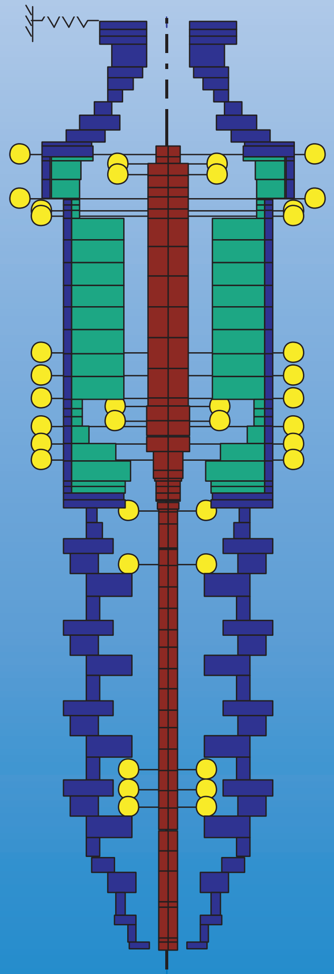
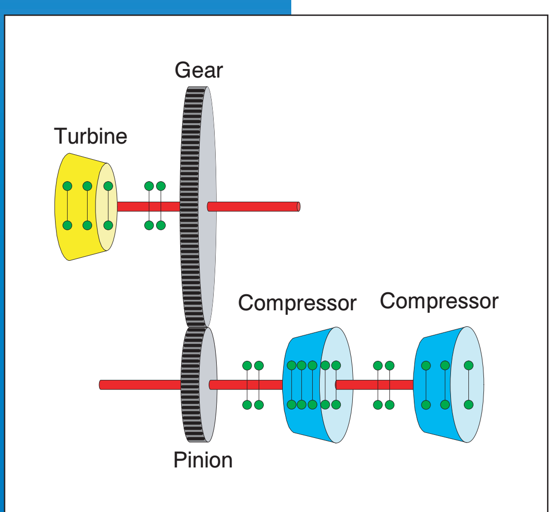
XLTRC^2



Multi Level (3 shaft model)

Rotordynamics Software Suite

Turbomachinery Research Consortium



Turbomachinery Laboratory
The Texas A&M University System
http://turbolab.tamu.edu

What is *XL*TRC²?

***XL*TRC²** is a suite of very fast, accurate, and user- friendly codes for executing a *complete lateral and torsional rotordynamic analysis* of rotating machinery including pumps, compressors and turbines. ***XL*TRC²** runs on Windows 95, 98, Me, NT, 2000 and XP with Microsoft Office 97 or later version. SI or American units can be used interchangeably. Extensive help files are provided for the base and support-library codes.

How does *XL*TRC² work?

For lateral rotordynamics, ***XL*TRC²** uses a Timoshenko-beam, finite-element formulation to model the rotor and housing elements to any degree of accuracy that the analyst feels appropriate. Model dimensionality and execution time are dramatically reduced by using real, zero-running speed modes in a component-mode synthesis formulation. By using real modes (instead of complex modes) the initial modal calculation time is minimized (dramatically), and interpolation and extrapolation of modal parameters is eliminated. Constraint modes are used only at bearing locations and connection points that require nonlinear or frequency-dependent force or moment impedances. ***XL*TRC²** generates rotordynamic results faster than most experienced engineers can input data and evaluate results. Stated differently, engineers don't wait on ***XL*TRC²**.

***XL*TRC²** uses an Excel-based Graphical User Interface (GUI) to access a suite of rotordynamic codes developed at the Turbomachinery Laboratory (TL) of Texas A&M University (TAMU). The Excel base is ideal for generating or transferring rotordynamic-model data and for translating rotordynamic results into final reports. In addition, the Excel GUI allows a great deal of flexibility for individual or corporate customization. The core of ***XL*TRC²** is optimized with the latest compilers from Intel FORTRAN 9. The IMSL libraries, that are used, provide fast and accurate computation of results. ***XL*TRC²** also runs on 64-bit Windows operation systems, while maintaining backward compatibility with older systems.

What Advanced Features Does *XL*TRC² Provide?

