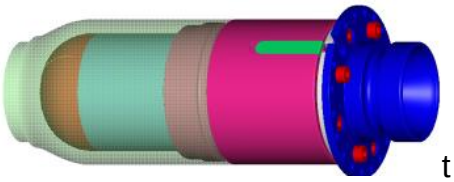
RBTS, Inc. Rotor Bearing Technology & Software, Inc.
1041 West Bridge Street, Phoenixville, PA 19460, USA • Tel: 610-415-0412 • Fax: 610-415-0413 • www.rbts.com

Rotating Machinery Dynamics & Bearings Tailored Seminar

RBTS offers one day to few weeks tailored technology transfer courses and training sessions on rotating equipment dynamics covering the following major subjects;

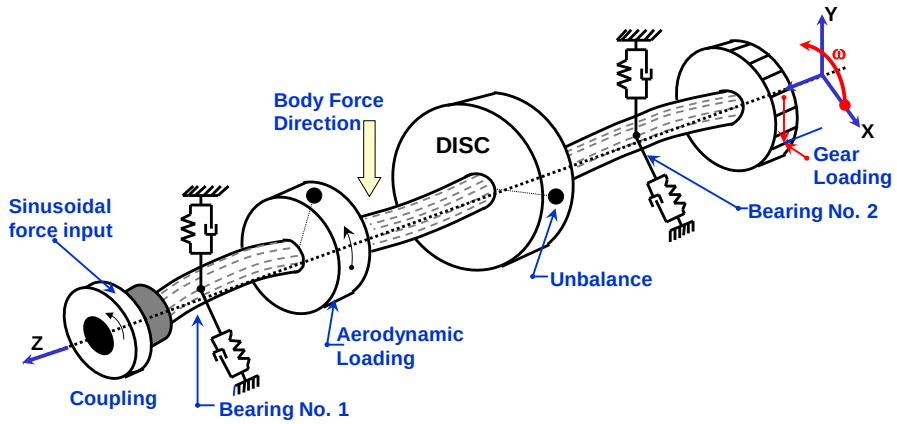
- Fluid-Film Lubricated Bearings.
- Rolling Element Bearings.
- Rotor Dynamics.
- Torsional Vibration.
- Vibration Monitoring, Analysis, and Diagnostics.
- Torsional Vibration Measurements and Analysis.
- Failure Analysis & Trouble Shooting.

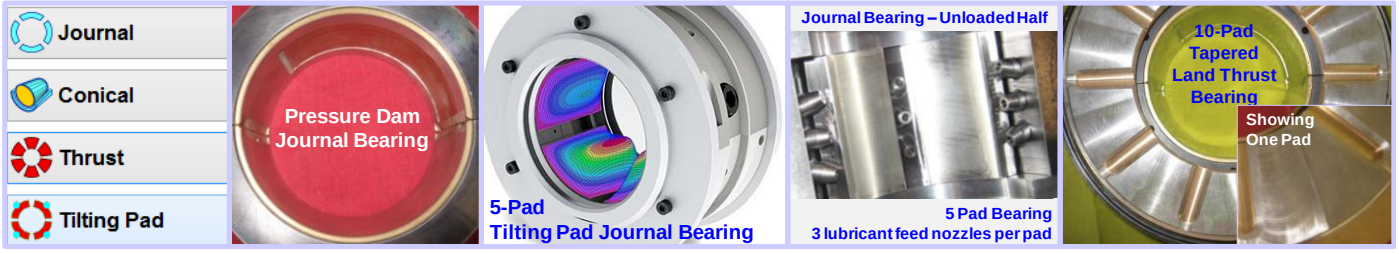
From **Blood Pumps**



to **Turbine-Generator-Sets**.

A sample training seminar covering the above is presented in this document that focuses on rotor dynamics (Lateral/Torsional vibration) & bearings technologies and application to rotating machinery, failure analysis and trouble shooting.





