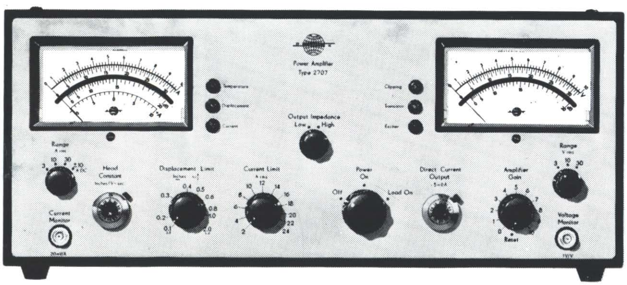
2707

Instructions and Applications



Power Amplifier Type 2707

The amplifier is a high power, low distortion vibration exciter driver, providing good protection from over-testing and system component failure. Feedback modes are switchable and the amplifier can be used in single- or multiple-shaker applications.
A balanced preamplifier, monolithic operational amplifiers and silicon transistors have ensured good rejection of temperature and supply line variations.

BRÜEL & KJÆR

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POWER AMPLIFIER TYPE 2707

March 1971

CONTENTS

1. INTRODUCTION

The 2707 is a Power Amplifier designed to drive highly reactive loads, such as small vibration exciters, and particularly the Exciter Body Type 4801 and the associated heads. The amplifier has a useable frequency range from DC to 100 kHz and full output (220 VA) over the range 40 Hz–10 kHz.

Current or voltage mode negative feedback can be used, giving a highly linear output and a selectable output impedance. The amplifier can be operated as a low output impedance voltage generator or as a high output impedance current generator.

The output is directly coupled to provide static table centring and to exclude bulky output transformers.

As well as power amplification, the 2707 provides monitoring, continuous metering and protective functions. The RMS values of the moving coil voltage and current are continuously shown on front panel meters and the associated waveforms can be monitored using the oscilloscope connectors provided.

Fast acting protective circuitry gates off the signal input to the amplifier if pre-set moving coil current and exciter head displacement limits are exceeded. The protection is also triggered by excessive temperature rise of the output transistors in the amplifier. On shut-down the relevant front panel fault indicator is lit. Any clipping of the output voltage, caused by too high a driving voltage or output current peaks, and any power transistor failures are also indicated.

2. CONTROLS

2.1. FRONT PANEL

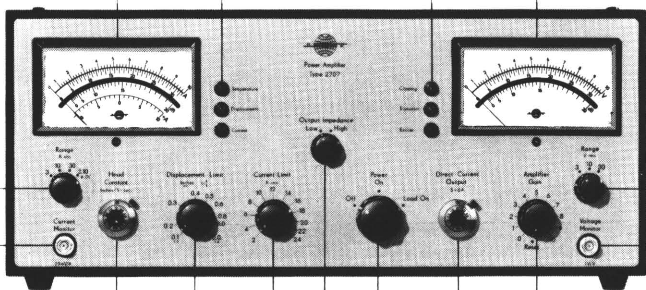

Fig.2.1. Front Panel of 2707

RANGE A RMS

A four-position switch located under the ammeter. The first three positions select full scale indications of 3, 10, and 30 A RMS. The fourth selects a centre-zero scale with ±10 A DC full scale deflection and is used when centring the moving element or to apply a static force to the test specimen.

CURRENT MONITOR

A BNC socket provides an oscilloscope display of current waveform, including the DC component. The output is short-circuit protected by a 100Ω internal series resistor. Sensitivity is 20 mV/A. A phase inversion occurs at this socket.

HEAD CONSTANT	This provides a lockable setting from 0 to 10 inches/V-sec. on a ten-turn control. The proper setting depends on the shaker head being used, and is stamped on a label by the connector on each B & K Exciter Head. This must be properly set to ensure accurate settings of the DISPLACEMENT LIMIT.
DISPLACEMENT LIMIT	The setting controls the displacement level above which the DISPLACEMENT trigger circuit fires and removes the input signal. The limit can be set anywhere between 0.1 to 2.0 inches (2.5 to 50 mm) peak to peak displacement.
CURRENT LIMIT	The setting controls the RMS output current level, including the DC component, above which the CURRENT trigger circuit will fire and remove the input signal. An averaging time-constant of 50 sec. is used, matching the minimum thermal time-constant of moving coils typically used with the 2707. This time-constant can be reduced to 2.5 sec. as in section 3.4. The maximum current for each B & K Exciter Head is shown on a label by the connector on each head.
OUTPUT IMPEDANCE	A two-position switch to select the feedback mode of the amplifier. The "Low" impedance position selects voltage feedback and the "High" impedance position selects current feedback.
POWER	A three-position, high-current switch which first connects mains power to the amplifier and exciter and then connects the amplifier to the exciter moving coil. In the "Off" position, power and shaker load are disconnected from the amplifier. In the "Power On" position only the AC power is applied energizing the Amplifier and Exciter Body (via the AC POWER EXCITER cable entry), and lighting

the meter lamps. In the "Load On" position, AC power remains applied, and the amplifier is connected to the Exciter Head moving coil. When switching from "Power Off" to "Load On" the switch must be allowed to remain at "Power On" for a short time ($>$2 sec.).

