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Accelerometers

Instructions and Applications

Accelerometer Types:

4332	4340	8303
4333	4343	8304
4334	4344	8305 (3506 set)
4335	4345	8306
4338	8301	8307
4339	8302	8309



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ACCELEROMETER

TYPES: 4332, 4333, 4334, 4335, 4338, 4339, 4340, 4343, 4344, 4345, 8301, 8302, 8303, 8304, 8306, 8307, and 8309

Reprint January 1974

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1. INTRODUCTION

The purpose of the manual is to provide all necessary information required to understand and successfully use B & K piezoelectric accelerometers in shock and vibration measurements.

Chapter 2 contains basic step by step instruction to enable the Vibration Engineer to select, mount and obtain accurate results when making straightforward vibration measurements.

Chapters 3 to 10 present all the background material needed to fully understand piezoelectric accelerometers and successfully use them in all types of shock and vibration measurements.

Finally, Chapter 11 contains individual specifications for the range of accelerometers available from B & K.

2. BASIC SELECTION AND APPLICATION INFORMATION

This chapter outlines the basic steps to be taken when making straightforward vibration measurements using an accelerometer.

2.1. THE PIEZOELECTRIC ACCELEROMETER

A piezoelectric accelerometer is an electromechanical transducer that generates an electrical output when subjected to vibration. The electrical output will be directly proportional to the acceleration of the accelerometer base, over a limited frequency range and dynamic range as shown in Fig.s 2.1 and 2.2.

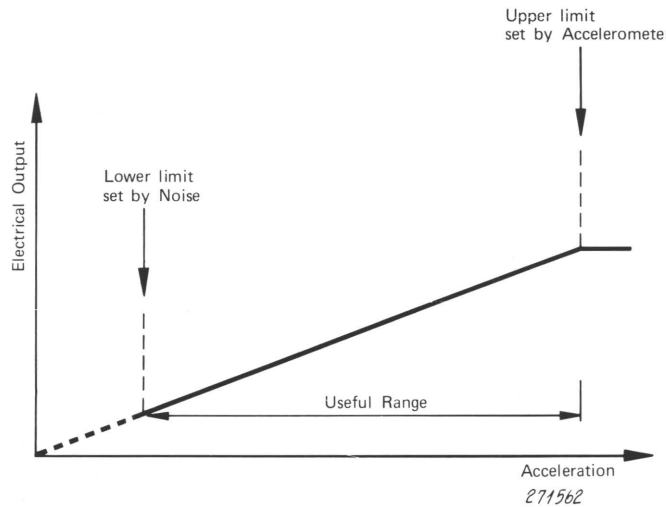


Fig.2.1. Electrical output versus acceleration in g for a piezoelectric accelerometer

The ratio of the accelerometer's electrical output to the mechanical input is defined as the sensitivity of the accelerometer. It may be expressed in

terms of voltage per unit of acceleration (mV/g) or charge per unit of acceleration (pC/g). It is important to note that:

$$mV/g = mV_{RMS}/g_{RMS} = mV_{peak}/g_{peak}$$

$$pC/g = pC_{RMS}/g_{RMS} = pC_{peak}/g_{peak}$$

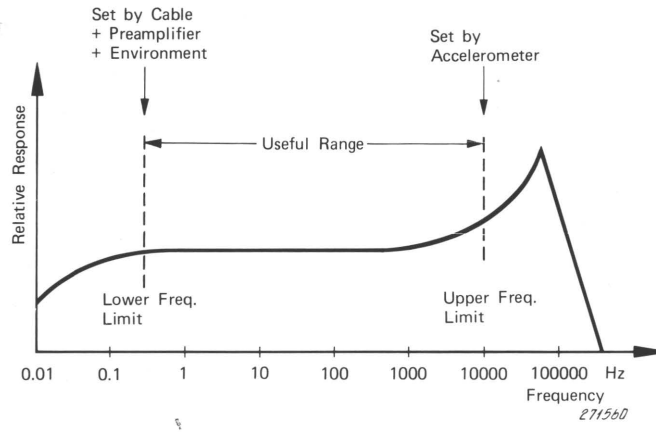


Fig.2.2. Frequency response of an accelerometer when subjected to constant acceleration

2.2. SELECTING AN ACCELEROMETER

Ideally we would like to have an accelerometer having high sensitivity, maximum frequency range, and minimum weight. Unfortunately the requirement for high sensitivity is in direct conflict with the requirement for low weight and max. frequency range, so that some compromise must always be found. Furthermore some accelerometers have been designed to overcome extreme environmental conditions and for special applications, and therefore some design compromise is inevitable.

To simplify selection of an accelerometer for a vibration measurement refer to Table 2.1 and check the following points:

(1) The weight of the accelerometer should be at least 10 times less than the weight of the specimen on which it is mounted.

(2) Estimate what frequency range will be required and check that this lies within the frequency range of the accelerometer.

Accelerometer Type no.	Weight grams	Voltage sensitivity *Unigain® mV/g	Charge sensitivity *Unigain® pC/g	Useful frequency range. 10% limit. Hz	Max. Temperature °C/°F	Max. Base strain sensitivity g/μstrain	Maximum shock g	Temp. transient sensitivity LLF 3 Hz g/°C	Water cooling	Main Applications (Suitable preamplifier indicated by V.A. for voltage and C.A. for charge amplifier)
4339	16	10.0*	10	1–12.000	260/500	0.1	10.000	2	no	V.A. General purposes
4343	16	10	10.0*	1–12.000	260/500	0.1	10.000	2	no	C.A. Vibration Measurements
8301	21	10.0*	10	1–8.000	260/500	0.0005	10.000	1	yes	V.A. Vibration Testing and Control
8302	21	10	10.0*	1–8.000	260/500	0.0005	10.000	1	yes	C.A. Large installations with multichannel unified systems
4338	60	100	100.0*	1–3.600	260/500	0.00005	1.000	0.2	yes	Measurements of Low Level, Low Frequency Vibrations C.A.
4344	2	3	3	1–21.000	260/500	0.05	14.000	10	no	High Frequency (and high level) Vibration Measurements. Shock Measurements. Measurements on Light Weight Structures.
8303	3.5	3	3	1–14.000	260/500	0.002	10.000	10	no	
4345	27	5	5	1–9.000	400/752	0.04	3.000	4	no	Flat temperature response High Temperature Environments C.A.
4340	35	20	20	1–7.000	260/500	0.2	500	2	yes	For Vibration Measurements in Three Mutually Perpendicular Directions
4332	30	60	60	1–8.000	260/500	0.06	3.000	0.6	no	Non-critical purposes General Vibration Measurements
4333	13	20	20	1–10.000	260/500	0.2	7.000	3	no	
4334	30	60	60	1–8.000	260/500	0.06	3.000	0.6	yes	
4335	13	20	20	1–10.000	260/500	0.2	7.000	3	yes	
8304	30	–	1.2	(0)–9.000	260/500	0.002	10.000	0.1	no	Very low freq. long shock durations Low pyroelectric effect C.A.
8305	40	–	1.2	(0)–9.000	260/500	0.0001	1.000	0.1	no	Back-to-back Calibration of Accelerometers C.A.
8306	600	10.000*	10.000*	0.3–1.000	85/185	0.0001	1	0.00004	no	Ultra-low level, low freq. measurements, e.g. building vibrations
8307	0.4	1.2	0.4	1 - 25.000	200/400	0.005	10.000	3	no	Measurement on ultra light Structures
8309	3	0.3	0.04	1 - 60.000	120/248	0.5	100.000	64	no	High Level and short duration shock

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Table 2.1.

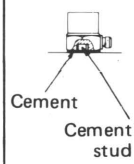
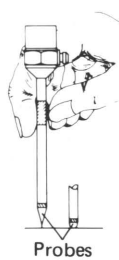
(3) Check that the maximum operating temperature of the accelerometer is sufficient for the measuring set-up. Some accelerometers have provision for water cooling and may be used on specimens with temperatures of up to approximately 1000°C, otherwise air cooling may be employed in all cases (Ref. Section 6.7).

(4) Consider any unfavourable environmental conditions and check from the specifications whether the accelerometer will be able to operate under such conditions.

TYPE	SPECIAL FEATURES
 2616 (V.A.)	1) Internal battery power supply or external 6-35 V supply 2) Adjustable gain
2623 (V.A.)	1) Small light weight 2) Can be mounted directly on the accelerometer or in the close proximity 3) Simple calibration with Uni-Gain® accelerometer 4) Fixed gain 0 dB ± 0.05 dB
 2624 (C.A.)	1) Fixed amplification with two lower limiting frequencies per setting 10 mV/pC LLF 30 Hz or 0.3 Hz 1 mV/pC LLF 3 Hz or 0.03 Hz 0.1 mV/pC LLF 0.3 Hz or 0.003 Hz 2) Simple calibration with Uni-Gain® accelerometer
 2625 (V.A.)	1) Three selectable inputs, one output 2) Adjustable gain as well as fixed gain setting 3) Simple calibration with Uni-Gain® accelerometer 4) Velocity and Displacement integrating network 5) Internal battery power supply or external 28 V input
 2626 (C.A.) 2628 (C.A.)	1) A 3 digit sensitivity adjustment network which enables the amplifier sensitivity to be adjusted to the particular accelerometer, making calibration with all types of accelerometers very simple 2) Selectable, high gain up to 60 dB 3) Stepwise adjustable high pass and low pass filters 4) Selectable transformer output (2626 only) 5) Extremely low LLF down to 10^{-5} Hz (2628 only)
 4292 (V.A.)	1) A small built-in shaker table adjustable to 1 g peak allowing easy calibration of complete set-up 2) Variable gain 0–20 dB 3) Velocity and Displacement integrating networks

271609

Table 2.2.

	APPLICATIONS	REMARKS
 Steel stud	General Purpose	Max. Torque: 10–32 NF studs 18 kgcm (15 lbin) M 3 studs 6 kgcm (5 lbin) Mounting surface must be clean and carefully machined. A small amount of oil or grease between the surfaces will improve the contact.
 Mica washer Isolated stud	To avoid ground loops and other unwanted signal paths	Max. Torque: 10–32 NF isolating stud 18 kgcm (15 lbin) (not available for M 3 thread)
 Thin layer of wax	When no mounting holes can be made	Recommended cements: Eastman 910 marketed by Armstrong Industry Cyanolit 201 + 202 manufactured by 3M I.S. 12 manufactured by Intercontinental Chemical Co. Ltd., Ireland Dental cement epoxy resins are also very useful
 Cement Cementing stud	When no mounting holes can be made while facilitating easy removal of the accelerometer	
 Magnet	NON CRITICAL	Can only be used up to about 200 g Max. Temperature 150° C Reduced frequency range
 Probes	SPECIAL APPLICATIONS	Should not be used for frequencies above 1000 Hz

271608

Table 2.3.

2.3. PREAMPLIFIERS

The signal from the accelerometer must first be fed through a preamplifier before it can be analysed. This is true in all cases except: (1) When using Accelerometer Type 8306 which has a built-in preamplifier and (2) When feeding the signal into measuring instruments having built-in preamplifiers such as the Vibration Meter Type 2510 and the Sound Level Meters Type 2203 and 2209.

Preamplifiers are designed according to two different amplifier principles. The B & K accelerometer preamplifiers are shown in Table 2.2.

1. the voltage amplifier (V.A. in Table 2.2)
2. the charge amplifier (C.A. in Table 2.2)

When using voltage amplifier the voltage sensitivity will decrease with increase in capacitive loading applied by long cables. When using charge amplifiers the cable length has practically no effect on the charge sensitivity, so that it is recommended to use charge amplifiers when long cables are necessary, or when switching inputs between cables of varying length.

2.4. ACCELEROMETER MOUNTING TECHNIQUES

Some of the possibilities for mounting accelerometers, which are provided with the B & K accelerometer sets are shown in Table 2.3. Special recommendations apply for Types 8307 and 8309 – see sections 11.11 and 11.12.

2.5. OPERATION

1. Mount the accelerometer to the specimen using one of the methods outlined in Table 2.3.
2. (a) Connect the accelerometer cable from the accelerometer output to the preamplifier input.

   (b) To avoid mechanically caused noise it may be necessary to clamp the cable to the structure as shown in Fig.2.3.

   (c) In very moist environments and in liquids it is necessary to seal the cable entry with a suitable sealant such as Dow Corning Silastic RTV 731 or equivalent as shown in Fig.2.4.

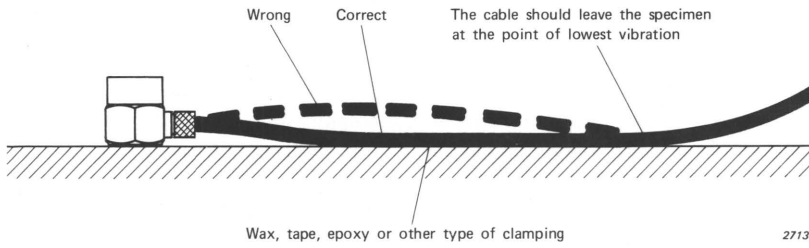


Fig.2.3. Clamping of cable to the vibrating specimen

(d) For high temperature measurements check maximum permissible temperature for the cable.

AO 0037, AO 0051, AO 0089 (AC 0010, AC 0032)	Max. Temp. 100°C (212°F)
AO 0038, AO 0052, AC 0005	Max. Temp. 260°C (500°F)
AO 0500	Max. Temp. 400°C (752°F)

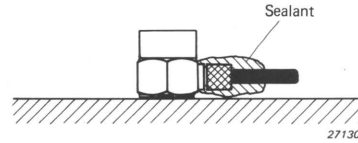


Fig.2.4. Sealing of the accelerometer cable entry

3. (a) When using a voltage preamplifier it is preferable to use the cable supplied with the accelerometer, between the accelerometer and preamplifier, as a different cable capacitance will affect the sensitivity of the accelerometer.

   (b) When using a charge preamplifier long cables can be used between the accelerometer and preamplifier without affecting the sensitivity significantly (1000 m cable will normally give less than 1% change) but it is advisable to use long cables only when absolutely necessary as they cause an increase in noise from the charge amplifier input stage.

   Charge amplifiers have selectable lower limiting frequencies and it is always advisable to use the highest possible lower limiting frequency that will not affect the measurement, as this will considerably reduce low frequency noise.

4. Calibration of the set-up can be performed by a) theoretical calculation accepting the factory calibration of the accelerometer, or b) subjecting the accelerometer to 1 g peak using the Accelerometer Calibrator Type 4291 or the built-in shaker of the Accelerometer Calibrator and Preamplifier Type 4292 (see 4292 manual).

2.5.1. Theoretical Calculation (only possible with preamplifiers having fixed gain settings)

(a) When using a voltage preamplifier the voltage sensitivity in mV/g of the accelerometer plus cable supplied can be obtained from the accelerometer calibration chart. (Fig.2.5).

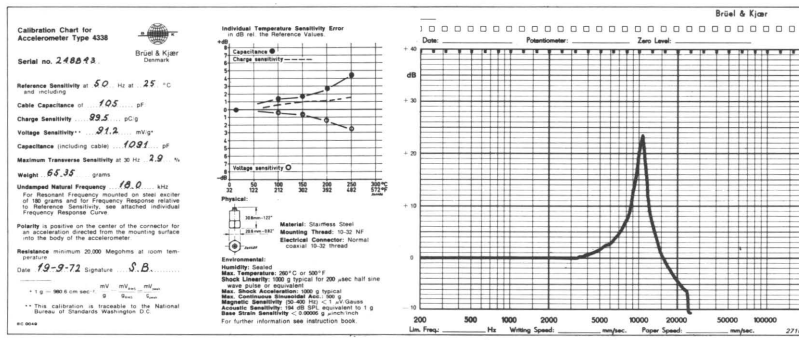


Fig.2.5. Example of the individual calibration chart supplied with each B & K Accelerometer

If a long cable is used or if the accelerometer is used in extreme temperatures a new voltage sensitivity must be calculated. (Ref. Section 5.2.8 and 7.3).

By adding the gain (if any) of the preamplifier the overall voltage sensitivity is obtained.

(b) When using a charge amplifier the charge sensitivity S_Q (in pC/g) of the accelerometer can be obtained from the accelerometer calibration chart.

Different cable lengths will not change the charge sensitivity. If the accelerometer is operating at a high temperature the new charge sensitivity must be obtained from the calibration chart. (Ref. Section 5.2.8).

When using the 2624 Charge Amplifier multiply charge sensitivity of the accelerometer in pC/g by the sensitivity in mV/pC of the 2624 to obtain the overall sensitivity of the set-up in mV/g.

When using the 2626 Conditioning Amplifier the overall sensitivity in Volt/g of the set-up is obtained directly by the setting on the central "Volt/g" knob, when the sensitivity of the accelerometer is read into the 3 digit sensitivity adjustment network (See 2626 manual).

2.5.2. Calibration at 1 g Peak

By exciting the accelerometer at 1 g peak and measuring the resultant voltage output, the overall sensitivity can be obtained directly.

The Accelerometer Calibrator Type 4291 (Fig.2.6) is specially designed for this purpose.

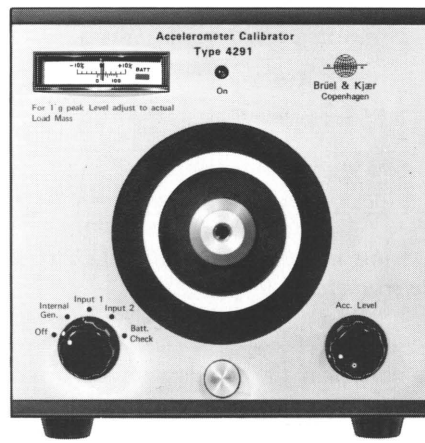


Fig.2.6. Accelerometer Calibrator Type 4291

An example of a typical calibration set-up is shown in Fig.2.7 using for example a Type 2606 Measuring Amplifier to measure the signal from the accelerometer.

1. Calibrate the Measuring Amplifier using the 50 mV RMS reference voltage.

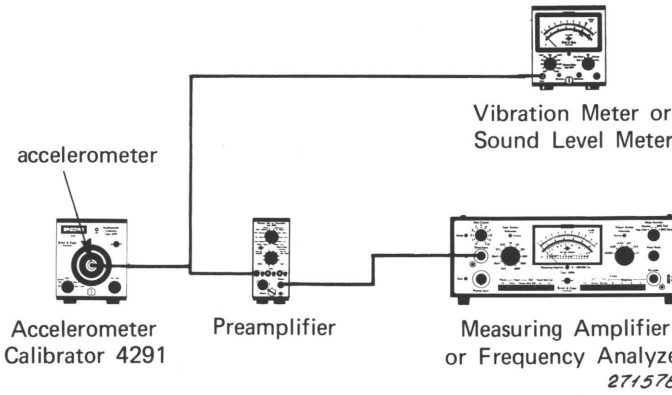


Fig.2.7. Calibration of accelerometers at 1 g peak

2. Switch the 4291 to "Internal Generator". The calibrator will now vibrate the accelerometer at 79.6 Hz.

3. Adjust the "Acc. Level" control until the indicator reads the correct mass of the accelerometer (obtained from the calibration chart).

4. Read off the voltage output indicated on the Measuring Amplifier.

Since the 2606 reads out in RMS voltage and the acceleration is a peak value, the voltage obtained should be multiplied by $\sqrt{2}$.

Overall Sensitivity of the set-up = $mV_{RMS}\ \sqrt{2} = mV_{peak}/g_{peak} = mV_{RMS}/g_{RMS} = mV/g$.

If a measuring amplifier having peak measuring facilities is used and the peak voltage is measured then the overall sensitivity is obtained directly.

3. CONSTRUCTION

The basic construction of a piezoelectric accelerometer is shown schematically in Fig.3.1.

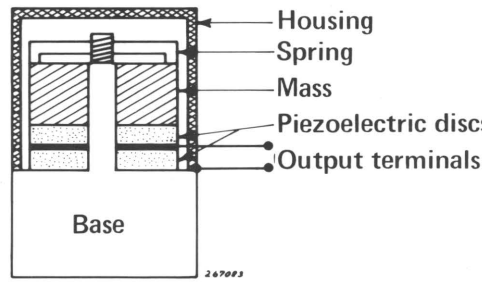


Fig.3.1. Schematic drawing of a piezoelectric accelerometer

The transducing element consists of piezoelectric discs which are clamped between a mass and a base. When the accelerometer is subjected to vibration, the mass will exert a variable force on the piezoelectric discs, and a variable potential will be developed across the element. The potential will be directly proportional to the acceleration over a particular frequency range. The mathematical theory is developed in Section 10.1.

3.1. PIEZOELECTRIC MATERIALS

A piezoelectric material is one which generates a charge when subjected to a stress. The important properties of piezoelectric materials for use in construction of accelerometers are:

PIEZOELECTRIC CONSTANT d: This constant relates the charge generated to the applied force.

$$d = \frac{q}{F}$$

STIFFNESS K: This is the stiffness of the individual piezoelectric element in Newtons/meter. Since the piezoelectric element acts as a spring, this constant will affect the natural frequency of the accelerometer.

DIELECTRIC CONSTANT (ϵ): For a particular piezoelectric element geometry, this determines the internal capacitance. High internal capacitance is advantageous, as the lower limiting frequency decreases with increase in internal capacitance.

RESISTANCE: High internal resistance of the piezoelectric material will reduce the leakage of charge and so improve the low frequency response.

CURIE POINT: This is the temperature at which artificially polarized piezoelectric material will permanently lose or change its piezoelectric properties.

The piezoelectric materials that may be used for accelerometer applications include all the intrinsic piezoelectric monocrystals and the polarized ferroelectric ceramics.

The piezoelectric properties of all monocrystalline material (e.g. quartz and Rochelle salt) are determined by the basic crystal symmetry. This will impose restrictions on the shape of the transducing element which has to be cut out of a larger crystal. Most monocrystals have small sensitivities and dielectric constants. Their advantages are high stability and small variations in parameters. Furthermore, the pyroelectric effect (the effect of charge release caused by temperature changes) which exists in all ferroelectric ceramics is not present in some monocrystals (e.g. quartz).

Some of the problems associated with monocrystalline material were overcome with the development of synthetic ferroelectric ceramics which exhibit piezoelectric properties when artificially polarized. These ferroelectric ceramics are mixtures of different compounds such as barium titanate, lead zirconate and lead metaniobate, and by varying the composition special properties suited for different applications may be obtained. Ferroelectric ceramics have high sensitivities and high dielectric constants, and the element can be made in any required shape.

The manufacture of polarized ferroelectric ceramic elements begins with careful weighing and proportioning of the required ceramic powders. The powders are first mixed and then calcined at a high temperature to produce chemical combination of the ingredients. The compound is then repowdered in a ball mill and a binder is added. The powder is compressed into the

desired shape, which is fired in a kiln under carefully controlled conditions. After this is completed the element is cleaned and electrodes are plated onto it. The last step is the application of a high voltage across the electrode for a certain time. This polarizes the element, permanently inducing a piezoelectric axis between the electrodes.

Manufacturers of piezoelectric materials are continuously investigating and improving their compositions in order to make them more suitable for particular purposes. B & K accelerometers utilize three different piezoelectric materials indicated by MT 8, MT 40, and MT 100.

MT 8 belongs to the well-known lead titanate zirconate family. It has high sensitivity (approx. 300 pC/N) and can be used up to 260°C. It is used in most B & K accelerometers due to its good all round properties.

MT 40 is a specially developed ceramic which can be used up to 400°C. It also has a very flat temperature response curve.

MT 100 is a carefully selected and prepared quartz crystal. It has very good long term stability, very flat temperature response curve and extremely low temperature transient sensitivity. It is used in standard and other accelerometers where optimum stability or low pyroelectric effect is desired.

3.2. DESIGN

The modes of operation most often used in piezoelectric accelerometers are shown in Fig.3.2.

PERIPHERAL MOUNTED COMPRESSION DESIGN (P.M.) gives a very rugged accelerometer with a high sensitivity to mass ratio, and a high

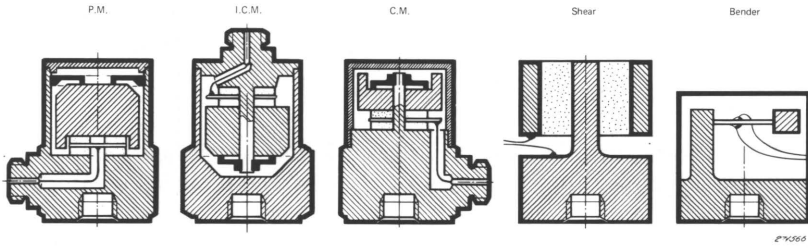


Fig.3.2. Types of accelerometer construction

resonant frequency. It has some shortcomings, especially with regard to environmental sensitivity (e.g. acoustic, base strain, and temperature transient).

The transducing element consists of two piezoelectric discs mounted with like poles face to face, thus isolating the two central electrodes from the housing and grounding the other two electrodes. A mass preloaded by a stiff spring (which is mounted at its periphery by a screw thread on the housing) holds the piezoelectric element in compression against the base. When the accelerometer is subjected to vibration the mass will exert a variable force on the piezoelectric discs, and a charge will be generated across the discs, which is directly proportional to the acceleration of the base.

As can be seen from Fig.3.2 the housing and the spring provide between them the force which preloads the mass. The spring is designed to be less stiff than the housing so as to isolate the performance of the accelerometer from environmental conditions that will directly affect the housing walls.

THE CENTER MOUNTED COMPRESSION DESIGN (C.M.) combines the ruggedness and high resonant properties of the P.M. design with an increased mechanical isolation of the sensing element (basic spring mass system) from the accelerometer housing. It is one of the most frequently employed designs today.

Preloading of the mass is accomplished here by screwing the compression spring down on a threaded center post set in a thick base. The housing in this construction serves only as a protection to the sensing element, and is added after completion of the assembly of the sensing elements.

THE INVERTED CENTER MOUNTED COMPRESSION DESIGN (I.C.M.) gives better isolation from base strain, but suffers a slight reduction in resonant frequency compared with the C.M. The construction is similar to the C.M. design except that the sensing element is secured to the top of the housing instead of the base. The reduction in resonant frequency is due to the elasticity of the walls of the housing, which in this construction carry the sensing element.

SHEAR DESIGN employs a piezoelectric element in the shear mode. It has a very good isolation from case effects and a reasonably high resonant frequency. A cylindrical mass is bonded to a cylindrical piezoelectric element which is itself bonded to a center post. When the accelerometer is subjected to vibration the piezoelectric element will experience a varying stress in the shear mode.

BENDER DESIGN is constructed with special piezoelectric benders and can give a very high sensitivity with a correspondingly low resonant frequency. Its main applications are in the medical and other fields where low frequency response is most important. The design is often used with piezoresistive beams which can measure DC accelerations.

3.2.1. Polarity

The polarity of the electrical output will be determined by the interface polarity of the piezoelectric elements and the reaction of the mass. B & K design all accelerometers such that an acceleration directed from the mounting surface into the body of the accelerometer results in a positive e.m.f. on the center conductor of the output terminals. The only exception is the Standard Accelerometer Type 8305 which has opposite polarity so as to simplify comparison calibration measurements.

3.2.2. Uni-Gain®

Certain B & K accelerometers are designed so that all the accelerometers of that particular B & K Type will have identical sensitivities. This sensitivity is made to be a simple figure for instance 10 mV/g or 10 pC/g. B & K accelerometers of this type are called "Uni-Gain®".

The adjustment procedure is only possible with accelerometers which are of the C.M. or I.C.M. constructions.

During production, the accelerometers are made to have slightly higher sensitivities than is required. Before final sealing the sensitivity of the accelerometer is measured and the appropriate amount of material is machined from the mass.

The use of these Uni-Gain® accelerometers with appropriate preamplifiers makes sensitivity adjustment of the measuring instrumentation before measurement unnecessary. Setting-up time is thus reduced to a minimum and calculations during measurement avoided. They are also particularly useful in vibration measuring set-ups having numerous accelerometers.

3.2.3. Integral Preamplifier

For optimum frequency response the signal from the accelerometer must always be fed through a preamplifier. This is normally mounted remotely from the accelerometer, but in some instances it will be an advantage to build a preamplifier into the accelerometer housing such as in the B & K Type 8306. Although building the preamplifier into the accelerometer increases the weight of the accelerometer, it makes possible the measurement of very low level low frequency acceleration.

4. CHARACTERISTICS

4.1. SENSITIVITY

The sensitivity of an accelerometer is defined as the ratio of its electrical output to the mechanical input. Accelerometers are calibrated for voltage per unit acceleration (mV/g = mV RMS/g RMS = mV peak/g peak) and charge per unit acceleration (pC/g = pC RMS/g RMS = pC peak/g peak). Accelerometers utilizing MT 100 piezoelectric elements are normally only calibrated for pC/g as it is not recommended to use these accelerometers with voltage preamplifiers due to their low internal capacitance.

The equivalent circuit of an accelerometer and cable is shown in Fig.4.1

where q = charge generated by the piezoelectric
C_a = accelerometer internal capacitance
R_a = accelerometer internal resistance
C_c = cable capacitance

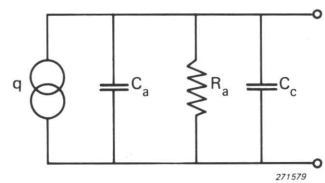


Fig.4.1. Equivalent circuit of accelerometer with cable

Since the accelerometer internal resistance is extremely high it can be neglected. The Charge and Voltage equivalent circuits can thus be represented as shown in Fig.4.2.

From these circuits it is seen that the voltage output $E = q/(C_a + C_c)$ is dependent on the cable capacitance but the charge output is not. For this reason the voltage sensitivity is always calibrated with the cable supplied

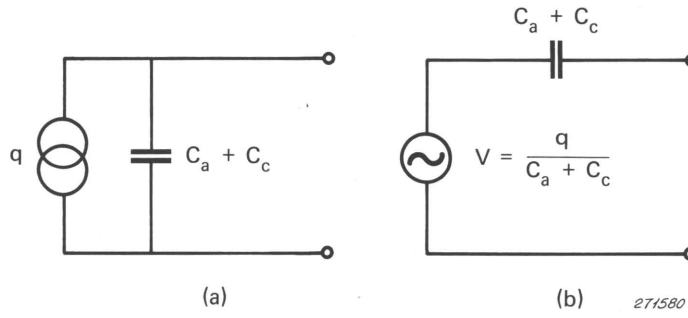


Fig.4.2. a) Charge equivalent circuit
b) Voltage equivalent circuit

with the accelerometer and if a different cable is used the new sensitivity must be determined (refer to Section 7.3).

Within the useful frequency range of an accelerometer the voltage sensitivity is independent of frequency. With accelerometers having MT 8 as the piezoelectric, the charge sensitivity decreases slightly with increasing frequency as shown in Fig.4.3.

The charge sensitivity is always calibrated at 50 or 160 Hz, and the max. deviation occuring in the range of B & K accelerometers is less than 5%. This phenomena is not present in the range of B & K accelerometers having MT 40 and MT 100 as the piezoelectric material.

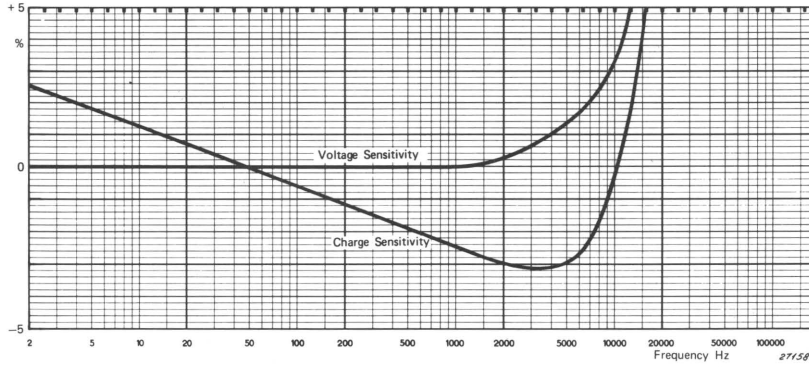


Fig.4.3. Typical frequency response of accelerometer having MT 8 as the piezoelectric

4.2. FREQUENCY RESPONSE

A typical plot of voltage sensitivity versus frequency is shown in Fig.4.4.

