Optimized field balancing using Model Based Balancing (MBB)

Application to Ringhals 32

November 10, 2017

Introduction & Motivation

Balancing of flexible Rotors with MBB

Why is site balancing needed ?

- In the life time of a machine train, **rotor balancing usually cannot be avoided** to meet vibration criteria which ensure long term integrity of the different components including shafts and bearings
- Typical site balancing
  - is conducted using the **Influence Coefficients (IC's)** method
  - has **two main drawbacks**

Time consuming activity → Performed under **time pressure**

Balancing of flexible Rotors with MBB

Influence coefficients method drawbacks

Time consuming activity

Because...

- **Test runs** are needed to gather IC's → 1 test run per plane
- Unit **needs to be stopped/cooled down/restarted** → ranges from time consuming to very time consuming when hot sections (i.e. HP) or H2-filled generators need to be accessed

Because...

- Usually on the critical path (end of inspection or forced outage) → last step before the unit goes back to **commercial operation**
  - Not all required test runs always performed («one plane approach»)
  - Compromises regarding selection of balancing planes
- High customer expectations

Performed under **time pressure**

Balancing of flexible Rotors with MBB

Why MBB will help ?

Idea supporting the new approach

Replace all field **test runs** required for final balancing of the unit by **model-based run-ups**

➔ **virtual influence vectors** generated via **digital twin**

Expected key benefits

Maximized availability on the balanced unit (shorter inspections/outages)

Cost reduction of the balancing activity

No compromise on the balancing quality

Preconditions

OEM knowledge for accurate calculation models including all significant effects

Tight collaboration between R&D and execution teams

System linearity as for any balancing activity

Balancing of flexible Rotors using influence coefficients

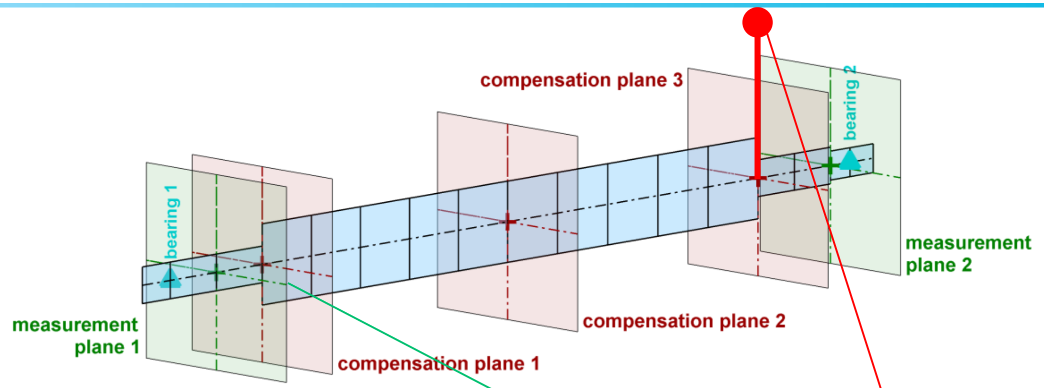
Influence Coefficients

Theoretical approach...

- IC's are output / input ratios....

Influence Coefficient

$$\alpha_{ik}(\Omega) = \frac{x_i(\Omega)}{U_k}$$



$$\left(\boldsymbol{K} + j\Omega\boldsymbol{D} - \Omega^2\boldsymbol{M}\right)\boldsymbol{x}(\Omega) = \boldsymbol{F}(\Omega)$$

System parameters

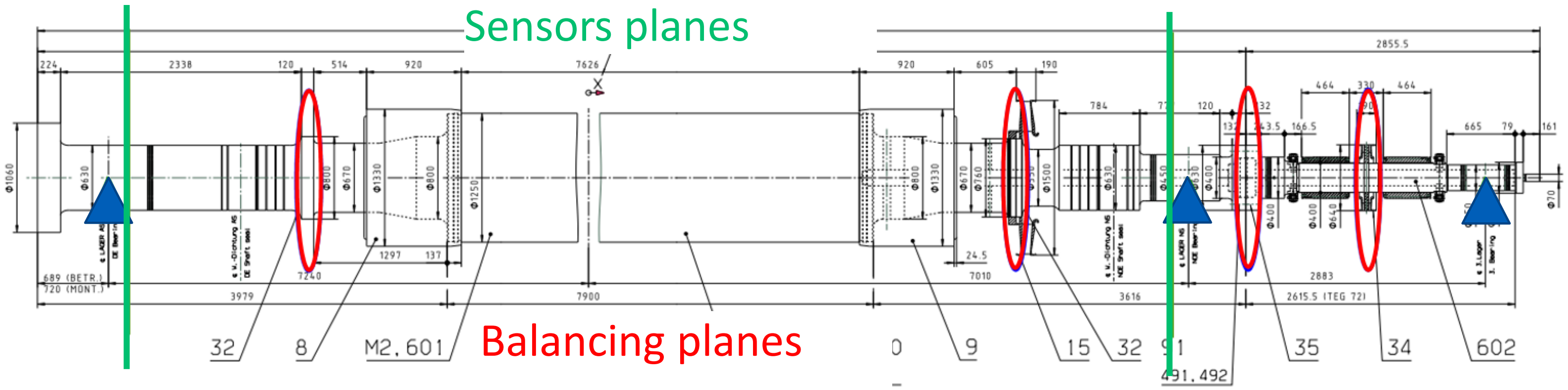
$$\boldsymbol{F}(\Omega) = \boldsymbol{U}\cdot\Omega^2$$

$$U_k = m_k \cdot e_k$$

Influence Coefficients: complex ratio of the response x_i to a given unbalance U_k (the testweight)

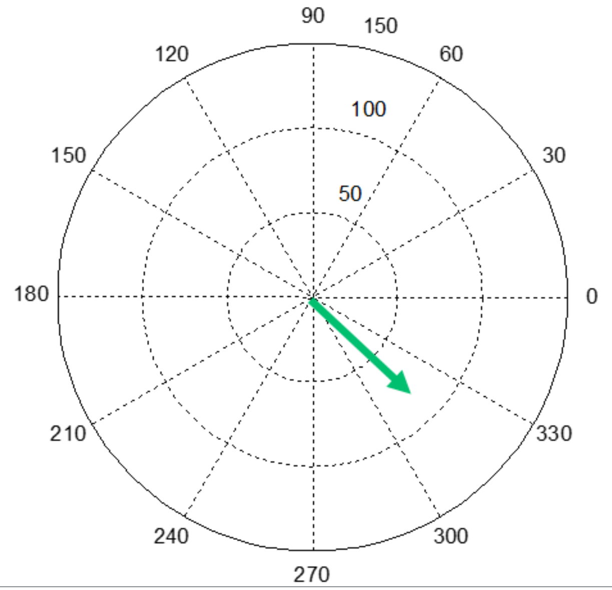
Influence Coefficients

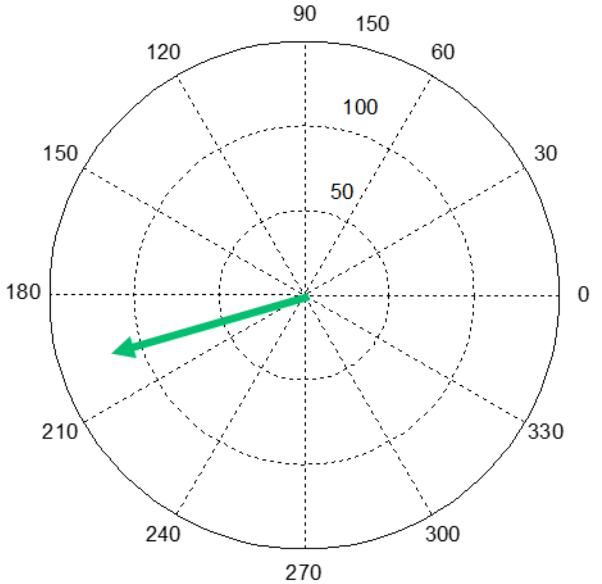
Practical approach... a simple example



1

Reference run

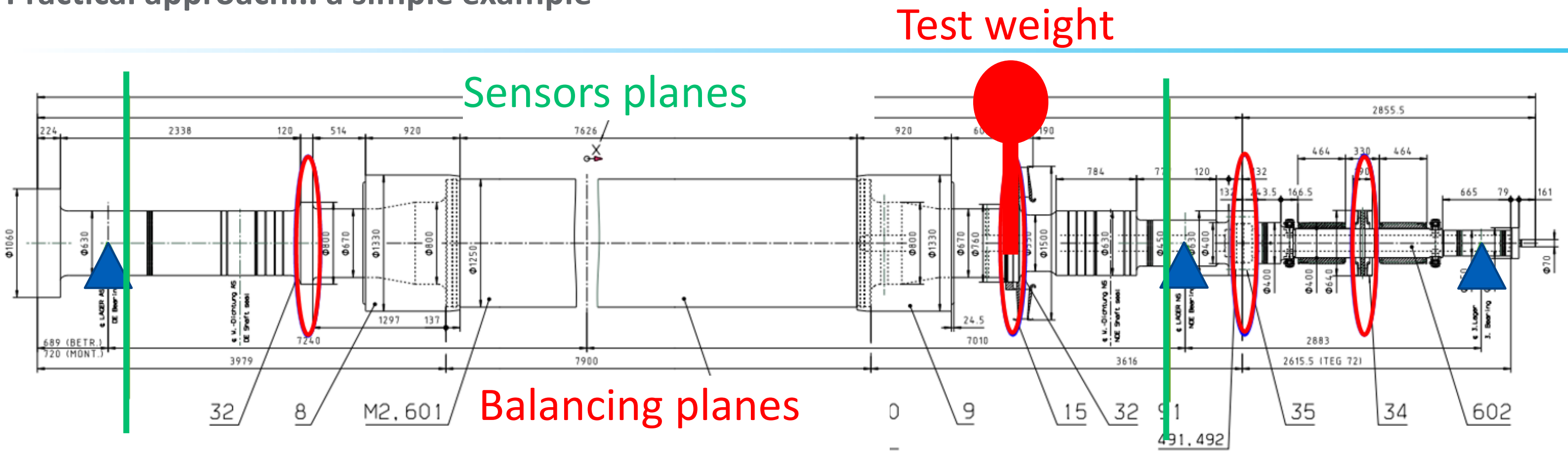




Vibration response amplitude to «residual» unbalance distribution @ e.g. 3000rpm

Influence Coefficients

Practical approach... a simple example



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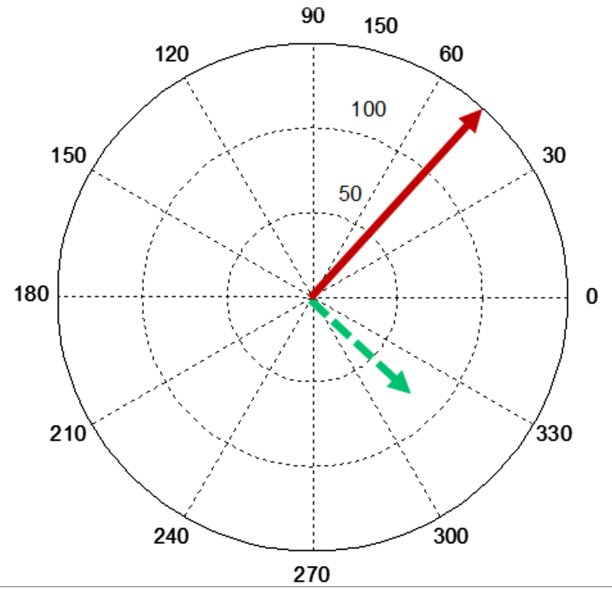
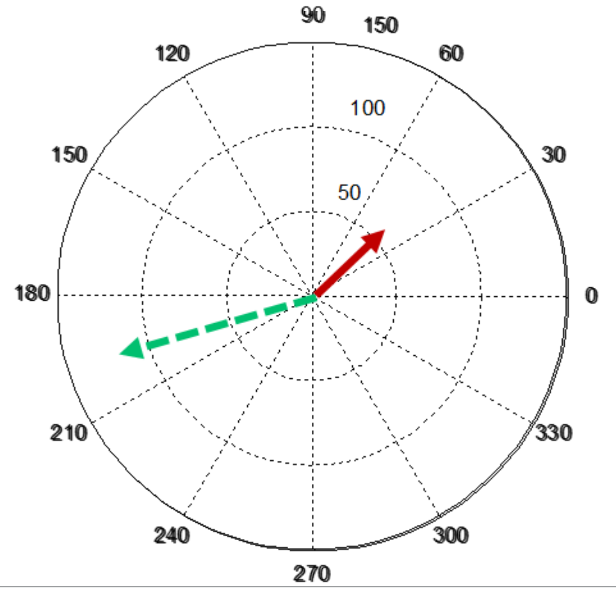
Test run



