ÚJV Řež, a. s.

LTO Problems of the WWER 440/213 Core Barrel

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Motivation

- **To explain main problems of the WWER 440/213 core barrel LTO i. e.:**
  - to define main safety related parts
  - methods of the solution

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Content

- Upper flange and the couple key-groove as the safety related parts of the core barrel: LTO problems
- Stress state of the upper flange
- The couple key and the groove in the lower part of the reactor pressure vessel

Upper Flange of the Core Barrel

- **Loading cases of the core barrel upper flange**
  - Bending moment induced by the pendulum motion of the core barrel and the RPV generated by the main circulation pump pressure pulsations
  - Maximal design earthquake
- **Input for the calculations: bending moments**
- **Method of the solution: FEM**
- **Results of the solution: all calculated stresses are under allowable stress limits**

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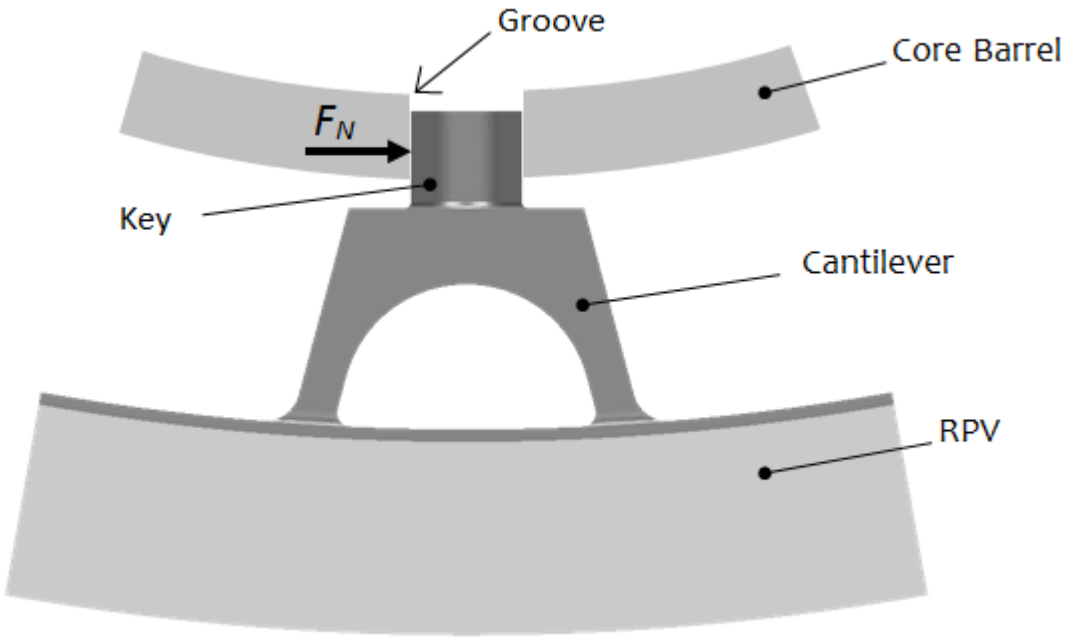
Couple the Key and the Groove in the Lower Part of the RPV

- Basic design
- Design gap 0,05 ÷ 0,17 mm



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Couple the Key and the Groove in the Lower Part of the RPV (cont. 1)

- **Increasing of the gap above the allowable gap limits results in impacts.**
- **Main questions**
  - Is this phenomenon detectable using reactor vibrations diagnostic system?
  - Is it possible to predict this increasing?

Couple the Key and the Groove in the Lower Part of the RPV (cont. 2)

- Original method of the prediction based on the work of friction forces:

$$\Delta m = \mu \frac{f(\omega)}{f_0} W \frac{t_{op}}{T_0}$$

Where:

Δm… loss of the mass due to friction wear [g]

μ … friction wear coefficient: results of experiments [g/J]

$f(\omega)$ … friction coefficients, depends on ω, [-]

f_0 … design value of the friction coefficient [-]

t_{op} … time of operation [s]

T_0 …period of the exciting forces [s]

W … work of the friction forces [J]

