Proactive Shop Strategy to Avoid Field Balancing after a Major Outage

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The Main Problem

- Forced trip or shutdown of a unit on the first restart after a planned outage
- Can lead to days or weeks of downtime for field balancing or other repairs
- We'll look at:
  - Why this happens
  - Steps to incorporate into an outage plan

    ahead of time

    that can guarantee a smooth first restart

High Cost of Post-Outage Work

- Field balancing and work delays can cost a utility $Millions
  - Lost time of power production
  - Spent fuel
- Why is this common in the industry?
- Why is it accepted as "expected"?
- Why can't we always get it right the first time?
- How can we guarantee no field balancing?

Current Rotor Service Procedures

- Accepted by industry, despite common need for post-outage work
  - Assumed to already be optimized and streamlined
  - Developed and researched by OEMs
  - Modeled and supported by academia
- So where can we still improve?

Proactive Shop Strategy to Avoid Field Balancing after a Major Outage

Current Rotor Service Procedures

Specifically, regarding balancing methods, and field alignment methods and tolerances…

- Developed for and work well for **NEW** installations, with all rotor tolerances to OEM factory specs
  - Procedures contain **assumptions** on rotor condition
  - It is **required** that rotors meet factory dimensional specs for the standard methods to be reliably successful

The Risk of Assumptions

- Applying OEM methods and assumptions about new rotors to used service rotors in the shop,

  without proper and thorough verification

  - Assuming rotors are concentric
  - Assuming couplings are perpendicular

  And especially problematic…
  - Assuming that **any** found defects can be "balanced"

Two Key Causes of Post-Outage Vibration

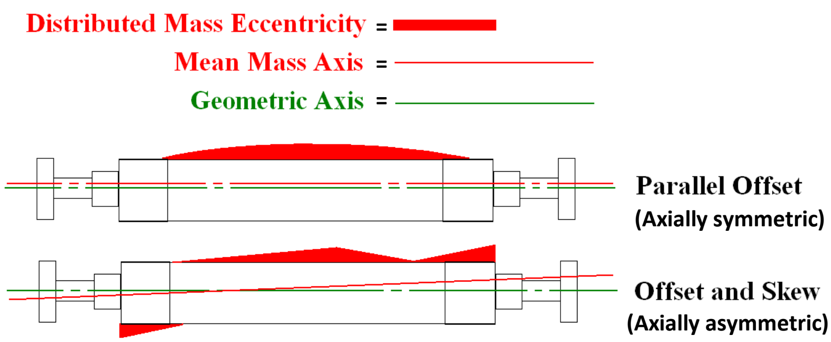
1. Unmeasured, unobserved, and uncorrected **non-perpendicular rotor couplings**

2. Improperly balanced (or unidentified) residual **distributed mass eccentricities**

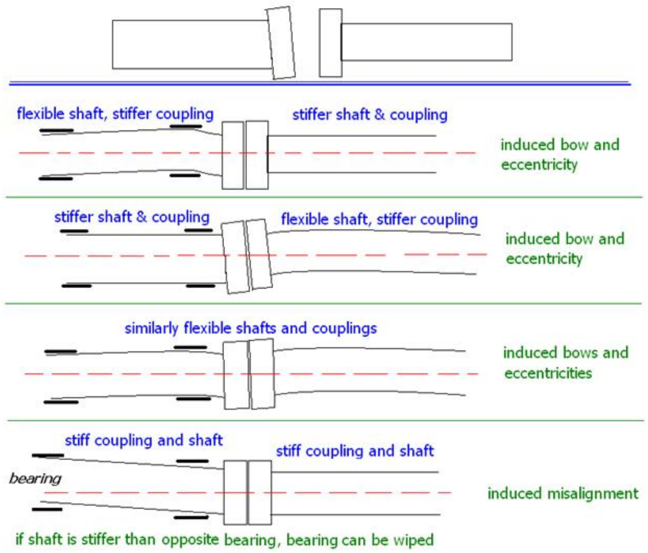
   - Both are "static" causes integral to the rotor, which can be proactively identified and resolved in the shop
   - By resolving these two areas, a smooth restart can be ensured

Rotordynamic Effects of Eccentricity

- Definition of eccentricity: (differs from "unbalance"!)
  - Any distributed mass that notably alters or shifts the overall mean mass axis of the rotor itself (> 2 mils)



Induced Eccentricity from Off-Square Couplings

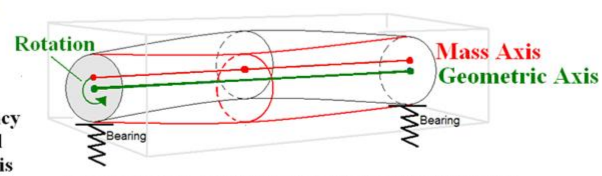


Proactive Shop Strategy to Avoid Field Balancing after a Major Outage

Bowed/Eccentric Rotor: Mass Axis not Coincident to Geometric Axis

We want the rotor to spin balanced about its geometric axis at all speeds...