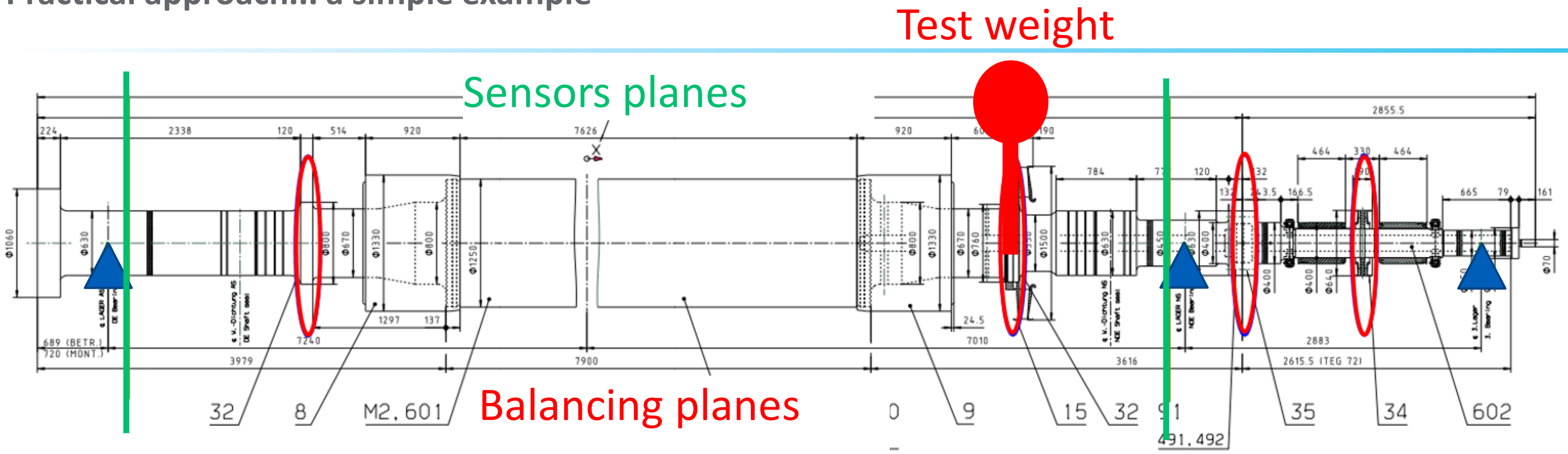


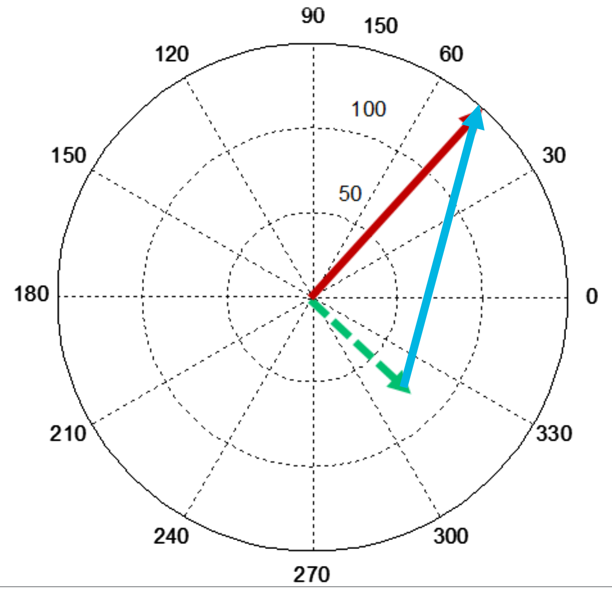
Response to «residual» unbalance @ e.g. 3000rpm

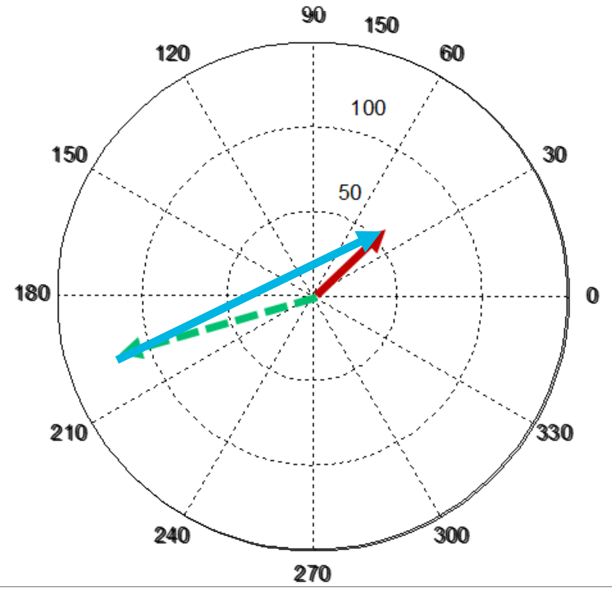
Response to resid. unbalance and test weight

Influence Coefficients

Practical approach... a simple example







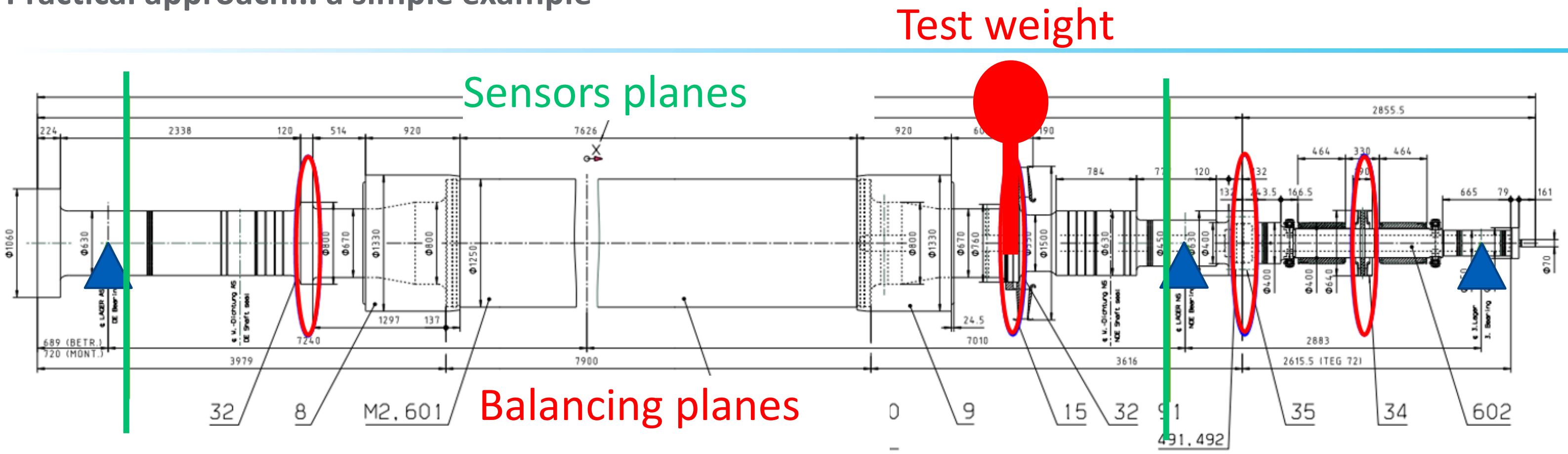
Response to «residual» unbalance @ e.g. 3000rpm

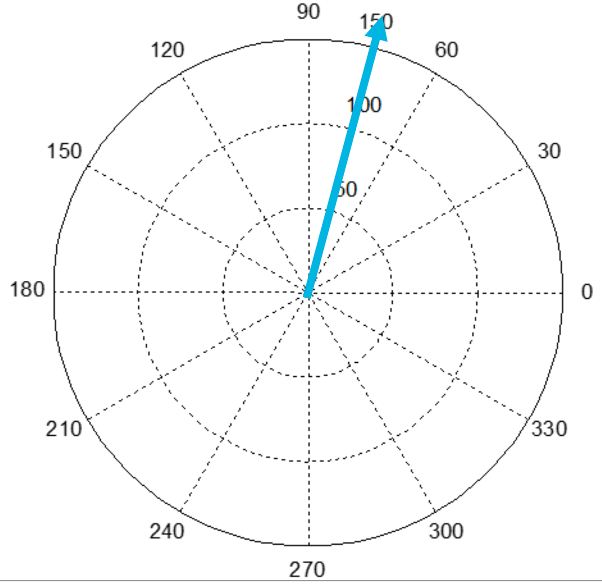
Response to resid. unbalance and test weight

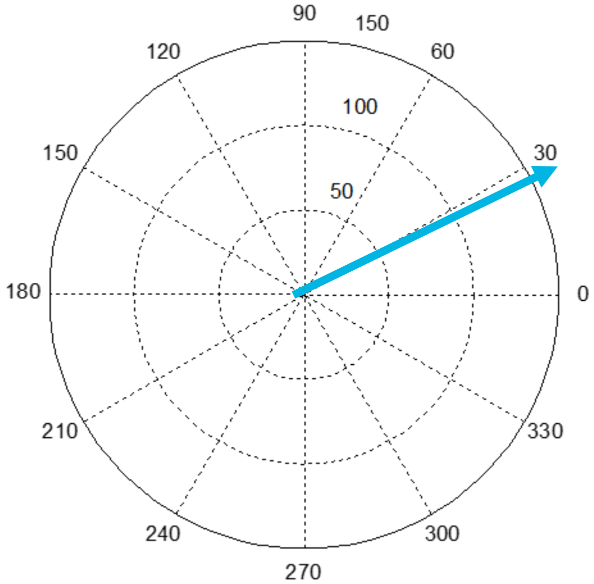
➔ **Influence of test weight**

Influence Coefficients

Practical approach... a simple example







3

Influence coefficient

Influence of test weight on both sensor planes

... for one speed
... for one test weight setup

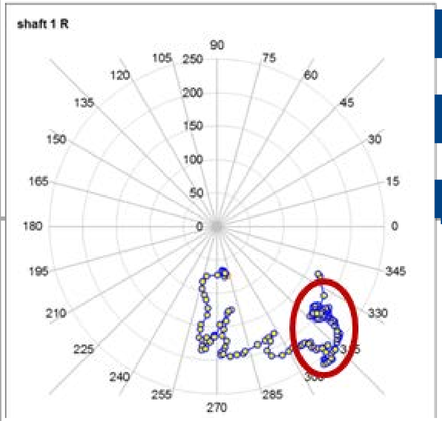
Replacing measured IC’s by virtual ones

How MBB replaces measurements

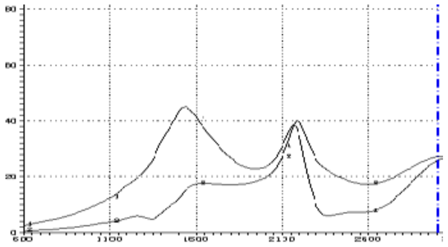
Excessive vibration – Balancing needed

Balancing completed – Acceptable vibration

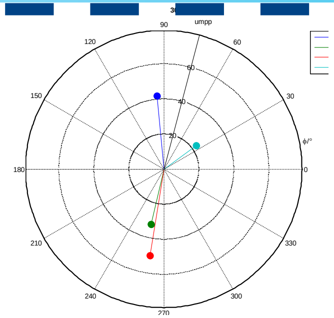
Classic balancing approach



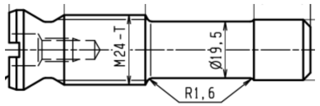
Influence coefficents runs



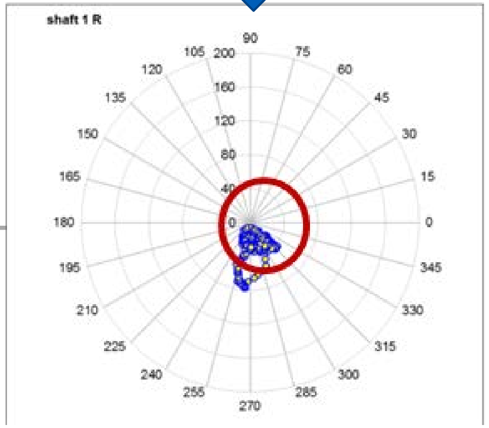
Unit run-up and coast down (*n)