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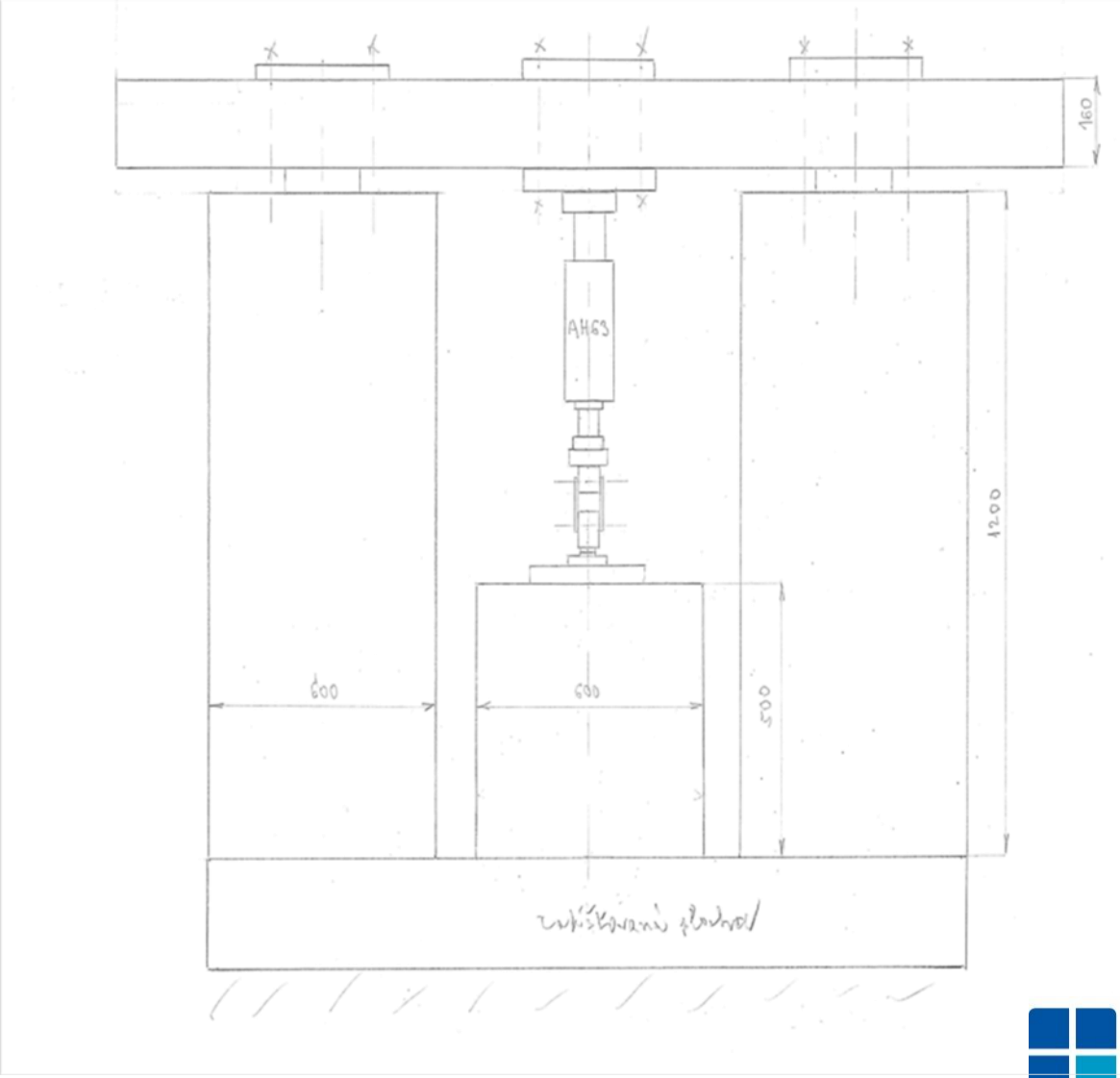
Couple the Key and the Groove in the Lower Part of the RPV (cont. 3)