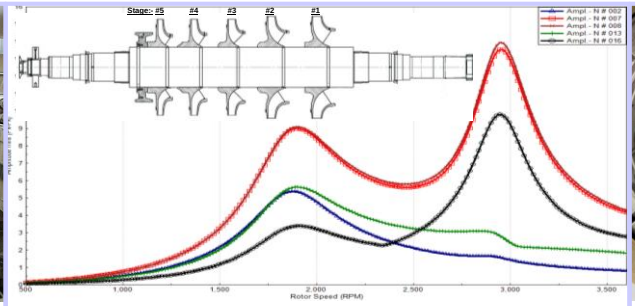
Call RBTS for a Tailored Seminar and/or Services to Suite Your Needs

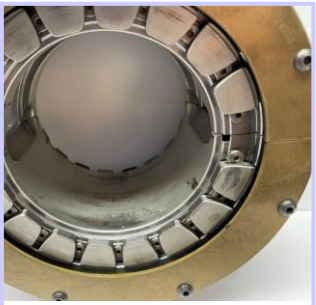
ROTOR DYNAMICS & BEARINGS TECHNOLOGIES AND APPLICATION TO ROTATING MACHINERY

Lateral & Torsional Vibration Analysis / Fluid-Film Bearings

Detailed coverage of the field of Rotor dynamics, Torsional vibration, and fluid-film bearings illustrated by the presentation of case histories and the application of advanced software for the modeling, analyses, maintenance and troubleshooting of real life vibration problems encountered in rotating equipment. No pervious experience is required and participants will have guided sessions for model development, analyses, results interpretation and troubleshooting bearings, rotor/bearing systems, and drive trains.


Torsional Vibration Failure


Rotating Machinery Dynamics


Journal/Thrust Bearings

This course is designed for engineers and technical managers who are involved in rotating machinery design, operation, maintenance, diagnosis, and trouble shooting, with emphasis on machinery rotor dynamics, drive train torsional vibration and bearing systems that support, guide, and locate the rotating assembly.

The course is designed to introduce the theory and practice of vibration analysis in rotating machinery ("**Rotor Dynamics**") from fundamental principles through present state-of-the-art analytical methodology for the solution of common, as well as, unique machinery vibration problems. Design consideration and application of fluid-film and rolling element bearings will be discussed along with a presentation of practical examples and case histories.

The interacting influence of bearings on the dynamic behavior (rotor dynamics) of machinery will be reviewed and illustrated by the construction of analytical models, and evaluated by computerized solutions. Workshops are intended to provide participants with adequate time to develop models, describe and solve problems encountered in BEARINGS, BEARING SYSTEMS, ROTOR DYNAMICS, and TORSIONAL VIBRATION utilizing **RBTS**' popular advanced rotating machinery dynamics software package **ARMD**™.

FLUID-FILM LUBRICATED BEARINGS

◆ This session is presented in a simple way to understand the technology of sliding surface bearings so that participants with or without previous knowledge benefit from the presentation and can apply it immediately in their profession.

It is an introduction to BEARINGS, the vital tribological elements of rotating machinery that support, guide, and locate the rotating assembly beginning with their fundamental principles of design and operation through computer-implemented evaluations of their operational performance characteristics and limitations. Design considerations and applications of sliding surface bearings with emphasis on HYDRODYNAMICALLY lubricated fluid-film bearings will be discussed along with presentations of practical examples and case histories.

1- INTRODUCTION TO BEARINGS

(Presentation of real life bearing failure & effective solution taking time/cost into consideration)

- Functional Roll.
- The Two Primary Classes.
- Noteworthy Differences between the two classes of bearings including basic design configuration and their operational limitation of size and speed.

2- SLIDING SURFACE BEARINGS - Fundamentals

- Types And Definition including load support functions, basic surface geometry including *Fixed* & *Tilting-Pad*, Journal/Thrust & Conical, design concept & construction, type of lubricant, and lubricant supply methods.
- Geometrical Forms, Load Supporting & Frictional Reactions.
- Mechanisms Of Lubrication – *Complete* boundary, *Mixed*-film, and *Full*-film.
- Frictional Response Characteristics – Material, Lubricant, and Design.

