ISMA 2010

Practical Aspects of Shaker Measurements for Modal Testing

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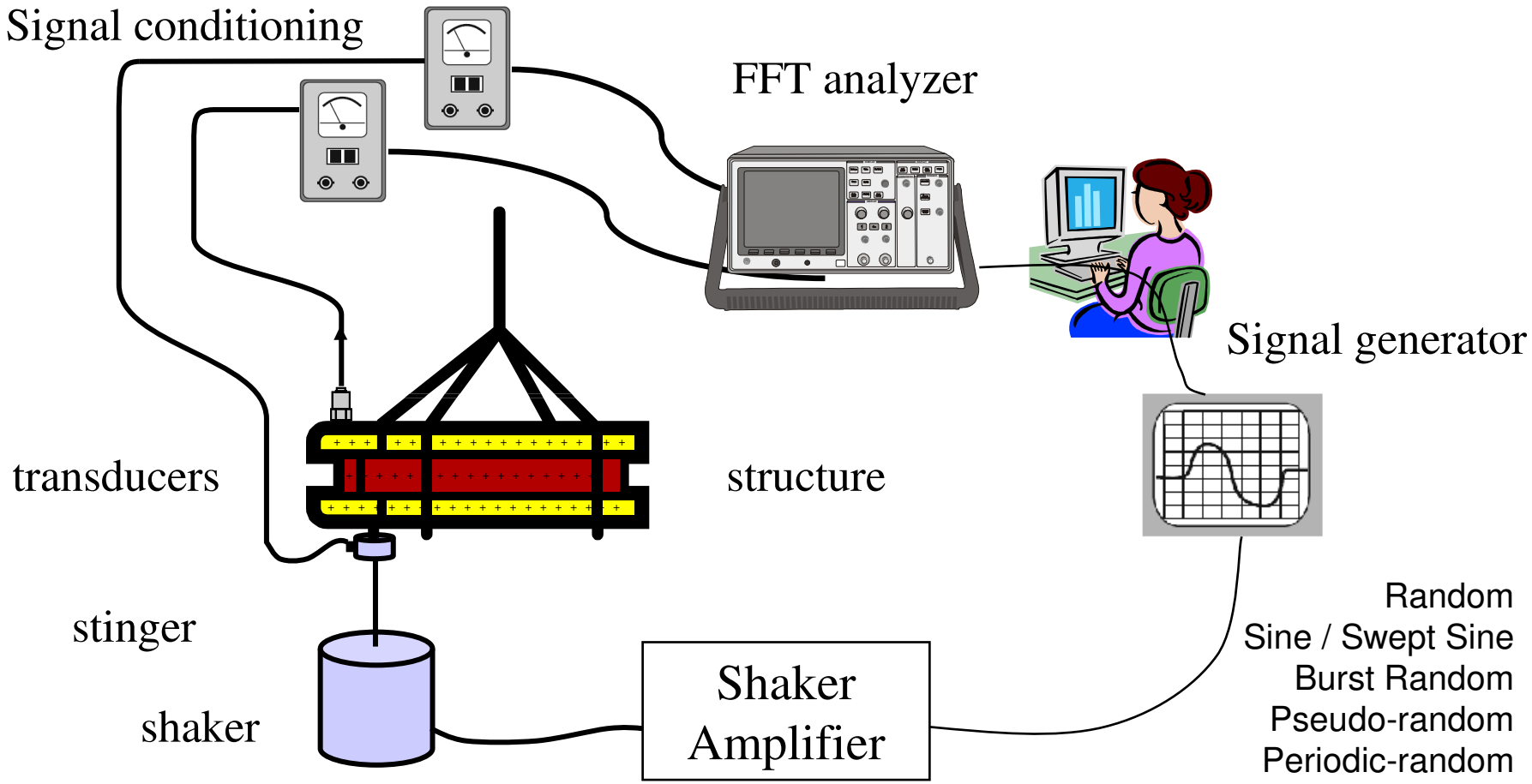
Typical modal shaker set up:

典型激振器布置



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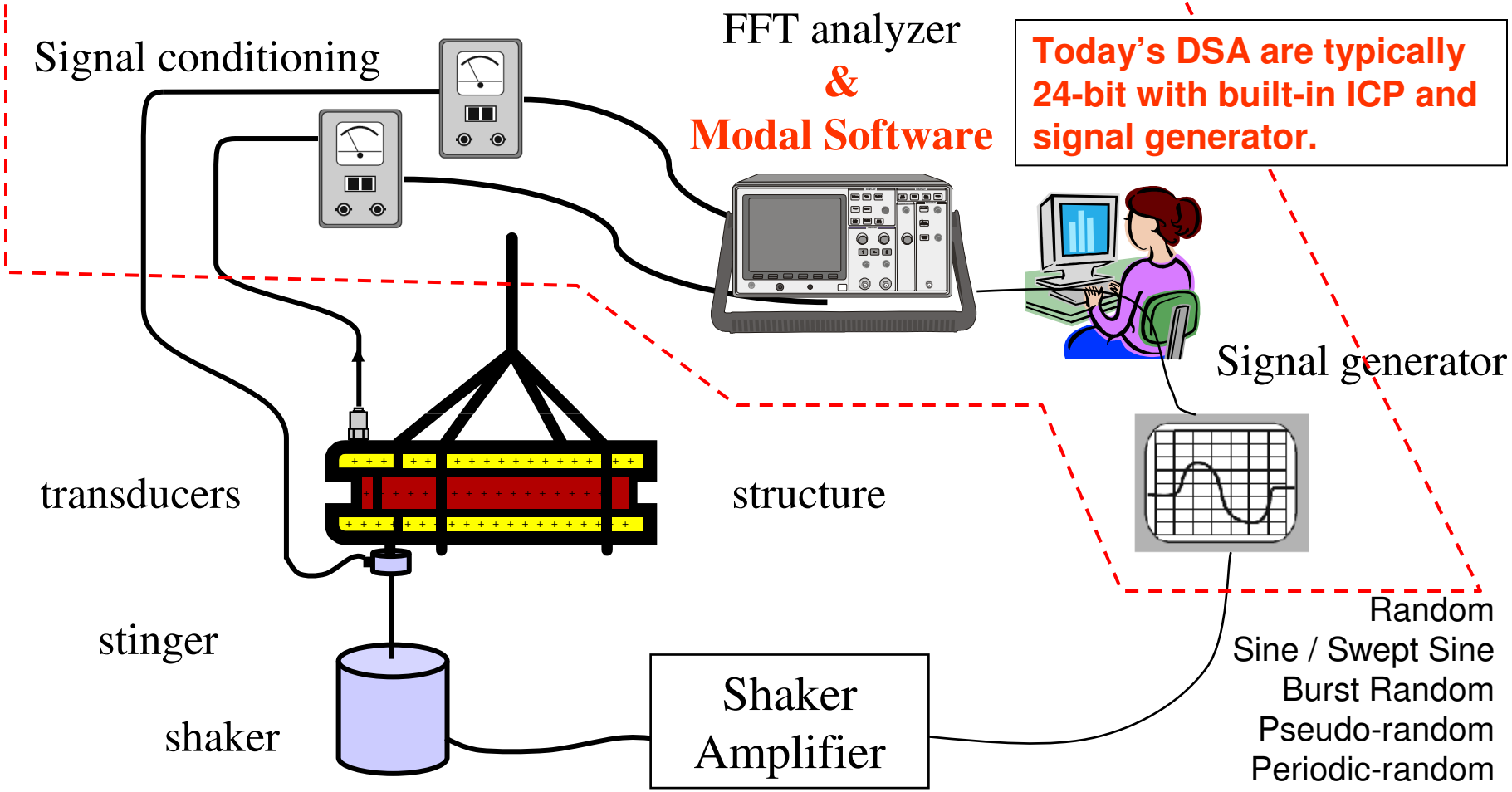

