8203

Instruction Manual

Force Transducer/Impact Hammer Type 8203

The Force Transducer/Impact Hammer Type 8203 is a structural testing kit specifically designed for force measurements on light-weight and delicate structures. The force transducer can be used either to measure the force applied to a structure from, for example an exciter, or it can be used with the hammer kit for impact force measurement. With the addition of an accelerometer and a frequency analyzer, the force transducer/hammer kit can be used to measure the frequency response function of a structure. The kit contains a single force transducer, a hammer kit for impact testing, a stinger kit, a cable and accessories to aid mounting.

Brüel & Kjær

FORCE TRANSDUCER/IMPACT HAMMER
TYPE 8203

From serial no. 1476675

February 1990

HANDLING PRECAUTIONS

- The force transducer must not be subjected to temperatures above 150°C as a permanent change in the sensitivity of the force transducer will result.
- The force transducer is supplied preloaded to precisely 1000N. The preloading nuts should **not** be disassembled unless the transducer is to be used with the impact hammer kit. See Chapter 3.
- The force transducer must not be dropped as the impact could cause permanent damage to the piezoelectric discs within the force transducer.

CONTENTS

Force Transducer/Impact Hammer — Type 8203

USES:

○ Dynamic and impact force measurements on small structures

○ Measurement of frequency response functions using both impact and continuous excitation techniques

○ As part of a dynamic structural testing system for modal analysis and the prediction of structural response

FEATURES:

○ Good linearity

○ Long term stability

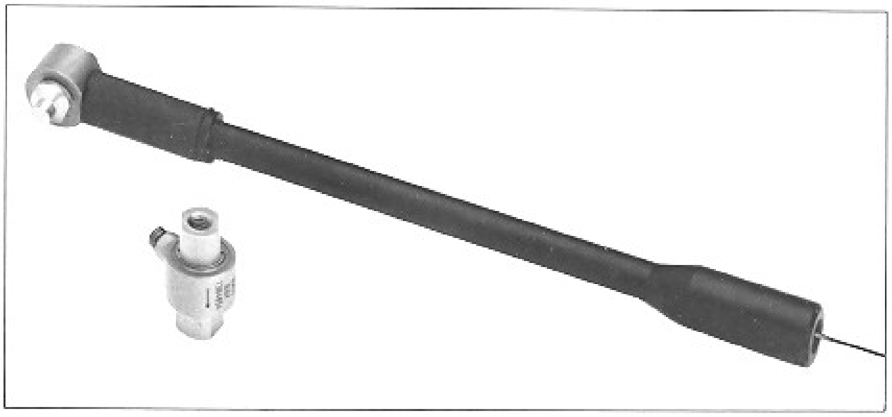
○ All welded construction

○ Compact size

○ Individually calibrated

○ Easily mounted

○ Easily attached to the stinger and hammer kits



The Force Transducer/Impact Hammer Type 8203 is a structural testing kit specifically designed for use with lightweight and delicate structures. The force transducer measures the force applied to the structure. It may be connected to the hammer kit for impact testing or to a small exciter (such as the Brüel & Kjær Type 4810) via the stinger kit supplied.

Force Transducer

The force transducer is designed to measure dynamic and impact forces. It is preloaded to precisely 1000 N allowing compressive force measurements of up to 1000 N and tensile force measurements of up to 250 N. The transducer is mounted on the test structure so that the force to be measured is transmitted through the transducer. When used with an exciter, the transducer signal can be used to measure and control the applied force. The frequency response function of the test structure can be measured by using a dual channel analyzer. The force transducer is used to measure the input force and an accelerometer (or laser velocity transducer) is used to measure the response of the structure (Fig. 1). The charge output of both the force transducer and accelerometer must be amplified and converted to a voltage output before being connected to the dual channel analyzer. The Charge Amplifiers Type 2635 shown in Fig. 1 or, alternatively, Line-Drive Amplifiers Type 2644 may be used for this purpose. The Line-Drive Amplifier Type 2644 is a miniature amplifier with a fixed gain. It may be powered either directly from the Dual Channel Analyzer Type 2032/2034 or from the two channel Line-Drive Supply Type 2813.

The transducer can be attached to an exciter via the stinger (Fig. 2). The stinger reduces the transmission of lateral forces to the transducer, thereby protecting the transducer, exciter and structure under test from damage.

The low mass of the force transducer ensures that when mounted on a test structure, the resulting changes in the dynamic properties of the structure are negligible.

The principle of operation of the transducer is the piezoelectric effect of quartz. When the quartz is subjected to a compressive or tensile force, it produces an electrical charge which is proportional to the applied force.

The quartz piezoelectric element has a very low sensitivity to temperature changes and temperature transients. The force transducer can be used in the range −196°C to 150°C.

Calibration of the Force Transducer

The force transducer is individually calibrated and a calibration chart is included with the instrument. The pi-

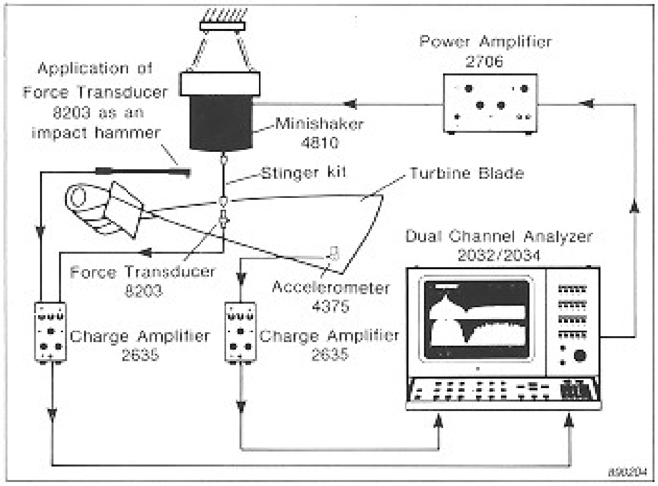


Fig. 1. Instrumentation for structural analysis, using vibration exciter and impact hammer excitation techniques

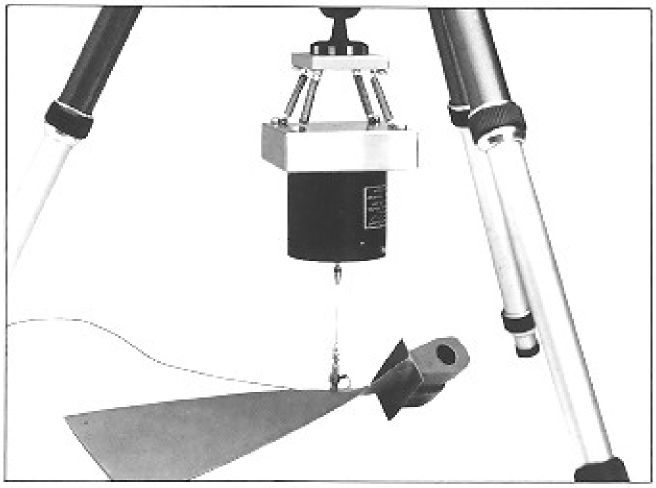


Fig. 2. Structural testing set-up using the stinger kit

ezoelectric discs are silicon treated and artificially aged. This process ensures that the force transducer is stable and should require only occasional recalibration.

The force transducer is calibrated with the preloading nuts mounted. The stated preloading force must be applied for the calibration to be valid. Typical charge sensitivity for the force transducer when used with the preloading nuts is 3,6 pC/N.

When used without the preloading nuts, the charge sensitivity will depend upon the method of fixing the force transducer to the test structure (using, for example a retaining screw). In this case, the set-up should be calibrated as a whole by applying a test force and measuring the force transducer output.

Impact Hammer

A plastic tip and a steel tip are supplied with the hammer kit. The specifications of the impact hammer are mainly determined by the force transducer and the choice of tip. An impact from the hammer imparts a force to the test structure with a continuous excitation spectrum over a broad frequency range. The bandwidth of the first lobe of the impact spectrum is inversely proportional to the pulse width. This width is dependent on the mass and structure of the hammer. In particular, the pulse width is dependent on the hardness of the tip and impact area. An example of the pulse shapes obtained when impacting a turbine blade with both the steel and plastic tips is shown in Fig. 3.

The impact hammer may be used, for example, to investigate resonances in structures as diverse as a turbine blade and cabinet of a disc drive. The force spectra of impacts on an aluminium plate using both hammer tips are shown in Fig. 4.

