

Modal

The Structural Dynamics Module

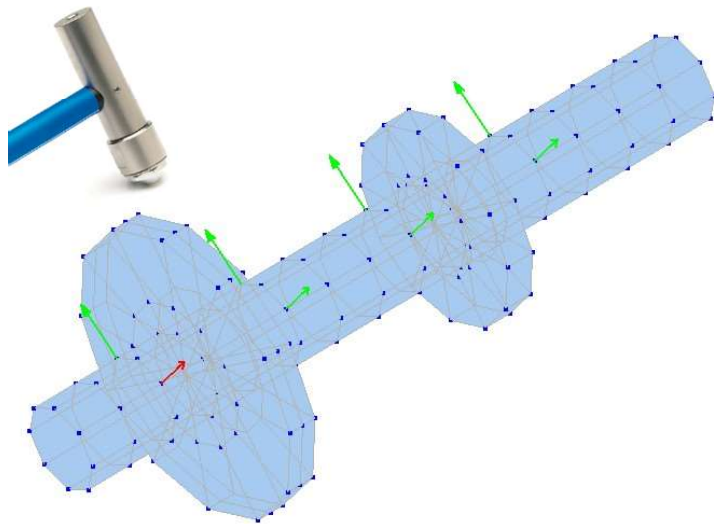


Fig1: Geometry of a turbine shaft

Introduction

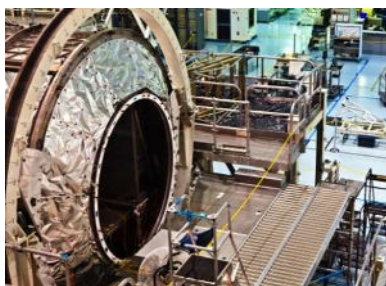
Modal analysis is a powerful technique for understanding structural behavior to validate simulation results, mechanical designs and maintenance.

OROS offers the modal solution, a comprehensive package for modal experts as well as novice engineers.

Discover OROS Modal, an application-oriented software associating the latest algorithms with a user-friendly interface and automatic procedures for Operating Deflection Shape (ODS) and modal parameter identification.

Industries

- > Energy & Process
- > Marine
- > Aerospace & Defense
- > Ground Transportation
- > Manufacturing & Automation
- > Education & Universities



Machine

- > Engine
- > Vehicles
- > Turbines
- > Pumps
- > Compressors
- > Generators
- > Aircraft component
- > Building & bridge
- > Ship hull



Applications

- > Research & Development
- > Field acceptance test
- > Troubleshooting & Diagnostic



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Description

The software guides the user through the different steps to realize a complete ODS or modal analysis of the measured structure.

- > Geometry builder
- > Acquisition
- > Operating Deflection Shape
- > Modal Analysis: Experimental and Operational
- > Validation Tools

Geometry builder

The software contains several functions to create a geometry in order to match any machines. Predefined standard elements (circle, cube, cylinder ...) are available as well as a dedicated interface to create a geometry manually. The local coordinates systems (Cartesian, cylindrical, spherical) allow to define the correct directions on each measurement points. A geometry can also be imported from others software (experimental and simulation software).

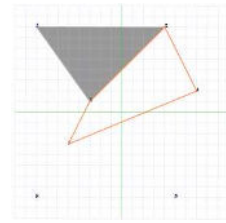


Fig2: Geometry building

Data acquisition

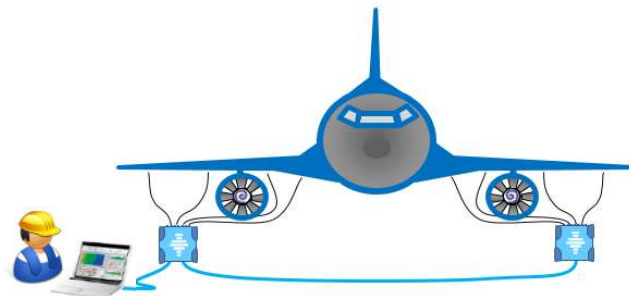
Data acquisition is a critical step for modal analysis: without correct data, no exploitable results. Thanks to the direct acquisition implemented in Modal, enjoy the Teamwork analyzers power and accuracy with a dedicated interface for structural acquisition. The interface works with the different excitation modes: impact hammer, shaker, operating excitation.