3- DISTRIBUTION OF BEARINGS HARDWARE – Demonstration

4- LUBRICANT TEMPERATURE DEPENDENT PROPERTIES

- Demonstration of lubricant analysis software and effects of temperature on lubricant properties and bearings performance.

- Participants Application of lubricant analysis software.

5- MODES BY WHICH FULL-FILM LUBRICATION IS ACHIEVED

6- *HYDRODYNAMIC* MODE OF LUBRICATION TERMS, CONCEPTS AND REQUIREMENTS

7- FORMATION OF FULL FLUID-FILM IN A TYPICAL TURBO-MACHINERY JOURNAL BEARINGS & RESULTING JOURNAL POSITION DUE TO LOAD, SPEED, LUBRICANT TEMPERATURE AND FLOW RATE

8- AIR BEARING SPINDLE DEMONSTRATION

9- TURBINE-GENERATOR SET SUB-SYNCHRONOUS HIGH VIBRATION
Bearings Detailed Description, Geometry, Modeling, Modes Of Operation From Zero To Full Speed, Analysis, Modifications, & Modification Concerns.

10- JOURNAL BEARINGS MODELING AND ANALYSIS – Basics

- Modeling a typical turbo-machinery journal bearing utilizing ARMD software.
- Guided session to participants for the development of bearing model and performing required evaluation including parametric studies.
- Detailed discussion of generated results including such parameters as;
  - Operating *Journal Position* in bearing.
  - *Power Loss* due to oil viscous shearing forces.
  - Acceptable operating *Minimum Film-Thickness*,
  - *Stability/Instability* – introduction of oil-whirl / oil-whip.
  - Acceptable lubricant *Temperature Rise* in bearings.
  - Supply oil *Temperature Effects* on above performance parameters.
  - Supply oil *Flow Rate Effects* on above performance parameters.
  - Supply oil *Pressure Effects* on above performance parameters.

11- FORMATION OF REQUIRED WEDGE FOR HYDRODYNAMIC THRUST BEARINGS – Fixed & Tilting-Pad Configurations

12- DEMONSTRATION OF TILTING PAD THRUST BEARING SPINDLE

13- *HYDROSTATIC* MODE OF LUBRICATION TERMS, CONCEPTS, AND REQUIREMENTS

14- FORMATION OF FULL FLUID-FILM IN A HYDROSTATIC BEARING SYSTEM

15- HYDROSTATIC AIR BEARING SPINDLE DEMONSTRATION

16- POWER PLANT GENERATOR BEARING PERFORMANCE WITH HYDROSTATIC LIFTERS (Jacking Oil Pump) DURING UNIT START-UP

Bearings Detailed Description, Jacking Oil Lubricant Supply System, Modeling, Performance, Analysis, Modifications, & Modification Concerns.

17- HYDROSTATIC MILL BEARING SYSTEM FAILURE PRESENTATION, DISCUSSION, TROUBLE SHOOTING, AND ROOT CAUSE ANALYSIS

18- *SQUEEZE-FILM* MODE OF LUBRICATION TERMS, CONCEPTS AND REQUIREMENTS

19- IDEAL APPLICATION OF ALL MODES OF LUBRICATION

20- SUMMARIZING THE INTERRELATED CONSIDERATIONS HAVING IMPACT ON BEARING PERFORMANCE AND REQUIREMENTS

- Bearing And Runner Hardware
- Lubricant, Operating Conditions, Thermal & Boundary Environment
- Past History

21- MACHINERY HYDRODYNAMIC BEARING TYPES, PERFORMANCE, DYNAMIC CHARACTERISTICS (STIFFNESS & DAMPING), ADVANTAGES/DISADVANTAGES AND COST