- Experimental device – vertical force



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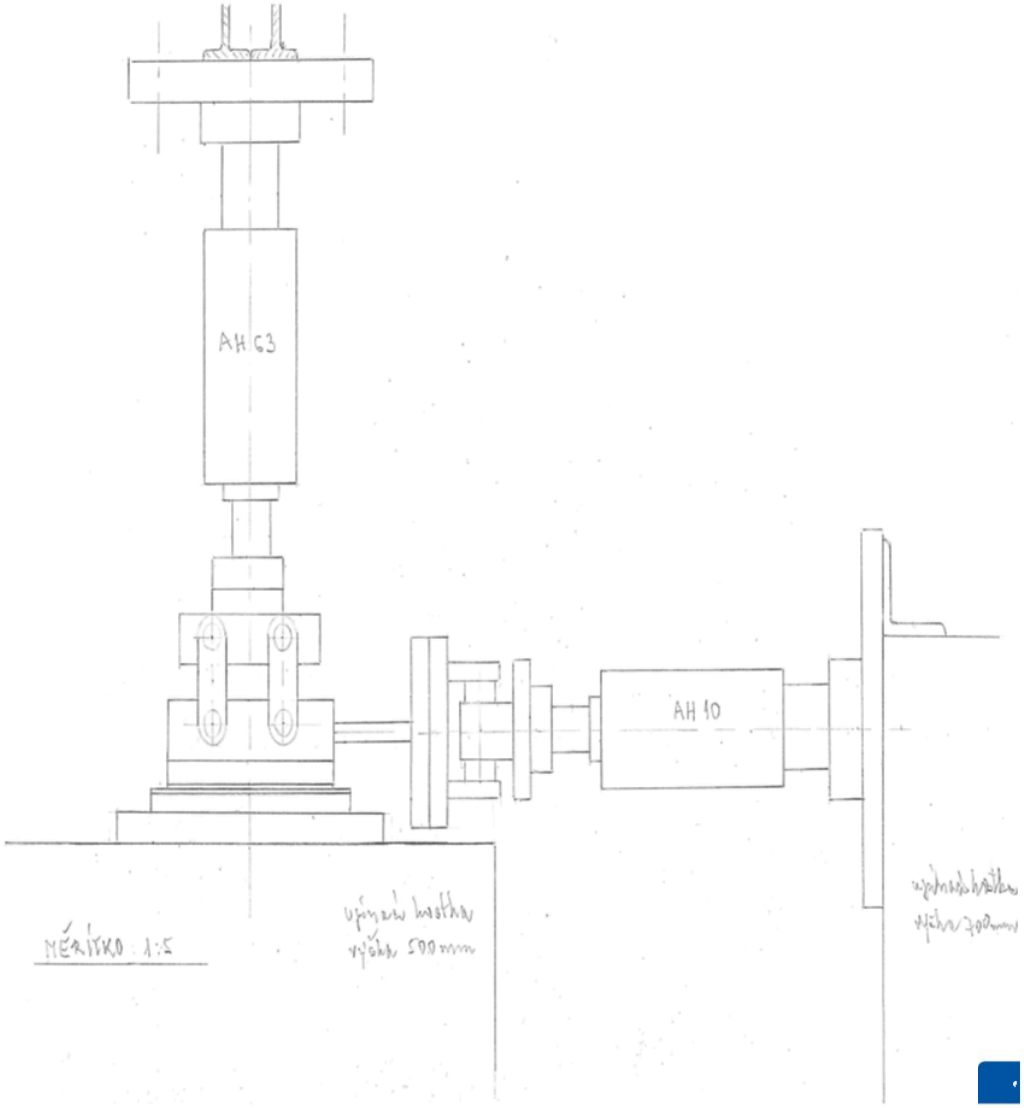
Couple the Key and the Groove in the Lower Part of the RPV (cont. 4)