Fig3: Generators outputs

To excite a large structure, up to 6 shakers per analyzers can receive signals from generators outputs. In order to fit the wide range of potential cases, the complete series of excitation signals from random, chirp, swept sine, stepped sine to normal modes can be generated.

For high channel count applications, Teamwork technology cascades several analyzers together to acquire simultaneously hundreds of channels. Teamwork instruments guarantee an efficient instrumentation thanks to the



different possible configuration. For example, this flexibility allows to highly reduce the cable length by distributing the instruments along the structure under test.



In the case of using several analyzers, the number of generators is multiplied by the number of systems and a high cross phase accuracy between units $\pm 0.2^\circ$ is guaranteed.

The sequencer, the geometry display, the control of the generators, the double hit detection are examples of functions that make the acquisition easier. To check data validity, several results are available to control the acquisition. Frequency Response Functions (FRFs), spectra, coherence and triggered blocks can be displayed in one layout during the measurements.

Operating Deflection Shape

The Operating Deflection Shape module allows to visualize the behavior of a structure under operating conditions, when it's excited by its own source. Time and frequency domain animations are available. In the frequency domain the Modes Identifications Functions (MIF) are used to display the response of the structure at each defined frequency. The mode shape at each frequency corresponds to the linear combination of all the modes that contribute to the total response of the system.

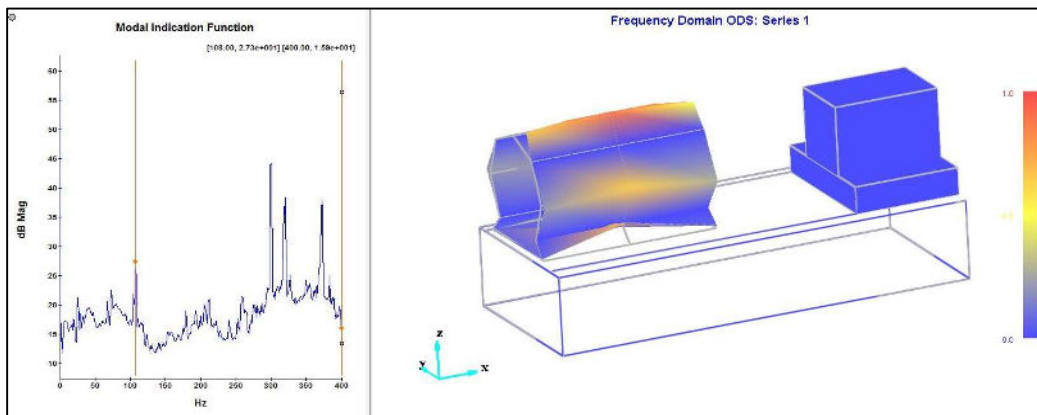


Fig3: ODS on a motor-pump unit

Modal Analysis

Modal analysis can be conducted via artificial excitation, e.g., shaker or instrument hammer excitation. Input force and output responses are measured. This is called an **Experimental Modal Analysis (EMA)**. The EMA approach can be divided into three levels based on Single Input Single Output (SISO), Single Input Multiple Output (SIMO), Multiple Input Multiple Output (MIMO).

Modal is **born with MIMO analysis**. However, SIMO algorithm is also implemented for simple applications. MIMO EMA has important advantages: not only consistent results can be obtained, but close spaced and even repeated modes can be identified.

Modal analysis can also be accomplished during operational conditions of a mechanical structure via responses measurements due to ambient or natural excitation, or other excitation but without input force measurements. This is called as **Operational Modal Analysis (OMA)**.

EMA and OMA methods are implemented in the software. The implemented methods have been chosen regarding their efficiency. They belong to the following categories:

- > **MDOF methods:**

Based on the assumption that each resonance peak in the measured frequency response functions can be viewed as the summed contribution of a number of modes in a particular frequency band.

