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Modal testing facility for Advanced LIGO

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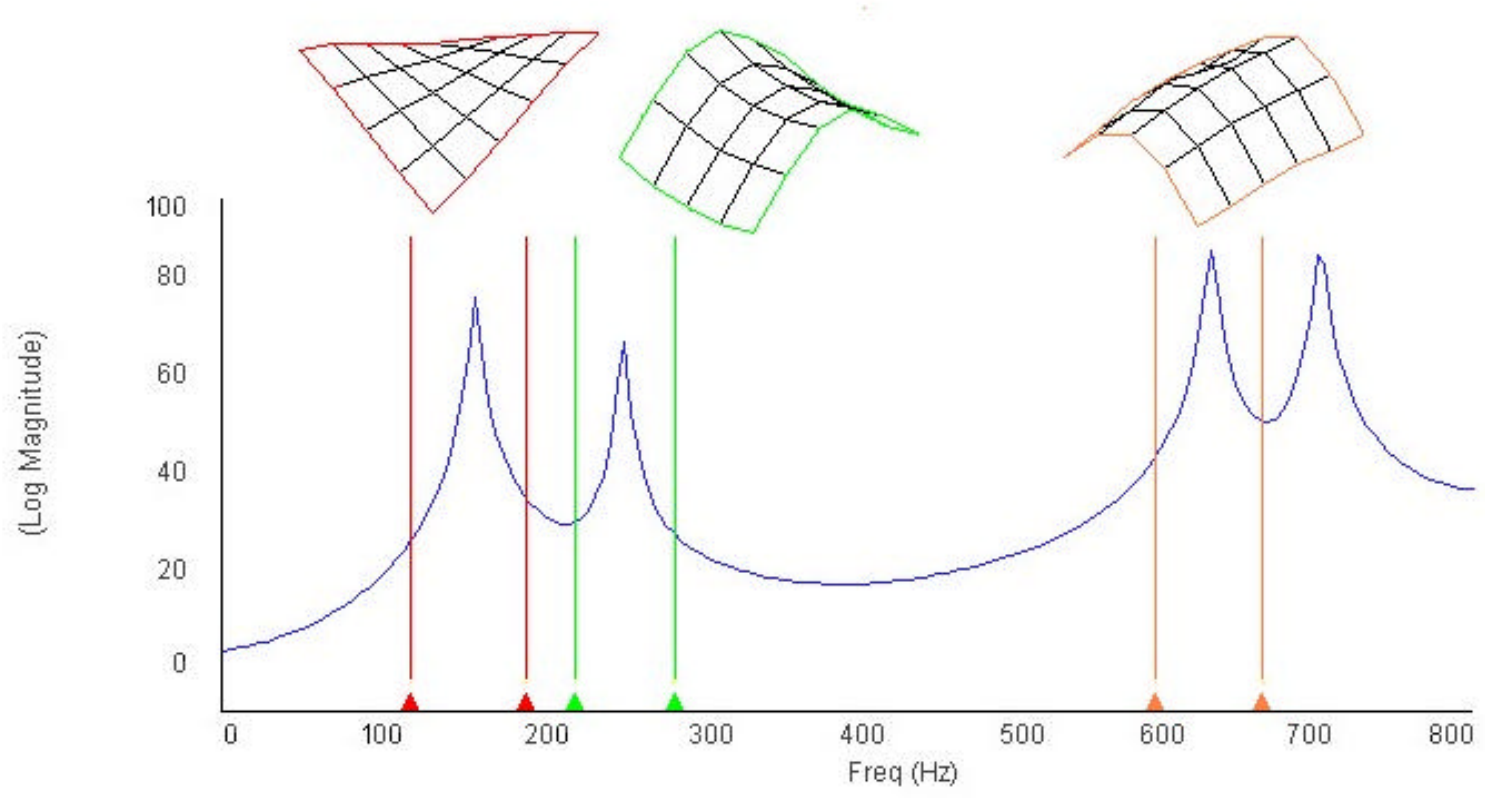
What is modal testing?

- Experimental process of characterising the dynamic behaviour of a structure in terms of its modal properties (frequencies / mode shapes / damping factors)



Why do we need a modal testing facility?