The construction of the hammer is lightweight and robust. The aluminium shaft reduces the incidence of double impact and the transducer seating, which is of rubber, is vulcanized to the shaft for strength. The seating of the plastic tip is made of titanium to reduce lateral deformation of the tip material during impact.

Calibration of the Impact Hammer

With this type of hammer, the impact force applied to the test structure is always greater than the measured force. This is because the mass of the tip is in front of the transducer and results in its effect being excluded from the measurement. The sensitivity of the impact hammer is therefore lower than that of the force transducer used alone. The ratio of these forces is given by:

$$F_a/F_m = M/(M - M_t)$$

where

F_a = actual force input to structure
F_m = measured force
M = effective mass of hammer plus tip
M_t = effective mass of tip

The effective mass differs from the actual mass due to the finite stiffness of the hammer and tip masses. A measurement of the actual masses would therefore yield an incorrect result. It is impossible to determine the effective masses directly. However, there are

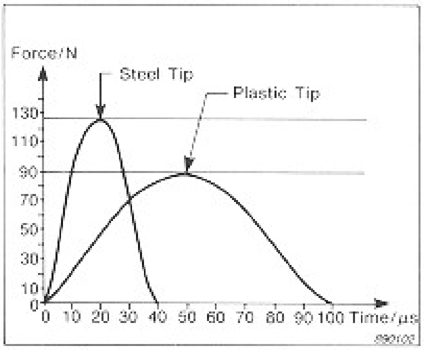


Fig. 3. Impulse shapes for the two hammer tips showing the plastic tip with the broadest pulse and lowest peak value

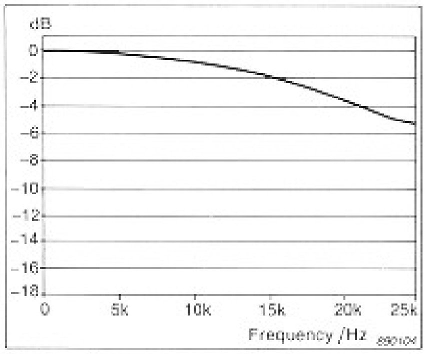


Fig. 4a. Force spectrum of an impact on an aluminium plate using the steel tip

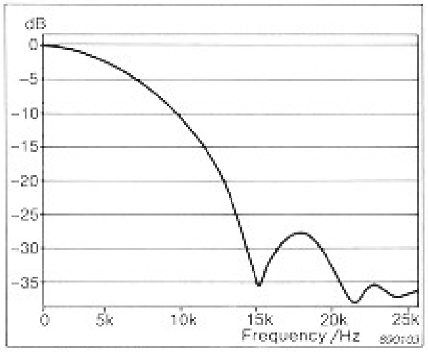


Fig. 4b. Force spectrum of an impact on an aluminium plate using the plastic tip

two methods of calibration which can be used. These are as follows:

1. Standard transducer
2. Block of known mass

The standard transducer method yields an absolute frequency response function for the channel being calibrated. The ratio method using a block of known mass involves the measurement of the frequency response function for the entire measurement chain and is preferred.

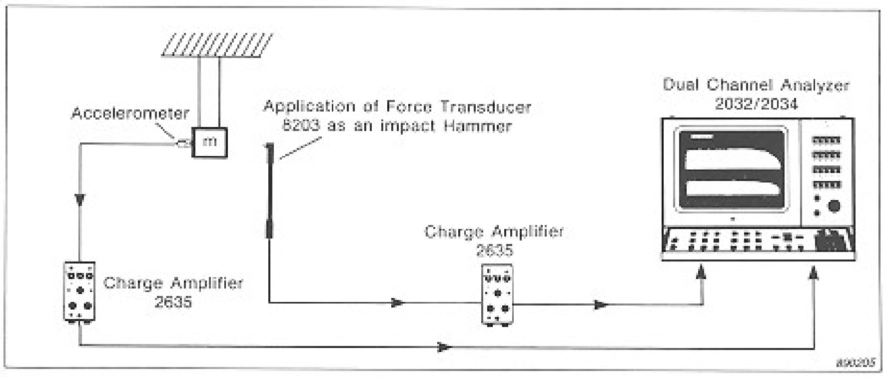


Fig. 5. Ratio calibration of the Impact Hammer consisting of a block of known mass and an accelerometer

Ratio calibration of the Impact Hammer using a block of known mass

A practical calibration set-up is shown in Fig. 5. A known mass is suspended to form a ballistic pendulum. An accelerometer is mounted on one side of the block. On the opposite side, an impact force from the hammer is applied and directed through the centre of the block. The impact force can be determined from Newtons second law:

$$F = ma$$

Where "m" is the known mass of the block and accelerometer and "a" is the instantaneous acceleration measured. Simultaneous measurement of the acceleration and force signals will yield the inertance (also called accelerance) frequency response function.

$$\text{Inertance} = \text{acceleration/force}$$

This function, multiplied by the known mass of the block, gives the ratio $M/(M - M_t)$ given above.

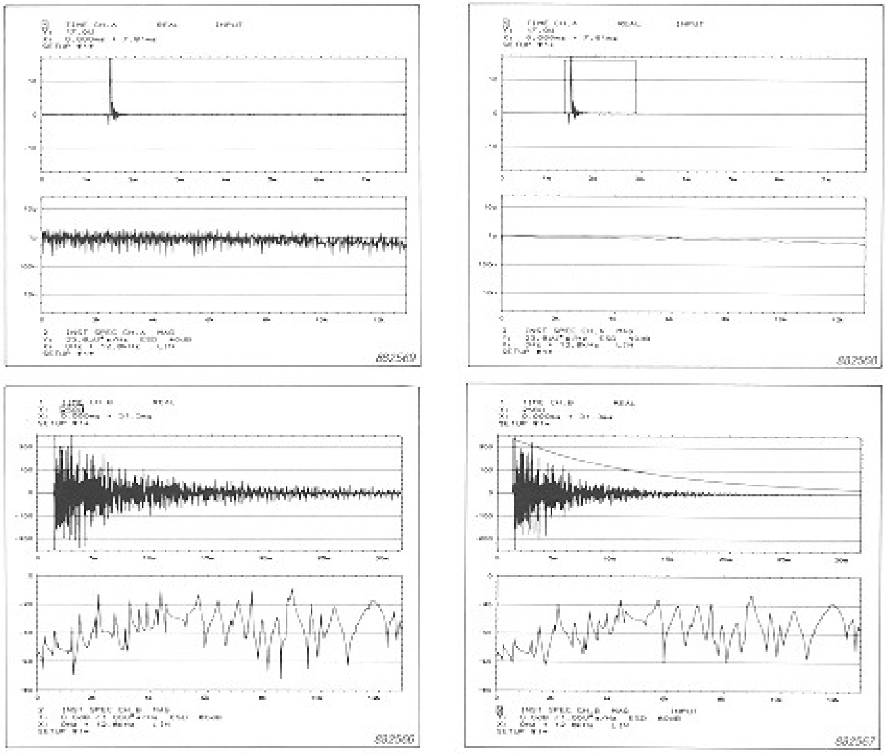


Fig. 6. Transient time weighting applied to the input signal obtained on impacting a turbine blade with the steel tip and exponential time weighting applied to the output signal from the accelerometer. Top left shows time and energy spectral density displays of the input signal without transient weighting and top right with transient weighting. Bottom left shows time and energy spectral density displays of the output signal without exponential weighting and bottom right with exponential weighting

Impact testing

A quick method of performing transient tests or determining frequency response functions is to use a hand held hammer to impact the structure. The force transducer attached to the hammer kit measures the input force and an accelerometer mounted on the structure measures the response. The advantages of impact testing are:

1. No elaborate fixture for the test structure required.
2. Small amount of equipment required.
3. It is the quickest method for low noise environments.
4. It can be used in confined spaces where an exciter would not fit.

The disadvantages are:

1. It has a very high crest factor which may drive the test structure beyond its region of linear response. The method is therefore not suitable for non-linear systems.
2. Since there is little energy input to the system, it has poor signal-to-noise characteristics. However this problem can be greatly reduced by averaging and/or using time weighting functions (Fig. 6).
3. Care must be taken to eliminate overloads and multiple impacts.

