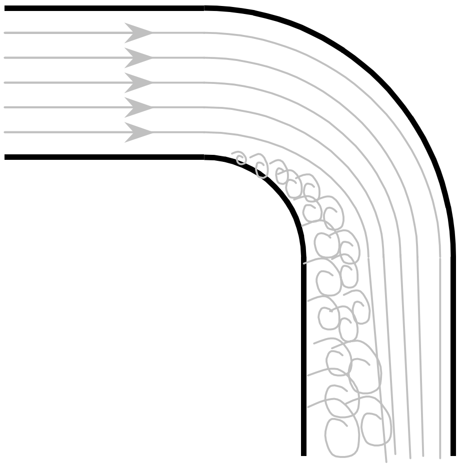
- Pressure reduction achieved by giving the gas kinetic energy
  - Source of turbulence that can cause dynamic loads on pipe
  - Broad range of frequencies including high frequencies
  - Possible source of periodic loading from vortex shedding – see later
- Some specific design features / types of regulators are particularly likely to cause vibration in the pipework.
- Severity of vibration is sensitive to flow rates / pressure reduction

# Sources of vibration

*Flow around bends and tees*

- Low frequency vibration



# Sources of vibration

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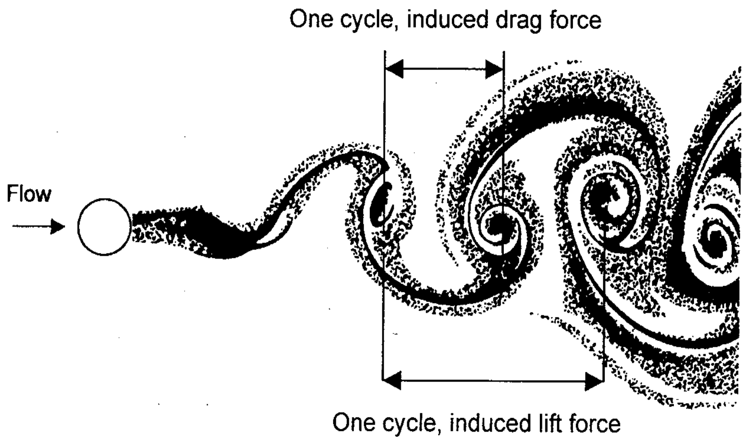
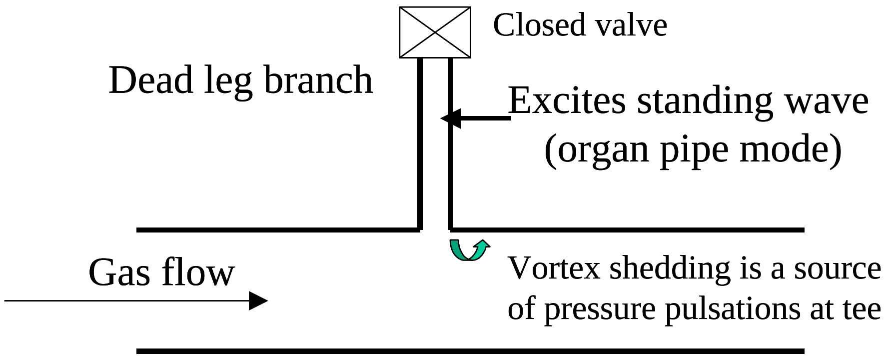
## *Vortex shedding*

- **Flow induced vibration** (vortex shedding locks on to and excites structural mode of vibration) :
  - e.g. Thermowell
- **Flow induced pulsation** (vortex shedding locks on to and excites acoustic mode) :
  - e.g. Dead leg branch



# Transmission

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- Dynamic loads can by transmitted to other parts of the pipe system by:

  Mechanical:

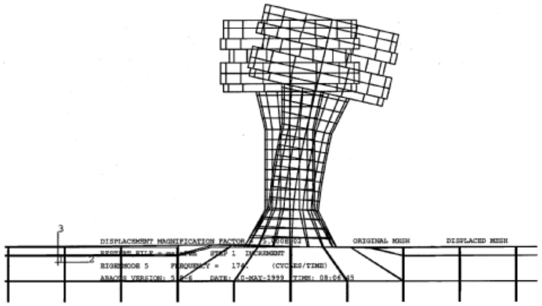
  - Vibration of the pipe (acting as a beam at low frequencies, or a thin walled vessel high frequencies). Attenuated or reflected back at supports or where the pipe is buried.