- Overall view on the horizontal hydraulic cylinders



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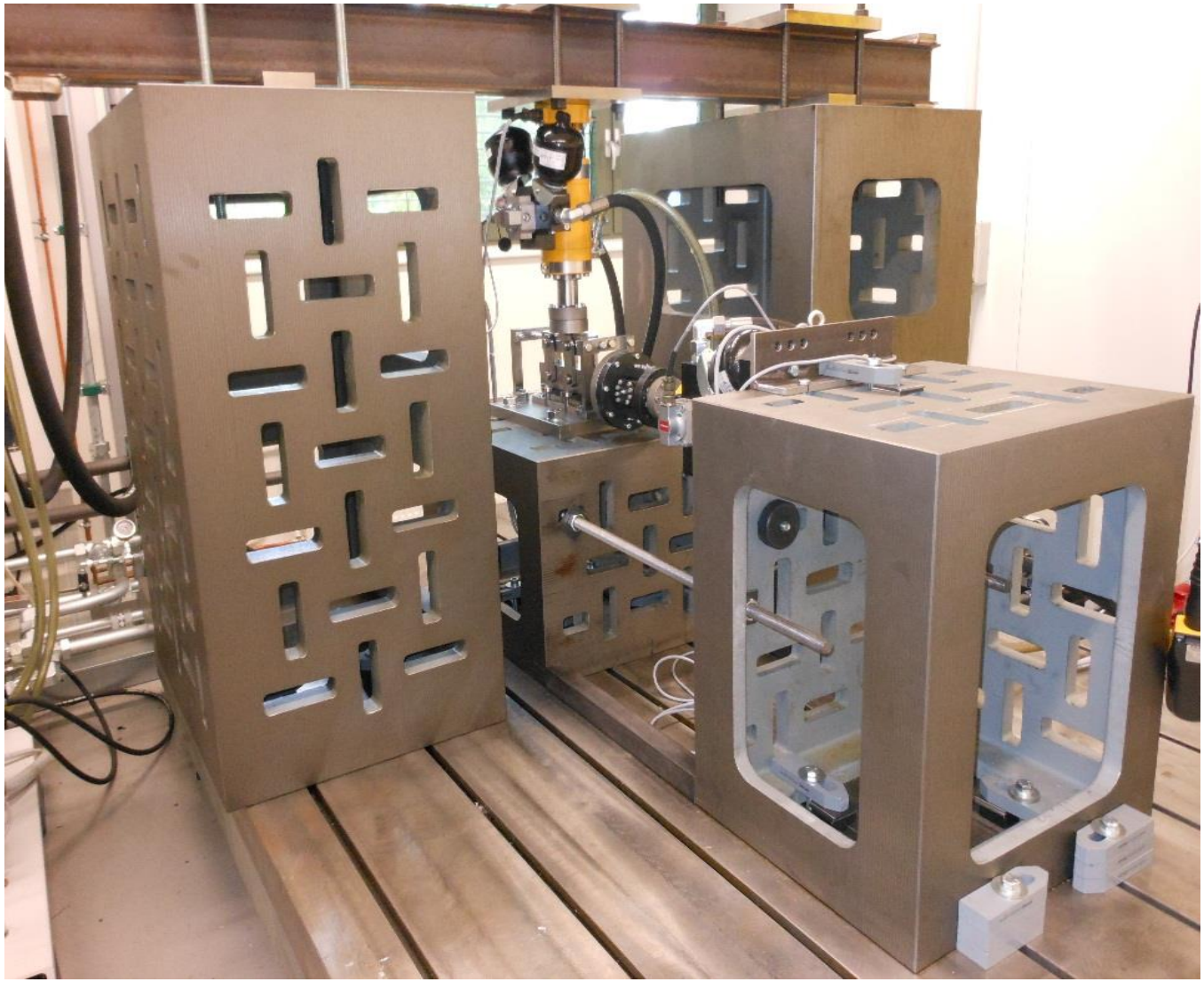
Couple the Key and the Groove in the Lower Part of the RPV (cont. 5)

- Overall view on the experimental device



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Couple the Key and the Groove in the Lower Part of the RPV (cont. 6)

- Evaluation of the experiments
- Friction coefficient as the function of frequency:

