Brüel & Kjær

application notes

The Design of Large Impactors for Structural Testing

Introduction

Impact excitation provides the fastest means of performing a structural test. Although impact excitation is not always appropriate for a particular structural test, due either to the nature of the structure under analysis or to the specific application of the test data, impact testing techniques are widely used particularly for trouble-shooting noise and vibration problems.

Large impactors are generally used for exciting large structures, implying that the frequencies of interest are low, often below 50 Hz.

The objective of the impactor is to provide sufficiently high excitation energy, and to concentrate this energy in the frequency range of interest. The ideal impactor has provision for *spectrum shaping.*

The impactor must produce an excitation waveform which can be measured accurately. This waveform is normally measured by using a high quality force transducer or an accelerometer.

Theory

An impact is a transient phenomenon where energy is transmitted over a relatively short period of time. The spectrum of the force impulse depends partly on the shape of the impulse but most of all on the duration.

Fig. 1 shows the relation between impulse duration and the energy spectrum. A short duration impulse dilutes the energy over a wide frequency band, in contrast to a longer duration impulse which concentrates the energy at low frequencies. One invariant of impulses is that the highest energy density is at 0 Hz. (We cannot build a “zoom hammer”.) The useful excitation range of the impulse spectrum is considered to be from 0 Hz to f Hz, where ***f*** designates the frequency at which the energy density has decreased by approximately 20 dB.

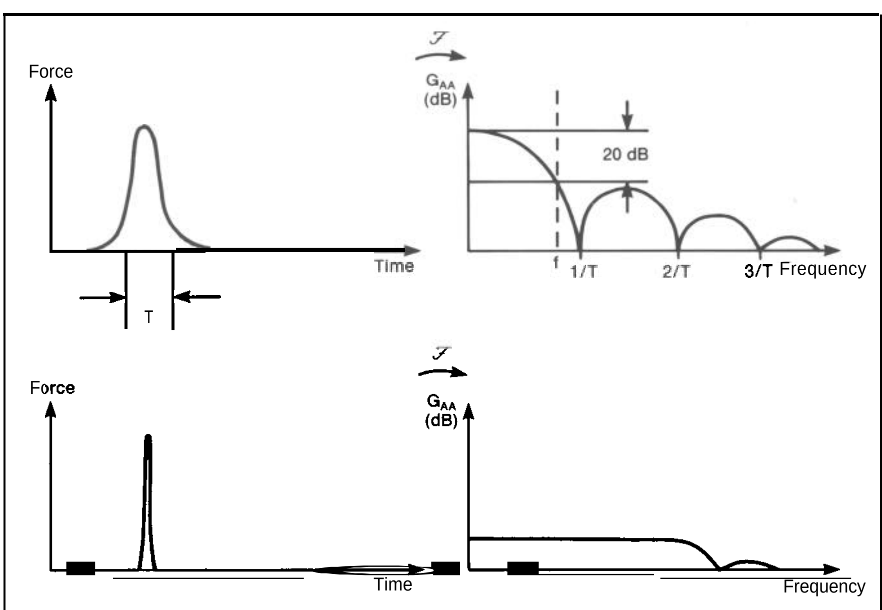
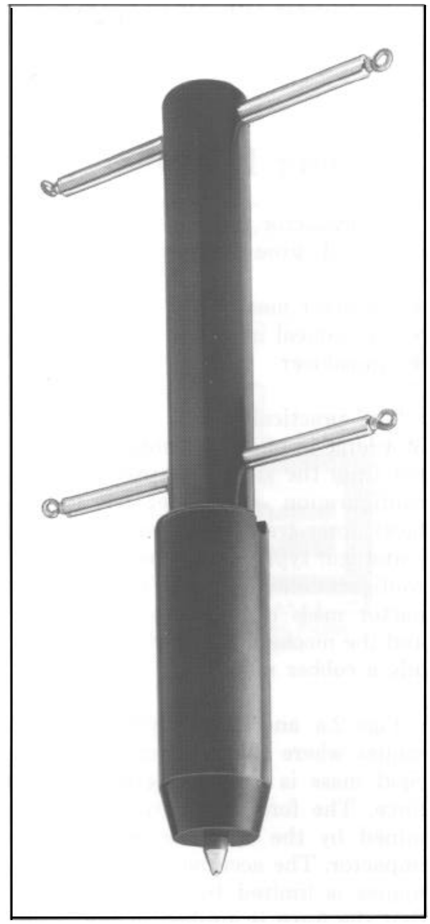


Fig. 1. A broad impulse concentrates the excitation energy at the lower frequencies, whereas a narrow impulse spreads the available energy over a wider frequency range



The impulse duration for a specific impactor mass is determined by the elasticity of materials of the structure and impactor (structure/impactor interface) which are in contact during impact. This interface is therefore the principle element which we can use to control the spectral energy distribution.

