DATASHEET

Modal

The Structural Dynamics Module

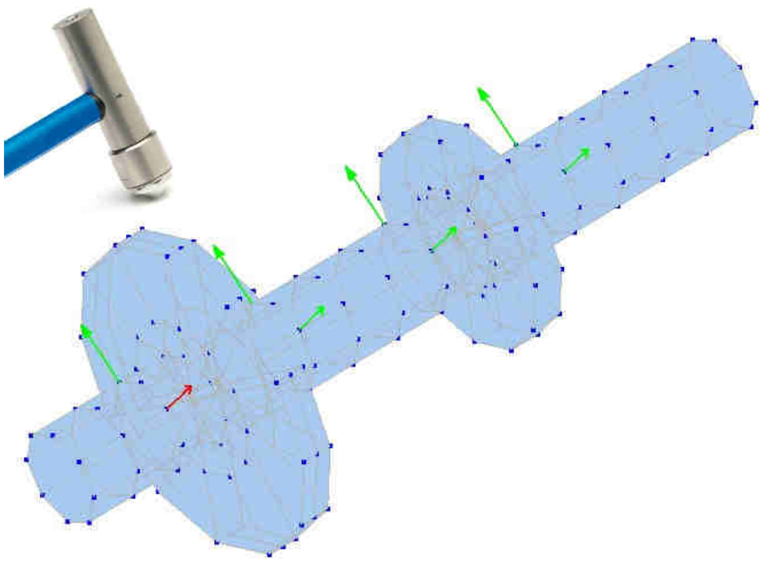


Fig1: Geometry of a turbine shaft

Introduction

Modal analysis is a powerful technique for understanding structures behavior to validate simulation results, mechanical designs and maintenance.
OROS offers the modal analyzer, 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 and modal parameters 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

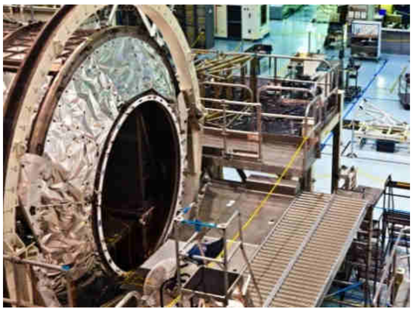


Table of Content

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).

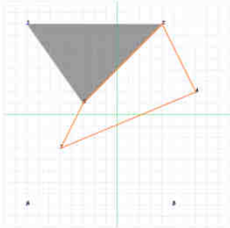


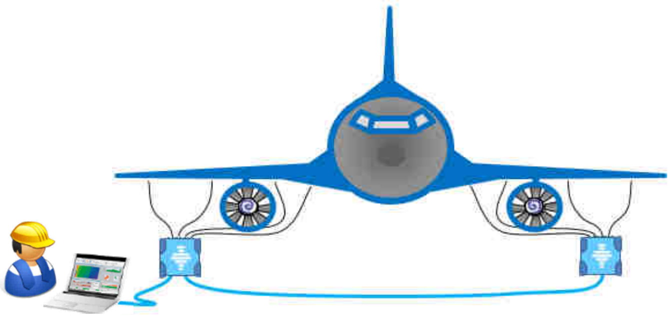
Fig2: Geometry building

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 <+/-0.2° is guaranted.

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, 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.

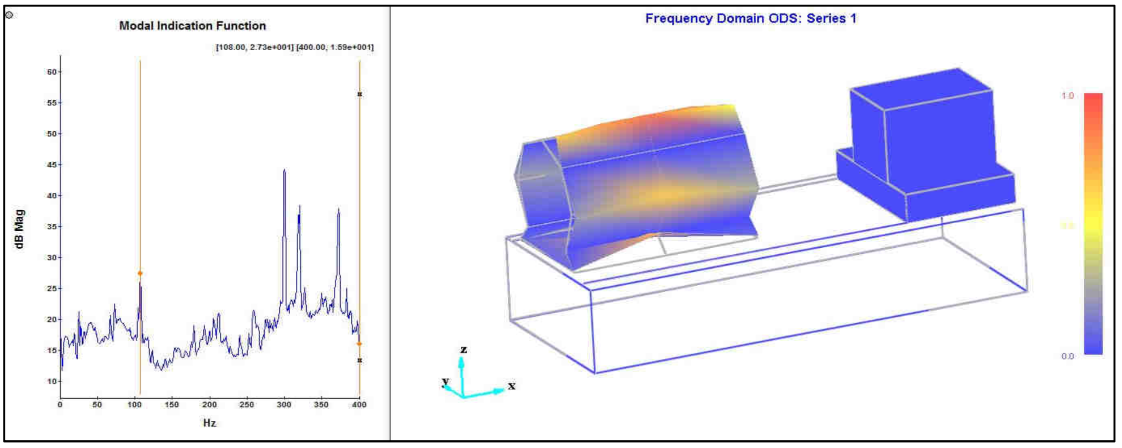


Fig3: ODS on a motor-pump unit

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.

