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PIPE VIBRATIONS

VIBRATIONS IN NUCLEAR APPLICATIONS, OCTOBER 4 2016

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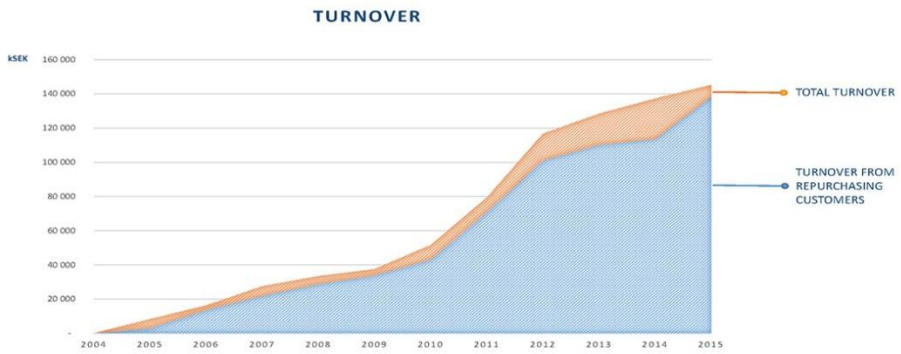
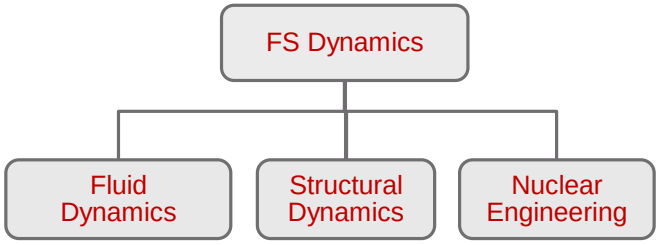
Introduction

FS Dynamics

FS Dynamics' Organisation

- Founded in January 2004 in Sweden
- Head Office in Gothenburg
- 8 Local offices, 6 countries
- Corporation + 6 daughter companies
  - FS Dynamics Denmark founded in 2009
  - FS Dynamics Finland founded in 2010
  - FS Dynamics Norway founded in 2013
  - FS Dynamics Portugal founded in 2016
  - FS Dynamics UK founded in 2016
- 3 competence based departments
- 170 co-workers, 33 in Finland





The FS Dynamics Concept

- Focus on CAE only
  - FEM, CFD, MBS
- Multiple Industries
- In-house & On-site services
- Collaboration & Learning
- Excellent engineers
- Long-term relations

Business infrastructure

- Full In-house CAE – environment
- ISO 9001:2000 Certified
- Partnerships with major clients & Satellite setups available

Introduction

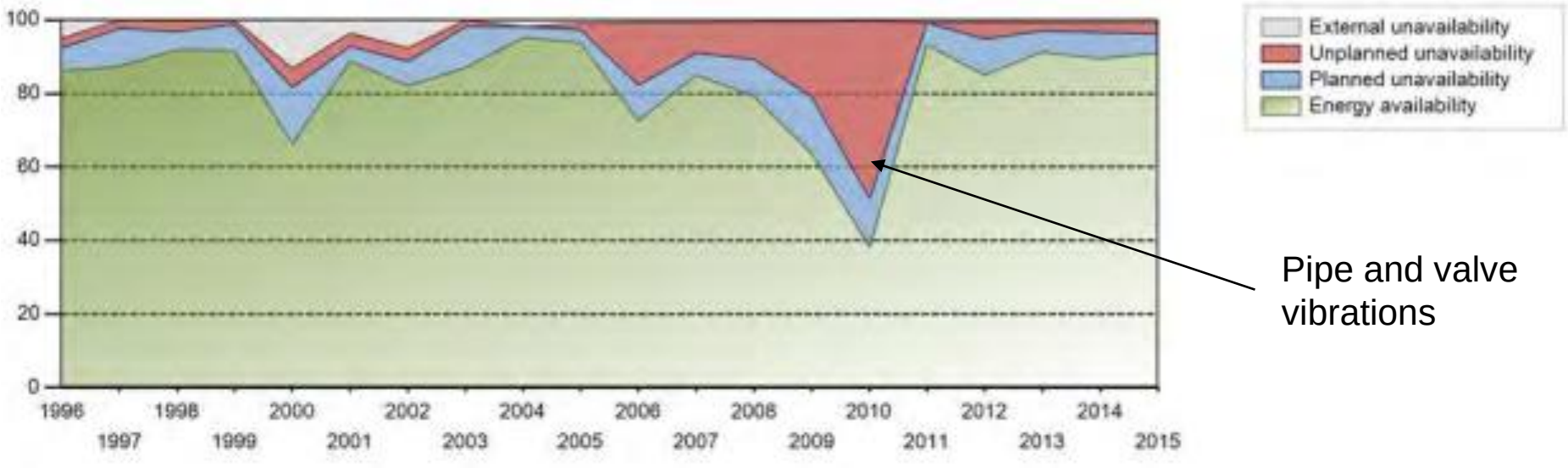
”Pipe vibration – analysis and mitigation” project