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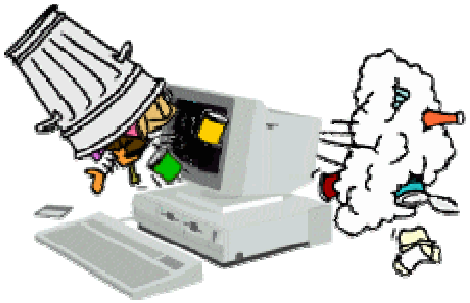
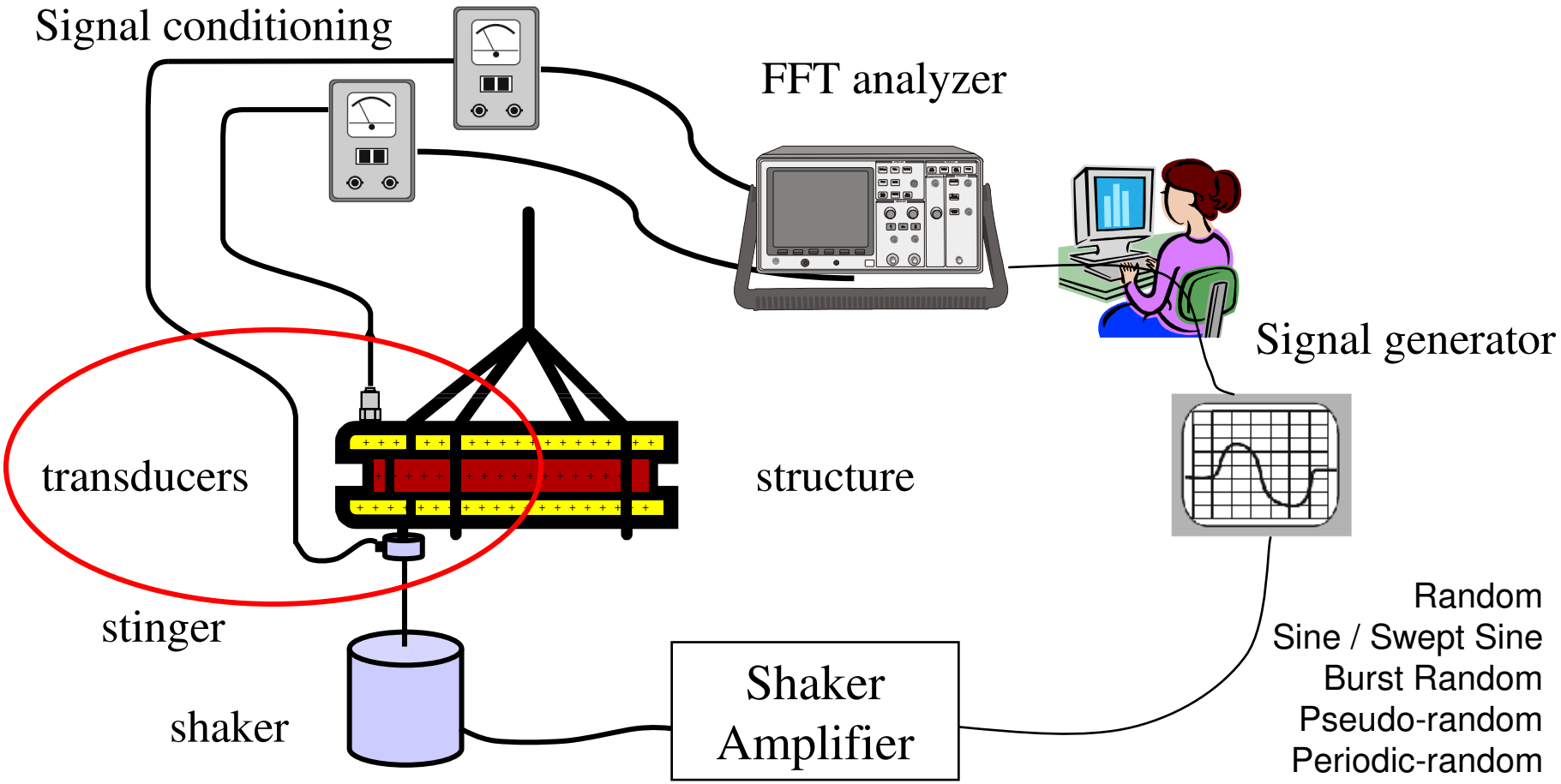


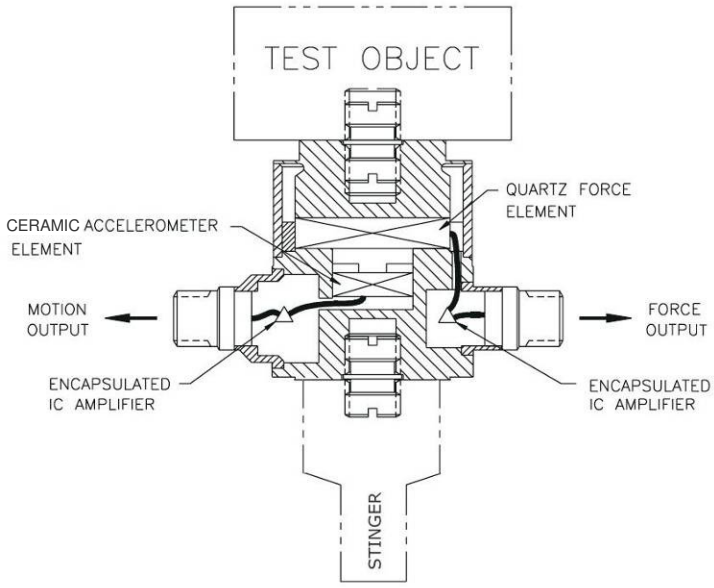
Regardless how good your DSA and software are, if you don't set up your system properly, you will not get good results!

Typical modal shaker set up:



Obtaining Valid Measurements – the role of the transducer

- **Sensor Selection**
  - Piezoelectric type
  - Built-in electronics (ICP®)
  - Force Sensors
  - Impedance Heads
    - Force sensor & accelerometer together
    - Reciprocity validation
  - Force Sensitivity
    - 11 to 22 mV/N (50 to 100mV/lbf)
  - Dynamic Range
    - ±450N (±100lbf)
  - TEDS (IEEE1451.4) available



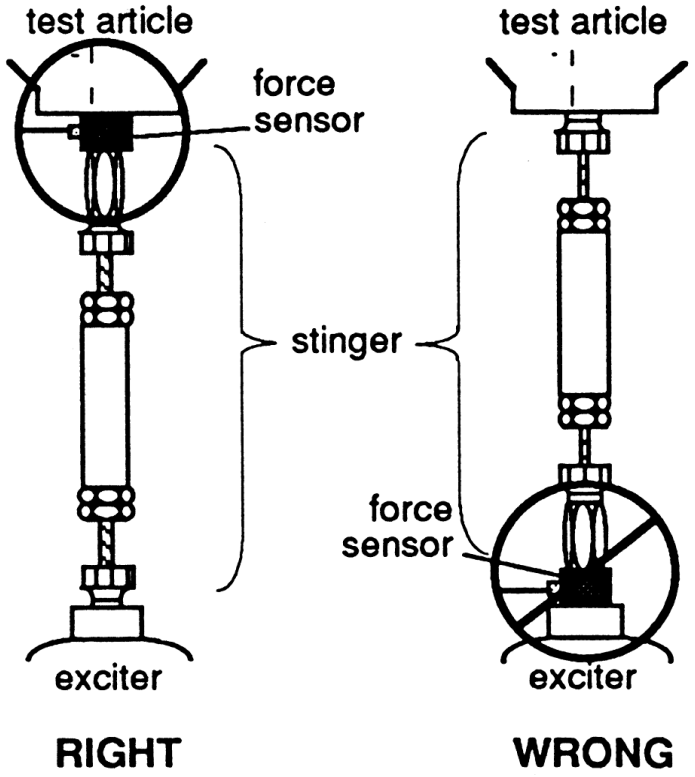
Obtaining Valid Measurements – the role of the transducer

- **Sensor Mounting**
  - Orientation
    - Force transducers have polarity
    - TOP/BASE indication or "*mount this end to the test structure*" label
  - Installation
    - Stud mount (thread attached directly to the structure)
    - Adhesive base
      - Two-part quick epoxy
      - Superglue (cyanoacrylate)
      - Dental cement

