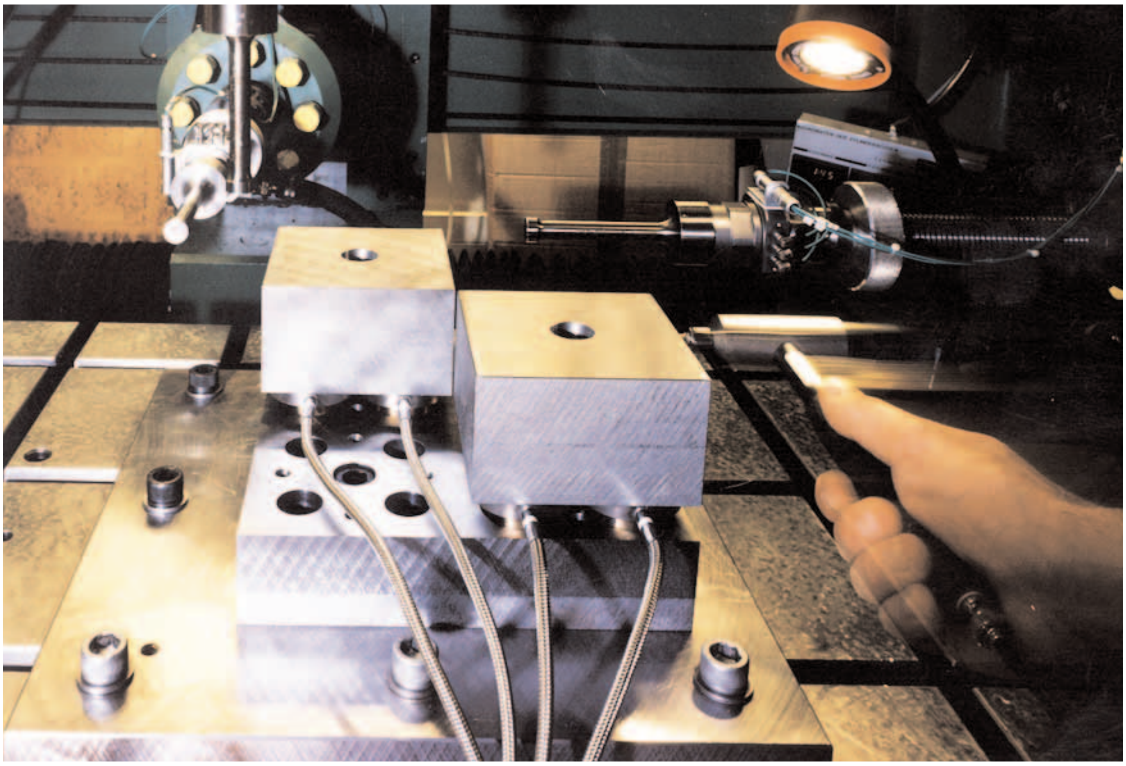
Bernhard Bill, Kistler Instrumente AG Winterthur, Switzerland

Basic Theory of The Hammer Test Method



Kistler Instrumente AG Winterthur
Winterthur, Switzerland
Tel + 41 - 52 - 224 11 11, Fax 224 14 14
sales@kistler.ch

Kistler Instrumente GmbH
Ostfildern, Germany
Tel (07 11) 34 07-0, Fax (07 11) 34 07-159
info@kistler-deutschland.de

Kistler SA
Les Ulis Cédex, France
Tel 01 69 18 81 81, Fax 01 69 18 81 89
info@kistler.fr

Kistler Instruments Ltd.
Mill Lane, Alton, Hampshire, UK
Tel (0 14 20) 54 44 77, Fax (0 14 20) 54 44 74
sales@kistler.co.uk

Kistler Italia s.r.l.
Milano, Italy
Tel (02) 481 27 51, Fax (02) 481 28 21
kistler@tin.it