DIRECT CURRENT OUTPUT

A lockable ten-turn potentiometer provides an internal DC signal for centring the exciter head so that maximum displacement can be obtained with AC signals. This control can also be used to apply a static force for cyclic fatigue or other studies. Zero amperes DC corresponds approximately to a dial setting of 5.0.

Note that since the rear panel "Phase" switch reverses the direction of current through the moving coil, any standing table deflections will also be reversed when switching from 0° to 180°.

AMPLIFIER GAIN

This is a single-turn potentiometer with an approximately logarithmic characteristic. Before turning the POWER switch to the "Power On" position, the AMPLIFIER GAIN should be put to "Reset". Otherwise an internal electronic interlock will cause the input gate to block the input signal and turn on the CURRENT lamp, preventing possible amplifier and/or shaker overdrive.

If the interlock is triggered, the AMPLIFIER GAIN must be turned fully anticlockwise to the "Reset" position (switch clicks) to reset the input gates. Similarly when any of the four protection circuits cause the input gates to block the input to the amplifier, the amplifier must be "Reset".

RANGE V RMS

A three-position switch located under the voltmeter. The switch selects full scale indications 3, 10, and 30 V RMS.

VOLTAGE MONITOR — A BNC socket provides an oscilloscope display of voltage waveform, including the DC component. The output is short-circuit protected by an internal 100Ω resistor for short term faults.

Six front panel indicators have also been provided. Four red lamps to indicate input cut-off conditions and two yellow lamps each indicating an abnormal situation, but that operation can continue at the operator's discretion.

TEMPERATURE — A red lamp which indicates the firing of the trigger circuit due to excessive transistor junction temperature.

DISPLACEMENT — A red lamp which indicates the firing of the trigger circuit due to excessive shaker table displacement.

CURRENT — A red lamp which indicates the firing of the trigger circuit due to excessive moving coil current over the selected averaging time (see section 3.4).

EXCITER — A red lamp which indicates that blocking of the input gates has occurred because the Exciter Body over-temperature circuit indicates trouble, the Exciter Head/Body are separated or an Exciter Body fuse has blown. An external trigger can be given using the ACCESSORY socket. If the EXCITER INTERLOCK switch is in the "Bypass" position, Exciter protection is removed and the EXCITER lamp will not light.

CLIPPING — An amber lamp which indicates excessive voltage output with voltage clipping in the output transistor stage or current clipping in the peak current limiter. The amplifier will continue to operate. However, input level must be reduced to resume operation with a good waveform.

TRANSISTOR

When an output transistor fails, the amber TRANSISTOR lamp is lit. The input gates are not affected, and the amplifier will operate satisfactorily on reduced power output. Transistors should not be replaced before the checks of section 3.3.4 have been carried out.

2.2. REAR PANEL

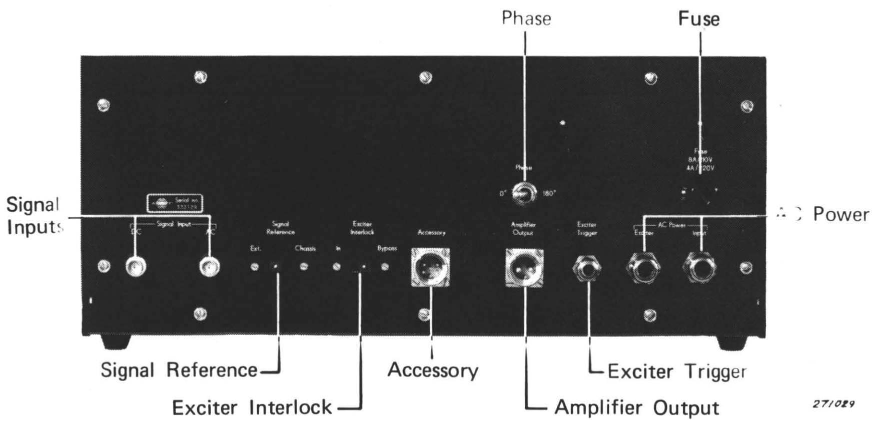

Fig.2.2. Rear Panel of 2707

SIGNAL INPUT DC

A BNC connector, insulated from the amplifier chassis, is used to give a directly coupled input. Input impedance is greater than 10 kΩ. Full output is produced by a signal of 2–3 Volts RMS.

SIGNAL INPUT AC

A BNC connector, insulated from the amplifier chassis, is used to give a capacitive coupled input. The low frequency cut-off is at 10–15 Hz, which gives an inherent displacement limiting.

SIGNAL REFERENCE

This is a two-position switch so that the signal can be referenced to the amplifier "Chassis", or to an "External" reference point to eliminate earth loops.