$$f = \frac{F_{exp}}{F_N} + \frac{mX\omega^2}{F_N} - \frac{2f_p r_p}{l}$$

f_p … coefficient of the pin friction

r_p … radii of the pin

F_{exp} … measured force

F_N … pushing force

m … accelerated mass

X … amplitude

ω … angular frequency

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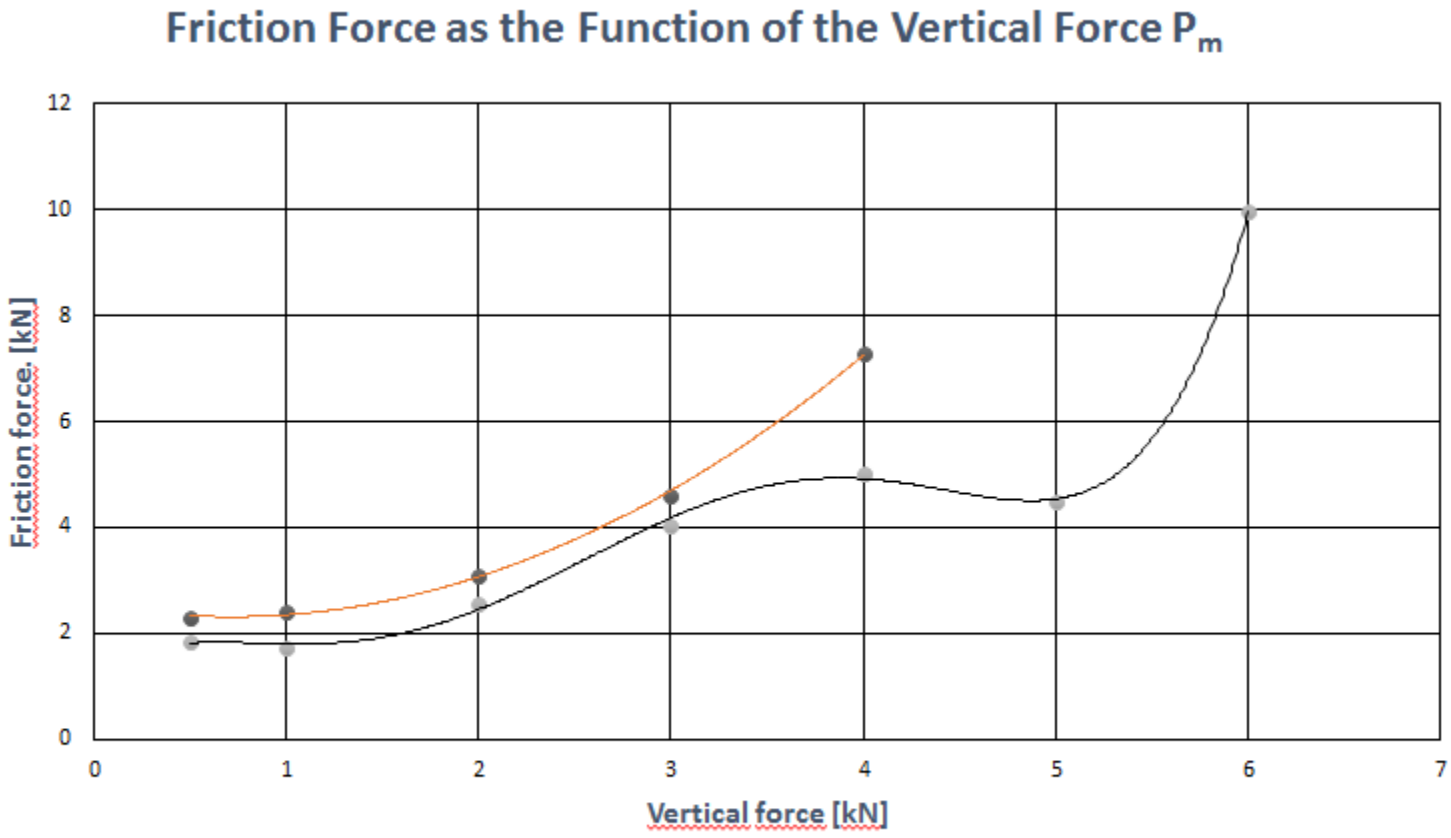
Couple the Key and the Groove in the Lower Part of the RPV (cont. 7)