Measured influence coefficients



Selection of bolt weight and position for **final balancing**

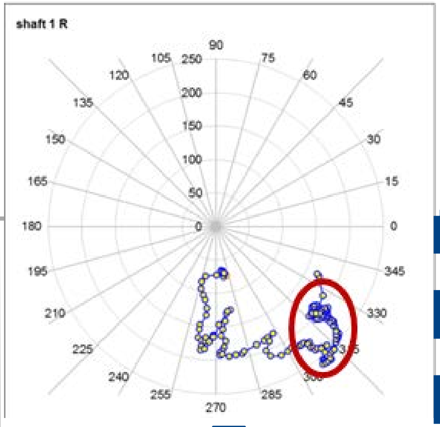


How MBB replaces measurements

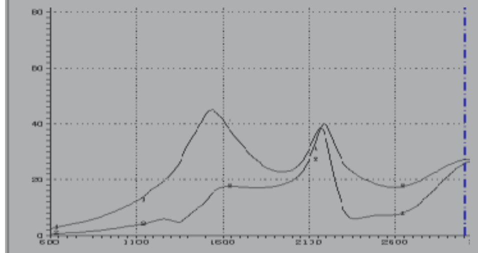
Excessive vibration – Balancing needed

Balancing completed – Acceptable vibration

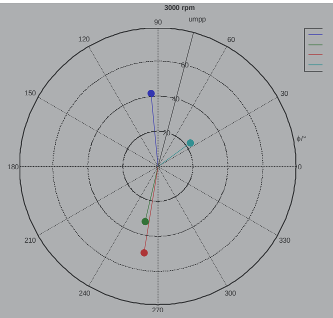
Classic balancing approach



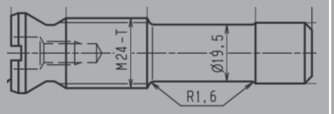
Influence coefficents runs



Unit run-up and coast down (*n)



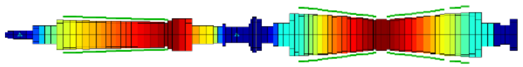
Measured influence coefficients



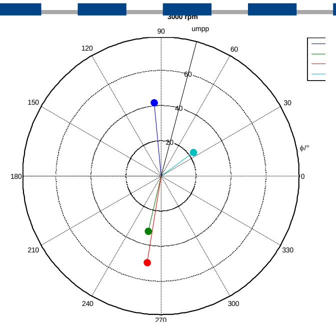
Selection of bolt weight and position for **final balancing**

MBB

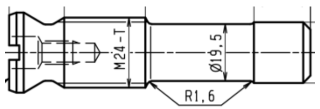
Calculation with **digital twin** replaces physical runs



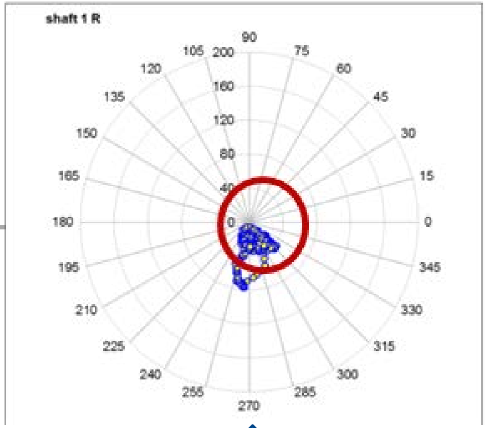
NO NEED to run the unit !



Virtual influence coefficients



Selection of bolt weight and position for **final balancing**

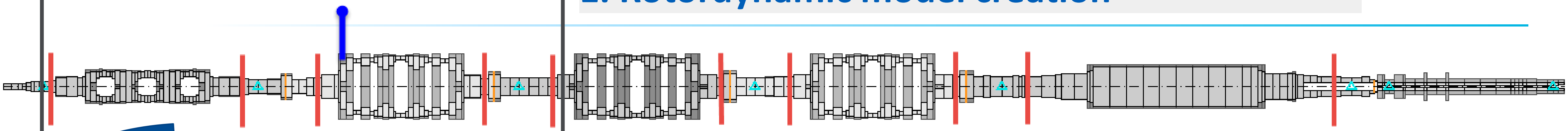


Key benefits

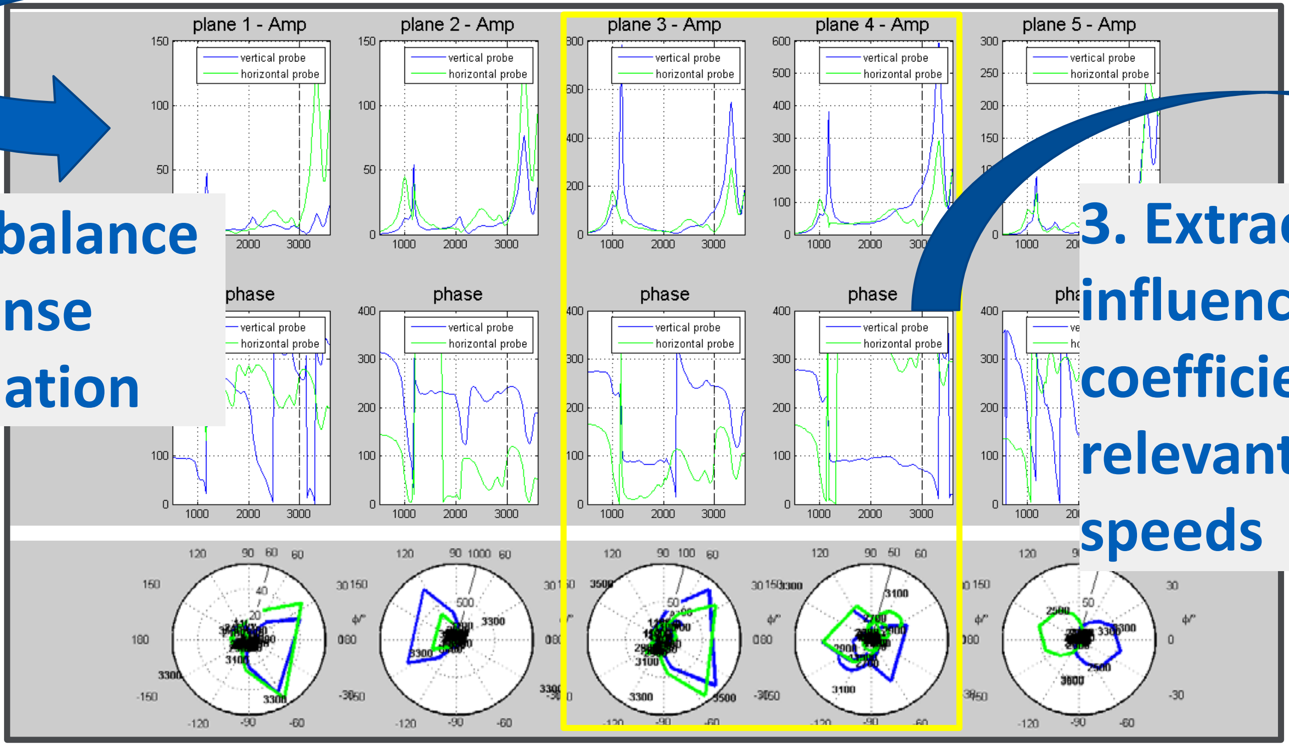
MAXIMIZED UNIT AVAILABILITY	COST REDUCTION	BALANCING QUALITY
~3 days saved in average	~0.5M€ / day saved	No compromises with MBB

How to produce model-based virtual IC’s

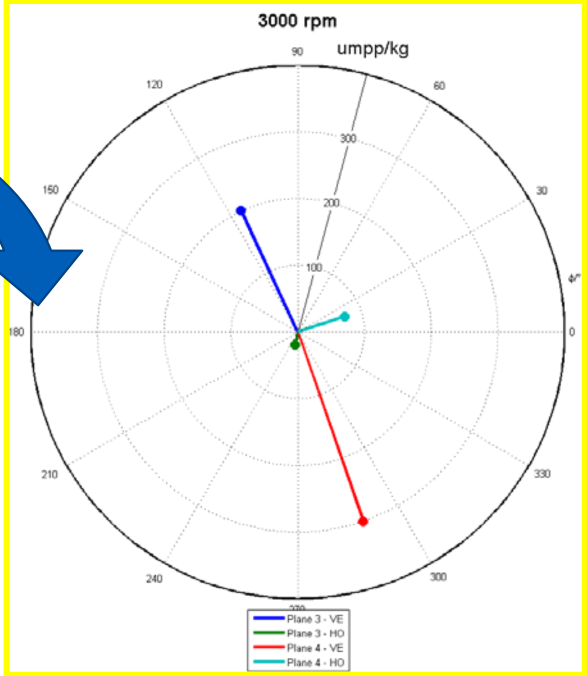
1. Rotordynamic model creation



2. Unbalance response calculation



3. Extraction of influence coefficients at relevant speeds

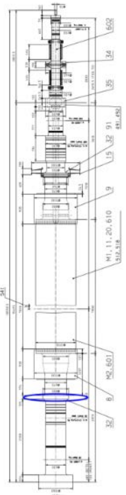


5x3x~15 > 200 similar plots for MBB

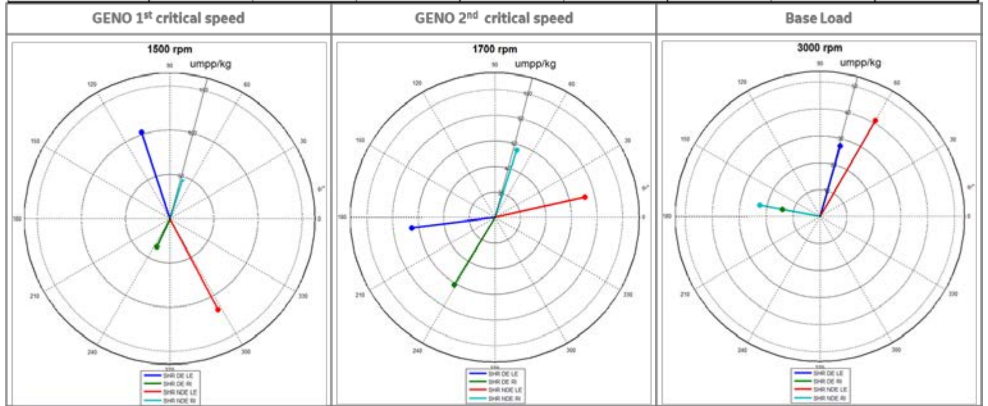
Inputs for balancing actions

Example of Generator rotor balancing

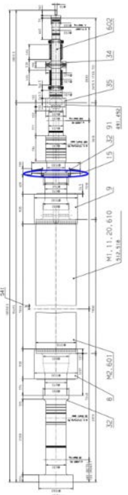
!! 1kg Unbalance Mass at 0° !!