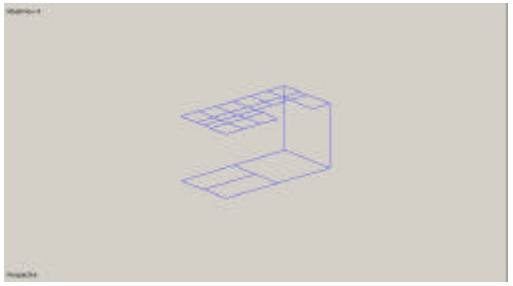
- **Modal analysis of structure**
  - Establish modal parameters (dynamic properties)
    - Natural frequencies
    - Mode shapes
    - Damping factors
- **Can be done by:**
  - **Theoretical FE analysis**
    - *Approximate* theoretical method
    - *Accuracy* always should be questioned
    - *Validation* is important consideration

    or
  - **Experimental modal analysis**
    - *Accurate* since based on *measured* not predicted behaviour
    - Design/troubleshooting tool
    - Validation tool for FE
    - restriction - the physical structure must exist

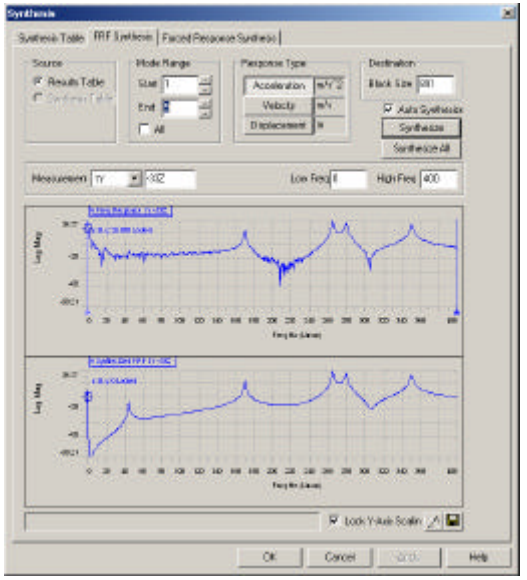
    or
  - **Both (complementary tools)**
    Design stage FE analysis → manufacture prototype → experimental modal analysis → modal model → verification or structural modification within modal model → structural modification of prototype → FINAL STRUCTURE

Modal testing: step details

- 5 main steps:
  - (1) MODEL – creation of the structure
    - Points, lines and surfaces used to define the shape of an object



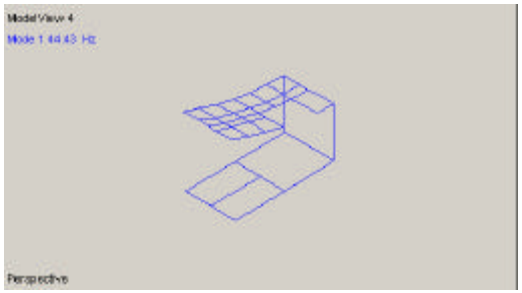
  - (2) MEASUREMENTS - acquire the data
    - Driving point DOF (may be more than one)
    - Response (3 DOF multi-point)



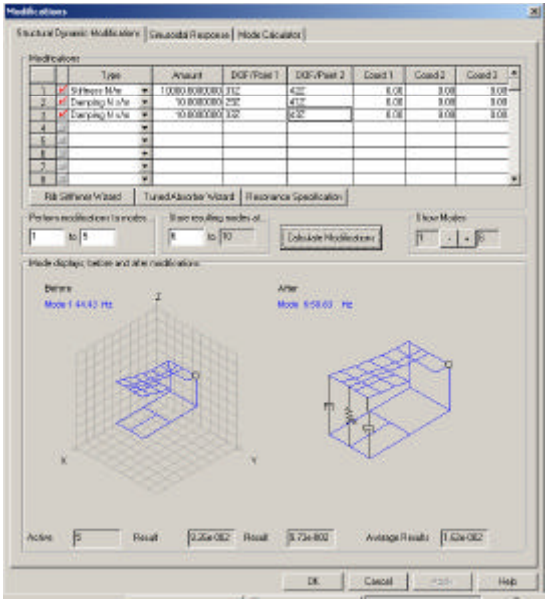
  - (3) ANALYSIS - analyse the data
    - Frequency , identify peaks and curve fit, FRF synthesis

Modal testing: step details

- (4) RESULTS – synthesis of mode shapes time domain animation



- (5) MODIFICATIONS – modify the structure
  - To simulate the effects of a structural modification
    - Mass, stiffness, damping



Applications to Advanced LIGO

- Suspension design:
  1) Support structures (1st mode <150Hz?)
  2) Cantilever blades (internal modes)
  3) Other substructures e.g. tablecloth modes

- Other:
  1) Optics table
  2) Silica/sapphire mirror substrates (thermal noise predictions)
  3) Silica fibres/ribbons

The task in hand

- Source suitable equipment for proposed ‘Modal Testing Facility’ for Advanced LIGO

- Three equipment functions to consider in the process of modal testing:
  - Excitation method
  - Response measurement method
  - Data acquisition & analysis software

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Requirements for the various applications

Applications	***Requirements***				
	Excitation Method		**Response Measurement Method**		**Data Acquisition & Analysis Software**
	CONTACT (shaker or impact hammer)	NON-CONTACT (acoustic or electrostatic)	CONTACT (accelerometers)	NON-CONTACT (laser vibrometer)	
Suspension support structures	•		•	•	**Rule of thumb – don't overspecify**
Cantilever blades	•		(•)	•	
Mirror substrates		•		•	
Silica ribbons/fibres		•		•	