Kistler Instrument Corp.
Amherst, NY, USA
Tel (716) 691 51 00, Fax (716) 691 52 26
kicsales@kistler.com

Kistler Japan Co., Ltd.
Tokyo, Japan
Tel (03) 35 78 02 71, Fax (03) 35 78 02 78
sales@kistler.co.jp

Kistler Instruments (Pte) Ltd.
Singapore
Tel 469 67 73, Fax 469 56 84
kistler.sales@kistler.com.sg

Kistler China Ltd.
North Point, Hong Kong
Tel 2591 5930, Fax 2591 1885
kcnlibin@vol.net

Kistler Korea Co., Ltd.
Seoul, ROK
Tel (02) 555 60 13, Fax (02) 555 60 15
kistler@kornet.net

20.195e 10.98

Basic Theory of The Hammer Test Method

Bernhard Bill, Kistler Instrumente AG, Winterthur, Switzerland

The following is a short description of impulse force hammer testing theory. Additional information is contained in [1], [2], [3], [4].

Hammer testing is a straight forward method which yields good results under most conditions. This testing technique makes use of the fact that when a (mechanical) structure is excited by means of a Dirac pulse, the structure responds with all its eigenvalues (i. e. natural frequencies and damping). An example of this effect can be demonstrated by impacting a piano with a short, impulsive blow. If the piano pedals are depressed during the blow, each piano string will clearly vibrate.

In practice, a true Dirac pulse does not exist since its theoretical duration is zero. In general, as the impact duration increases the range of excited frequencies decreases. Impact tips mounted to a force impulse hammer consist of different materials (steel, plastic, various rubbers), each yielding different excitation durations and different excitation frequency ranges. Depending upon the frequencies of interest of the structure under test, the appropriate impact tip is mounted to the hammer.

A typical experimental setup is shown in *Figure 1*. It consists of the structure (with test sensor) to be tested, a signal conditioner (e.g. a charge amplifier) which converts the test sensor's signal to an analog voltage signal, a force impulse hammer with signal conditioner, and a two channel dynamic signal analyzer. This analyzer decomposes a time signal, consisting of multiple frequencies, into its individual frequencies.