- > **Global methods:**
Use a formulation where all frequency response functions are considered simultaneously. Global methods deliver superior results compared to local methods. But global estimation method requires reasonably high-quality measurement data. Indeed, these methods are sensitive to small variations in the data.
- > **Frequency domain methods:**
Based on a model formulation in the frequency domain. These methods distinguish physical (structural) modes from computational (noise) modes more easily than time domain methods. For application to real-world structures, locating structural modes reliably is the most important task of a modal analysis.

Mode identification tools

These tools allow a better identification of the modes than the Frequency Response Functions (FRFs) of Power Spectral Density (PSD). Indeed, it's very difficult to identify the exact number of the modes by viewing the FRFs one by one. All the modes may not be active in the particular measured FRF. For example, closely spaced modes are generally observed with difficulty. Two different modes identifications are implemented in the software:

- > **CMIF:** Complex Modal Indicator function

The Complex Mode Indicator Function is based on Singular Value Decomposition of the FRF or PSD matrix. It determines all the main modes observed in the set of measurements.

- > **Stability Diagram**

The basic philosophy is that poles that are extracted from increasing order mathematical model will repeat as the order is increased if the pole is a global characteristic of the system.

Modal Identification methods

The following table describes the different methods implemented in OROS Modal with their advantages and limits.

| Method | Technique | Advantages | Limits |
|--|---|---|---|
| EMA/OMA Narband Based on the Complex Mode Indicator Function (CMIF) | Narrowband MIMO modal identification algorithm. Identify one mode at a time. | Very easy-to-use. | Require the mass matrix uniformity assumption and consequently modal vector orthogonality. Theoretically, this assumption is perfectly respected for simple structure like beam but not for complex structures. |
| EMA/OMA Broband Based on the algorithm of Polyreference Least Squares Complex Frequency (p-LSCF) | Selected-band MIMO modal identification technique. Identify modes in broad frequency band including full band. | Yield clear stability diagram. Distinguish automatically structural modes from 'noise' modes, or real modes from spurious modes. Identify modes in broad frequency band automatically in one run. | Not the best method if you are especially interested by damping and if there is noise. |

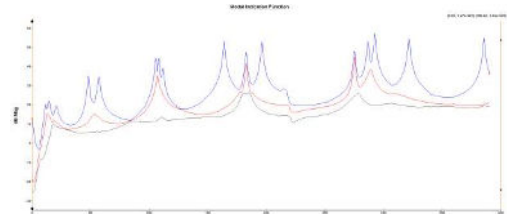


Fig4: CMIF

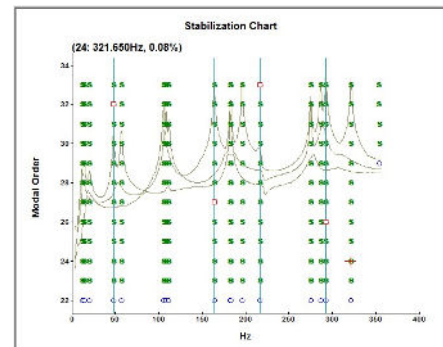


Fig5: Stability diagram

| Method | Technique | Advantages | Limits |
|--|---|---|---|
| EMA MIMO1 Based on Frequency Domain Poly-Reference (FDPR) algorithm. | Selected-band MIMO modal identification technique. Identify few modes at a time in user-selected frequency bandwidth. | A rank chart is displayed to be sure of the number of modes within the frequency band. Modal parameters within the frequency band are automatically identified. Good results with 3 or more references. | Use Singular-Value Decomposition (SVD) of FRF data for distinguishing structural modes from noise modes. The number of measurements should be larger than the number of modes. |
| EMA MIMO2 Based on Rational Fraction Polynomial formulation of transfer function. To improve numerical performance, orthogonal polynomial is adopted instead of power polynomial. | Selected-band MIMO modal identification technique. Identify a few modes at a time in user-selected frequency bandwidth. | Can be applied in modal testing with a few response measurements. | It is preferred to limit the number of references DOFs of the FRF matrix, e.g. less than three. |
| EMA SIMO Based on Rational Fraction Polynomial formulation of the transfer function. | It is a special case of MIMO 2 with only one excitation or one reference, e.g., a single shaker or single reference for impact tests. | Have similar features as its MIMO counterpart. | Only measurements with one reference are admitted. |