The following capabilities and features are provided for lateral rotordynamic analysis:

- Rotors with multiple load lines such as a rotor with a through bolt can be analyzed.
- Steady state rotor response is calculated due to base harmonic motion. This feature allows calculation of steady-state rotor response of a rotor due to motion of an off-shore oil platform.
- Multi-rotor/housing models can be easily developed including dual-rotor "shaft-in-shaft" systems.
- Multi-bearing, statically-indeterminate rotor/shaft systems can be directly analyzed to calculate equilibrium bearing loads.
- *General* linear transfer-function matrices can be used *directly* to model reaction elements versus speed-dependent stiffness and damping coefficients: e.g., the transfer function of a magnetic bearing is readily and directly accepted. Force (2x2) and combined force and moment (2x2) transfer-matrices are accepted.
- Reaction-load/motion transfer-functions are accepted with sensor measurements of motion at one location and force application at another location.
- The influence of bearings and seal misalignments can be directly modeled. For a statically indeterminant rotor, a bearing or seal can be arbitrarily misaligned, changing the bearing loads and (for a hydrodynamic bearing) changing the rotordynamic coefficients and response.
- Rotor Response due to bent-shaft excitation can be calculated.
- Rotor response and housing acceleration levels due to base excitation can be calculated. This feature can be used to easily calculate relative rotor response and housing acceleration levels for a compressor on a moving off-shore platform.
- Steady-state response calculations can be calculated due to nonsynchronous rotating loads at a frequency Ω different from running speed ω.
- A stiffness matrix can be inserted to replace a beam element stiffness matrix; e.g., a general structural analysis program can be used to separately calculate the stiffness properties of a conical shell element for insertion into ***XL*TRC²**.
- Rotor response can be calculated due to prescribed base maneuver motion. This feature can be used to calculate rotor deflections and bearing loads of aircraft gas turbine rotors due to the mass-center acceleration and pitch, yaw, and roll of the aircraft.
- Bending stresses can be calculated using the bending moments and the shaft sectional modulus. Three maximum bending stresses are reported corresponding to static load, forward whirl imbalance loading and reverse whirl imbalance loading.

- A time-transient nonlinear feature is available to analyze the influence of nonlinearities such as bearing dead bands, rubbing, hydrodynamic bearings, etc. Blade loss phenomena, limit-cycle motion of vertical pumps, etc.can be analyzed with this feature.
- Fast fourier transform (FFT) of the time transient data can be easily plotted by selecting the data range.
- User-defined nonlinear connections can be handled using user defined DLLs (dynamic linked libraries).
- External torques, constant or time varying, can be specified for each shaft to simulate transients motion during start-up and run-down.

***XL*TRC²**-TORSION is an independent torsional analysis code incorporated within ***XL*TRC²**. It uses the same FEM formulation and modeling techniques as the lateral code and provides the following features:

- Data form a lateral model can be translated to torsional input sheets by the click of a button.
- Undamped and damped torsional frequencies can be calculated. Concentrated damping can be specified at bearings as well as shaft damping. Bearing damping is from a rotor station to ground. Shaft damping arises from relative station motion along the shaft.
- Torsional interference diagrams (Campbell diagram) can be easily created once the undamped (or damped) torsional frequencies are calculated. The line frequencies (usually 60 Hz in USA or 50 Hz in Europe) is used to calculate the slip line speed. A straight line is drawn in the diagram connecting the twice slip line speed (y-axis) to the rotor synchronous speed (x-axis). The torsional frequencies are plotted on the same graph to form the Torsional interference diagram.
- Torsional forced (steady-state) response is similar to imbalance response calculation in the lateral analysis.
- Multiple shafts can be connected at specific locations by torsional stiffness and damping for branched systems as well as for closed loop systems.
- The following four different motor torque input and output options are available: (a) Synchronous motor with drive torque and pulsating torque input as a function of speed, (b) Synchronous motor with drive torque, pulsating torque and arbitrary pulsating frequency, (c) Load torque, i.e. Input of load torque as a function of speed, and, (d) Torque as a specified function of time.
- Torque inputs are used for the startup transient analysis. The driving and load torques are specified at different stations by specifying them as one of the available types of motor torque inputs.
- Once the data on variation of torque with respect to time are available, the user can perform the Cumulative Fatigue Analysis (predicted number of starts the machine will survive).