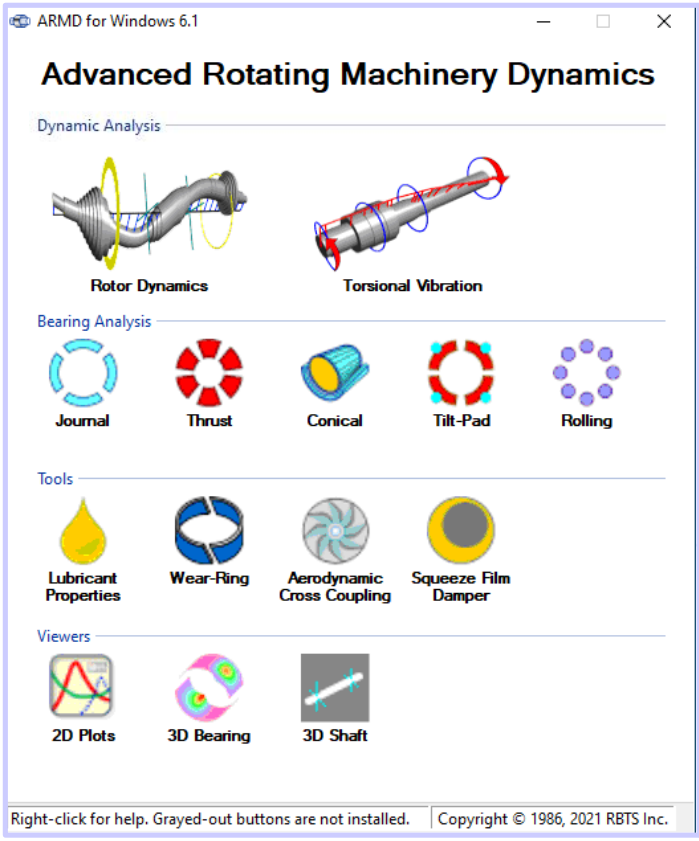
A complete coverage of turbo-machinery bearings available in the industry and for unique applications demonstrating advantages/disadvantages, fabrication, dimensional geometries, tolerances, and cost.

22- PLAIN SLEEVE, ELLIPTICAL/LEMON, AND TILTING PAD JOURNAL BEARINGS PERFORMANCE AND COMPARISON INCLUDING

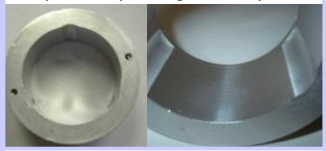
- Load Capacity
- Viscous Power Loss
- Side Leak
- Inlet Flow
- Temperature Rise
- Minimum Operating Film-Thickness
- Spring & Damping Coefficient
- Stability

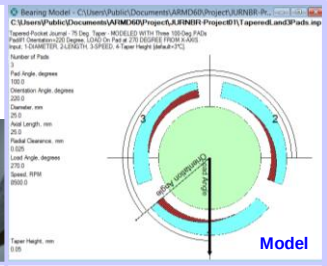
23- JOURNAL & THRUST BEARINGS MODELING AND ANALYSIS – Advanced

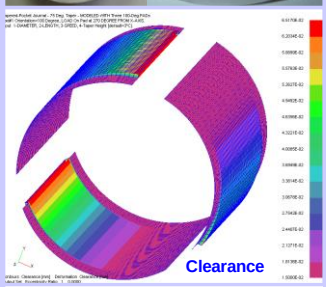
- Modeling and analysis of turbo-machinery journal and thrust bearings utilizing ARMD software.
- Guided session to participants for the development of advanced bearing models and performing required evaluation including parametric studies along with detailed discussion of generated results.

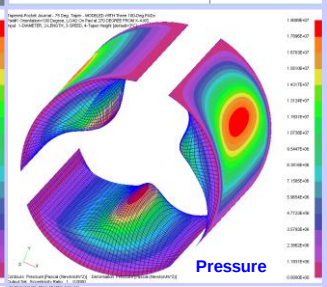


Sample - Three (3) pad, fixed geometry cylindrical journal bearing, with tapered pocket configuration for high speed multi-stage centrifugal compressor operating at 8500 rpm.

