Modal-Tuning improves impact testing

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Abstract:
The natural resonances of conventional impact hammer structures were determined to be the cause of spurious glitches in frequency response function (FRF) measurements made during impact testing. By modaltuning, or tuning the mode shapes of the hammer structure, an impact hammer was developed which functions and feels better.

Introduction:

As many as ten years ago, the first production hammer was available after its development at the University of Cincinnati. It was a simple hammer structure with a force sensor installed on the head.

It was initially used at low frequencies to conveniently excite a test object's resonances for modal testing. As impact testing became more prominent and widely used, the hammers were used over the entire frequency range they were capable of exciting. In early testing, it was noticed that the otherwise smooth roll-off spectrum of the hammer impact contained glitches in the 600 Hz and 1600 Hz region (1). These appeared as glitches in the corresponding FRF measurements computed from this data, The glitches did not represent behavior of the test object.

In general, these glitches were we11 known and repeatable. They were regarded as unavoidable natural behavior of the hammer. In FRF measurements, they were either ignored or a complete frequency response calibration curve was stored to be subtracted from the measured FRF's. This calibration procedure measured and removed the glitches hom the FRF's. At this point in the hammer evolution (approx. 1983), the problem of the glitches was identified and a solution devised.

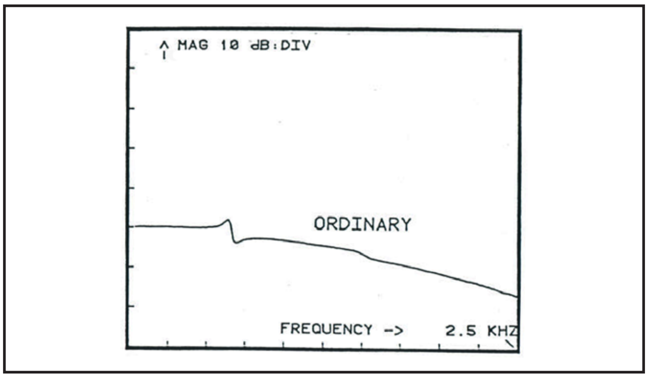

Figure 1: Glitches in force spectrum

Cause of The Glitches:

Force sensors, as with a11 sensors, are imperfect devices. Along with their sensitivity to force, they have same degree of motion sensitivity. It was suspected that this sensitivity to motion was sensing the natural resonances of the hammer structure excited after impact. This resulted in the glitches in the force spectrum and corresponding FRF.

The test needed to verify this was to perform a modal survey on the hammer itself to obtain frequency values and mode shapes. This was accomplished using a miniature piezoelectric accelerometer, the force sensor on the impact hammer and a two channel FFT analyzer. The accelerometer was moved along the hammer handle in the axial direction to the hammer head. The force sensor was left on the hammer head and the: face was struck against a convenient mass to supply the input force.

Just as suspected, the frequencies of the first two bending modes matched the two prominent glitches in the hammers force spectrum [2]. From this, it was confirmed that motion sensitivity of the force sensor, which was amplified by an impact tip, allowed the natural resonances of the impact hammer to contaminate data. With the problem defined, solutions were investigated.

First Attempts:

Conventional techniques that involved changes in mass, stiffness and damping were attempted first. Stiffer materials used for the handle on1y shifted the resonances to higher values. Constrained-layer damping reduced the magnitude of the glitches, but did not eliminate them. Changes in the length of the hammer head and handle produced an awkward feeling instrument along with little improvement in behavior.

Reduction in motion sensitivity of the force sensor by reducing impact tip mass helped reduce the glitches, but adversely affected the repeatability of force measurements.

The Solution::

If excited, any mode of vibration that resulted in axial, linear motion of the hammer head ,would contaminate data with a glitch. This observation was the key to the solution. If each mode shape could be modified (modal-tuned) so that a node existed at the hammer head, then there would be no motion sensed.

This was achieved by two means. The total hammer mass was redistributed leaving the head much heavier than the handle. Then, a soft neoprene grip was used to provide damping and isolation of the operator's hand.