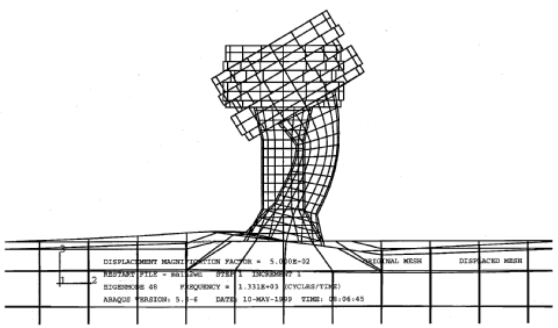
  Through the gas:

  - Turbulence carried with the gas flow.
  - Pressure pulsations travelling as plane waves. Can travel a long way, and are attenuated / reflected at a change in cross-sectional area.

# Dynamic Amplification

- Amplification of dynamic loading will occur at the natural frequencies of the pipe or acoustic system.  In particular, problems can occur in:
  - Lightly damped systems
  - Systems with low natural frequency (since turbulence is often concentrated at low frequencies)
  - Modes of secondary systems, such as small-bore attachments





# Typical small bore connection

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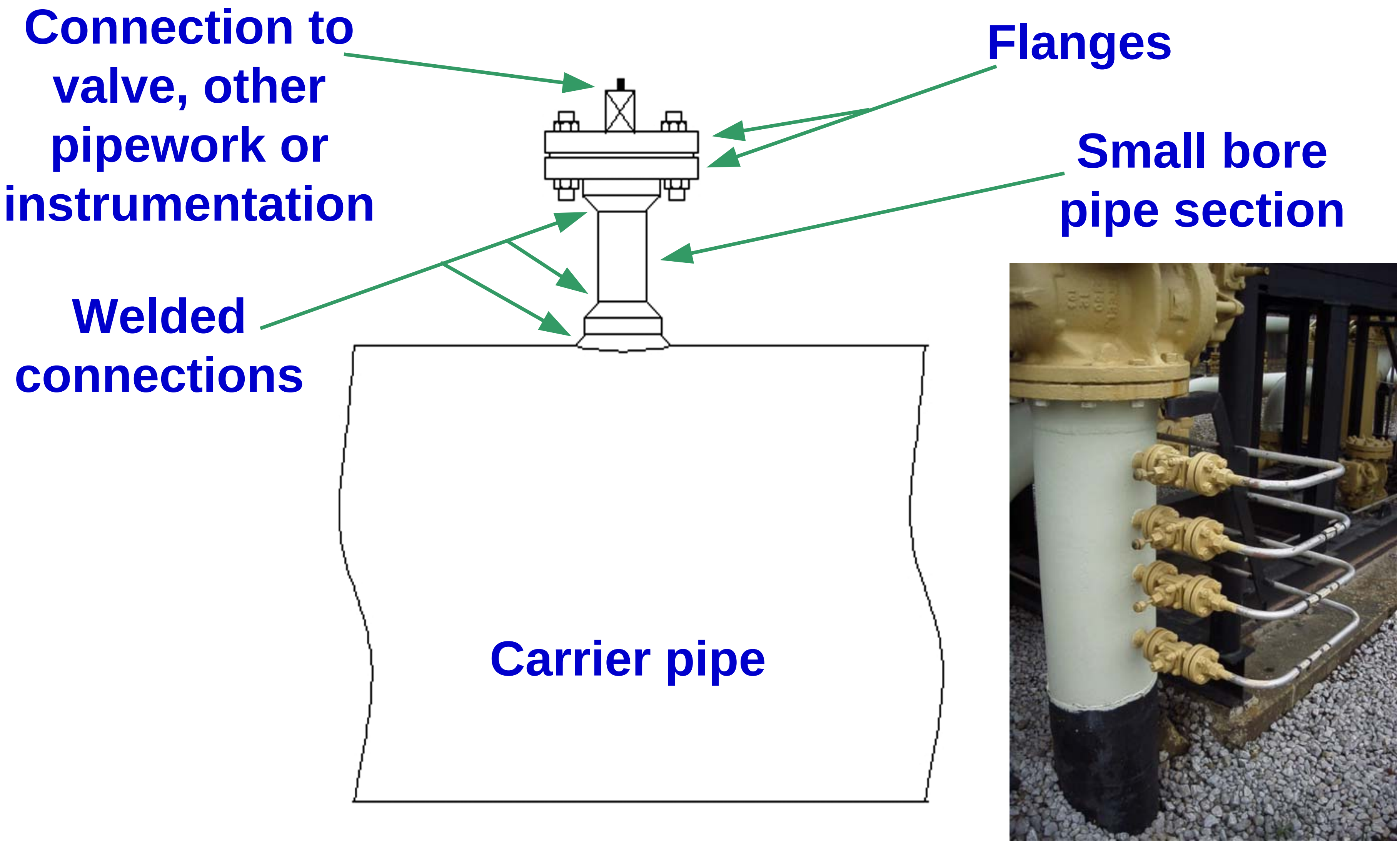
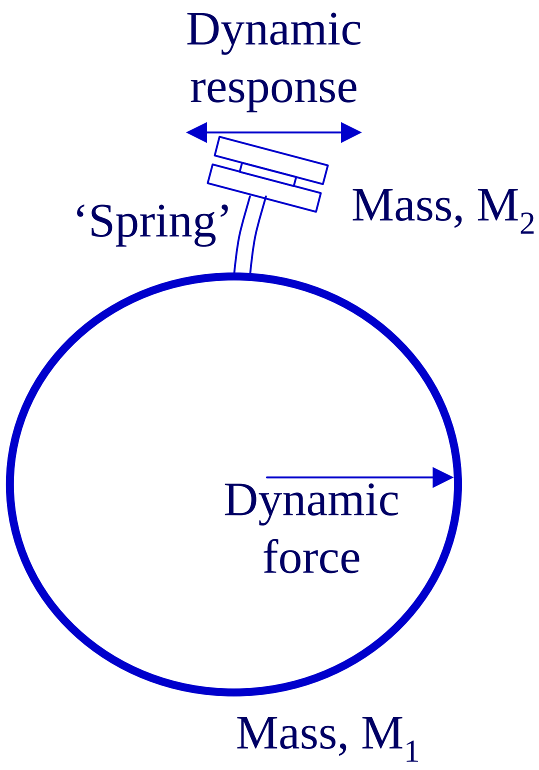