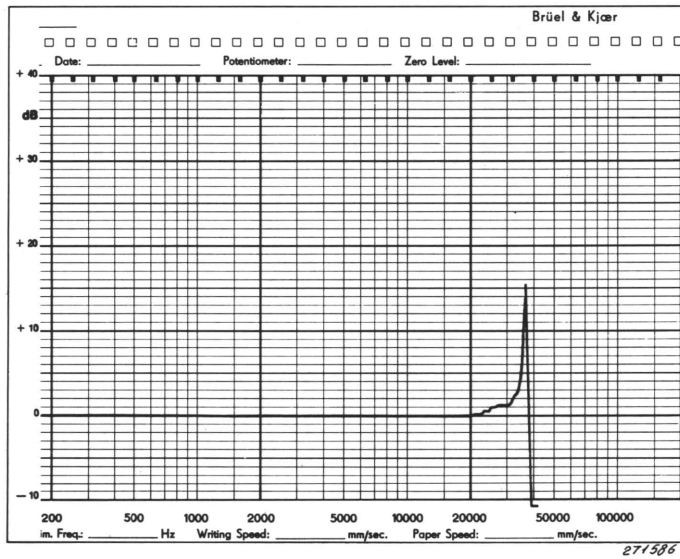


Fig.4.4. Typical plot of voltage sensitivity versus frequency

From the curve it can be seen that the useful frequency range of an accelerometer will be primarily limited by the natural resonance frequency of the accelerometer. The natural resonance frequency of an accelerometer is not fixed. It depends not only upon the mass and stiffness of the accelerometer but also upon the mass (and stiffness) of the object on which it is mounted, and on the stiffness of the mounting method.

Some confusion persists as to what is the natural frequency and different definitions are seen. The situation is best illustrated with the drawing Fig.4.5a, which shows schematically an accelerometer which consists of several masses and springs connected in series. These springs are representations of the contact stiffness between the various parts of the accelerometer.

This mechanical system can be further simplified into that of Fig.4.5b. Here M is the seismic mass resting on the piezoelectric element, B is the mass of the accelerometer base and housing. K is the equivalent stiffness of

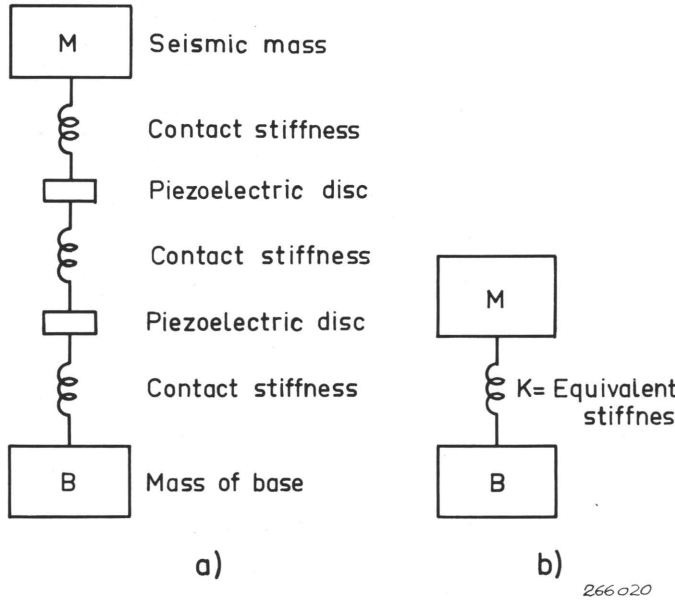


Fig.4.5. a) Schematic drawing of accelerometer as a dynamic system
b) Simplified system

the system between M and B. The natural frequency of such a system is equal to

$$f_o = f_M \sqrt{1 + \frac{M}{B}}$$

where f_M is the natural resonance frequency of the mass M upon the spring of stiffness K.

Now two resonance frequencies are easily thought of:

1. The free hanging resonance frequency, i.e. the resonance frequency obtained with the system freely suspended in air.

   This resonance frequency is entirely dependent upon the ratio of M and B, and it is seen that making the base B very light the resonance frequency may be very high. This resonance frequency is therefore of no practical value, in fact the higher it is compared with the mounted resonance frequency defined below the poorer is the mechanical construction of the transducer. (A thin base may cause bending of the

piezoelectric due to strain from the mechanical part on which the vibration is measured).

2. The mounted resonance frequency with the accelerometer firmly fixed to a structure of infinite stiffness and mass.

   This results in a value for B of infinity and the resonance frequency is equal to f_M which is the natural resonance frequency of the mass M on the spring of stiffness K.

   This resonance frequency is of great practical value as it is approximately the one obtained when the accelerometer is mounted on a structure which is heavy compared with the accelerometer mass.

Unfortunately it is difficult to measure the mounted resonance frequency as defined above. A compromise has therefore to be made and there are standards which define the mounted resonance as that obtained with the accelerometer mounted on an one inch cube of steel (B & K use a steel block of weight 180 grams). The mounted resonance frequency obtained in this manner is used when determining the upper frequency limit (see section 4.2.2 High Frequency Response).

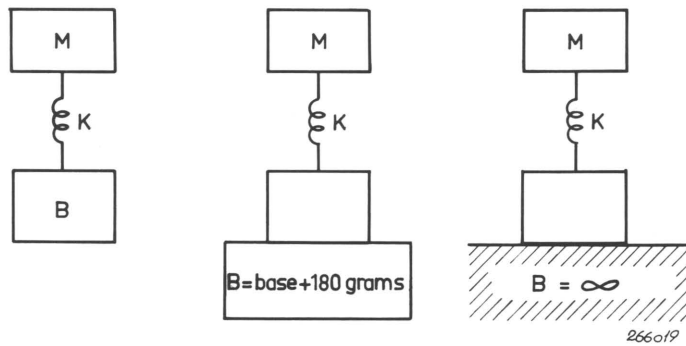


Fig.4.6. Possible configurations for definition of natural resonance frequency

Typically the ratio of weights of the seismic mass to the weight of the base is about 1 : 1 and therefore the free hanging resonance will be about 1.5 times the mounted resonance obtained on the 180 grams block of steel which is 2 – 4% higher than the resonance that would be obtained on an infinite mass.

A small difference in resonance frequency is obtained by considering the damping present in the accelerometer. Thus, the undamped natural frequency is defined as the frequency at which the motion of the mass lags the motion of the base by a phase angle of 90^{o}. The damped natural frequency is the frequency of decaying oscillations after an initial excitation. The difference is negligible for high Q piezoelectric accelerometers such as the ones manufactured by B & K.

4.2.1. Low Frequency Response

The low frequency response of a measuring set-up depends primarily on the type of preamplifier used in the system. With voltage preamplifiers the low frequency limit is a function of the RC time constant formed by the accelerometer output impedance and the input impedance of the preamplifier. (See section 7.1 Voltage Preamplifiers). With charge preamplifiers the low frequency limit is normally determined only by low frequency limit of the preamplifier. (See section 7.2 Charge Preamplifiers).

When low frequency measurements are attempted, particular attention must be paid to the temperature transient sensitivity of the accelerometer being used. Accelerometers will always generate a low frequency output when subjected to temperature variations. The extent to which this will affect the measurement will depend on the temperature transient sensitivity of the individual accelerometer and the level of acceleration being measured. It is advisable when low frequency measurements are not required to limit the low frequency response in order to reduce the effect from temperature transients, especially when a preamplifier is used which has selectable low frequency cut off values.

4.2.2. High Frequency Response

The high frequency response of a piezoelectric accelerometer is a function of its mechanical characteristics.

This response depends primarily upon the resonant frequency f_n and the damping factor ξ, and can be expressed by the following equation:

$$\text{Relative Response} = \frac{1}{\sqrt{(1 - (\frac{f}{f_n})^2)^2 + (2\,\xi\,\frac{f}{f_n})^2}}$$

Since most piezoelectric accelerometers have very low damping factors, of the order 0.01, the equation may be simplified to:

$$\text{Relative Response} = \frac{1}{1 - (\frac{f}{f_n})^2}$$

Two upper frequency limits are usually specified for piezoelectric accelerometers. They are 1/3 of the resonant frequency for less than 1 dB (12.2%) error, and 1/5 of the resonant frequency for less than 0.5 dB (5.9%) error. This can be verified from the above equation.

Poor mounting methods will lower the resonance frequency and therefore also lower the upper frequency limit of the operating range. For a detailed analysis of this problem refer to section 6.2.

4.3. DYNAMIC RANGE

The dynamic range of an accelerometer defines the range over which the electrical output of the accelerometer will be directly proportional to the acceleration of its base.

4.3.1. Lower Limit

The piezoelectric accelerometer is theoretically linear down to zero g, but a practical lower limit is imposed by the noise level of the measuring system. This noise is usually introduced by the preamplifier, but in some cases it may be largely due to temperature transient effects. For noise levels of individual B & K preamplifiers refer to section 7.5.

4.3.2. Upper Limit

The maximum acceleration which can be measured by an accelerometer depends on whether transient or continuous vibrations are measured.

Fig.4.7 shows a typical output versus shock amplitude plot for a compression design of accelerometer. In the compression construction the mass is preloaded against the piezoelectric element with a certain force. This force determines the upper limit to which the accelerometer output will increase linearily when subjected to shock pulses in the negative direction (tending to lift the mass from the piezoelectric element). For shock pulses

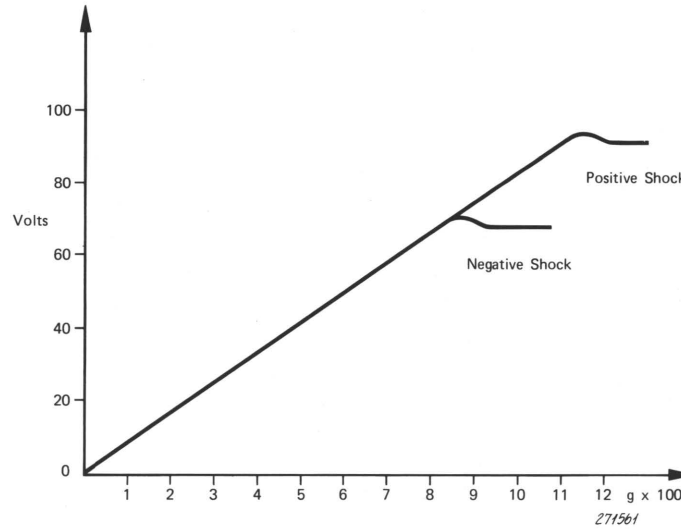


Fig.4.7. Typical output versus shock amplitude plot

in the positive direction the upper limit is determined by the construction strength of the accelerometer only. This upper limit will be considerably higher than that obtained in the negative direction. The Maximum Shock acceleration specified by B & K for the different types of accelerometers is always for shock pulses in either direction, in practice the maximum shock level in the negative direction.

For measurements of continuous vibration the upper limit will be determined only by the structural strength of the accelerometer. This upper limit specified by B & K usually reflects limitations in the test equipment available (max. cont. 3000 g) rather than actual damage to the accelerometer.

Both of the upper limits specified for individual B & K accelerometers are also applicable to shocks and vibrations applied at any direction to the accelerometer.

4.4. ZERO SHIFT

When a piezoelectric accelerometer is subjected to extremely high shock levels the crystal may retain a certain amount of charge, resulting in an

output voltage which disappears again at a rate corresponding to the time constant of the accelerometer-preamplifier system. This phenomenon is called "zero shift" or "DC shift". It is always difficult to predict when a zero shift will occur and care should therefore be taken to allow for this phenomenon especially when the signal is integrated. When measuring shock pulses in the range of 1,000 – 10,000 g a 1 or 2% zero shift may be expected in some tests.

4.5. PHASE SHIFT

The phase shift of an accelerometer is defined as the time delay between the mechanical input and the resulting electrical output signal. All vibration met in practice is complex and is composed of a number of frequencies superimposed in a specific way. If the accelerometer time delay is not linear with frequency, the various frequency components will be shifted relative to one another. The resultant electrical output will hence be a distorted representation of the mechanical input. Phase shift will occur due to damping being present in the mass spring system of the accelerometer but since B & K accelerometers have very small damping factors, the phase shift will be negligible to near the resonance frequency, well beyond the rated frequency range.

4.6. RESPONSE TO TRANSIENT VIBRATIONS

Due to the lower limiting frequency of the system and also to the resonance frequency of the accelerometer, transient vibrations will be distorted when passing through the system. Typical response curves for half sine pulses and useful thumb-rules to secure amplitude errors less than 5% are given in Fig.4.8.

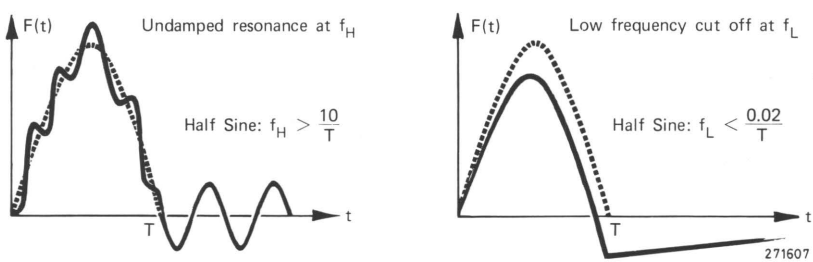


Fig.4.8. Determining the required frequency range of a shock measurement system, when the shock pulse length is known

An analysis of accelerometer transient response is performed in section 10.1.2. For a detailed discussion on shock measurement, reference can be made to B & K Technical Review 1966 No. 3 or the B & K booklet "Mechanical Vibration and Shock Measurement".

4.7. TRANSVERSE SENSITIVITY

The transverse sensitivity of an accelerometer is its maximum sensitivity to an acceleration applied at right angles to its principal axis. It can be regarded as the result of the sensitivity axis of the accelerometer being not quite aligned with the geometric axis, as illustrated in Fig.4.9.

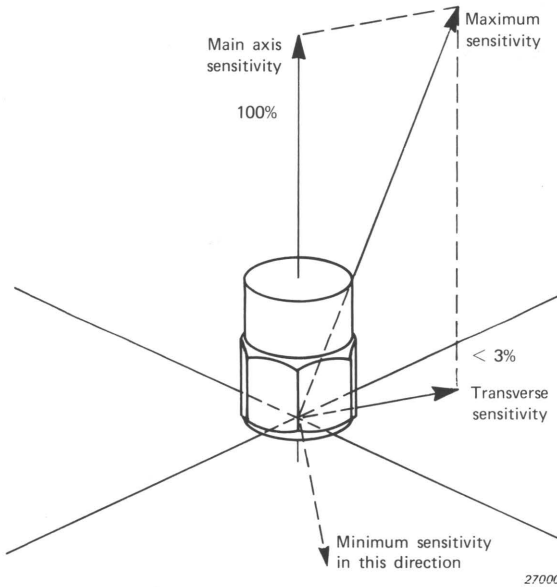


Fig.4.9. Graphical illustration of transverse sensitivity

Transverse sensitivity of accelerometers is primarily due to irregularities in the piezoelectric element and to limitations in the mechanical coupling between piezoelectric element and metal parts. It can be minimized by careful machining in manufacture, and by making the ceramic as homogeneous as possible.

Imagining the accelerometer placed in a rectangular coordinate system, as shown in Fig.4.9, the vector representing the maximum sensitivity can be resolved into two components:

1. The main axis sensitivity, which is the voltage or charge sensitivity and

2. the transverse sensitivity normally quoted as a percentage of the main axis sensitivity.

The voltage obtained from an accelerometer is a product of the acceleration vector and the component of the sensitivity in the same direction, so that in a certain transverse direction at right angles to both the main axis and the max. transverse sensitivity axis the accelerometer output will be minimum. In order to maintain a low transverse sensitivity the accelerometer should always be mounted on a flat, clean surface and care should be taken to avoid damage from very large shocks in the transverse direction, such as might be caused by dropping the accelerometer on the floor.

If the accelerometer is properly handled and mounted, the transverse sensitivity will normally be below 3% at 30 Hz and below 10% up to 5000 Hz. Above 5000 Hz it is very difficult to establish useful test facilities for transverse measurements. The type of mounting of the accelerometer will, however, undoubtedly set a limit at a frequency somewhat lower than that for operation in the main direction.

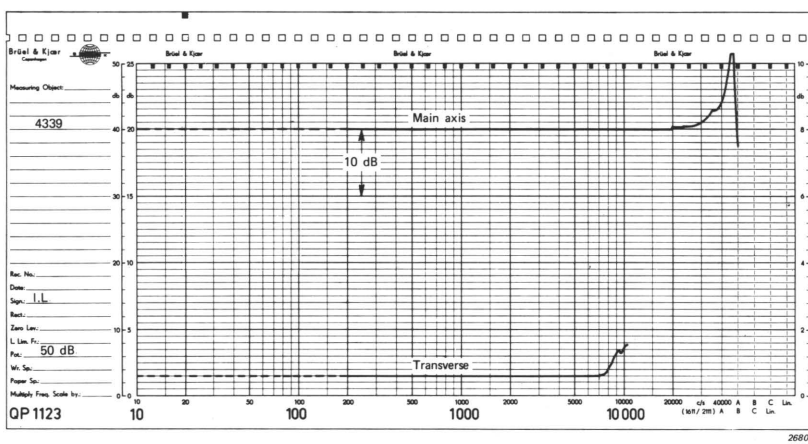


Fig.4.10. Frequency response curve for transverse sensitivity of an accelerometer

Fig.4.10 is a typical frequency response for transverse sensitivity at frequencies up to 10,000 Hz.

The maximum transverse sensitivity at a frequency of 30 Hz is given on the individual calibration chart of the accelerometer and the direction of minimum transverse sensitivity is marked on the accelerometer case by a red spot.

4.8. NON-VIBRATION ENVIRONMENT

Accelerometers are often used to measure vibration in the field or on specimens subjected to severe environmental tests. It is therefore important that their sensitivity to nonvibration environment, or to environmental changes is as small as possible.

4.8.1. Temperature

All B & K accelerometers are rated for a specified temperature range. Within this usable temperature range the piezoelectric materials will show variations in sensitivity, capacitance, and resistance. The variation of voltage and charge sensitivity for the different piezoelectric materials are shown in Fig.4.11.

As the accelerometer temperature is increased beyond its maximum operating range the piezoelectric material begins to depolarize with a result-

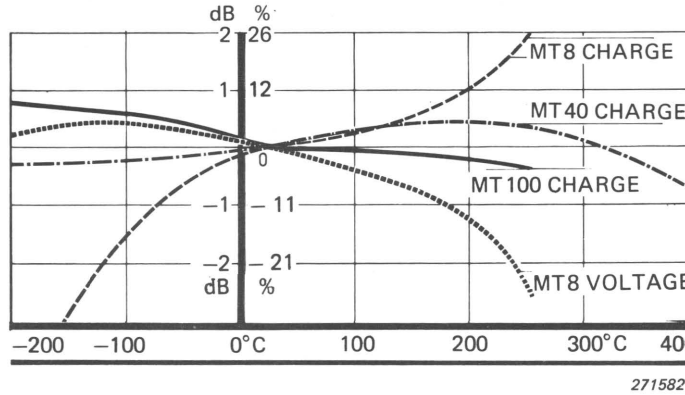


Fig.4.11. Charge and voltage sensitivity versus temperature for different piezoelectric materials

ing loss of sensitivity. If the temperature is increased until the piezoelectric material reaches its Curie point, the accelerometer will become depolarized and the sensitivity will drop to a lower value.

When using accelerometers under high temperature conditions, different methods of cooling may be employed or high temperature accelerometers may be used. For different cooling methods refer to Section 6.7.

In addition to the temperature characteristics described above, accelerometers also exhibit a slowly varying electrical output when subjected to temperature transients. This output is due primarily to two effects. (1). Temperature transients may cause non-uniform stresses in the accelerometer structure. This will result in varying forces on the sensing element which will in turn generate an electrical output. (2). Polarized ferroelectric ceramics exhibit a pyroelectric effect in which an electrical output is generated by the ceramic when it is subjected to temperature transients. Usually these effects will not interfere with measurements but where low frequency or low level accelerations are being measured these effects must be taken into consideration. In conditions where temperature transients cause complications they may be eliminated or reduced by:

1. Selecting accelerometers having low temperature transient sensitivities.
2. Shielding the accelerometer so as to reduce the temperature variations at the accelerometer.

4.8.2. Acoustic Noise

Effects due to acoustical excitation are unavoidable with piezoelectric accelerometers, but this is reduced by careful design. Most accelerometers are of rigid, mechanically isolated construction and pressure variations in the air will have little effect on the force transmitted to the piezoelectric element. One may generally assume that the vibrations induced in the vibrating specimen will give rise to a much higher acceleration signal than the direct acoustical excitation of the accelerometer itself. In cases where very low accelerations are to be measured in an intense acoustic field however, care must be exercised in order to obtain correct results. Acoustic sensitivity is quoted under the specifications for individual accelerometers. (Chapter 11).

4.8.3. Humidity

To eliminate the risk of inferior performance in moist atmospheres or in environmental test chambers where heavy condensation may take place, accelerometers are sealed against entry of water. When an accelerometer is used for measurement in liquids or in very moist environments it is necessary also to seal the cable entry. (Ref. Section 6.6). Apart from these precautions to exclude water from the interior of the accelerometer there are generally no problems with operation in a wet or humid environment.

4.8.4. Base Strain

When an accelerometer is mounted to the surface of a structure that is undergoing strain variations, an output will be generated by the accelerometer as a result of the strain being transmitted to the sensing element. The base strain sensitivity is usually specified for individual accelerometers in g/μ strain.

Generally accelerometers are designed with thick bases so as to reduce base strain effects. Further reduction in base strain sensitivity is achieved from I.C.M. designed and shear designed accelerometers. Also in some B & K types (i.e. 8304 and 8305) a Beryllium disc is used between the piezoelectric discs and the housing to increase isolation.

4.8.5. Magnetic Fields

The magnetic sensitivity of piezoelectric accelerometers is normally very low. For different B & K types it is less than 0.1 to 0.3 g per kGauss for the least favourable orientation of the accelerometer in the magnetic field.

4.8.6. Radiation Effects

All the accelerometers (except 8306) can be used under heavy X-rays (10 – 100 kRad/h) and up to accumulated doses of several MRad without important changes in performance. 4345 can be used under radiation of γ rays and neutrons at least up to accumulated doses of hundreds of MRads and $10^{18} - 10^{19}$ thermal neutrons per cm^2. (Dose rates: approx 1 MRad/h, 10^{12} $n/cm^2/s$).

5. CALIBRATION

5.1. CALIBRATION METHODS

The calibration of an accelerometer is primarily based on obtaining the accelerometer sensitivity. Once this has been determined, by varying different parameters and possibly using the same calibration system, the frequency response, temperature response and amplitude linearity may be obtained.

Some of the more commonly used calibration methods are outlined below.

5.1.1. Comparison Method

In the comparison calibration method the unknown accelerometer is mounted as close as possible (e.g. back to back) to a reference standard accelerometer on a carefully controlled vibration generator. The sensitivity of the unknown accelerometer is obtained by comparing the outputs of the two accelerometers. Accuracies better than 2% may be obtained by careful application of this method.

5.1.2. Absolute Methods

Two methods have been used extensively: The reciprocity method and the interference method, especially by the use of lasers. The accuracy of both methods is about $\pm 0.5\%$. The reciprocity calibration method is based on the principle that reciprocal correspondence exists between input and output of transducers which are reversible, passive and linear. The reciprocity calibration employs two reciprocal transducers (e.g. a piezoelectric accelerometer and a velocity coil) and an exciter. The exciter is used to determine the sensitivity ratio, and by using one of the transducers (e.g. the velocity coil) as driver the product of the two sensitivities can be determined. From $R = S_1/S_2$ and $P = S_1 \cdot S_2$ the sensitivities S_1 and S_2 can be calculated. In general complex calculations have to be used, but in a limited frequency range the calculus can be simplified. For full calibration proce-

dure using this method refer to the B & K Instructions and Applications manual for the Accelerometer Calibrator Type 4291. The procedure is rather time-consuming even in its most simple form.

The laser interferometry method is based on the theory of the Michelson interferometer. The laser beam is divided in two parts, one is reflected by a fixed mirror, the other by a reflecting surface on the transducer or on the structure to which it is attached.

The combination of the two beams will shift between maximum and minimum intensity each time the path length difference is changed by half a wavelength. The number of changes per vibration period can be counted and gives directly the vibration-amplitude. The method is well suited for rapid and accurate calibrations. For a detailed discussion on this method refer to B & K Technical Review 1971 No. 1.

5.2. FACTORY CALIBRATION

The following section applies in general to all B & K accelerometers except for Type 8305. The differences in factory calibration for this type are outlined in Section 5.3.

Each individual accelerometer has before leaving the factory undergone a very thorough aging, testing and calibration procedure to ensure the user a high quality product. A typical calibration chart as supplied with each accelerometer is shown in Fig.5.1.

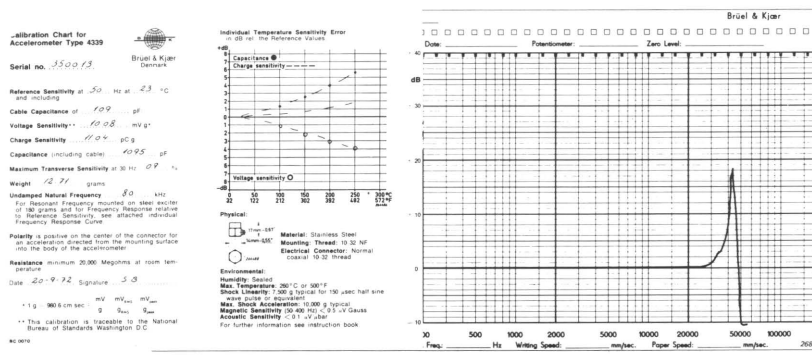


Fig.5.1. A typical calibration chart

5.2.1. Cable Capacitance

The connecting cable supplied with the accelerometer is that used for its voltage sensitivity calibration. When other cables are used, the change in cable capacitance must be taken into account, as this influences the effective voltage sensitivity of the accelerometer. To find the capacitance of the accelerometer alone, deduct the cable capacitance from the capacitance (including cable) given on the calibration chart. The standard length of cable included is 1.2 m (4 ft.). The capacitance of the 1.2 m cable is around 105 pF, but the individual value is given on the calibration chart, as well as on the cable.

5.2.2. Voltage Sensitivity

The voltage sensitivity of the accelerometers with connecting cable is determined at a frequency of 50 or 160 Hz and at room temperature (appr. 20°C). Fig.5.2 shows the instrumentation employed.

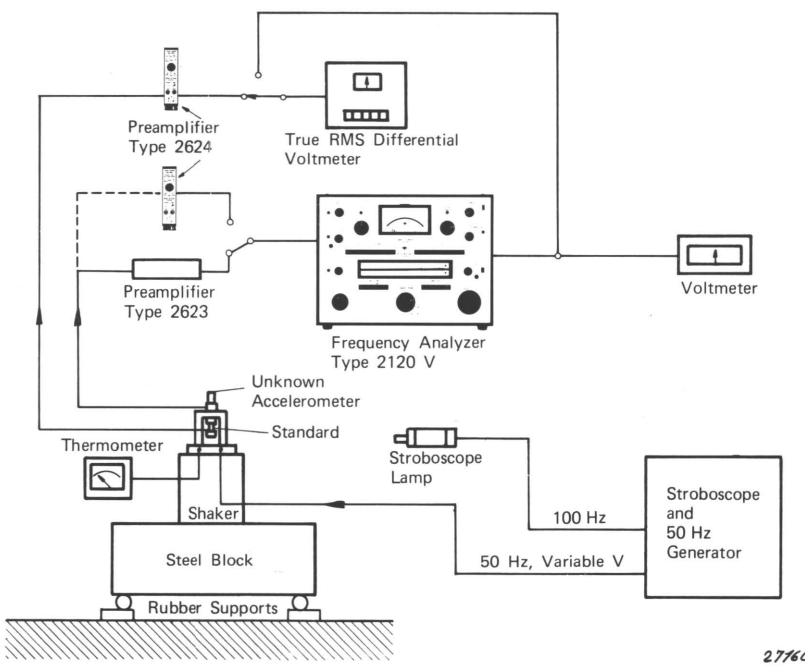


Fig.5.2. Set-up used for sensitivity calibration of the accelerometers

The shaker providing the mechanical excitation is mounted on a large steel block which is supported on rubber dampers, the whole assembly has a natural resonance frequency of about 1 Hz. This ensures isolation from background vibration.

The calibration of all units is achieved by comparison between a standard accelerometer and the unknown in a back to back mounting as shown in Fig.5.2. The standard is frequently checked with a microscope to measure the displacement amplitude directly, or recalibration is made by the laser-interferometry method.

The total accuracy of the sensitivity calibration of the accelerometers is better than $\pm 2\%$.

Note that the calibration is valid for the accelerometer with its individual connecting cable, and remember to take any change of cable capacitance into account when different cables are employed.

5.2.3. Charge Sensitivity

The calibration of the accelerometer charge sensitivity is achieved with the same set-up as described in the previous section. The voltage preamplifier (2623) is replaced by the charge amplifier (2624), see Fig.5.2, and the accuracy of the calibration is the same as before. The charge sensitivity is expressed in pico-Coulomb/g and is independent of the capacitive loading on the accelerometer.

5.2.4. Capacitance

The capacitance of the accelerometer is given including the cable capacitance as specified on the calibration sheet. Accelerometer capacitance comes into the question when the low frequency cut-off of the measuring system is computed as it determines the effect of loading on the accelerometer.

The capacitance is calculated from the voltage sensitivity and the charge sensitivity. The relationship is given by:

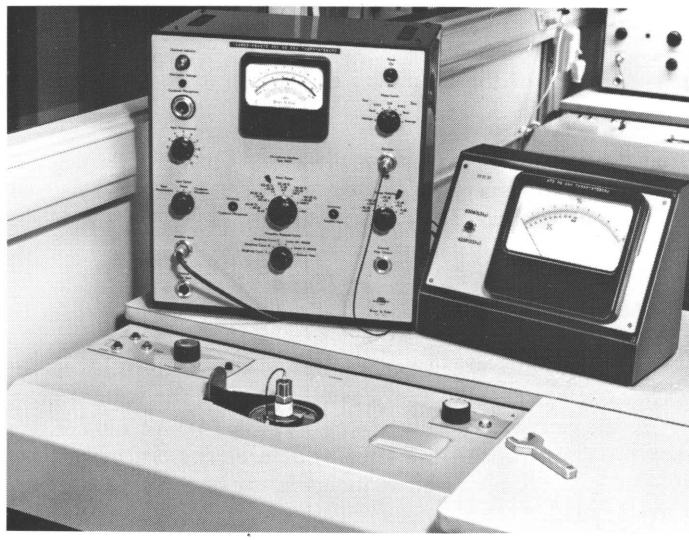
$$S_{charge} = S_{voltage} (C_a + C_c)$$

$$C_a + C_c = \frac{S_{charge}}{S_{voltage}}$$

where C_a = accelerometer capacitance and C_c = cable capacitance

5.2.5. Transverse Sensitivity

In the factory calibration the transverse sensitivity is measured at approximately 30 Hz on a rotating table (Fig.5.3) whose motion along a horizontal axis is more than 1000 times larger than the motion in the vertical direction.



272220

Fig.5.3. Part of the arrangement for obtaining transverse sensitivity

The accelerometer is first mounted with its main axis parallel to the direction of motion of the table (horizontal) and the deflection on the meter is adjusted to a reference mark (100%). Then the accelerometer is mounted with its main axis vertical and the table is rotated slowly about a vertical axis. The meter is set to indicate full scale deflection for 10% transverse sensitivity and the maximum value is noted. The direction of the

minimum (zero) sensitivity is marked with a red dot at the side of the accelerometer housing. This information is useful when measurement only in a certain direction is desired. Effects of cross motion can then be filtered out by mounting the accelerometer with its direction of minimum sensitivity coinciding with the direction of the cross motion.