Modes 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:

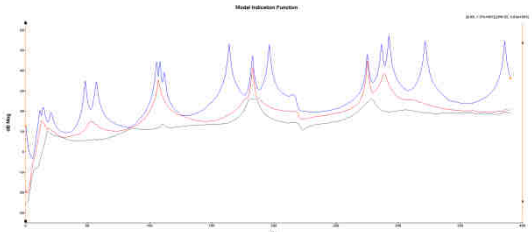


Fig4: CMIF

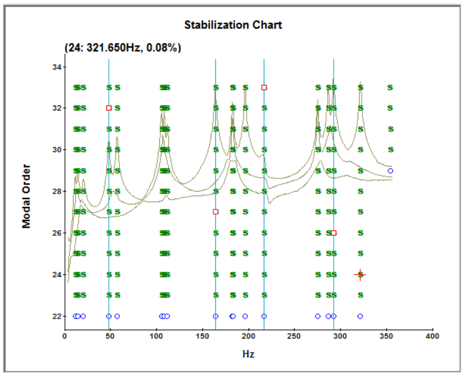


Fig5: Stability diagram

- **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 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.	Has similar features as its MIMO counterpart.	Only measurements with one reference are admitted.
EMA/OMA Narband Based on the Complex Mode Indicator Function (CMIF)	Narrowband MIMO modal identification algorithm. Identifies one mode at a time.	Very easy-to-use.	Requires 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.

Method	Technique	Advantages	Limits
EMA MIMO1 Based on Frequency Domain Poly-Reference (FDPR) algorithm.	Selected-band MIMO modal identification technique. Identifies 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 will be 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. Identifies a few modes at a time in user-selected frequency bandwidth.	Can be applied in modal testing with few response measurements.	It's preferred to limit the number of references DOFs of the FRF matrix, e.g. less than three.
EMA/OMA Broband Based on the algorithm of Polyreference Least Squares Complex Frequency (p-LSCF)	Selected-band MIMO modal identification technique. Identifies modes in broad frequency band including full band.	Yields clear stability diagram. Distinguishes automatically structural modes from 'noise' modes or real modes from spurious modes Identifies modes in broad frequency band automatically in one time.	Not the better method if you are especially interested by damping and if there is noise.

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.

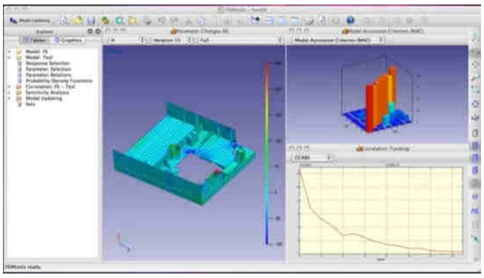


Fig7: FEMtools interface

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

Modes 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	• MIMO1: Frequency Domain Poly-reference (FDPR), • MIMO2 : Rational Fraction Orthogonal Polynomials for MIMO (RFPM), • Narband: Complex Mode Indicator Function (CMIF), • Broband: based on the algorithm of Polyreference Least Squares Complex Frequency (p-LSCF)

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-MOD300	ODS (Operating Deflection Shape)
ORNVS-MOD330	ODS + EMA SIMO
ORNVS-MOD350	ODS + EMA SIMO + EMA MIMO
ORNVS-MOD380	ODS + EMA SIMO + EMA MIMO + OMA
ORNVS-MOD180	OMA (Option to ORNVS-MOD300 or ORNVS-MOD330)

Example of instrument configurations

Reference	Description
OR36-OBODS-16	ORBIGate + MOD300 Package with a 16 Channel OR36 with 4 DSPs (48 SPUs)
OR34-FREQ-4	OR34-4 Ch. FFT analyzer (12 SPU), real-time bandwidth 20 kHz

Training

Reference	Description
ORSC-TR	Modal Analysis Introduction - The basics of Modal Analysis - ODS - EMA - OMA- Theoretical Overview and Best practice
ORSC-TR	Modal Software Main training - Designing Geometry - EMA - ODS

OROS, Leadership through Innovation

About Us
Celebrating 30-years of innovation, OROS' designs and manufacturing have been renowned for providing the best in noise and vibration analyzers as well as in specific application solutions.

Our Philosophy
Reliability and efficiency are our ambition everyday. We know you require the same for your measurement instruments: comprehensive solutions providing performance and assurance, designed to fit the challenges of your demanding world.

Our Emphasis
Continuously paying attention to your needs, OROS collaborates with a network of proven scientific affiliates to offer the latest of the technology, always based on innovation.

Worldwide 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 Inc	OROS French Sales Office	OROS GmbH	OROS China
Tel: +33.811.70.62.36	Tel: +1.888.200.OROS +1.703.478.3204	Tel: +33.169.91.43.00	Tel: +49.261.133.96.50	Tel: +86.10.59892134
Mail: info@oros.com	Mail: info@orosinc.com	Mail: info@orosfrance.fr	Mail: info@oros-deutschland.com	Mail: info@oroschina.com
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