Modal analysis

Modal Analysis

Modal Analysis is the study of the dynamic properties of structures under vibrational excitation. Modal analysis, or more accurately experimental modal analysis, is the field of measuring and analyzing the dynamic response of structures and or fluids when excited by an input.
Modern day modal testing systems are composed of transducers (typically accelerometers and load cells), an analog-to-digital converter frontend (to digitize analog instrumentation signals) and a host PC to view the data and analyze it.

Classically this was done with a SIMO (single-input, multiple-output) approach, that is, one excitation point, and then the response is measured at many other points. In the past a hammer survey, using a fixed accelerometer and a roving hammer as excitation, gave a MISO analysis, which is mathematically identical to SIMO, due to the principle of reciprocity. In recent years MIMO has become more practical, where partial coherence analysis identifies which part of the response comes from which excitation source. Typical excitation signals can be classed as impulse, broadband, swept sine, chirp, and possibly others. Each has its own advantages and disadvantages.

The analysis of the signals typically relies on Fourier analysis. The resulting transfer function will show one or more resonances, whose characteristic mass, frequency and damping can be estimated from the measurements. The animated display of the mode shape is very useful to engineers. The results can also be used to correlate with finite element analysis normal mode solutions.

Structural dynamics

Structural dynamics is a subset of structural analysis, which covers the behavior of structures subjected to dynamic loading. Dynamic loads include people, wind, waves, traffic, earthquakes, and blasts. Any structure can be subject to dynamic loading. Dynamic analysis can be used to find dynamic displacements, time history, and modal analysis.
A static load is one which does not vary. A dynamic load is one which changes with time. If it changes slowly, the structure's response may be determined with static analysis, but if it varies quickly (relative to the structure's ability to respond), the response must be determined with a dynamic analysis. Dynamic analysis for simple structures can be carried out manually, but for complex structures finite element analysis can be used to calculate the mode shapes and frequencies.

Dynamic Displacements

A dynamic load can have a significantly larger effect than a static load of the same magnitude due to the structure's inability to respond quickly to the loading (by deflecting). The increase in the effect of a dynamic load is given by the dynamic amplification factor (DAF):

$$DAF = \frac{u_{max}}{u_{static}}$$

where u is the deflection of the structure due to the load.

Natural Frequency

Damping

Any real structure will dissipate energy (mainly through friction). This can be modeled by modifying the DAF:

$$\mathbf{DAF} = 1 + e^{-\xi \pi}$$

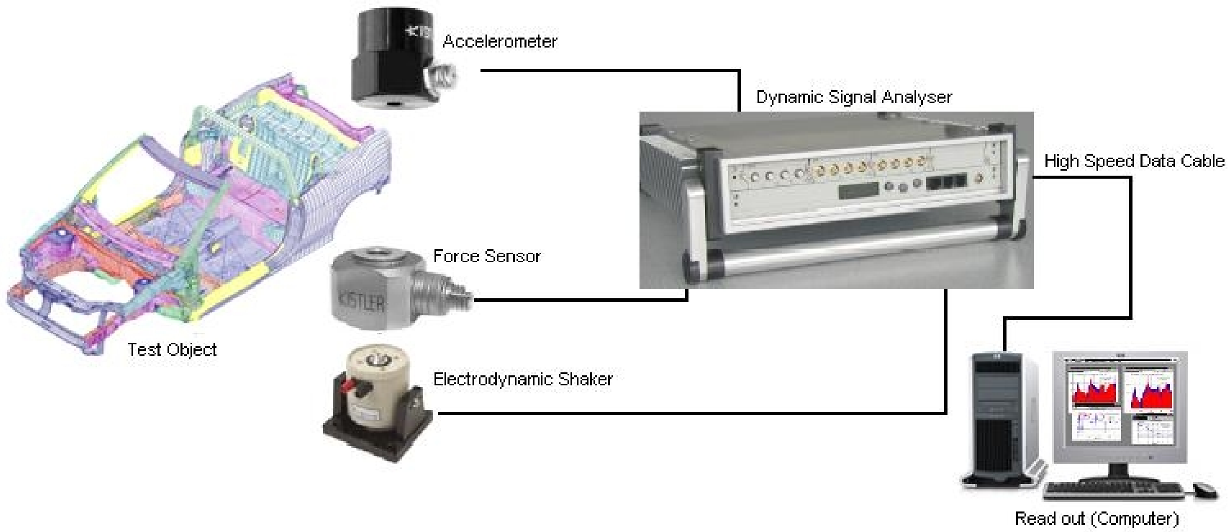
Where $\xi = \frac{\text{Damping Coefficient}}{\text{Critical Damping Coefficient}}$

Generally, damping would be ignored for transient events (for example, an impulse load such as a bomb blast), but would be important for non-transient events (such as wind loading or crowd loading).

Modal testing

Modal Testing is a form of vibration testing of an object where the **fundamental frequencies** of the object under test are determined. A modal test not only consists of an acquisition phase, but also of an analysis phase as well. The complete process is often referred to as a **Modal Analysis** or Experimental Modal Analysis.

There are several ways to do modal testing. The most widely used are Impact Hammer modal testing and Shaker modal testing.



Impact Hammer Modal Testing

When an object is subjected to the strike, it is excited. It will vibrate according to the bandwidth of the impulse. While it vibrates, the object will behave in such a way that some of the frequencies will not be responded at all (attenuated) and some frequencies will be amplified. Some of the frequencies will be amplified in such a way that the only limiting factor is the energy available for the vibration. This is called resonance.

These frequencies where the object resonates are known as the fundamental frequencies of that particular object or the modal frequencies.

Shaker Modal Testing

Another method is by using an instrument called a shaker. A shaker is a device that excites the structure according to its amplified input signal. Several input signals are available for modal testing, but the sine sweep and random frequency vibration profiles are by far the most commonly used signals.

Shaker armature is attached to the body to be tested by way of piano wire (pulling force) or stinger (Pushing force). When the signal is transmitted through the piano wire or the stinger, the object responds the same way as impact testing, by attenuating some and amplifying certain frequencies. These frequencies are measured as modal frequencies.

When the impact hammer or the shaker stinger is fitted with a device called a load cell, one can measure the excitation signal. The response signal is acquired through an accelerometer fitted to the object under test. Comparing these two signals in the frequency domain (By calculating the transfer function) will reveal how the object moves or vibrates at modal frequencies.

If adequate measurement points are available, mode shapes of the object can be evaluated from the transfer functions.

These transfer functions are referred to as Frequency Response Functions, or FRFs for short.

References

- D. J. Ewins: *Modal Testing: Theory, Practice and Application*