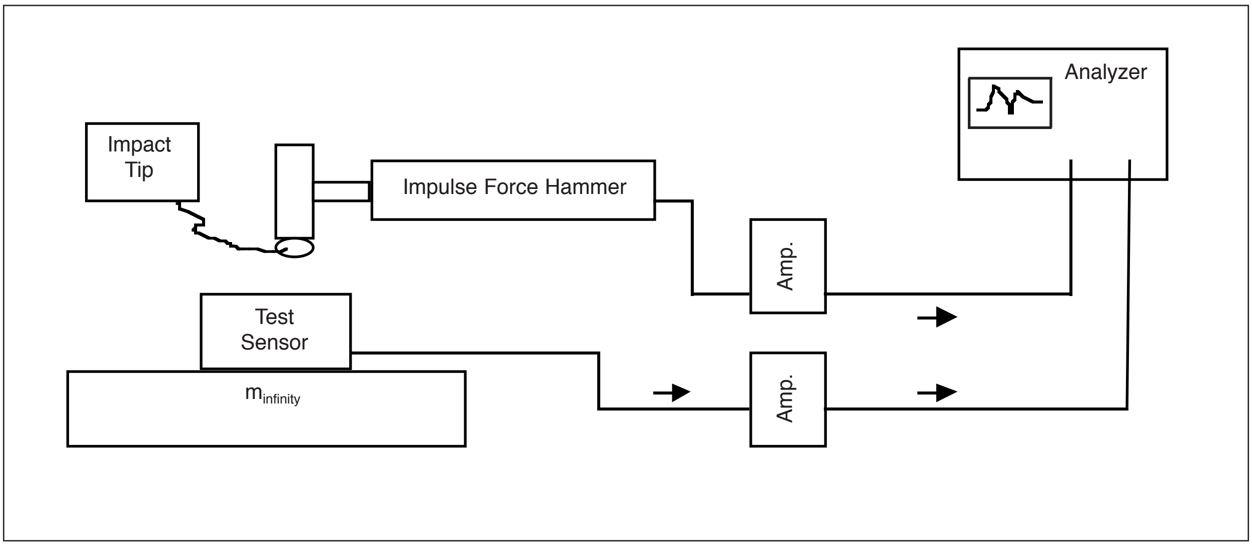


Fig. 1: Experimental setup of hammer test

The excitation signal of the hammer and the response signal of the test specimen are acquired in the time domain by the two channel analyzer. The Fast Fourier Transform (FFT) yields the corresponding power spectral densities. Performing the complex division of (power spectrum response)N^2/(power spectrum excitation)N^2 results in the Frequency Response Function (FRF). The FRF contains natural frequencies, useable frequency range magnitude, and phase information. The unit of the FRF is 1, since (in this case) $N^2 / N^2 = 1$.

Figure 2 shows the z-axis results for a typical frequency analysis of a multicomponent force plate used in a biomechanics application. The excitation has been performed by means of an impulse force hammer with a plastic impact tip. In *Figure 2*, the left column shows the time domain signals (top: hammer, bottom; force plate), the middle column shows the power spectra, i. e. the Fourier transform of the corresponding time signals (top: hammer, bottom; force plate), and the right column shows the FRF with the magnitude (top) and the phase (bottom). The results for the x and y axes can be similarly produced and shown.

From the FRF it clearly can be seen, that the first natural frequency coincides with 1187,5 Hz (1st peak; phase shifts by –90 °). Also from this plot, the useable frequency range can be determined. A convenient scaling of the ordinate (dB, log, lin) facilitates the evaluation.

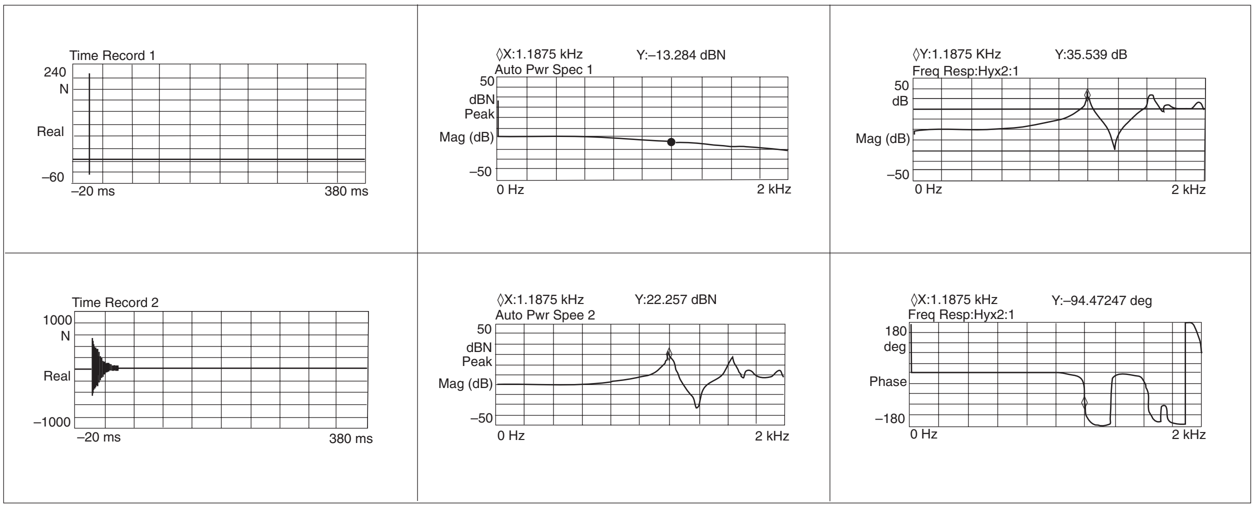


Fig. 2: Frequency analysis of a multicomponent force plate for biomechanics (z axis only)

When the measuring chain is properly calibrated (i. e. the calibration values of the hammer and the test specimen, respectively, are properly set on the analyzer), the FRF shows 0 dB results (or 1, when scaled linearly) at low frequencies. Additionally, a hammer test may be used to determine the test specimen's sensitivity at low frequencies, when the amplifiers and the analyzer are set accordingly.