How Accurate is the Code ?

Exhaustive comparisons to predictions from other codes and classical exact solutions show accurate results with no perceptible errors using ***XL*TRC²**. These comparisons have specifically included rotors with high damping levels at the bearings and heavily damped modes.

Supporting Library Codes

The base rotordynamics codes provide the strong skeleton for an accurate and efficient structural- dynamic rotor and housing model. However, accurate rotordynamics analysis for real turbomachinery units also requires careful modeling of bearings, seals, squeeze-film dampers, etc. ***XL*TRC²** provides an unmatched support library to define the forces developed by these elements. A brief summary of these support codes is provided below.

Turbulent, Liquid Annular Seals for Pumps

XLAnSeal, (San Andres) calculates leakage, pressure distributions, reaction forces, and force and moment coefficients for annular turbulent seals in the laminar, turbulent, and transition flow regimes. A CFD algorithm is used to solve bulk-flow Navier Stokes equations and yields solutions for centered or statically displaced seals (radial or angular misalignment can be specified). Solutions are developed for incompressible or barotropic fluids.

XLCGrv (Childs, Marquette) calculates leakage and rotordynamic coefficients for centered grooved- stator, turbulent flow, annular pump seals. XLCGrv uses a three-control-volume, bulk-flow model.

Gas Labyrinth Seals for Compressors and Turbines

XLLabyCV-1 calculates pressure distributions, leakage rates, and (2x2) stiffness and damping coefficients for tooth-on-rotor or tooth-on-stator gas labyrinth seals. The code is based on a one-control- volume bulk-flow model. The results are valid for small motion about a centered seal position. By comparison to measurements, this code gives reasonable predictions for the effective damping of see-through labyrinth seals.

Smooth-Rotor/Honeycomb Stator Seals

XLIsotSL (Kleynhans, Childs, D'Souza) calculates leakage and rotordynamic coefficients for smooth rotor/honeycomb stator (or hole-pattern stator) annular seals. The code is based on a two-control volume model that yields strongly frequency- dependent predictions for stiffness and damping and has been validated by comparison to measurements at pressures to 70 bars and speeds to 20000 rpm.

Annular Viscous Seals for Compressors and Pumps

XLLubGT (San Andres) predicts rotordynamic coefficients for high-pressure oil bushing seals (floating multi-ring oil seals) of compressors but can also be used for smooth pump seals in the laminar flow regime. The code works for laminar or transition-flow regime applications, calculating leakage rate, power loss, axial temperature and pressure distributions, and (2x2) stiffness and damping coefficients. The code includes energy transport and thermal models and is valid for centered and eccentric rotor positions.

Hydrodynamic and Hydrostatic Bearings

XLJrnl is a computer implementation of Someya's, *Bearing Data Hand Book*. This code calculates stiffness and damping coefficients for fixed-arc and tilting-pad bearings on a "table look-up" basis. It is extremely quick and excellent for preliminary design work.

XLHydPad (San Andres) is used to analyze hydrostatic and hybrid (combination hydrostatic and hydrodynamic) journal-pad bearings in the laminar flow regime. Arbitrary geometries can be prescribed for the recesses (rectangles, triangles, etc.). A finite-element (FEM) algorithm is used to calculate flowrate, pressure distributions, and (2x2) stiffness and damping coefficients. The program generates (2x2) stiffness and damping matrices for small amplitude motion about on arbitrary journal position.

XLTFPBrg, (San Andres) This program is used to analyze fixed-arc, tilting-pad, and flexure-pivot hydrostatic bearings in laminar and turbulent flow regimes. A CFD algorithm is used to solve bulk-flow Navier Stokes equations and calculate (2x2) stiffness and damping coefficients. Numerical solutions are calculated for pressure, flow, and film forces using a thermo-hydrodynamic (THD) model for radial heat flow and uniform bearing and journal temperatures (adiabatic and isothermal energy models).

XLPresDm (San Andres) Stiffness and damping coefficients are calculated for (i) multi-lobed, rigid- pad arc bearings with preload and (ii) pressure-dam bearings with relief tracks. A finite-element solution is developed for the Reynolds equation for incompressible, isoviscous, inertialess, laminar flow.