Like this:



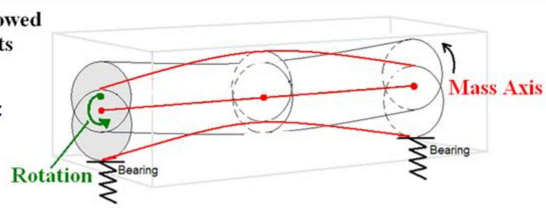
However,

Any rotor's natural tendency is to rotate about its actual center of mass axis, which is offset due to eccentricity

When coupled, this natural tendency is constrained. This produces forces and vibration.

Natural tendency of a bowed rotor is to rotate about its center of mass axis.

Like this:



(produces very high bearing forces if bearing clearances are insufficient to allow the increased displacement)

Proactive Shop Strategy to Avoid Field Balancing after a Major Outage

Resolving Eccentricity

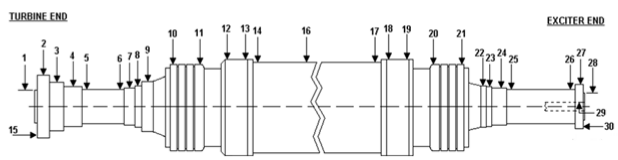
- Our goal is to bring the mass axis coincident to the rotor's geometric axis
  - … by "mirroring" it with balancing weights, not by "unbending" the rotor!
- This ensures the rotor's natural state of rotation is about its geometric axis, in line with its couplings
- **All eccentricity can be found and resolved in the service shop before installation and startup**

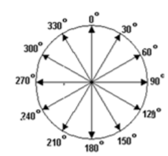
Service Shop Procedure: Runout Evaluation

- TIR (total indicator runout) measurements are a critically important step
- Provides a clear map for required work and procedures to resolve all eccentricities
- No room for assumptions or skipped measurements (especially coupling faces)
- **We can identify FIVE essential conditions that must be met in the shop regarding TIR evaluation…**

Service Shop Procedure: Runout Evaluation

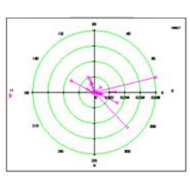
- **Requirement #1: Record sufficient data points**
- Record data points every 45° radially (better, 30°)
  - At least 8 – 12 points per measurement plane
- Record data at each axial point of diametral change of the rotor

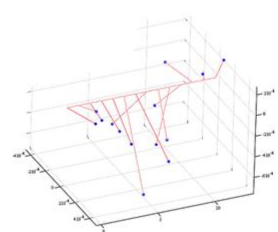


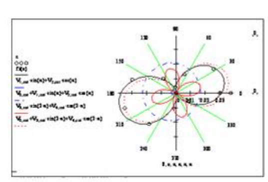


Service Shop Procedure: Runout Evaluation

- **Requirement #2: Mathematical evaluation for 1x (offset) and 2x (ovality) eccentricity**
- Evaluate all eccentricities relative to a common reference line (connecting the journal centers)
- Must identify amplitude and phase angle of net eccentricity at each measurement plane







Service Shop Procedure: Runout Evaluation

- **Requirement #3: Measure and evaluate runout on all coupling faces, rims, and fits**
- Properly square/concentric coupling faces are absolutely essential
- **Perpendicular and concentric couplings are critical to achieving proper field alignment**

Service Shop Procedure: Runout Evaluation

- **Requirement #4: Collect all TIR data on a single setup on the lathe**
- The only way to ensure that all data is evaluated to a common reference line
- Only way to achieve meaningful runout data for evaluation
- Rotor must remain free - No coupling can be held/constrained in a chuck on the lathe during measurement

Service Shop Procedure: Runout Evaluation

- **Requirement #5: Journal TIR evaluation**
- Each journal should be measured in at least 3 planes
- Each journal should be evaluated independently as well for concentricity, taper, ovality, roughness, and any diametral deviation

Service Shop Procedure: Runout Evaluation

- **Eccentricity tolerances for couplings and journals:** (following ISO 1940-1, or major OEM guidelines)
  - All journal eccentricity must be **< 0.5 mils**
  - Coupling rims and fits **< 0.5 mils**
  - Coupling faces must be perpendicular to **< 1 mil**
- **Coupling and journal eccentricity MUST be brought to tolerances by machining**
  - This will guarantee successful field alignment (by standard method of using 16-point gap/rim readings)

Service Shop Procedure: Rotor Balancing

- Balancing cannot be relied upon as a cure-all
- Eccentricities on journals & couplings cannot be resolved by balancing
- However, any eccentricity on the rotor body between the journals **CAN** be balanced
- Rotor body 1x eccentricity over ~2 mils requires a special balancing procedure to ensure successful field operation

Balancing Significant Rotor Body Eccentricity

- Key goal: **The rotor must be balanced about its geometric axis for all speeds**
- Note: An eccentric/bowed rotor will naturally rotate about its mass axis above its 1st critical speed
- This means a rotor balanced by standard methods will inadvertently be balanced around its mass axis
- BUT, in the field, it will be constrained to its geometric axis
  - The rotor will not be balanced for operation
- This is what creates vibration problems, when bowed or eccentric rotors are balanced by traditional methods