- **Results of the experiments**



Black curve A = 5 mm, f = 15 Hz

Red curve A = 3 mm, f = 25 Hz

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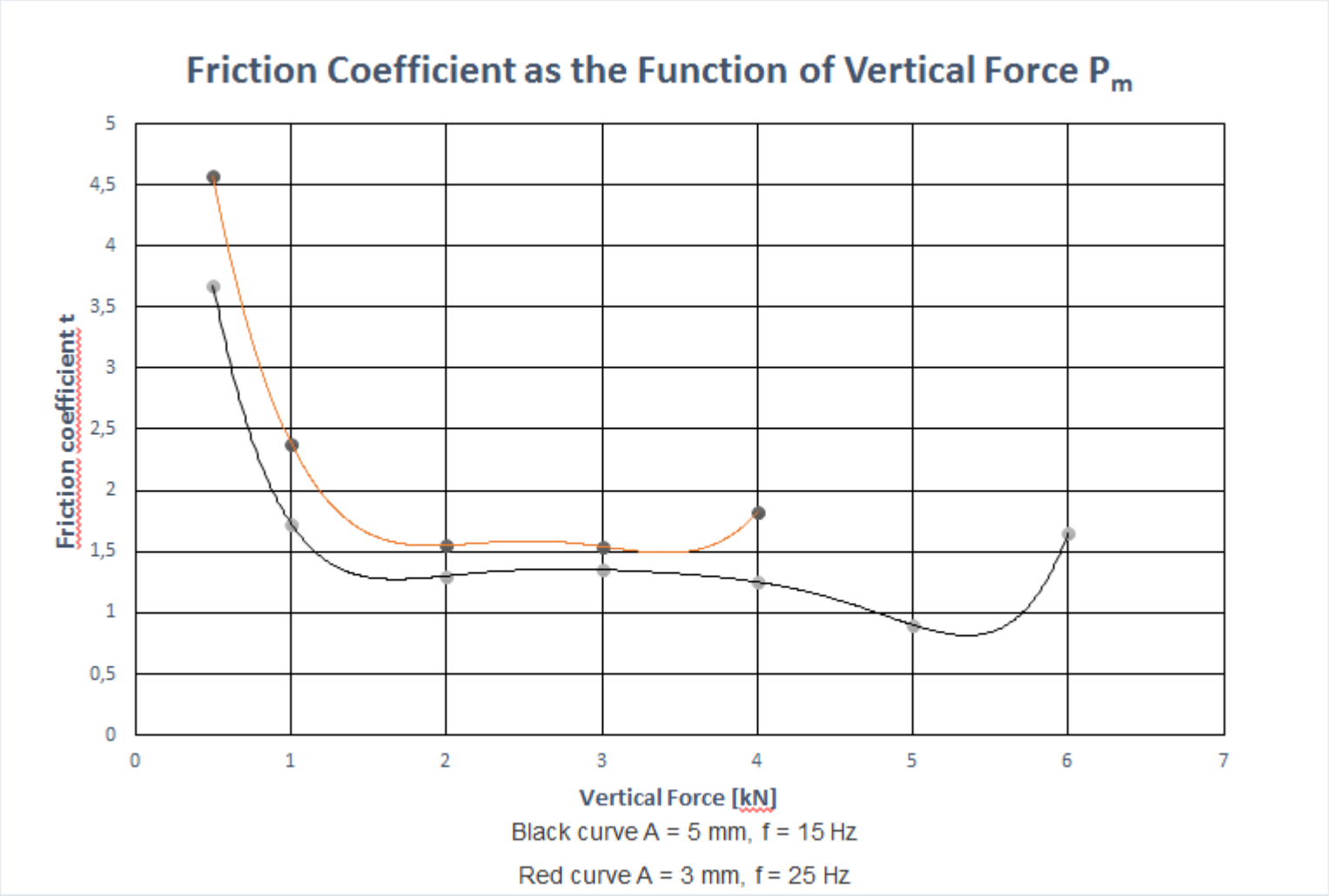
Couple the Key and the Groove in the Lower Part of the RPV (cont. 8)

- **Results of the experiments**



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Couple the Key and the Groove in the Lower Part of the RPV (cont. 9)

- Question: is the increasing of the gap detectable using reactor vibration monitoring system?
- Results of the measurement, NPP Dukovany

Frequency Hz	Description
6.3	First acoustic standing wave in primary circuit
8.6	RPV and reactor internals in vertical direction
11	Nonidentified
12.8	Second acoustic standing wave in primary circuit
16	Nonidentified
22.4	RPV and reactor internals in vertical opposite direction
24.8	Pressure pulsations generated by main circulation pump
27.9	Vertical vibrations of the upper block
37.5	3/2 ultrasubharmonic to the frequency 24.8

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Couple the Key and the Groove in the Lower Part of the RPV (cont. 10)

- **Explanation of the frequencies 11 and 16 Hz**
  - Calculation of the reaction eigenfrequencies with zero gap
  - Existence of double frequencies $\Omega_{22} = \Omega_{23} = 12.7$ Hz and $\Omega_{28} = \Omega_{29} = 18.15$ Hz
  - Increasing of the gap represents from the mechanical point of view nonlinear problem
  - It results in splitting of the double frequencies in skeleton curves
  - Shape of the skeleton curves as the function of the gap explains the nature of the frequencies 11 and 16 Hz
  - This phenomenon is possible to be understood as the diagnostic symptom
  - Increasing of the frequencies 11 and 16 Hz represents increasing of the gap