Background

- Elforsk/Energiforsk project in 2014 – 2015:
  - “Pipe vibrations – Analysis and Mitigation”
- The objective was to:
  - Assemble knowledge and experience in the area of pipe vibrations problems
  - Obtain information of how they were examined and mitigated.
- The nuclear power plants participating in the project were:
  - Oskarshamn
  - Ringhals
  - Forsmark
  - Olkiluoto

Motivation: Example of losses due to unplanned unavailability

Forsmark 2: Energy availability 1996-2015



Source: IAEA Operating Experience with Nuclear Power Stations in Member States 2016 edition

Conducting the work

- Obtaining and investigating reports from the participating nuclear power plants
- Visiting the sites and interviewing the staff.
- Obtaining and investigating additional documentation as agreed in the interview meetings.
- Analyzing and grouping the pipe vibration problems and mitigation methods.

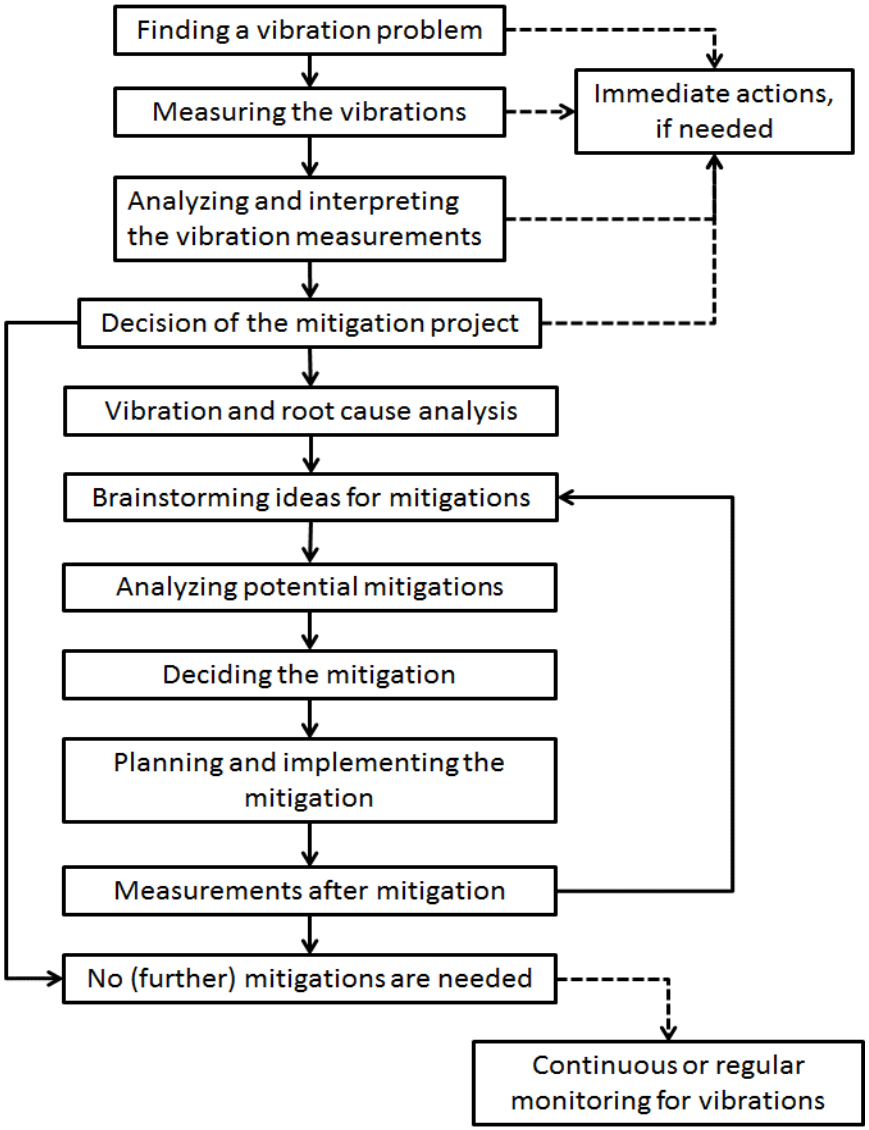
Workflow for the analysis and mitigation of pipe vibrations