Rolling-Element Bearings

XLBalBrg is a C++ implementation of the A.B. Jones model to calculate stiffness coefficients for ball bearings. The bearing-contact loads and angles, reactions, and deflections are also calculated.

Squeeze-film Dampers (SFDs)

XLLSFD produces dimensionless damping and mass coefficients for locally-sealed squeeze-film dampers with circular centered orbits at specified whirl amplitudes.

XLOSFD calculates damping and mass coefficients for open-ended squeeze-film dampers. The results are valid for small journal motions about a statically eccentric position.

XLSFDFEM uses a FEM algorithm to compute damping coefficient for SFDs with various types of end seals.

Pump and Compressor Impellers and Turbine Stages

XLPIMPLR produces (2x2) stiffness, damping, and mass matrices for centrifugal pump impellers. The code provides a library of pump impellers based on Sulzer-pump empirical data.

XLWachel uses Wachel's empirical formula to calculate destabilizing cross-coupled force coefficients for impellers of centrifugal compressors.

XLClrEx calculates destabilizing cross-coupled stiffness coefficients for unshrouded turbine stages using the Thomas or Alford formula.

User-defined Force and Moment Coefficients

As specified by the user, the code will accept arbitrary and independently calculated (2x2) force coefficients (**XLUseKCM**) for stiffness, damping, and mass coefficients or (4 x 4) combined force and moment (**XLUseMoM**) stiffness, damping, and inertia coefficients.

User-defined Linear Transfer-function Matrices

The user can specify transfer function input defined with poles, zeros, and gain (**XLTFuncPZ**) or numerator/ denominator coefficients (**XLTFuncND**). Force (2 x 2) and combined (4 x 4) force and moment transfer-matrices can be defined in the model.

User-defined, Eccentricity Dependent Coefficients

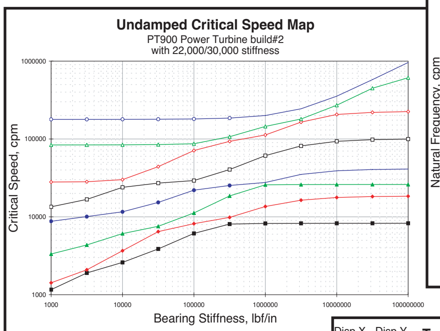
XLUseEcc_nd allows the user to obtain speed- dependent stiffness and damping coefficients and whirl frequency ratio versus eccentricity ratio for specified journal bearing dimensions and loads. Dimensionless stiffness and damping, eccentricity ratio, attitude angle, and Sommerfeld are input by the user.

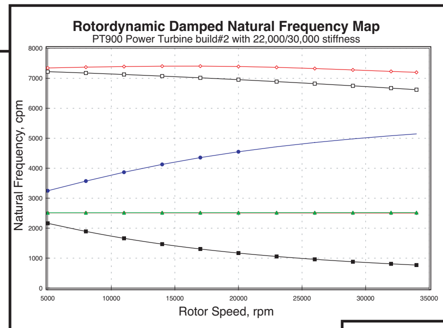
User-defined Foundation Parameters

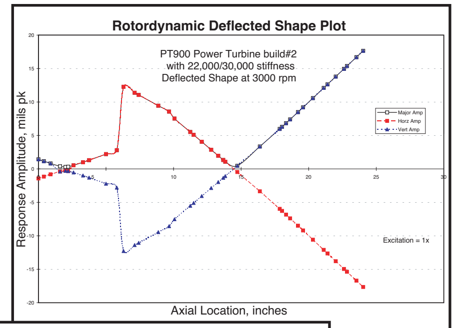
From measured mobility transfer-function data obtained by the mechanical impedance method, user defined horizontal (**XLFKCMH**) or horizontal and vertical (**XLFKCMHV**, for foundation asymmetry) stiffness, damping, and mass foundation parameters can be accepted.