Use of Impact Hammer with Dual Channel Analyzers

The Brüel & Kjær Dual Channel Analyzers Type 2032 and 2034 have a number of features which make them ideally suitable for impact testing. These features include:

1. Autoranging of the input for impulse measurements to optimize the signal-to-noise ratio.

2. Automatic rejection of "overloaded" signals.
3. A wide range of time weighting functions, including transient weighting, to improve the signal-to-noise ratio of the force signal; and exponential weighting to reduce leakage effects and noise in the response signal (Fig. 6).
4. Advanced triggering facility.
5. A pre-programmed set-up for impact testing.
6. Line-drive to enable the force and the response transducers to be connected directly to the Analyzer via a line-drive amplifier such as the Brüel & Kjær Type 2644.

The Force Transducer/Hammer set is shown in Fig. 7. It contains a single force transducer in a mahogany case complete with hammer kit, stinger kit, cable and accessories to aid mounting.

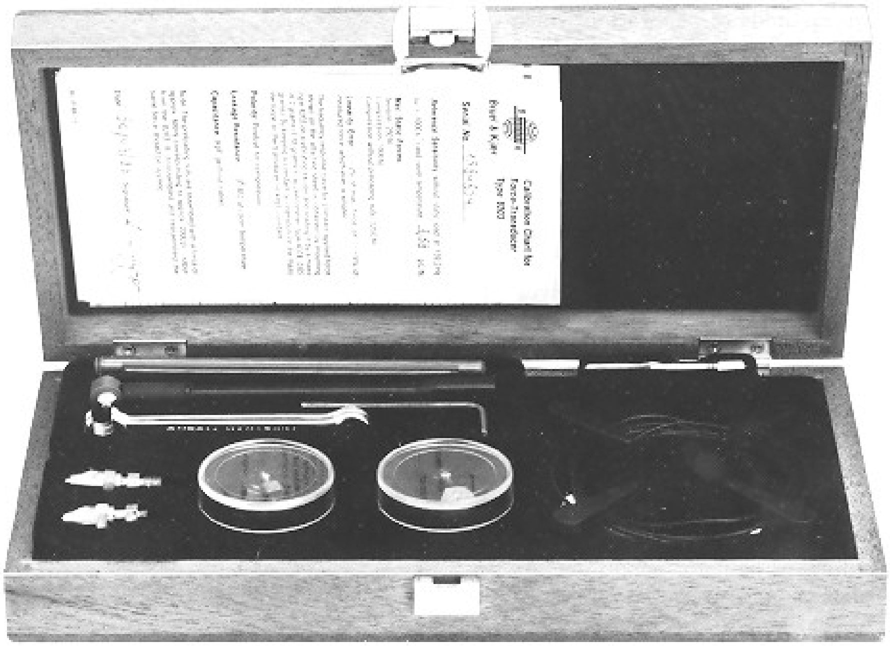


Fig. 7. Transducer/Hammer Set

Specifications 8203

FORCE TRANSDUCER TYPE 8203:
Force range:
250 N tensile to 1000 N compressive with preloading nuts
1250 N compressive without preloading nuts
Linearity error: <1% of maximum force
Charge sensitivity*: (typical) 3.6 pC/N with preloading nuts
Capacitance: (typical) 9 pF
Leakage resistance (at 25°C): $>10^5$ MΩ
Stiffness:
1×10^8 N/m with preloading nuts
2×10^8 N/m without preloading nuts
Deformation of the transducer at maximum force:
10 μm with preloading nuts
5 μm without preloading nuts
Resonance frequency with 5 grams load mounted on top: (typical)
21 kHz with preloading nuts
30 kHz without preloading nuts
Effective seismic mass:
Above piezoelectric element (top):
1,1 g With preloading nuts
0,4 g without preloading nuts
Below piezoelectric element (base):
2,1 g with preloading nuts
1,2 g without preloading nuts
Temperature range: −196°C to 150°C
Temperature transient sensitivity: (typical) 0,6 N/°C
Transverse sensitivity: (typical) 7%
Bending moment sensitivity: (typical) 100 pC/Nm
Max. Bending moment for stated bending moment sensitivity: 0,5 mN
Strain sensitivity (top and base): <0,002 N/μstrain with preloading nuts
Magnetic sensitivity at 50 Hz: (typical) 0,1 N/T
Material: Titanium and Steel (type AISI 303)
Weight:
3,2 g with preloading nuts
1,6 g without preloading nuts
Dimensions:
Diameter: 9,0 mm
Height:
15,8 mm with preloading nuts
7 mm without preloading nuts

HAMMER:
Handle material: Anodized Aluminium
Transducer seating: Rubber
Weight:
Plastic tip: 0,3 g
Steel tip: 0,3 g
Impact duration (on a heavy steel target):
Plastic tip: 100 μs
Steel tip: 30 μs
Dimensions:
Length: 106 mm

STINGER:
Chuck material: Monel
Max. tensile force: >250 N

ACCESSORIES INCLUDED:

Cable	AO 0339
Steel Tip	DB 3041
Plastic Tip	UC 0205
Tip Mounting Screw	YS 9202
Preloading Nut (M3 Thread, M2 Screw)	UC 5322
Preloading Nut (M3 and M2 Thread)	YM 0249
M3/10-32 UNS Adaptor	DB 1425
M3 Screw for DB 1425 (×2)	YQ 2004
Tap for M3 Thread	QA 0041
5 mm Spanner (×2)	QA 0186
Allen Key	QA 0042
For Stinger:	
Stainless Steel Rod (×10)	DA 9984
Chuck for Shaker	DB 3146
Chuck for Transducer	DB 3147
Chuck Tightening Collar (×2)	DB 3145
Instruction Manual	
Calibration Chart	

ACCESSORIES AVAILABLE:
Line-Drive Amplifier Type 2644
Line-Drive Supply Type 2813

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* Individual values are given on the calibration chart.

2. FORCE TRANSDUCER

2.1. DESCRIPTION

The Force Transducer Type 8203 is a compact and robust device which is designed to operate in a wide temperature range. It is preloaded and may be used to measure tensile forces of up to 250 N and compressive forces of up to 1000 N without any variation in its characteristics. Use of the stinger kit ensures that dynamic modification of the test structure is avoided. Another advantage of using the stinger kit is that the transmission of transverse and bending moment forces to the transducer are eliminated (thus avoiding errors in the electrical output due to misalignment of the set-up).

Fig. 2.1 shows an exploded view of the Force Transducer Type 8203 with the stinger kit. An explanation of the components illustrated is given overleaf.