Different workflows

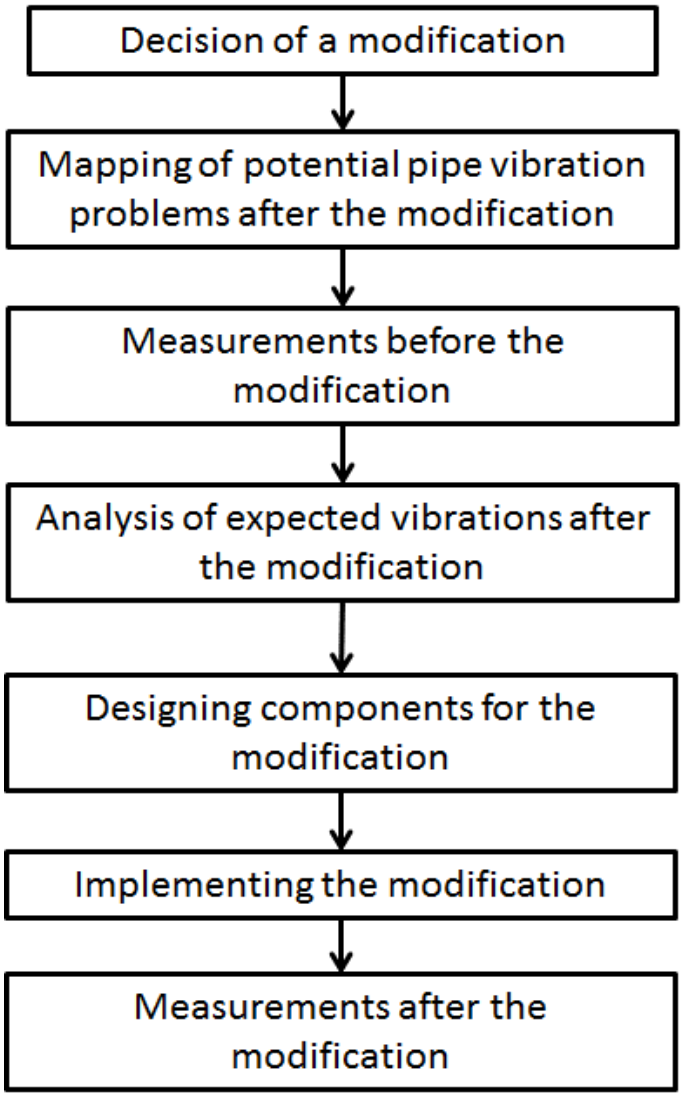
- Existing vibrations
  - Vibrations that have already been observed or are suspected to exist at the plant
  - The emphasis in the analysis is often in measurements of the existing system

- Potential future vibrations
  - Vibrations which do not exist or are at low levels
  - There is a suspicion that vibrations might arise, e.g. due to:
    - Power uprate
    - Component replacement
  - Typical analysis methods are simulations or physical model tests.