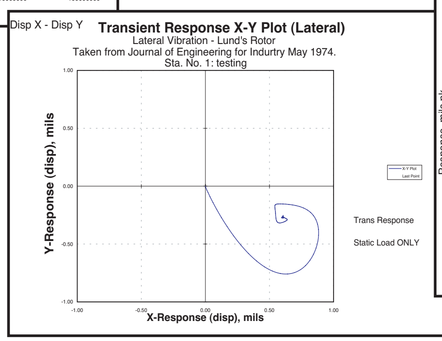
Lubrication and Material Databases

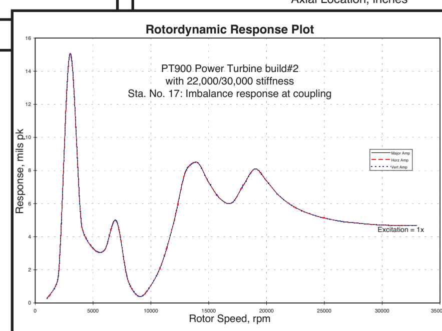
To assist the user with selection and input, **Lube** provides viscosity, density, and thermal properties versus temperature for various commercial lubricants. **Material** provides a tabulation of density, modulus, and thermal conductivity for a number of common metals.

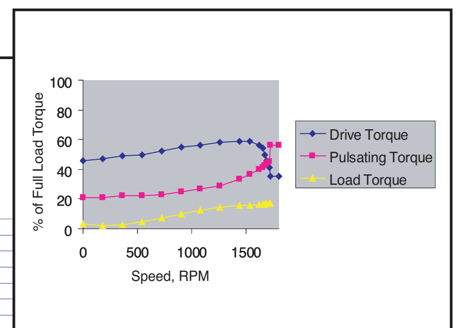


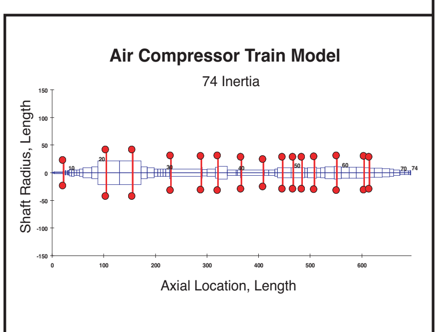


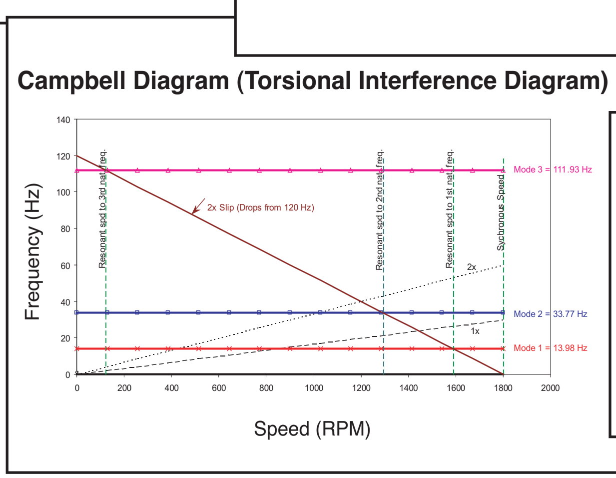


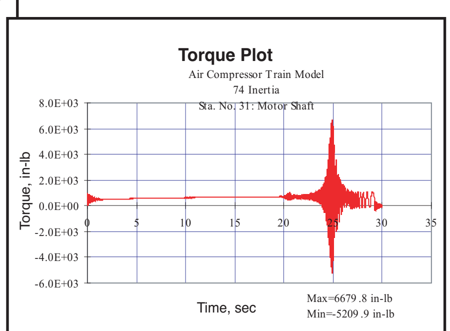












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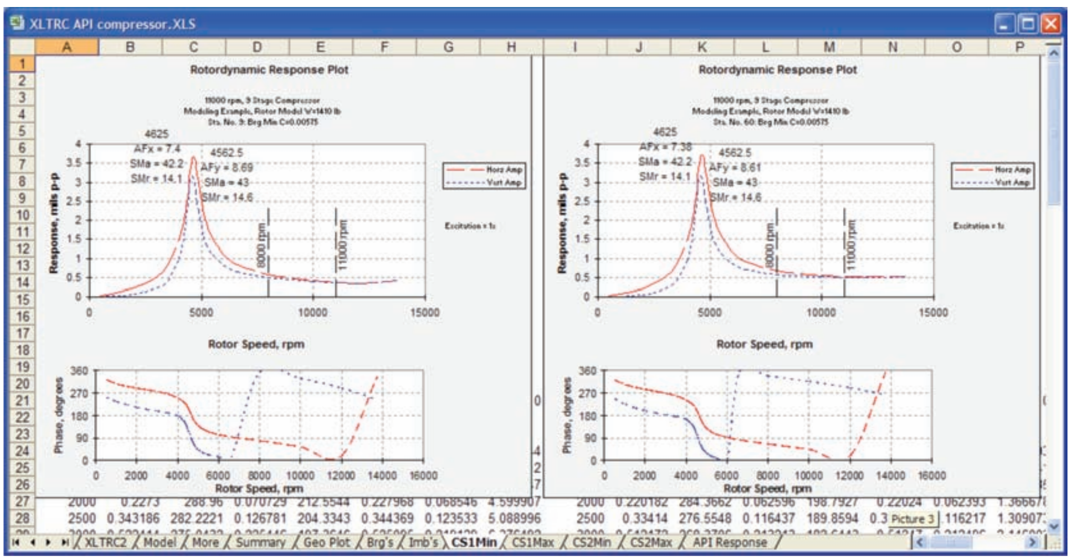
One Touch API 684 Reporting

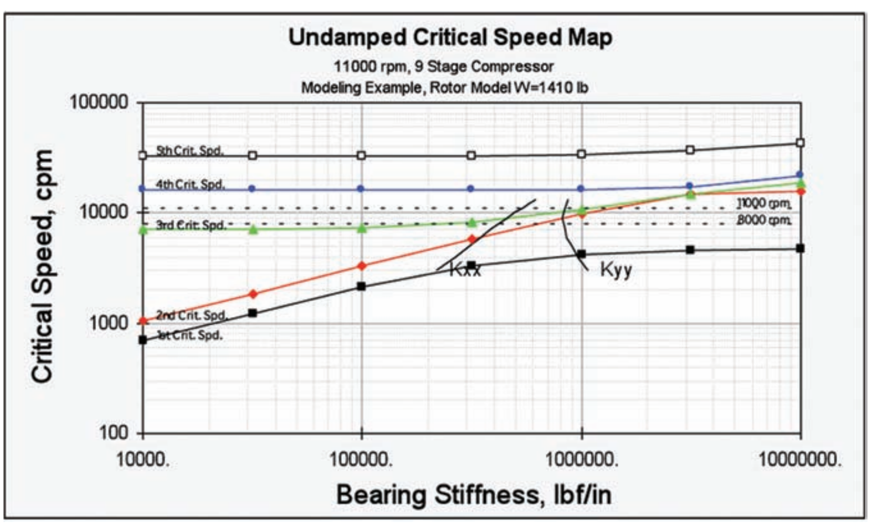
Because of the extensive research conducted in the Turbo-Lab (TL), and the close contact of the TL with the industry through the Turbomachinery Research Consortium, XLTRC2 is being continually upgraded. A recent major update was the API module. This module greatly facilitates