# Small-bore attachments





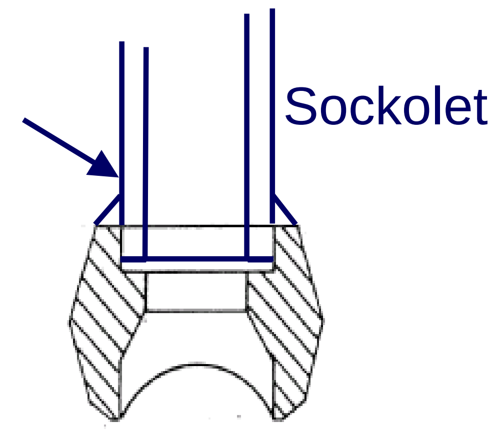

At resonance of the small-bore attachment, the inertia loads are sensitive to:

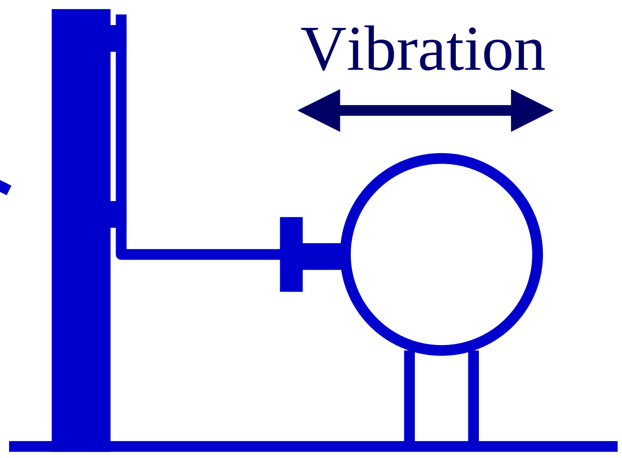
- The ratio $M_2/M_1$.
- The system damping
- Length/diameter of attachment.
- Natural frequency

Slender, heavy small-bore attachments on low mass carrier pipe are particularly vulnerable to vibration.