Obtaining Valid Measurements – the role of the transducer

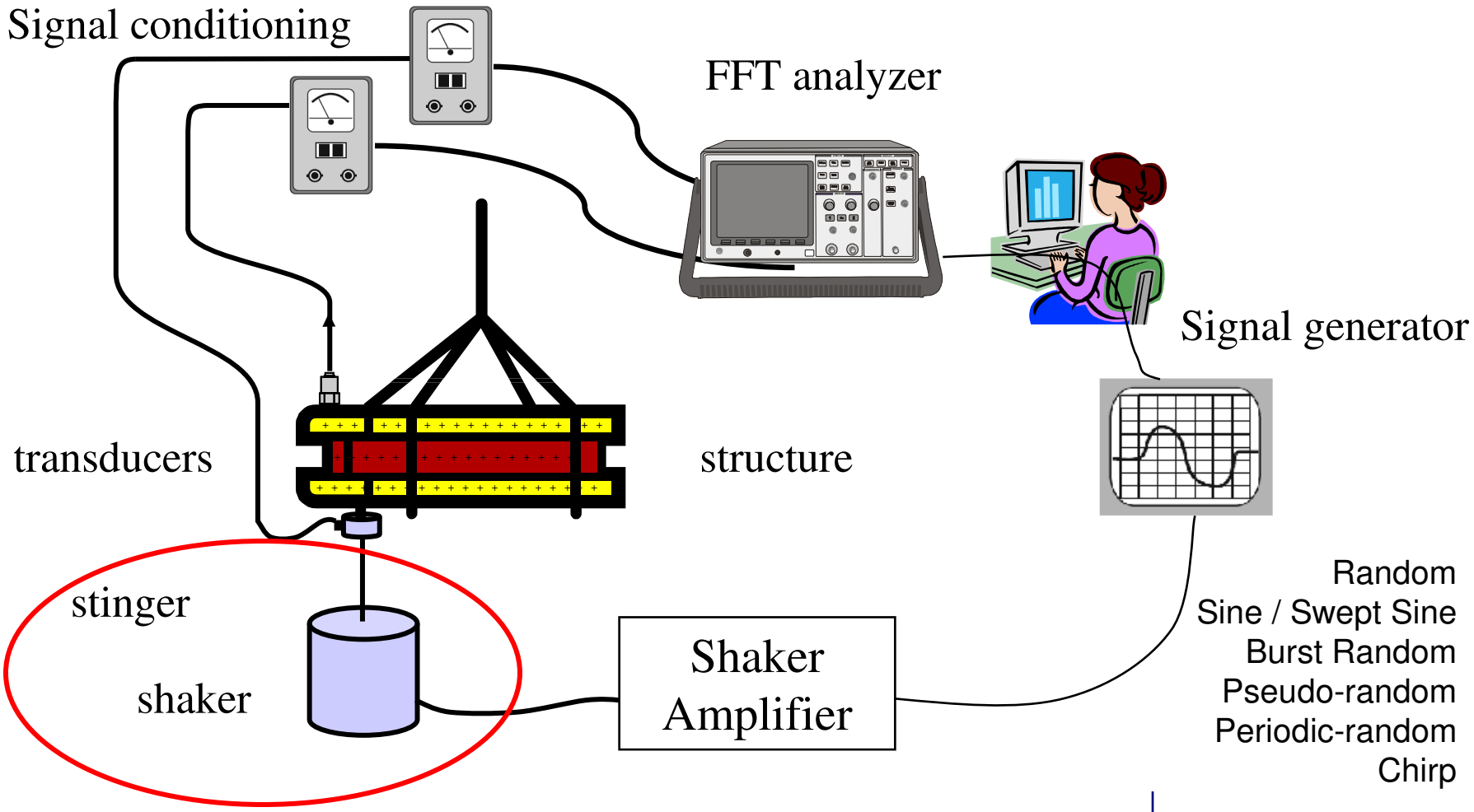
- **Sensor Mounting – directly mount to the structure, not to the shaker**

CORRECT
Force gage "divorces" the stinger / shaker from the structure



WRONG
Stinger becomes part of the test structure

Typical modal shaker set up:



Shakers

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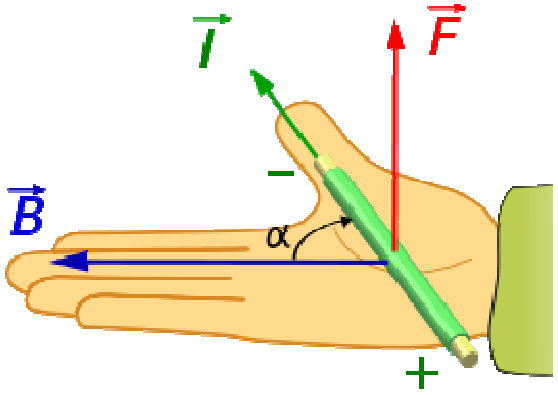
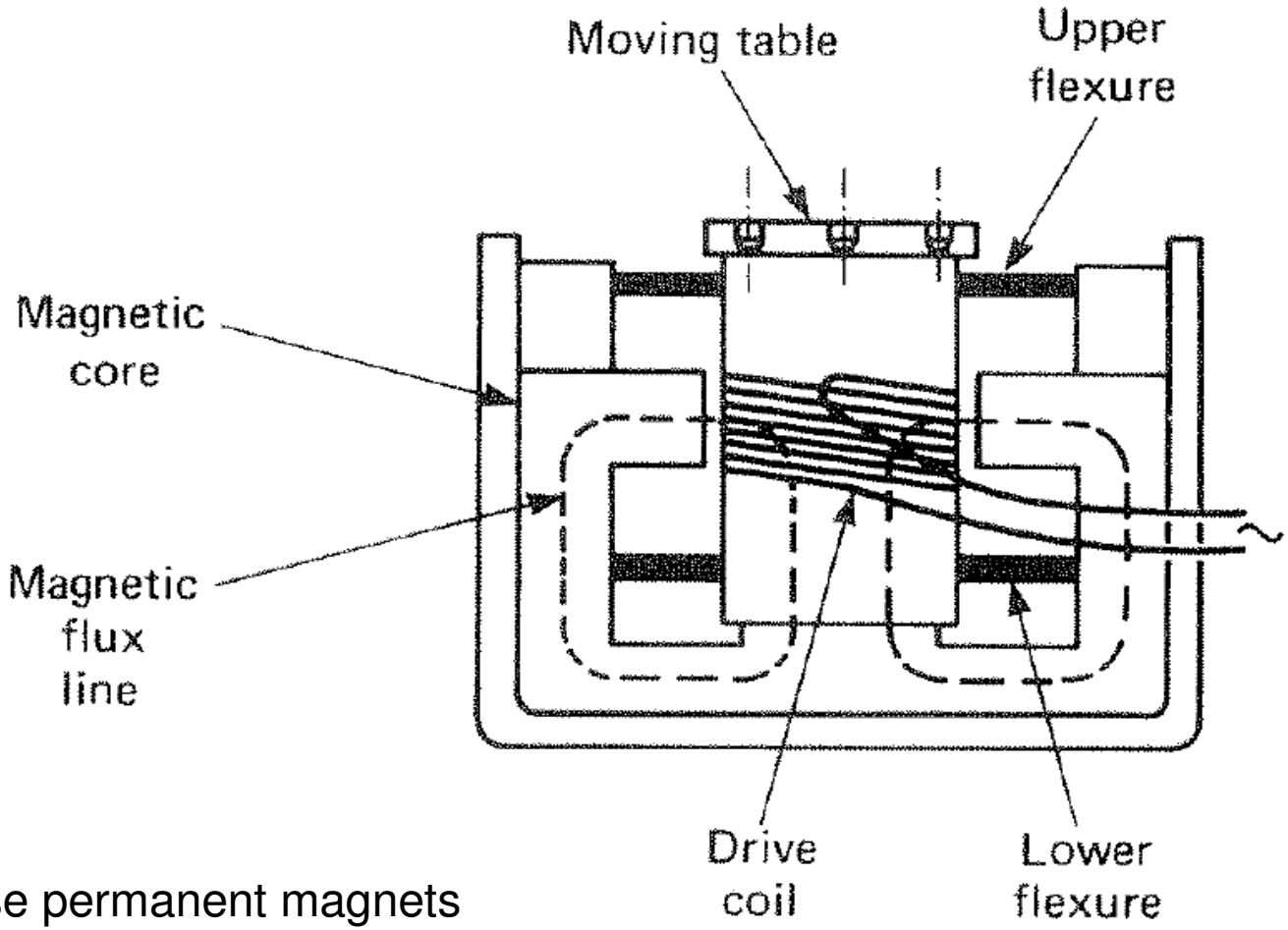
Shakers: principles of operation



Force on a current-carrying wire

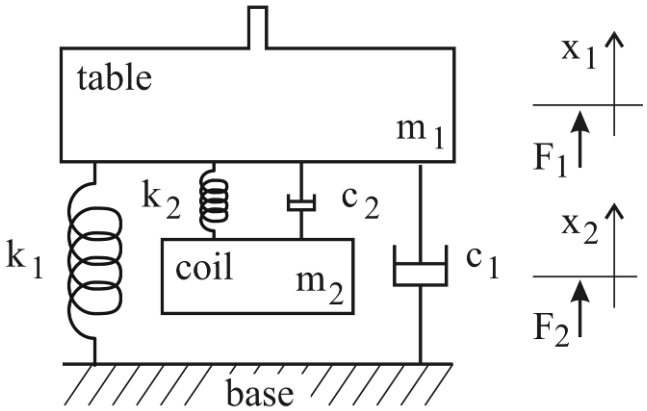
$$\vec{F} = L \cdot \vec{I} \times \vec{B}$$