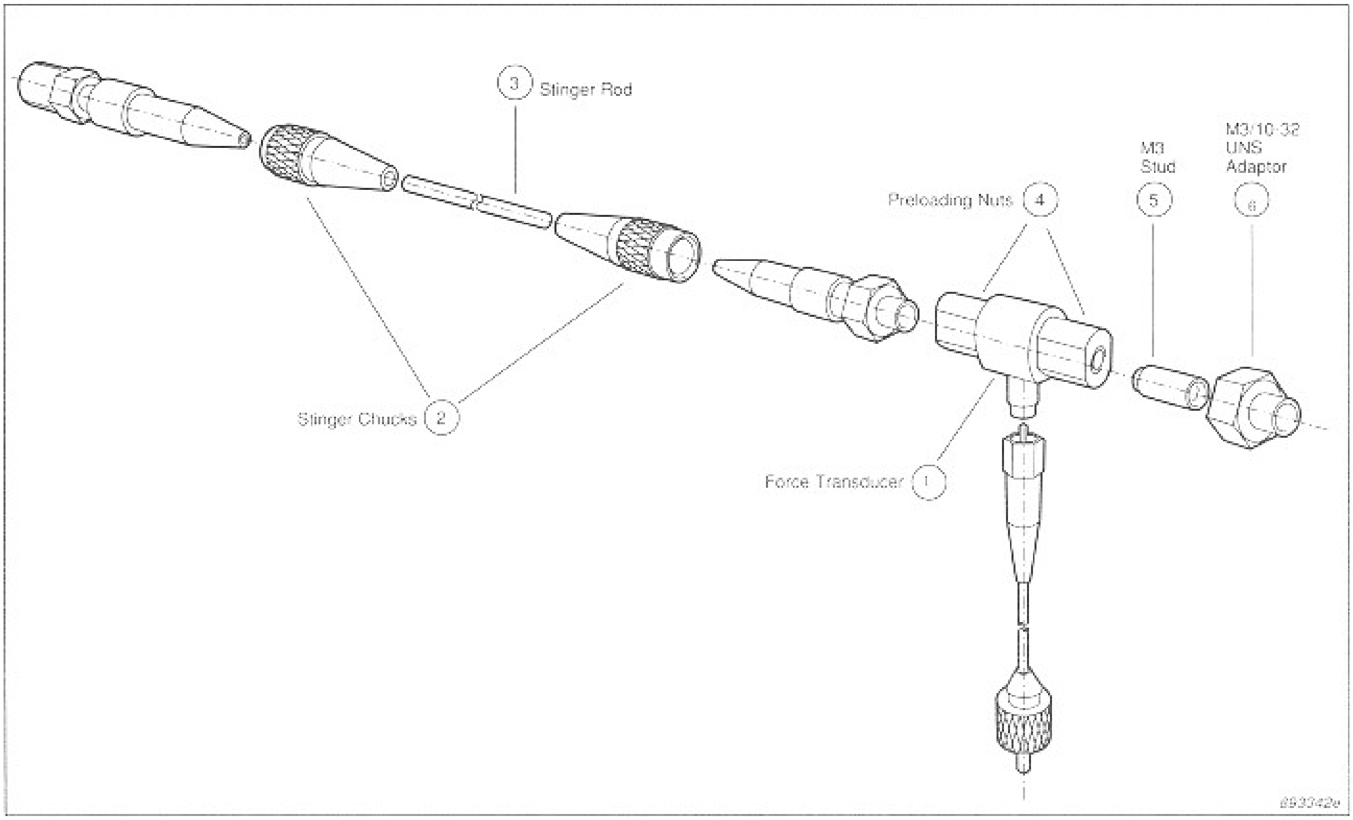


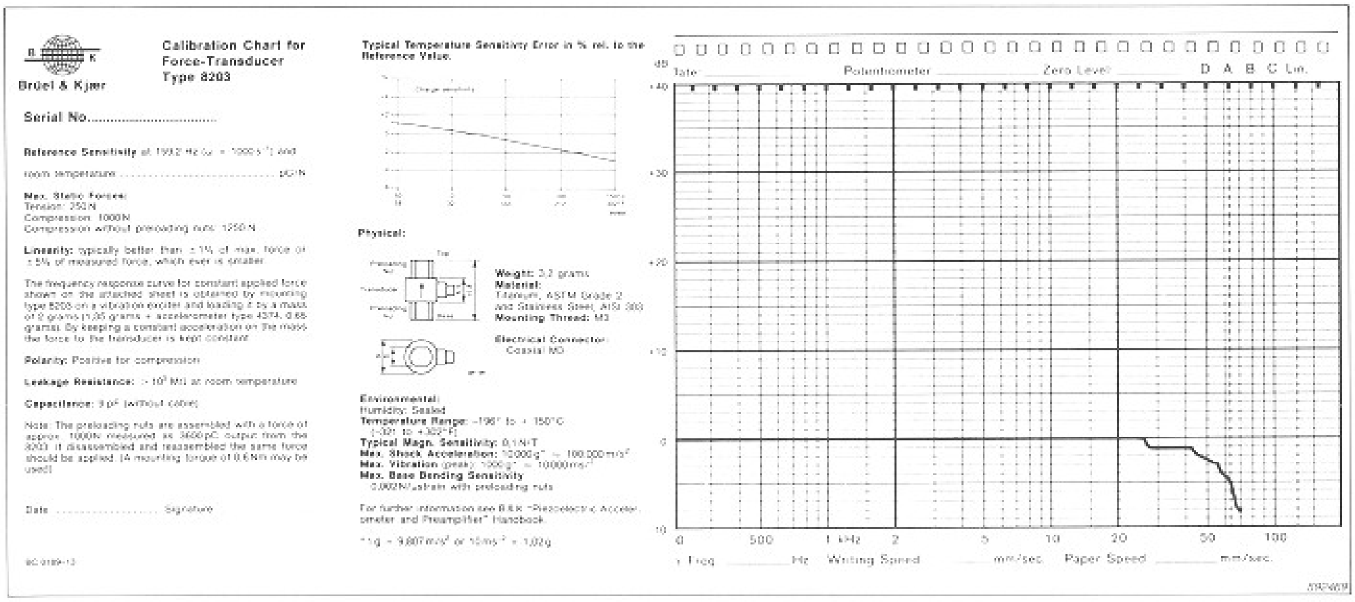
Fig. 2.1. Exploded view of the Force Transducer Type 8203 with the stinger kit

① FORCE TRANSDUCER:	The force transducer is small, rugged and has an all welded construction. Typical charge sensitivity when preloaded is 3,6 pC/N. The force transducer can be used for force measurements up to a maximum of 1000 N compressive and 250 N tensile.
② STINGER CHUCKS:	The stinger chucks are used to connect the stinger rod between an exciter and the test structure. Both chucks have a knurled collar for finger tightening, and 5 mm flats to allow tightening using spanners. Both chucks are made of a copper-nickel alloy.
③ STINGER ROD:	The stinger rod de-couples the test structure from the exciter in all degrees of freedom other than in the direction of the excitation force. Undesirable dynamic modification of the test structure is thereby avoided. Ten stainless steel stinger rods are supplied.
④ PRELOADING NUTS:	Both preloading nuts are provided with M3 threads for mounting onto the stinger kit and for fixing to the test structure. One of the preloading nuts has an M2 thread and the other an M2 screw. Both preloading nuts are manufactured from stainless steel and have 5 mm flats to allow tightening using spanners.
⑤ M3 STUD:	The stud can be used either to fix the force transducer to the test structure or to the M3/10–32 UNS adaptor. The screw is provided with a hexagonal socket for tightening to the force transducer.
⑥ M3/10–32 UNS ADAPTOR:	This adaptor is used for attaching the force transducer to a structure with a 10–32 UNS mounting point.

A full list of the accessories supplied is given in Chapter 1 – Product Data.

2.2. CALIBRATION

Each force transducer is preloaded to precisely 1000 N and individually calibrated before leaving the factory. A calibration chart like that shown in Fig. 2.2 is supplied with each



Calibration Chart for Force-Transducer Type 8203

Brüel & Kjær

Serial No...................................

Reference Sensitivity at 159,2 Hz ($\omega = 1000\,s^{-1}$) and room temperature .... pC/N

Max. Static Forces:
Tension: 250 N
Compression: 1000 N
Compression without preloading nuts: 1250 N

Linearity: typically better than ±1% of max. force or ±5% of measured force, which ever is smaller.

The frequency response curve for constant applied force shown on the attached sheet is obtained by mounting type 8203 on a vibration exciter and loading it by a mass of 2 grams (1,35 grams + accelerometer type 4374, 0,65 grams). By keeping a constant acceleration on the mass the force to the transducer is kept constant.

Polarity: Positive for compression

Leakage Resistance: > 10[illegible] MΩ at room temperature

Capacitance: 9 pF (without cable)

Note: The preloading nuts are assembled with a force of approx. 1000N measured as 3600pC output from the 8203. If disassembled and reassembled the same force should be applied. (A mounting torque of 0,6Nm may be used)

Date .... Signature

BC 0189-13

Typical Temperature Sensitivity Error in % rel. to the Reference Value.

Physical:

Weight: 3,2 grams
Material:
Titanium, ASTM Grade 2
and Stainless Steel, AISI 303
Mounting Thread: M3

Electrical Connector:
Coaxial M3

Environmental:
Humidity: Sealed
Temperature Range: −196° to +150°C
(−321 to +302°F)
Typical Magn. Sensitivity: 0,1 N/T
Max. Shock Acceleration: 10000 g* = 100000 m/s²
Max. Vibration (peak): 1000 g* = 10000 m/s²
Max. Base Bending Sensitivity
0,002 N/μstrain with preloading nuts

For further information see B & K "Piezoelectric Accelerometer and Preamplifier" Handbook.

*1 g = 9,807 m/s² or 10 m/s² = 1,02 g

Fig. 2.2. Calibration chart for the Force Transducer Type 8203

transducer. The force transducer is stable and will therefore require only occasional recalibration. Should the user wish to recalibrate the force transducer, then the method of factory calibration described in Appendix 4.1 can be used.