# Vulnerable connections

- Sockolet
- Inadequate support type or spacing
- Stiff connection where flexibility is needed
- Rubbing/wear at supports / adjacent pipes



# Summary of mechanism

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Severe source of dynamic loading

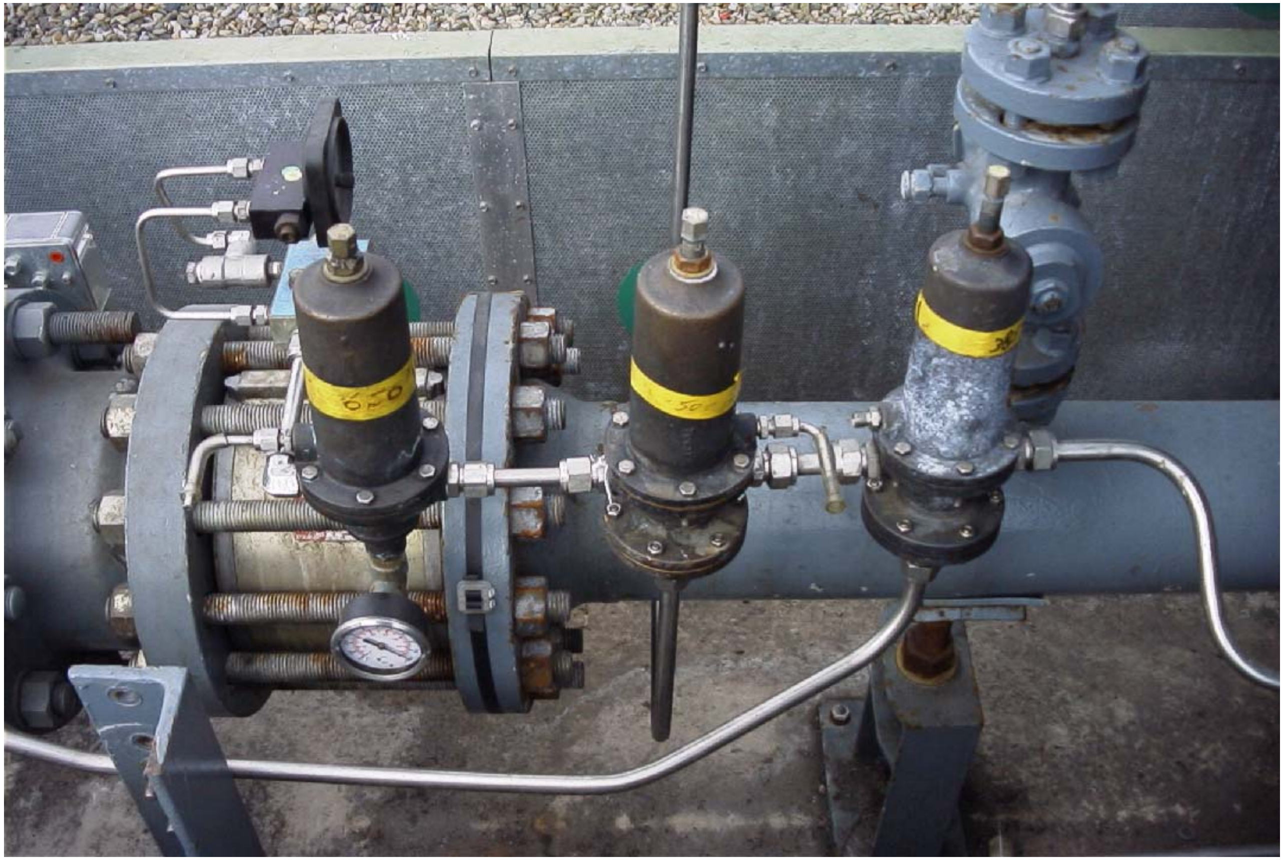
→ Efficient transmission and dynamic amplification