For a specific mechanical interface, the total energy delivered by the impact is determined by the mass and the velocity of the impactor.

When making mobility measurements on a structure the energy requirements depend on:

- structural damping
- the size of the structure
- mechanical background noise.

The peak force which we can apply to a structure is limited by:

- the non-linear character of the structure
- the strength of the structure at the impact point
- the maximum force rating of the force transducer

An unfavourable combination of these two sets of factors may prohibit impact excitation.

Impactor Designs

An impactor can be considered to consist of three components:

- impactor mass
- mechanical interface
- transducer

The practical design configuration of a large impactor is generally different from the smaller impact hammer configuration – hammer tip (interface), force transducer, hammer mass – and will typically be one of the four configurations shown in Fig.2. The impactor mass can be any rigid body, and the mechanical interface is generally a rubber material.

Figs. 2.a and 2.c both show techniques where the acceleration of the rigid mass is used to determine the force. The force calibration is determined by the dynamic mass of the impactor. The accuracy of these techniques is limited by the assumption that the force is applied in the direction of the main sensitivity axis of the accelerometer.

Figs. 2.b and 2.d show techniques where the force is measured directly by a force transducer. Fig. 2.b. shows a design which is attractive because of the very simple mechanical implementation. One undesirable consequence is that the force is measured at the interface rather than directly at the structure. In addition the interface, in practice a rubber patch (weighing 1/2 to 2 kg) glued to the structure, may have some structural modification effect.

The optimum design choice is shown in Fig. 2.d., where the most accurate force measurement is achieved, and the interface may be designed to act as an adjustable mechanical low pass filter.

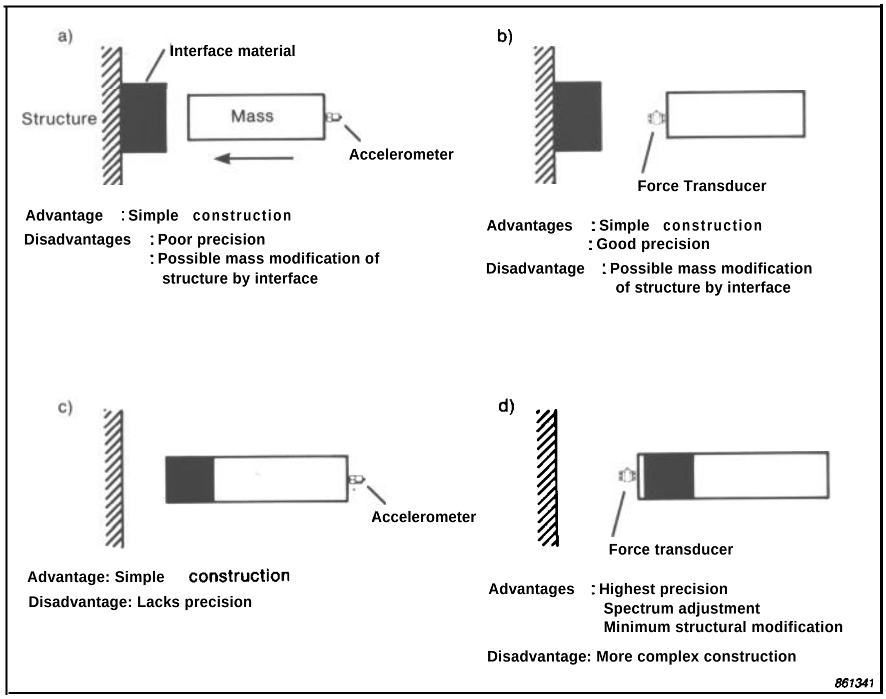


Fig. 2. Four alternative configurations *for large impactor design. The configuration in d) gives the optimum performance*

Practical Impactor Design

Fig. 3 shows the assembly drawing of an ideal impactor. The impactor consists of a cylindrical steel body weighing approximately 40 kg. At the impact end the cylinder is machine turned to reduce its dimension to fit a sleeve ball-bearing. The impactor head is a closed cylinder carrying a Brüel & Kjær Force Transducer Type 8201 with a semi-spherical anvil, and containing a set of rubber discs for controlling the stiffness of the interface. When assembled, the impactor constitutes a self-contained unit.