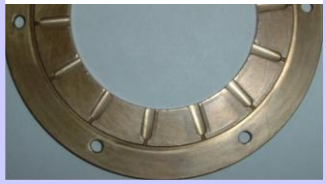


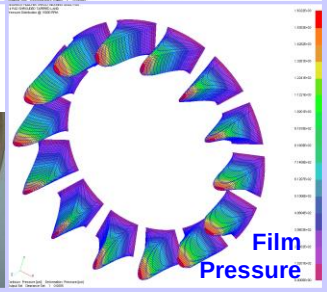




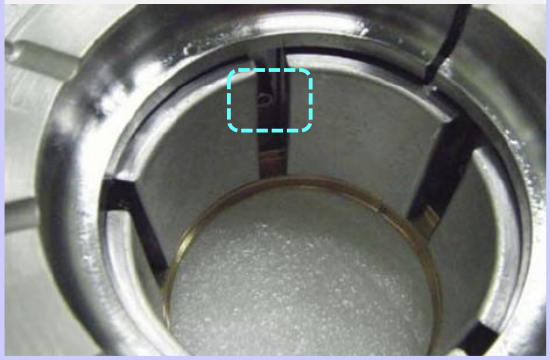


Gearbox thrust bearing with 14 pad shrouded tapered land configuration operating at 15K rpm.