Typical workflow, existing vibrations



Typical workflow, uprate or replacement



Pipe vibration analysis methods

Analysis methods

- Can be divided into two main categories:
  - Measurements
  - Calculation methods

- Often measurements and calculation methods complement each other

Calculation methods

- Different process conditions and mitigation solutions can be tested without restrictions
- Relevant variables can be investigated at any location
- Different calculation methods include:
  - Spreadsheet calculations
  - Structural simulations (FEM)
  - Fluid dynamics simulations (CFD)
  - Thermohydraulic simulations
  - Acoustic simulations

Measurement methods

- Will be covered in the next presentation in the agenda

Classification of pipe vibration problems occurred

Classification

- Two different kinds of classification are used for the problems based on
  - Location
  - Physics
- Different classes of these two categories were created
- The mapping between problems and classes is not one-to-one
  - Many of the problems belong to several classes

Classification based on location

- Pipe vibrations related to valves
- Main steam line vibrations (not valve related)
- Pump induced vibrations
- Other vibrations

Classification based on physics

- Flow induced vibrations
- Acoustic resonances
- Water hammer
- Structural resonance
- Flexible piping
- Multiphase mixture
- Other vibrations

Classification of occurred problems

		Location				Physics						
Problem	Section	Pipe vibrations related to valves	Main steamline vibrations (not valve related)	Pump induced vibrations	Other vibrations	Flow induced vibrations	Acoustic resonances	Water hammer	Structural resonances	Flexible Piping	Multiphase mixture	Other vibrations
Oskarshamn 3: Steam dryer	A.1.		x			x						
Oskarshamn 3: Main steamline vibrations after extended power uprate	A.2.		x									x
Oskarshamn 3: Main steam isolation valves	A.3.	x				x	x					
Oskarshamn 1: Steam and condensate lines	A.4.				x		x				x	
Oskarshamn 1: Cooling system for RPV top	A.5.			x					x			
Forsmark 1/2: Control valves in the 314 system	A.6.	x				x			x	x		
Forsmark 2: High pressure turbine valves	A.7.	x				x						
Forsmark 3: Steam dryer	A.8.		x			x						
Forsmark 3: Condensate water system	A.9.	x		x		x						
Forsmark 3: Steam lines from reactor to turbines	A.10.				x							x
Forsmark 1/2/3: Oil pipe vibrations excited by gear oil pumps	A.11.			x		x						
Forsmark: Other pumps	A.12.			x					x			
Ringhals 3: Main steam lines	A.13.		x			x						
Ringhals 3: Piping between high pressure turbine and the reheaters	A.14.				x							x
Ringhals 2: Main condensation system	A.15.				x			x				
Ringhals 1: Emergency core cooling system	A.16.			x				x			x	
Olkiluoto 1/2: Coolant piping of the generator stator circuit	A.17.	x		x					x			x
Olkiluoto 1/2: Main steam lines	A.18.	x	x			x	x		x			
Olkiluoto 1/2: Auxiliary feed water system	A.19.			x			x				x	
Olkiluoto 1/2: System 351	A.20.			x		x						
Olkiluoto 1/2: Fire water pump	A.21.			x		x			x			

Pipe vibration mitigation

Classification of mitigation methods

- The mitigation methods were divided into two main categories:
  - Methods that aim to reduce excitation for vibrations
  - Methods that aim to reduce vibration response

Mitigation reducing excitations

- Improved fluid dynamic design
- Reduced gas/liquid interaction
  - Dissolved air
  - Condensation/vaporization cycles
- Expansion chamber
- Replacing a component
- Avoiding certain operating conditions
- Other possible mitigation methods (not used in the studied cases):
  - Reducing excitation from a pump
  - Modified system to reduce acoustic resonances
  - Frequency converters