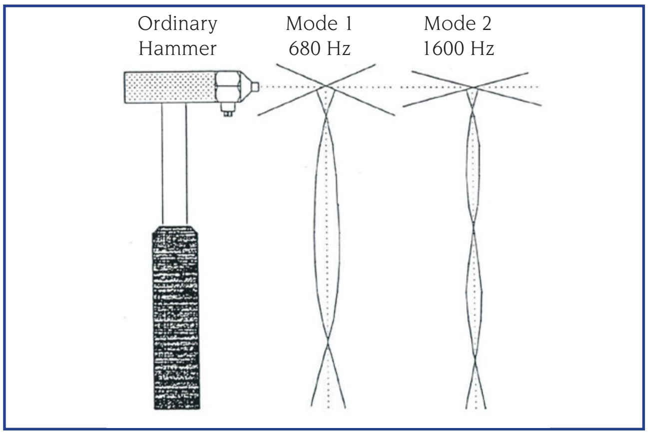

Figure 2: Mode shapes ordinary hammer

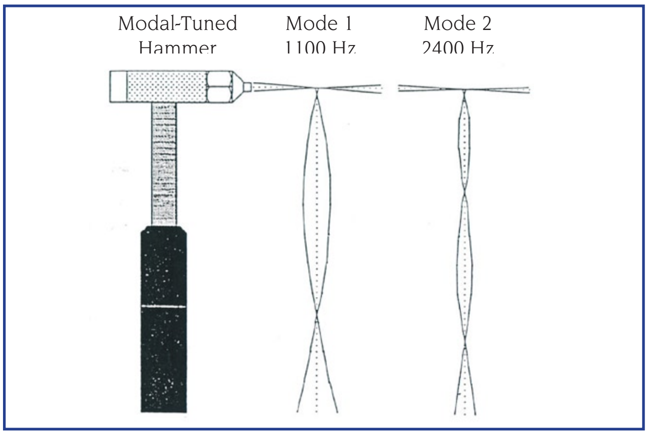

Figure 3: Mode shapes modal-tuned hammer

Chosen for its lightweight and strength, a composite graphite bar was used for the handle. Custom molded soft neoprene foam was used for the grip because of its lightweight, damping and isolation qualities. A tungsten tuning mass on the head he1ped redistribute mass while maintaining a „shorter" profile and even balance. Figure (3) illustrates the modified mode shapes of the modal-tuned hammer. Although frequency values have shifted somewhat, the emphasis of change is in the mode shape.

Benefits of Modal-Tuning:
The head of a modal-tuned hammer experiences little or no motion during hammer resonance due to its proximity to a node. For the same reason, the resonances tend not to be excited. If they are excited, there is little motion to be sensed. By removing the g1itches from the input signal, the modal-tuned hammer provides a more accurate measurement of input force (4).

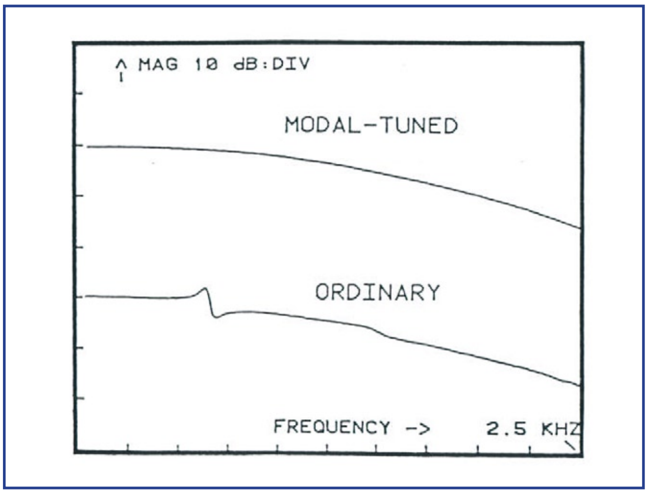

Figure 4: Glitch-free modal-tuned vs. ordinary

Another less obvious benefit is that the hammer produces less multiple impacts when testing. Since the head no longer vibrates after impact, the incidence of multiple hits is reduced. In general, multiple impacts are undesirable because their spectral content contains „zeros" at periodic intervals. In a given situation, the operator may use a modu1-tuned hammer with greater ease and less skill due to its favorable behavior.
Over lower frequency ranges the hammer's head behaves as a rigid body. It can be used for simple behavior tests and crude calibration. Mounting the accelerometer on the back of the head and impacting any convenient object allows the user to verify operation and scaling procedures. Using the effective mass of the hammer head with accelerometer installed, the proper scaling constant can be computed from the FRF of the head. During this exercise, resonances of the entire hammer structure may be sensed depending on how well tuned it is.

All together, the modal-tuned hammer has a better balance and feel to the operator. This makes it easier and more confortable to perform impact testing, especially on smaller object.

Conclusion:
Modal-tuning solved a structural behavior problem, producing a product that behaves better for its intend use. As a less conventional method of structural modification, it may be an attractive solution to other structures vibration problems.

References:

1) Course notes „Modal Analysis Theory and Measurement", University of Cincinnati, Cincinnati, OH 1984

2) Technical brief „Transduction", Robert W. Lally, PCB Piezotronics, Inc., Depew, N.Y. 1982

3) „Impact Testing Considerations", D. Correlli and O. Brown, Quixote Measurement Dynamics Inc., Cincinnati, OH 1984

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