→ Vulnerable connections

→ Possible failure

# Example 1

**Problem:** A failure was reported on ½” impulse tubing associated with the pilot valves for one of the regulators.



# Example 1

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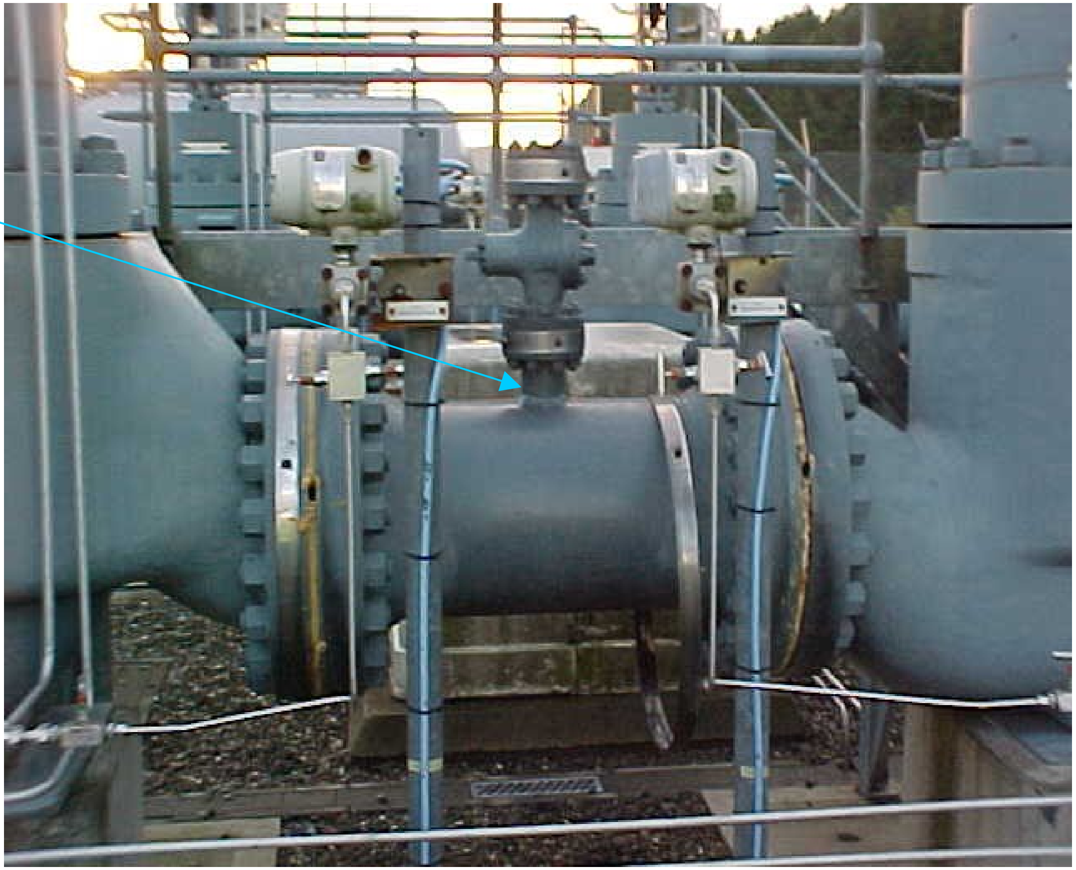
- Cause: Pilots supported by impulse pipework (large mass and slender support)
- Solution:
  - Support pilots from ground, and ensure flexible impulse pipework between pilots and regulators
- This is an example where the source of the vibration is 'normal', but the vulnerability is high.

# Example 2

**Problem:** Two separate failures experienced at weld toe of a 2” welded outlet branch connection between two regulators.

2” stabbing



# Example 2

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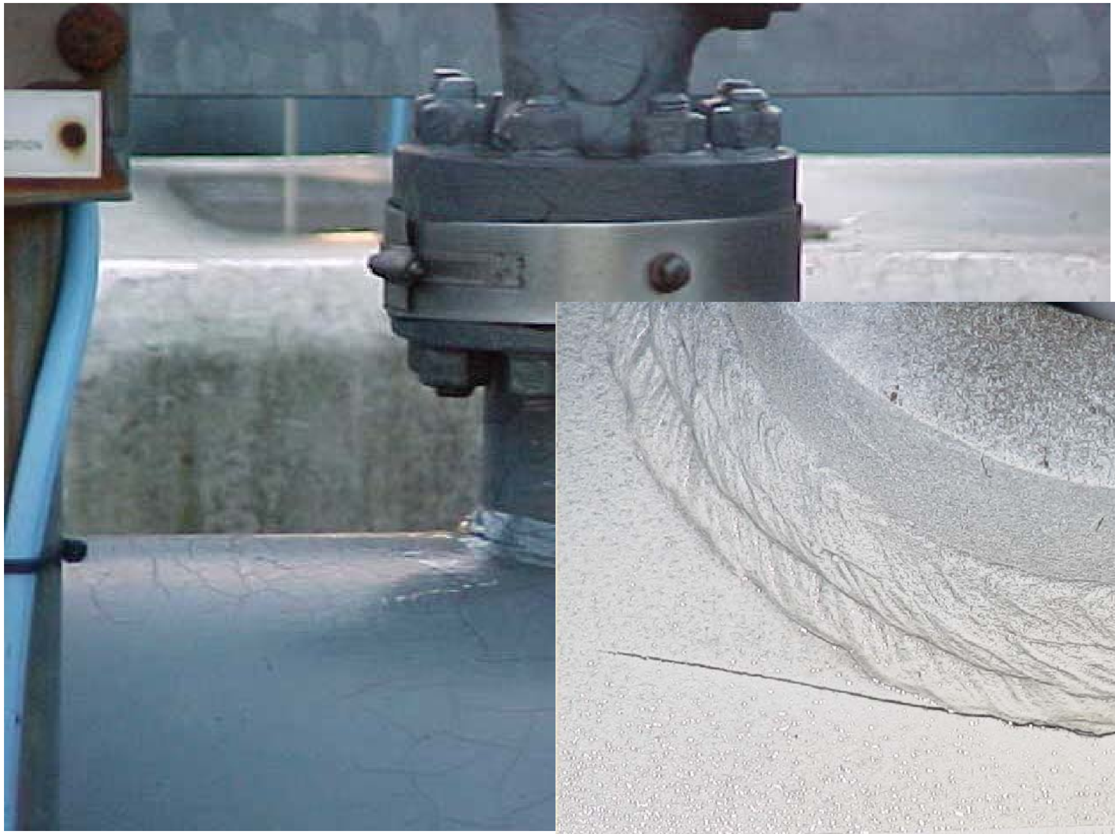