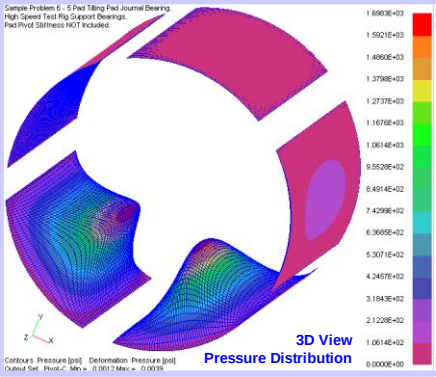
5-Pad Tilting Pad Journal Bearing

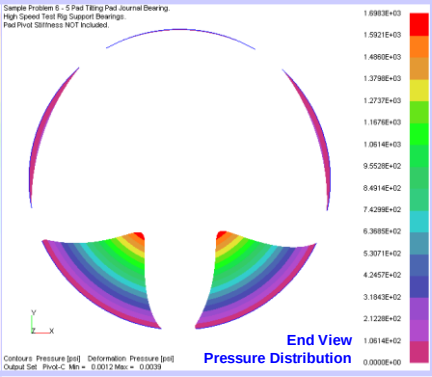


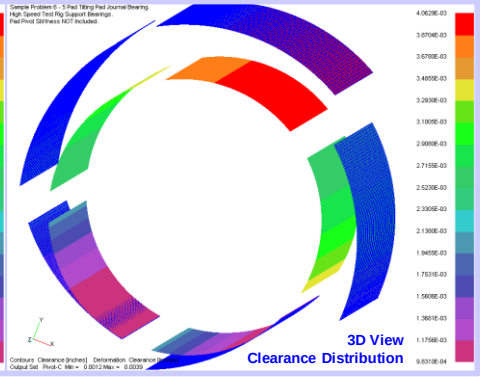
1 lubricant feed nozzle per pad

Journal Bearing – Unloaded Half

5 Pad Bearing
3 lubricant feed nozzles per pad

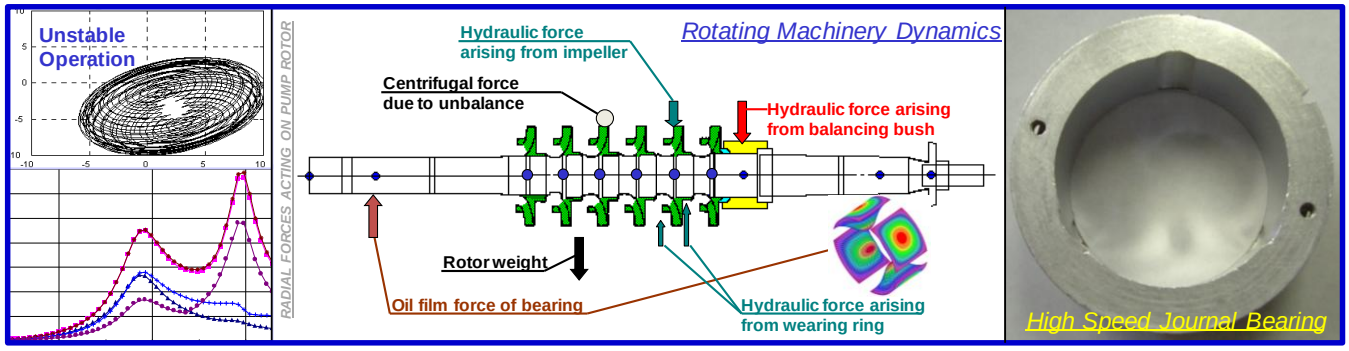






ROTOR DYNAMICS & TORSIONAL VIBRATION

◆ This session is presented in a simple way to understand the technology so that participants with or without previous knowledge benefit from the presentation and can apply it immediately in their profession. Commonly used terminology in the industry such as critical speed, mode shapes (rigid body and bending), stability, bearing whirl/whip, phase angle, critical damping, gyroscopic effects, unbalance, API-amplification factors & required separation margins, etc. will be discussed and illustrated throughout the course by the presentation of practical examples and case histories. The course handout includes sufficient details to be used as a reference including a *tutorial section on rotor dynamic* fundamentals and terminology.



1- INTRODUCTION & OVERVIEW (Presentation of real life vibration problem in a rotating system and cost/time effective corrective-actions taken as a solution)

2- BASICS OF MACHINERY VIBRATION
- Vibration Theory – Single mass system, planar vibration.
- Response & Shaft Dynamics – Displacement, velocity & acceleration amplitude & phase.
- Controlling Mechanisms.
- Forces In Rotating Equipment – Bearings, Cavitation, Imbalance, Hydraulic, Aerodynamic.

3- GEARBOX HIGH SPEED PINION VIBRATION PROBLEM AND COST/TIME EFFECTIVE CORRECTIVE-ACTIONS TAKEN AS A SOLUTION

4- ROTOR DYNAMICS & TORSIONAL VIBRATION - Basics
- Introduction & Application.
- Parameters Of Interests.
- Vibration Analysis Types.

5- ROTOR DYNAMICS - Basics
- Lateral, Torsional, & Axial.
- Stability & Response.

6- THEORY
- Rigid Rotor – One degree of freedom free & forced vibration.
- Simplified Rotor System Behavior – Dynamic vectors (displacement & force), critical speed, phase angle, stability parameter and the effects of system mass, stiffness, and damping.
- Flexible Rotor – Multi degree-of-freedom system.

7- ROTOR DYNAMICS - Advanced
- Synchronous Steady-State Response.
- Non-Synchronous Time-Transient Response.

8- SAMPLE PROBLEM – ILLUSTRATION OF SYNCHRONOUS & NON-SYNCHRONOUS VIBRATION ANALYSIS AND RESULTS.

9- ROTATING MACHINERY BALANCING GRADES & GUIDELINES

10- API STANDARDS & GUIDELINES
- Amplification Factor, Critical Response Envelope.
- Required Separation Margins For Operation Below & Above Critical Speed.
- Shaft Vibration Orbit properties.

11- REQUIREMENTS FOR ROTOR DYNAMIC ANALYSES - Modeling
- Shafting.
- Disks – Impellers, Couplings, Thrust Collars, Blades, Balanced pistons, etc.
- Bearings – Fluid-Film & Rolling Element
- Seals – Wear-rings, Labyrinth.
- Housing/Pedestal.
- Aerodynamic, Steam Whirl, Hydraulic Effects.
- External Excitations.

12- GYROSCOPIC EFFECTS

Detailed description of rotating masses with gyroscopic effects will be presented supported by the development of rotor/bearing system models and rotor dynamic solution. Splitting of modes will be demonstrated along with detailed coverage of forward and reverse processional modes and their excitability.

