MULTIPLE STEADY STATE RESPONSE SOFTWARE FOR NONLINEAR BEARING AND GEARED SYSTEMS

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INTRODUCTION AND JUSTIFICATION

Unlike linear system which exhibits a single steady state response, nonlinear systems may have multiple steady-state orbits (e.g., multiple synchronous, multiple harmonic orbits, multiple whirl or whip) which coexist at the identical location, rpm and unbalance (e.g. Fig.1). It is impractical and unreliable to utilize the common approach "Transient Numerical Integration to Steady State TNISS" to identify all coexisting responses. In contrast, "Multiple Response States Prediction MRSP" employs an algorithm directed search to determine all steady state response. MRSP nonlinear vibration analysis insures that a high vibration state was not missed by the TNISS.

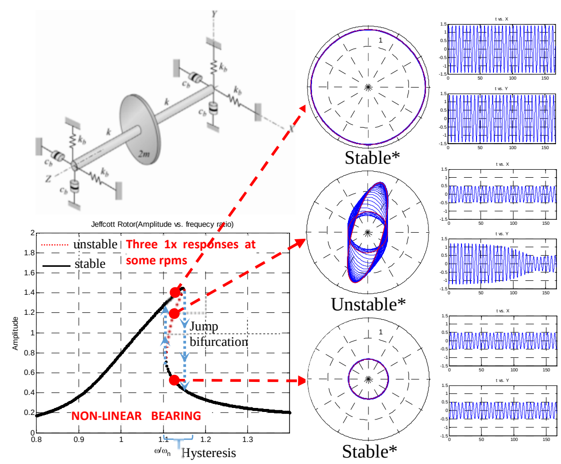

Fig. 1: Example of multiple responses in nonlinear rotor system (*Stability evaluated by Floquet multiplier)

The project objective is to develop a general, finite element shaft rotordynamic software based on MRSP algorithms such as Shooting, Deflation, Continuation, Genetic Algorithm, etc. so that the solver has a capability to determine (a) all Coexisting Solution CS with nonlinear bearings, gear box, seals, dampers, etc, (b) conditions for sudden, unexpected jump between CS, and (c) conditions for quenching limit cycle vibration by intentionally adding unbalance (i.e., synchronization). The nonlinear MRSP solver for the TRC software can be a diagnostic technique to avoid unexpected vibrations in rotor-bearing system.

DELIVERABLES

(1) Primary deliverable is software with user friendly EXCEL based input interface which can predict all coexistent steady state response of general, finite element rotor bearing systems with nonlinear force

- Calculate all harmonic and limit cycle responses for a fixed speed and unbalance distribution.
- Built in nonlinear force models for rub, fixed and tiling pad, gear box, pressure dam, offset bearings, floating ring bearings, seals, squeeze film dampers
- Calculate forces created by whirl in the bearing and their display in the output
- Evaluate stability and bifurcation of the solutions
- Predict sudden vibration jumps at identical operation condition
- Determine conditions for quenching whirl orbit vibration by intentionally adding unbalance

Fig. 2: The developed user software with EXCEL interface

(2) The coding language is hybrid MATLAB/C++. The embedded C++ segments accelerate execution. The software may be run on a PC and does Not require MATLAB to be loaded on the computer

(3) Detailed worked examples

(4) User's manual

COST

1 PhD Student, 12 months $2,200/mo. Salary, $200/mo. Insurance, 2.5% Fringe on salary, Approx. $9,000 tuition and fees, Total: 40,000

STATUS OF CURRENT WORK

ACCOMPLISHMENTS

(1) Improved MRSP solvers are developed: autonomous/non-autonomous shootings, deflation, arc-length continuation, component mode synthesis and parallel computing strategy
(2) Development of user software with EXCEL interface: capable of finite element based rotor and bearing modeling and investigation of nonlinear phenomena
(3) Case study of rigid/flexible rotor models supported by floating ring bearings and multi (fixed/tiling) pad journal bearings were presented: multiple response states and various nonlinear behaviors (e.g., jump, bifurcation, chaos)
(4) Effects of thermo-hydrodynamic (THD) floating ring bearing model on rotordynamic bifurcation
(5) Preliminary results for synchronization (i.e., quenching oil whirl)

PROPOSED WORK

(1) Nonlinear phenomena of fluid film bearings
   a. Extension of nonlinear bearing applications to MRSP solver: squeeze film dampers (SFDs), SFDs in series with TPJBs, pressure dam, offset bearings, seals, steady state rub, etc.
   b. High fidelity rotor-bearing model developments: Timoshenko beam model, deformable elements (e.g., pads, pivots, and floating rings), spherical pivots, oil feed hole, fluid inertia effect, etc.
   c. Lubricant thermal effects on rotordynamic bifurcations: investigation of relationship between lubricant supply temperatures and multiple response states, bifurcations, stability of response, etc.
   d. Nonlinear phenomena due to accumulated unbalance distributions (aging) on rotors/disks during long-term operations
   e. Quenching effects of the intentionally added imbalance on rotors/disks to large oil whirls
(2) Nonlinear force modeling of gearbox
   a. Parametric excitation from time-varying mesh stiffness and backlash
   b. Coupling modes corresponding to gear types (e.g., Torsional/lateral/axial coupling for helical gear pair)
   c. Selectable simulation conditions such as start-up, coast down and various speed/load operations
(3) Nonlinear solution verification with literature and experimental test data from TRC member
(4) Development of enhanced MRSP algorithms: improve algorithm efficiency and reliability
(5) User software with EXCEL interface
   a. More functionality stand-alone code, friendlier EXCEL interface: 3D visualization for the multiple responses, orbit jump scenario, pressure and thermal distribution in bearing area, and etc.
   b. XLTRC-II Integration

HOW WILL THE WORK BE ACCOMPLISHED

(1) Nonlinear response and bifurcations investigation by using multi-variable shooting/continuation algorithm as well as transient numerical integrations method
(2) High fidelity rotor-bearing model development: large order of Euler/Timoshenko beam models, simplex-three node finite elements lubricant layer, oil feed holes, rocker/spherical pivots, etc.
(3) Thermo elastic hydrodynamic (TEHD) model development: finite element based solutions of the variable viscosity Reynolds equation, the 1D/2D energy equation and the thermal expansion
(4) Accelerate execution with major code segments coded in C++ and CPU/GPU parallel computing
(5) Floquet theory based stability analysis of the periodic response
(6) Model condensation technique for large-order nonlinear rotor system
(7) Develop stand-alone code and user interface with many worked example: MATLAB, C++, Visual Basic Editor for EXCEL