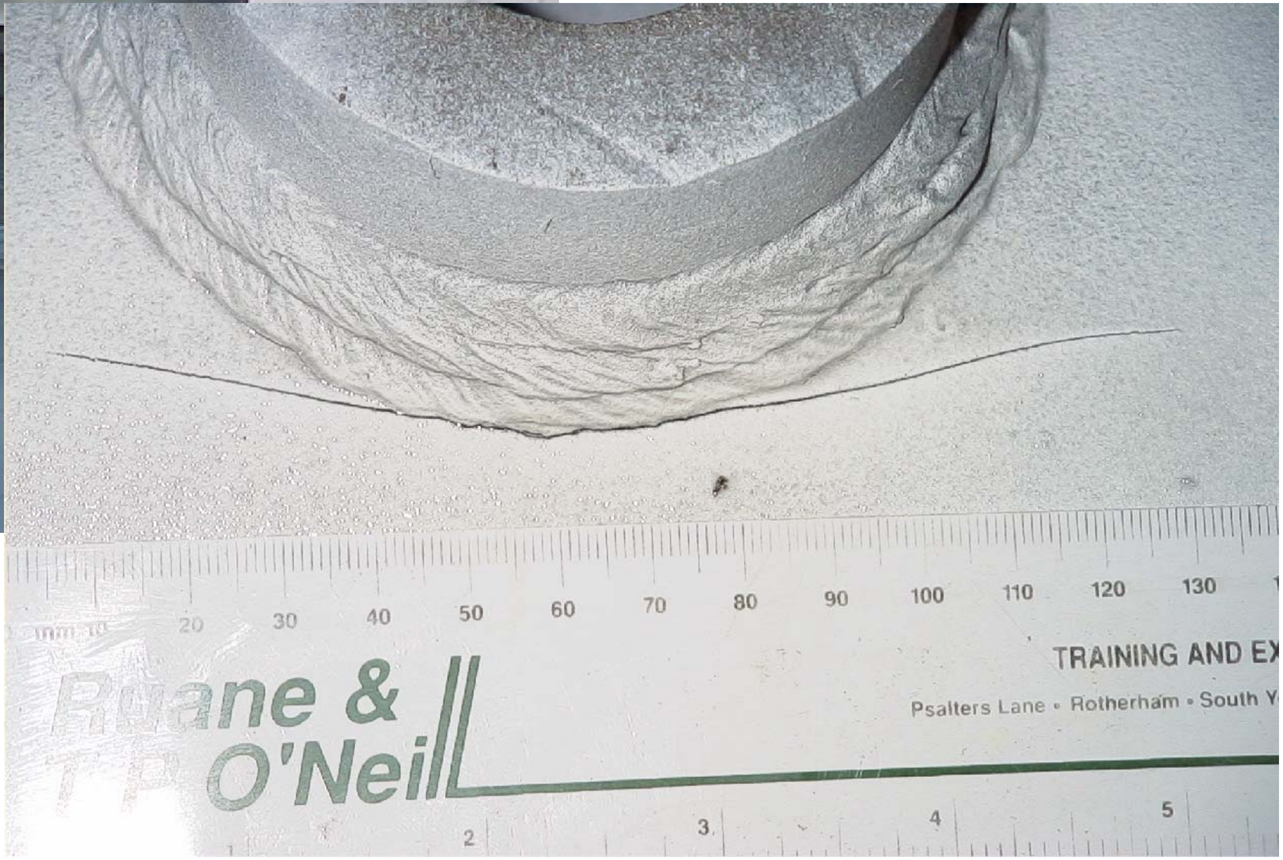

# Example 2 - Conclusions

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Cause: Severe vibration from the regulators when operating nearly closed that became worse over time. Cantilevered valve was the weakest connection.