2.3. MOUNTING THE FORCE TRANSDUCER

2.3.1. General Considerations

The force transducer must always be mounted with the arrow (on the side of the force transducer) pointing toward the test structure. This ensures that there is minimum transducer mass between the sensing element and the point of measurement, and thus minimizes the measurement error. A theoretical explanation is given in Appendix 4.2.

The force transducer is designed to measure dynamic forces along its longitudinal axis. The area on the structure to which the force transducer is to be fixed must be clean, smooth and carefully lined up. Bending moments and transverse forces can be tolerated to some extent, but they will introduce errors and should thus be avoided if possible (see Appendix 4.3).

2.3.2. Mounting Configuration

Caution: The force transducer must be tightened to the test structure using a spanner applied to the preloading nut **closest** to the test structure. Tightening using the other preloading nut will cause an increase in the preloading force which may, in turn, result in permanent damage to the piezoelectric discs within the transducer.

Possible mounting configurations are almost limitless. The user may therefore devise a specific mounting configuration to suit a particular application. The mounting configuration will largely depend on the structure to be tested and on the method of testing. However, the method of mounting shown in Fig. 2.3 will cover most applications.

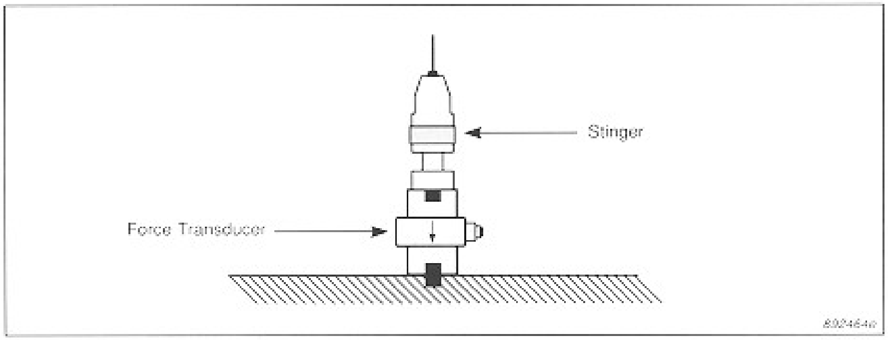


Fig. 2.3. Force transducer mounting configuration using the stinger kit

Refer to Fig. 2.3 for a diagram of this mounting configuration. Bore and tap an M3 threaded hole at the selected measuring point in the structure to be tested, ensuring that the surface to be drilled is perfectly flat and that the hole is drilled perpendicular to the surface. Screw the M3 threaded stud YQ 2004 into the preloaded force transducer. To improve the contact between the test structure and force transducer surfaces, spread a small amount of oil or grease on the test structure at the measuring point. Screw the complete transducer/stud assembly into the structure. The stinger kit can then be mounted as described in section 2.4. Alternatively, an M3 threaded nylon stinger rod can be made by the user and screwed directly into the force transducer as shown in Fig. 2.4.

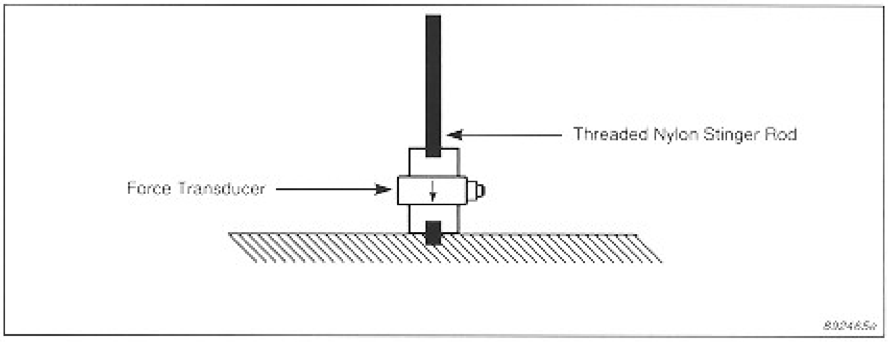


Fig. 2.4. Force transducer mounting configuration using a threaded nylon stinger rod

2.4. MOUNTING THE STINGER KIT

Caution: Be careful not to overtighten the stinger chuck when mounting it onto the force transducer. Overtightening will cause an increased preloading force which may, in turn, result in permanent damage to the piezoelectric discs within the force transducer.

The force transducer must be mounted so that the arrow on the side of the force transducer points toward the test structure. With reference to Fig. 2.1, mount the stinger kit as follows:

1. Mount the force transducer as described in section 2.3.
2. Mount the stinger chuck (M3 screw) onto the force transducer.
3. With reference to the caution given above, carefully tighten the stinger chuck to the force transducer using the spanners supplied.
4. Screw the other stinger chuck into the vibration exciter.
5. Tighten the stinger chuck onto the vibration exciter using the 5mm spanner.
6. Cut one of the stainless steel stinger rods to the desired length and push the rod ends into each of the chucks as far as they will go.
7. Finger tighten the knurled collar on each of the chucks.
8. Finally, carefully tighten the chucks using the spanner.

2.5. CABLE CONNECTION

The teflon insulated cable AO 0339 supplied can be used over the full temperature range of the transducer. In very humid environments, it is necessary to seal the cable entry to the force transducer. A sealant such as the Dow Corning Silastic RTV 738 (Brüel & Kjær number AW 8858) can be used.

When making low level force measurements, the signal-to-noise ratio will be reduced due to mechanically induced cable noise. To avoid this effect, it is useful to tape the cable to the test structure as indicated in Fig. 2.5.

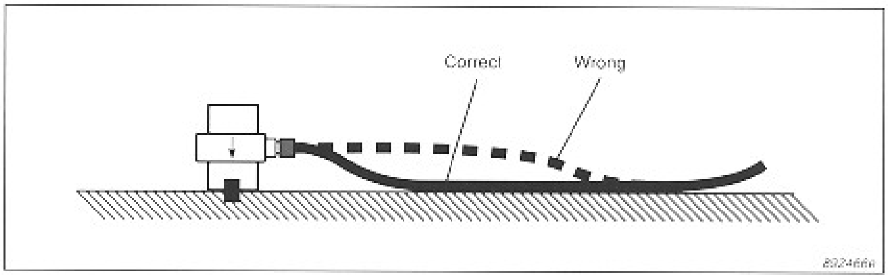


Fig. 2.5. Clamping the transducer cable

3. IMPACT HAMMER

3.1. DESCRIPTION

The hammer kit supplied allows the Force Transducer Type 8203 to be used for impact testing on lightweight and delicate structures. Fig. 3.1 shows an exploded view of the force transducer with the hammer kit. An explanation of the components illustrated is given below.

① FORCE TRANSDUCER:	The force transducer is small, rugged and has an all welded construction. In this illustration, the force transducer is shown without the preloading nuts.
② HAMMER TIPS:	Two hammer tips are supplied, one of steel and one of plastic. The seating of each tip is provided with flats which accept a 5 mm spanner.
③ HAMMER SHAFT:	The hammer shaft is made of anodized aluminium and a rubber collar which has been vulcanized to the shaft holds the force transducer in place. The cable from the force transducer is fed through the shaft to exit at the base.
④ TIP MOUNTING SCREW:	The tip mounting screw secures the hammer tips to the force transducer.

3.2. ASSEMBLY

The hammer kit consists of an aluminium handle, two hammer tips (one of steel and one of plastic) and a retaining screw. The hammer assembly is illustrated in Fig. 3.1.

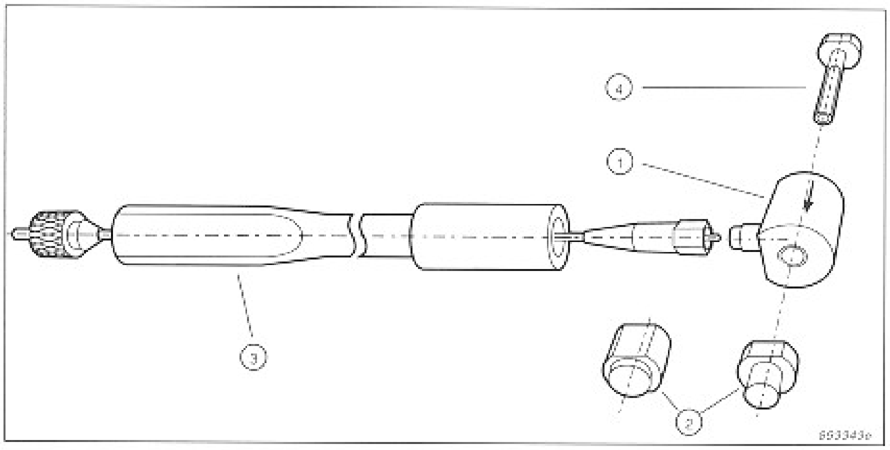


Fig. 3.1. Exploded view of the Force Transducer Type 8203 with the hammer kit

Note: Assembling the impact hammer involves removing the preloading nuts. The procedure for any future reassembly is to slowly preload the force transducer until a charge of 3600 pC is output from the force transducer. If this method of preloading is inconvenient, then a torque wrench can be used. In this case, a mounting torque of 0,6 Nm will preload the force transducer to approximately 1000 N.