$$F = L \cdot I \cdot B$$

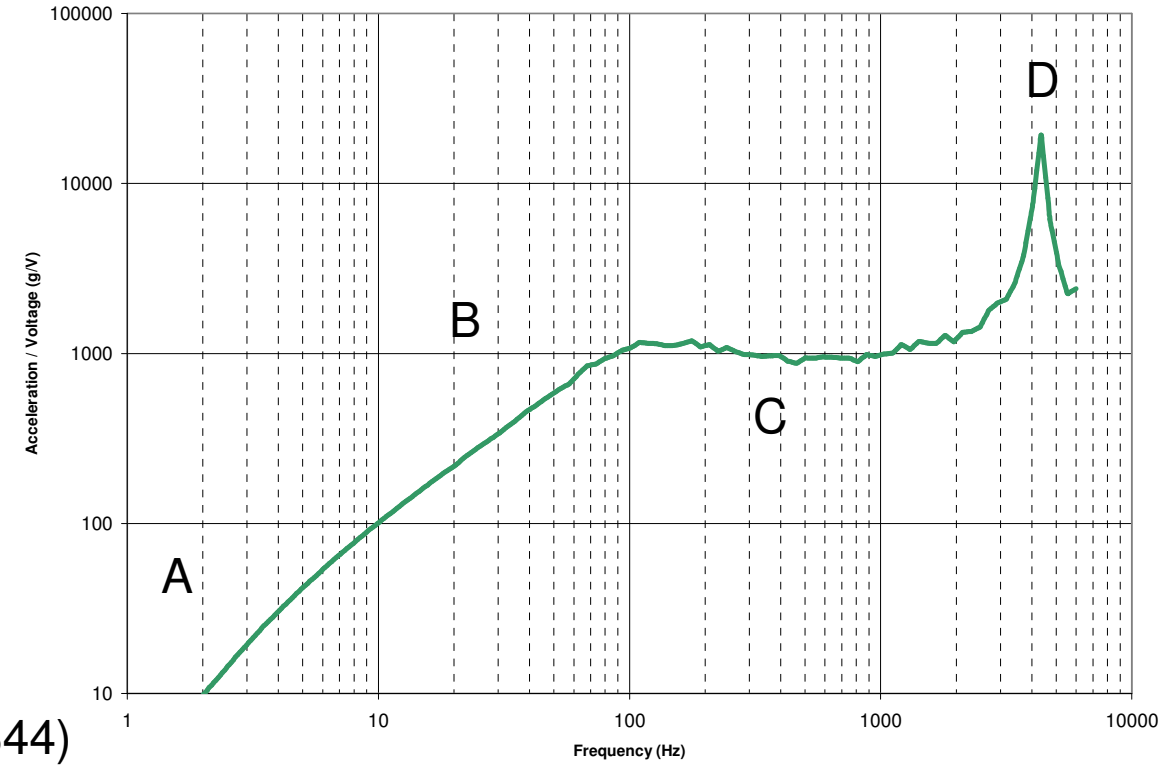


- Small size shakers use permanent magnets
- Mid/large size shakers use a field coil for electromagnetic field

Mechanical Model



- **Lower frequency**
  - Stroke limited
- **Mid /high freq**
  - Force limited (current limited)
- **Freq. range**
  - 0 to ~1.5·f_D (ISO-5344)



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Modal Shakers

2025E

2100E11

2060E

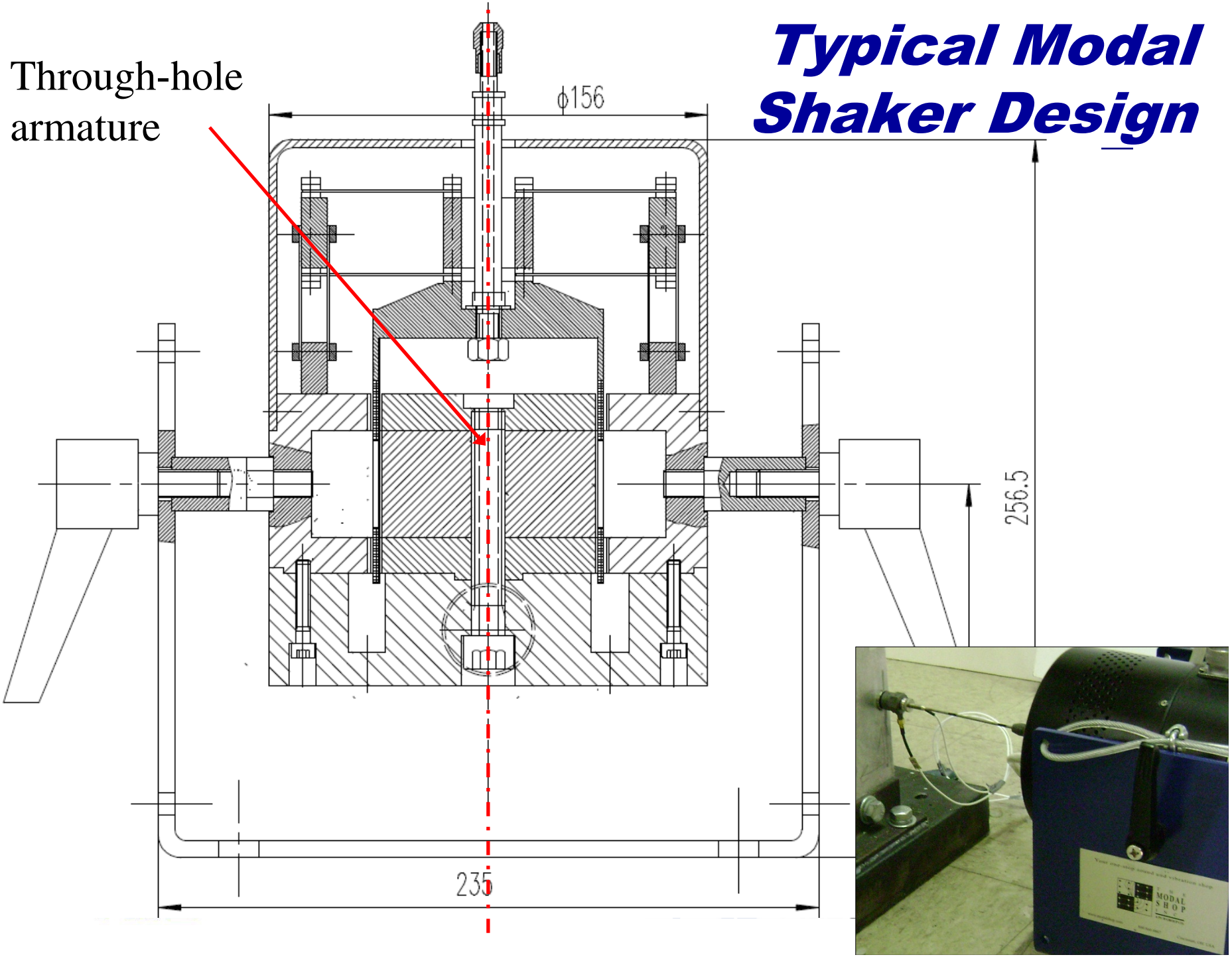
Modal Shaker

- **Electromechanical shaker with <u>through-hole armature</u> – key benefit of "modal" shaker**
  - Chuck/collet type stinger supports stinger rods and piano wire style stingers for simple attachment
  - Reduces/eliminates lateral inputs (measurement noise)
  - Significantly easier test structure setup