13- TURBINE-GENERATOR SET SUB-SYNCHRONOUS HIGH VIBRATION

A turbine-generator set consisting of three rotors, HP/IP turbine, LP turbine, and Generator rotors experienced high sub-synchronous vibration when operated at certain speed and above. Each rotor is supported by two fluid-film journal bearings. This problem **can** be presented in details to cover the following.

- Static Deflection & Bearing Loads Analyses.
  - A- All Bearings Same Elevation
  - B- COLD Bearing Alignment/Elevation
  - C- HOT Bearing Alignment/Elevation
  - D- CATENARY Curve Alignment/Elevation

- Critical Speed Map Generation. Explanation to why this map is not useful will be given.
- Create/Use Bearing Model In Bearing Module.
- Connect Bearing Model To Rotor Model & Supporting Structure Flexibility.
- Natural Frequency, Mode Shapes, and Stability Analysis.
- Natural Frequency & Stability Map Generation (Campbell Diagram).
- Unbalance Response Analysis.
- Time Transient Response Analysis – Faults & Excitations.

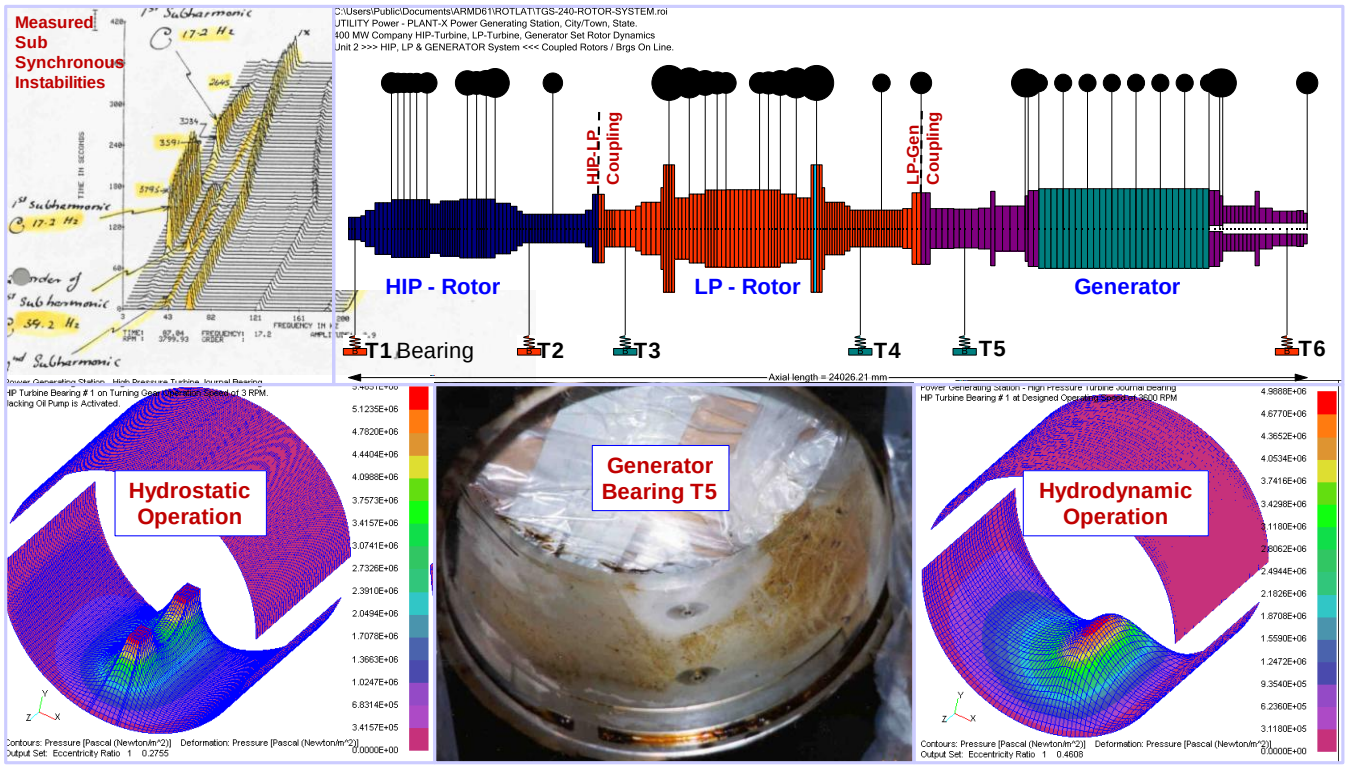
14- SIX STAGE BOILER FEED PUMP

Presented to illustrate rotor/bearings system modes of vibrations and how they are affected by bearing dynamic characteristics (stiffness & damping), shaft flexibility, stability and cause of instability, whip without whirl and corrective actions for stabilizing the system.

- Step-by-step rotor-bearing system modeling, analysis, and problem solution.
- Bearing interaction with the rotating assembly, oil-whirl/whip phenomena, rotor-bearing response, and stability illustrations.

ARMD™ (Advanced Rotating Machinery Dynamics Software)

◆ During the course, the software package ARMD will be used to demonstrate the modeling, analyses, and interpretation of results generated by rotor dynamics, tosional vibration, and bearing software packages. A detailed description of the software will be presented and illustrated by the construction of real life rotor and bearing systems. Participants will access the software for hands-on modeling, operation, and analysis of rotor/bearing systems performance simulation and troubleshooting.



