Morton Effect Prediction Software

(Thermally Induced Rotor Instability)

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INTRODUCTION AND JUSTIFICATION

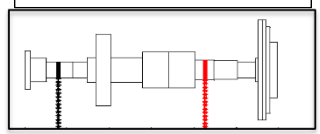
(a) **Morton Effect (ME)**: This synchronous rotor instability is caused by the temperature difference (ΔT) across the journal circumference in fluid film bearings. The ΔT may bend the rotor, increase vibrations and drive the system unstable. Precise modeling of the rotor dynamics, thermodynamics and elastic deformation of rotor and bearing included for the ME.

(b) **Simplified Morton Effect**: This is a newly developed Morton effect prediction software which is at most 6 times faster than the current high-fidelity one.

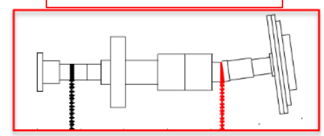
(c) **Non-ME Dynamic Coefficients**: High fidelity dynamic coefficients for tilting and fixed pad/pressure dam/flexure pivot/gas bearings including effects of 3D lubricant temperature, nonlinear pivot stiffness, 3D flexible pad model, misalignment effect, bearing structure deformation and 3D deformation of the shaft and bearing.

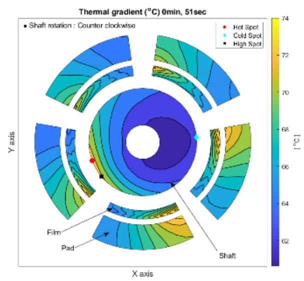
(d) **Tilting Pad / Flexure Pivot / Fixed Pad / Pressure Dam / Gas Bearings (**Flexure pivot gas bearing, bump foil gas bearing): Various types of bearing design are provided for Morton effect prediction and dynamic coefficients software.

Non-Thermal Bow

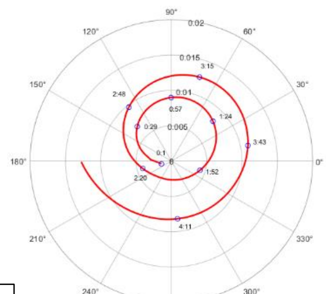


Thermal Bow





Thermal gradient of shaft, fluid film and bearing

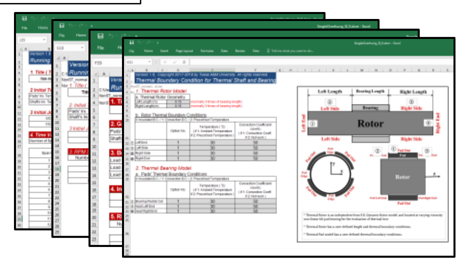


Spiral vibration

DELIVERABLES

Standalone user-friendly software including

- High-fidelity Morton effect software with steady/transient analysis
- Simplified Morton effect software with steady analysis
- Dynamic coefficients software with an ultra-high fidelity(detail) bearing model for tilting/fixed pad, flexure pivot, pressure dam, gas bearings etc.



ME Prediction and Dynamic coefficient software

STATUS OF CURRENT WORK

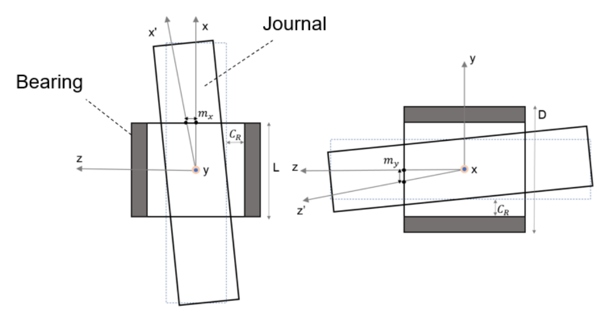
(a) High-fidelity ME software with transient and steady analysis for rotor dynamics and temperature vs. time and speed.

(b) New dynamic coefficient software for tilting/fixed pad, pressure dam, flexure pivot and gas bearings with 3D thermal expansion of journal and pads, 3D pad flexibility, nonlinear pivot stiffness and 3D lubricant temperature based on MATLAB and C programming (speed-up of execution time by 20 times faster)

(c) Included journal misalignment effect and analyze its effect on ME

(d) Adopted CFD-based new mixing coefficient model and accuracy of ME software has been improved

(e) Used current ME software to build ME test rig and conducted parametric studies which will be verified with the rig



Misalignment ratio = $\frac{M_y(\text{misaligned displacement})}{C_R(\text{Bearing radial clearance})}$