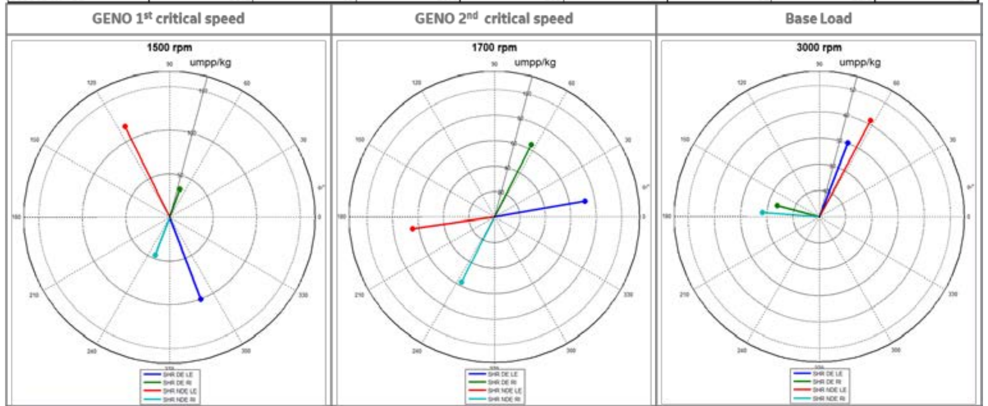
FAN HUB DE	SHR DE LE		SHR DE RI		SHR NDE LE		SHR NDE RI	
LAG CONVENTION	Amp (pk-pk)	phase	Amp (pk-pk)	phase	Amp (pk-pk)	phase	Amp (pk-pk)	phase
1500 RPM (Hot)	102.6	108	35	245	116	298	47	72
1700 RPM (Hot)	65.6	187	61.4	239	72.4	13	55.4	72
3000 RPM - BL	27.2	74	14.2	169	41	60	22.8	169



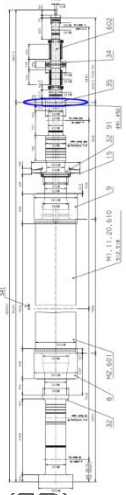
!! 1kg Unbalance Mass at 0° !!



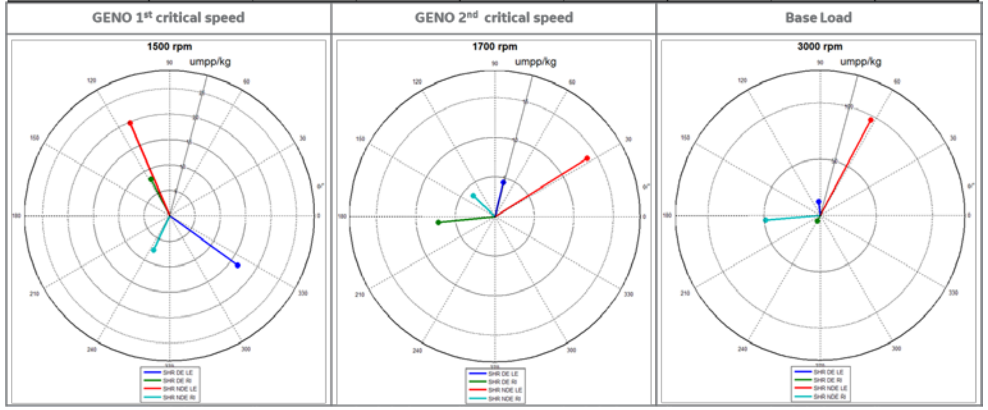
FAN HUB NDE	SHR DE LE		SHR DE RI		SHR NDE LE		SHR NDE RI	
LAG CONVENTION	Amp (pk-pk)	phase	Amp (pk-pk)	phase	Amp (pk-pk)	phase	Amp (pk-pk)	phase
1500 RPM (Hot)	100.2	291	34.4	70	116.2	116	45.8	249
1700 RPM (Hot)	72.4	10	63.6	63	65	188	57.2	243
3000 RPM - BL	30.2	69	16.6	165	41.4	62	21.8	176



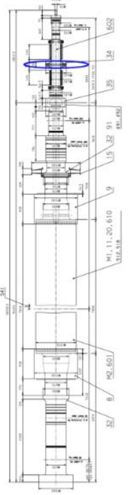
!! 1kg Unbalance Mass at 0° !!



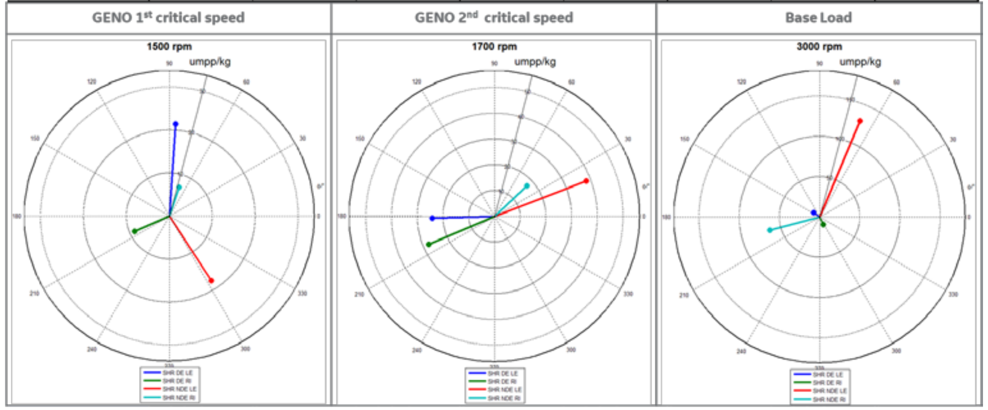
NDE COUPLING	SHR DE LE		SHR DE RI		SHR NDE LE		SHR NDE RI	
LAG CONVENTION	Amp (pk-pk)	phase	Amp (pk-pk)	phase	Amp (pk-pk)	phase	Amp (pk-pk)	phase
1500 RPM (Hot)	16.6	324	8	117	19.8	113	7.4	245
1700 RPM (Hot)	4.4	76	7.2	186	13.8	32	3.8	136
3000 RPM - BL	12.2	96	5.6	244	96.2	62	48.8	185



!! 1kg Unbalance Mass at 0° !!



EXCITER FAN	SHR DE LE		SHR DE RI		SHR NDE LE		SHR NDE RI	
LAG CONVENTION	Amp (pk-pk)	phase	Amp (pk-pk)	phase	Amp (pk-pk)	phase	Amp (pk-pk)	phase
1500 RPM (Hot)	21.4	86	8.8	204	18	303	7	71
1700 RPM (Hot)	24.2	182	27.8	203	38.2	21	17.2	43
3000 RPM - BL	9	146	10.6	295	129	67	64	195



Previous experiences with MBB

MBB experience

Benefits seen on every occasions

- Applied to > 8 power plants
- Typical reduction around 30...50% of the total balancing time
- Success rate: 100 %

Feedbacks from the field

Benefits seen on every occasions

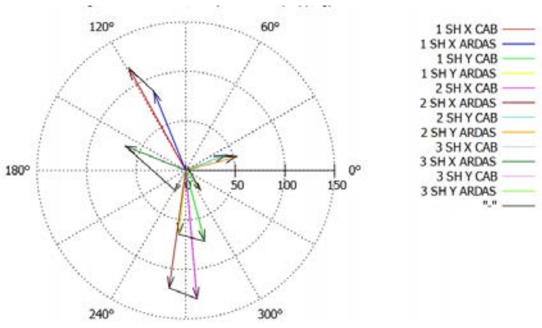
"The customer could return the machine to the load dispatcher two days earlier, which was a huge benefit for them"

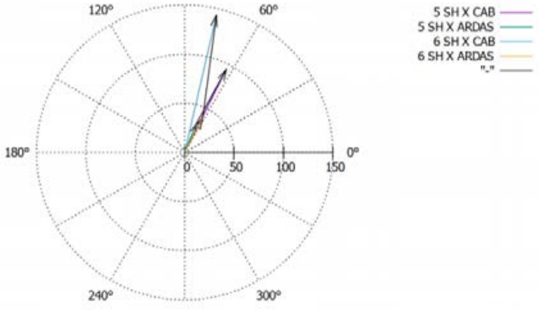
1000MW fossil plant
Malaysia

660MW fossil plant
UK

"The customer was satisfied with the success of the balancing.
Especially considering the fact that two years ago a third party needed 5 balancing runs for LP balancing and had less success with the reached vibration level"

It works





"Using the calculated influence coefficients it was possible to balance with one balancing run.
The customer was very satisfied!
Normally three balance runs would be necessary for a comparable task."

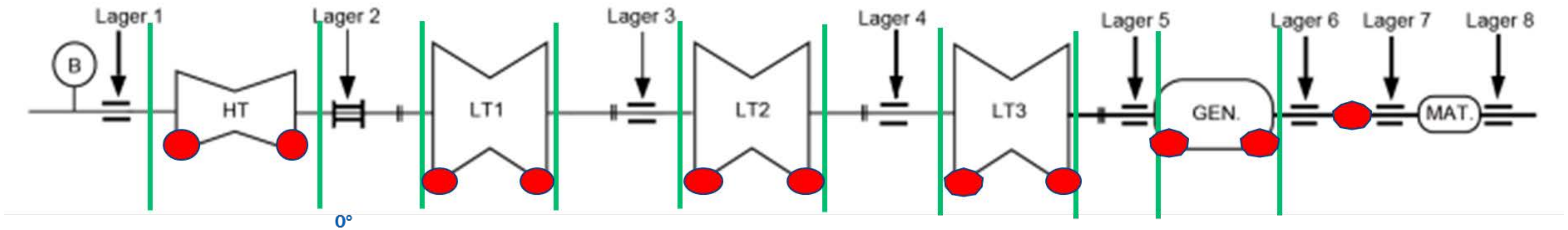
550MW fossil plant
Germany

MBB for Ringhals 32

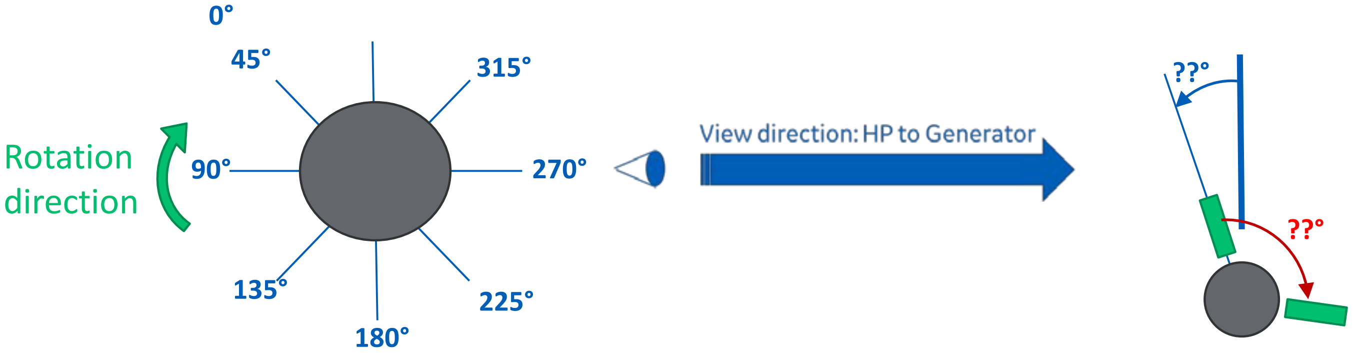
Ringhals 32 - shaft line configuration

Required information

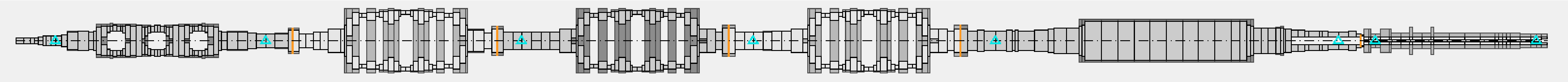
Axial position of
- balancing planes
- sensors planes