Impactor Properties

A dynamic analysis of the impactor shows that there exists a double hammer effect.

The complete impactor may be considered as a small hard impactor (impactor head) which is followed by a large soft impactor (impactor body/interface). The resulting force impulse is the sum of the two separate impulses as shown in Fig. 4.

The presence of the first, parasitic, hard impact is a disadvantage, as the high frequency energy may overload the conditioning amplifiers used for the force and response transducer channels. The effect is minimized by reducing the head/body mass ratio, and may be totally removed from the

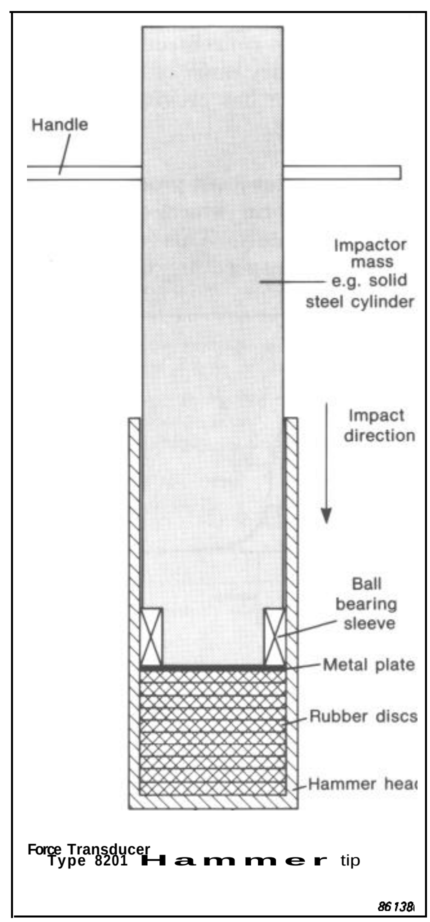


Fig. 3. Assembly drawing of a large impactor using the Briiel & Kjcer Force Transducer Type 8201

measurements by attaching a small rubber patch to the structure at the point of impact.

The advantage of the design is that the force spectrum can be adjusted over a relatively wide range by proper selection of the number, thickness, and material characteristics of the rubber discs.

Force Transducer Performance

Frequency response functions cannot be measured accurately unless high quality transducers are used to measure both the force and response signals. For impact testing of large structures the Brüel & Kjær Force Transducer Type 8201 is particularly suitable for measuring the excitation force, and the following transducer characteristics are of particular importance:

- Solid, all welded, hermetically sealed construction
- Wide force range, 4000N tensile to 20000 N compressive
- Extremely linear, max. deviation $< \pm 2\%$ of maximum force
- High axial stiffness 7×10^8 N/m. Deformation at maximum force 0,03 mm
- Transverse sensitivity typically <4%
- Low sensitivity to both long term and transient temperature changes
- High long term stability

Test Measurements on a Railway Bridge

Frequency response measurements were made on a railway bridge using an impact hammer based on the construction shown in Fig. 3.

Intrumentation

The instruments used for the field measurements and subsequent analysis in the laboratory are illustrated in Fig. 5. The instrumentation used in the field was battery powered.

A high sensitivity accelerometer, Brüel & Kjær Type 4379 (31,6 pC/ms^{-2}, 310 pC/g), was used to measure the structural response. The force and response signals were fed to the built charge preamplifiers of a Brüel & Kjær Portable Tape Recorder Type 7007. The tape recorder's 1 kHz reference signal was recorded on a third channel. A lower limiting frequency of 0,3 Hz and a tape speed of 15 in/s were used.