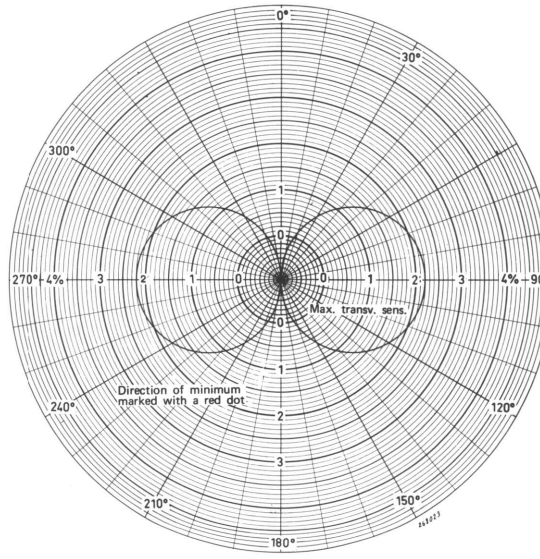


Fig.5.4. Chart for finding transverse sensitivity in any direction, when maximum value is given

If it is desired to find the transverse sensitivity in any particular direction use may be made of Fig.5.4 as follows: Find the maximum transverse sensitivity from the calibration chart and use this value as the measure for the diameter of two circles as shown in the figure. (3.4% is used as an example). The figure-eight curve obtained is the transverse sensitivity pattern for the accelerometer in question. Since the axis of minimum transverse sensitivity is marked on the accelerometer, its sensitivity in any direction is easily determined. Fig.5.5 gives a typical sensitivity pattern as recorded with a B & K Level Recorder Type 2305.

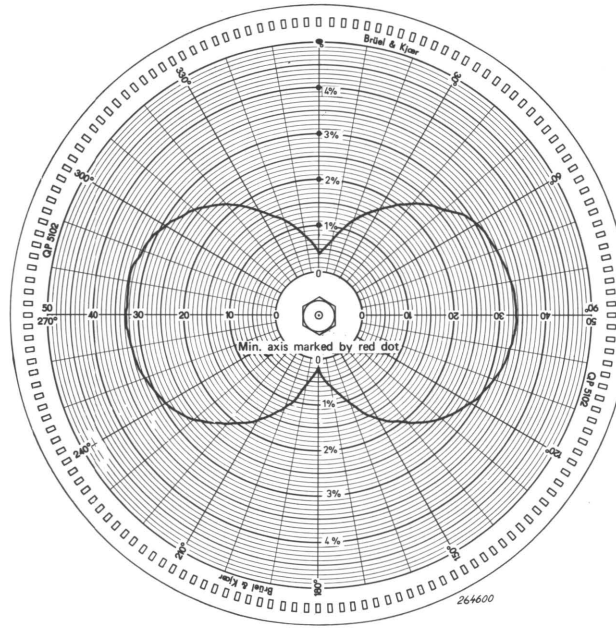


Fig.5.5. Typical transverse sensitivity curve for an accelerometer

5.2.6. Undamped Natural Frequency

The undamped natural frequency is the frequency at which the motion of the seismic mass element lags 90^{o} behind the motion of the accelerometer housing.

The damping ratio, which is the ratio between the actual damping of the accelerometer and the damping for which the system would be critically damped, is very low: in the order of 0.02. Therefore the damped natural frequency, f_d, is nearly identical to the undamped natural frequency, f_u, since

$$f_d = f_u \sqrt{1 - 0.02^2}$$

The undamped natural frequency is measured electrically by finding the lowest frequency at which the 90^{o} phase shift occurs when an electrical signal is applied to the terminals in series with a 1000 pF capacitor, and with the accelerometer freely suspended in air.

The mounted resonance frequency is the frequency at which the sensitivity of the pick-up is a maximum when mounted on a stainless steel block of approximately 180 grams. The block has a built-in accelerometer and is driven by a coil. A compressor circuit maintains the acceleration constant thus making the impedance of the block much higher than the actual weight implies. In practice one considers the mounted resonance as given on the calibration chart as being more useful than the undamped natural frequency. The mounted resonance will depend upon the mass of the structure on which the accelerometer is mounted, and upon the compliance of the contact between the accelerometer and the structure. As the mounted resonance given is obtained under actual operating conditions with the best possible contact between the accelerometer and the vibrating steel block, this resonance can be taken as a practical upper limit. In practice the mounting will generally be less effective and a lower resonance frequency is obtained. See "Mounting Methods" section 6.2.

5.2.7. Frequency Response Curve

An individual frequency response curve is supplied with each accelerometer except 8309. This is taken with the transducer mounted on a steel block of weight 180 grams with a plane mounting surface.

The set-up for measuring the frequency response is shown in Fig.5.6. This consists of the Calibration Exciter Type 4290 (a small electrodynamic shaker) with a built-in accurately calibrated control accelerometer. With the test accelerometer mounted on the shaker the frequency is swept from

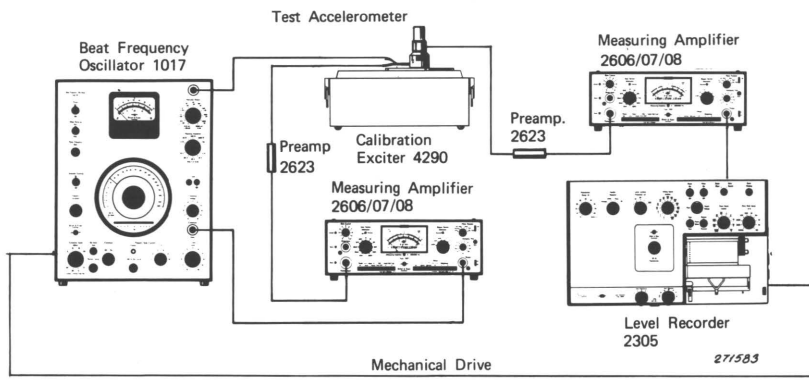


Fig.5.6. Set-up for measuring frequency response

200 – 50,000 Hz while the acceleration is kept constant by using the control accelerometer in a feedback loop. The resulting frequency response is plotted using a Level Recorder Type 2305.

In practice, a frequency response similar to that of the calibration chart is to be expected from the accelerometer provided the method of fixing to the vibrating specimen is satisfactory. It is generally accepted that the piezoelectric transducer may be used for frequencies up to about 1/3 of the resonance frequency shown by this curve for less than 1 dB (12.2%) error, or to 1/5 of the resonance frequency for less than 0.5 dB (5.9%) error, but poor mounting methods will lower the resonance frequency and therefore also lower the upper frequency limit of the operating range.

5.2.8. Temperature Sensitivity

Changes in accelerometer capacitance, charge sensitivity and voltage sensitivity with temperature are given with reference to the values given at room temperature. These are individual values obtained while heating the accelerometers to the appropriate temperatures, reaching a steady temperature before measurement is taken. The information is given in curve form so that interpolation can be readily performed.

When an accelerometer is used as a voltage generator, the transducer output in mV/g will depend upon the temperature of the piezoelectric and on the external loading. The calibration curve given is valid for the accelerometer with the cable supplied (for a capacitive loading of about 105 pF). Any change in loading capacitance will change the voltage sensitivity variation with temperature. By loading the accelerometer with a capacitor it is therefore possible to optimize the voltage sensitivity over a required temperature range.

The leakage resistance may also vary and alter the low frequency response when the accelerometer is used as a voltage generator. This effect is, however, negligible for the B & K accelerometers which are recommended for use with voltage preamplifiers, since the leakage resistance is larger than 20,000 Ω for all temperatures in the operating range.

Charge amplifiers eliminate any influence of parallel capacitance on the charge sensitivity versus temperature curve. Only series capacitance should be considered, if present.

Considering the accelerometer as a charge generator it can be seen from

Fig.5.7 that the voltage sensitivity at any temperature with any amount of cable capacitance

$$E_t = \frac{Q_t}{C_t}$$

where E_t = voltage sensitivity at temperature t
Q_t = charge sensitivity at temperature t
C_t = total capacitance in the circuit at temperature t.

Now, the increase in charge sensitivity is given on the calibration chart in dB, so that knowing the charge sensitivity at room temperature the charge sensitivity at temperature t is easily found by using the conversion table for dB to ratio given in the Appendix, Section 10.2.

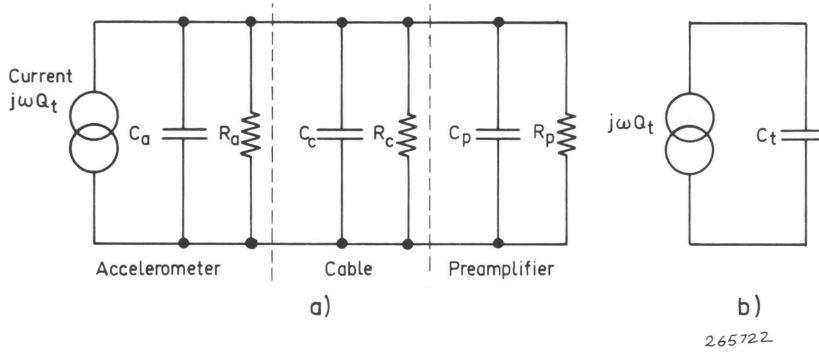


Fig.5.7. a) Equivalent circuit for accelerometer and preamplifier input
b) The same circuit simplified for normal operating frequency range

C_t is also easily found when the capacitance external to the accelerometer is known. The increase in accelerometer capacitance with temperature is given on the calibration chart, as well as the capacitance at room temperature.

Therefore

$$Q_t = Q_o \times K_Q$$

$$C_t = C_a \times K_c + C_{ext} - C_c$$

where Q_o = charge sensitivity at room temperature
K_Q = charge sensitivity factor
C_a = capacitance of accelerometer plus associated cable (1.2 m) at room temperature
K_c = capacitance factor
C_{ext} = total capacitance external to the accelerometer (long cable plus preamplifier)
C_c = capacitance of accelerometer cable used during factory calibration (1.2 m)

Then we have

$$E_t = \frac{Q_t}{C_t} = \frac{Q_o \times K_Q}{C_a \times K_c + C_{ext} - C_c}$$

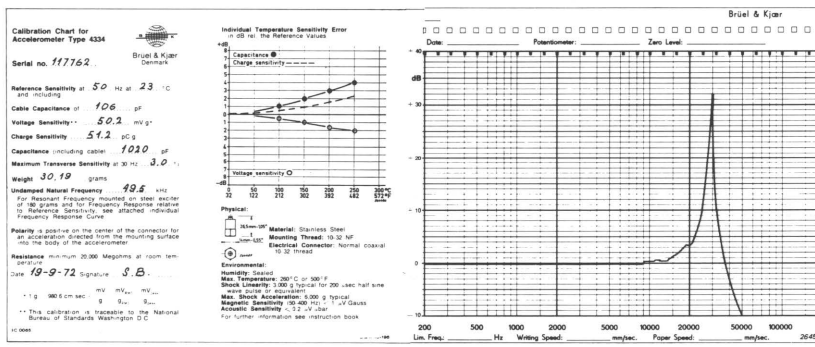


Fig.5.8. Calibration chart

Example:

What is the voltage sensitivity of the accelerometer Type 4334, Serial No. 117762 at a temperature of 250°C and with a total external capacity (long cable plus preamplifier) of 1000 pF.

Solution:

From the calibration chart (Fig.5.8) we find

Q_o = 51.2 pC/g
K_Q = 2.5 dB = 1.33

C_a = 1020 pF
K_c = 4.5 dB = 1.68
C_c = 106 pF

Then the voltage sensitivity at 250°C

$$E_{250} = \frac{51.2 \times 1.33}{1020 \times 1.68 + 1000 - 106} = 0.026 \text{ V/g}$$

$$E_{250} = 26 \text{ mV/g}$$

5.3. FACTORY CALIBRATION OF TYPE 8305 and 3506 SET

The Standard Accelerometer Type 8305 has been designed especially for comparison calibration of unknown accelerometers. Each accelerometer therefore undergoes an extremely accurate calibration process for charge sensitivity using the laser interferometer method. The total error in calibration is verified to be below 0.5%. No voltage sensitivity calibration is made as this accelerometer is not recommended for use with voltage preamplifiers. A special calibration procedure is used to obtain the frequency response of the 8305, so as to give the user as much information as possible. The set-up is shown in Fig.5.9.

The Standard Accelerometer Type 8305 with a load and a Miniature Accelerometer Type 4344 attached to the top, is mounted on the shaker.

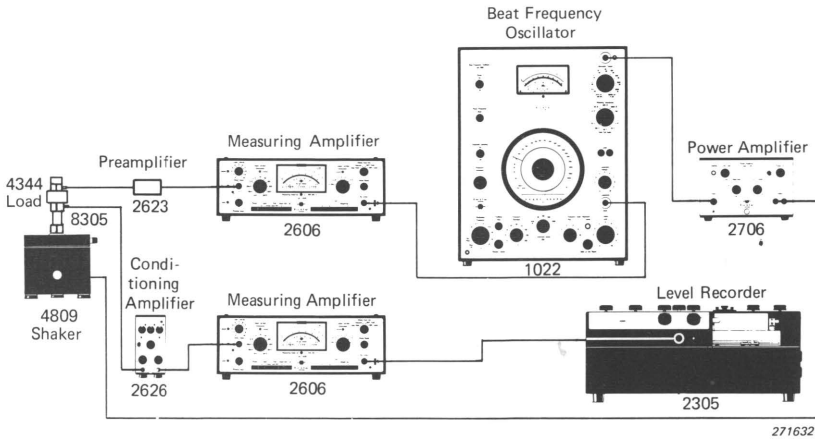
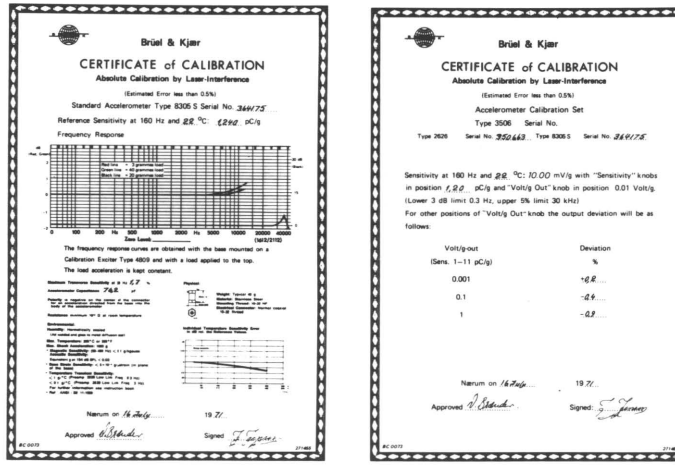


Fig.5.9. Set-up for obtaining frequency response of the 8305 Accelerometer

The 4344 has a high resonant frequency (75 kHz) and is used in the compressor loop to keep the acceleration of the load constant in the range 200 – 10,000 Hz.

The two upper curves on the calibration chart (Fig.5.10) are taken with two different total loads (3 and 40 grams). The total paper width corresponds to 5 dB giving a resolution of 0.5%. The third curve (paper width ~37.5 dB) is taken with a 20 gram load and shows the actual resonance peak.



(a) (b) 271640

Fig.5.10. Typical calibration certificate as supplied with Accelerometer Type 8305 and Calibration Set Type 3506

The reason for the different resonances, obtained with different loads, is that there are two resonances interacting and partly compensating each other. The one is the 8305 accelerometer resonance while the other is the resonance occuring between the accelerometer and the attached load due to the finite mounting stiffness.

The standard Calibration Set Type 3506 consisting of a Standard Accelerometer Type 8305 and a Conditioning Amplifier Type 2626, is calibrated as an integral unit in the Brüel & Kjær calibration laboratory by the laser interference method, giving a maximum probable error within ±0.5%. The precision voltage dividers used for signal conditioning within

the Charge Amplifier 2626 have a tolerance of ±0.1%. The distortion at normal calibration levels and frequencies is below 0.1% and the wide band noise referred to input is below an equivalent of 0.005 g (with 2626 in position 0.01 V/g).

A certificate of calibration is included in the system quoting the conditions under which the calibration has been carried out and giving percentage deviation from the stated data for other settings of the output knob on the 2626. Fig.5.10 shows a typical calibration certificate for the 3506.

A factory recalibration service is available for subsequent calibration checks on the 8305 and 3506 or other units. The laser interference method is used and a new calibration certificate issued.

5.4. CALIBRATION EQUIPMENT

A number of different instruments are available from B & K for (1) Recalibration of accelerometers in the laboratory or in the field prior to the start of extensive tests, (2) Calibrating a special measuring arrangement or a tape recording.

5.4.1. Accelerometer Calibrator and Preamplifier Type 4292

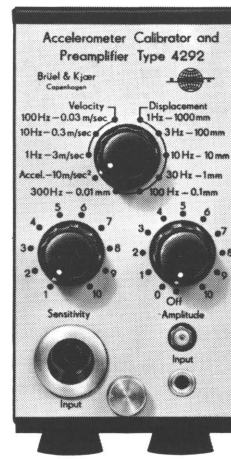


Fig.5.11. Photograph of Accelerometer Calibrator and Preamplifier Type 4292

The Type 4292 has a small built-in vibrator driven by a 79.6 Hz Wien bridge oscillator, see Fig.5.11.

The electromechanical circuit of the vibration is tuned in resonance with the oscillator, by means of a knob, and the amplitude is adjusted until its peak acceleration level corresponds to 1 g. The calibration accuracy is better than 10%.

The 4292 is powered from the PREAMPLIFIER INPUT socket of a B & K Measuring Amplifier.

5.4.2. Accelerometer Calibrator Type 4291

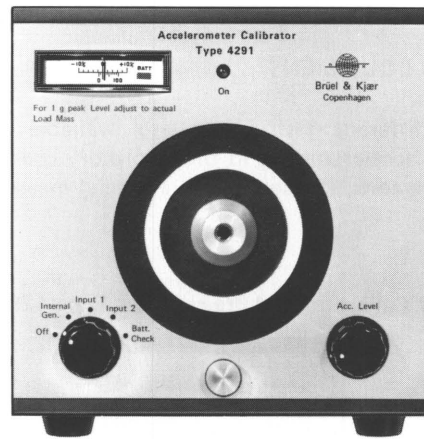


Fig.5.12. Photograph of the Accelerometer Calibrator Type 4291

The Type 4291 Calibrator is shown in Fig.5.12 and is considerably more sophisticated in its construction. Here the peak acceleration level of 1 g can be read conveniently and accurately on a built-in meter, and the vibration frequency is 79.6 Hz, controlled by an internal Wien bridge type of oscillator. The accuracy of the calibration will, when this calibrator is correctly used, be better than ±2%. The built-in oscillator can be substituted by an external generator for calibration in the frequency range 50 to 2,000 Hz. Provision is also made for back-to-back calibration of transducers, and reciprocity calibration.

The Type 4291 can be powered, either from internal batteries or from an external 28 Volts DC source.

5.4.3. Calibration Exciter Type 4290

This calibrator has been designed basically to check the frequency response of accelerometers in the frequency range 50 Hz to 30 kHz, utilizing a measuring and control arrangement of the type shown in Fig.5.13. It may also be used for sensitivity calibration by the substitution method. The maximum attainable acceleration level is, however, relatively low (0.1 – 1 g). The Calibration Exciter is shown in Fig.5.14.

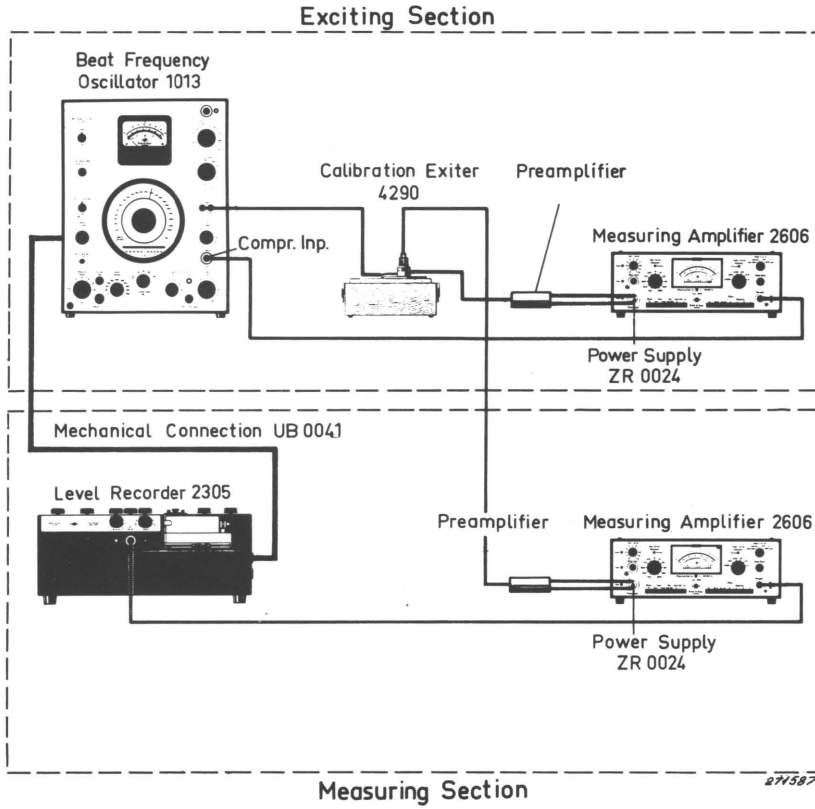


Fig.5.13. Set-up for obtaining the frequency response of accelerometers

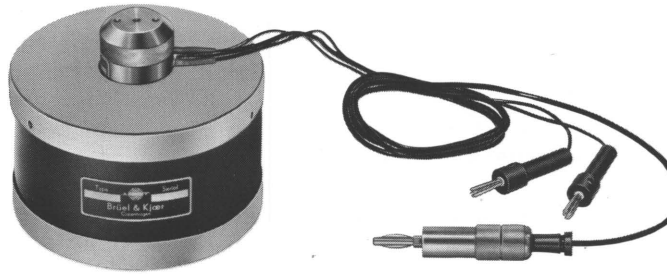


Fig.5.14. Photograph of the Calibration Exciter Type 4290

5.4.4. Calibration Head Type 4815

A special calibration head, with minimum cross-axial motion, is available for the B & K 100 lb force (4801) vibration exciters (Fig.5.15). The head has a built-in Standard Accelerometer Type 8305 for the purpose of comparison. Accurate accelerometer calibration is possible at acceleration levels up to 100 g over a frequency range of 5 Hz to 10 kHz. This allows calibration of most accelerometers at their usual service acceleration levels.



Fig.5.15. Photograph of Calibration Head 4815

5.4.5. Sensitivity Comparator Type 2970

The Type 2970 facilitates rapid comparison calibration of accelerometers in conjunction with a pair of Conditioning Amplifiers. A set-up is shown in in Fig.5.16.

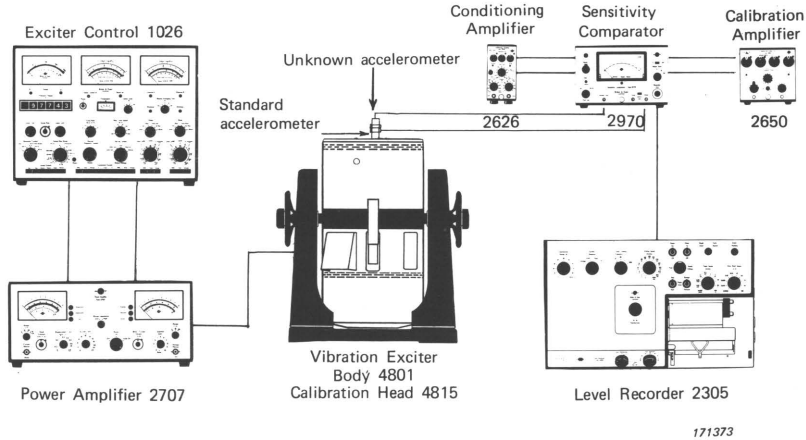


Fig.5.16. Set-up for comparison calibration of accelerometers using the Sensitivity Comparator Type 2970

The basic circuit of the 2970 is a summation amplifier which can be balanced by two equal and opposite inputs. The gain of the conditioning amplifier in the unknown accelerometer line is adjusted to achieve the balance condition, which is indicated by minimum deflection on the built-in meter. The actual sensitivity of the unknown accelerometer can be read directly on the conditioning amplifier in the unknown line.

5.4.6. Standard Accelerometer Type 8305

This accelerometer (Fig.5.17) has been designed especially to allow calibration of accelerometers by the back to back method where the sensitivity of the investigated accelerometer is compared with that of the reference accelerometer. Full details for this accelerometer are given in Section 11.9.

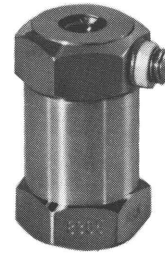
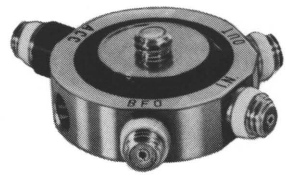


Fig.5.17. Photograph of the Standard Accelerometer 8305

5.4.7. Insert Voltage Adapter UA 0322

The Insert Voltage Adapter (Fig.5.18) is used for determining the open circuit sensitivity of an accelerometer. The open circuit output voltage of the accelerometer is the voltage which appears at its terminals when it is working at an effectively infinite impedance. In the Insert Voltage Method, the voltage which is normally supplied by the mechanical movement of the accelerometer is supplied by a substitute voltage source. This method is especially useful where a multichannel instrument combination is in use or when vibration data is being fed to recorders or to a computer input. In a complicated measurement set-up it may not be convenient to remove the accelerometers. If they are calibrated by the Insert Voltage Method beforehand they can be rechecked in place when necessary.



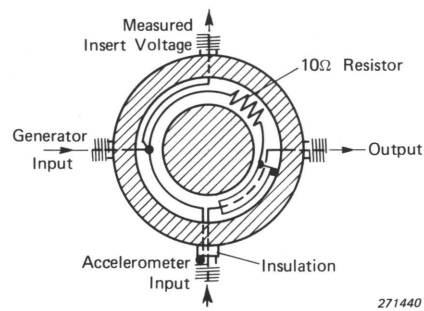


Fig.5.18. The Insert Voltage Adapter UA 0322 and schematic drawing

A typical set-up for obtaining the Insert Voltage is shown in Fig.5.19 and the function of the adapter is shown schematically in Fig.5.20.

The calibration is performed as follows:

1. Put the switch in position 1.

2. Adjust the output of the oscillator in order to get a suitable acceleration level.

3. Read the level V_1 in mV RMS from the Measuring Amplifier (1).

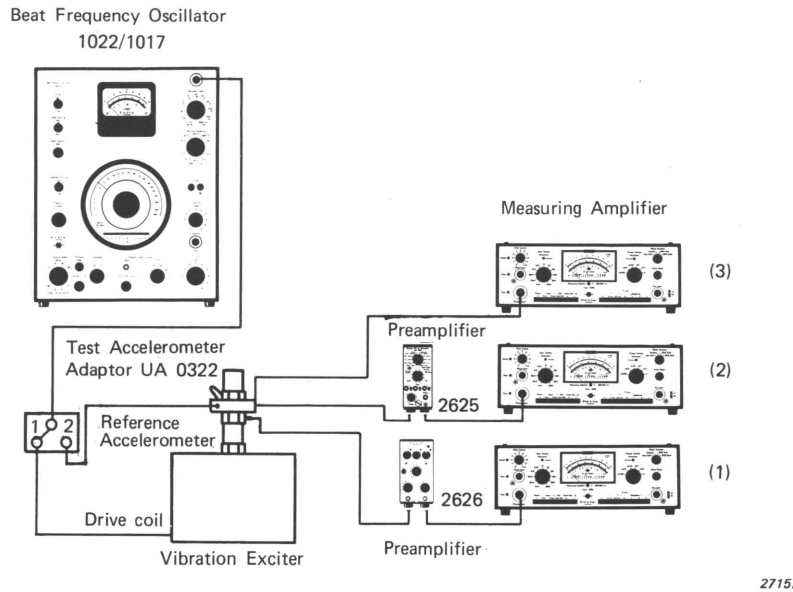


Fig.5.19. Set-up for insert voltage calibration

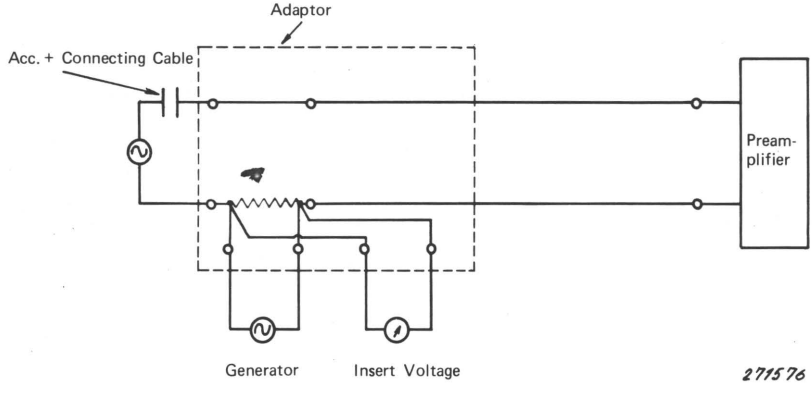


Fig.5.20. Schematic diagram of Adapter UA 0322 and related instruments

4. Read the level V_2 in mV RMS from the Measuring Amplifier (2).

5. Put the switch in position 2.

6. Adjust the output of the Oscillator until the same voltage is obtained on the Measuring Amplifier (2) as in 4 above.

7. Read the insert voltage V_3 in mV RMS from the Measuring Amplifier (3).

Since the sensitivity of the reference accelerometer is known the reference acceleration level a_o can be calculated. Then the open circuit Voltage Sensitivity S_o is given by

$$S_o = \frac{V_3}{a_o} \text{ mV/g}$$

Note that the open circuit voltage sensitivity obtained in this manner is referred to the "Acc" input socket of the Adapter, i.e. to the accelerometer plus the cable between the accelerometer and the Adapter. Normally the open circuit voltage sensitivity of the accelerometer alone is not required since the same cable set-up will be used in any subsequent calibrations performed with the Adapter. If the open circuit voltage sensitivity of the accelerometer S_a is required it can be obtained from the following equation:

$$S_a = \frac{S_o (C_a + C_c + C_i)}{C_a}$$

where C_a = Capacitance of the accelerometer

C_c = Capacitance of the cable between the accelerometer and the Adapter (capacitance of the cable supplied is approx. 9 pF)

C_i = Input capacitance of the Adapter (approx. 3 pF).

6. MOUNTING

6.1. PHYSICAL DIMENSIONS

It is generally true that an accelerometer should be as light as possible in order not to influence the vibration of the specimen on which it is mounted.

This requirement originates from the fact that any "extra" load will change the original motion of the structure and thus invalidate the measurement results. If measurements are made on thin plates use should therefore be made of small, lightweight accelerometers. To estimate the influence of accelerometer mass-loading, the following formula can be applied:

$$a_r = a_s \frac{m_s}{m_s + m_a}$$

where a_r = acceleration response of the structure with accelerometer
a_s = acceleration response of structure without accelerometer
m_s = equivalent mass (weight) of that "part" of the structure to which the accelerometer is attached
m_a = accelerometer mass (weight).

Also, the mass-loading may change the resonance frequencies of the structure, according to the following formula

$$f_r = f_s \sqrt{\frac{m_s}{m_s + m_a}}$$

where f_s and f_r are the resonant frequencies of the structure respectively before and after the accelerometer is added.

Thus any mass added to a vibrating structure will influence the vibration to some extent, but provided the added mass is small compared with the mass of the structure the effect on the structure motion is not significant and the apparent weight of the accelerometer can be ignored.

The sensitivity of a piezoelectric accelerometer is directly proportional to the mass acting on the piezoelectric disc. This limits the extent to which the accelerometer weight may be reduced without losing too much of the sensitivity. For many applications it is also important that any strain

developed in the material on which the accelerometer is fixed is not transmitted to the piezoelectric element as this would show up in the output signal, indicating an acceleration which actually is not present. It is therefore necessary to make the accelerometer base thick in order to isolate the piezoelectric disc from such strain. The requirements of high sensitivity, and low strain sensitivity are in conflict with requirements for small physical dimensions, weight, and good high frequency response, so that for some set-ups some compromise may be necessary.

6.2. MOUNTING METHODS

A proper mounting of the accelerometer to the specimen is of utmost importance when measurements are taken, especially at higher frequencies. The frequency response curve given on the calibration chart is for the most rigid possible mounting of the accelerometer. (Screwed tightly with a steel stud onto a polished metal surface). When other methods are used the resonance frequency will generally be lower. How much lower will be determined by the mass of the accelerometer and the stiffness of the mounting.