Orientation of all probes

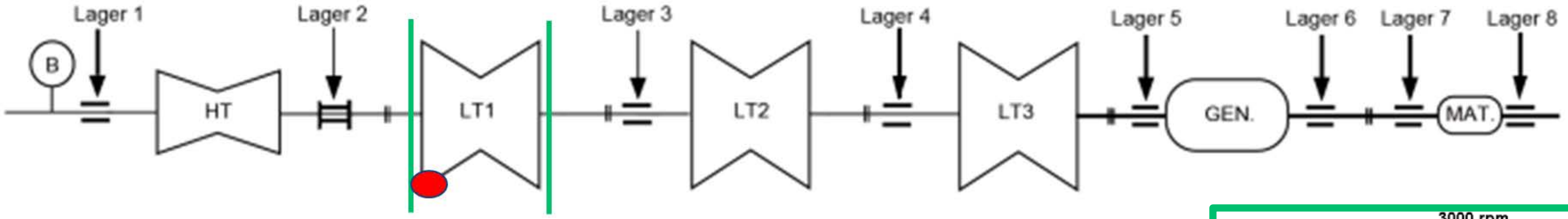


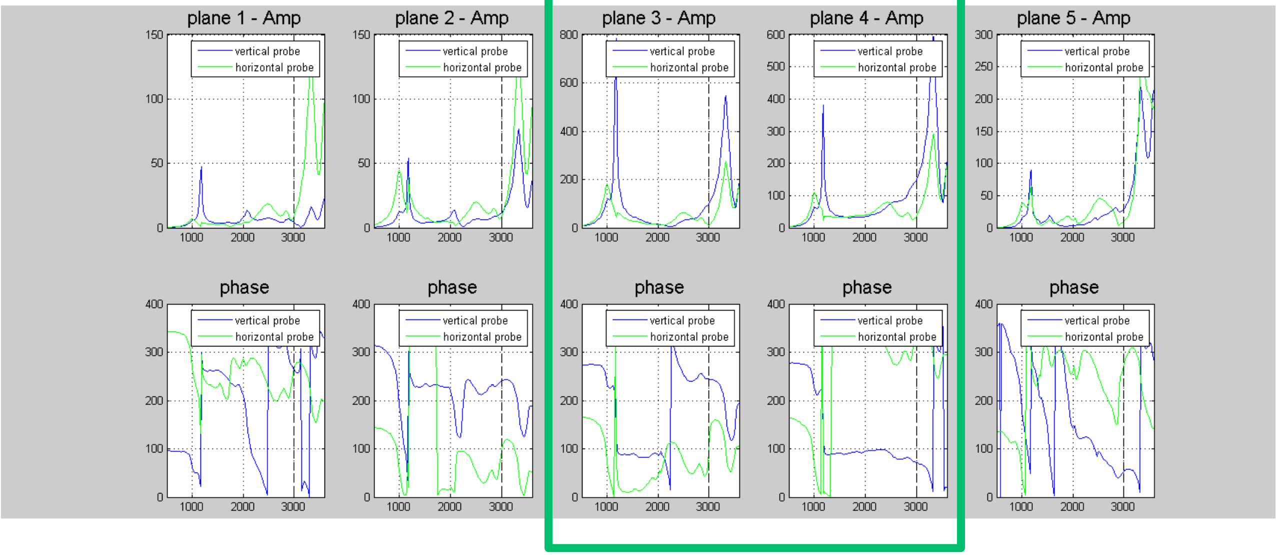
Rotordynamic model

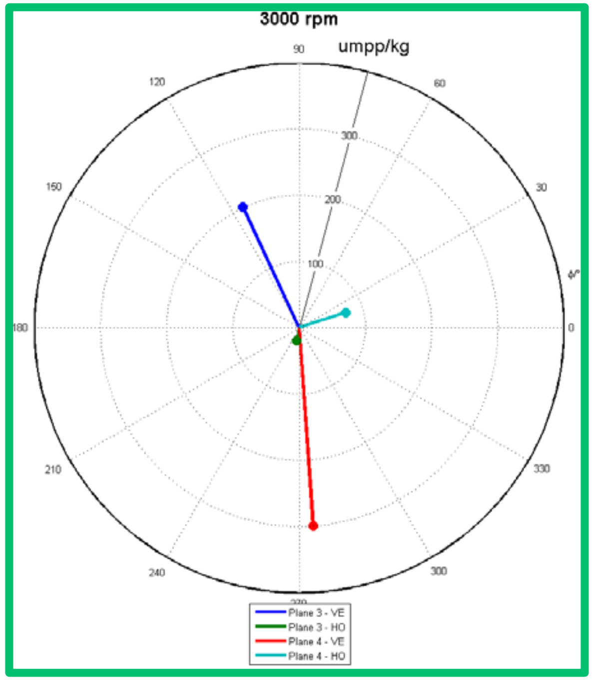


Ringhals 32 - IC’s calculation

Example case – LP1.1 / relative shaft vibration (plane 3 & 4)