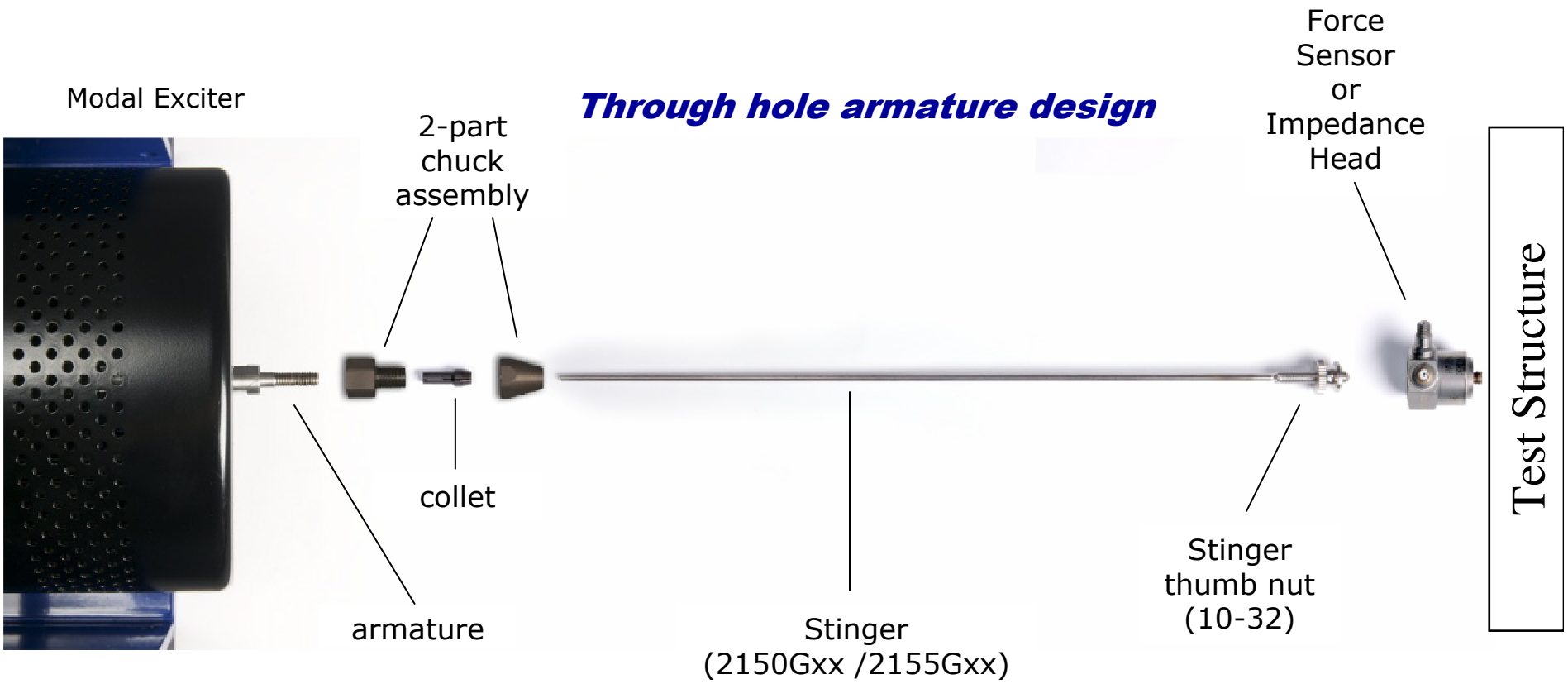
- **Shaker used to excite "self-supported" test structure rather than shaker table directly supporting test structure**

Typical Modal Shaker Design

Through-hole armature



Through-hole Armature Design



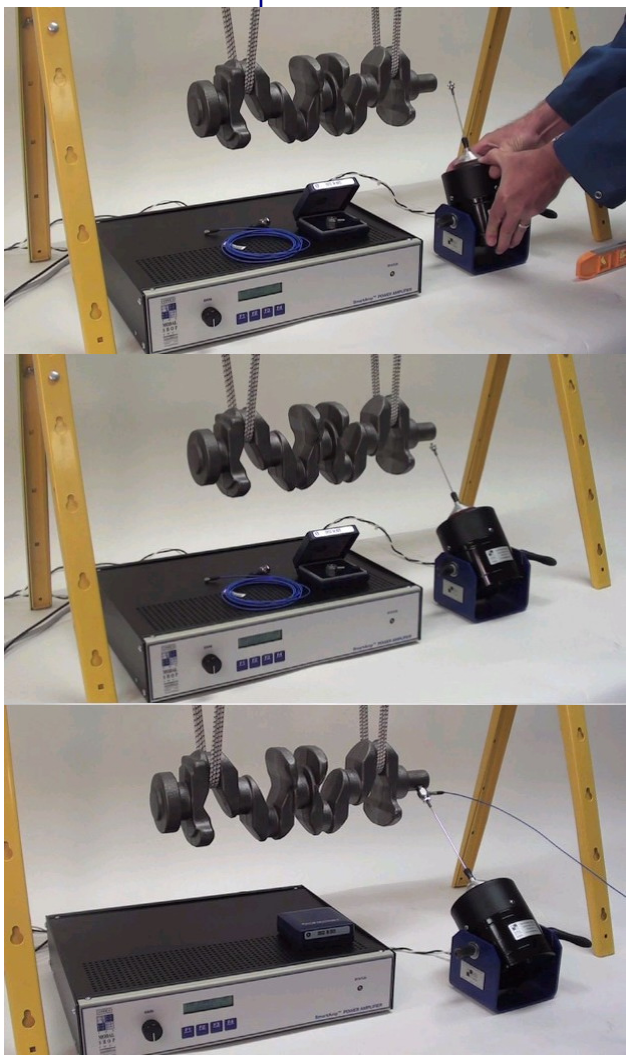
Attaching the Stinger

Attaching the Stinger

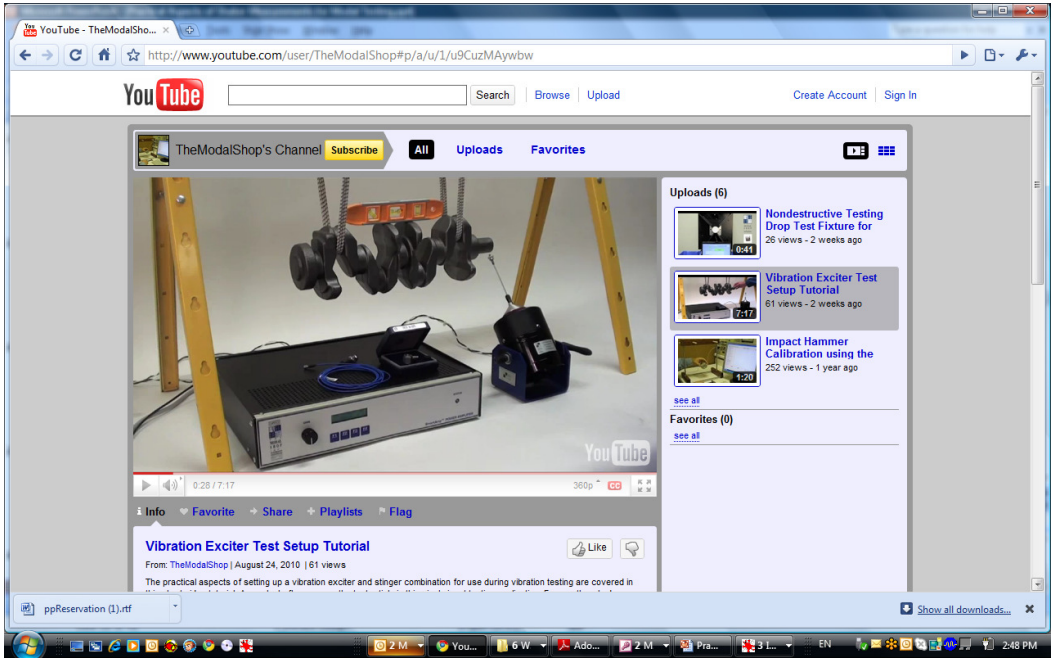
Installation Example

Check video at: **http://youtube.com/watch?v=VP_X-8TUtOU**

Installation Example 2



www.youtube.com/TheModalShop



http://www.youtube.com/watch?v=u9CuzMAywbw

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Shaker Quantity

Meet *observability* assumption

- Enough shakers to adequately excite modes of interest
- Avoid node locations

1. SIMO (single input multiple output)

- Orthogonal orientation
- Skewed (better excite highly uncoupled modes)

2. MIMO (multiple input multiple output)

- Distribute the low level energy better which allows to be more effective to excite the variety of modes of interest
- Resolve repeated roots and/or closed spaced modes
- Limited by the number of shakers & source ch. available
- 2 to 4 shakers are typical for larger structures (automobile or aircraft); more than 5 shakers are rare.

Force Levels

- **More force is not better!**
  - Larger force levels tend to overdrive the structure, exciting nonlinear characteristics and providing poorer overall measurements than with lower level force tests
  - On larger structures, it is often desirable to use multiple shakers at lower force levels to more evenly distribute force than a few single shakers operating at high level forces
  - *Just enough* is better!
    - Helped by proper transducer selection (higher sensitivity) and high quality, high resolution DSA (i.e 24-bit)