1. Remove the preloading nuts using the spanners.

2. Place the selected hammer tip on the face of the force transducer indicated by the arrow on the side of the force transducer.

3. Put the retaining screw through the centre hole of the force transducer and screw it into the back of the hammer tip.

4. Lightly tighten the selected hammer tip and retaining screw together using the spanners supplied. Do not overtighten as too much torque could damage the retaining screw thread.

5. Thread the transducer cable through the hammer handle and attach it to the force transducer.

6. Finally, push the force transducer into the rubber collar of the hammer handle.

3.3. RATIO CALIBRATION

3.3.1. Description

The charge sensitivity of the impact hammer will always be less than that of the force transducer. This is because the mass of the tip is in front of the force transducer and results in its effect being excluded from the measurement. The impact hammer must therefore be calibrated before use.

Calibration of an impact hammer involves the measurement of the inertance (sometimes called accelerance) function of a calibration block of known mass. A typical measuring arrangement is shown in Fig. 3.2. It is assumed that the calibration block has infinite stiffness across the frequency range of the impact signal. An impact is applied to the block by using the hammer. The resulting charge output from the hammer is used to obtain the apparent impact force. An accelerometer at the opposite side of the block measures the instantaneous acceleration. If this acceleration is multiplied by the known mass of the calibration block, then we obtain the actual impact force. The ratio of these measurements can then be used to determine the sensitivity of the impact hammer.

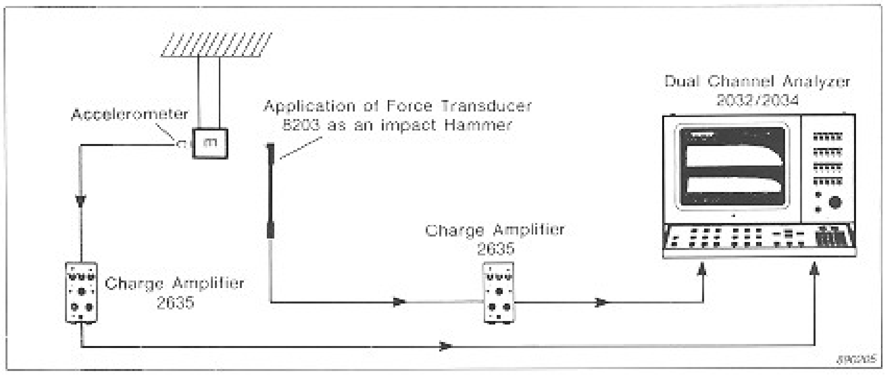
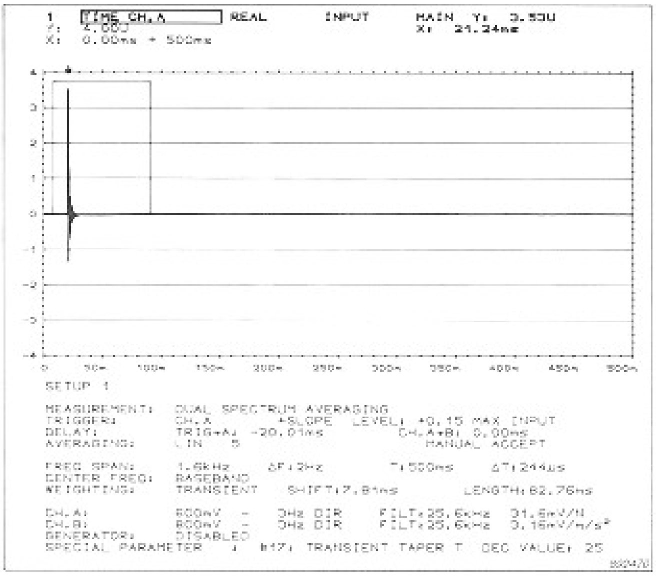


Fig. 3.2. Ratio calibration of the impact hammer consisting of a calibration block of known mass and an accelerometer

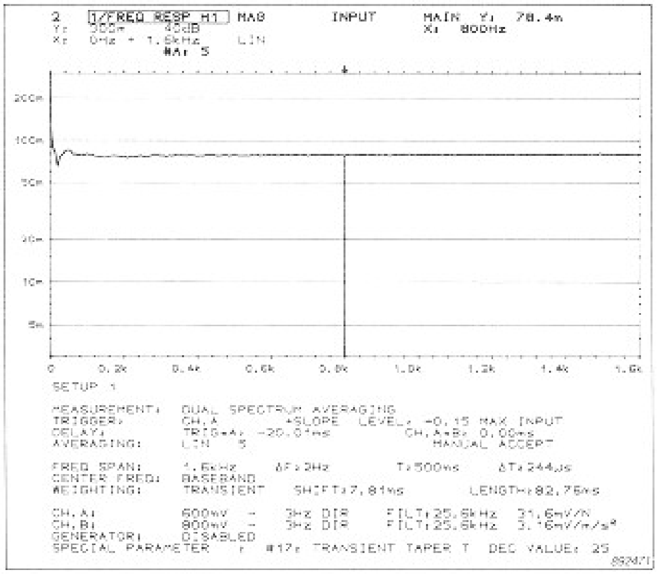
3.3.2. Procedure

To obtain the inertance function of the calibration block, it is necessary to process the accelerometer and force transducer signals using a dual channel signal analyzer. The Brüel & Kjær Dual Channel Signal Analyzer Type 2032 has a predetermined measurement set-up for impact testing which allows the input signals from both the accelerometer and force transducer to be weighted, improving the accuracy of the measurement. Transient weighting must be used for both the force transducer and accelerometer signals in order to remove any noise present after the input pulse and accelerometer response signals. This process ensures that the signal-to-noise ratio of the measurements is maximized. A Brüel & Kjær Dual Channel Signal Analyzer, two Brüel & Kjær Type 2635 charge amplifiers, a Brüel & Kjær Type 4375 accelerometer and a 122 g cylindrical calibration block were used to make the measurements shown in Fig. 3.3 and Fig. 3.4.



```
1    TIME CH.A      REAL           INPUT          MAIN   Y:   3.53U
Y:   4.00U                                        X:   21.24ms
X:   0.00ms + 500ms

SETUP 1

MEASUREMENT:    DUAL SPECTRUM AVERAGING
TRIGGER:        CH.A        +SLOPE  LEVEL: +0,15 MAX INPUT
DELAY:          TRIG+A: -20,01ms           CH.A+B: 0,00ms
AVERAGING:      LIN   5                      MANUAL ACCEPT

FREQ SPAN:      1.6kHz    ΔF:2Hz         T:500ms     ΔT:244µs
CENTER FREQ:    BASEBAND
WEIGHTING:      TRANSIENT    SHIFT:7,81ms          LENGTH:82,76ms

CH.A:           600mV  -   3Hz DIR    FILT:25,6kHz  31,6mV/N
CH.B:           800mV  -   3Hz DIR    FILT:25,6kHz  3,16mV/m/s²
GENERATOR:      DISABLED
SPECIAL PARAMETER   :  #17: TRANSIENT TAPER T  DEC VALUE: 25
```

Fig. 3.3. Analyzer display of the impact pulse obtained by impacting the calibration block



```
2    1/FREQ RESP H1  MAG           INPUT          MAIN   Y:   78.4m
Y:   300m     40dB                                X:   800Hz
X:   0Hz + 1.6kHz     LIN
             #A: 5

SETUP 1

MEASUREMENT:    DUAL SPECTRUM AVERAGING
TRIGGER:        CH.A        +SLOPE  LEVEL: +0,15 MAX INPUT
DELAY:          TRIG+A: -20,01ms           CH.A+B: 0,00ms
AVERAGING:      LIN   5                      MANUAL ACCEPT

FREQ SPAN:      1.6kHz    ΔF:2Hz         T:500ms     ΔT:244µs
CENTER FREQ:    BASEBAND
WEIGHTING:      TRANSIENT    SHIFT:7,81ms          LENGTH:82,76ms

CH.A:           600mV  -   3Hz DIR    FILT:25,6kHz  31,6mV/N
CH.B:           800mV  -   3Hz DIR    FILT:25,6kHz  3,16mV/m/s²
GENERATOR:      DISABLED
SPECIAL PARAMETER   :  #17: TRANSIENT TAPER T  DEC VALUE: 25
```

Fig. 3.4. Analyzer display of the 1/magnitude frequency response function of the calibration block

The calibration procedure is as follows:

1. Set up the equipment in the configuration illustrated in Fig. 3.2. Connect the impact hammer via it's charge amplifier to the **"Ch. A"** input of the analyzer, and the accelerometer via it's charge amplifier to the **"Ch. B"** input of the analyzer.