Journal Misalignment

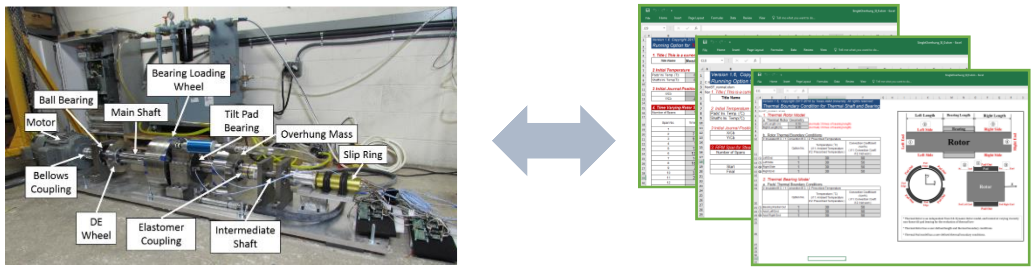
(f) Modeled the friction in tiling pad spherical pivot and evaluated its influence on ME

(g) Developed gas bearing (Flexure pivot tilting pad and bump foil gas bearings) model and investigated its effect on ME

(h) Conducted experiments to measure journal circumferential temperature at various journal eccentricity and supply oil temperature. (For the published paper based on this result, see [3])

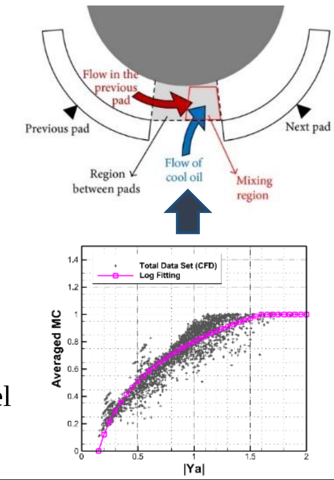
(i) Developed the simplified ME software which is at most 6 times faster than the high-fidelity code. The accuracy of the software has been validated by comparison with measurements and high-fidelity one. (For the validation result, see [3])

PROPOSED WORK 2019-2020



Calibration between ME Test rig and ME software

(a) Improve the accuracy of the current ME software by calibration of its dynamic and thermal models with new ME test rig's measurements
(b) Include high-fidelity squeeze film damper and automatic balancer models into ME software and investigate their effect on ME suppression
(c) Improve current pad-(spherical) pivot friction model of tilting pad bearing by including Stribeck curve for friction coefficient calculation and analyze its effect on ME
(d) Predictions of rubbing effect (Newkirk effect) between rotor and stator
(e) Include full 3D solid structural and thermal shaft models for ME prediction
(f) Include Floating ring/Rolling element bearings and ME prediction with those bearings
(g) Investigate the effect of pedestal stiffness (including nonlinear stiffness) on ME
(h) Investigate the effect of CFD-based new mixing coefficient (hot oil carryover ratio) model on ME prediction
(i) Upgrade journal misalignment model by including dynamic moment coefficients effect
(j) Investigate the bump foil gas bearing induced thermal instability problem
(k) Add bump foil thrust bearing model into current ME software
(l) Develop flow starvation (reduced flow rate) model and analyze its effect on ME
(m) Develop probabilistic ME code with bearing uncertainties (clearance/pad thickness/preload etc.)
(n) Include advanced cavitation model such as JFO and Elrod models
(o) Update the simplified ME software for more accurate and efficient predictions.
(p) Combine the simplified and transient high-fidelity analysis to develop a "smart software", which is able to search for all possible sets of operating conditions that could cause ME using optimization and machine learning techniques.
(q) Decrease the execution time of ME software using C++ and optimized mesh for 3D lubricant/bearing/shaft FEM
(r) Predict the rotor thermal bow caused by asymmetric cooling, not heating, in compressors and turbines.
(s) Combine the surface roughness effect into Reynold's equation and investigate its effect on ME.
(t) Model the jacking grooves, shaft/pad scratches, worn bearing and damaged parts in current bearing models
(u) Model the babbitt fatigue life using the current 3D finite element bearing model.



CFD new Mixing coefficient model

Floating ring bearing

More than **8 TRC companies assisted** with Morton effect modeling of their equipment. We'll continue to provide technical support to solve your problems and also to improve the TRC ME software's accuracy and efficiency.

Some of Our Related Publications

[1] Tong, Xiaomeng, Palazzolo, Alan and Suh, Junho, 2016, "Rotordynamic Morton Effect Simulation with Transient, Thermal Shaft Bow." *ASME Journal of Tribology*, 138(3), 031705. **2016 Best Paper Award**, Journal of Tribology.

[2] Tong, Xiaomeng, Palazzolo, Alan and Suh, Junho, 2017, "A Review of the Rotordynamic Thermally Induced Synchronous Instability (Morton) Effect," *ASME Applied Mechanics Reviews*. **Review Paper Invited by Editor**.

[3] Tong, Xiaomeng, and Alan Palazzolo. "Measurement and Prediction of the Journal Circumferential Temperature Distribution for the Rotordynamic Morton Effect." Journal of Tribology 140.3 (2018): 031702.

Budget for 2019-2020 ($50,000)

1 PhD Student, Salary \$2200/mo×12 months; \$2500 for insurance and fringe benefits; \$13000 tuitions and fees; \$3000 for experiment; \$2400 for computer cost, \$700 for software cost, \$2000 for traveling to conference.