Validation tools

Modal Assurance Criterion (MAC) values can be used to compare two arbitrary complex vectors. The MAC value between two vectors who have linear relationship is near to one. The MAC value between two linearly independent vectors will be near zero. MAC calculation has two applications in modal analysis:

- > It can be used to compare two mode shapes obtained from two different modal parameter estimation processes on the same test data. Two similar mode shapes have a high MAC value, and two identical mode shapes have a MAC value of 1.
- > Second, it can be used to check the orthogonality of mode shapes when weighted by the mass matrix. Even when no exact mass matrix is available, the orthogonality of mode shapes is approximately satisfied. It can be used to validate the modal results.

The Coordinate Modal Assurance Criterion (COMAC), an extension of the MAC, is used to identify which measurement degrees of freedom contribute negatively to a low value of MAC.

Opening and compatibility

The Modal import/export capabilities facilitate its integration in various test environments.

It's also a good complementary tool to Finite Elements software for model updating.

For example, Modal is compatible with FEMtools from Dynamic Design Solution, specialist software for:

- > Structural static and dynamics simulation,
- > Validation and updating of FE models for structural analysis,
- > Design optimization.

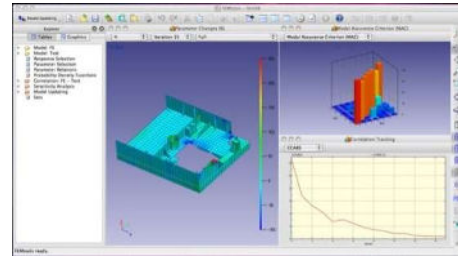


Fig7: FEMtools interface

Boost your efficiency with OROS Teamwork range

OROS Modal can run on or analyze results from all Teamwork analyzers providing flexible choices of the hardware platform size.

- > 4,10,16,32 channels instruments
- > Portable and rugged
- > Handling any transducers (accelerometers, strain gauges, microphones ...)
- > Real-time, multi-analysis
- > Accurate
- > Cascadable up to 1000+ channels
- > Distributed configuration

Modal belongs to the comprehensive OROS product line. Other software modules such as FFTDiag, ORBIGate, Advanced Swept Sine, Balancing, and acoustics are provided on the same instrument platform.



On-Site Measurements & Applied Trainings

Experts from OROS may come on-site for applied trainings. They will help you using your OROS system. They can provide assistance in your measurement. They are also able to recommend optimization in your measurement process depending on your application and field constraints.

Applied trainings

Modal basics

> Objective

Understand the basics of modal analysis. What the different types of measurements, ODS, EMA, OMA are and their specific features.

To be able to process a complete modal analysis with the OROS system.

> Public

Technician or engineer with knowledge in vibration analysis

> Program

Modal analysis basic concepts (natural frequency, damping, mode shape);
 Procedure for ODS, EMA, OMA;
 Use of the available tools: FRF, MIF;
 Practice on a test structure;
 Results comparison.

> Duration 1 day

EMA with Modal

> Objective

Through a real case (test structure or your own machine) you will learn to use Modal, the structural dynamics module to perform a complete Experimental Modal Analysis

> Public

Technician or engineer with knowledge in vibration analysis

> Program

Presentation of the software interface;
 Geometry modeling;
 Sequencer to define the different measurement sets;
 FRF measurement with impact hammer;
 Modal identification;
 Results validation and comparison.

