47th TURBOMACHINERY SYMPOSIUM
PROPOSED SHORT COURSE

TORSIONAL ROTORDYNAMICS OF MACHINERY EQUIPMENT STRINGS

BY

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One of the foremost concerns facing rotating equipment users today is that of torsional vibration. In contrast to lateral vibration, torsional vibration is rarely monitored. As a result, torsional failures can be especially heinous since the first symptom of a problem is often a broken shaft, gear tooth, or coupling. In the past, torsional vibration problems were considered to be rare; however the number of torsional field problems has markedly increased recently with the advent of higher power, higher complexity variable frequency drives (VFD's). The increased risk plus the difficulty of detecting incipient failures in the field makes the performance of a thorough torsional vibration analysis an essential component of the turbomachinery design process.

There are three primary objectives to this Short Course. First, it will provide users with a basic understanding of steady-state torsional vibrations, their potential for generating problems, and methodologies that are commonly used to analyze and avoid these problems. This portion of the course is aimed at younger, less experienced users, although veteran users will probably also benefit from the review. Second, it will provide users with some understanding of the more complex issues related to transient torsional vibration and acceptance based on stress analysis. Third, it will educate users on how VFD's work, and why they are a concern from a torsional standpoint. This portion will be beneficial to all users since modern VFD's are not well understood, especially by mechanical engineers.

The course will be based on practical examples starting from the simple to the complex with some material based on a tutorial the lead author presented at this very show in 1996, "Practical Design Against Torsional Vibration." Among the topics that will be discussed include description of torsional vibration, modeling, undamped analysis, Campbell diagrams, excitations generated by various mechanical and electrical components, steady-state and transient analyses, synchronous motor startups, and fatigue life analysis. At the conclusion of this portion, the user should have a good grasp of the fundamentals of this topic.

A significant portion of time will be spent on VFD's. Topics covered will include VFD types, excitation frequencies generated by various VFD's, typical excitation amplitudes, control loop instabilities that can lead to problems, coupled electro-mechanical analyses, and design procedures for preventing VFD-related torsional issues up-front.
At the conclusion of this course, all users should have sufficient understanding of the relevant concepts so that they should be able to take the proper steps to prevent torsional vibration problems from occurring in their equipment, even when their system contains a VFD.

Syllabus

1. Introduction
    a. Course Objectives
    b. Course Agenda
    c. Torsional Vibration – What it is, Why we care

2. Basics of Problem Avoidance
    a. API Requirements
    b. Excitation Frequencies, Separation Margins and Campbell Diagrams
    c. Stress Margin - Goodman Diagrams
    d. Transient Stress Margin - Allowable Number of Starts

3. Achieving Separation Margins: System Modeling and Tuning from the Simple to the Complex
    a. Modeling
    b. Undamped analysis
    c. Generation of Campbell diagrams & excitations to plot
    d. Two Inertia System Model
        i. Basic Equations
    e. A Turbine – Compressor String with Couplings
        i. Considerations in Modeling Real Machinery.
        ii. Frequencies to Avoid
        iii. Couplings and Tuning
    f. Turbine – Gear – Compressor String with Couplings
        i. Gear Modeling
        ii. Effect of Gear Ratio on the System Model
        iii. Frequencies to Avoid
        iv. Couplings and Tuning
    g. Induction Motor – Gear – Compressor String
        i. Induction Motor Modeling
        ii. Frequencies to Avoid
        iii. Couplings and Tuning
    h. Other Cases

4. Steady-State Response Analysis
    a. Excitations and damping
    b. Stress Concentration Factors
    c. Couplings
        1. Design Against Slippage
        2. Peak Torque Capacity
        3. Maximum Momentary Torque

5. Transient Response Analysis
    a. Synchronous Motor Startup
        i. Low-Cycle fatigue analysis
        ii. The Holset Coupling
    b. Induction motor starts and re-starts
    c. Motor and Generator Faults
    d. Other Cases

6. Modeling Considerations
    a. Geared systems
    b. Hydraulic couplings
    c. Voith Vorecons
    d. Torsional-to-lateral coupling

7. The Problem of VFDs
    a. Components Found in All VFDs (Rectifiers, DC-links, Inverters, etc.)
    b. Types of VFDs (CSIs, LCIs, VSIs, etc.)
    c. Pulse-Width Modulation
    d. Harmonic Excitations
    e. Inter-harmonic Excitations
    f. Transient analyses of LCI start-ups
    g. Broadband excitations
    h. Control Loop Instabilities
    i. Coupled Electro-Mechanical Simulations
    j. Recommended Design Procedure

8. Reciprocating Machinery
    a. Reciprocating engines
    b. Reciprocating compressors

9. Torsional testing

10. Field Problems/Case Studies
    a. Field Problems From The Literature
    b. Our experiences

11. Q&A