Mitigation reducing response

- Vibration dampers
- Added weight
- Added supporting
- Building valves together
- Hydraulic hoses
- Other mitigations:
  - Changing pump rubber feet and foundation
  - Steel wool dampers
  - Welding stiffener in the foundation
  - Stiffening pipes to the wall
  - Wood bars to support the piping
  - Motion limiters

Applied and considered mitigations (excitation)

	Mitigation	Flow induced vibrations	Acoustic resonances	Water hammer	Structural resonances	Flexible Piping	Multiphase mixture	Other vibrations
Mitigation for excitations	Improved fluid dynamic design	A.1.						
		A.13.						
		A.8.						
		A.3.	A.3.					
	Replacing a component				A.21.			
		A.7.						
	Reduced gas/liquid interaction			A.16.			A.16.	
			(A.4.)				(A.4.)	
			(A.19.)					(A.19.)
	Avoid certain operationg conditions			A.15.				
					A.17.			A.17.
	Expansion chamber	A.11.						
	Reducing excitation from pump				(A.17.)			(A.17.)
	Modified system to reduce acoustic resonances		(A.19.)					(A.19.)

Applied and considered mitigations (response)

Mitigation for response	Mitigation	Flow induced vibrations	Acoustic resonances	Water hammer	Structural resonances	Flexible Piping	Multiphase mixture	Other vibrations
	Vibration dampers	A.11.						
				A.15.				
			A.4.				A.4.	
		A.1.						
		A.13.						
		A.9						
								A.10.
					A.12.			
	Added weight				A.12.			
					A.5.			
		A.18.	A.18.		A.18.			
					(A.17.)			(A.17.)
	Added support		A.4.				A.4.	
					A.17.			A.17.
			A.19				A.19	
		A.21.			A.21.			
						A.6.		
	Building valves together					A.6.		
	Hydraulic hoses	A.7.						

Evaluation of the mitigation methods

Evaluating mitigation

- Evaluation of a mitigation project consists of:
  - How much pipe vibrations have been reduced
  - What kind of problems have there been during the mitigation project
  - What kind of adverse effects has the mitigation caused