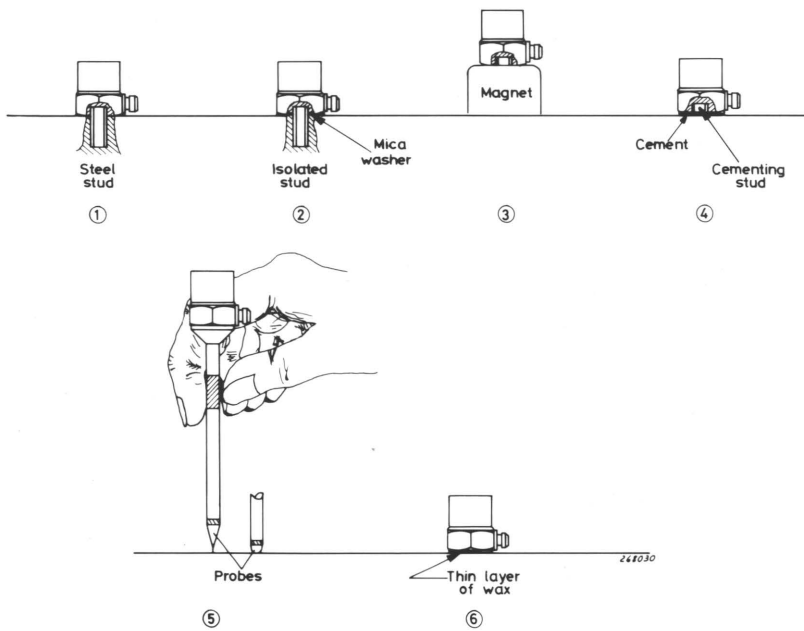


Fig.6.1. Different ways of mounting the accelerometer

The possible ways of applying the accelerometer to the vibrating specimen are depicted in Fig.6.1. Note it is not possible to use methods 2, 3 and 5 with Accelerometer Types 4344 and 8303. It is only possible to use method 6 with the 8307 and method 1 with the 8309 (M5 stud).

Type 1 mounting is the best solution for optimum frequency response approaching a condition corresponding to the actual calibration curve supplied with the accelerometer. If the mounting surface is not quite smooth it is a good idea to apply a thin layer of silicon grease to the surface before screwing down the accelerometer. This increases the mounting stiffness. It is essential whenever using a mounting screw, not to screw it fully into the accelerometer as it may introduce base bending affecting the sensitivity of the accelerometer.

Type 2 mounting is convenient when electrical isolation between accelerometer and vibrating body is necessary. It employs the isolated stud and a thin mica washer. Frequency response is good due to the hardness of the mica. Make sure that the washer is as thin as possible. (It can easily be split up into thinner layers).

Type 3 mounting employs the permanent magnet which also gives electrical isolation from the vibrating specimen. A closed magnetic path has been used and there is virtually no magnetic field at the accelerometer position. This mounting method should not be used for acceleration amplitudes higher than about 100 g and 200 g for the large and small accelerometers respectively. The magnet attachment can be used at temperatures up to 150°C.

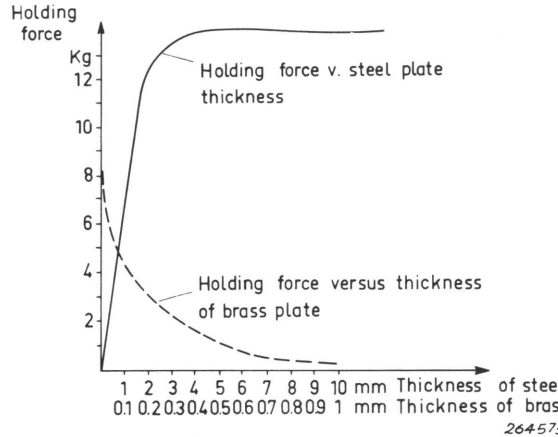


Fig.6.2. Holding force of the mounting magnet versus thickness of steel plate and versus thickness of intermediate brass plate

The holding force of the magnet has been investigated for various steel plate thickness and for various thickness of brass (non-magnetic) between the magnet and the steel. See Fig.6.2.

Type 4 mounting is convenient when a cementing technique is appropriate, with the possibility of removing the accelerometer from time to time.

Type 5 mounting employs the probe with interchangeable round and pointed tips. The method may be convenient for certain applications, but should not be used for frequencies much higher than 1000 Hz, since the natural resonance frequency in this case is very low. In general, this method of mounting should not be used unless no rigid mounting is practical.

Type 6 mounting employs a thin layer of wax for sticking the accelerometer onto the vibrating surface. The wax delivered with the Accelerometer Sets is ordinary bees wax. A frequency response curve is given in Fig.6.3. It is seen that this method of mounting gives a very good frequency response due to the stiffness of the wax. At higher temperatures this will decrease. Double sided tape is supplied with the 8306 accelerometer since its low frequency range makes this type of mounting possible.

Soft setting glues or gum should be avoided because of decoupling and bad frequency response.

For minimum weight and optimum performance recommended cements are the Eastman 910 cement, marketed by the Armstrong Industry, or Tiox K-1 manufactured by Tiox-Tinten und Klebstoffwerk G.m.b.H., Vienna, or Cyanolit 201 + 202 manufactured by 3 M. Dental cement epoxy resins are also very useful, especially in connection with the cementing stud which is intended for use in applications where cementing is preferred, while retaining the possibility of removing the accelerometer itself.

Fig.6.3 shows some frequency response curves obtained for the various methods of mounting. The curves may serve as guide-lines when selecting the most convenient mounting type for a particular measurement problem.

In concluding the discussion on accelerometer mounting technique it should be mentioned that the mounting torque for 10–32 NF threaded screws should be around 18 kgcm or 15 lbin. The accelerometers are not harmed by a larger torque, but the isolated stud may not stand more than 20 lb in (24 kg cm). A mounting torque, of the correct value is applied with a 10 cm (4") spanner with normal pressure on the handle. A 15 cm (6") or larger spanner should be used with care. If a smaller spanner is used, one can-

not do any harm to the thread, but the accelerometer may not be sufficiently secured. For the miniature accelerometers utilizing M3 studs a maximum torque of 5 lb in (6 kg cm) is recommended.

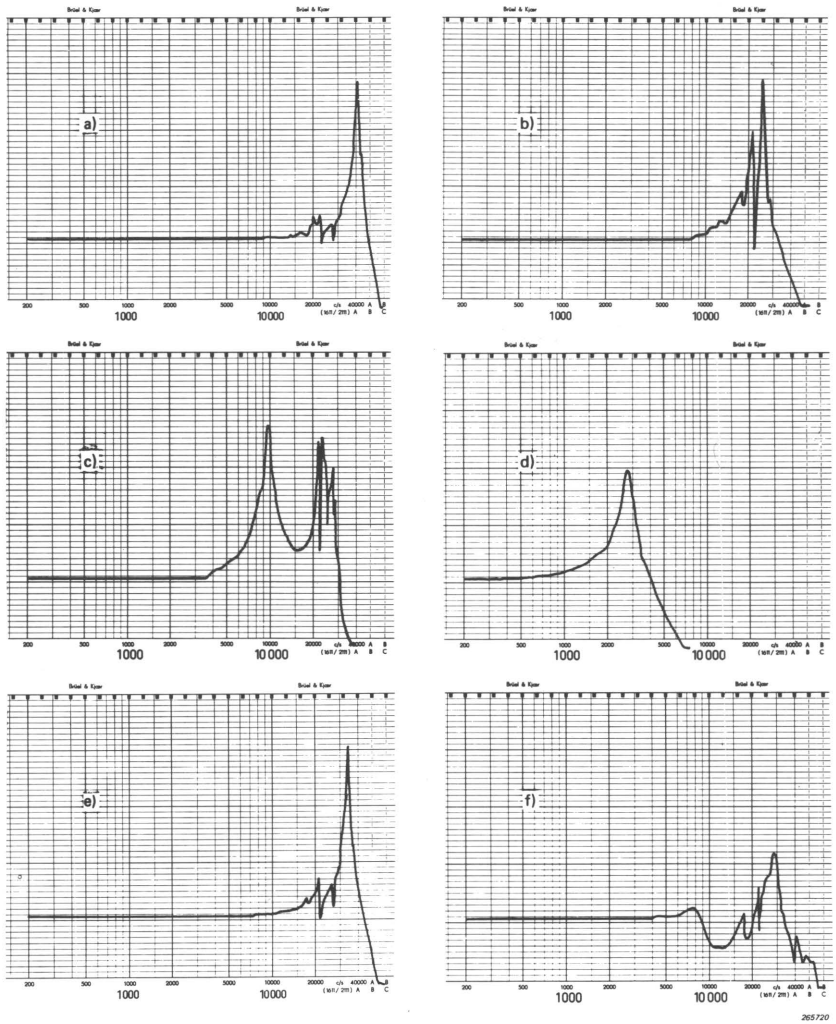


Fig.6.3. Typical frequency response curves for an accelerometer Type 4339 mounted by some of the methods suggested in Fig.6.1
a) Steel stud, b) Isolated stud, c) Permanent magnet, d) Hand held with probe, e) Wax, f) Soft glue (not recommended)

6.3. MOUNTING THREAD

All B & K accelerometers have 10–32 NF mounting thread except for
1) the miniature accelerometers which have M3 mounting threads
2) the 8307 which is intended for wax or cement mounting
3) the 8309 which has an integral M5 stud

If a metric thread is preferred to 10–32 NF thread, the thread may easily be changed to 5 mm by using a M 5 x 0.8 standard hand tap with flat tip. The M 5 x 0.8 thread is very close to the 10–32 NF thread in dimensions, the diameter being 5 mm (0.197") compared with the 4.826 mm (0.190") and the pitch being 0.8 or 31.8 threads per inch compared with 0.794 or 32 threads per inch. Thus all the normal accessories may be used even when the thread has been modified to M 5 x 0.8.

6.4. NOISE AND CABLE WHIP

Because piezoelectric accelerometers are high impedance devices certain problems may arise from connecting cable noise. This noise, due to "triboelectric effects", can originate from mechanical motion of the cable. It originates from local capacitance and charge changes due to dynamic bending or compression and tension of the cable, and may be particularly disturbing at lower frequencies. The B & K accelerometer cables are designed and treated for noiseless operation. It is, however, always good policy to clamp the cables as firmly as possible in order to avoid relative movement, as shown in Fig.6.4.

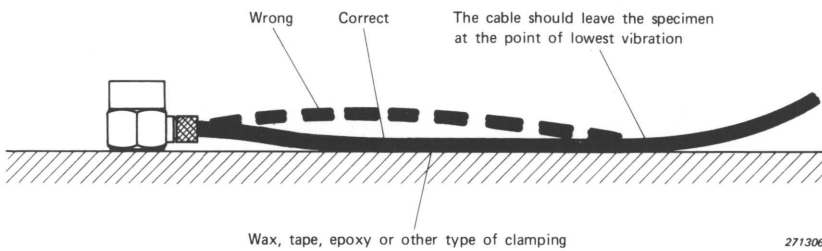


Fig.6.4. Clamping of cable to the vibrating specimen

Of course many applications do not allow such an arrangement. On very hot surfaces an accelerometer with top mounting of the cable should be used and the cable taken away from the measuring point as soon as possible.

Cable whip occurs when the cable is not sufficiently well clamped, near the accelerometer. The cable may then introduce deformation in the accelerometer through the plug. This is especially pronounced with peripheral mounted accelerometers at low frequencies.

6.5. GROUND LOOP

Another noise effect may be induced due to ground loops which may sometimes pose serious problems, particularly in large vibration measurement installations. Fig.6.5 illustrates how a ground loop is formed, and noise introduced (the voltage drop, ΔV adds directly to the, sometimes very weak, signal from the accelerometer). The only way to avoid the formation of ground loops is to ensure that grounding of the installation is made only in one point, Fig.6.5 (b). Where ground loops could exist the accelerometer

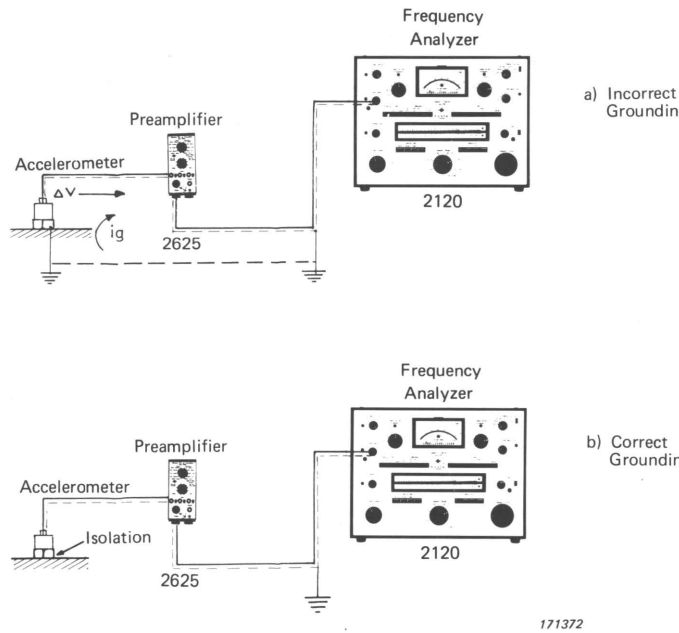


Fig.6.5. Illustration of ground-loop phenomena
a) This method of connection forms ground loop and should be avoided
b) No ground loop is formed. Recommended method of connection

should be electrically isolated from the structure on which it is mounted by means of the isolated stud and mica washer (Type 2 mounting, Fig.6.1). Grounding should preferably be made at the analysing or read-out device.

6.6. SEALING

If measurements are to be made in liquids or in very moist environments, it is necessary to seal the cable entry into the accelerometer as shown in Fig.6.6. A good sealant for the cable entry is for example Dow Corning Silastic RTV 731 (room temperature vulcanizing silicon rubber) or General Electric equivalent.

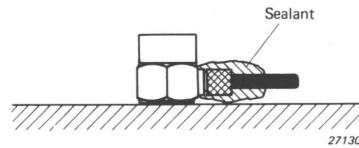


Fig.6.6. Sealing of the accelerometer cable entry

These sealants show excellent performance for a wide temperature range $-70^{o}C$ to $+ 260^{o}C$ ($-100^{o}F$ to $+ 500^{o}F$).

6.7. COOLING

When the accelerometers are to be fixed on surfaces with temperatures exceeding the recommended limit for the accelerometer, it is possible to reduce the temperature of the accelerometer base by inserting a cooling plate between the base and the measuring surface. When a mica washer is used between the mounting surface and the cooling plate, temperatures up to $350 - 400^{o}C$ may be measured on the mounting surface with less than $250^{o}C$ in the accelerometer base. By directing a stream of air across the surface higher surface temperatures can be tolerated. The set-up is shown in Fig.6.7.

Water cooling, by passing water through the base of the accelerometer, however, is a more efficient method of cooling. Some B & K accelerometers (see specifications Chapter 11) have provision for water cooling, whereby measurements can be carried out on surfaces with a temperature up to at least $1{,}000^{o}C$ ($1{,}800^{o}F$).

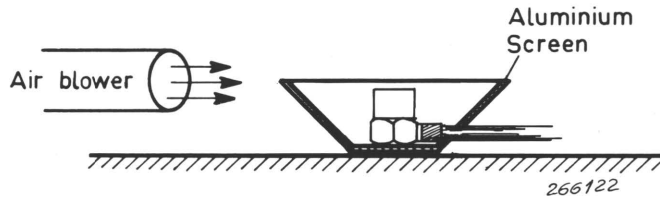


Fig.6.7. Forced air cooling of an accelerometer

Two short tubes delivered with the accelerometer are screwed into the accelerometer. Silicone rubber tubing is then used for connection to a water supply. Water consumption may be from 1 to 20 litres (0.25 to 5 gallons) per hour.

For higher temperatures, or where cooling is not possible the "High Temperature Accelerometer" Type 4345 may be used. This accelerometer has a maximum working temperature of 400°C (752°F).

For high temperature measurements special cables should be used. Teflon insulated cable AO 0038 is rated to 260°C or the B & K silver screened cable AO 0500 is rated to 400°C, see "Accessories" Chapter 8.

7. PREAMPLIFIERS

When measuring vibration by means of an accelerometer it is necessary to incorporate a preamplifier between this and the measuring amplifier. The preamplifier is introduced in the measuring circuit for two reasons:

1) to transform the high output impedance of the accelerometer into a lower value and 2) to amplify the relatively weak output signal from the accelerometer. The signal from the piezoelectric accelerometer appears as a voltage across a capacitive impedance. This voltage is proportional to the acceleration to which the accelerometer is exposed.

As the capacitive output impedance of the accelerometer is very high the associated preamplifier must be of a special design having a high input impedance. This is necessary in order to avoid loading of the accelerometer and thereby obtaining decreased sensitivity and limitation at the low end of the frequency range.

Preamplifiers are designed according to two different amplifier principles 1) the voltage preamplifier and 2) the charge preamplifier. The output signal of the voltage preamplifier is directly proportional to the input voltage whereas the output signal of the charge preamplifier is proportional to the input charge.

7.1. VOLTAGE PREAMPLIFIERS

When used as a voltage source the accelerometer must be loaded by an extremely high impedance in order to retain its sensitivity versus frequency characteristic. Capacitive loading reduces the sensitivity over the whole frequency range, while conductive loading reduces the sensitivity at low frequencies. This can be seen from the following:

The equivalent circuit of an accelerometer with external loading can be simplified to the form shown in Fig.7.1.

Q = charge generated across the accelerometer capacitive element

V_1 = voltage generated across accelerometer capacitance

V_2 = voltage at preamplifier input

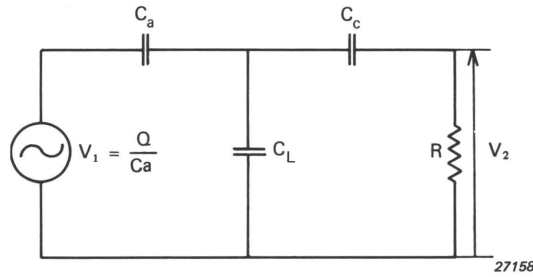


Fig.7.1. Equivalent circuit of accelerometer and preamplifier

C_a = accelerometer internal capacitance
C_L = cable capacitance
C_c = preamplifier coupling capacitance
R = preamplifier input resistance

Assuming a sinusoidal acceleration of angular frequency ω we have

$$\frac{V_2}{V_1} = \frac{C_a}{C_a + C_L + \frac{1}{j\omega R}\left(\frac{C_a + C_L + C_c}{C_c}\right)} \qquad (1)$$

This shows that when

$$\frac{1}{\omega R}\left(\frac{C_a + C_L + C_c}{C_c}\right) \ll C_a + C_L$$

i.e. when the shunt resistance in the circuit is very high or at high frequencies the output voltage depends only upon the capacitive loading:

$$V_2 = \frac{C_a V_2}{C_a + C_L} = \frac{Q}{C_a + C_L}$$

It is also seen that the output is directly proportional to

$$\frac{1}{C_a + C_L}$$

This must be taken into account when long accelerometer cables are employed.

From the equation (1) it can also be seen that when

$$\frac{1}{\omega R}\left(\frac{C_a + C_L + C_c}{C_c}\right) \geqslant C_a + C_L$$

i.e. for low frequencies or for low shunt resistance the output is frequency dependent. This means that the output falls off at the same rate as the frequency at the low frequency end. The corner frequency where the output is 3 dB down is where

$$C_a + C_L = \frac{1}{\omega R}\left(\frac{C_a + C_L + C_c}{C_c}\right)$$

$$f_c = \frac{1}{2\pi R} \frac{C_a + C_L + C_c}{(C_a + C_L)\, C_c} \qquad (2)$$

where f_c is called the "cut-off frequency".

When using preamplifiers having no coupling capacitor $C_c \rightarrow \infty$ then

$$f_c = \frac{1}{2\pi R\,(C_a + C_L)}$$

The internal resistance of an accelerometer is extremely high, always exceeding 20,000 MΩ at room temperature (~ 20°C). The resistance of the piezoelectric material is lower at high temperatures but usually still higher than 20,000 MΩ at 250°C. This large resistance gives a low frequency cut-

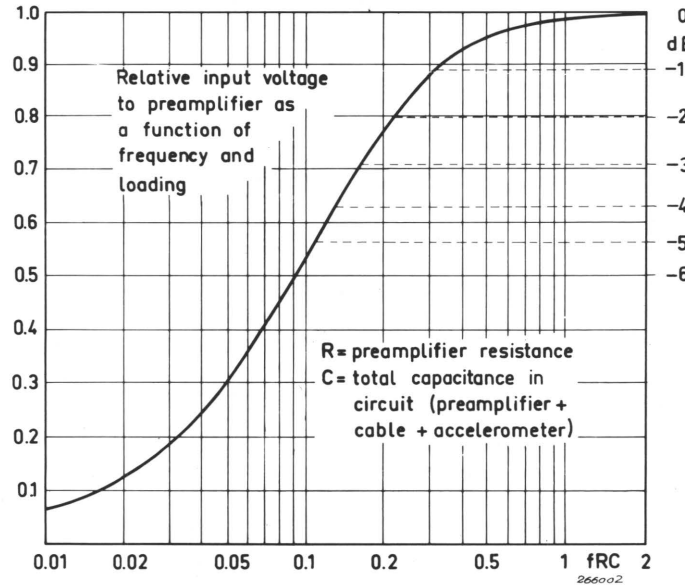


Fig.7.2. Chart for finding required input impedance when accelerometer capacitance and low frequency cut-off is given

off value of 0.008 Hz for the accelerometer alone and thus makes measurement possible down to practically DC with specially designed amplifiers. Fig.7.2 gives a chart for finding the lower limiting frequency for a given accelerometer and preamplifier.

Example:

Find the lower limiting frequency for a 1 dB cut off using an accelerometer with capacitance 1000 pF and cable capacitance 105 pF, and a preamplifier with coupling capacitance of 1000 pF and input resistance 2000 MΩ.

Solution:

A 1 dB cut-off is seen to give a value of about 0.3 for fRC, i.e.

$$fRC = 0.3$$

$$f = \frac{0.3}{RC}$$

$$R = 2000 \times 10^6\ \Omega$$

and from equation (2)

$$C = \frac{(C_a + C_L)\, C_c}{C_a + C_L + C_c} = \frac{(1000 + 105)\, 1000}{1000 + 105 + 1000} = 0.525 \times 10^{-9} \text{ Farads}$$

thus

$$f = \frac{0.3}{(2000 \times 10^6)\,(0.525 \times 10^{-9})} = 0.3 \text{ Hz}$$

7.2. CHARGE PREAMPLIFIERS

The charge preamplifier is gaining widespread acceptance mainly because of its simplicity of operation. It eliminates the effect of shunt capacitance in the input circuit, so that the operator can work without attention to variable accelerometer cable lengths. The only information required is the charge sensitivity of the accelerometer.

Basically a charge preamplifier consists of a high gain operational amplifier with a feedback capacitor. An equivalent circuit diagram for accelerometer, cable and charge preamplifier is given in Fig.7.3. C_f is the feedback

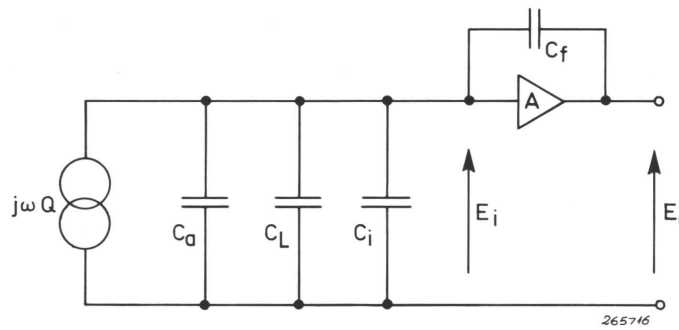


Fig.7.3. Equivalent circuit diagram for accelerometer, cable and charge amplifier

capacitor. It is found that the output voltage is

$$E_o = \frac{QA}{C_a + C_L + C_i - C_f (A - 1)}$$

Since the open loop gain of the amplifier, A, is very large, then usually

$$C_f (A - 1) \gg C_a + C_L + C_i$$

so the output becomes

$$E_o = \frac{QA}{-C_f (A - 1)} \simeq \frac{Q}{C_f}$$

Hence if C_f remains constant, the output is directly proportional to the charge appearing across the accelerometer, and the cable capacitance, C_L, normally has a negligible effect. Only for very long cables where C_L becomes of the same order as AC_f will it affect the gain. When using charge amplifiers, the accelerometer low frequency response is determined only by the low frequency response of the amplifier. RC time constant considerations do not apply.

The charge sensitivity of a piezoelectric accelerometer does in general change with temperature, but the change is less than the change in voltage sensitivity and capacitance. All three quantities are normally supplied as a function of temperature on the individual accelerometer calibration chart so that corrections can be made accordingly.

7.3. EFFECT OF CABLE CAPACITANCE ON SENSITIVITY

In the discussion on the Voltage Preamplifier, it was seen that output voltage of the preamplifier could be appreciably influenced by the variation of cable capacitance. When the charge sensitivity of the accelerometer is given the easiest way to obtain the voltage sensitivity for any particular system is to divide the charge sensitivity by the total shunt capacitance in the input circuit, i.e. accelerometer capacitance, cable capacitance and pre-amplifier input capacitance.

The capacitance of an accelerometer cable is often about 90 pF/m (27 pF/ft).

Example:

An accelerometer has a charge sensitivity of 11.18 p Coulomb/g and a capacity without cable of 1014 pF. What is the voltage sensitivity with a connection cable of 4 m length? Preamplifier input capacitance negligible.

Solution:

Cable capacitance $4 \times 90 = 360$ pF
Total capacitance $360 + 1014 = 1374$ pF

$$\text{Voltage sensitivity } \frac{11.18}{1374} = 0.00816 \text{ V/g} = 8.16 \text{ mV/g}$$

Procedure in working from the voltage sensitivity is illustrated by a second example:

Figures from the accelerometer calibration chart:

Voltage sensitivity 20 mV/g
Capacitance incl. cable 1100 pF
Cable capacitance 100 pF

Find the sensitivity with a new cable of capacitance 200 pF.

Solution:

Accelerometer capacitance is $1100 - 100 = 1000$ pF
New total capacitance is $1000 + 200 = 1200$ pF

$$\text{The new sensitivity will be } 20 \frac{1100}{1200} = 18.3 \text{ mV/g}$$

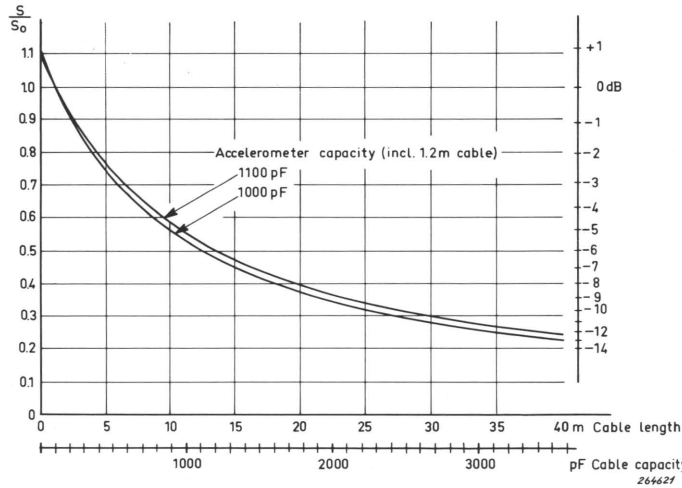


Fig.7.4. Chart for finding change in accelerometer sensitivity due to long connection cables. S/S_0 is the ratio of the new sensitivity to the sensitivity given on the calibration chart (with 1.2 m cable)

Fig.7.4 gives a chart for calculating the new sensitivity when long cables are used with the accelerometers. When cable of capacitance approximately 90 pF/m is used, the sensitivity change may be read off directly versus cable length. For other types the capacitance should be measured or calculated from manufacturer's data.

7.4. SELECTION OF PREAMPLIFIERS

The basic differences between charge and voltage preamplifiers are:

Voltage amplifiers employ a simple impedance conversion in the input stage.

Charge amplifiers employ a certain amount of feedback to compensate for capacitive load.

Voltage amplifiers are thus simple, reliable, low current consumption devices. It is important to know the input characteristics well in order to use them properly.

The large amplification necessary for proper operation of the charge

amplifier requires more components than are necessary for a voltage amplifier. In practice this means higher costs and less reliable operation in severe environments.

It is possible to use long cables with charge amplifiers without reducing the sensitivity and necessarily having to recalibrate the system.

Charge amplifiers are available with lower limiting frequencies of down to 0.003 Hz. This is an advantage when measuring shock pulses, but this facility should be used with care as it will introduce low frequency noise, due to temperature transients, in a measurement.

Other considerations to be taken into account are:

(1) When using Uni-Gain® accelerometers, fixed gain preamplifiers should be chosen. Naturally Uni-Gain® accelerometers designed for a standard voltage sensitivity should be used with voltage preamplifiers and similarly accelerometers designed for a standard charge sensitivity should be used with charge preamplifiers.

(2) Velocity or displacement can be measured when using preamplifiers that have built-in integrating networks.

(3) Wide conditioning possibilities for all accelerometers and measuring requirements are available when using conditioning preamplifiers.

7.5. B & K ACCELEROMETER PREAMPLIFIERS

7.5.1. Preamplifier Type 2616



Fig.7.5. Preamplifier Type 2616

The Preamplifier Type 2616 is designed for mounting near to the accelerometer thus enabling short cables to be used to the transducer and long cables to the indicating instrument. This ensures that noise and loss in the cable do not interfere with the measurements when the measuring instrument is a long distance from the accelerometer. A field effect transistor (FET) in the input stage assures a high input impedance (1200 MΩ), wide frequency range and low noise. The input is decoupled by a 2000 pF series capacitor and the input stage is DC coupled to the second feedback amplifier stage.

The equivalent circuit of the preamplifier is shown in Fig.7.6.

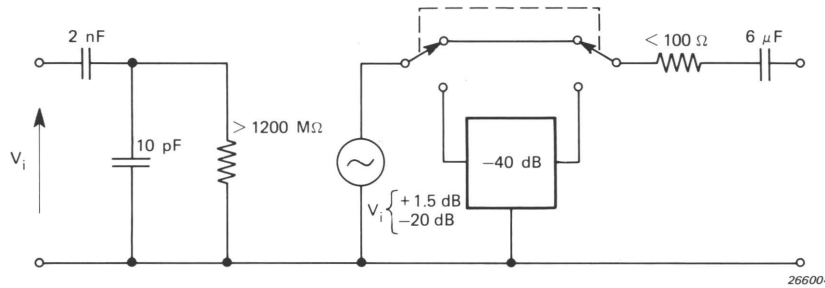


Fig.7.6. Equivalent circuit diagram of Type 2616

The maximum output current where clipping occurs is 1 mA, which gives the high frequency limits for different capacitive loads as shown in Fig.7.7.

The maximum input voltage is 1 V RMS (switch position "0 dB") and 100 V RMS (switch position "−40 dB"). The gain of the amplifier can be switched from 0 dB to −40 dB and a potentiometer attenuates the signal over a range of about 20 dB. A peak-indicating overload indicator shows the peak value of the input signal for crest factors up to 10 and for frequencies higher than 20 Hz and indicates when the amplifier is clipping. The output impedance is less than 100 Ω. The 2616 is powered by 6 Mallory cells (1.35 V each) which are contained in a battery compartment attached to the preamplifier (Fig.7.8).