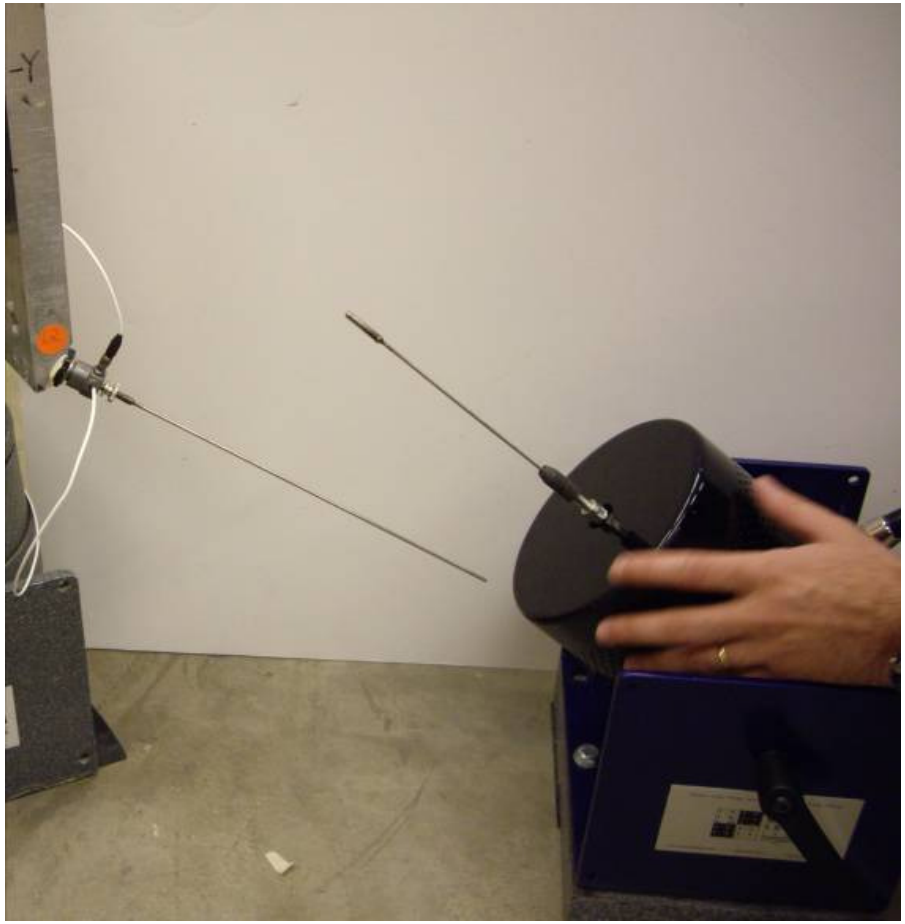
Shaker Size

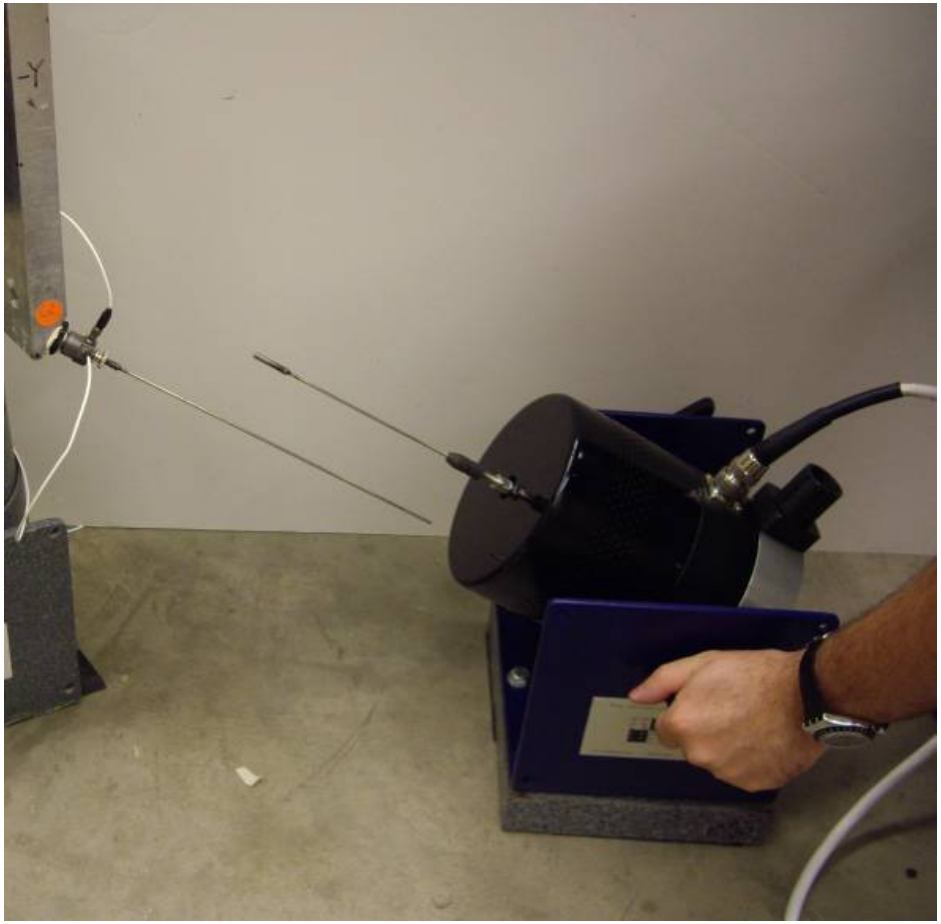
- **Small size / Lightweight**
  - Easier to handle → one-man handling job
    - Key for large size jobs, multiple excitation points
  - Easier to fixture
  - Typically below 17kg (37lbs)
- **Almost all new permanent shaker designs use Neodymium (rare earth) magnets**
  - About 4 times strongest than AlNiCo
  - Same force, one-third the weight
- **Force ratings**
  - Typically below 500N (100lbf)

Shaker Mounting & Alignment

- **Fundamental to avoid side loads and measurement errors**
- **Through hole design & stingers → facilitate alignment**
- **Floor mounting**
  - Trunnion → angle adjustment
  - Rubber/Dead blow hammer → minor adjusts
  - Hot glue or bolt to the floor
- **Suspended Mounting**
  - Shaker Stands
    - Special fixturings for major height adjustment
    - Turnbuckles, bungee cords
    - Inertial masses to minimize shaker displacements

Shaker Alignment





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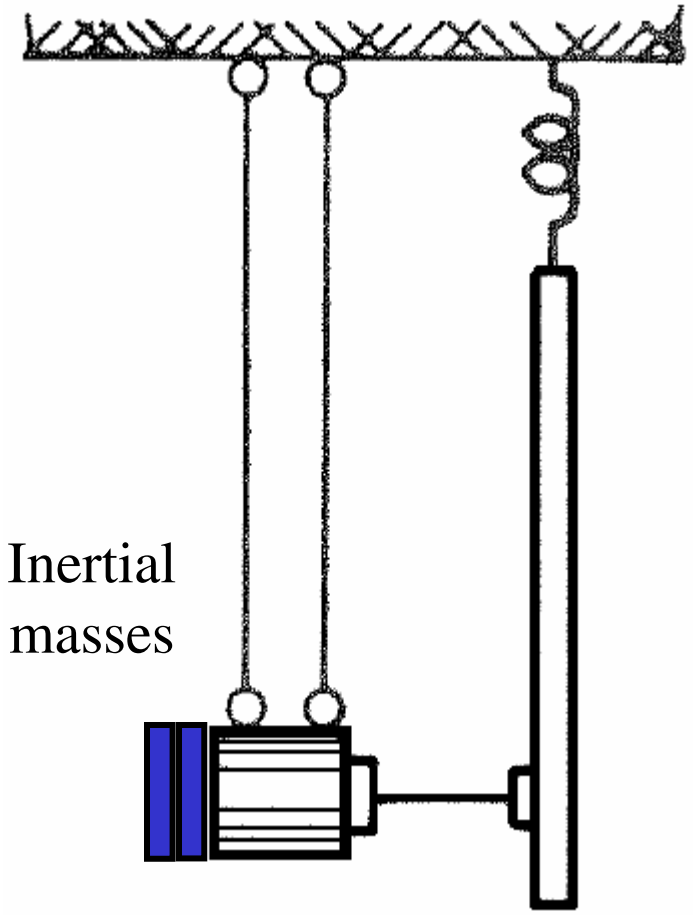
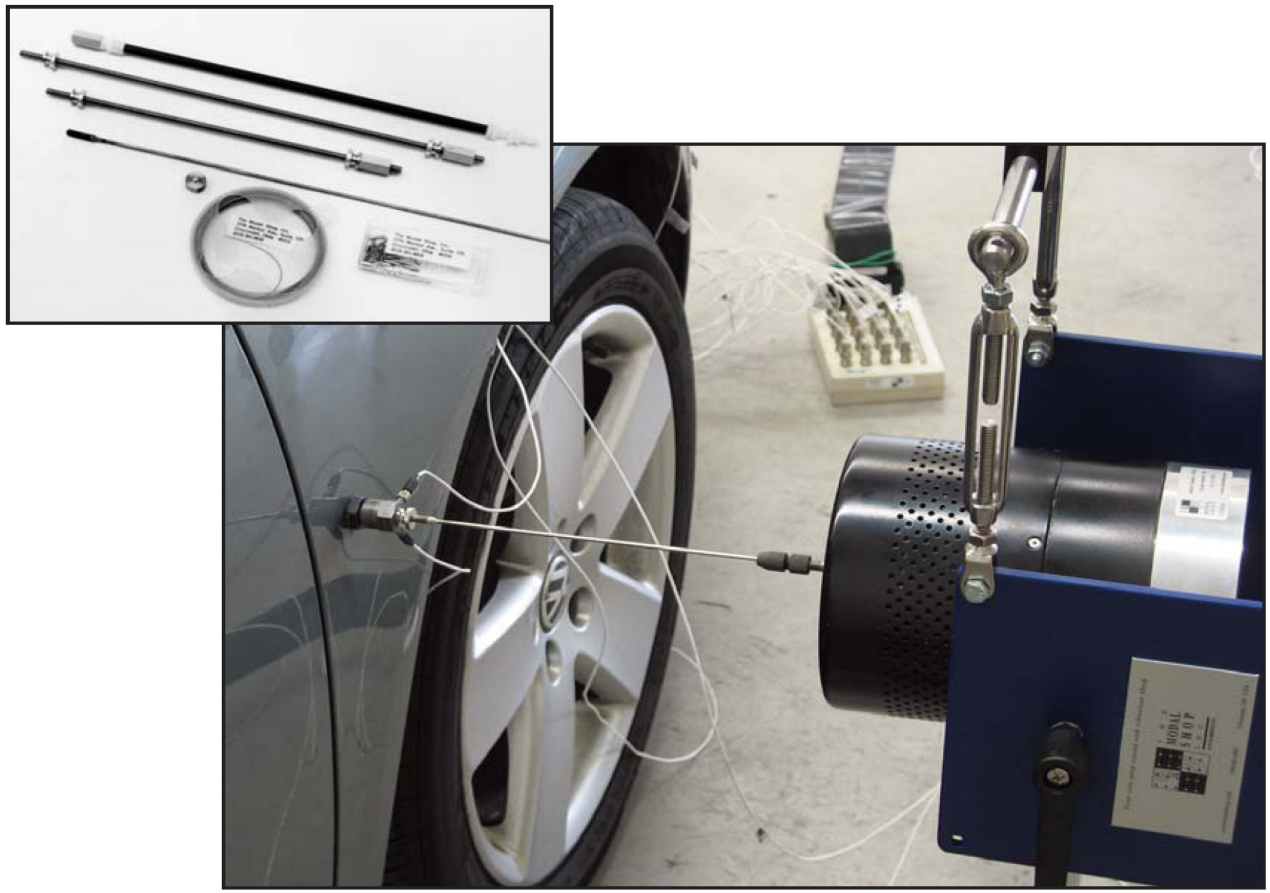
Floor Mounting Final Set Up