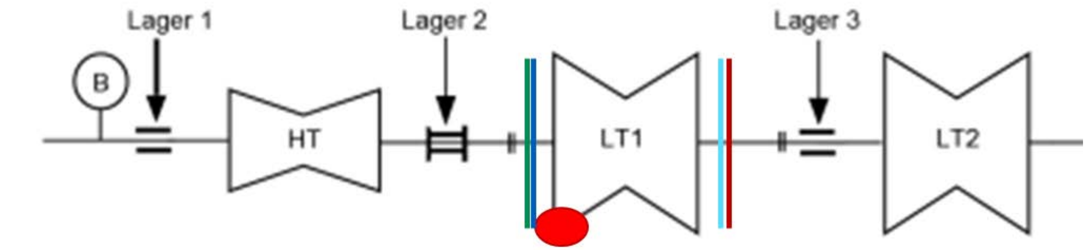




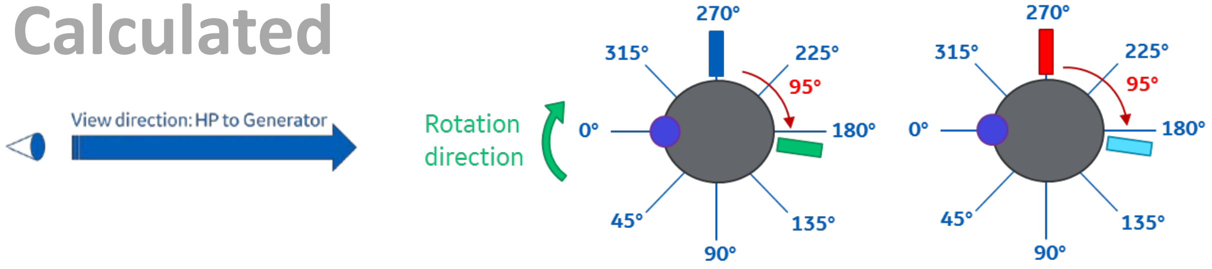


Ringhals 32 - results validation

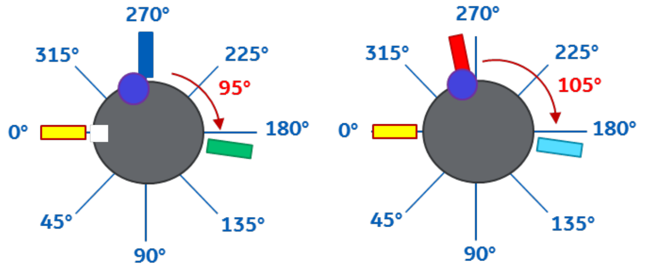
Calculation vs measurement



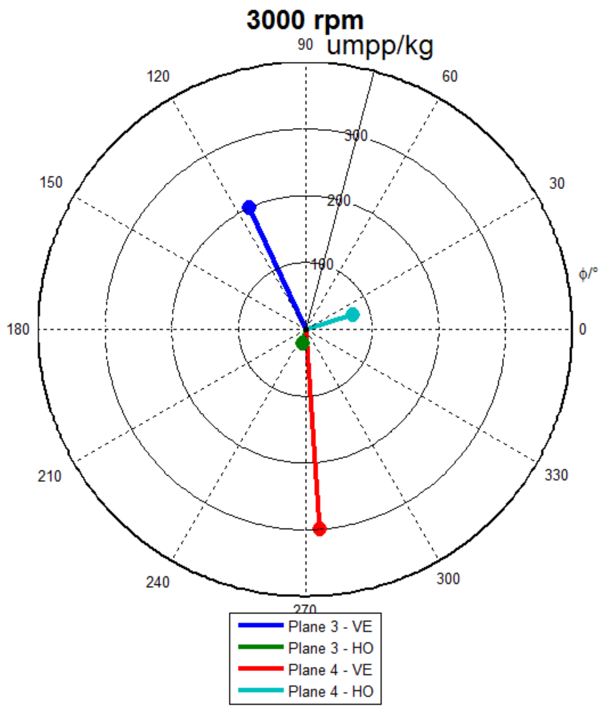
Calculated



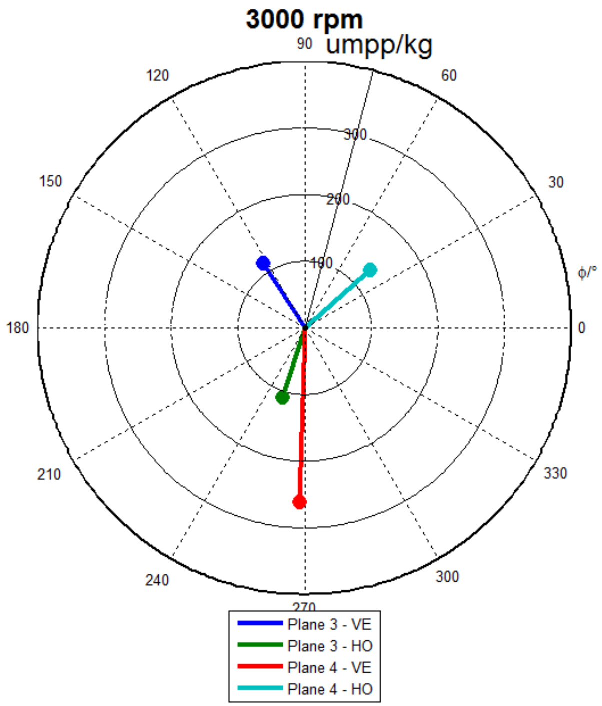
Measured



Calculated

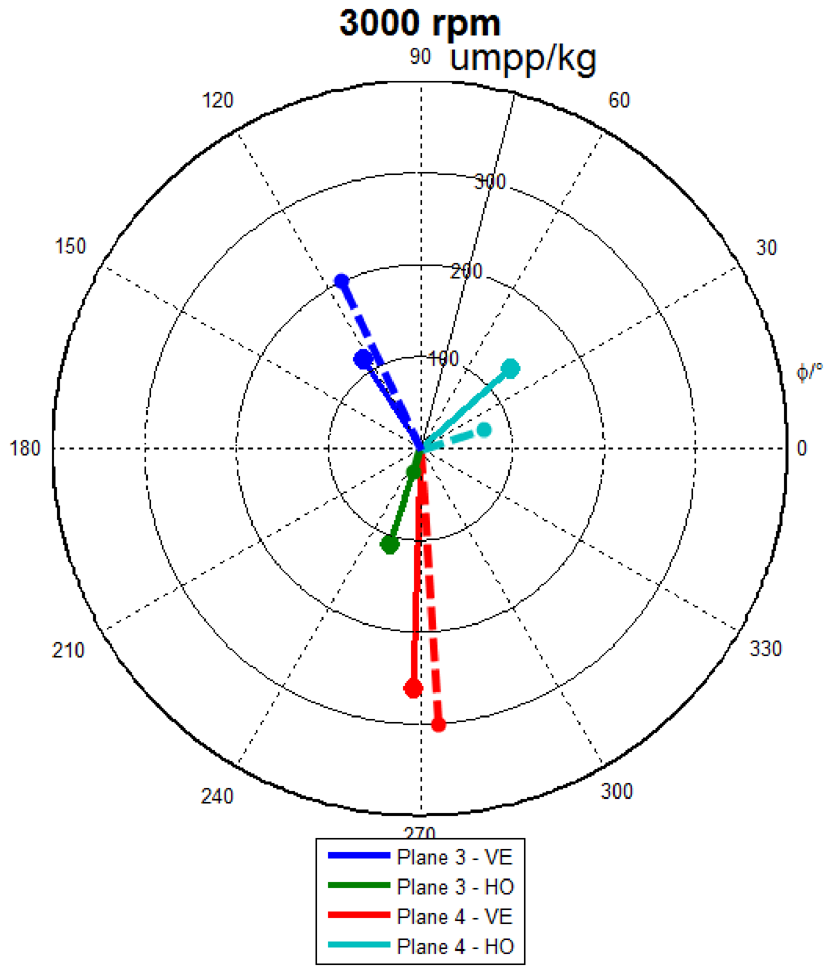


Measured



Ringhals 32 - results validation

Calculation vs measurement

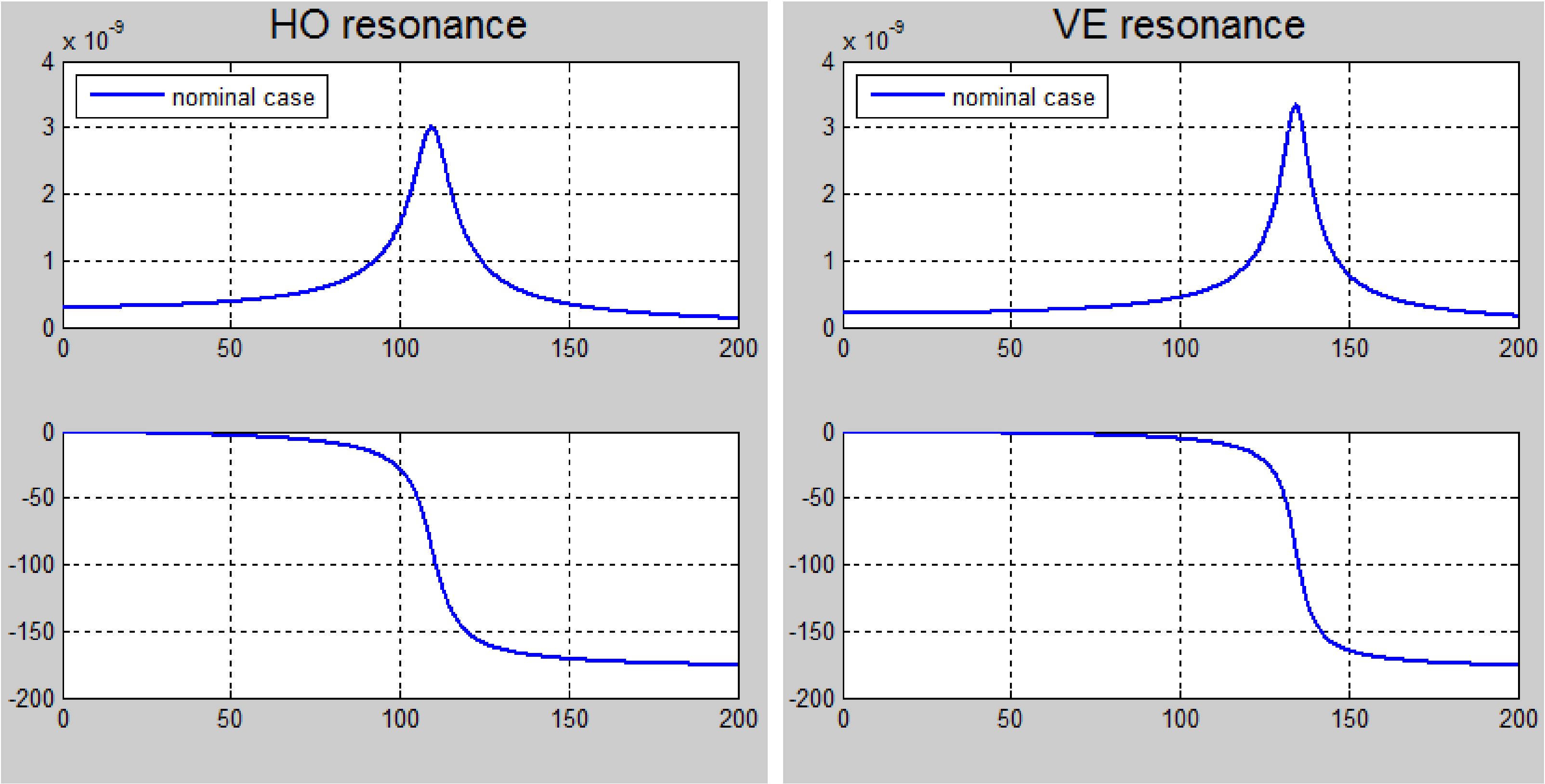


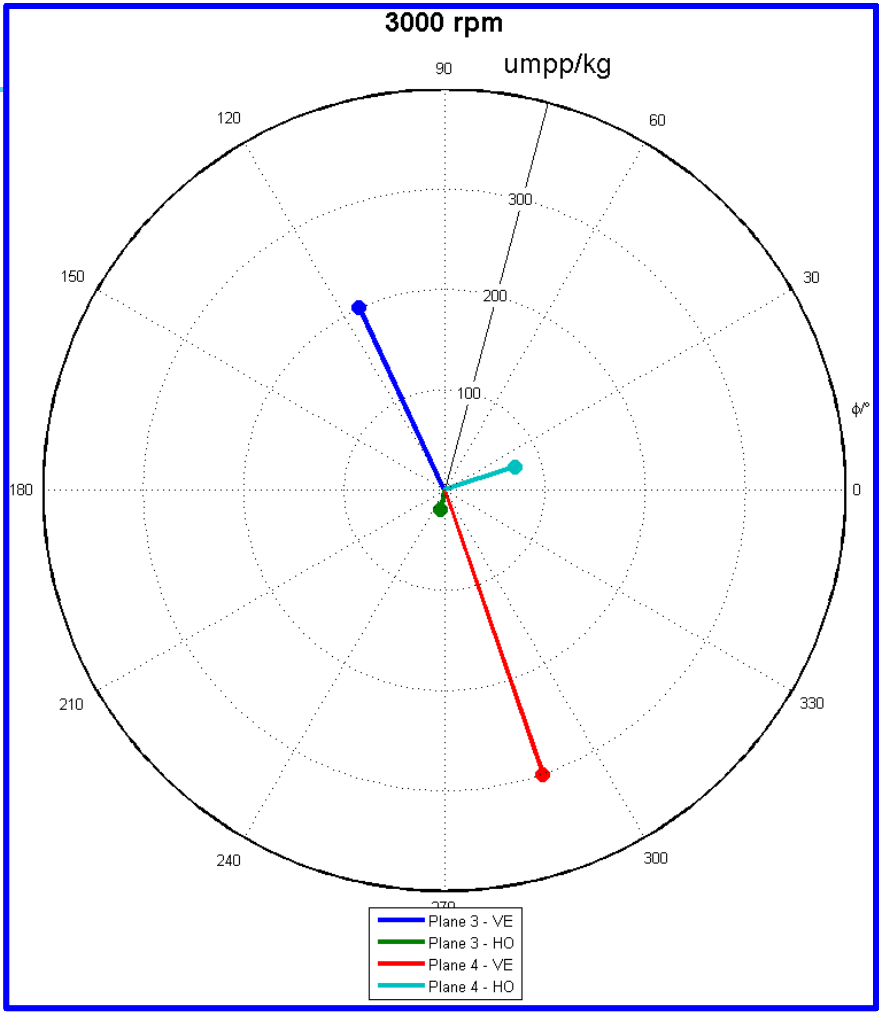
Good matching!