> Duration 1 day

On-site measurement

- > Assistance in your measurement, ODS, modal analysis
- > Expertise in diagnostics



Specifications

Geometry

Building

| Features | Description |
|---------------------------|---|
| Manual design | Node, line, surface creation with an oriented grid |
| Standard elements library | Line, circle, cube, trapezia, cylinder, sphere, user designed element |
| Local coordinate system | Cartesian, cylindrical, spherical |

Display and animation

| Features | Description |
|-------------------|--|
| Display options | Show/Hide node, node number, coordinate system, Input/Output tag |
| Animation action | Start/Pause/Stop animation |
| Animation options | Setup amplitude, speed, zoom |

Data acquisition

Measurement settings

| Features | Description |
|----------------|---|
| Sequencer | Creation of measurement sets for ODS, EMA or OMA test with display on the geometry – auto run |
| Transducer | Transducer definition and in database storage |
| Output signals | Random noise, sine, chirp for test with shaker |
| Trigger | Free run, manual, impact hammer edge detection, source synchronization |
| Data control | Manual accept – overload rejection – double hit rejection |

Signal processing

| Features | Description |
|-------------------------|--|
| Bandwidths / Resolution | DC to 40 kHz - 101 to 25601 lines |
| Window | Uniform, exponential, force/exponential, hanning, hamming, flattop |
| Averaging | Linear, exponential, peal hold |
| Overlap | 0 – 99.9% |

Data

| Features | Description |
|-------------------|---|
| Time results | Triggered block, weighted block |
| Frequency results | Auto-spectrum, cross-spectrum, FRF H1, FRF H2, coherence, Power Spectral Density, Half Power Spectral Density |

Analysis

Mode identification tools

| Features | Description |
|-------------------|--|
| CMIF | Based on Singular Value Decomposition of the FRF or PSD matrix – available with ODS, SIMO and MIMO methods |
| Stability diagram | Manual or automatic modes selection – available with Broband method |

Modal parameters calculation methods

| Features | Description |
|----------------------------|--|
| Operating Deflection Shape | In time and frequency domain |
| SIMO method | Rational Fraction Orthogonal Polynomials (RFOP), |
| MIMO method | <ul style="list-style-type: none"> Narband: Complex Mode Indicator Function (CMIF) Broband: based on the algorithm of Polyreference Least Squares Complex Frequency (p-LSCF) MIMO1: Frequency Domain Poly-reference (FDPR) MIMO2: Rational Fraction Orthogonal Polynomials for MIMO (RFPM) |

Modal results

| Features | Description |
|----------------------|-----------------------------------|
| Curve-fitting result | Synthesized FRF/PSD |
| Modal parameters | Frequency, damping and mode shape |
| Modal scaling | Modal A and Modal B |

Modal validation

| Features | Description |
|--|---|
| Experimental/synthesized FRF correlation | Display on the same graph the experimental and synthesized FRF (curve-fitting result) |
| Modal Assurance Criterion | Compare two arbitrary complex vectors, results of experimental test or simulation |
| Coordinate Modal Assurance Criterion | Identify which measurement degrees of freedom contribute to a low value of MAC |

Import/Export

| Features | Description |
|-----------------------|--|
| Geometry | Node, line and surface from .uff 15/24/82/2412 and IGES file |
| Time domain data | Signal file and triggered block from .uff 58/58b |
| Frequency domain data | Spectrum, Frequency Response Function, coherence from .uff58/58b |
| Modal results | Identified modes (frequency, damping, mode shape, modal A, modal B) from .uff 55 |
| Animation | Save animation in .avi file |

Ordering Information

Modal licences

| Reference | Description |
|-----------------|---|
| ORNVS-MOD-BA | Modal Base & Geometry editor |
| ORNVS-MOD-ACQ | Modal Acquisition Module |
| ORNVS-MOD-ODS | Operating Deflection Shapes |
| ORNVS-MOD-EMA | Experimental Modal Analysis (Narband & Broband) |
| ORNVS-MOD-XPERT | Expert EMA (SIMO, MIMO1, MIMO2) |
| ORNVS-MOD-OMA | Operational Modal Analysis |
| ORNVS-MOD | Modal software pack |

Training

| Reference | Description |
|-------------|---|
| ORSC-TR-MAI | Modal Analysis Introduction - The basics of ODS, EMA, OMA - Theoretical overview and best practices |
| ORSC-TR-MAG | Modal Software Main training - Designing Geometry - EMA - ODS |

OROS, Leadership through Innovation

About Us

OROS has been designing and manufacturing noise and vibration testing systems (instruments and software) for more than 35 years, meeting the requirements and expectations of automotive, aerospace, marine energy & process, manufacturing and automation industries.