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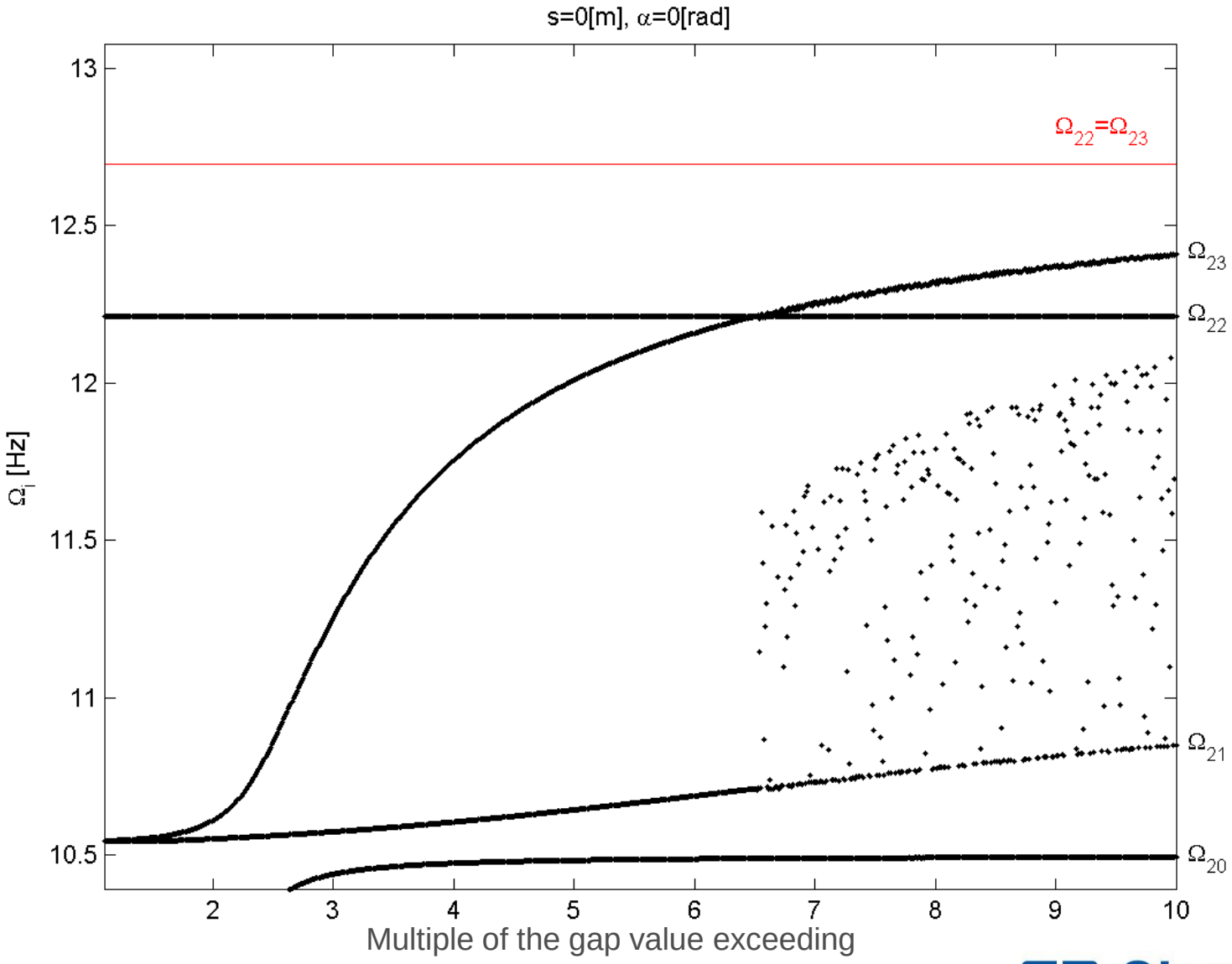
Couple the Key and the Groove in the Lower Part of the RPV (cont. 11)