Suspended Mounting Set Up

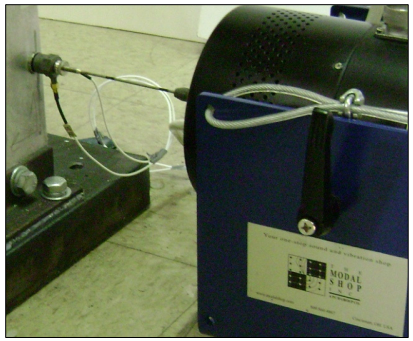


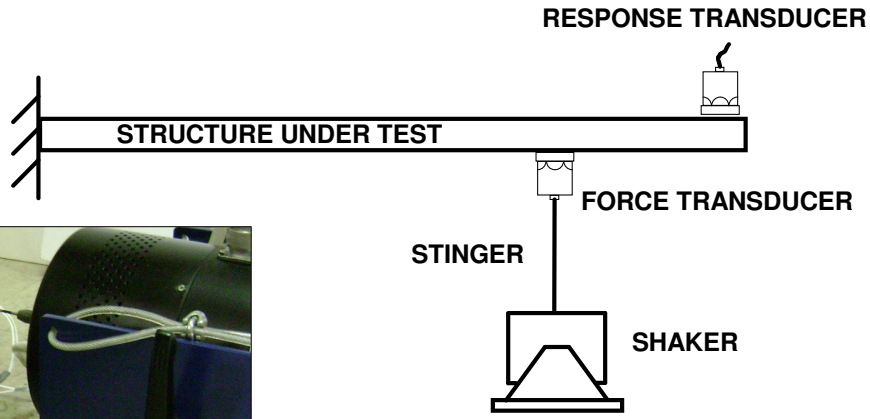
Stingers



Stingers

Excitation device is attached to the structure using a long rod called a "stinger" or "quill"



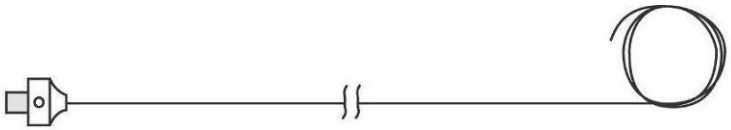


- **Its purpose is to provide input along the shaker excitation axis with essentially no excitation of the other directions**
- **It is also intended to be flexible enough to not provide any stiffness to the other directions**
- **The force gage is always mounted on the structure side of the stinger**
  - NOT ON THE SHAKER SIDE

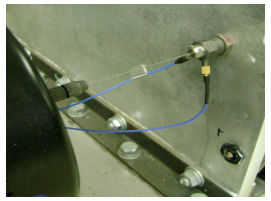
Exciter Stingers

- **Link between the shaker and the structure**
  - Provides convenient excitation connection
- **Also called "quills", rods, push-pull rods, etc.**
- **Stiff in the direction of Excitation**
- **Weak in the transverse directions**
  - No moments or side loads on force transducer
    - Reduce force sensor measurement error
  - No moments or side loads on shakers
  - Function as a mechanical fuse
- **Alleviates need for alignment accuracy**
- **Isolates fragile exciter armatures**
- **Adapts to different mounting threads**