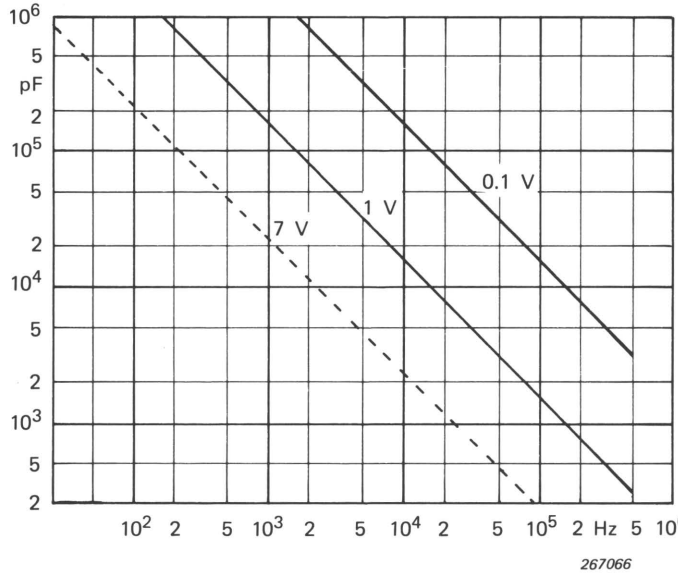


Fig.7.7. High frequency limits of Type 2616 for different loads and output voltages

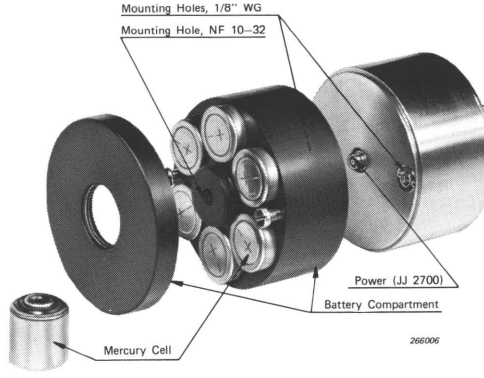


Fig.7.8. Exploded view of the battery compartment in Type 2616

Specifications 2616

Input impedance:	>1.2 GΩ
Input capacitance:	10 pF
Max. Input Signal:	100 V RMS (in pos. "–40 dB")
Output Impedance:	<100 Ω
Max. Output Current:	1 mA
Output Load Impedance:	>10 kΩ
Frequency Range (3 dB limits):	0.13 Hz to 500 kHz (1 nF at input)
Noise:	25 μV (2 Hz to 40 kHz 1 nF at input)
Harmonic Distortion:	$<1\%$
Gain:	+ 1.5 dB to –20 dB (attenuator on 0 dB)
Rise Time:	1 μsec
Power Supply:	6 to 35 V DC, 3 to 10 mA or internal battery
Internal Battery Supply:	six mercury cells 1.35 V Mallory RM LR IEC Type MR 7 (B & K part no. QB 0007)
Dimensions:	
Height	66 mm (2.6 in)
Width	52 mm (2 in)
Weight:	290 g (10.3 oz)
Accessories included:	1 Cable AO 0037 1 Hexagon Key QA 0013 6 Batteries QB 0007

7.5.2. Preamplifier Type 2623

The Voltage Preamplifier Type 2623 (Fig.7.9) is designed as an impedance transformer having a very high input impedance and a low output impedance. This compact, rugged unit operates in extreme dynamic environments, eliminating the effects of noise and losses in connecting cables and permitting the use of readout instrumentation at a considerable distance from the measuring point. The Preamplifier is ideal for low level, low frequency measurements, yet its dynamic range of 110 dB from 0.1 Hz to 500 kHz also permits measurements at high signal levels.

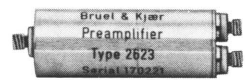


Fig.7.9. Preamplifier Type 2623

Noise due to direct vibration of the unit is not measurable because of vibration noise of the connecting cables. The preamplifier can be mounted directly onto an accelerometer for which a special adapter is provided, or very close to the accelerometer, for which purpose a mounting bracket is also provided (Fig.7.10).

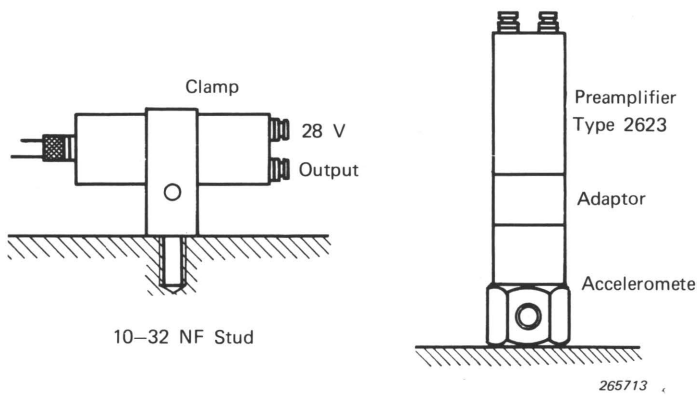


Fig.7.10. Mounting of the Preamplifier Type 2623 near or on top of the accelerometer

The 2623 contains a two stage preamplifier, having a gain of unity (0 dB). From Fig.7.11, which shows the equivalent circuit of the unit it can be seen that the input is led via a 1000 pF capacitor to a very high input impedance of more than 2 GΩ (2×10^9 Ω) at room temperature obtained by using a field effect transistor.

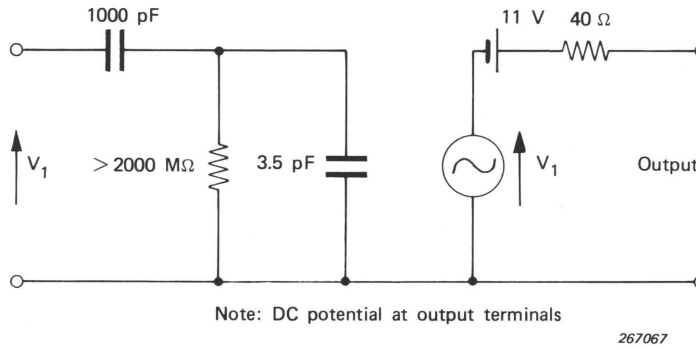


Fig.7.11. Equivalent circuit diagram of Type 2623

The input impedance reduces with temperature, but is still greater than 200 MΩ at 100°C. Temperature does not affect the gain of the amplifier. The input coupling capacitor and the input impedance determine the low frequency cut-off and this varies with temperature as shown in Fig.7.12.

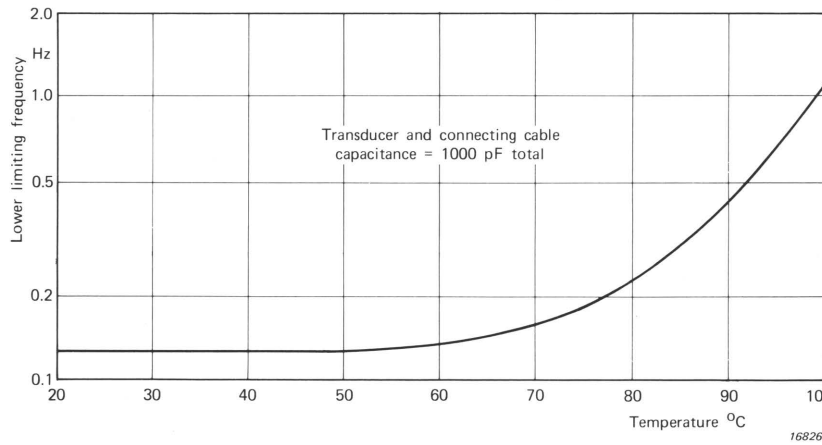


Fig.7.12. Variation of low frequency cut-off with temperature

The 2623 requires an external power supply of 28 V DC. Current consumption is 2 mA. When used in conjunction with one of the B & K measuring units, Power Supply Adapter ZR 0024 can be used to supply the necessary voltage and provide miniature plug connections. The Modular Power Supply Type 2805 can also be used, which can supply up to ten units at a time.

Specifications 2623

Input Impedance:	2 GΩ
Input Capacitance:	3.5 pF
Max. Input Signal:	7 V RMS
Output Impedance:	$<$40 Ω
Max. Output Current:	1 mA
Output Load Impedance:	$>$50 kΩ
Frequency Range:	0.16 Hz to 500 kHz (1 nF at input)
Noise:	15 μV (2 Hz to 40 kHz) (1 nF at input)
Harmonic Distortion:	$<$1%
Gain:	0 dB ± 0.05 dB
Rise Time:	3 μsec
Power Supply Required:	28 V DC 2 mA
Internal Battery Supply:	None
Dimensions:	
Height	45 mm (1.77 in)
Diameter	14 mm (0.5 in)
Weight:	20.6 gm (0.73 oz)
Accessories Included:	1 Adapter UA 0144 1 Clamp DH 0120 2 Cables AO 0037 1 Hexagon Key QA 0013

7.5.3. Charge Amplifier Type 2624

The Charge Amplifier Type 2624 is independent of type and length of cable to the accelerometer within wide limits making it especially attractive in vibration measurements where cables of different type and length are used to the accelerometer. The preamplifier also gives the possibility of measurements at very low frequencies such as is required for measurement of shocks.



Fig.7.13. Charge Amplifier Type 2624

The preamplifier contains an input circuit with a field effect transistor which gives a high input impedance of more than 10 GΩ. See block diagram Fig.7.14. The input circuit is followed by a high gain operational amplifier and a class B output stage which delivers the relatively high capacitive current required by the feedback capacitor C_f at high frequencies. The feedback resistor R_f stabilizes the DC level of the amplifier. The output voltage is proportional to the charge appearing across the accelerometer.

The preamplifier is provided with an overload indicator which lights up when the dynamic range is exceeded and when the amplifier is blocked due to saturation. A reset button is used for recovery of normal working conditions after overload. The output may be scaled to 0.1, 1 or 10 mV/pC giving different low frequency limits. Table 7.1 gives the frequency response of the 2624 in the different sensitivity ranges. The values are valid when the capacitive load at the .input is negligible. Input and output sockets are miniature sockets 10–32 NF, and the preamplifier is completely protected against overload and short circuits.

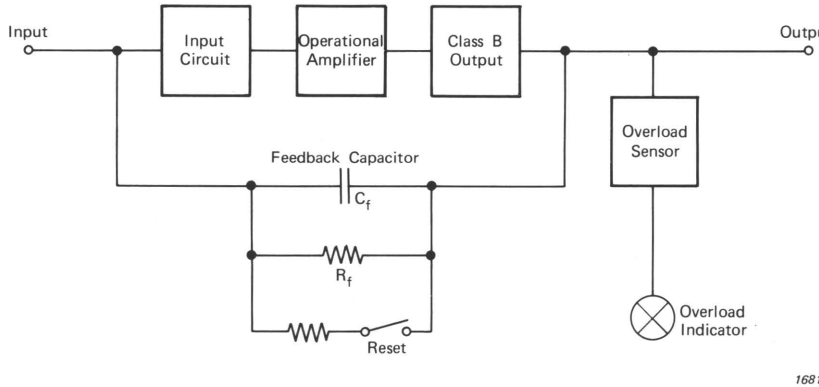


Fig.7.14. Block diagram of Type 2624

Sensitivity mV/pC	−3 dB point, Hz	Frequency Range Hz
0.1	0.003	0.03–30,000 ±1%
1	0.03	0.3 –30,000 ±1%
10	0.3	5 –10,000 ±5%
0.1	0.3	3 –30,000 ±1%
1	3	30 –10,000 ±1%
10	30	150 –10,000 ±5%

Table 7.1. Frequency response for different sensitivity settings

Specifications 2624

Input impedance: $>10\ G\Omega$ (input DC shunt resistance)

Max. Input Signal: 10^5 pC

Max. Input Load: 1 μF for 1% error (in pos. 0.1 mV/pC)

Output Impedance: 1 Ω (1/4 loaded, 3 – 5 Ω (full load)*

Max. Output Voltage/Current: ± 10 V, ± 10 mA

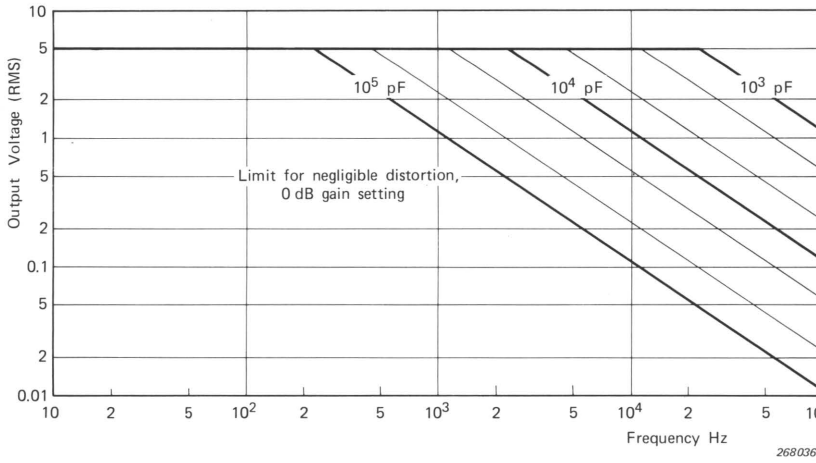


Fig.7.15. Distortion limits for Type 2624 for different loads and output voltages

Output Load Impedance:	>1 kΩ
Frequency Range:	0.003 Hz to 100 kHz (see Table 7.1 and Fig.7.15)
Noise:	max. 20 μV + max. 10 μV/100 pF**
Harmonic Distortion:	$<0.5\%$ (no cap. load) $<5\%$ (full cap. load)
Gain:	0.1 – 1 – 10 (–20, 0, + 20 dB)
Rise Time:	proportional to pulse height. Typically 1.8 V/μsec
Overload Recovery Time:	$\geqslant 5$ msec
Power Supply:	28 V DC, 17 to 40 mA
Internal Battery Supply:	None

* Charge Input
** Source Capacitance

Dimensions:	
Height	132.6 mm (5.22 in)
Width	30.3 mm (1.19 in)
Depth	200 mm (7.87 in)
Weight:	585 g (1.29 lb)
Accessories Included:	2 Cables AO 0037

7.5.4. Vibration Pick-up Preamplifier Type 2625

The Vibration Pick-up Preamplifier Type 2625 (Fig.7.16) is provided with integration networks and is therefore also suitable for the measurement of velocity and displacement as well as acceleration.

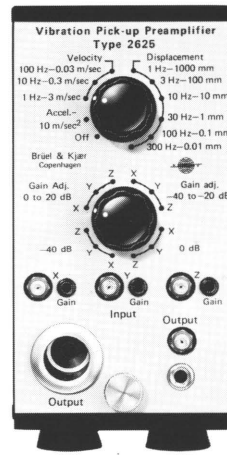


Fig.7.16. Vibration Pick-up Preamplifier Type 2625

It has three inputs (Miniature Socket Type 10–32 NF). The three input sockets are connected to the Selector Switch (see Fig.7.17), which selects one of the three inputs and short circuits the other two. It accommodates three accelerometers very conveniently, which makes the preamplifier ideally suited for triaxial measurements.

The Selector Switch also controls four different gain ranges for the three inputs: 1) variable from –40 dB to –20 dB, 2) variable from 0 dB to 20 dB,

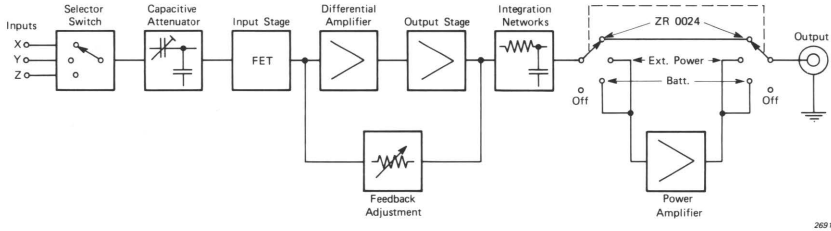


Fig.7.17. Block diagram of Type 2625

3) fixed at −40 dB, 4) fixed at 0 dB. The signal is fed to the differential amplifier and output stage (each of which has feedback adjustment) via the field effect transistor input stage (input impedance variable between 450 MΩ and 3 GΩ depending on gain setting) and further into the integration networks. These networks provide for the velocity and displacement function.

The integration networks are passive RC networks with the frequency ranges as in Table 7.2. The networks used should be chosen so as to obtain the best possible signal to noise ratio by setting the low frequency limit as high as possible.

Mode	Range	Frequency Range Hz
Vel.	3.16 m/sec	1–4000
Vel.	0.316 -	10–10,000
Vel.	0.0316 -	100–30,000
Displ.	1000 mm	1–30
Displ.	100 -	3–100
Displ.	10 -	10–300
Displ.	1 -	30–1000
Displ.	0.1 -	100–3000
Displ.	0.01 -	300–10,000

Table 7.2. Frequency ranges of the integration networks

The low frequency response for different gain settings is shown in Fig.7.18.

Fig.7.19 shows the upper frequency response for two different gain and four different signal levels. The curves give the response with and without the power amplifier.

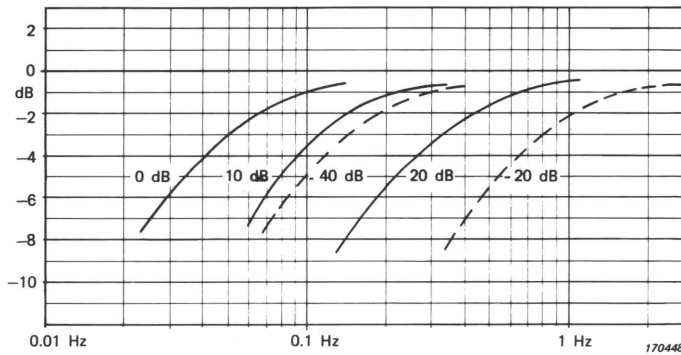


Fig.7.18. Lower frequency response curves of Type 2625 for different gain settings

In the acceleration mode the integration networks are not incorporated. The Preamplifier has a Power Supply selector for choice of three sources of supply: 1) Power Supply ZR 0024, 2) other external power supply 28 V DC, 3) built-in batteries. In the two latter positions the output is taken via the built-in power amplifier.

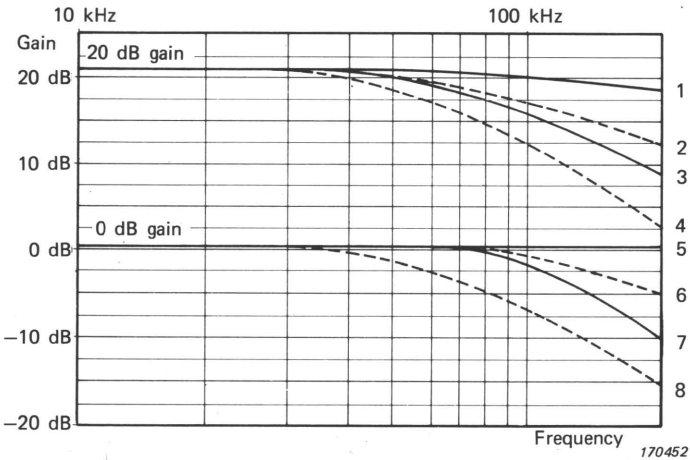


Fig.7.19. Upper frequency response curves of Type 2625. Curve identification
Full line curves: response with output amplifier. Dashed curves: without output amplifier. Input signal levels: 1 and 2; 0.1 V RMS. 3 and 4; 0.5 V RMS. 5 and 6; 1 V RMS. 7 and 8; 5 V RMS

When the preamplifier is operated from the ZR 0024 Power Supply the maximum output voltage and current available in position Accel. is ± 7 V and ± 1 mA. Fig.7.20 shows the limitation of high frequency performance when working with capacitive loads.

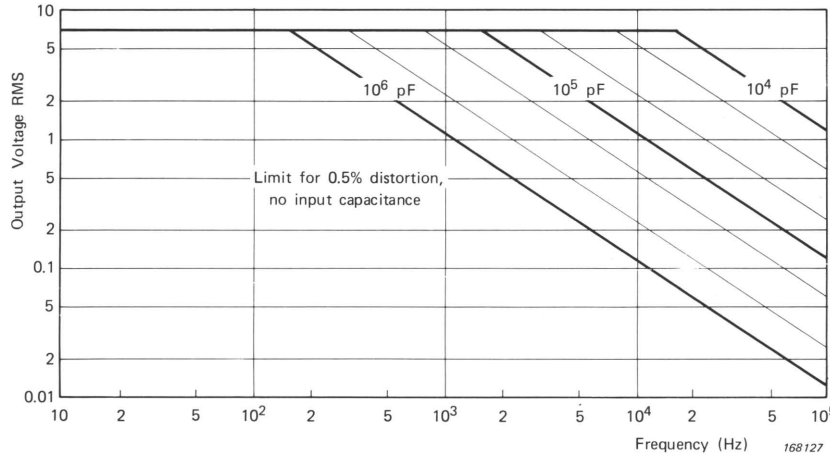


Fig.7.20. High frequency limits of Type 2625 without output amplifier for different loads and output voltages

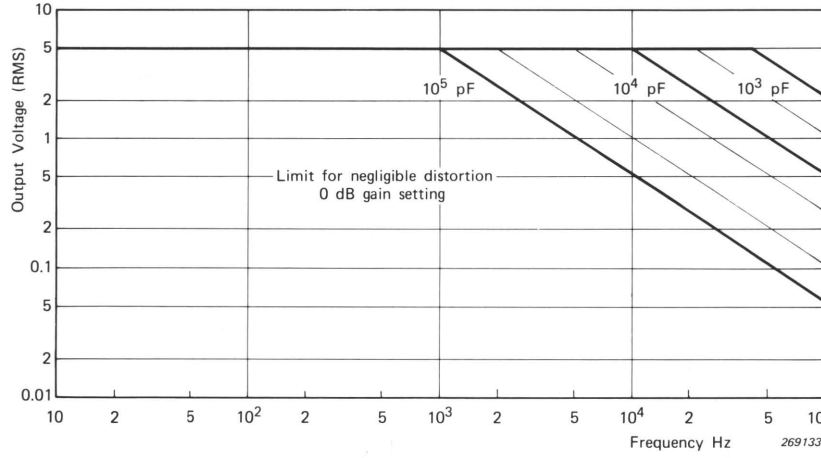


Fig.7.21. High frequency limits of Type 2625 with output amplifier for different loads and output voltages

When operated from Ext. Power or Batt. the power amplifier is incorporated. This gives a maximum output voltage and current of ± 7 V

and ± 2.3 mA, thus reducing the loading restriction considerably as shown in Fig.7.21.

Specifications 2625

Input Impedance:	450 MΩ to 3 GΩ
Input Capacitance:	14 pF
Max. Input Signal:	± 700 V (in pos. −40 dB)
Output Impedance:	< 30 Ω (Power amplifier)
Max. Output Voltage/Current:	± 7 V/± 2.3 mA (Power amplifier)
Output Load Impedance:	> 1 MΩ (In output switch pos. "ZR 0024") > 3.5 kΩ (Power amplifier)
Frequency Range:	1 Hz to 35 kHz (see Figs.7.18 to 7.21 and Table 7.2)
Noise:	< 20 μV (2 Hz to 40 kHz) (1 nF at input)
Harmonic Distortion:	< 1% (5 V RMS input acc. mode)
Gain:	Fixed 0 dB and −40 dB Variable 0 to 20 dB and −40 dB to −20 dB
Power Supply:	28 V DC either Internal Battery (7 mA), ZR 0024 (2 mA) or External Power Supply (7 mA)
Internal Battery Supply:	Three 9 V batteries IEC Type 6 F 22 (B & K Type QB 0010)
Dimensions:	
Height	132 mm (5.22 in)
Width	61 mm (2.40 in)
Depth	200 mm (7.87 in)
Weight:	820 gm (1.8 lb)

Accessories included: 2 Cables AO 0037
1 Coaxial Plug JP 0101

7.5.5. Conditioning Amplifier Type 2626

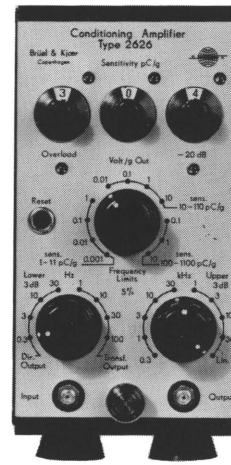


Fig.7.22. Conditioning Amplifier 2626

The Conditioning Amplifier Type 2626 (Fig.7.22) is designed as a charge preamplifier. It offers wide conditioning possibilities to different transducers and measuring requirements. The preamplifier has a 3 digit sensitivity adjustment network which enables its sensitivity to be adjusted to the particular transducer used. The network is calibrated in pC/g. The preamplifier has rated output stepwise adjustable between 1 mV/g and 10 V/g, dependent to a certain extent on the sensitivity of the transducer. The maximum gain is 60 dB. Adjustable HP and LP filters are included. The filter switch scales give 5% as well as the 3 dB frequency limits.

Fig.7.23 shows the block diagram of the preamplifier. The signal from the transducer is fed to the input section of the 2626 which contains an amplifier stage with capacitive feedback forming a charge preamplifier. The signal goes on to the conditioning section where the sensitivity is adjusted to match the transducer and further to a Low Pass filter (2 pole Butterworth) and a High Pass filter (single pole) where the upper and lower frequency limits of the amplifier are determined. From the filters the signal is fed to an output amplifier and further to the output. The signal is available either directly coupled or through a transformer (switchable) for floating output.

Two neon indicators are connected to the output, one acts as an overload indicator, the other indicates when the signal level is less than 20 dB below full output.

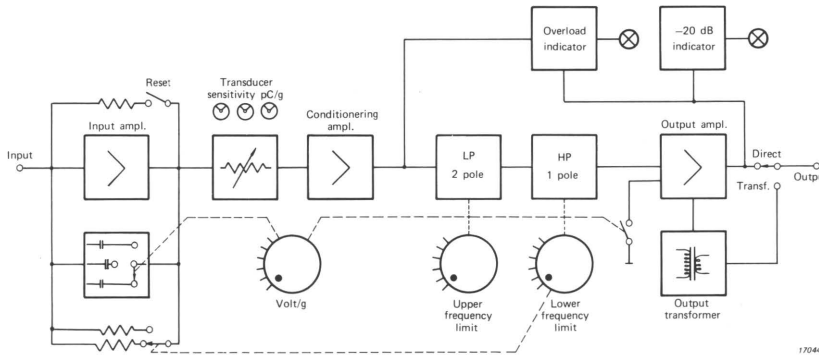


Fig.7.23. Block diagram of Type 2626

Specifications 2626

Input Impedance:	>10 GΩ (input DC shunt resistance)
Max. Input Signal:	10^5 pC
Output Impedance:	<10 Ω (Direct)
Max. Output Voltage/Current:	± 10 V, ± 10 mA
Output Load Impedance:	Direct: >1 kΩ Transformer: >1 kΩ
Frequency Range:	0.3 Hz to 100 kHz (3 dB) 1 Hz to 30 kHz (5%)
Noise:	<5 μV RMS referred to input
Harmonic Distortion:	<1%
Gain:	–20 to + 60 dB
Rise Time:	Proportional to pulse height. Typically 5 V/μsec
Overload Recovery Time:	200 μsec

Power Supply:	100 to 240 V AC $<$25 mA
Internal Battery Supply:	None
Dimensions:	
Height	132.6 mm (5.22 in)
Width	69.5 mm (2.75 in)
Depth	200 mm (7.87 in)
Weight:	1.75 kg (3.89 lb)

7.5.6. Low Frequency Charge Amplifier Type 2628

The LF Charge Amplifier Type 2628 is an impedance converter and signal conditioning device for use with piezoelectric force and vibration transducers, and is particularly suitable for handling very low frequency and quasi-static signals. Depending on the gain setting it has time constants of up to 100 000 seconds, which corresponds to a low frequency limit of 2 μHz.

A three digit "dial-in" sensitivity adjustment feature is incorporated which conditions the amplifier to the exact sensitivity of the transducer between 1 and 100 pC/unit, the position of the decimal point being auto-

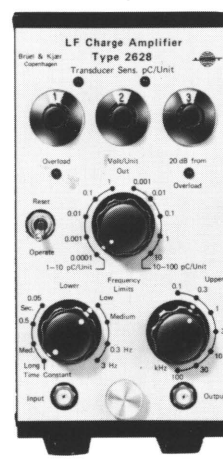


Fig.7.24. Low Frequency Charge Amplifier Type 2628

matically indicated by a light emitting diode. This feature greatly simplifies the calibration and reading of a measuring system, especially when using transducers which have "odd" sensitivity values, i.e. non Uni-gain® types.

A block diagram of the instrument is shown in Fig.7.25. The input stage uses a MOSFET transistor operating at an extremely low input current to secure a satisfactory low frequency response. Stepwise adjustment of the stage gain allows the signal output from the instrument to be chosen between 0.0001 V/unit and 10 V/unit. The time constant of the stage can also be adjusted in four steps between 100 000 seconds and 0.05 seconds, corresponding to 3 dB cut off frequencies of 2 μHz to 3 Hz. The shorter time constants are used for the low frequency dynamic applications while the longer time constants will be used for quasi-static applications. The circuit is cleared by a manual reset switch on the front panel or from a remote switch or logic circuit connected to a socket on the rear panel.

From the input stage the signal is fed to the active LP filter which is used to suppress unwanted higher frequency signals such as mechanical resonances etc. The upper limiting frequency of the filter can be adjusted in steps

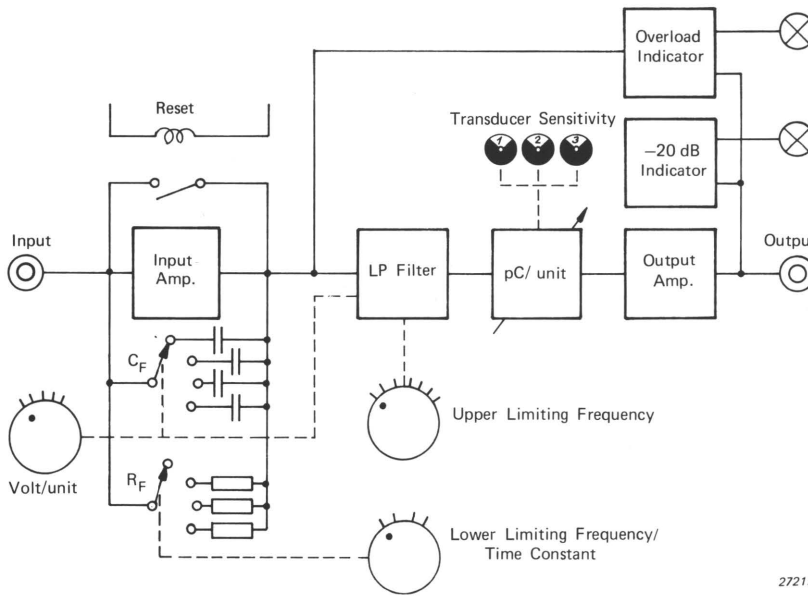


Fig.7.25. Block Diagram of Type 2628

between 100 Hz and 100 kHz, the cut-off slope being 12 dB/octave.

Two signal level indicators are provided. The first indicates overload at the input or output stage and the second lights when the signal level is within 20 dB of full output, thus indicating the best output signal level for minimum noise.

Both input and output sockets on the front panel suit B&K standard miniature plugs. Duplicate input and output sockets are provided on the rear panel, the duplicate output socket being of the BNC type.

Specifications 2628

Input Impedance	10^{14} Ω (input DC shunt resistance)
Max. Input Signal	10^{6} pC
Output Impedance	< 1 Ω
Max. Output Voltage/Current	± 10 V, ± 10 mA
Output Load Impedance	1 kΩ
Frequency Range	2 μHz to 100 kHz (3 dB)
Noise	< 30 μV RMS (refered to input)
Harmonic Distortion	< 1%
Gain	−40 to + 60
Slew Rate	1 V/μs
Recovery Time	~ 100 μs
Power Supply	100 to 240 V AC < 25 mA
Dimensions:	
Height	132.6 mm
Width	69.5 mm (2.75 in)
Depth	200 mm (7.87 in)
Weight:	1.45 kg (3.25 lb)

7.5.7. Accelerometer Calibrator and Preamplifier Type 4292

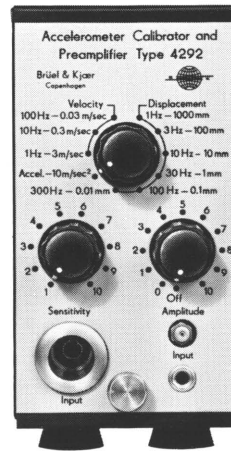


Fig.7.26. Accelerometer Calibrator and Preamplifier Type 4292

The Type 4292 (Fig.7.26) is designed as a small compact calibrator and preamplifier unit for vibration measurements. The preamplifier contains integration networks, allowing measurements of vibration acceleration, velocity and displacement. A small built-in shaker table adjustable to 1 g peak allows easy sensitivity check of the accelerometer and calibration of the complete vibration measuring set-up.

The instrument is made for direct connection to the 7 pin preamplifier input socket on the B & K Measuring Amplifiers and Frequency Analyzers or to the B & K Microphone Power Supplies 2801 and 2807. Power for the preamplifier and built-in calibrator is supplied via this 7 pin plug which also feeds the output signal from the preamplifier to the instrument to which it is connected.