Contact excitation

- Mechanical shaker
  - White noise
    - wide range of frequencies
  - Sinusoidal testing
    - sweep through frequency until hit resonance – test at this frequency

- Impact hammer
  - Impulse response
    - frequency range depends on properties of hammer tip so choose the tip for the application
      - hard tip (high frequency modes)
      - soft tip (low frequency modes)

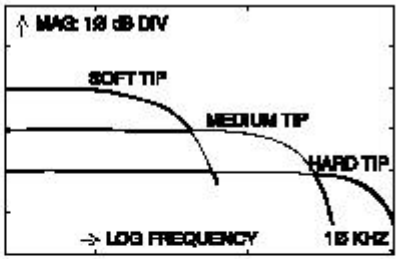
Non-contact excitation

- Electrostatic
  - Swept sine
    - Currently used to locate modes on mirror substrates and then perform *Q* measurements (ringdown)
  - White noise
- Acoustic
  - White noise
    - would work for ribbon/fibre excitation (limited to measurements in air only)

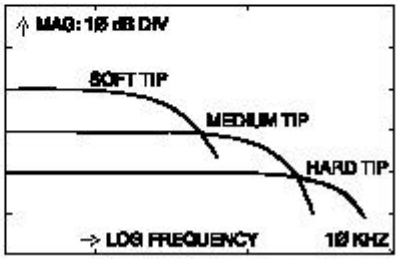
Impact hammers

- Impact Hammers
  - PCB Impact Hammers by Techni measure
  - instrumented hammers for measuring the force input during modal impact testing. Kits which include power supplies, two accelerometers and cabling, are also supplied.
  - General purpose hammer kit £2.5K
  - Sledge hammer kit £3.5K

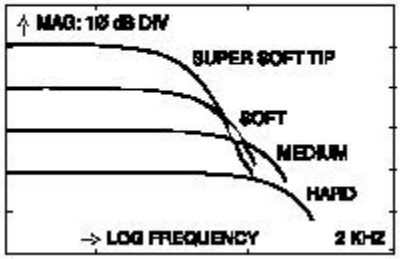
Models 086C01, 086C02, 086C03, 086C04 (shown with cable attached)



Model 086C01



Models 086C02, 086C03, 086C04



Model 086D50

Response measurement

- Accelerometers (contact)
  - Two main types
    - (Capactive – simple battery hookup – static acceleration measurement)
    - Piezoelectric – ICP charge output (integrated circuit piezoelectric) with built-in signal conditioning
      - e.g. ICP structural test / array accelerometers (PCB 333 series)
      - Lightweight for multi-point modal and structural testing
- Laser systems (non-contact)
  - Laser vibrometer – Doppler effect
    - 1D - basic
    - 3D – measures shear from perpendicular offset
    - Scanning – precision applications
    - Lambda Photometric (Polytec)

Laser Vibrometer

- 1D general purpose use ~ £28K

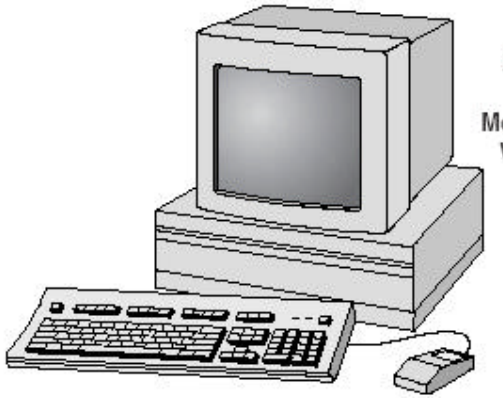
OFV-3001 controller with OFV-303 standard optics head

- 3D contains 3 independent laser Doppler sensors in one common optical head ~ £32K

OFV-3001 3D laser vibrometer controller and optics

Data acquisition and analysis

- Data acquisition
  - Dual channel (~£15K)
    - Larson Davis FFT analyser
  - Multi-channel (x few £10K's)
    - Zonic data acquisition system
- Data analysis software
  - STAR6 modal - simple, PC based user friendly (<£11K)
  - IDEAS – advanced (x few £10K's)
  - LMS -advanced (x few £10K's)



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Preliminary conclusions

- Testing time is not a major consideration.
  Facility required intermittently.

- OPTION ‘1’
  - Impact hammer kit. ICP accelerometers with dual channel Larson Davis. STAR6 modal analysis software mounted on available PC (~£23K to ~£31K depending on STAR6 edition)

- OPTION ‘2’
  - Impact hammer kit. 1D laser vibrometer with STAR6 modal (~£34K to ~£42K depending on STAR6 edition).

- Laser vibrometer modal tests will be starting soon at Glasgow.

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Next steps

- Feedback from this discussion
- Detailed prices
- Final recommendations to follow