Assumptions taken still need to be validated

Ringhals 32 - sensitivity analysis

Influence of PEDESTAL MASS on IC's at nominal speed





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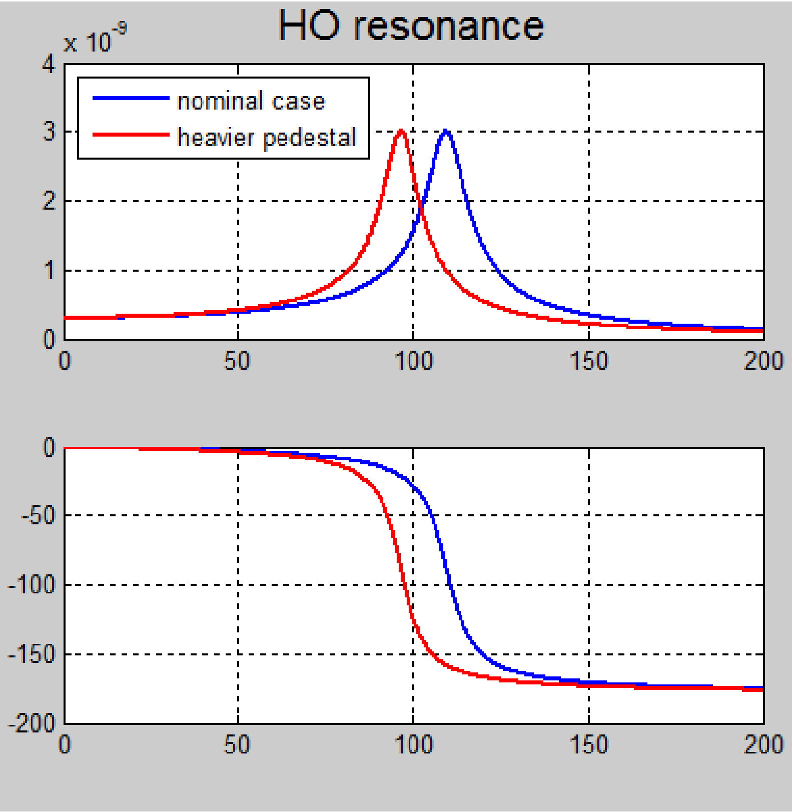
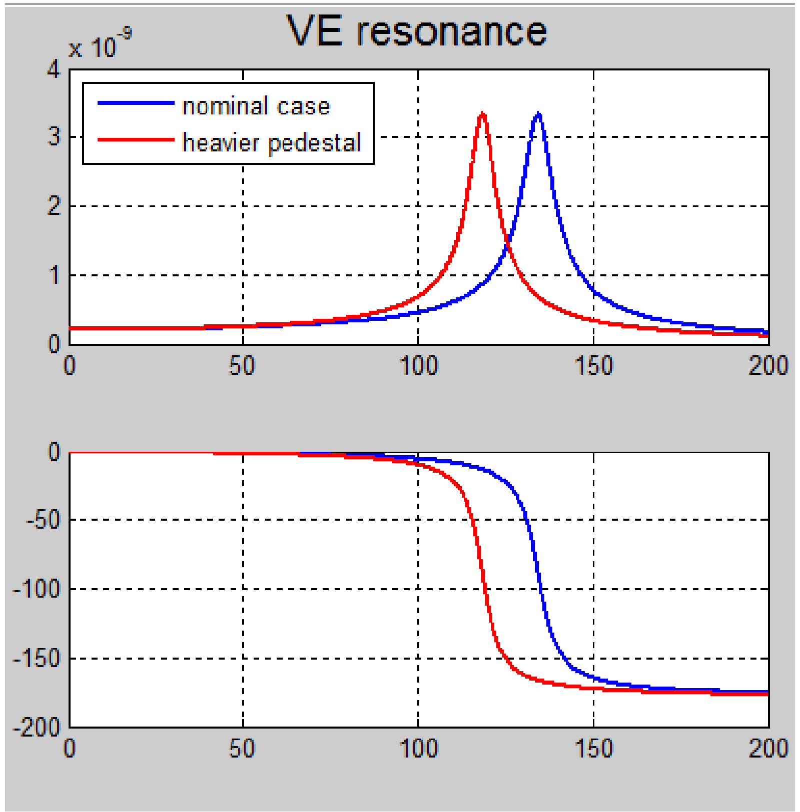
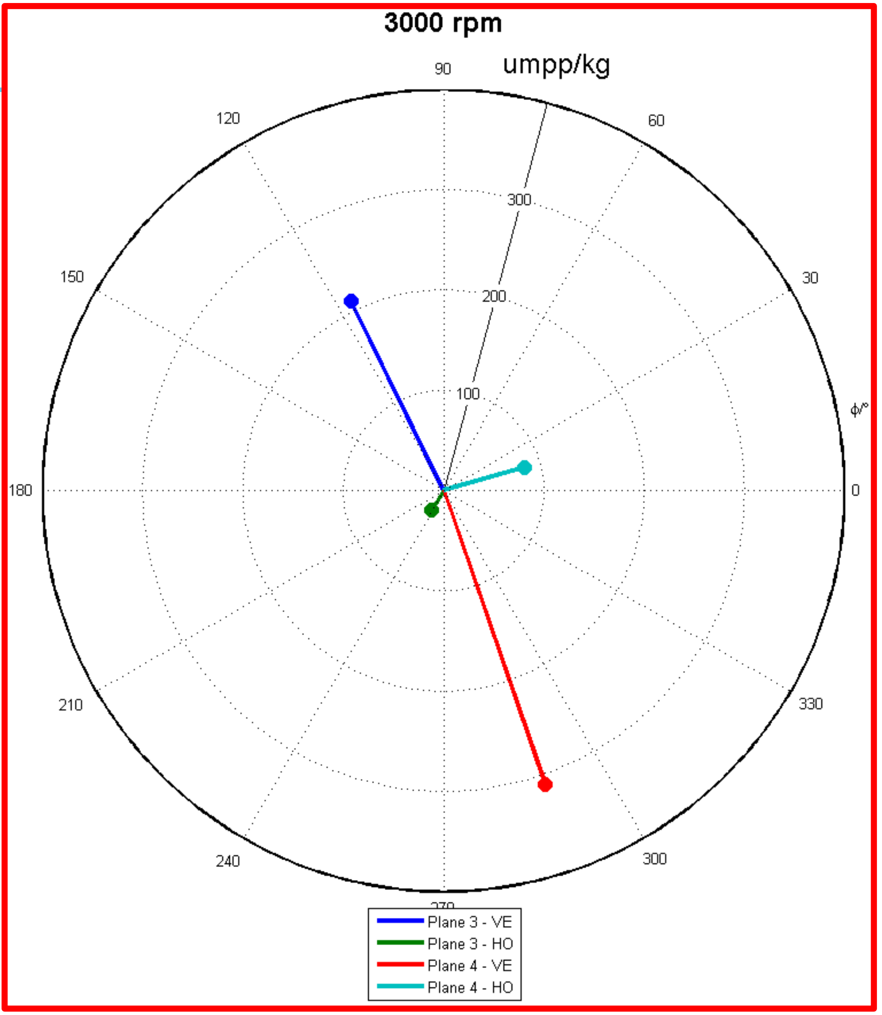
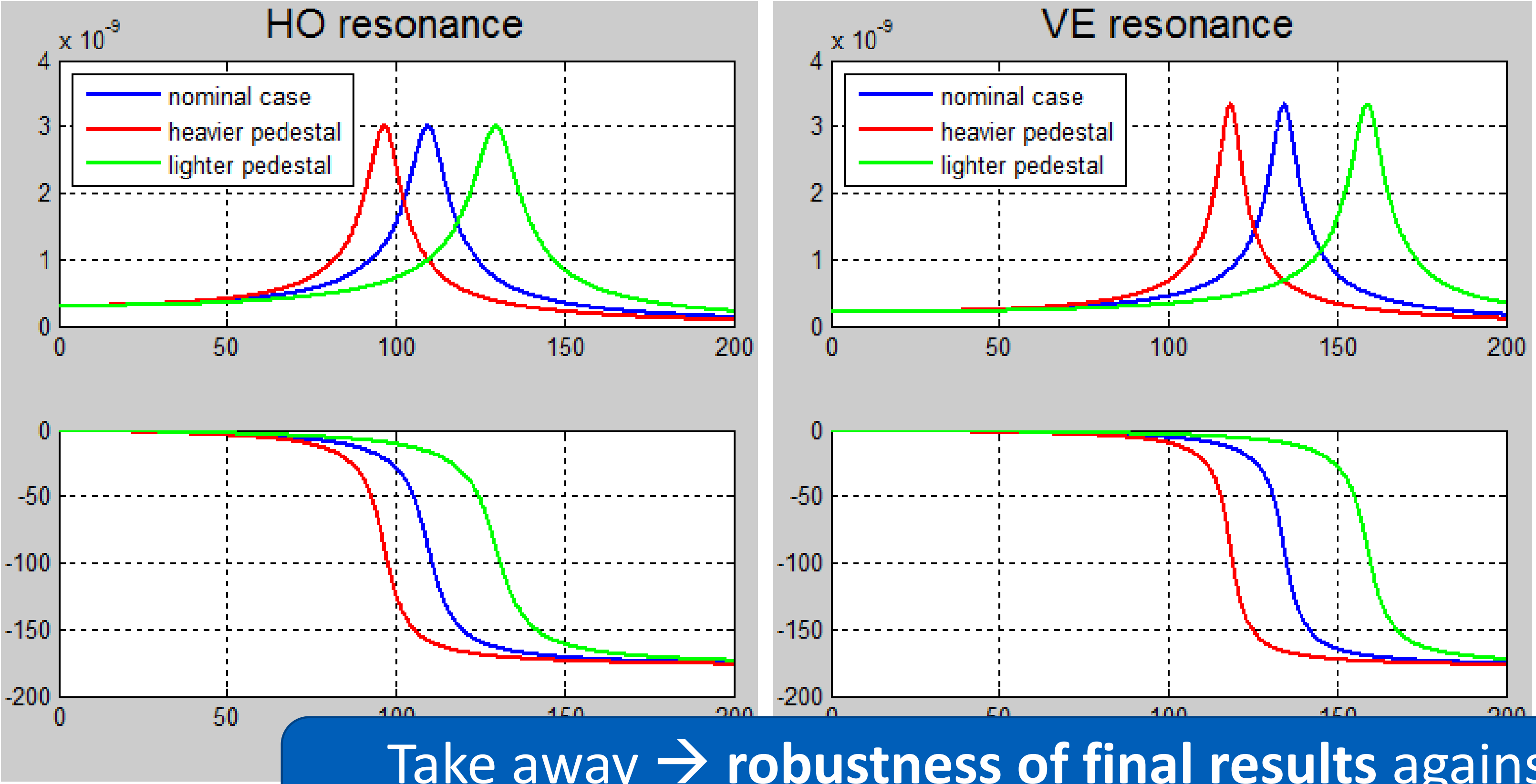


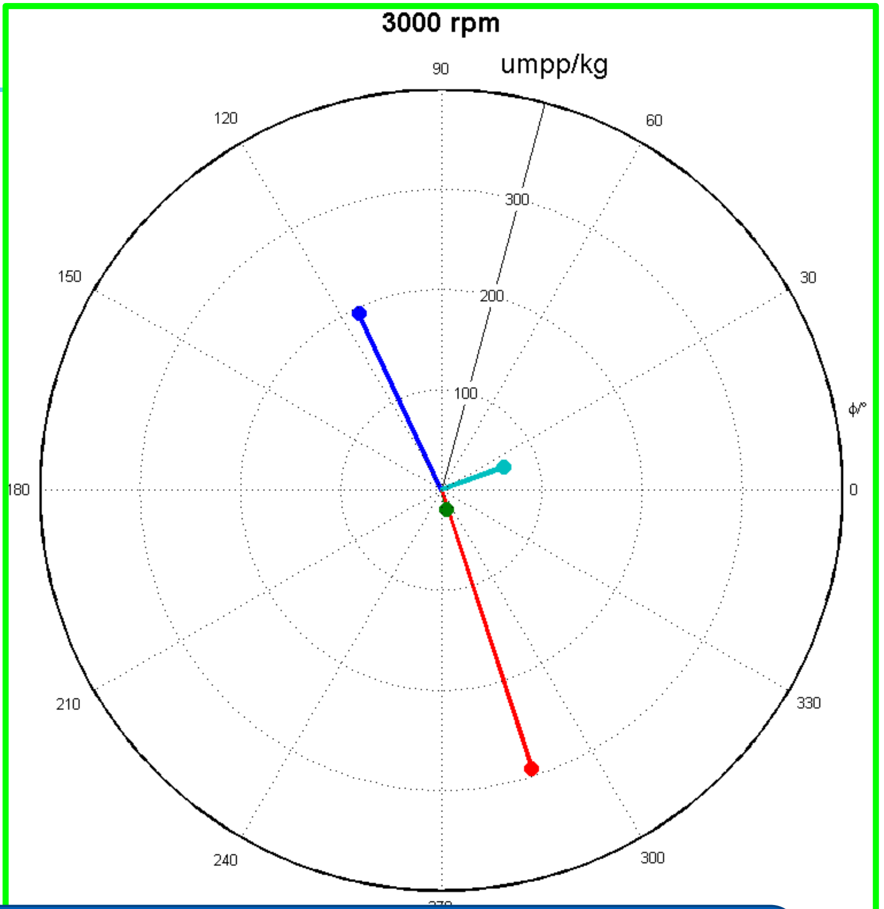




Ringhals 32 - sensitivity analysis

Influence of PEDESTAL MASS on IC's at nominal speed





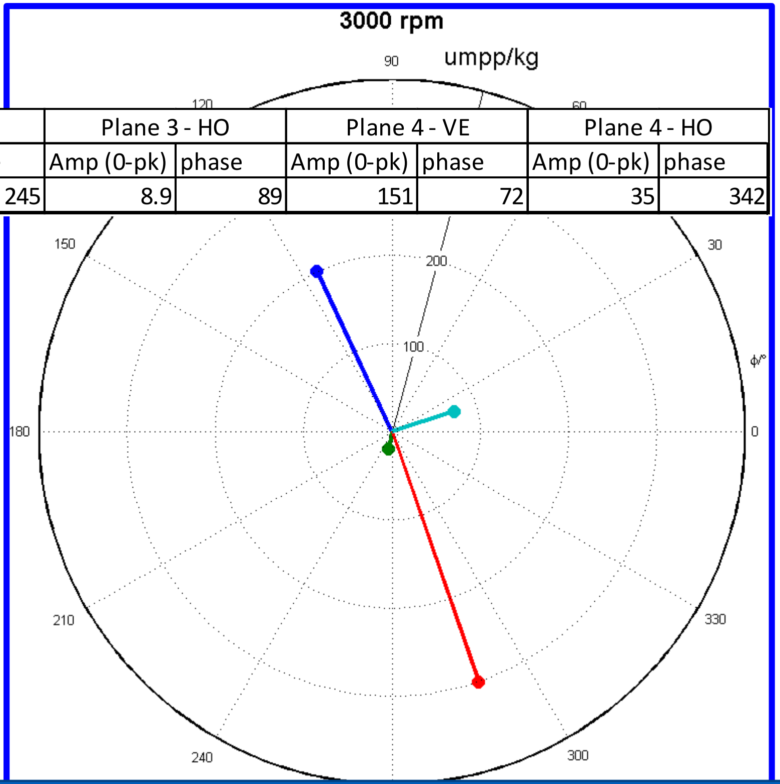
<u>Take away</u> → **robustness of final results** against pedestal mass properties