Preamplifier Section

The preamplifier consists of an input stage, an amplifier and integration networks. Two parallel connected input sockets allow connection of cables fitted either with standard miniature plugs 10–32 NF or fitted with the standard B & K coaxial plug. The input stage uses a FET (field effect transistor) giving a high input impedance whereby a low lower limiting frequency is obtained from the combination of accelerometer capacitance and preamplifier input impedance.

Frequency Range	Mode	Range
1 to 35,000	Acc.	10 m/sec^2
1 to 4000	Vel.	3.16 m/s
10 to 10,000	Vel.	0.316 -
100 to 30,000	Vel.	0.0316 -
1 to 30	Displ.	1000 mm
3 to 100	Displ.	100 -
10 to 300	Displ.	10 -
30 to 1000	Displ.	1 -
100 to 3000	Displ.	0.1 -
300 to 10,000	Displ.	0.01 -

Table 7.3.

The amplifier has gain adjustable from 0 to 20 dB. This allows sensitivity correction to be made for easy reading of the measured vibration value with accelerometers not having simple sensitivity figures.

The integration networks give single or double integration whereby the output signal will be proportional to vibration velocity or displacement. Three velocity positions and six displacement positions with different low frequency cut-off points can be chosen to obtain the best possible signal to noise ratio for the required frequency range of measurements. A position where the integration networks are bypassed allows direct measurement of vibration acceleration. Table 7.3 gives the frequency limits for the integration network.

Calibration Section

The calibrator is made as an electrodynamic exciter driven by a 79.6 Hz Wien bridge oscillator and a driver amplifier (79.6 Hz corresponds to ω = 500 rad/sec, and affords simple calculation). The tension of the bronze band suspension, which controls the resonance of the shaker system can be adjusted by means of a knob on the rear panel of the preamplifier. This corrects for different loads on the exciter table. The vibration level is adjusted by regulation of the input voltage to the driver amplifier. The entire exciter system is hung in a spring suspension so as to isolate it from extraneous vibrations.

The shaker table has a 10–32 NF tapped hole for mounting the accelerometer. A hermetically sealed cylinder mounted inside the table contains a small bronze ball resting on three points.

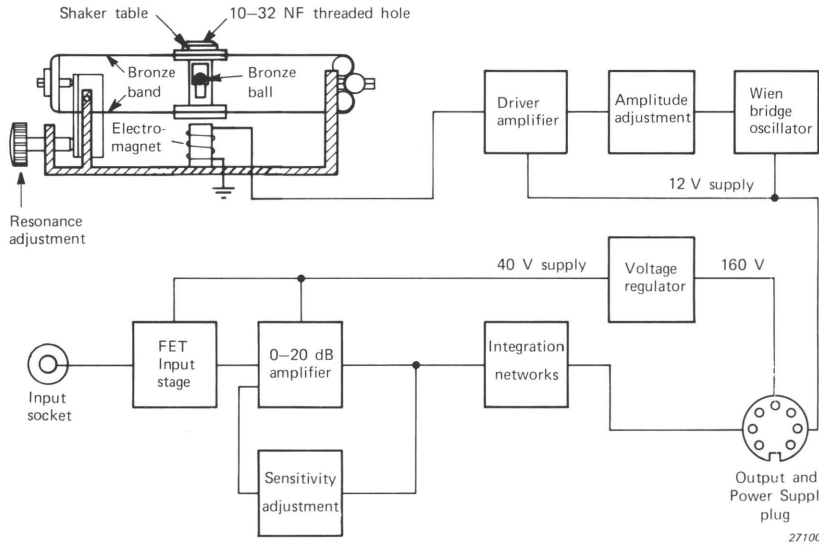


Fig.7.27. Block diagram of the Type 4292

Calibration is made at 1 g peak by adjusting the vibration level of the table until the ball balances at the threshold of rattling. This condition can be heard and at the same time seen on the indicating instruments. Fig.7.27 shows a sketch of the principle of operation of the complete unit Type 4292.

Specifications 4292

Preamplifier:

Input Impedance:	min. 2 GΩ at 0 dB gain min. 450 MΩ at 20 dB gain
Input Capacitance:	8 pF
Max. Input Signal:	± 15 V at 0 dB gain ± 1.5 V at 20 dB gain
Max. Output Voltage:	± 15 V in acc. mode
Output Load Impedance:	Min. 1 MΩ
Frequency Range:	1 Hz to 35 kHz (accel. mode)

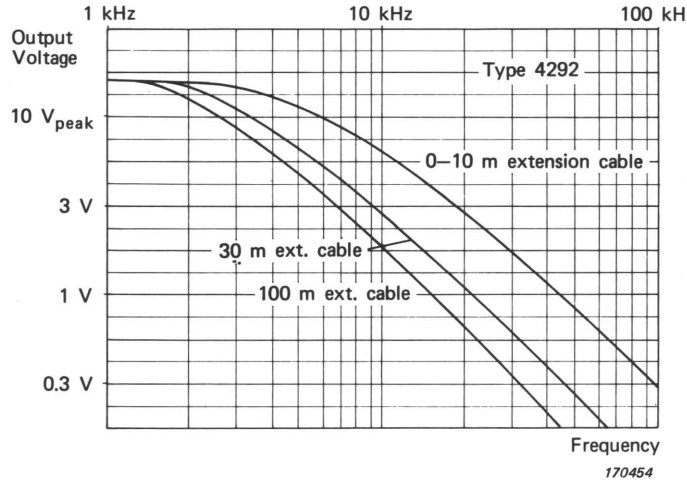


Fig.7.28. Upper limits of dynamic range (1% distortion) due to load by extension cables as a function of voltage and frequency. Minimum sensitivity. Cable capacitance 5 nF/100 m

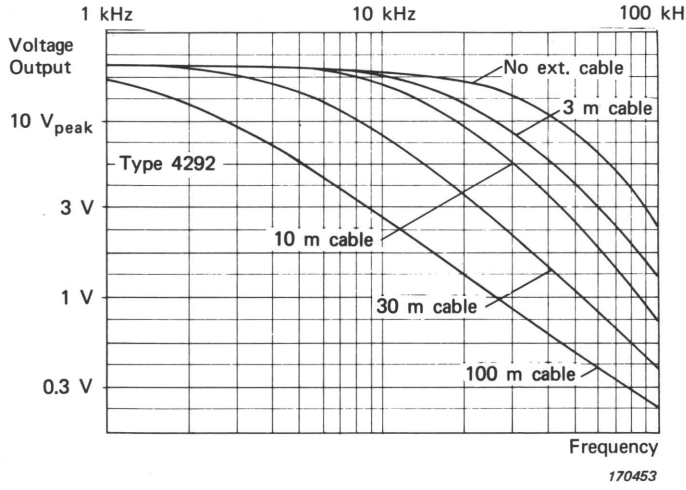


Fig.7.29. Upper limits of dynamic range (1% distortion) due to load by extension cables as a function of voltage and frequency. Maximum sensitivity. Cable capacitance 5 nF/100 m

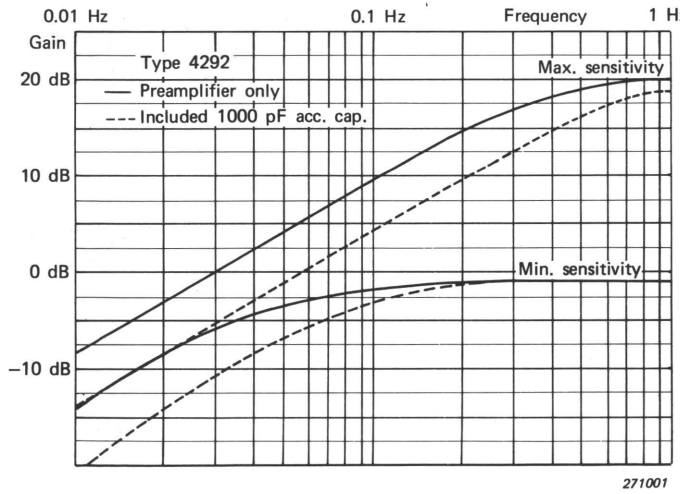


Fig.7.30. Lower frequency response with and without accelerometer capacitance included

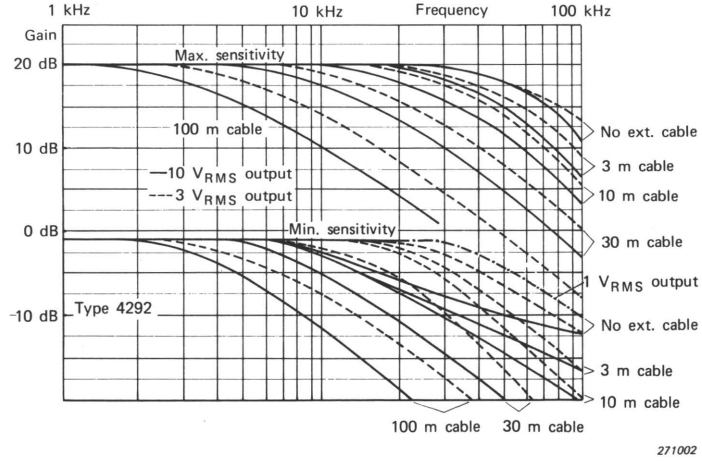


Fig.7.31. Upper frequency response due to load by extension cables at different output voltages and at max. and min. sensitivity. Cable capacitance 5 nF/100 m

Noise:	from 2 Hz to 40 kHz with 1 nF across input (referred to input) Min. sensitivity $<60\ \mu V$ Max. sensitivity $<20\ \mu V$
Harmonic Distortion:	less than 1% with 10 V RMS input at 0 dB gain, acceleration mod and $f<3$ kHz
Gain:	variable from 0 to 20 dB
Calibrator: Frequency:	79.6 Hz
Table Load for 1 g peak:	0 to 70 gram
Accuracy of Calibration:	± 10%
Q at Resonance:	approx. 40 dB
Mounting Thread:	10–32 NF
Power Supply:	from B & K 7 pin input plug on measuring amplifiers, frequency analyzers and power supplies.
Dimensions: Height Width Depth	 132.6 mm (5.2 in) 69.5 mm (2.74 in) 200 mm (7.9 in)
Weight:	2.9 kg (6.4 lb)

7.5.8. Microphone Preamplifier Type 2619

This microphone FET preamplifier is suitable for piezoelectric accelerometers due to its extremely high input impedance and very wide frequency and dynamic ranges. Among other accessories an Adapter JJ 2615 is included for the connection of miniature accelerometer cables. This adapter contains a 50 pF capacitor for blocking the polarization voltage. With its wide frequency range and short rise and fall times, the preamplifier is ideal for measurements of transient signals and shocks. The preamplifier can be plugged into any B & K instrument with a microphone input socket.



Fig.7.32. Microphone Preamplifier Type 2619

Specifications 2619

Supply Voltage DC	120 V	28 V
Input Resistance at 20°C at 80°C	>4000 MΩ >2500 MΩ	>2600 MΩ >1500 MΩ
Input Capacitance	<0.8 pF	<1 pF
Max. Input Signal	40 V RMS	5 V RMS
Output Impedance	Approx. 25 Ω	Approx. 70 Ω
Max. Output Current	1.5 mA peak	0.5 mA peak
Current Consumption	2 mA	1 mA
Gain	−0.01 dB	−0.04 dB

Frequency Range:	2 Hz – 200 kHz
Rise Time:	0.2 μsec
Noise, 20 Hz – 200 kHz: (JJ 2615 at input):	<18 μV <17 μV with heating element disconnected
Dimensions:	1/2" dia

Connection Type:	7 pin B & K
Cable Length:	2 m (6.6 feet)
Accessories Included:	Adapter for 1" microphone (DB 0375) Coaxial input plug adapter for miniature cables (JJ 2615) Gooseneck (UA 0196)

7.5.9. Microphone Preamplifier Type 2615

This preamplifier, which has a vacuum tube input stage, is also suitable for measurements with piezoelectric accelerometers due to its high input impedance and very wide frequency and dynamic range. Small size and a rugged construction make it suitable for operation in most laboratory and field measuring set-ups.



Fig.7.33. Microphone Preamplifier Type 2615

The 2615 may be plugged into any B & K instrument with a microphone input socket. For connection of an accelerometer the Adapter JJ 2615 which contains a built-in 50 pF capacitor, is used.

Specifications 2615

Input Resistance:	700 MΩ
Input Capacitance:	3 pF

Max. Input Voltage:	20 V RMS
Output Impedance:	Approximately 1300 Ω
Output Load Impedance:	$>$50 kΩ
Frequency Range:	Only limited by the capacitance connected at the output (up to above 100 kHz with B & K equipment and without extension cables)
Noise:	40 μV (2 Hz – 200 kHz) 20 pF
Gain:	–0.9 dB ± 0.2 dB
Connection Type:	2 m long cable
Diameter of housing:	12.7 mm (0.5 in)
Length of housing:	70 mm (2.75 in)

8. ACCESSORIES

8.1. CONNECTING CABLES AND PLUGS

Flexible coaxial cables are used for the connection between accelerometer and preamplifier. Unless otherwise ordered the cables delivered with the accelerometers are as indicated in the individual accelerometer specifications.

Three types of cable are available from B & K:

AC 0005 Teflon insulated mininoise cable 90 pF/m (30 pF/ft) for application to 260°C (500°F). Available in lengths up to 180 m (600 ft).

AC 0010 PVC insulated mininoise cable 90 pF/m (30 pF/ft) for operation to 100°C (212°F). Available in lengths up to 180 m (600 ft).

AC 0032 PVC insulated reinforced mininoise cable 90 pF/m (30 pF/ft) for operation to 100°C (212°F). Available in lengths up to 180 m (600 ft).

These are made up with the 10–32 NF miniature plugs JP 0012 for standard sized accelerometer and preamplifier sockets and with the micro-miniature connectors for Accelerometer Type 4344 as follows:

AO 0037 1.2 m (4 ft) of AC 0010 cable fitted with two JP 0012 miniature plugs.

AO 0038 1.2 m (4 ft) of AC 0005 cable fitted with two JP 0012 miniature plugs.

AO 0051 1.2 m (4 ft) of AC 0010 cable fitted with one JP 0012 miniature plug and one micro-miniature plug. (The micro-miniature plug can only be fitted by B & K).

AO 0052 1.2 m (4 ft) of AC 0005 cable fitted with one JP 0012 miniature plug and one micro-miniature plug. (The micro-miniature plug can only be fitted by B & K).

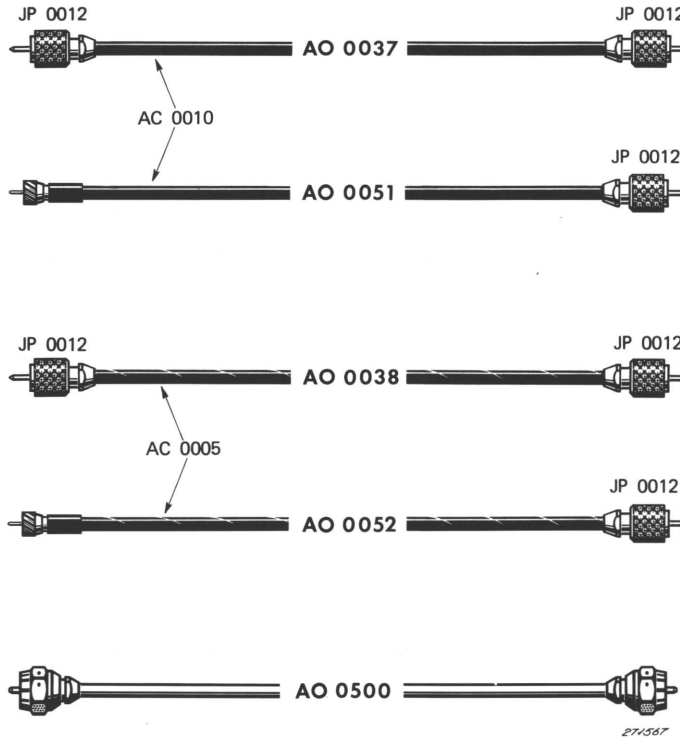


Fig.8.1. Accelerometer cables

AO 0089 3 m (10 ft) of AC 0032 cable fitted with two reinforced plugs JP 0049. (The plugs can only be fitted by B & K).

AO 0500 1.2 m (4 ft) Kapton insulated silver screened cable for operation to 400°C (752°F).

The micro-miniature plugs are only available fitted to the cables AO 0051 and AO 0052. The standard miniature plugs JP 0012 are available



Fig.8.2. Standard B & K miniature connector

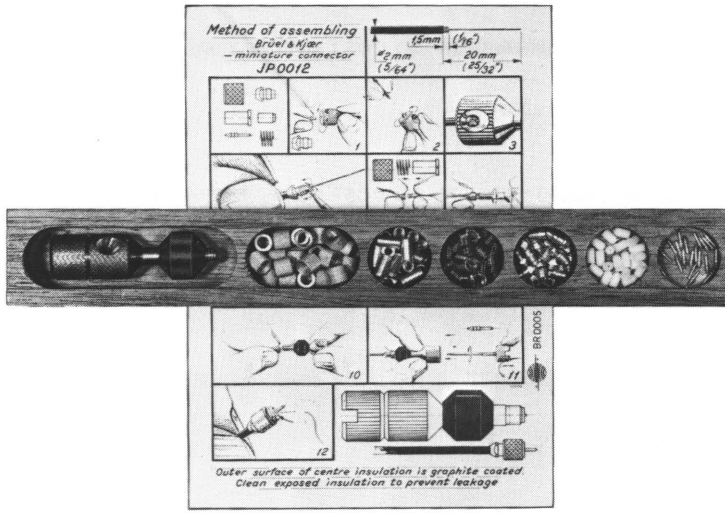


Fig.8.3. Plug Mounting Kit UA 0129

with the assembly kit UA 0129 (Fig.8.3), which includes 20 plugs with all accessories, tools, and fitting instructions for mounting the connector. A refill set of 25 JP 0012 plugs is available under the stock number UA 0130.



Fig.8.4. Extension connector JJ 0032

Two standard JJ 0012 connectors can be joined, for the purpose of cable extensions using the extension connector JJ 0032 (Fig.8.4). These are available in sets of 25 under stock number UA 0186.

8.2. MOUNTING SETS

For all accelerometer types except 4434, 8303, 8307 and 8309

UA 0125 Set of 10–32 NF studs containing 10 isolated studs YS 0420, 10 steel studs YQ 2960, 10 nuts YM 0414, 10 mica washers YO 0534, and 1 tap 10–32 NF.

UA 0142 1 set of clamping magnets containing 5 permanent magnets UA 0070 with isolated mounting 10–32 NF.

8.3. PREAMPLIFIER POWER SUPPLY

Power for the preamplifiers is obtained in different ways:

1. Internal batteries. Types of batteries are indicated in section 7.5 for the preamplifiers. Possible with Types 2616, 2625.

2. External 28 V DC obtainable from 3 different sources:

   a) The Power Supply Adapter ZR 0024 which plugs into the Preamplifier Input socket on the B & K Measuring Amplifiers and Frequency Analyzers. Current from this Adapter is limited to 2 mA. Suitable for Types 2623, 2625 and 8306.

   b) The Power Supply Type 2805 which is mains operated. Suitable for Preamplifiers Types 2616, 2623, 2624, 2625 and Accelerometer Type 8306.

   c) The battery operated Microphone Power Supply 2804 which is designed primarily to supply the microphone assemblies but which also has two 28 Volt outlets 2 mA each for accelerometer preamplifiers. Suitable for Preamplifiers Types 2623, 2625, 2619 and Accelerometer Type 8306.



Fig.8.5. Power Supplies 2804, 2805 and ZR 0024

3. Directly from the Preamplifier Input socket on the B & K Measuring Amplifiers and Frequency Analyzers or the B & K Microphone Power Supply units. Appropriate to Types 2615, 2619, 4292.

4. Direct mains. Types 2626 and 2628.

9. APPLICATIONS

A complete range of equipment is available from B & K for all types of vibration measurement and testing. B & K instruments are all matched with respect to impedance and output voltage so that interconnection is a simple matter. Several remote control facilities and automatic control functions add to the possibility for combining single instruments into complete systems for automatic measurements.

Numerous measuring testing and calibration systems covering practically all types of requirements are outlined and shown schematically in the B & K booklet "Examples of Applications". Furthermore individual B & K instrument instruction manuals detail complete applications set-ups which include accelerometer applications.

10. APPENDICES

10.1. ACCELEROMETER THEORY

10.1.1. Response to Continuous Vibration

The accelerometer consists basically of the element shown in Fig.10.1.

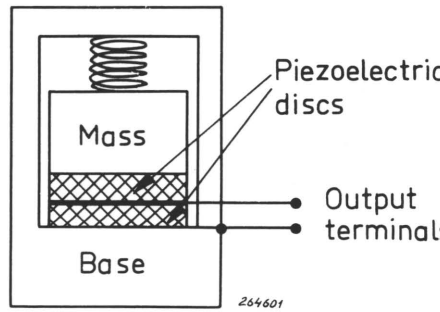


Fig.10.1. Schematic drawing of a piezoelectric accelerometer

A mass rests on a piezoelectric element. The mass is preloaded by a stiff spring and the whole assembly is mounted in a metal housing. When the accelerometer is subjected to acceleration the mass will be displaced relative to the base. Due to the piezoelectric effect a variable potential will be developed across the output which is direct proportional to the displacement. In order to perform meaningful measurements it is necessary to determine the relationship between the acceleration experienced by the accelerometer and the output from the piezoelectric.

The accelerometer can be considered as a Single Degree of Freedom system as shown in Fig.10.2.

The mass m is held to the case by a spring of stiffness k and a damper of damping coefficient c. Let y be the displacement of the base and x the displacement of the mass relative to the base.

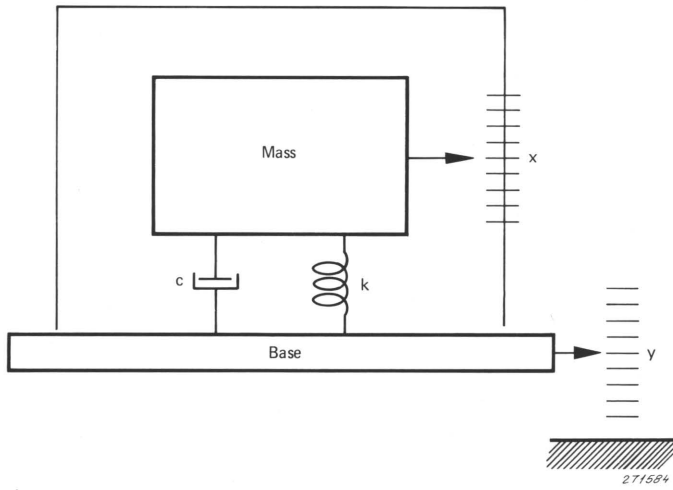


Fig.10.2. Spring Mass system of an accelerometer

The forces acting on the mass are then: the spring force kx, damped force $c\frac{dx}{dt}$ and the inertial force $m\frac{d^2(x+y)}{dt^2}$

The equation of motion is:

$$m\frac{d^2(x+y)}{dt^2} + c\frac{dx}{dt} + kx = 0$$

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = -m\frac{d^2y}{dt^2}$$

Assume that the displacement of the base is sinusoidal, $y = y_o \cos \omega t$. Ignoring transients the solution of the differential equation is:

$$\frac{x_o}{\ddot{y}_o} = -\frac{1}{\omega_n{}^2}\left[\frac{1}{\sqrt{[1-(\frac{\omega}{\omega_n})^2]^2 + (2\xi\frac{\omega}{\omega_n})^2}}\right] \ldots\ldots \quad (1)$$

and

$$\theta = \tan^{-1}\left(\frac{2\xi\frac{\omega}{\omega_n}}{1-(\frac{\omega}{\omega_n})^2}\right)$$

where

x_o = peak amplitude of the displacement of mass m
$\ddot{y}_o$ = acceleration of base
θ = phase angle between x and y

$$\omega_n = \sqrt{\frac{k}{m}}$$

$$\xi = \frac{c}{2\sqrt{km}}$$

The basic equation for the charge produced by a piezoelectric when it is subjected to force is:

$$q = d \cdot F$$

Since $F = k_1 x_o$ the equation becomes

$$q = d \cdot k_1 x_o$$

where d is the piezoelectric constant of the material and k_1 is the stiffness of the material.

Equation (1) then becomes:

$$\frac{\text{Charge generated}}{\text{Accel. of base}} = \frac{q}{\ddot{y}_o} = A \left| \frac{1}{\sqrt{[1 - (\frac{\omega}{\omega_n})^2]^2 + (2\xi\frac{\omega}{\omega_n})^2}} \right|$$

where

$$A \text{ is a constant} = -\frac{d \cdot k_1}{\omega_n^2}$$

The relation between $q/\ddot{y}_o$ and the frequency ratio ω/ω_n is plotted for various fractions of critical damping ξ in Fig.10.3.

From the curves it can be seen that for low values of ξ, i.e. when using a stiff spring the response is substantially flat for frequencies below ω_n. The useful frequency range increases as ω_n increases. However, the output q is inversely proportional to ω_n^2. Thus in practical accelerometers a compromise must be made between high natural frequencies and high sensitivity.

Although damping can be used to extend the useful frequency range of an accelerometer, the resultant non linear phase shift introduced is undesirable. For this reason accelerometers are designed to have very little damping.

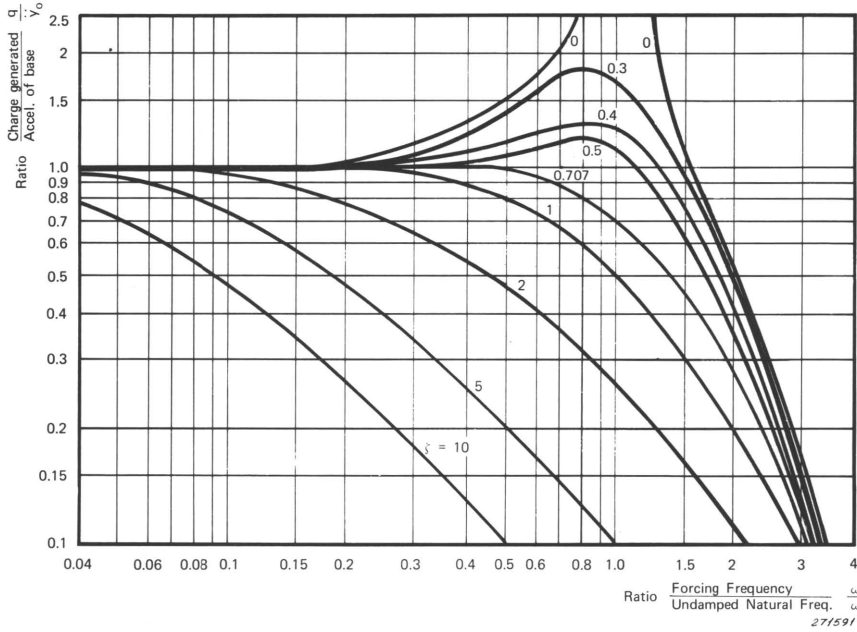


Fig.10.3. Relationship between $q/\ddot{y}_o$ and ω/ω_n for various fractions of critical damping

10.1.2. Response to Transient Phenomena and Shocks

From Fourier analysis it is known that in order to give complete information about a shock pulse the measuring system must have an infinte frequency range. For this reason the response of accelerometers to transient vibration depends upon their resonance frequency and damping.

The response of accelerometers with different values of critical damping to three typical shock pulses is shown in Fig.10.4. For each of the three pulse shapes the response is given for accelerometers having natural periods equal to 1.014 to 0.338 or 0.203 times the pulse duration T. From the curves it is seen that for the best response the accelerometer natural period should be as short as possible relative to the input pulse duration. Also damping will improve the response but the resultant phase distortion makes damping undesirable.

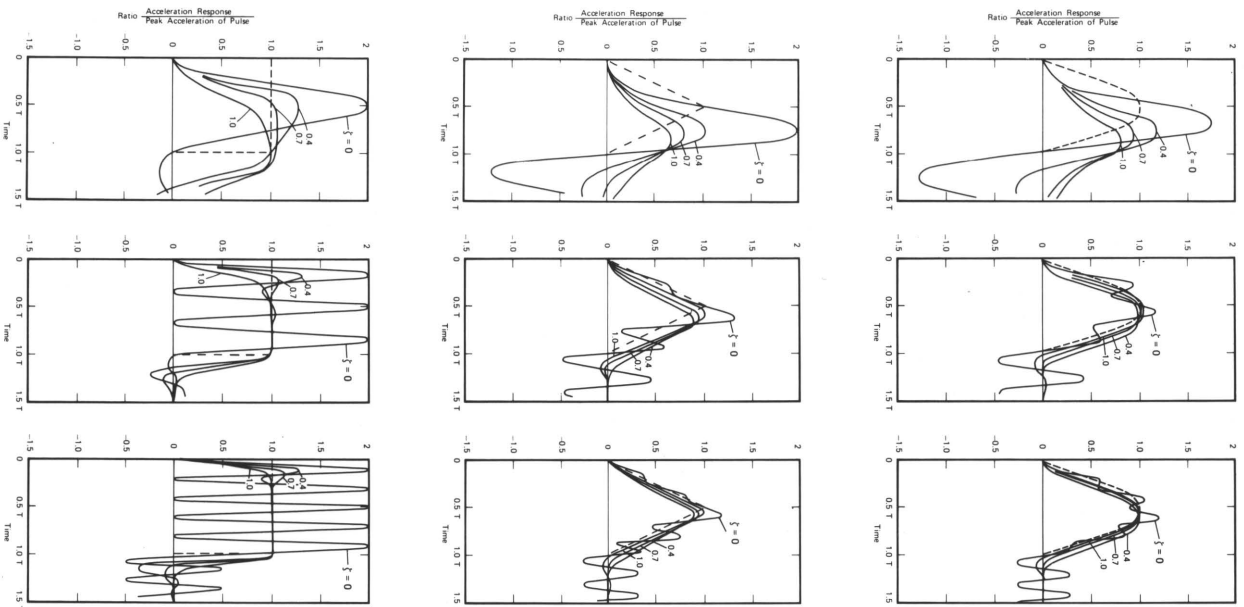


Fig.10.4. Acceleration response to (a) a half sine, (b) a triangular and (c) a rectangular acceleration pulse of duration T of a spring mass system whose natural period is (from left to right) 1.014; 0.388; and 0.203 times the pulse duration. Curves are shown for various fractions of critical damping

10.2. CONVERSION CHARTS, TABLES, etc.

Table 10.1 facilitates the conversion from dB to a (voltage) ratio. It is used as follows:

dB	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.000	1.012	1.023	1.035	1.047	1.059	1.072	1.084	1.096	1.109
1	1.122	1.135	1.148	1.161	1.175	1.189	1.202	1.216	1.230	1.245
2	1.259	1.274	1.288	1.303	1.318	1.334	1.349	1.365	1.380	2.396
3	1.413	1.429	1.445	1.462	1.479	1.496	1.514	1.531	1.549	1.567
4	1.585	1.603	1.622	1.641	1.660	1.679	1.698	1.718	1.738	1.758
5	1.778	1.799	1.820	1.841	1.862	1.884	1.905	1.928	1.950	1.972
6	1.995	2.018	2.042	2.065	2.089	2.113	2.138	2.163	2.188	2.213
7	2.239	2.265	2.291	2.317	2.344	2.371	2.399	2.427	2.455	2.483
8	2.512	2.541	2.570	2.600	2.630	2.661	2.692	2.723	2.754	2.786
9	2.818	2.851	2.884	2.917	2.951	2.985	3.020	3.055	3.090	3.126
10	3.162	3.199	3.236	3.273	3.311	3.350	3.388	3.428	3.467	3.508
11	3.548	3.589	3.631	3.673	3.715	3.758	3.802	3.846	3.890	3.936
12	3.981	4.027	4.074	4.121	4.169	4.217	4.266	4.315	4.365	4.416
13	4.467	4.519	4.571	4.624	4.677	4.732	4.786	4.842	4.898	4.955
14	5.012	5.070	5.129	5.188	5.248	5.309	5.370	5.433	5.495	5.559
15	5.623	5.689	5.754	5.821	5.888	5.957	6.026	6.095	6.166	6.237
16	6.310	6.383	6.457	6.531	6.607	6.683	6.761	6.839	6.918	6.998
17	7.079	7.161	7.244	7.328	7.413	7.499	7.586	7.674	7.762	7.852
18	7.943	8.035	8.128	8.222	8.318	8.414	8.511	8.610	8.710	8.910
19	8.913	9.016	9.120	9.226	9.333	9.441	9.550	9.661	9.772	9.886

Table 10.1.