Structural changes like cracks or other structural damage to a unit under test results in a change of the FRF. Since $\omega_d = \omega_n \sqrt{1 - \zeta^2}$

where ω_d: damped natural frequency
ω_n: undamped natural frequency $\omega_n = \sqrt{k/m}$
ζ: damping ratio $\zeta = c/2\sqrt{km}$
m: mass
k: stiffness
c: damping

changes to m and/or k and/or c will change the FRF (frequency shifts, different shapes, different magnitudes).

As long as a structure to be tested is linear and time independent, the ambient and boundary conditions are the same and the place of excitation (i. e. the spot, where the impact tip of the hammer contacts the test specimen) is identical, the FRF yields repeatable results each time the test is conducted. If over time (e.g. one year) subsequent frequency analysis yields significantly different results, the test specimen has likely experienced structural changes like cracks or other damage, which have to be investigated accordingly.
Nonlinearities are difficult to detect by means of hammer testing [5]. However, shaker excitation techniques offer the best results currently obtainable.

Important Conditions When Performing A Hammer Test

- Mount test specimen properly to a big mass ($m_{infinity}$).
- $m_{infinity} > 10m_{test\ specimen}$-Otherwise, the FRF of the system will be altered by the mass of the test specimen ($m_{system} = m_{test\ specimen} + m_{infinity}$).
- Choose the appropriate impulse force hammer (Kistler offers seven different models, from a lightweight 500 N unit up to a heavy 20 kN sledge).
- Choose the appropriate impact tip according to the required frequency range. The data sheet for each hammer shows the frequency range for each impact tip.
- Choose the appropriate range and scale of the analyzer. Don't accept overloads.
- Depending on the time signals, windowing of the time signals may be necessary [1], [2], [3], [4]. It is extremely important, that the time signal outputs return to zero at the beginning and the end of each time block. Otherwise incorrect results may mislead interpretation of the resulting data.
- Perform at least 5 measurements and evaluate the resulting mean value.
- Double or multiple hits are strictly prohibited, i. e. the impact tip of the hammer cannot be allowed to bounce on the test specimen. The analyzer must be set accordingly.
- At the frequency of interest (e. g. f_n), the value of the hammer spectrum (*see Fig. 2*, middle column, top) should not be less than –20 dB below the value of the hammer spectrum at low frequencies. Otherwise, a harder impact tip must be used.
- In order to reproduce the measurement later, all settings, setups, boundary and ambient conditions, etc. should be documented properly and applied during subsequent testing.

Benefits of Hammer Test Method To Crash Barrier

- Fast, easy, and straight forward method to determine the frequency response function(s) of a structure.
- Fast and simple method for checking sensitivity at low frequencies and assuring quality as opposed to a complete, labor intensive force recalibration.
- Detection of changes in structure (e.g. cracks, other structural changes) is possible.

References

[1] Harris, C. M., *Shock & Vibration Handbook*, 3rd ed., McGraw-Hill, 1988
[2] Ewins, D. J., *Modal Testing: Theory And Practice*, Research Studies Press Ltd., 1984
[3] Hewlett-Packard, *Application Note 243-3: The Fundamentals of Modal Testing*, 1986
[4] Brüel & Kjær, *Structural Testing, Part 1: Mechanical Mobility Measurements*, 1987
[5] Frachebourg, A., *A Reduced Volterra-Model To Identify Nonlinear Elements of Time-Invariant Mass-Spring-Damper Systems*, Thesis (Diss. ETH No. 10093), 1993