2. Suspend the calibration block from two cords of equal length. Attach the accelerometer to the centre of one end of the calibration block (a threaded stud or wax may be used for this purpose).

3. Assuming the use of a Type 4375 accelerometer, set the controls of the Charge Amplifier Type 2635 for the accelerometer as follows:

   Transducer Sens. (range): **"0,1—1"**
   Transducer Sens. (pC/ms^{-2}): **",316"**
   mV/Unit Out: **"3,16"**
   Upper Freq. Limit (kHz): **"30"**
   Unit Out: **"ms^{-2}"**

4. Set the controls of the Charge Amplifier Type 2635 for the hammer as follows:

   Transducer Sens. (range): **"1—11"**
   Transducer Sens. (pC/ms^{-2}): **"3,60"**
   mV/Unit Out: **"31,6"**
   Upper Freq. Limit (kHz): **"30"**
   Unit Out: **"ms^{-2}"**

5. Select measurement "SETUP 19" on the dual channel signal analyzer. This is a preprogrammed measurement set-up specifically for frequency response measurements using impact excitation.

6. With reference to Fig. 3.3, change the averaging fields of the analyzer so that they read:

   AVERAGING: LIN 5

7. With reference to Fig. 3.3, change the channel A and channel B fields of the analyzer so that they read:

   CH. A: - 3Hz DIR FILT:25.6kHz 31.6mV/N
   CH. B: - 3Hz DIR FILT:25.6kHz 3.16mV/m/s^2

8. Change the weighting function of channel B (the accelerometer channel) from EXPONENTIAL to TRANSIENT weighting. The optimum settings for transient weighting window shift and window length depend on the width of the impact pulse. However, a shift of approximately 8 ms and a length of approximately 80 ms in both channel A and channel B will give satisfactory results.

9. The accuracy of the results can be increased by tapering the first and last 25 samples of the transient weighting function. To do this, make the following changes to measurement set-up 19:

Move the cursor to the bottom left-hand field of the analyzer screen and select SPECIAL PARAMETER.

Select special parameter number 0 so that this field reads # 0: MAIN KEY. Now select DEC VALUE and set 2032 so that together these fields read DEC VALUE: 2032.

Select special parameter number 16 so that this field reads # 16: TRANSIENT TAPER L. Now select DEC VALUE and set 25 so that together these fields read DEC VALUE: 25.

Select special parameter number 17 so that this field reads # 17: TRANSIENT TAPER T. Now select DEC VALUE and set 25 so that together these fields read DEC VALUE: 25.

10. Press the **"Input Autorange"** key on the analyzer and impact the calibration block several times in succession to set the input attenuators of both channel A and channel B. Stop when the word triggered appears at the bottom left hand corner of the analyzer screen. The LED on the **"Record Continuous"** key will be on. The input attenuators are now set.
11. With reference to Fig. 3.3, select TIME CH. A and REAL in the display set-up field of the analyzer.
12. Press the **"Averaging Start"** key. The LED on this key will light.
13. Being careful to avoid double hits, impact the calibration block with the same force as when setting the input attenuators. Impact the block another four times. The **"Averaging Start"** key LED will then go off.
14. Select 1/FREQ RESP H 1 and MAG in the display set-up fields of the analyzer.

A flat curve similar to that shown in Fig. 3.4 should be seen. In theory, a perfectly flat curve across the frequency range should be obtained (that is, the magnitude would be constant with frequency). However, as shown in Fig. 3.4, there is a slight variation in the 1/frequency response function at low frequencies. This effect is caused by an unavoidable resonance in the hammer shaft. However, this resonance has been minimized by careful design and will have a negligible effect on the accuracy of impact test measurements.

Move the cursor to the flat area of the curve and read the y-axis value.

Finally, use the following equation to calculate the sensitivity of the impact hammer:

$$S_h = S_f \,.\, Y \,/\, M_{(b+a)}$$

where S_h = Sensitivity of the impact hammer (pC/N)

S_f = Sensitivity of the force transducer (pC/N)

Y = y-axis value (1/magnitude of the frequency response function) (grams)

$M_{(b+a)}$ = Mass of the block and accelerometer (122 g + 2,4 g in this set-up)

The sensitivity, S_f, of this particular force transducer is 3,61 pC/N. The y-axis value is 78,4 grams (as can be seen from Fig. 3.3) and $M_{(b+a)}$ is 124,4 grams. Substituting these values into the above equation gives S_h equal to 2,28 pC/N for this particular impact hammer.

4. APPENDICES

4.1. FACTORY CALIBRATION METHOD

The sensitivity of a force transducer is defined as the ratio of the electrical output to the force input. This is usually quoted in pico Coulombs/Newton (pC/N).

The Force Transducer Type 8203 is primarily designed for dynamic force measurements. The reference sensitivity is measured by applying a dynamic force at a frequency of 159,2 Hz (1.000 Rads^{-1}).

Part of the set-up for obtaining the reference sensitivity is shown in Fig. 4.1. The force transducer is subjected to a fixed acceleration, "a" of 100 ms^{-2} controlled by a reference accelerometer (Type 8305). The resulting output of the force transducer is measured both with and without a load mass of 100 grams mounted on top.

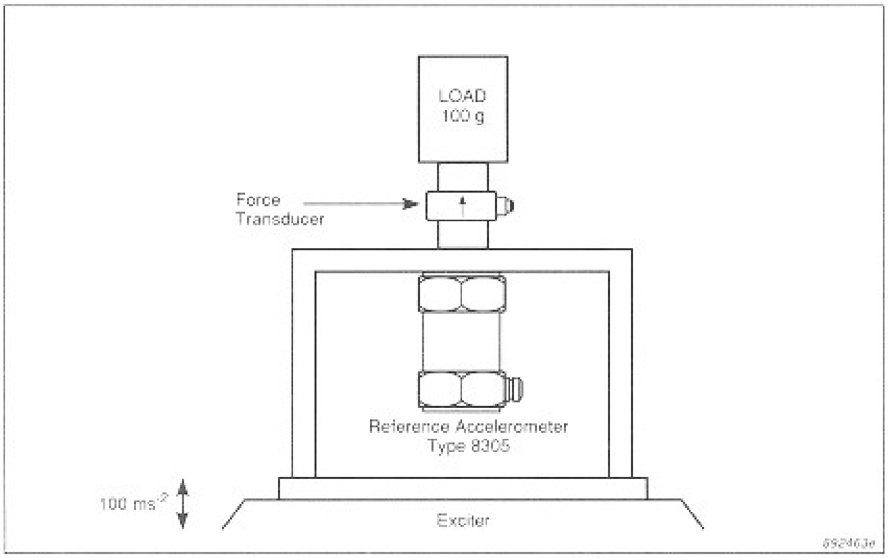


Fig. 4.1. Part of the set-up for determination of the reference sensitivity

Let F_1 and F_2 be the dynamic forces applied to the force transducer with and without the 100 gram load mass, respectively. If the resulting charge outputs in each case are q_1 and q_2, then:

$$F_1 = (M + m_t)a = \frac{q_1}{S}$$

$$F_2 = m_t a = \frac{q_2}{S}$$

where M = Load mass

m_t= Top mass of the force transducer

S = Sensitivity of force transducer

Therefore, the reference sensitivity is:

$$S = \frac{q_1 - q_2}{M \cdot a}$$

In the set-up, "M" and "a" are chosen so that $F_1 - F_2$ equals 10 Newtons (that is $M.a = 10$). The reference sensitivity (pC/N) is thus given by $(q_1 - q_2)/10$.