No «deep dive» required into the tuned pedestal. **Approximation OK**

Ringhals 32 - sensitivity analysis

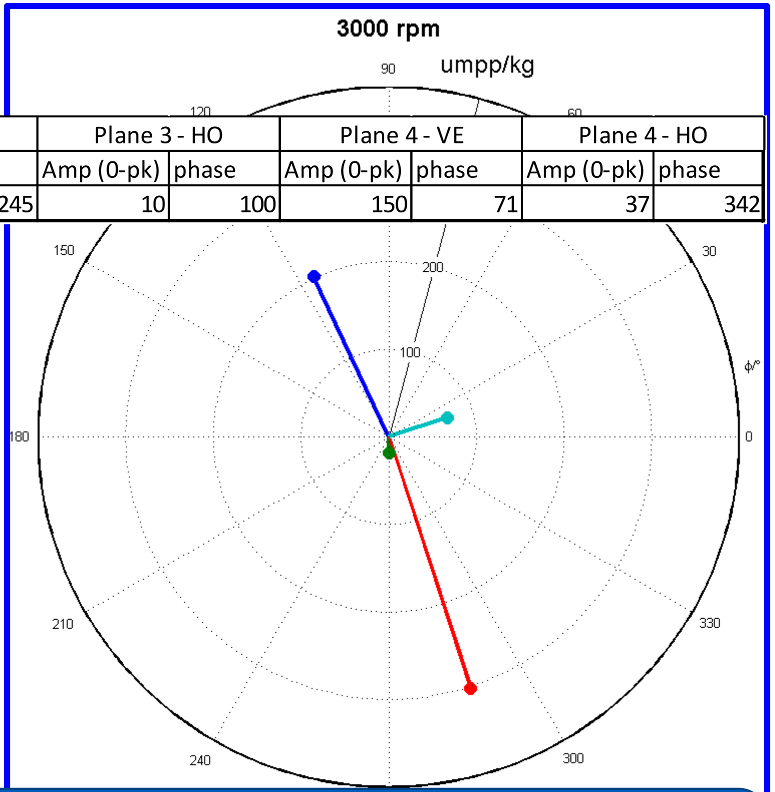
Influence of OIL GRADE on IC's at nominal speed

VG46



	Plane 3 - VE		Plane 3 - HO		Plane 4 - VE		Plane 4 - HO	
	Amp (0-pk)	phase	Amp (0-pk)	phase	Amp (0-pk)	phase	Amp (0-pk)	phase
3000 RPM - BL	101	245	8.9	89	151	72	35	342

VG32



	Plane 3 - VE		Plane 3 - HO		Plane 4 - VE		Plane 4 - HO	
	Amp (0-pk)	phase	Amp (0-pk)	phase	Amp (0-pk)	phase	Amp (0-pk)	phase
3000 RPM - BL	100.6	245	10	100	150	71	37	342

Take away → **robustness of final results** against oil grade

→ Oil temperature will also marginaly affect the results

Conclusion

Conclusions

MBB principles and applicability to RINGHALS 32

- MBB aims at replacing measured IC’s by **calculated IC’s** produced via **digital twin** → time and costs benefits
- Relevance has been demonstrated by **various successful applications** on the field confirming expected savings
- Applicability to **Ringhals 32** is confirmed
- **More results to come...**

Back up

MBB workflow

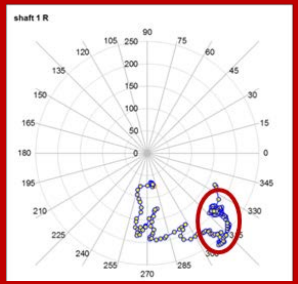
X-business collaboration

R&D and service collaboration for solving field balancing issue in a **timely manner**

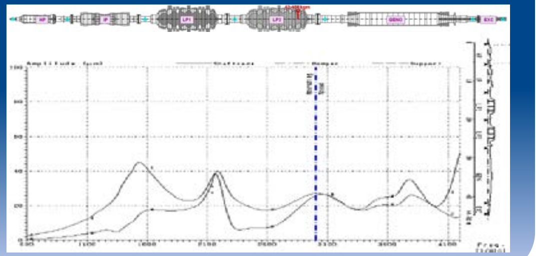
Site/Field Service

R&D

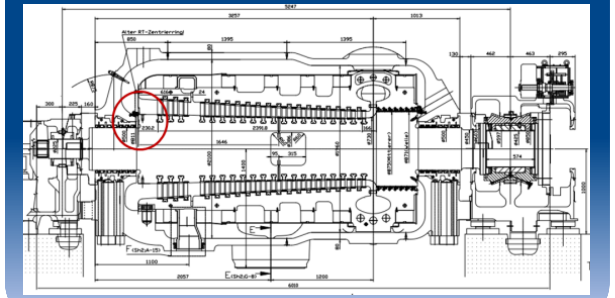
Excessive vibrations measured on site



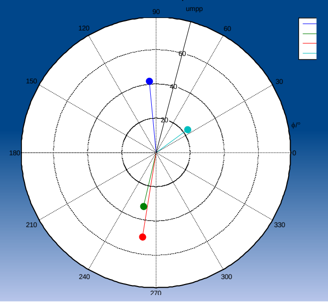
Rotordynamic Model -> Calculation of unbalance response at all balancing planes



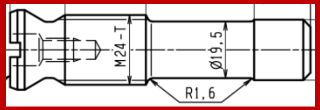
Rotordynamic Model -> Selection of best suitable balancing planes



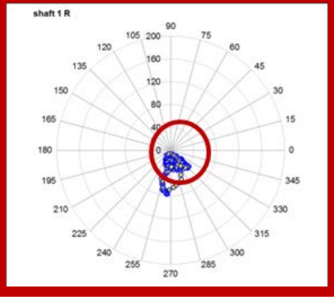
Extraction of influence vectors and transfer to service team



Estimation of balancing bolt weight and position based on calculated influence vectors & application at the shaft



Optimised vibrations with low amplitudes at 1st shot



Critical review of balancing by using IC’s

Advantages

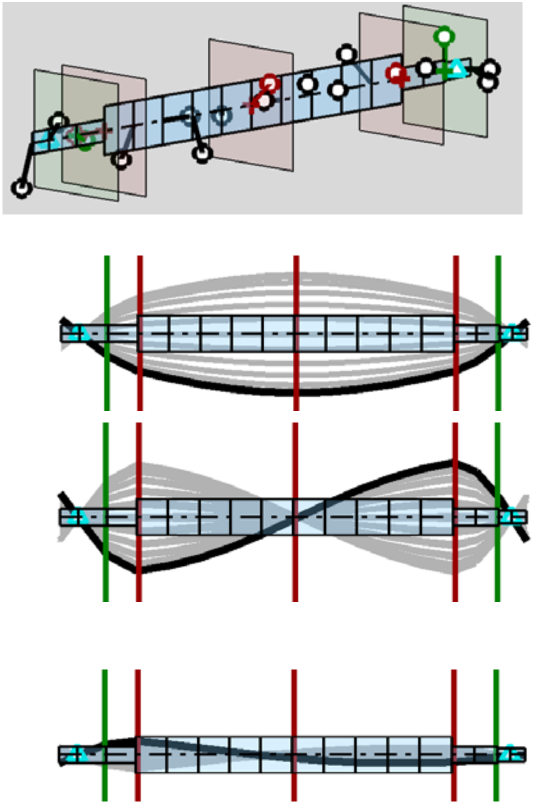
- Test runs automatically contain in-situ conditions (rotor, bearings, pedestals, foundations)
- Very well suited for “off-resonance” balancing i.e. operating speed
- Need little system knowledge
- Typically only a few balancing planes

Disadvantages

- Test runs very time consuming, esp. for generator & HP balancing planes (>12h per run)
- No a-priori knowledge about most suitable BP’s

Dynamic behavior of flexible Rotors

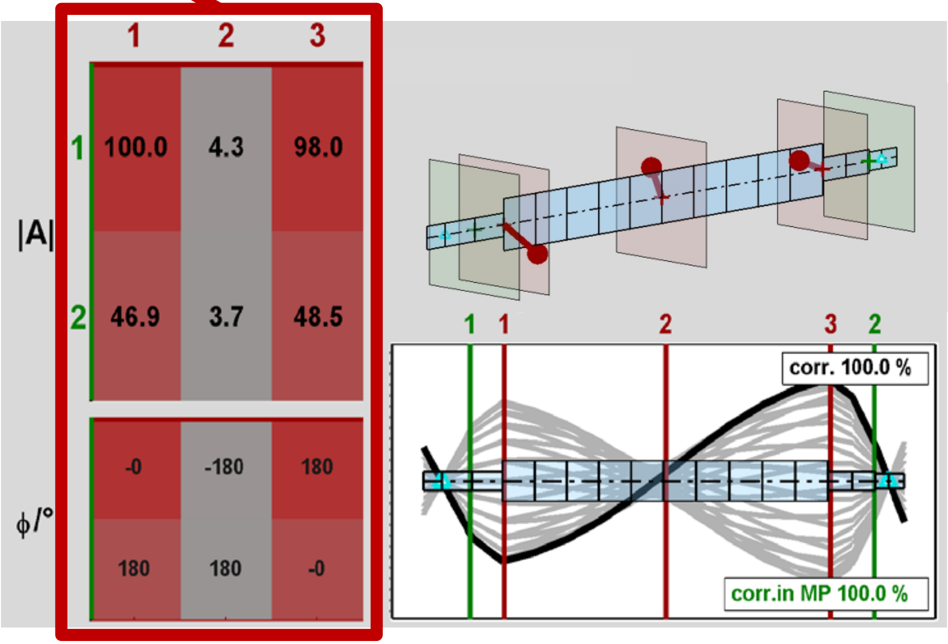
- All rotors have a unknown, residual unbalance distribution
- During runup, several critical speeds are passed.
  → eigenforms are excited by the suitable «modal» part of the unbalance → vibration shape and effective unbalance is speed dependent
- At operating speed, rotors are typically off-resonance
  → vibration shape is composed out of numerous eigenforms → accurate models needed



Extension to multiple BP’s

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \boxed{\begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \end{bmatrix}} \begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix}$$

- Measured displacements x_i and
- Unbalances U_k are connected via
- Matrix of Influence Coefficients α_{ik}



Example
2 measurement planes
3 compensation planes