the day-to-day job of the rotordynamics analyst, saving valuable time in preparing API reports. The repetitive tasks of defining and running all the different combinations of imbalance, bearing coefficients, and aerodynamic cross coupling that are required by the API standards are now automated. Experienced users of XLTRC2 have found this module to be a great help in accelerating the design process and in producing standardizing API reports.

The API module is an Excel add-in. This additional toolbar will enable the user to define and run all API standards.

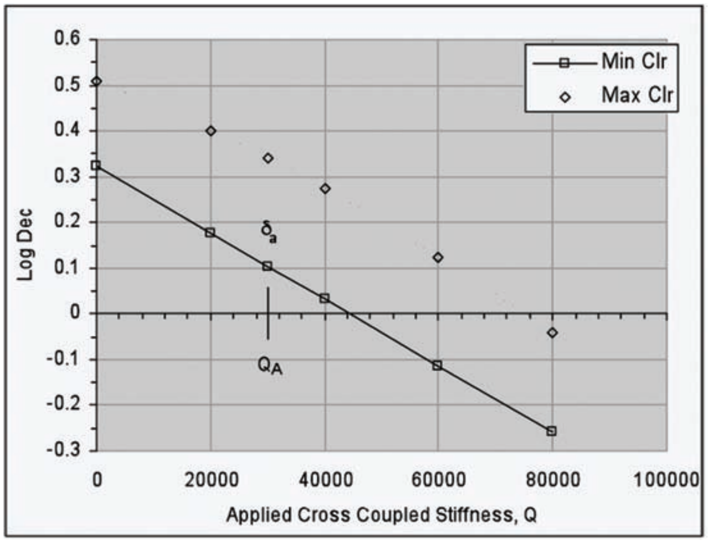
With minimum user inputs and instructions, the response analysis let you define different cases of imbalance and bearing coefficients. The module then loops through the cases and shows the response results with all the margins specified and vibration limits checked against the API standards. You can also specify stations to check for potential rubbing, clearances, and bearing-probe responses.