Solution:

- Overhaul of regulators.
- One of the branch connections removed by replacing spool piece
- Solution was effective, but high vibration eventually returned. A further failure occurred on an adjacent stream.
- Ongoing discussions with manufacturer.

# Example 3



**Problem:** A failure was reported on a ¾" BSP taper nipple, which was subsequently replaced.

# Example 3 - Conclusions

Cause:  Severe vibration from Fisher V25 regulators at high flow rates, particularly on the lead stream.  Failure occurred at the most vulnerable connection.

Solution:

- As an interim solution, it was recommended that more than one stream be used at a time, so the maximum flows through the individual streams are reduced (demonstrated to be effective).
- More radical review of the site / regulators is underway.

# Example 4 - Recycle line failure

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- Longitudinal crack detected in girth weld on compressor station recycle line

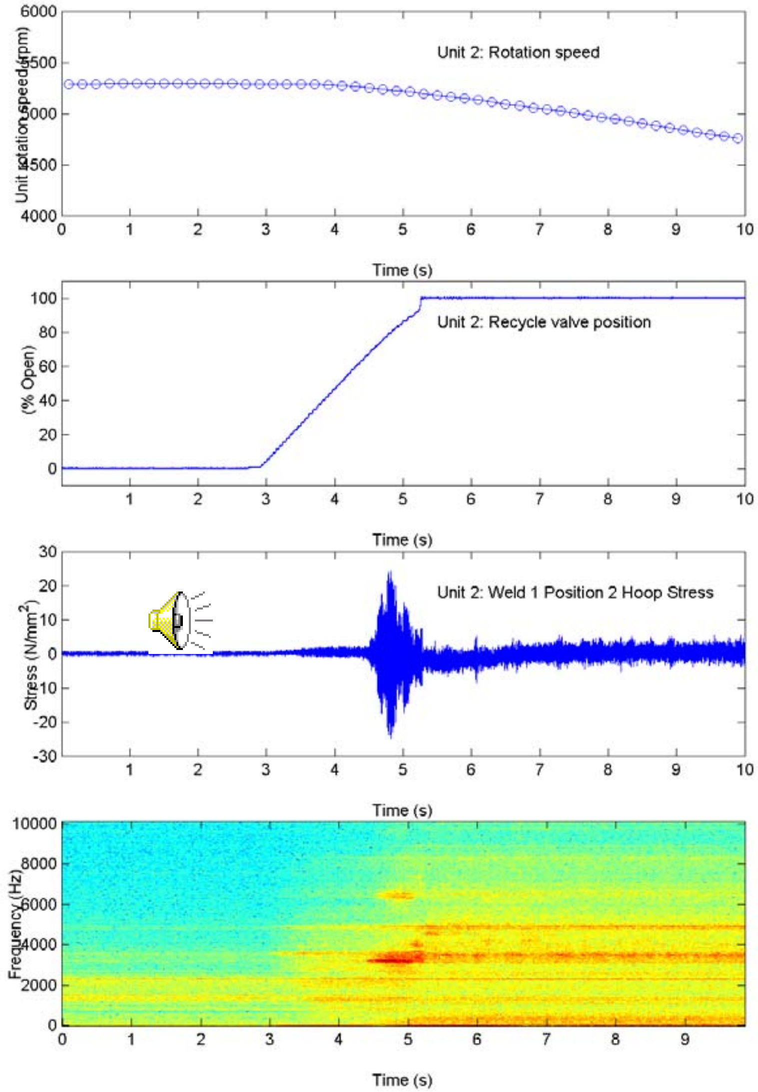
# Example 4 - Test results

Cause:

- Severe vibration caused by Fisher V25 when the valve is nearly fully open
- At this condition the dominant vibration is at 3.2kHz – exciting pipe wall flexural modes

Solution:

- Replacement (thicker) pipework



# Summary of what causes vibration failures

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- Many different mechanisms for vibration failures, but generally, failures occur as a result of the combination of:
    - Severe source of dynamic loading – most relevant sources described.
    - A mechanism for transmission and amplification.
    - Vulnerable connections.
- Examples of recent failures
    - Examples reviewed in terms of the vibration mechanisms and the approach to reducing the vibration to acceptable levels

# Vibration screening at Pressure reduction stations

- How to find the needle in the hay stack?