Subtract a whole number of n x 20 from the dB value to be converted which gives a positive remainder between 0 and 20. Look up the ratio in the table corresponding to the remainder. The value sought is then 10^n x value from the table.

Example:

Convert 65.3 dB re. 1 g into units of g.
65.3 = (3) x 20 + 5.3.
5.3 gives from Table 10.1 a ratio 1.841. The g value is then
10^3 x 1.841 = 1841 g.

With negative values the procedure is the same, e.g.

Convert –31.8 dB re. 1 g into units of g.
–31.8 = (–2) 20 + 8.2.
8.2 gives from Table 10.1 a ratio 2.570. The g value is then
10^{-2} x 2.570 = 0.02570 g.

Frequency, Acceleration, Velocity Displacement Nomograph (RMS-values)

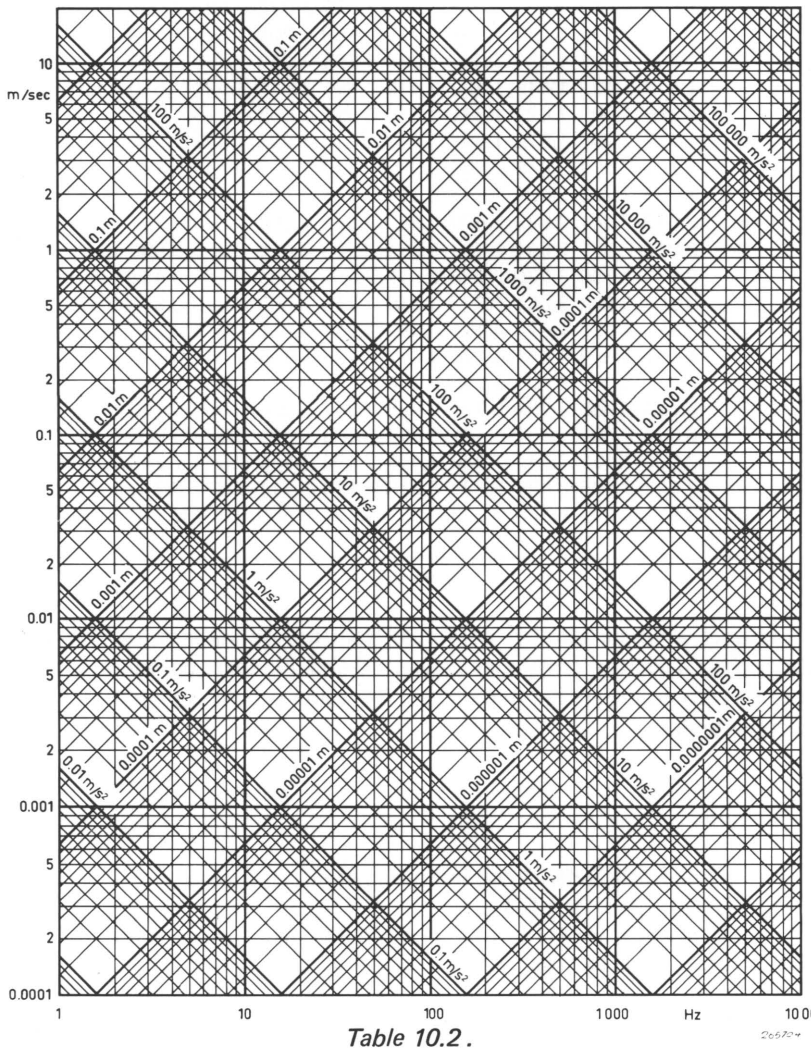


Table 10.2.

Conversion of Length

	m	cm	mm	ft	inch
1m	1	100	1000	3,281	39,37
1 cm	0,01	1	10	0,0328	0,3937
1 mm	0,001	0,1	1	0,00328	0,03937
1 ft	0,3048	30,48	304,8	1	12
1 inch	0,0254	2,54	25,4	0,0833	1

Table 10.3.

Conversion of Acceleration

	g	m/s^2	cm/s^2	ft/s^2	in/s^2
1 g	1	9,81	981	32,2	386
1 m/s^2	0,102	1	100	3,281	39,37
1 cm/s^2	0,00102	0,01	1	0,0328	0,3937
1 ft/s^2	0,03109	0,3048	30,48	1	12
1 in/s^2	0,00259	0,0254	2,54	0,0833	1

Table 10.4.

Conversion of Weight (Mass)

	kg	g	lbs	oz
1 kg	1	1000	2.205	35.3
1 g	0.001	1	0.0022	0.0353
1 lbs	0.4536	453.6	1	16
1 oz	0.02835	28.35	0.0625	1

Table 10.5.

For Single Frequency (Sinusoidal) Vibration

Acceleration	Velocity	Displacement
$a \cos \omega t$	$\frac{1}{\omega} a \sin \omega t$	$-\frac{1}{\omega^2} a \cos \omega t$
$-\omega v \sin \omega t$	$v \cos \omega t$	$\frac{1}{\omega} v \sin \omega t$
$-\omega^2 d \cos \omega t$	$-\omega d \sin \omega t$	$d \cos \omega t$

Table 10.6.

RMS Values

A	A/ω	A/ω^2
ωV	V	V/ω
$\omega^2 D$	ωD	D

Table 10.7.

11. INDIVIDUAL ACCELEROMETER SPECIFICATIONS

11.1. UNI-GAIN® ACCELEROMETERS TYPE 4339, 4343, 8301 AND 8302

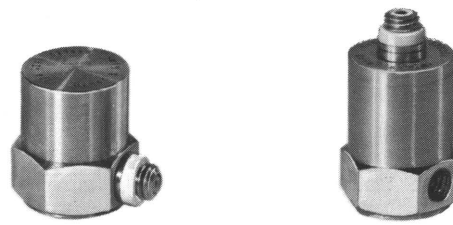


Fig.11.1.

The B & K Uni-Gain® Accelerometers Type 4339, 4343, 8301 and 8302 are suitable for general applications in Vibration Measurements. The construction of the accelerometers gives a low sensitivity to unwanted environmental excitations. The accelerometers Types 4339 and 8301 have been designed to have a sensitivity of 10 ± 0.2 mV/g. The Types 4343 and 8302 accelerometers have been designed to have a sensitivity of 10 ± 0.2 pC/g. The accelerometers are specially for use with fixed gain voltage and charge amplifiers. Types 8301 and 8302 have provision for water cooling of the base so that operation is possible on surfaces with temperatures up to 1000°C and their construction is specially designed for minimum base strain sensitivity.

The accelerometers are available as Accelerometer Sets or as Accelerometer Packages. The Accelerometer Sets Type 4339 S, 4343 S, 8301 S and 8302 S contain:

One Accelerometer	
One low noise cable for operation to 100°C (212°F)	AO 0037
Five threaded steel studs, 10–32 NF	YQ 2960
One electrically isolated stud, 10–32 NF	YS 0420
One nut, 10–32 NF	YM 0414
One cementing stud	DB 0756

One mica washer	YO 0534
Electrically isolated permanent magnet	UA 0070
Cable clip	DL 3014
Wax	YJ 0216
Probe with sharp tip	YP 0080
Round tip for probe	DB 0544
Screw tap, 10–32 NF	QA 0029
Hexagon key for studs	QA 0013
Microplug to B & K plug adapter	JP 0028
Individual calibration chart	
Two tubes for cooling (8301 or 8302 only)	DB 0524

The Accelerometer Packages Type 4339 P, 4343 P, 8301 P and 8302 P contain five packets, in each of which is:

One Accelerometer	
One low noise cable for operation to 100°C	AO 0037
One threaded steel stud, 10–32 NF	YQ 2960
One individual calibration chart	
Two tubes for water cooling (8301 and 8302 only)	DB 0524

Individual specifications for the accelerometers are:

Accelerometer Type	4339	4343	8301	8302
Contained in Accelerometer Set	4339S	4343S	8301S	8302S
Contained in Accelerometer Package	4339P	4343P	8301P	8302P
Sensitivity (mV/g)*	10 ±0.2	~10	10 ±0.2	~10
Charge Sensitivity (pC/g)*	~10	10 ±0.2	~10	10 ±0.2
Free Resonance (kHz)*	75	75	40	40
Mounted Resonance* (Solid Steel) (kHz)	40	40	25	25
Freq. Range* 5%	1–8000	1–8000	1–5000	1–5000
10%	1–12,000	1–12,000	1–8000	1–8000
Dynamic Range continuous rating (g's)	±3000	±3000	±3000	±3000
Max. shock (g's)	±10,000	±10,000	±10,000	±10,000
Capacitance Includ. Cable (pF)*	1000	1000	1000	1000
Transverse Sensitivity (%)*	<3	<3	<3	<3
Base Strain Sensitivity** (g per μStrain in plane of base)	<0.1	<0.1	<0.0005	<0.0005
Max. Ambient Temperature (°C)	260	260	260	260
Temperature Transient Sensitivity LLF 3 Hz (g/°C)**	<2	<2	<1	<1
Lowest Leakage Resist: at 20°C (MΩ)	2×10^4	2×10^4	2×10^4	2×10^4
Typical value at 250°C (MΩ)	2×10^4	2×10^4	2×10^4	2×10^4
Magnetic Sensitivity (g/kGauss) (50–400 Hz)	<0.1	<0.1	<0.2	<0.2
Max. Acoustical Sensitivity Equivalent g at 154 SPL**	0.01	0.01	0.01	0.01
Torque Sensitiv. 6–60 kgcm (%)	<1	<1	<1	<1
Max. g with Magnetic Attachment (approximately)	200	200	200	200
Construction	C.M.	C.M.	I.C.M.	I.C.M.
Piezoelectric Material	MT 8	MT 8	MT 8	MT 8
Weight in gm*	16	16	21	21
Type of Connection	Side	Side	Top	Top
Material	Stainless Steel AISI 316	Stainless Steel AISI 316	Stainless Steel AISI 316	Stainless Steel AISI 316
Provision for Water Cooling	No	No	Yes	Yes
Mounting thread	10–32 NF	10–32 NF	10–32 NF	10–32 NF
Height (mm)	17	17	25.4	25.4
Spanner Size (mm)	14	14	14	14

* Individual values given on the calibration chart

** Re. ANSI S2.11-1969

11.2. UNI-GAIN® ACCELEROMETER TYPE 4338

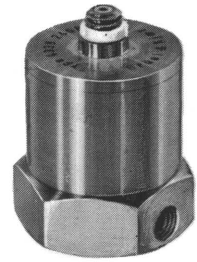


Fig. 11.2.

The B & K Uni-Gain® Accelerometer Type 4338 is suitable for a wide variety of applications where a high sensitivity accelerometer is required. Its inverted centre mounted compression design produces the desirable characteristics of low sensitivity to unwanted environmental excitations. It is especially designed to have a sensitivity of 100 ± 2 pC/g for use with fixed gain charge preamplifiers. The robust construction allows for operation in extreme environmental conditions, and provision is made for water cooling so that operation is possible on surfaces with temperatures up to 1000°C.

The accelerometer is available as Accelerometer Set or as an Accelerometer Package. The Accelerometer Set Type 4338 S contains:

One Accelerometer Type 4338	
One low noise cable for operation to 100°C	AO 0037
Five threaded steel studs, 10–32 NF	YQ 2960
One electrically isolated stud 10–32 NF	YS 0420
One nut, 10–32 NF	YM 0414
One cementing stud	DB 0756
One mica washer	YO 0534
Electrically isolated permanent magnet	UA 0070
Cable clip	DL 3014
Wax (for mounting accelerometers)	YJ 0216
Probe with sharp tip	YP 0080
Round tip for probe	DB 0544
Screw tap 10–32 NF	QA 0029
Hexagon key for studs	QA 0013
Microplug to B & K plug adapter	JP 0028
Individual calibration chart for accelerometer	
Two tubes for water cooling	DB 0524

The Accelerometer Package Type 4338 P contains five packets, in each of which is:

One Accelerometer Type 4338	
One low noise cable for operation up to 100°C	AO 0037
One threaded steel stud, 10–32 NF	YQ 2960
One individual calibration chart	
Two tubes for water cooling	DB 0524

Specifications for the accelerometer are:

Voltage Sensitivity:*	~100 mV/g
Charge Sensitivity:*	100 ± 2 pC/g
Frequency Range:*	
5%	1 – 2500 Hz
10%	1 – 3600 Hz
Dynamic Range:	±500 g continuous rating
Max. Shock:	1000 g
Resonance:*	
Free	20 kHz
Mounted	12 kHz
Transverse Sensitivity:*	<3%
Max. Ambient Temperature:	260°C
Temperature Transient Sensitivity:**	
(LLF 3 Hz)	0.2 g/°C
Magnetic Sensitivity:	<0.01 g/kGauss (50 – 400 Hz)
Max. Acoustic Sensitivity:**	
(equivalent g at 154 dB SPL)	0.01
Capacitance including Cable:*	1000 pF
Lowest Leakage Resistance:	
At 20° C	2×10^4 MΩ
Typical value at 250°C	2×10^4 MΩ

Base Strain Sensitivity:** (in plane of base)	$<5 \times 10^{-5}$ g/μstrain
Torque Sensitivity (6 – 60 kgcm):	$<1\%$
Max. g with Magnetic Attachment:	75
Construction:	I.C.M.
Weight*	60 gm
Piezoelectric Material:	MT 8
Type of Connection:	TOP
Material:	Stainless steel AISI 316
Mounting Thread:	10–32 NF
Provision for Water Cooling:	yes
Height:	30.8 mm (1.2 in)
Spanner Size:	21 mm

* Individual values given on calibration chart
** Re ANSI S2.11–1969

11.3. MINIATURE ACCELEROMETER TYPE 4344



Fig. 11.3.

The Miniature Accelerometer Type 4344 is designed especially with a view to vibration measurement on light weight structures, where a heavy transducer would change the mode of vibration and thereby invalidate the results obtained. It has a weight of 2 grams and a linear frequency range, within 10%, of 1 – 21,000 Hz.

The Miniature Accelerometer Type 4344 is available as Accelerometer Set Type 4344 S or as Accelerometer Package Type 4344 P.

The Accelerometer Set Type 4344 S contains:

One Miniature Accelerometer Type 4344	
One low noise cable for normal temperatures up to 100°C	AO 0051
One low noise cable for high temperatures up to 260°C	AO 0052
Six threaded steel studs (M 3)	YQ 2007
One nut (M 3)	YM 0334
One cementing stud	DB 0757
Wax	YJ 0216
Screw tap for 3 mm thread	QA 0041
Hexagon key for steel studs	QA 0042
Microplug to B & K plug adapter	JP 0028
Individual calibration chart	

The Accelerometer Package Type 4344 P contains five packets, in each of which is:

One Miniature Accelerometer Type 4344	
One low noise cable for normal temperatures up to 100°C	AO 0051
One low noise cable for high temperatures up to 260°C	AO 0052
One steel stud (M 3)	YQ 2007
Individual calibration chart	

Specifications for the Miniature Accelerometer Type 4344 are:

Voltage Sensitivity:*	~2.5 mV/g
Charge Sensitivity:*	~2.5 pC/g
Frequency Range:	
5%	1 – 14,000 Hz
10%	1 – 21,000 Hz
Dynamic Range:	±3,000 g continuous rating
Max. Shock:	14,000 g
Resonance:*	
Free	125 kHz
Mounted	70 kHz

Transverse Sensitivity:*	$<4\%$
Temperature Range:	-200 to $260^{o}C$
Temperature Transient Sensitivity:** (LLF 3 Hz)	10 g/^{o}C
Magnetic Sensitivity:	<0.1 g/kGauss (50 – 400 Hz)
Max. Acoustic Sensitivity:** (equivalent g at 154 dB SPL):	0.01
Capacitance (including cable):*	900 pF
Lowest Leakage Resistance:	
At $20^{o}C$	2×10^{4} MΩ
Typical value at $250^{o}C$	2×10^{4} MΩ
Base Strain Sensitivity:** (in plane of base):	<0.05 g/μstrain
Torque Sensitivity, 6 – 60 kgcm:	$<1\%$
Construction:	C.M.
Weight*	2 gm
Piezoelectric Material:	MT 8
Material:	Titanium
Output Socket (side entry):	M 3
Mounting (Thread):	M 3
Height:	10.2 mm (0.4 in)
Spanner Size:	7 mm

* Individual values given on calibration chart
** Re. ANSI S2.11–1969

11.4. MINIATURE ACCELEROMETER TYPE 8303



Fig. 11.4.

The B & K Miniature Accelerometer Type 8303 is designed with a view to vibration measurement on light weight structures, where a heavy transducer would change the mode of vibration and thereby invalidate the results obtained. It has a weight of 3.5 grams and a linear frequency range, within 10%, of up to 14,000 Hz. The inverted single ended construction gives the accelerometer a low base strain sensitivity of less than 0.002 g per μstrain (in plane of base).

The Miniature Accelerometer Type 8303 is available as Accelerometer Set Type 8303 S or as Accelerometer Package Type 8303 P.

The Accelerometer Set Type 8303 S contains:

One Miniature Accelerometer Type 8303	
One low noise cable for operation to 100°C	AO 0037
Six threaded steel studs (M 3)	YQ 2007
One nut (M 3)	YM 0334
One cementing stud	DB 0757
Wax	YJ 0216
Screw tap for 3 mm thread	QA 0041
Hexagon key for steel studs	QA 0042
Microplug to B & K plug adapter	JP 0028
Individual calibration chart	

The Accelerometer Package Type 8303 P contains five packets, in each of which is:

One Miniature Accelerometer Type 8303	
One low noise cable for operation to 100°C	AO 0037
One steel stud (M 3)	YQ 2007
Individual calibration chart	

Specifications for the Miniature Accelerometer Type 8303 are:

Voltage Sensitivity:*	~2.5 mV/g
Charge Sensitivity:*	~2.5 pC/g
Frequency Range:*	
5%	1 – 9,000 Hz
10%	1 – 14,000 Hz
Dynamic Range:	±3,000 g continuous rating
Max. Shock:	10,000 g
Resonance:*	
Free	75 kHz
Mounted	45 kHz
Transverse Sensitivity:*	<4%
Temperature Range:	–200 to 260°C
Temperature Transient Sensitivity:**	
(LLF 3 Hz)	10 g/°C
Magnetic Sensitivity:	<0.2 g/kGauss (50 – 400 Hz)
Max. Acoustic Sensitivity:**	
(equivalent g at 154 dB SPL)	0.01
Capacitance (including cable):*	900 pF
Lowest Leakage Resistance:	
At 20°C	2×10^4 MΩ
Typical value at 250°C	2×10^4 MΩ
Base Strain Sensitivity:**	
(in plane of base)	<0.002 g/μstrain
Torque Sensitivity, 6 – 60 kgcm:	<1%
Construction:	I.C.M.

Weight*	3.5 gm
Piezoelectric Material:	MT 8
Material:	Titanium
Output Socket (top entry):	10–32 NF
Mounting (Thread):	M 3
Height:	15 mm (0.6 in)
Spanner Size:	8 mm

* Individual values given on calibration chart
** Re. ANSI S 2.11–1969

11.5. HIGH TEMPERATURE ACCELEROMETER TYPE 4345



Fig. 11.5.

This accelerometer has been designed with the special intention of making a transducer suitable for vibration measurements at high temperatures. Typical application areas are with internal combustion engines and jet engines, for vibration monitoring, for example in power plants and in all kinds of experimental work.

The accelerometer is made of stainless steel, and an all welded, hermetically sealed construction makes it suitable for use under severe environmental conditions. The input connector uses an aluminium oxide insulation material and the accelerometer is delivered with a silver screened cable, also withstanding temperature up to 400°C. The accelerometer cable is not sensitive to humidity and a new plug construction seals the connector when tightened.

Both accelerometer and cable plug can be locked in their mounting position by means of a thin wire through holes in the accelerometer base and in the cable plug retaining nut respectively. This is of especial value when the accelerometers are used for vibration monitoring and for instance in airborne vehicles.

As the leakage resistance of the accelerometer decreases with increasing temperature it should be used with a charge preamplifier in order to maintain a good low frequency response. Lowest measurable frequency will thus normally only be limited by noise occuring from pyroelectric effects or caused by the low input load impedance at high temperature.

The Accelerometer is available as Accelerometer Set Type 4345 S and Accelerometer Package Type 4345 P.

The Accelerometer Set Type 4345 S contains:

One Accelerometer Type 4345	
One low noise teflon cable for operation to 250°C	AO 0038
One high temperature cable for operation to 400°C	AO 0500
Extension cable connector	JJ 0032
Five threaded steel studs, 10–32 NF	YQ 2960
One electrically isolated stud 10–32 NF (maximum 250°C)	YS 0420
One nut, 10–32 NF	YM 0414
One cementing stud	DB 0756
One mica washer	YO 0534
Electrically isolated permanent magnet	UA 0070
Cable clip	DL 3014
Wax (for mounting accelerometers)	YJ 0216
Probe with sharp tip	YP 0080
Round tip for probe	DB 0544
Screw tap 10–32 NF	QA 0029
Hexagon key for studs	QA 0013
One microplug to B & K plug adapter	JP 0028
Individual calibration chart for accelerometer	

The Accelerometer Package Type 4345 P contains five packets, in each of which is:

One Accelerometer Type 4345	
One low noise teflon cable for operation up to 250°C	AO 0038
One high temperature cable for operation up to 400°C	AO 0050
One threaded steel stud, 10–32 NF	YQ 2960

One extension cable connector JJ 0032
One individual calibration chart

Specifications for Accelerometer Type 4345:

Voltage Sensitivity:*	~5 mV/g
Charge Sensitivity:*	~5 pC/g
Frequency Range:*	
5%	1 – 6,000 Hz
10%	1 – 9,000 Hz
Dynamic Range:	±3,000 g
Max. Shock:*	±3,000 g
Resonance:*	
Free	45 kHz
Mounted	30 kHz
Transverse Sensitivity:*	<3%
Temperature Range:	–200 to 400°C
Temperature Transient Sensitivity:**	
(LLF 3 Hz)	4 g/°C
Magnetic Sensitivity:	<0.1 g/kGauss (50 Hz)
Max. Acoustic Sensitivity:**	
(equivalent g at 154 dB SPL)	0.01
Capacitance including Cable:*	900 pF
Lowest Leakage Resistance:	
At 20°C	2×10^4 MΩ
Typical value at 400°C	2 MΩ
Base Strain Sensitivity:**	
(in plane of base)	<0.02 g/μstrain
Torque Sensitivity (6 – 60 kgcm):	<1%

Max. g with Magnetic Attachment:	200
Construction:	C.M.
Weight:*	27 gm
Piezoelectric Material:	MT 40
Material:	Stainless steel AISI 316
Output Socket (side entry):	10–32 NF
Mounting (Thread):	10–32 NF
Height:	21.5 mm (0.8 in)
Spanner Size:	14 mm

* Individual values given on calibration chart
** Re. ANSI S 2.11–1969

11.6. TRIAXIAL ACCELEROMETER TYPE 4340

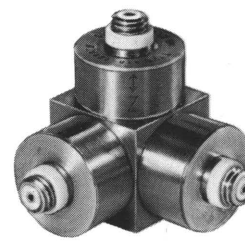


Fig. 11.6.

The Triaxial Accelerometer is virtually three accelerometers mounted in one housing. It indicates the vibration in three mutually perpendicular directions. Principal application areas are, balancing of machinery, vibration testing, multidirectional shock testing and others where the direction of vibration is not known or where measurements in more than one direction are of interest. The accelerometer is made of titanium and has provision for water cooling of the base.

The accelerometer is available as Accelerometer Set Type 4340 S containing:

One Accelerometer Type 4340	
Three low noise cables for operation to 100°C	AO 0037
Five threaded steel studs, 10–32 NF	YQ 2960
One electrically isolated stud 10–32 nF	YS 0420
One nut, 10–32 NF	YM 0414
One cementing stud	DB 0756
One mica washer	YO 0534
Wax (for mounting accelerometers)	YJ 0216
Counterweights	DB 0754
Screw tap 10–32 NF	QA 0029
Hexagon key for studs	QA 0013
Three microplug to B & K plug adapters	JP 0028
Individual calibration chart for accelerometer	
Two tubes for water cooling	DB 0524

Specifications for Accelerometer Type 4340 are:

Voltage Sensitivity:*	14 – 24 mV/g
Charge Sensitivity:*	14 – 20 pC/g
Frequency Range:*	
5%	1 – 5,000 Hz
10%	1 – 7,000 Hz
Dynamic Range:	±500 g continuous rating
Max. Shock:*	500 g
Resonance:*	
Free	45 kHz
Mounted	23 kHz
Transverse Sensitivity:*	<4%
Temperature Range:	up to 260°C

Temperature Transient Sensitivity:** (LLF 3 Hz)	2 g/^{o}C
Magnetic Sensitivity:	$<$0.1 g/kGauss (50 – 400 Hz)
Max. Acoustic Sensitivity:** (equivalent g at 154 dB SPL)	0.1
Capacitance including Cable:*	1000 pF
Lowest Leakage Resistance:	
At 20^{o}C	2 x 10^{4} MΩ
Typical value at 250^{o}C	2 x 10^{4} MΩ
Base Strain Sensitivity:** (in plane of base)	$<$0.2 g/μstrain
Torque Sensitivity (6 – 60 kgcm):	$<$1%
Max. g with Magnetic Attachment:	75
Construction:	P.M.
Weight:*	35 gm
Piezoelectric Material:	MT 8
Material:	Titanium
Output Socket (Top Entry):	10–32 NF
Mounting (Thread):	10–32 NF
Height:	26 mm (1 in)

* Individual values given on calibration chart
** Re. ANSI S 2.11–1969

11.7. ACCELEROMETERS TYPE 4332, 4333, 4334 AND 4335

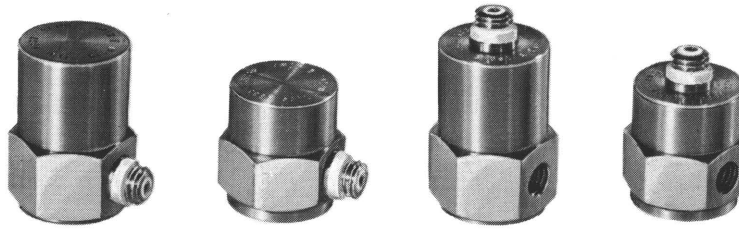


Fig. 11.7.

These accelerometers are suitable for non-critical general vibration measurements.

The accelerometers are available as Accelerometer Sets or as Accelerometer Packages. The Accelerometer Sets Type 4332 S, 4333 S, 4334 S and 4335 S contain:

One Accelerometer	
One low noise cable for operation to 100°C	AO 0037
Five threaded steel studs, 10–32 NF	YQ 2960
One electrically isolated stud 10–32 NF	YS 0420
One nut, 10–32 NF	YM 0414
One cementing stud	DB 0756
One mica washer	YO 0534
Electrically isolated permanent magnet	UA 0070
Cable clip	DL 3014
Wax (for mounting accelerometer)	YJ 0216
Probe with sharp tip	YP 0080
Round tip for probe	DB 0544
Screw tap, 10–32 NF	QA 0029
Hexagon key for studs	QA 0013
Microplug to B & K plug adapter	JP 0028
Two tubes for cooling (Types 4334 S and 4335 S only)	DB 0524
Individual calibration chart for accelerometer	

The Accelerometer Packages Type 4332 P, 4333 P, 4334 P and 4335 P each packet contains five packets, in each of which is:

One Accelerometer	
One low noise cable for operation to 100°C	AQ 0037
One threaded steel stud, 10–32 NF	YQ 2960
Two tubes for cooling (Type 4334 and 4335 only)	DB 0524
One individual calibration chart	

Individual specifications for the accelerometers are:

Accelerometer Type	4332	4333	4334	4335
Contained in Accelerometer Set	4332S	4333S	4334S	4335S
Contained in Accelerometer Package	4332P	4333P	4334P	4335P
Sensitivity (mV/g)*	45–65	14–24	45–65	14–24
Charge Sensitivity (pC/g)*	40–60	14–20	40–60	14–20
Free Resonance (kHz)*	45	55	45	55
Mounted Resonance* (Solid Steel) (kHz)	25	35	25	35
Frequency Range* 5% 10%	1–5000 1–8000	1–7000 1–10,000	1–5000 1–8000	1–7000 1–10,000
Dynamic Range continuous rating (g's)	3000	3000	3000	3000
Max. shock (g's)	+ 10,000 –3000	+ 10,000 –7000	+ 10,000 –3000	+ 10,000 –7000
Capacitance Including Cable (pF)*	1000	1000	1000	1000
Transverse Sensitivity (%)*	<4	<4	<4	<4
Base Strain Sensitivity** (g per μStrain in plane of Base)	0.06	0.2	0.06	0.2
Max. Ambient Temperature (^{o}C)	260	260	260	260
Temperature Transient Sensitivity LLF 3 Hz (g/^{o}C)**	0.6	3	0.6	3
Lowest Leakage Resistance at 20^{o}C (MΩ) Typical value at 250^{o}C (MΩ)	2×10^4 2×10^4	2×10^4 2×10^4	2×10^4 2×10^4	2×10^4 2×10^4
Magnetic Sensitivity (g/kGauss) (50–400 Hz)	<0.1	<0.1	<0.1	<0.1
Max. Acoustical Sensitivity Equivalent g at 154 dB SPL**	0.05	0.1	0.05	0.1
Torque Sensitivity 6–60 kgcm (%)	<1	<1	<1	<1
Max. g with Magnetic Attachment (approximately)	100	200	100	200
Construction	P.M.	P.M.	P.M.	P.M.
Piezoelectric Material	MT 8	MT 8	MT 8	MT 8
Type of Connection	Side	Side	Top	Top
Weight (grams) *	30	13	30	13
Material	Stainless Steel AISI 303	Titanium	Stainless Steel AISI 303	Titanium
Provision for Water Cooling	No	No	Yes	Yes
Mounting Thread	10–32 NF	10–32 NF	10–32 NF	10–32 NF
Height	22 mm	16 mm	26 mm	20 mm
Spanner Size	14 mm	14 mm	14 mm	14 mm

* Individual values on the calibration chart

** Re. ANSI S2.11-1969

11.8. QUARTZ ACCELEROMETER TYPE 8304



Fig. 11.8.

This quartz accelerometer has been designed with the special intension of making a transducer with minimum sensitivity to temperature changes and temperature transients. A special construction gives a very low sensitivity to base strain and an all welded stainless steel construction makes it completely waterproof and ideally suited for use in very moist and corrosive atmospheres. The ceramic insulated, glass sealed input socket ensures complete sealing even after several temperature cycles up to 260°C. The accelerometer is calibrated in pC/g and should be used with the Charge Amplifiers Type 2624 or 2626. Due to the accelerometer's low sensitivity the Type 2626 is recommended.

The Quartz Accelerometer Type 8304 is available as Accelerometer Set Type 8304 S or as Accelerometer Package Type 8304 P.

The Accelerometer Set Type 8304 S contains:

One Accelerometer Type 8304	
One low noise cable for operation to 100°C	AO 0037
Five threaded steel studs, 10–32 NF	YQ 2960
One electrically isolated stud 10–32 NF	YS 0420
One nut, 10–32 NF	YM 0414
One cementing stud	DB 0756
One mica washer	YO 0534
Electrically isolated permanent magnet	UA 0070
Cable clip	DL 3014
Wax (for mounting accelerometer)	YJ 0216
Probe with sharp tip	YP 0080
Round tip for probe	DB 0544
Screw tap, 10–32 NF	QA 0029
Hexagon key for studs	QA 0013

Microplug to B & K plug adapter JP 0028
Individual calibration chart for accelerometer

The Accelerometer Package Type 8304 P contains five packets, in each of which is:

One Accelerometer Type 8304
One low noise cable for operation to 100°C AO 0037
One threaded steel stud, 10–32 NF YQ 2960
One individual calibration chart

Specifications for Accelerometer Type 8304:

Charge Sensitivity:*	1.2 pC/g
Frequency Range:*	
5%	(0) – 6,000 Hz
10%	(0) – 9,000 Hz
Dynamic Range:	±3,000 g continuous rating
Max. Shock:	10,000 g
Resonance (Mounted):*	30 kHz
Transverse Sensitivity:*	<4%
Temperature Range:	–200 to 260°C
Temperature Transient Sensitivity:**	
(0.3 Hz LLF)	1 g/°C
(3 Hz LLF)	0.1 g/°C
Magnetic Sensitivity:	<0.02 g/kGauss (50 – 400 Hz)
Max Acoustic Sensitivity:**	
(equivalent g at 154 dB SPL)	0.05
Capacitance (including cable):*	180 pF
Leakage Resistance:	
At 20°C	10^6 MΩ
Typical value at 250°C	10^4 MΩ

Base Strain Sensitivity:** (in plane of base)	<0.002 g/μstrain
Torque Sensitivity, 6 – 60 kgcm:	$<1\%$
Max. g with Magnetic Attachment:	100
Construction:	C.M.
Weight:*	30 gm
Piezoelectric Material:	MT 100
Base and Housing Material:	Stainless steel AISI 316
Output Socket:	10–32 NF
Mounting (Thread):	10–32 NF
Height:	22 mm (0.9 in)
Spanner Size:	16 mm

* Individual values given on calibration chart
** Re. ANSI S 2.11–1969

11.9. STANDARD ACCELEROMETER TYPE 8305 AND ACCELEROMETER CALIBRATION SET TYPE 3506



Fig. 11.9.