Our Philosophy

Reliability and efficiency are our constant ambition. We know you have the same requirements for your measurement instruments: comprehensive solutions providing guaranteed performance, designed to meet the challenges of your demanding environments.

Our Emphasis

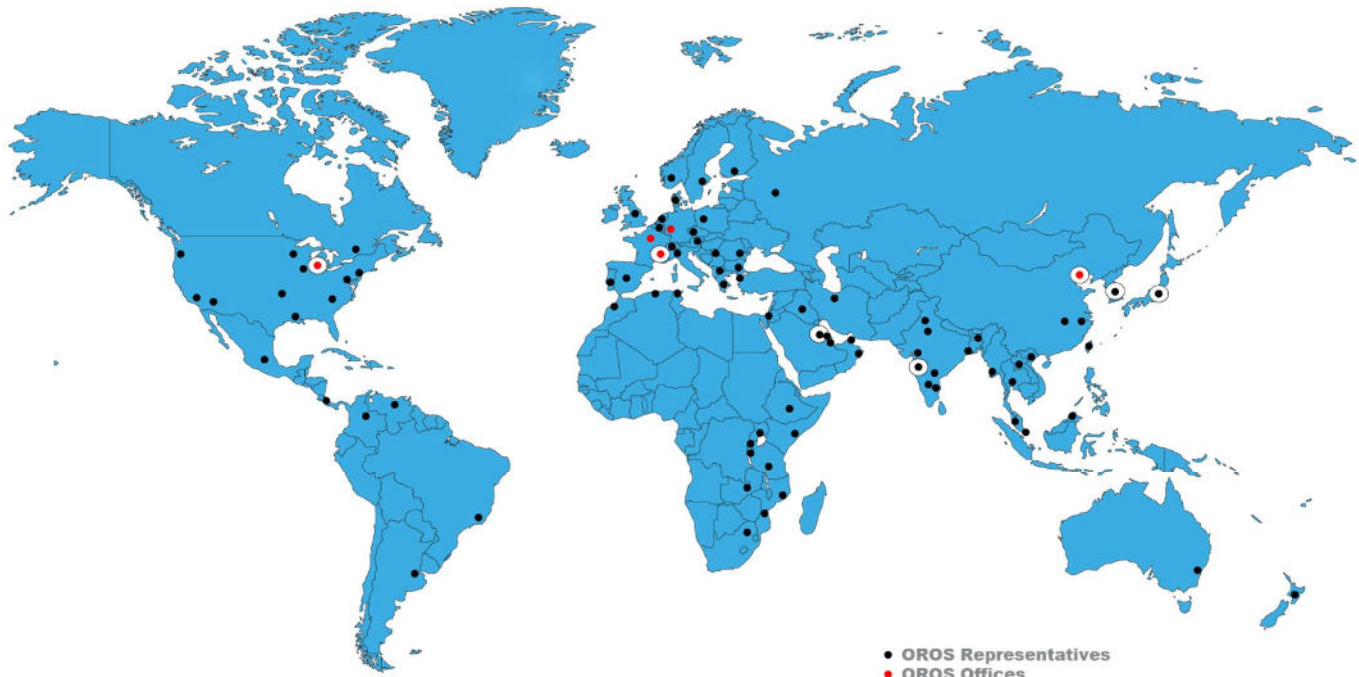
Constantly in tune with your needs, OROS collaborates with a network of proven scientific affiliates to offer the latest in technology in this field, always based on innovation.

Global Presence

OROS products are marketed in more than 35 countries, through our authorized network of representatives, offices and accredited maintenance centers.

Want to know more?

| OROS headquarters | OROS Americas Inc. | OROS French Sales Office | OROS GmbH | OROS China |
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