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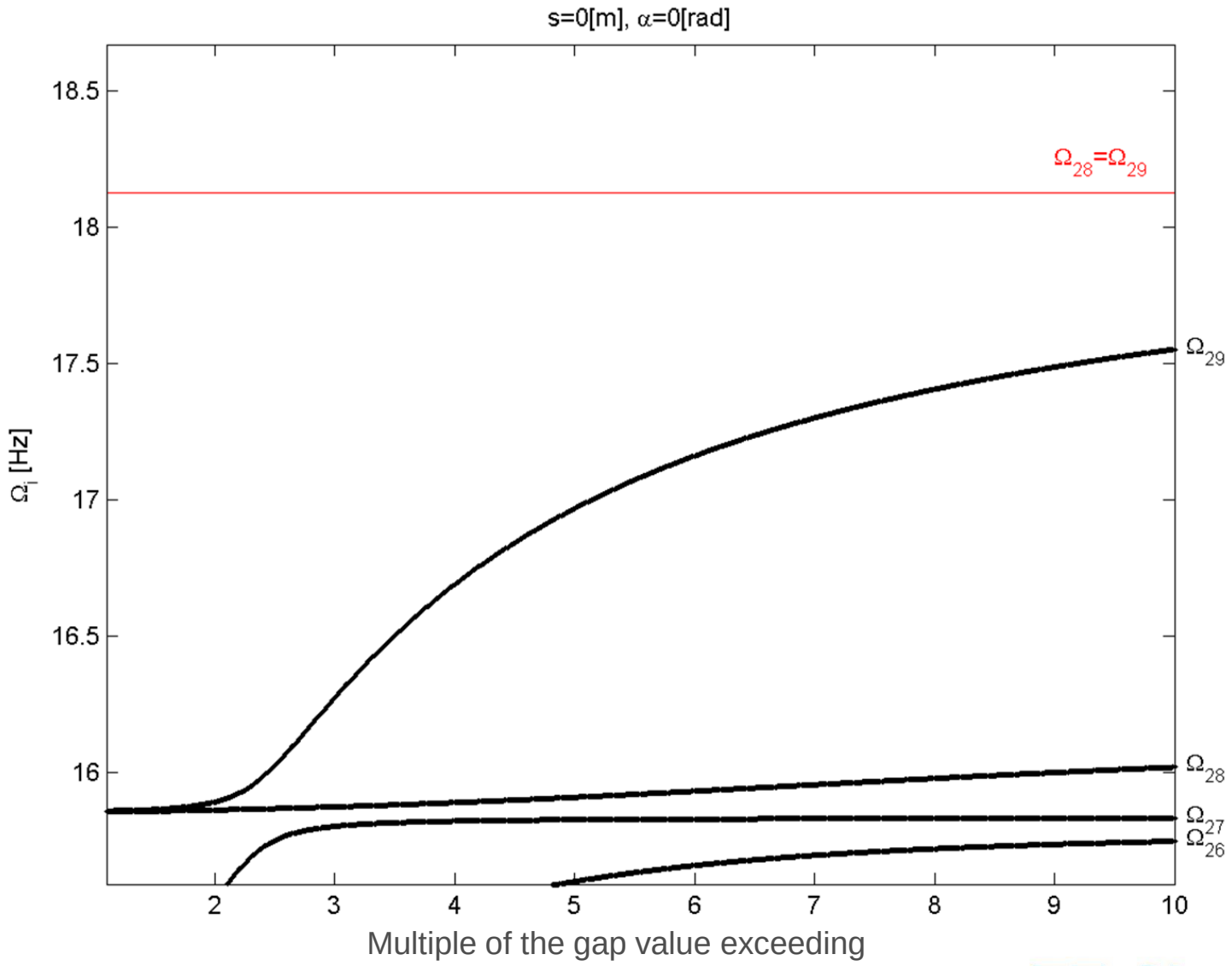
Couple the Key and the Groove in the Lower Part of the RPV (cont. 12)



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Conclusions

- LTO problems of the WWER 440/213 have been discussed
- The couple key – grrove in the lower part of the RPV represents main safety problem
- Potential increasing of the gap value between the key and the groove must be monitored
- Using the results of the experiments and appropriate mathematical model increasing of the gap is possible to predict
- Increasing of the value is possible to detect by the changes in reactor vibration frequency spectrum
- Further diagnostic measurements and experimental works are needed

Questions?

Thank you for your attention