The Standard Accelerometer Type 8305 has been designed particularly for the precise calibration of vibration transducers by the back to back comparison method. Careful design has resulted in very low transverse and

base strain sensitivities ensuring a high degree of accuracy in comparison measurements.

High stability over time and low sensitivity to temperature changes are obtained by using a piezoelectric element of quartz. A sectional drawing of the accelerometer is shown in Fig.11.10. Construction is of the inverted single ended compression type.

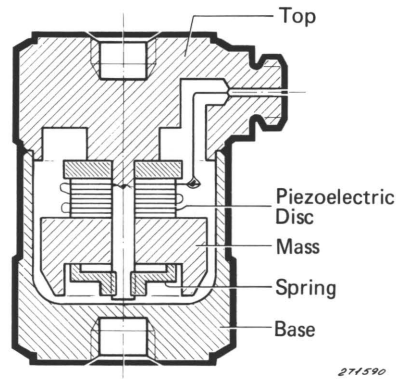


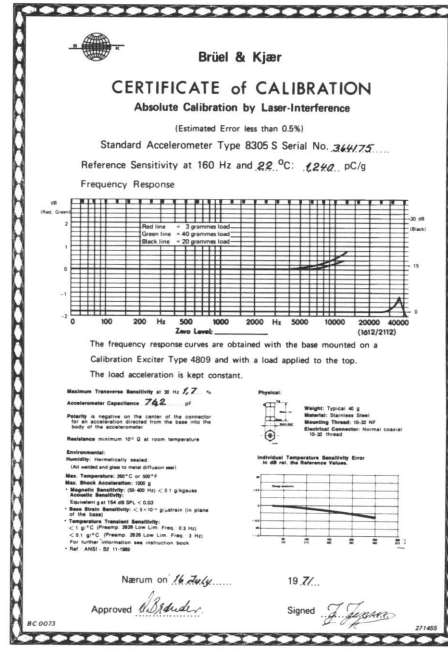
Fig.11.10. Cross section view of the accelerometer

Absolute calibration of the Type 8305 is performed at the factory by the laser interference method with an estimated error less than 0.5%. This degree of accuracy can be equalled by careful reciprocity calibration but the laser interference method is prefered because of its lesser dependence on human error.

Each accelerometer is supplied with a complete calibration certificate giving detailed calibration data and frequency response curve for the individual transducer. A typical calibration certificate is shown in Fig.11.11. A factory recalibration service is available for subsequent calibration checks on the 8305. The laser interference method is used and a new calibration certificate issued.

The accelerometer has a 10–32 NF mounting thread in both ends, one in the base for mounting it in the shaker table and one in the top for the mounting of the accelerometer to be tested.

The accelerometer is delivered as Type 8305 S in a case with various



Brüel & Kjær

CERTIFICATE of CALIBRATION

Absolute Calibration by Laser-Interference

(Estimated Error less than 0.5%)

Standard Accelerometer Type 8305 S Serial No. 364175

Reference Sensitivity at 160 Hz and 22 °C: 1.240 pC/g

Frequency Response

Red line = 3 grammes load
Green line = 40 grammes load
Black line = 20 grammes load

0 100 200 Hz 500 1000 2000 Hz 5000 10000 20000 40000

Zero Level (1612/2112)

The frequency response curves are obtained with the base mounted on a Calibration Exciter Type 4809 and with a load applied to the top.

The load acceleration is kept constant.

Maximum Transverse Sensitivity at 30 Hz: 1.7 %

Accelerometer Capacitance: 742 pF

Polarity is negative on the center of the connector for an acceleration directed from the base into the body of the accelerometer.

Resistance minimum 10^{13} Ω at room temperature

Environmental:

Humidity: Hermetically sealed
(All welded and glass to metal diffusion seal)

Max. Temperature: 350°C or 660°F

Max. Shock Acceleration: 1000 g

* Magnetic Sensitivity: (50-400 Hz): < 0.1 g/kgauss
Equivalent μ at 1784 gs SPL: < 0.03

* Base Strain Sensitivity: < 5×10^{-3} g/μstrain (in plane of the base)

* Temperature Transient Sensitivity:
< 1 g/°C (Preamp. 2626 Low Lim. Freq. 0.3 Hz)
< 0.1 g/°C (Preamp. 2626 Low Lim. Freq. 3 Hz)
For further information see instruction book.

* Ref. ANSI - S2 11-1969

Physical:

Weight: Typical 40 g
Material: Stainless Steel
Mounting Thread: 10-32 NF
Electrical Connector: Normal coaxial 10-32 Thread

Individual Temperature Sensitivity Error in dB rel. the Reference Values.

Nærum on 16 July 19 71

Approved

Signed

BC 0073

271455

Fig.11.11. Typical calibration certificate as supplied with Accelerometer Type 8305

accessories for fixing and an adapter UA 0322 for calibration according to the insert voltage method. The adapter also isolates the accelerometer electrically from the test object. See Fig.11.12.

The precision Charge Conditioning Preamplifier Type 2626 is ideal for use with the Type 8305. These two instruments are available as Accelerometer Calibration Set Type 3506 and represent an integral system calibrated from vibratory input to low impedance voltage output.

Calibration Set Type 3506 is primarily intended for the back to back comparison method of accelerometer calibration where the accelerometer to be calibrated is rigidly coupled to the reference standard accelerometer Type 8305. The two accelerometers are vibrated together at a fixed frequency and the two outputs are compared by means of a voltage divider or sensitivity comparator. As the sensitivity of the reference standard accelerometer is accurately known under these conditions it is simple to isolate the relative sensitivity of the unknown accelerometer.

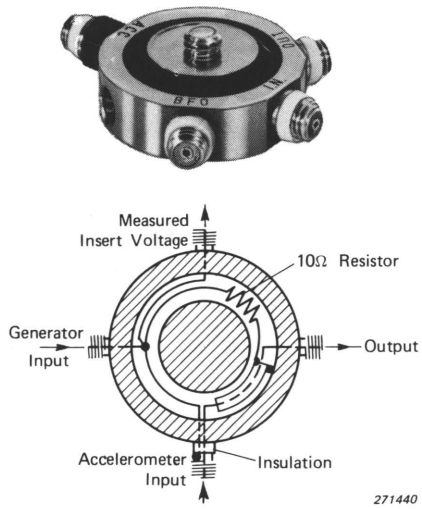


Fig.11.12. The Insert Voltage Adapter UA 0322 and schematic drawing



Fig.11.13. The Accelerometer Calibration Set Type 3506

By using the Calibration Set Type 3506 together with Sensitivity Comparator Type 2970 the comparative sensitivity of an unknown accelerometer can be determined within 0.2%. Comparative frequency response curves can be made by using a sweep generator. Suggested set-ups are shown in Fig.11.14 and 11.15.

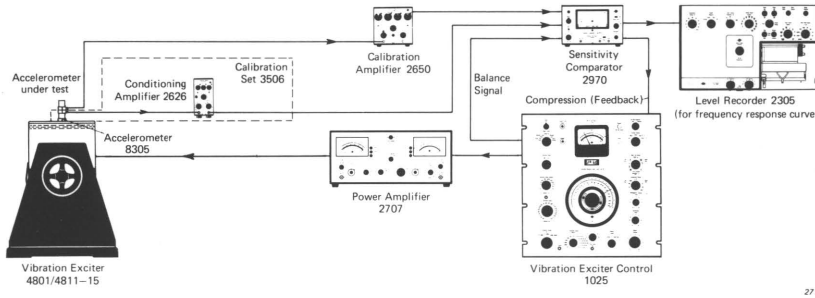


Fig.11.14. Suggested instrument set-up for performing back to back calibration at high g levels

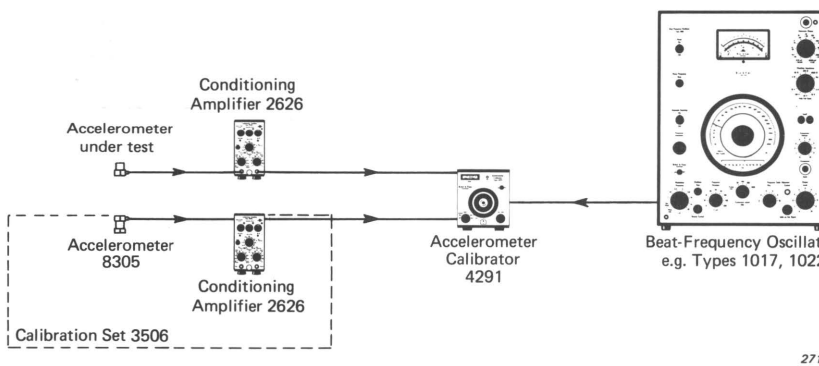
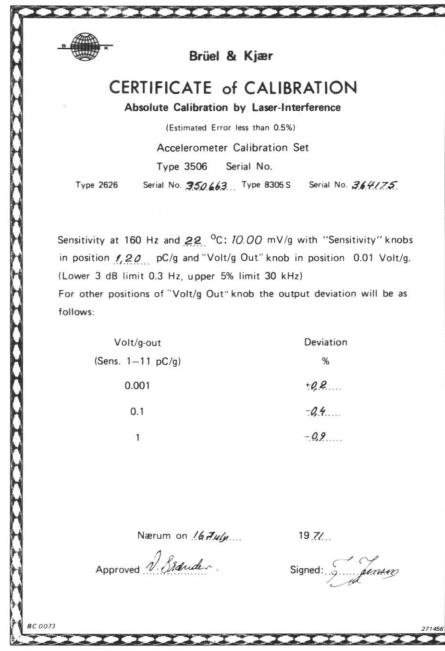


Fig.11.15. Suggested set-up for low level back to back sensitivity calibration of accelerometers. The two accelerometers are attached to the built-in shaker table of the 4291

The Standard Calibration Set Type 3506 is calibrated as an integral unit in the Brüel & Kjær calibration laboratory by the laser interference method giving a maximum probable error of within 0.5%. The precision voltage dividers used for signal conditioning within the Charge Amplifier 2626 have a tolerance of ±0.1%. The distortion at normal calibration levels and



Brüel & Kjær

CERTIFICATE of CALIBRATION

Absolute Calibration by Laser-Interference

(Estimated Error less than 0.5%)

Accelerometer Calibration Set

Type 3506 Serial No.

Type 2626 Serial No. 350663 Type 8305 S Serial No. 364175

Sensitivity at 160 Hz and 22 °C: 10.00 mV/g with "Sensitivity" knobs in position 1,20 pC/g and "Volt/g Out" knob in position 0.01 Volt/g. (Lower 3 dB limit 0.3 Hz, upper 5% limit 30 kHz)

For other positions of "Volt/g Out" knob the output deviation will be as follows:

Volt/g-out (Sens. 1–11 pC/g)	Deviation %
0.001	+0.2
0.1	-0.4
1	-0.9

Nærum on 16 July 19 71

Approved V. Ellerbeck

Signed: J. Larsen

BC 0073 271456

Fig.11.16. Typical calibration certificate as supplied with Calibration Set Type 3506

frequencies is below 0.1% and the wide band noise referred to input is below an equivalent of 0.005 g. A certificate of calibration is included in the system quoting the conditions under which the calibration has been carried out and gives % deviation from the stated data for other settings of the output knob on the 2626, Fig.11.16 shows a typical calibration certificate for the 3506.

The centre mounted quartz crystal accelerometer and the precision charge amplifier together with their carefully controlled calibration makes this system the most accurate reference available.

Specifications for Accelerometer Type 8305 S:

Sensitivity:* >1.2 pC/g

Mounted Resonance (Solid Steel):
(Nominal with 20 g mounted on top) 30 kHz

Capacitance Including Cable: (nominal)	180 pF
Capacitance (nominal):	70 pF
Transverse Sensitivity:*	$<2\%$
Base Strain Sensitivity:**	
Seen from top	0.002 (g per μStrain in plane of base)
Seen from base	0.0005
Max. Ambient Temperatures:	260°C (500°F)
Temperature Transient Sensitivity: (with Preamplifier Type 2624)	0.3 Hz LLF: 1 g/°C 3 Hz LLF: 0.1 g/°C
Leakage Resistance:	
At 20°C	10^6 MΩ
At 250°C	10^4 MΩ
Magnetic Sensitivity:** (50 to 400 Hz)	0.02 g/kGauss
Acoustic Sensitivity:	180 dB SPL equivalent to 1 g
Torque Sensitivity (6 to 60 kgcm):	1%
Max. Shock:	1000 g
Frequency Range:	+ 1%: 2^+ to 3100 Hz + 2%: 2^+ to 4400 Hz
Connection Type:	Side, 10–32 NF, ceramic isolator
Polarity:	Negative for acceleration directed from base to top
Height:	29 mm (1.1 in)
Spanner Size:	16 mm
Weight:*	40 gm

Material: Stainless Steel AISI 316

Mounting Threads: 10–32 NF

Accessories Included:

Accelerometer Cables	AO 0037 and AO 0047
Insert Voltage Adapter	UA 0322
Electrically Isolated Stud	YS 0420
Mica Washer	YO 0534
2 Threaded Steel Studs (1/2 inch)	YQ 2960
2 Threaded Steel Studs (5/16 inch)	YQ 2962
Nut	YM 0414
Screw Tap	QA 0013
Wrench	DA 0064
Adapter 4-40 UNC to 10–32 NF	DB 1440
Adapter 6-32 UNC to 10–32 NF	DB 1441
Adapter 8-32 UNC to 10–32 NF	DB 1442
Adapter 1/4-28 UNF to 10–32 NF	DB 1443

* Individual values given on calibration chart.
** Ref. ANSI S 2.11–1969.
\+ Lower limiting frequency determined by preamplifier used and environmental conditions.

Specifications for Accelerometer Calibration Set Type 3506

Includes:

Standard Accelerometer Type 8305 S
*Conditioning Amplifier Type 2626
Interconnecting Cable
Calibration Certificate

Overall Error in Factory Calibration: $<0.5\%$

Overall Distortion: 0.1%

Wide Band Noise:
(0.3 Hz to 100 kHz) Equivalent to 0.005 g

*See Section 7.5.5.

11.10. LOW g ACCELEROMETER TYPE 8306



Fig.11.17. Low Level Accelerometer Type 8306

The Low g Accelerometer Type 8306 has an extremely high sensitivity and a relatively low weight which allows acceleration measurement at levels as low as 10^{-5} g on light-structures. Careful design has resulted in a wide dynamic range and long term stability making this transducer suitable for a broad range of low level applications.

A preamplifier is built into the transducer to act as an impedance converter with unity gain (0 dB) see Fig.11.18. It eliminates the effects of noise and losses in long connecting cables and permits the use of readout instrumentation at remote positions. Two output terminals are provided, "Voltage" where a low impedance output voltage is proportional to the acceleration level. The preamplifier also incorporates an active low pass filter to give 18 dB per octave attenuation above 1000 Hz. Thus the

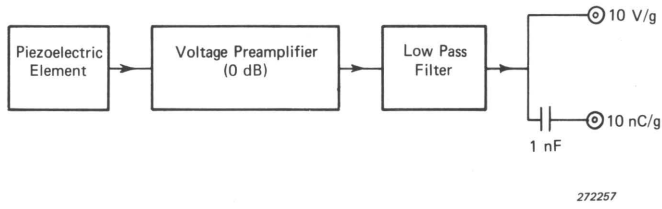


Fig.11.18. Block Diagram of 8306

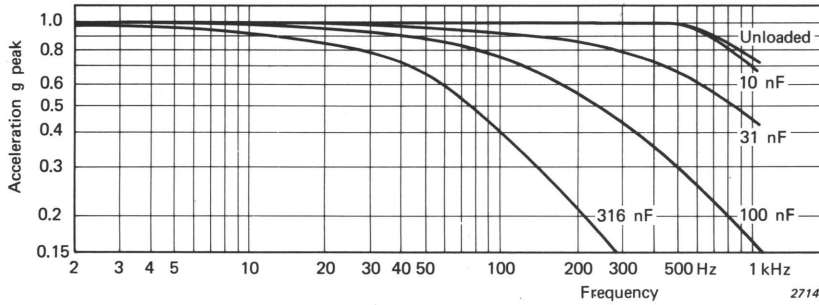


Fig.11.19. Maximum acceleration level (peak) for different load capacitances at the voltage output (1% distortion). For charge output "Unloaded" curve valid

accelerometer resonance and external high frequency vibration will not influence the measured results. Maximum acceleration levels (peak) for different load capacitances at the voltage output for 1% distortion are given in Fig.11.19.

The Low g Accelerometer Type 8306 is of the Uni-Gain® type. This indicates that the sensitivity has been adjusted to within 2% of a convenient value for direct measurement, in this case 10 Volt/g and 10,000 pC/g. Each accelerometer is supplied with a complete calibration chart giving detailed calibration data and frequency response curve for the individual transducer.

A sectional drawing of the accelerometer is shown in Fig.11.20. Construction is of the centre mounted compression type based on a piezoelec-

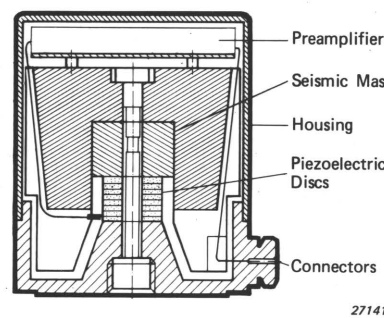


Fig.11.20. Construction of Type 8306

tric element of MT 8, giving the accelerometer a high acceleration sensitivity and low temperature, acoustic, magnetic and base strain sensitivities. The construction is epoxy sealed to ensure reliable operation in damp environment.

The Preamplifier in Type 8306 requires 2 mA at 28 V DC from an external source. When a single accelerometer is used in conjunction with one of the B & K measuring amplifiers or analyzers the small Power Adapter ZR 0024 can be used to provide the necessary power. For multiple accelerometer systems the Power Supply Type 2805, which has a current rating of 2 x 200 mA, may be used.

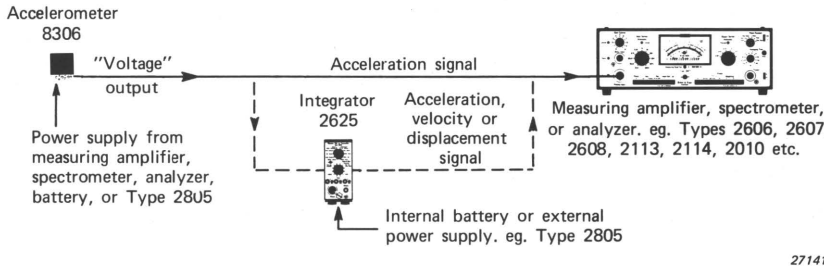


Fig.11.21. Typical set-up for vibration measurement in the range 2 Hz to 1000 Hz

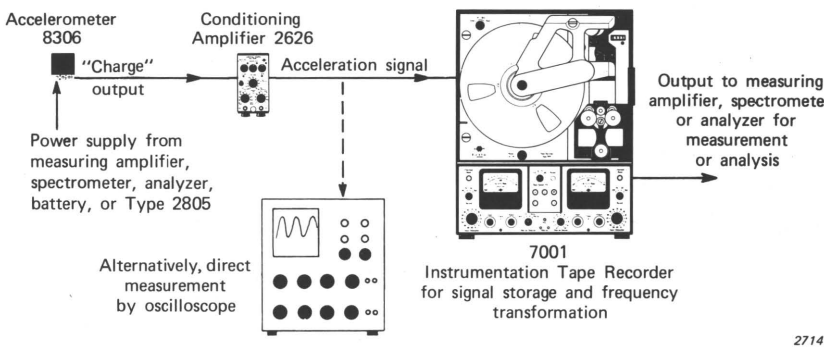


Fig.11.22. Typical set-up for vibration measurement in the frequency range 0.2 Hz to 1000 Hz (particularly for frequencies below 2 Hz)

Specifications for Type 8306 are as follows:

Charge Sensitivity:*	10,000 pC/g ± 2%
Voltage Sensitivity:*	10 V/g ± 2%
Frequency Range:	0.2 Hz to 1000 Hz (± 10% limits)
Acceleration Range:	10^{-5} g to 1 g (9.8 10^{-5} m/s^2 to 9.81 m/s^2)
Transverse Sensitivity:*	$<$5%
Base Strain Sensitivity:**	$<$0.0001 g/μstrain in base plane
Magnetic Sensitivity:**	0.03 g/kGauss (50 – 400 Hz)
Acoustic Sensitivity:	$<$0.003 g at 154 dB SPL
Temperature Transient Sensitivity:**	$<$0.0004 g/^{o}C at 0.3 Hz LLF with preamplifier Type 2626
Max. Ambient Temperature:	85^{o}C (185^{o}F)
Base Material:	Stainless steel AISI 303
Mounted Resonance (Nominal):	2500 Hz
Preamplifier Gain:	0 dB approx.
Output Terminals:	"Voltage" and "Charge" 10–32 NF miniature connectors
Construction:	C.M.
Piezoelectric Material:	MT 8
Voltage Output:	
Impedance	$<$500 Ω
Load impedance	$>$50 kΩ
Output voltage	10 V peak max.
Standing voltage at terminal	14 V DC
Output current	1.4 mA peak

Charge Output:	
Impedance	$<500\ \Omega$ in series with 1000 pF
Load	Charge amplifier
Noise:	40 μV equivalent to 4×10^{-6} g (2 Hz to 1 kHz)
Filter:	Active low pass. Attenuation 18 dB/ octave above 1000 Hz
Power Connection:	10–32 NF miniature plugs
Mounting Thread:	10–32 NF
Power Required:	2 mA at 28 V DC
Dimensions:	49 mm (1.93 in) dia 57 mm (2.24 in) high
Weight:	600 gm (1.32 lb)
Accessories Included:	1 Signal Cable (3 m) AO 0089 1 Power Cable (3 m) AO 0089 1 Miniature plug to B & K plug adapter JP 0028 5 Mounting studs 10–32 NF YQ 2960 Mounting Wax 5 Adhesive mounting discs Mahogany case

11.11. SUBMINIATURE ACCELEROMETER TYPE 8307

The Subminiature Accelerometer Type 8307 weighing only 0.4 grams satisfies the need for the very small, light weight transducer necessary where external mass influence is particularly critical. Heavy transducers would change the mode of vibration thus invalidating the results obtained.

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* Individual values given on calibration chart

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Fig.11.23. Subminiature Accelerometer Type 8307

The resonant frequency is 75 kHz which allows operation up to 25 kHz within + 10% sensitivity deviation level. Construction is of the shear type (Fig.3.2) based on a piezoelectric element of lead zirconate titanate. The whole construction is mounted on a base of beryllium which is drilled to take the low noise teflon cable. The cable is rigidly bonded to the base to minimise accelerometer response due to cable movement.

The combination of shear configuration for the sensing element and a beryllium base ensures a very low base strain sensitivity.

The accelerometer is designed to be mounted by means of wax for low level measurements or with a quick setting cyanoacrylate adhesive for the more severe applications.

Specifications for the accelerometer are:

Voltage Sensitivity: *	~1.2 mV/g
Charge Sensitivity: *	~ 0.4 pC/g
Frequency Range: *	
5%	1 – 15,000 Hz
10%	1 – 25,000 Hz
Dynamic Range:	± 3000 g continuous rating
Max. Shock:	10,000 g
Mounted Resonance Frequency:	75 kHz
Transverse Sensitivity: *	< 5%
Max. Ambient Temperature: (LLF 3 Hz)	200°C
Max. Temperature Transient Sensitivity ** **(3 Hz LLF):**	3 g/°C
Magnetic Sensitivity:	< 0.05 g/kGauss (50 – 400 Hz)

Max. Acoustic Sensitivity: ** (equivalent g at 154 dB SPL)	0.01
Capacitance including Cable: *	300 pF
Lowest Leakage Resistance: At 20°C	2 x 10^4 MΩ
Base Strain Sensitivity: ** (in plane of base)	0.005 g/μStrain
Construction:	Shear
Weight: *	0.4 gm excluding cable
Piezoelectric Material:	MT 8
Type of Connection:	Integral
Material:	
Base	Beryllium
Housing	Aluminium
Provision for Water Cooling:	No
Height:	6.5 mm (0.25 in)
Diameter:	5 mm (0.2 in)
Accessories Included:	1 AO 0037 Low noise cable with plugs (to 100°C). 1 JJ 0032 Extension connector 25 YO 0073 Adhesive Mounting Discs

11.12. 100000 g SHOCK ACCELEROMETER TYPE 8309



Fig.11.24. 100,000 g Shock Accelerometer Type 8309

Accelerometer Type 8309 is particularly applicable to the measurement and analysis of high level shocks. Typical applications are in the measurement of shocks due to explosions, tests on pneumatic impact tools such as rock drills, and shock measurements on the valves of the internal combustion engine. The transducer's rugged construction ensures reliable operation under the severe conditions imposed by such environments.

The 8309 is of the centre mounted compression design using a specially formulated piezoelectric ceramic. It is of small size and low weight, an essential requirement where extra mass can change the dynamic characteristics of smaller test objects. The 300 mm long integral cable gives the advantage of a reduced size and weight over transducers with plug and socket type connectors are of doubtful reliability at shock levels as high as 100000 g. An extension cable of 1.2 m length is supplied in addition to the integral cable.

The rather high transverse resonance frequency of the 8309 is a particularly acceptable feature in high shock measurement where the cross motion of a test object is sometimes difficult to define.

All of the B&K charge and voltage preamplifiers are suitable for use with the 8309 but care should be taken when using the Voltage Amplifier Type 2623 that the maximum input voltage of 10V peak is not exceeded. In this case the signal could be attenuated by adding extra cable between the transducer and the preamplifier.

When using conditioning amplifiers Type 2626, 2628 or 2650 with a Type 8309 having a sensitivity of, for example, 0.0326 pC/g, set the conditioning amplifiers to 3.26 pC/g and read the VOLTS/g OUT setting as VOLTS/100 g OUT.

It is normally accepted that for pulse shapes similar to a half sine, the minimum pulse length for less than 10% amplitude error is $5/f_r$ (f_r = accelerometer resonant frequency), the amplitude error being a result of the "ringing" effect. For the 8309 this gives a minimum pulse length of 30 μs. However, compensating for the accelerometer resonance by introducing a low pass filter in the preamplifier, it is possible to effectively damp the resonance and improve the frequency response as shown by Fig.11.25. Using a filter with 12 dB/octave roll off, and upper cut off frequency 0.5 of the accelerometer resonance frequency, pulse lengths down to $1/f_r$ (6 μs for 8309) can then be handled with an amplitude truth within 10%. Well suited to this purpose is Charge Amplifier Type 2626 or 2628 switched to "linear", where the upper cut-off frequency is 100 kHz.

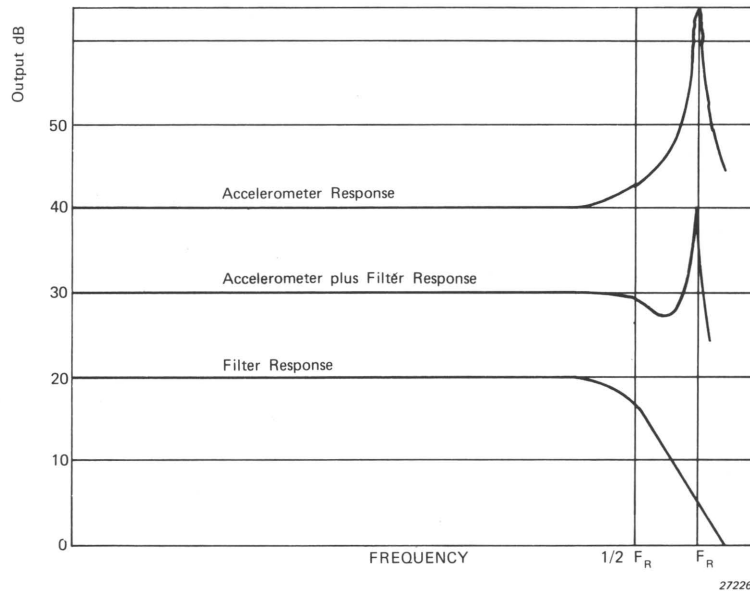


Fig. 11.25. (Use of low-pass filter to eliminate the effect of accelerometer resonance).

Zero shift is a phenomenon peculiar to piezoelectric accelerometers subjected to very high dynamic stresses. It manifests itself as a small voltage output from the accelerometer after the shock pulse has passed. Zero shift has been reduced to negligible proportions in the 8309 by careful treatment and handling of the piezoelectric disc.

Rigid mounting is particularly important when using the 8309 at high shock levels. The integral, threaded fixing stud is adequately dimensioned to transmit the motion of the test point to the piezoelectric element without distortion. It is important that the fixing surface should be smooth and flat and that the accelerometer is screwed down to the specified torque.

The Accelerometer Type 8309 is available as Accelerometer Set Type 8309 S or as Accelerometer Package Type 8309 P.

The Accelerometer Set Type 8309 S contains:

One 100,000 g Shock Accelerometer Type 8309	
One low noise extension cable	AO 0037
Two extension connectors	JJ 0032
Microplug to B&K plug adaptor	JP 0028
Wax	YJ 0216
Screw tap for 5 mm thread	QA 0068
Individual calibration chart	

The Accelerometer Package Type 8309 contains five packets, in each of which is:

One 100,000 g Shock Accelerometer	
One low noise extension cable	AO 0037
One extension connector	JJ 0032
Individual calbiration chart	

Specifications for the accelerometer are:

Voltage Sensitivity: *	
(with 1.2 m extension cable)	0.2 – 0.3 mV/g
(without extension cable)	0.5 – 0.6 mV/g
Charge Sensitivity: *	0.03 – 0.04 pC/g
Frequency Range: *	
5%	1 – 36,000 Hz
10%	1 – 60,000 Hz
Max. Shock:	
(Positive or Negative)	100,000 g
Resonance:	
Mounted	180 kHz
Transverse Sensitivity: *	max. 5%
Transverse Resonant Frequency:	28 kHz
Max. Ambient Temperature:	120°C (248°F)

Temperature Transient Sensitivity:**	
(LLF 3 Hz)	64 g/°C
Magnetic Sensitivity:	0.3 g/kGauss
Capacitance including Integral Cable:*	90 pF
Lowest Leakage Resistance:	
At 20°C	20,000 MΩ
Typical value at 120°C	20,000 MΩ
Base Strain Sensitivity:**	
(in plane of base)	0.5 g/μStrain
Construction:	C. M.
Weight:*	
Excluding integral cable	3 gm
Including integral cable	5 gm
Material:	Stainless Steel AISI 316
Mounting Thread:	M5, 5.6 mm long
Provision for Water Cooling:	No
Height:	
Excluding threaded spigot	10.7 mm (0.42 in)
Spanner Size:	7 mm

* Individual values given on calibration chart

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Noise Limit Indicators
Microphone Calibrators

ACOUSTICAL RESPONSE TESTING
Beat Frequency Oscillators
Random Noise Generators
Sine-Random Generators
Artificial Voices
Artificial Ears
Artificial Mastoids
Hearing Aid Test Boxes
Audiometer Calibrators
Telephone Measuring Equipment
Audio Reproduction Test Equipment
Tapping Machines
Turntables

VIBRATION MEASUREMENTS
Accelerometers
Force Transducers
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Accelerometer Preamplifiers
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