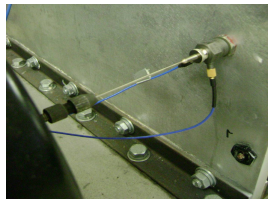
Stinger Types



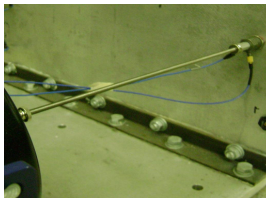
Piano wire



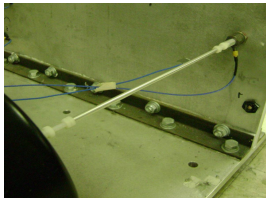
Modal stinger



Threaded metal rod

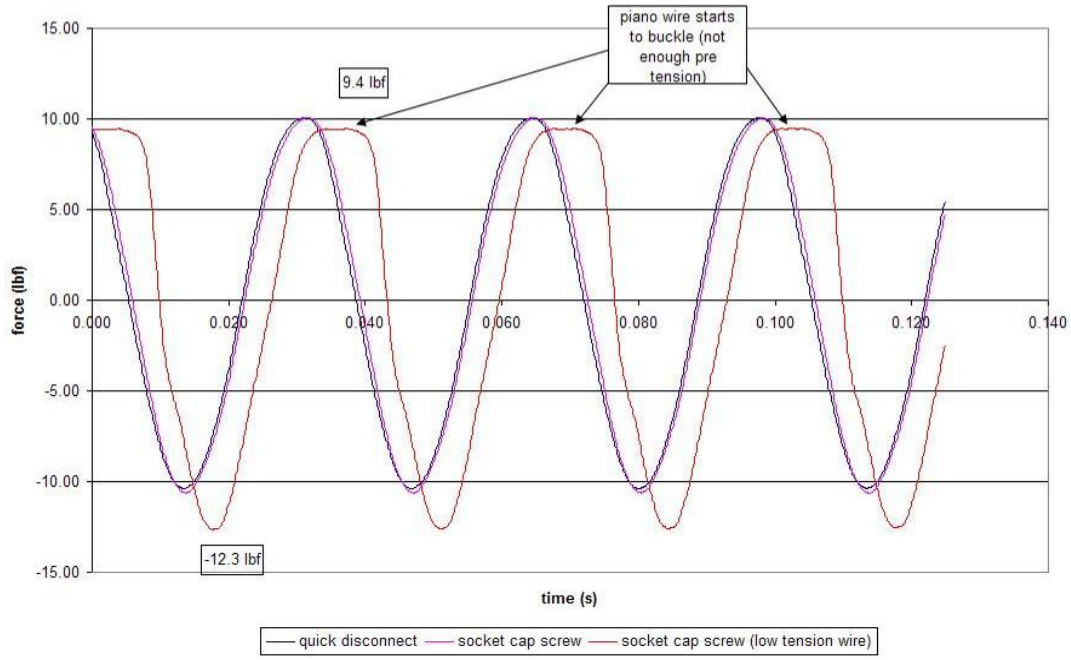


Threaded nylon rod



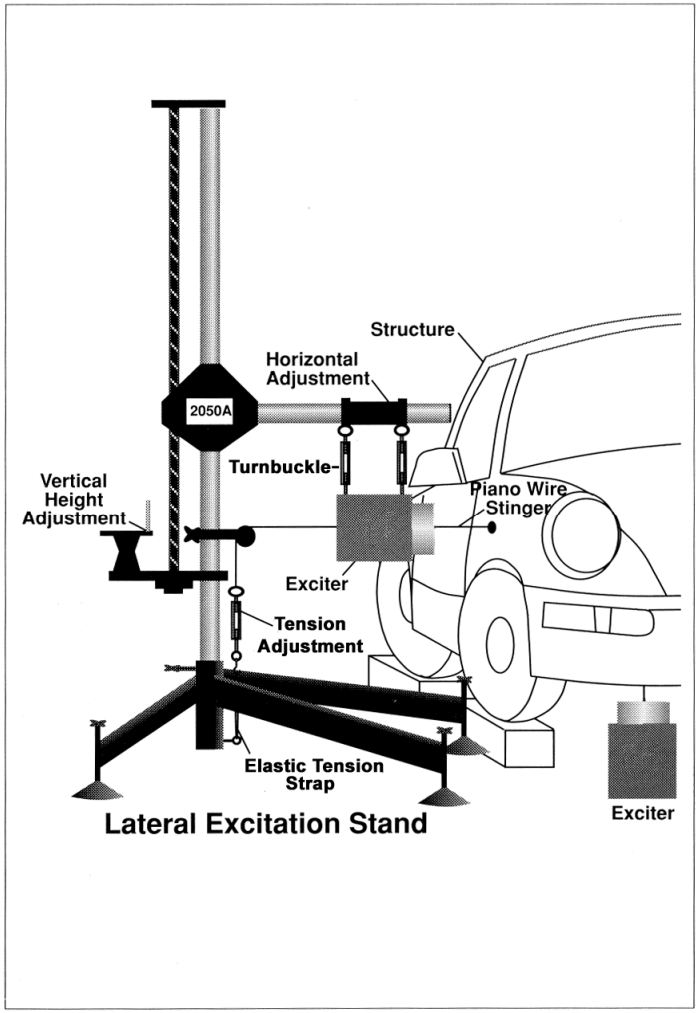
Piano wire considerations

- **Pretension required**
  - Dynamic excitation force (AC) rides on pretensioned force (DC)
  - Buckling occurs if excitation > pretension force



Typical Piano Wire Installation

Lateral excitation setup using a shaker stand and a piano wire stinger



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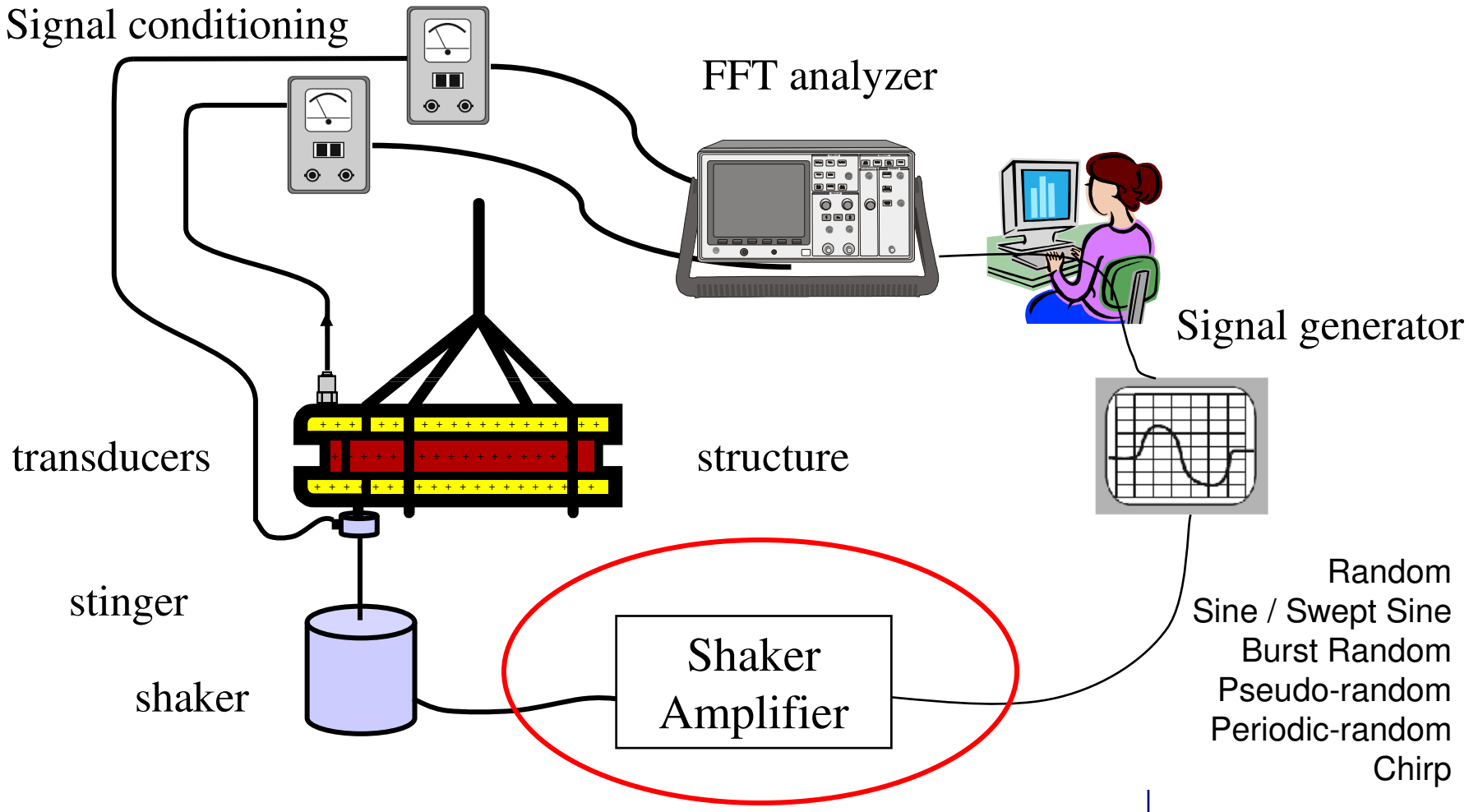
Typical modal shaker set up:



Shaker Amplifiers

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Amplifier Considerations

- **Compatibility**
  - Match shaker impedance
- **Frequency range**
  - Low frequency Response
- **Power rating**
  - Output capability
  - Voltage and Current versus Frequency
- **Voltage and Current mode**
- **Harmonic distortion**
- **Interlock capabilities**
  - Safety features (over-travel, over-temperature, emergency button..)
- **Safe Start**
- **Current / Voltage monitoring**
- **Input power**

Voltage & Current Mode

- As the shaker armature and coil move through a magnetic field during normal operation, a voltage is induced in the circuit called **back emf** (back electromotive force). This current associated with the back emf is proportional to the shaking velocity and it runs against the current coming from the amplifier. The **back emf** function as an electrodynamic damping term in the system. In **Voltage Mode** the amplifier's output voltage follows the input voltage signal with a gain associated to it. In **Current Mode** the amplifier's output voltage is adjusted to maintain the required current on the output (to follow the input signal) regardless of back emf generated in the system.

Voltage Mode

- Ideally used with burst random and burst sine test signals
- Back EMF created in the shaker adds damping to system allowing for faster decay, reducing leakage errors
- Typical mode for power amplifiers, if not otherwise specified

Current Mode

- Ideally used with sine and swept sine test signals, particularly for normal mode testing
- Back EMF created in the shaker does not add damping to system
- Preferred method for studying non-linearities, often the case in aerospace structures
- Avoids potential force dropouts at resonances, which compromise signal to noise of the force measurements
- Allows measurement of free decay damping of the structure (turn excitation signal off)

Power Amplifier Technologies

- **Many shaker amplifiers are still linear type, class A or class B**
  - Simple, well established design
  - Poor efficiency (50-70% range)
  - Typically heavy
- **New amplifier technology utilizes switching amplifiers, class D**
  - Very efficient (> 90%)
  - Lightweight
  - Small
  - No fans (quiet)

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References

- R. C. Merkel, K. B. Gatzwiller, D. L. Brown, Important Aspects of Precise Driving Point FRF Measurements Using a Mechanical Impedance Head Sensor, *Proceedings of the Sixteenth International Modal Analysis Conference, Santa Barbara, California, USA, 1998 February 2-5, pp. 795-799..*
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- Modal Shaker Setup videos – www.youtube.com/TheModalShop
- Modal Shaker FAQ - http://www.modalshop.com/excitation.asp?P=Modal_Shaker_FAQ&ID=336
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- N. L. Olsen, Using and Understanding Electrodynamic Shakers in Modal Applications, *Proceedings of the Forth International Modal Analysis Conference, Los Angeles, California, USA, 1986 February 3-6, pp. 1160-1167*

Thank you!

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