15- TORSIONAL VIBRATION OF ROTATING MACHINERY

Torsional modeling and analysis of drive trains illustrated by presentation and solution of problems associated with centrifugal compressor driven by synchronous/induction motor startup transients, and reciprocating equipment steady state operation. Drive train torsional natural frequencies, mode shapes, critical speed maps (Campbell diagram), separation margins, material/hysteresis damping, external damping, and excitations will be discussed in details.

- Theory.
- Modeling Considerations – Shaft, Inertia, Coupling, Bearings, Damping, etc.
- Analysis Types & Generated Results Interpretation.

16- TORSIONAL SAMPLE PROBLEMS

- Simple Two-Disc System.
- Direct Drive Fixed Speed – 75kw Electric motor driven 4 stage gas booster centrifugal compressor.
- Synchronous Motor–Gearbox–Compressor Drive Train Start-Up Simulation.
- Failure Analysis of 2000hp Electric Motor Driving A 4-Throw Reciprocating Compressor And Cost Effective Solution.

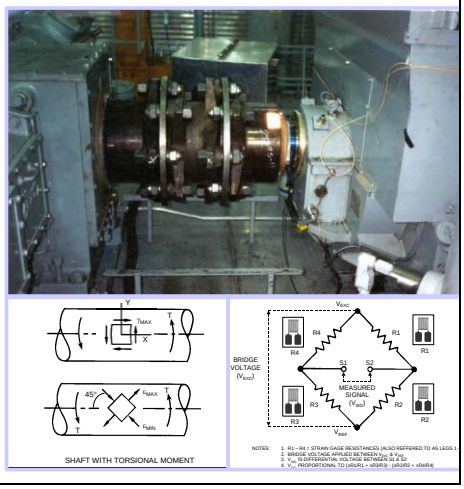
17- TORSIONAL SAMPLE PROBLEM DEVELOPMENT AND ANALYSIS

Guided session for the development of a drive train torsional model, evaluation, and interpretation of generated results with recommendations for effective modifications.

18- TORSIONAL VIBRATION MEASUREMENTS

If requested, a dedicated session for detailed presentation of the requirements for proper and accurate torque measurements in rotating equipment by the use of strain gages, conditioners, telemetry, and data acquisition systems.

- Basic Theory
- Strain Gage Description, Types, Terminology, and Application.
- Procedures for Strain Gage Mounting and Confirmation.
- Signal conditioning and data collection.
- Converting Strain Gage Electrical Signal To mechanical Torque & Stresses.



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