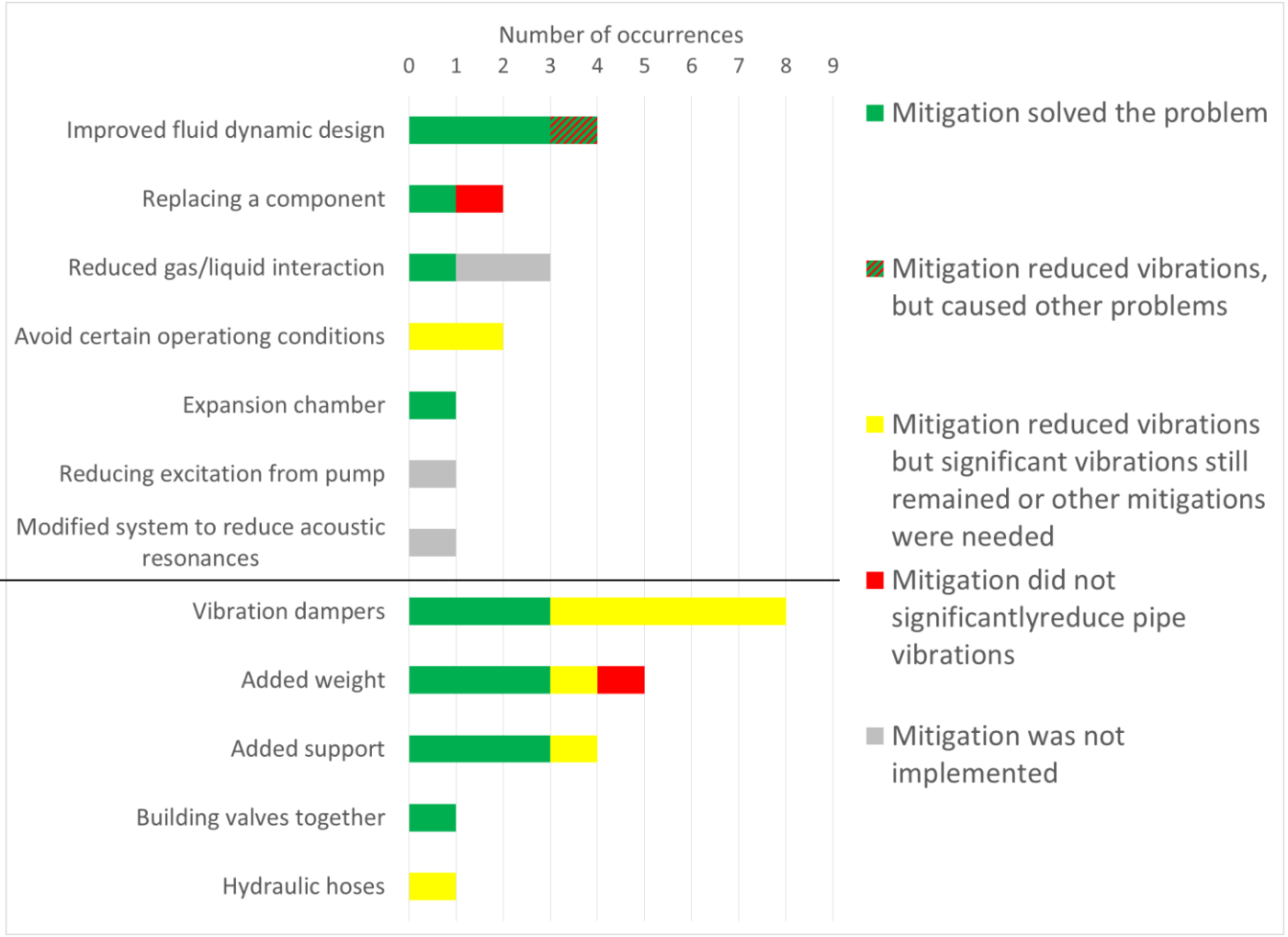
Problems and adverse effects

- Effect on RPV level measurement
- Increased valve opening times
- Accessibility and maintenance issues
- Increased pressure drop
- Attachment of the added weights

Success of reducing vibrations

Reducing excitations

Reducing response



Conclusions

Conclusions

- Knowledge of pipe vibration analysis and mitigation methods is very valuable for ensuring the continuous and safe production at the nuclear power plants
- Pipe vibration problems occurred at the sites over the years cover a wide range
  - Several small problems that can be easily mitigated
  - But also larger problems which have required years of work
    - Severe problems are not frequent
    - But when they occur, the effect on unit operation is large

Conclusions

- Many similarities between the problems at different sites
- Problems were grouped according to location and physics
  - Problems belonging to the same groups typically had many similarities with each other
- The investigation showed that there have already been very large benefits from cooperation between the sites
  - Information from other sites has been used to avoid problems
  - Used components have been exchanged between sites
- Many of the problems are still rather unique
  - It is not always possible to reuse a previously successful mitigation method

Conclusions

- It is always preferable to take into account possibility of pipe vibrations before:
  - Power uprates
  - Major modifications
- Handling the vibrations before they exist is often easier than when they already have occurred
- The workflows for analysing and mitigating vibrations are different for existing and potential future vibrations
- It is preferable to analyse vibrations both with measurements and simulations
  - Measurements give more accurate information of the current status
  - Simulations provide more predictive information

Conclusions

- Mitigation methods were divided into two main categories, based on whether they target:
  - The excitation for the vibrations

  or
  - The vibration response
- The mitigation targeting the excitation was found to be on average more successful
- Often mitigation targeting on response is implemented first
  - These kind of mitigations are usually simpler to implement
  - They give time for planning and implementing final mitigation

Future work

Ongoing work

- M.Sc. thesis work ongoing
  - B.Sc. Mikko Merikoski: ”Pipe vibrations and mitigation in power plants”
  - The previous work will be extended with:
    - Literature survey of pipe vibrations at other nuclear power plants worldwide
    - More quantitative information e.g. of the vibration levels in the problems studied in the previous work

Thank you!