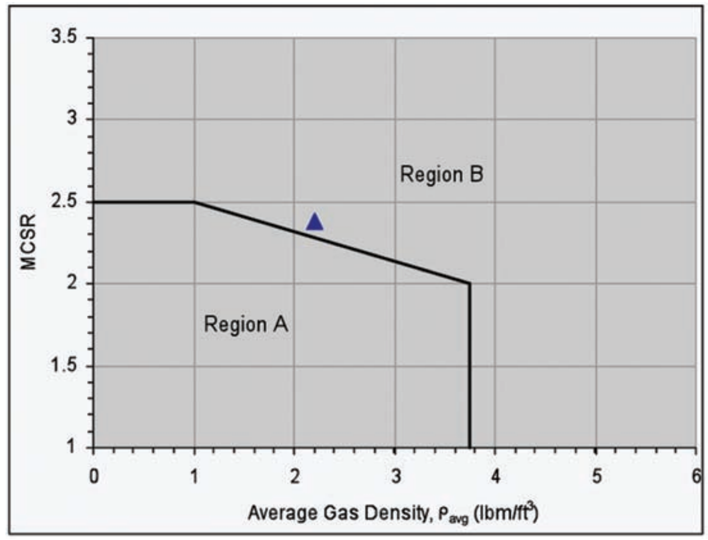


You can also run Undamped Critical Speed (UCS) analyses where the output is specifically tailored for API reports.

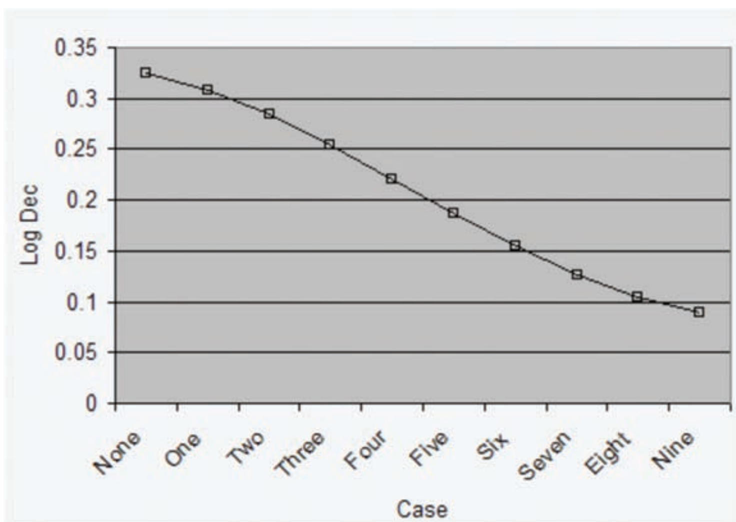


The API module lets you define the parameters to run level I and II stability analyses. In level I you can specify bearing coefficients and cross coupled aerodynamic destabilizing force levels. The results will show the log decrement and stability regions of the system.





The time-consuming drill of running the level II analysis is greatly automated by gradually adding all the destabilizing influences. A plot of those factors can be shown to investigate the sensitivity of loc decrement to the various contributing elements



In addition to the API module to XLTRC2, XLTorsion has also been upgraded to handle cases with multiple shafts including kinematic and/or flexible constraints at gears. Various bearing files have been added. A new Labyrinth Seal code has been developed to cover cases where the rotor surface speed approaches Mach 1. In addition to those upgrades the next release of XLTRC2, which is scheduled for May 2009 will include additional major updates.

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