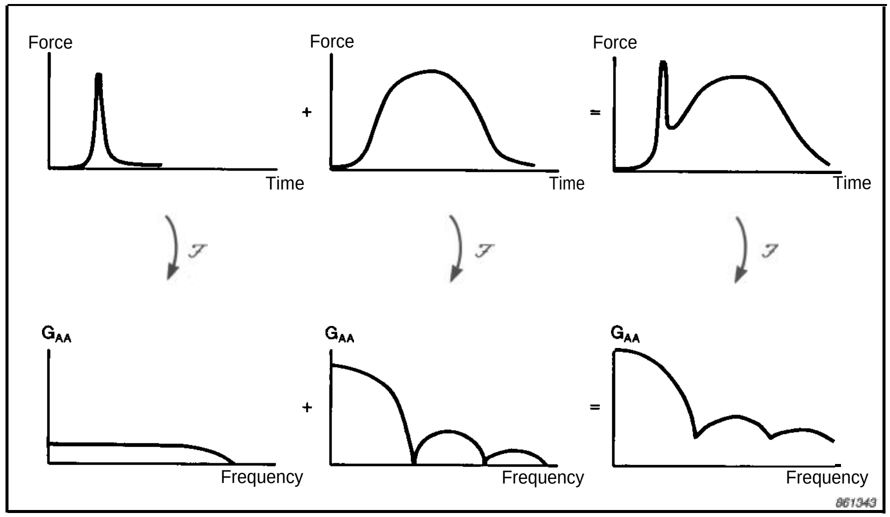


Fig. 4. In practice the impulse applied to a structure is the sum of two separate impulses. The first, parasitic impulse is undesirable, and can *to some extent be minimized*

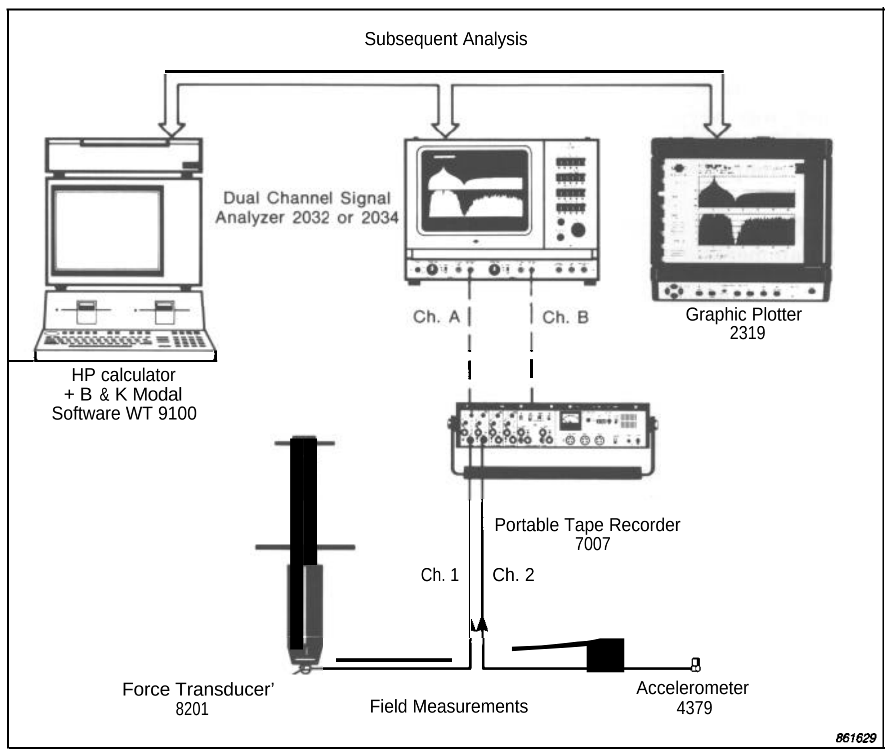


Fig. 5. Field and *laboratory instrumentation* used *for testing a steel girder bridge*

Back in the laboratory, the signals were replayed and analyzed using a Dual Channel Signal Analyzer Type 2034. Plots were obtained using Graphics Plotter Type 2319. Only the results relevant to the hammer construction are given here.

Measurement Results

The bridge, which was of a steel girder construction, had recently been damaged and repaired. The object of the test was to verify the integrity of the repaired side of the bridge.