4.2. FORCE TRANSDUCER FREQUENCY RESPONSE

The response of a force transducer to a particular force is frequency dependent. This is due to the inertial masses of the force transducer and the finite stiffnesses of the piezoelectric discs. Fig. 4.2 shows a simplified model of a force transducer. The model consists of a spring with a mass at each end (stiffness and inertial masses). The damping present in the force transducer is insignificant and may therefore be neglected.

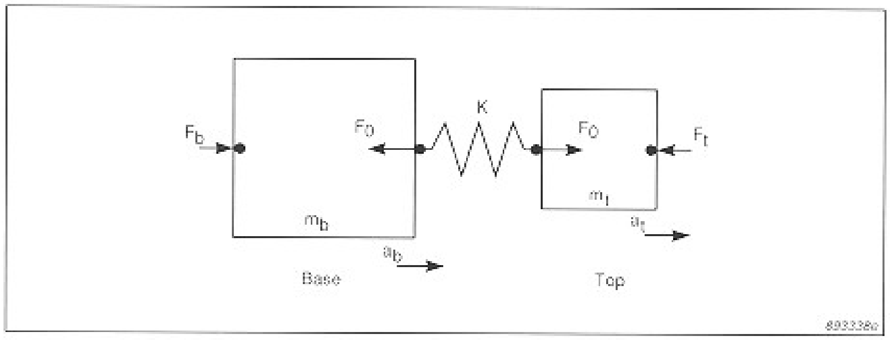


Fig. 4.2. Simplified mechanical model of the force transducer

Let the force acting on the quartz discs be F_o and let the preload forces be F_b and F_t acting on the base and the top respectively. According to Newton's second law of motion:

$$F_o = F_b - m_b\, a_b = F_t + m_t\, a_t$$

where a_b and a_t are the accelerations of the base mass (m_b) and the top mass (m_t) respectively.

To minimize the error due to the transducer's inertial masses, the transducer must be mounted such that the smallest inertial mass is in contact with the surface on which the force is to be measured (that is, the side of the transducer indicated by the arrow on it's edge). This condition has been assumed for the following explanation of the error caused by the inertial masses.

The Force Transducer Type 8203 is primarily designed to have the exciting force transmitted through it to the structure. Therefore, only this case will be considered in the following analysis.

With reference to Fig. 4.3, the transducer frequency response is defined as:

$$R(\omega) = \frac{F_o}{F_t} \qquad (4.1)$$

where $R(\omega)$ denotes the response at a frequency ω

Using the impedance diagram in Fig. 4.3 we obtain:

$$R(\omega) = \frac{F_o}{F_t} = 1 + \frac{j\omega m_t}{Z} \qquad (4.2)$$

where $\omega = 2\pi f$ and "Z" is the impedance of the test structure

The response is therefore dependent on the top inertial mass and the impedance of the structure (including mounting stiffness), but independent of the transducer stiffness.

This kind of response is measured using the measurement set-up shown in Fig. 4.3 and is demonstrated by the curve on the calibration chart (Fig. 2.2).

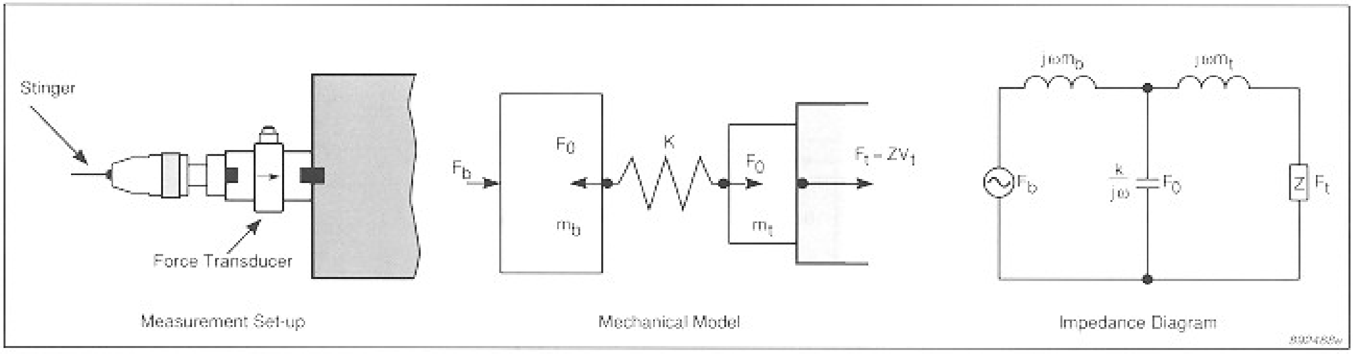


Fig. 4.3. Set-up for measurement of the force transmitted through the force transducer (left), the equivalent mechanical model (centre) and impedance diagram (right)

The set-up shown in Fig. 4.3 consists of a structure of mass m_L with a built-in accelerometer having a very high resonance frequency and a Type 4290 Vibration Exciter for transducer calibration. Keeping the acceleration of m_L constant while sweeping the frequency, F_t in equation 4.1 is also constant and $R(\omega)$ can be taken as $F_o(\omega)$. As long as $Z = j\omega m_L$, the curve should be flat (corresponding to equation 4.2). However, at high frequencies, Z becomes spring-like (mounting stiffness) and the curve shows an anti-resonance as derived from equation 4.3.

$$R(\omega) = 1 - \frac{\omega^2}{k_m / m_t} \qquad (4.3)$$

where k_m is the mounting stiffness.

In general, the frequency response is dependent not only on the force transducer but also on how it is mounted and on the mechanical impedance of the structure and its foundation.

4.3. SOURCES OF ERROR

There are three main sources of error in measurements made with a force transducer. These are bending moments, transverse forces and temperature.

The maximum measured bending moment and transverse force sensitivities for the force transducer are given in the specifications in Chapter 1. These sensitivities will vary with the direction of the action and will, in general, be lower than the specified values. It is therefore not possible to calculate exact errors in the force transducer output by analytical means. However, the following analysis will clarify how these influences act on the force transducer. This analysis may also be used to calculate the order of magnitude of these errors and therefore the possible influence on the measured results.

Fig. 4.4 (left) illustrates an unwanted force "*A*" acting at a distance "*x*" from the centre of the sensing element. This will result in a bending moment, $A.x$, which produces an erroneous charge at the output of the force transducer given by:

$$Q_a = S_{BM}\,A\,x$$

where S_{BM} = Bending Moment Sensitivity

In Fig. 4.4 (right), an unwanted transverse force "*B*" is acting at a distance "*y*" from the centre of the sensing element. In this case, there are two sources of error. One due to the transverse sensitivity of the force transducer and the other due to a bending moment $B.y$. The total error charge is then given by:

$$Q_b = S_T\,B + S_{BM}\,B\,y$$

where S_T = Transverse Sensitivity (this is given in the specifications as a percentage of the axial sensitivity)

The sensitivity of the force transducer will vary slightly with temperature. The typical variation in sensitivity with temperature from – 55°C to 150°C is given in the calibration chart. The force transducer must not be subjected to temperatures above 150°C as permanent changes in the sensitivity will result.

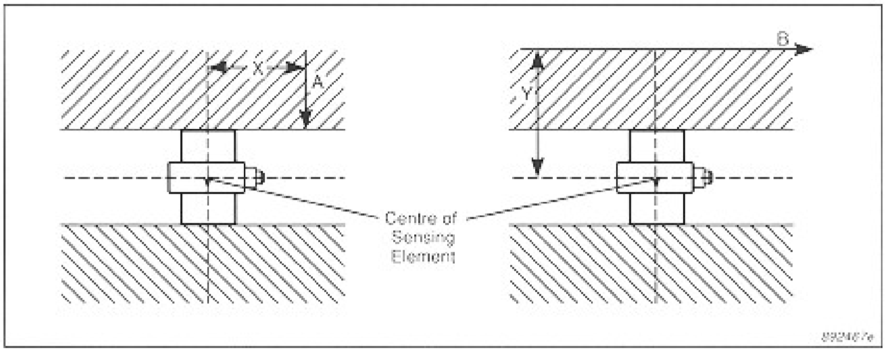


Fig. 4.4. The force transducer subjected to a bending moment (left) and to a transverse force (right)