Balancing Significant Rotor Body Eccentricity

- Key goal: Restore radial mass symmetry about the geometric axis **FIRST**, at lower speeds, before balancing critical speed responses
- "Rigid mode balancing"
- Full process performed at lower speeds, up to just above the first critical speed
- Because this removes excitation sources of higher critical speeds, often this procedure alone completes the balancing job
- Saves time and cost, fewer runs, better results

Balancing Significant Rotor Body Eccentricity

- Key Goal: **Must not bend or distort the rotor during "rigid mode" balancing**
  - Must distribute weights across **THREE or more** balancing planes
  - If only 2 planes (endplanes) exist, a third (midplane) must be added
- If not possible to add a central third plane, the eccentricity must be resolved mechanically:
  - Machining the full rotor to throw the centers
  - Thermal straightening

Balancing Significant Rotor Body Eccentricity

2N+1 Plane Balancing Method

*(**N** is the rotor's highest mode in its operating speed range)*

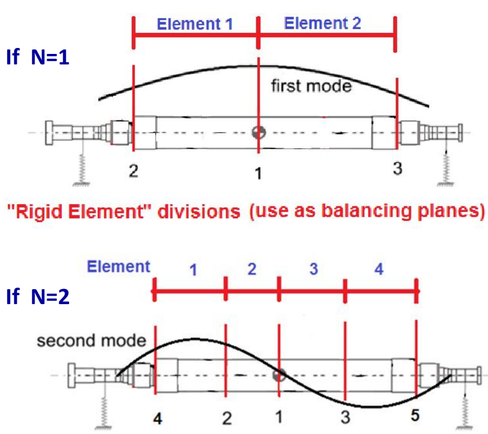
- Also called the "Quasi-High Speed Balancing Method"
- Based on theory from Finite Element Analysis
  - The rotor is conceptually divided into "Rigid Elements"
  - "Rigid" means the largest modal element in the FE model that doesn't bend, within the full operating speed range

Also based on the principle:

- *A truly rigid rotor can be balanced in any **2** arbitrarily-selected planes*

Balancing Significant Rotor Body Eccentricity

2N+1 plane balancing method



- Axial weight distribution prevents all bending/distortion
- The rotor runs "Dynamically straight"
- The rotor behaves as if it were concentric
- Remains balanced about its geometric axis at all speeds

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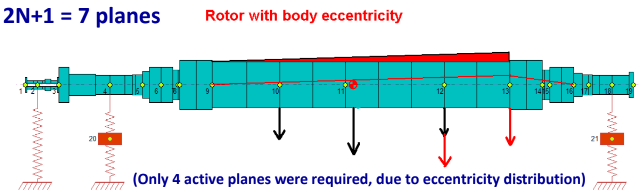
Balancing Significant Rotor Body Eccentricity

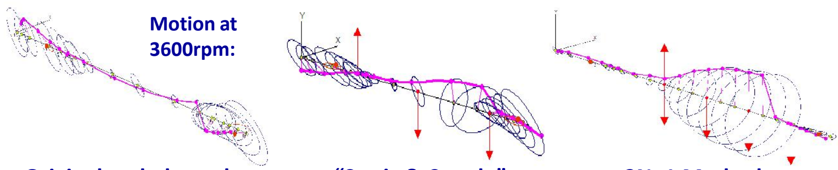
- Example Results of 2N+1 Balancing Method

N=3 , 2N+1 = 7 planes



(Arrows represent balancing weight placement)

- Comparison of results to standard balancing method:
  - 2N+1 Method: negligible motion at journals, undistorted, low forces



Original, unbalanced "Static & Couple" 2N+1 Method

Key Takeaways in Balancing Eccentric Rotors

- Mandatory to correct the 1st critical speed response in three planes simultaneously
- Use 2N+1 balancing planes if 1x evaluated body eccentricity is > 2 mils
- Resolve rigid mode forces **first**, before any balancing at higher speeds
- Weights should not bend or distort the rotor throughout its full speed range
- Restore symmetry to the rotor about its geometric axis

Proactive Shop Strategy to Avoid Field Balancing after a Major Outage

Summary

For a successful post-outage first restart without the need for field balancing:

- **Two main causes of vibration**:
  1. Misalignment during installation, from off-square couplings that were never evaluated or corrected
  2. Insufficient balancing approach for > 2 mils of distributed mass eccentricity or rotor bow

Summary

For a successful post-outage first restart without the need for field balancing:

- **Must incorporate into the outage process:**

  Leave no unchecked assumptions!

  - Measure and evaluate full rotor TIR, including couplings
  - Bring any coupling/journal to OEM specs by machining
  - Balance rotors with > 2 mils eccentricity using 2N+1 balancing planes (1st critical solution in 3 planes)

- *When all rotor eccentricities are identified and resolved in the service shop, a smooth startup can be guaranteed*

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Questions?

Find more details from our presentation at

Z-RConsulting.com

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