# Overview

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- A series of failures have been experienced on pressure regulator stations, which have led to a release of gas.
- Many different potential causes of failure, and in general these are complex to analyse and take time to understand.
- There are over 1500 sites, and detailed investigation at every site would be impracticable.  Also, this would be inefficient since the majority of sites do not experience problems.
- In response, NGT decided to screen all their Pressure Reduction Stations to assess the risk of vibration induced fatigue. NGT and Advantica developed 3-stage screening strategy in early 2003 to achieve this.

# Screening Strategy

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Stage 1 – Desk based questionnaire to be filled in at a central Network Office.

Stage 2 – Site based questionnaire and basic measurements.

Stage 3 – Study of sufficient depth to lead to the identification and implementation/verification of solutions

# Stage 1 Questionnaire

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- Desk based questionnaire – completed electronically by NGT personnel at the local office.
- Main aim to collate basic physical data and operational conditions as well as historical information about each site
- 29 questions, including information about:
  - Flow rates and design capacity
  - History of failures/known problems/noise
  - Regulator types
- The questions are scored, and relevant stations are progressed to Stage 2.

# Stage 2

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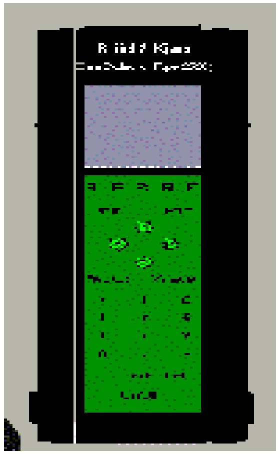
- Site based questionnaire completed by NGT Network personnel, including 'standardised' vibration measurements.
- Questions include:
  - Number and design of small bore connections
  - Supports for main carrier pipe, small-bore attachments and impulse pipework
  - Qualitative assessment of noise level from regulator streams
- Measurements provide basic measure of severity of source, and response of small-bore attachments.
- Highest scoring sites progressed to Stage 3.



# Stage 3

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Investigation of sufficient depth to resolve problems.

Can range from:

- Visual inspection / basic measurements

to:

- Detailed investigation using long-term continuous vibration monitoring to capture operating conditions that arise only occasionally.

- Has involved the development of assessment techniques/criteria that have been subjected to external review.

- Final outcome: Solution / verification

# Progress to Date



Start early 2003:

| | |
| --- | --- |
| 1015 Desk based Stage 1 surveys | Complete |
| 281 Site based Stage 2 surveys completed | 80% Complete (seasonal) |
| Stage 3 surveys | 10 higher priority sites completed (seasonal) |

# Stage 3 Surveys - lessons learned

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Category A: The source of vibration is high, and it can be challenging to identify solutions without changing process conditions or regulator types:

4 sites fit this category

Category B: The source isn't particularly severe, but a problem exists because the pipework configuration makes it vulnerable to vibration:

6 sites fit this category

Category C: Detailed investigation revealed that the vibration levels were acceptable:

0 sites fit this category

# Design specifications

- A key part of this process is to ensure that lessons learned are fed back into the design process to ensure that best practice is followed in future projects.

# Design specification [1]

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Example guidance:

- Use low noise regulators
- Share the pressure drop across pressure regulators
- Maximise the pipe wall thickness in vibration risk areas
- Maximise the diameter to reduce the gas velocity (normally less than 20 m/s)
- Use stiff pipe supports (and avoid stress concentrations at supports)
- Use a suitable number of appropriately designed supports
- Support bends and large masses
- Avoid sharp bends and tees that can causes turbulence

# Design Guidance [2]

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…continued)

- Bury pipe if practicable
- Use Weldoflanges for improved fatigue strength
- Maximise the fatigue strength of pipework connections – avoid fillet welds
- Dead leg branches to be shorter than 8 times the diameter of the small-bore branch.
- Avoid thermowells, but where surface mounted sensors cannot be used then use the approved type design.
- Do not support pilot valves or sensors on impulse pipework
- Use anti-vibration supports for impulse pipework
- Allow for relative movement between carrier pipe and sensors in impulse pipework design

# Summary

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Problems of tackling vibration in process pipework discussed through a case study

- Causes / examples of failures
- Practical problems:
  - How to pin point the areas/sites of concern?
  - Dealing with vibration that occurs only occasionally
- Approach adopted:
  - Described 3 stage approach to go from initial screening on large number of sites to detailed investigation and problem solving.
- Closing the loop through design guidance.