Optimized field balancing using Model Based Balancing (MBB)

Application to Ringhals 32

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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

Because...

- **Test runs** are needed to gather IC’s \(\rightarrow\) 1 test run per plane
- Unit needs to be *stopped/cooled down/restarted* \(\rightarrow\) 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) \(\rightarrow\) 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
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**

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

\[
(K + j\Omega D - \Omega^2 M)x(\Omega) = F(\Omega)
\]

System parameters

\[
F(\Omega) = U \cdot \Omega^2 \\
U_k = m_k \cdot e_k
\]

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

Practical approach... a simple example

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

Practical approach... a simple example

Response to «residual» unbalance @ e.g. 3000rpm
Response to resid. unbalance and test weight
Influence Coefficients

Practical approach... a simple example

Test weight

Sensors planes

Balancing planes

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

Test weight

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 coefficients runs

Unit run-up and coast down (*n)

Measured influence coefficients

Selection of bolt weight and position for final balancing
How MBB replaces measurements

Classic balancing approach

Excessive vibration – Balancing needed

Influence coefficients runs

Unit run-up and coast down (*n)

Measured influence coefficients

Selection of bolt weight and position for final balancing

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

MBB

Balancing completed – Acceptable vibration

Key benefits

MAXIMIZED UNIT AVAILABILITY
~3 days saved in average

COST REDUCTION
~0.5M€ / day saved

BALANCING QUALITY
No compromises with MBB

Presentation Title

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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° !!

!! 1kg Unbalance Mass at 0° !!

!! 1kg Unbalance Mass at 0° !!
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

“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”

660MW fossil plant
UK

“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

Rotation direction

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

View direction: HP to Generator
Rotation direction

3000 rpm
umpp/kg

3000 rpm
umpp/kg
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

![Graph showing influence of PEDESTAL MASS on IC's at nominal speed](image)
Ringhals 32 - sensitivity analysis

Influence of PEDESTAL MASS on IC’s at nominal speed

- HO resonance
- VE resonance

Graphs showing the effect of PEDESTAL MASS on resonances at nominal speed.
Influence of PEDESTAL MASS on IC’s at nominal speed

Take away \( \Rightarrow \text{robustness of final results} \) against pedestal mass properties
No «deep dive» required into the tuned pedestal. Approximation OK
Influence of OIL GRADE on IC's at nominal speed

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

**Oil temperature will also marginally affect the results**
Conclusion
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
X-business collaboration

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

1. Excessive vibrations measured on site
2. Rotodynamic Model -> Calculation of unbalance response at all balancing planes
3. Rotodynamic Model -> Selection of best suitable balancing planes
4. Extraction of influence vectors and transfer to service team
5. Estimation of balancing bolt weight and position based on calculated influence vectors & application at the shaft
6. 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 an 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

- Measured displacements \( x_i \) and
- Unbalances \( U_k \) are connected via
- Matrix of Influence Coefficients \( \alpha_{ik} \)

Example
2 measurement planes
3 compensation planes