The hammer was used to excite the structure by operating it in the vertical position as shown in Fig. 6. A small rubber patch was placed on the bridge at the point of impact, in order to reduce the "parasitic" short impulse imparted by the hammer head, and hence prevent any overloading of the charge preamplifiers. The overload indicators on the charge preamplifiers were observed throughout the test to prevent overloaded measurements from being used in the subsequent analysis.

The preamplifier settings and impact point and direction were noted for each measurement.

The laboratory analysis was performed in the frequency range 0 to 50 Hz. The time signal resulting from one impact is shown in Fig. 7, together with the averaged Autospectrum. The peak force of the impact is just under 5 kN, with a duration of approx. 10 ms. From the Autospectrum it is observed that the energy density is evenly distributed and decreases by approx. 11dB within the frequency range of interest (0 to 50 Hz). This implies that the excitation enegy level was adequate within the entire frequency range required by the test.

Fig. 8 shows a typical frequency response function obtained by the test, together with the measurement set-up used for the analysis.

Fig. 6 The operator excited the structure by applying an impact to a small rubber patch placed on the structure

Further Measurement Considerations

Before an impact test, "Ratio Calibration" is normally performed using a known mass. Since in this case the mass of the impactor is relatively large, Ratio Calibration is impractical. Instead the force transducer was calibrated in the laboratory. The subsequent effect of the mass of the anvil on the calibrated sensitivity of the hammer was very small, since the mass of the impactor body was very large by comparison.

The forces acting through the feet of the hammer operator should also be considered. One way of taking these forces into account is for the operator to stand on a platform, and to impact the platform itself. The force can then be measured using three transducers acting as the "legs" of the platform.

For a structure exhibiting modal deflections in directions lying in the horizontal plane, the hammer may be suspended horizontally from a separate structure and swung to impact the structure.

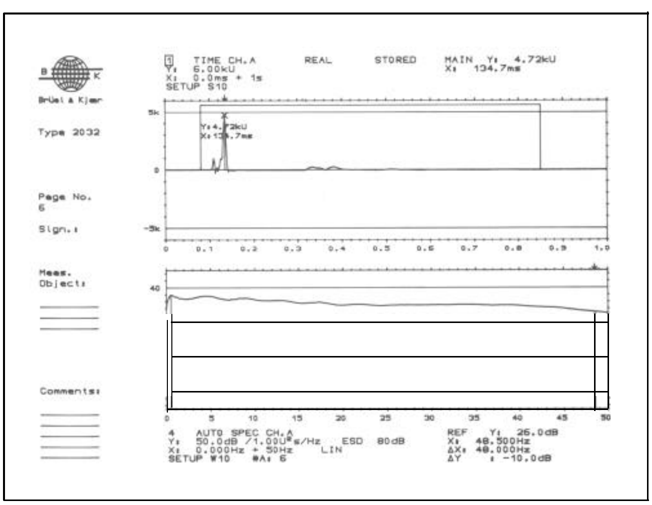


Fig. 7. The Autospectrum verifies that the excitation energy level was adequate within the frequency range of interest

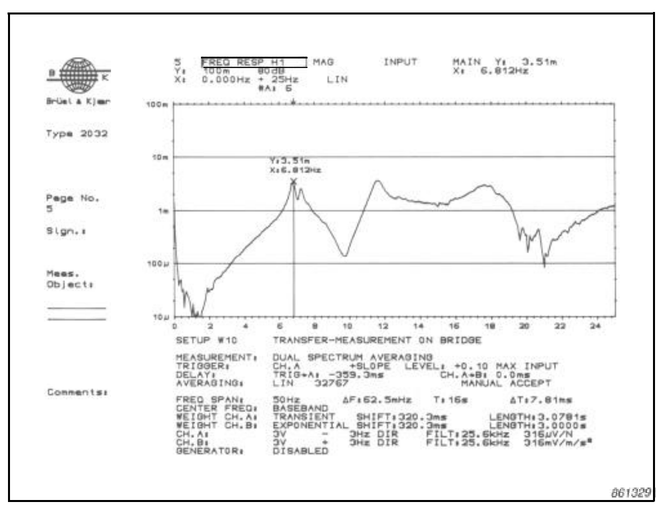


Fig. 8. A typical frequency response function obtained by the test

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