EXCITER INTERLOCK

The Exciter protection is disconnected by this two-position switch so that the 2707 can be used with non-B & K shakers or under reduced field conditions. The exciter is fully protected when the switch is at "In".

ACCESSORY

Plug: WK–6–32C
A 6 pin Cannon socket type WK–6–32S allowing an external pair of contacts to be connected into the Exciter protection circuitry, and also to provide protection during Multiple Exciter operation. For connection see sections 3.5 and 3.9.

AMPLIFIER OUTPUT

Plug: WK–C3–32C
A 3 pin Cannon socket type WK–C3–32S to connect power to the Exciter Head moving coil. The Head/Body interlock is also carried through this socket. For connection see Fig.3.4.

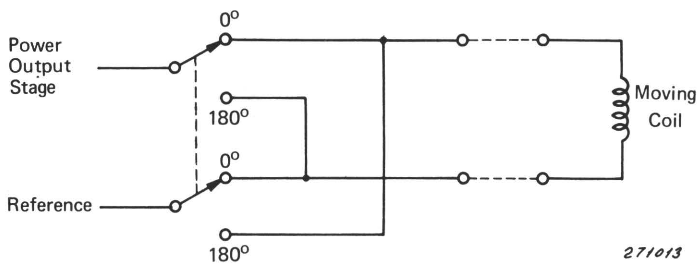

Fig.2.3. Phase Switch

PHASE

A double-throw double-pole switch that reverses the phase of the drive to the Exciter head (Fig.2.3). In the 0^{o} position the output is in phase with the input signal.

EXCITER TRIGGER	A cable entry carrying the EXCITER protection trip signal from the B & K Exciter Head/ Body combination.
AC POWER EXCITER	The main AC power supply to the field coil rectifier, etc. in the B & K Exciter Bodies is supplied via the POWER switch in the amplifier and is lead out through this cable entry. Non-B & K Exciters should also have their field supplies interlocked with the main POWER switch by supplying the field coil rectifier via this cable entry.
AC POWER INPUT	The main AC power supply cable is led into the amplifier through this cable entry and terminated on a rear mounted connector block. See section 3.2 for power connection instructions.
FUSE	This fuse protects the amplifier and is rated at 4 A for 220 V and 8 A for 110 V supplies.

3. OPERATION

3.1. PRELIMINARY

The 2707 amplifier is supplied with the mains power transformers connected for 220 V RMS, 50–60 Hz operation. The time constant of the CURRENT trip circuitry is set for 50 seconds and shorting links are in place across the relevant pins of the ACCESSORY socket.

Mains Voltage	Links Required Between Terminals		Connect Input from Power Switch To Terminals	
100 V	1 to 5	2 to 6	1	6
120 V	1 to 5	3 to 7	1	7
127 V	1 to 5	4 to 8	1	8
200 V	2 to 5		1	6
220 V	3 to 5		1	6
227 V	4 to 5		1	6
240 V	3 to 5		1	7
247 V	4 to 5		1	7
254 V	4 to 5		1	8

Fig.3.1. Connections to Transformer Connector block

If the amplifier is to be used on a mains supply other than 220 V the connections to the power transformer must be changed in accordance with Fig.3.1. The photograph (Fig.3.2) shows the transformer connector block connected for 220 Volts operation.

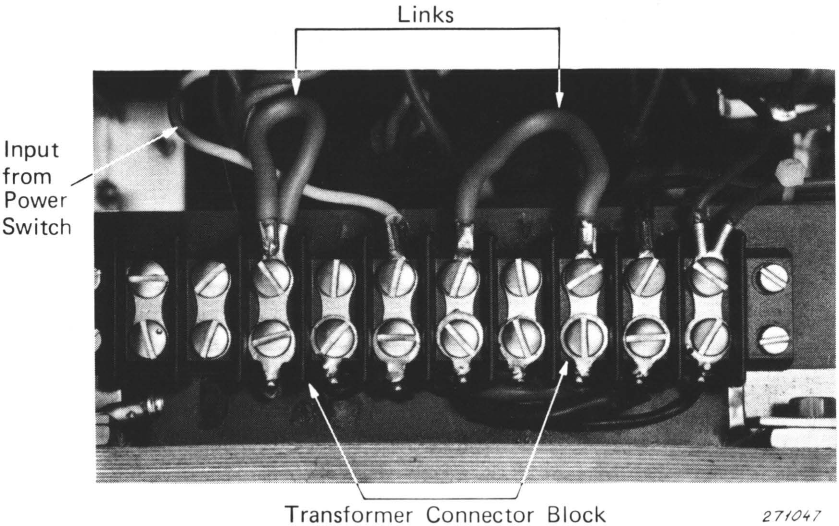

Fig.3.2. Mains Transformer Connector block for transformer interconnections and input Mains Power from the POWER switch

3.2. SYSTEM INTERCONNECTION

The B & K Exciter Body Type 4801 is supplied with the following cables for interconnection to the 2707:

a) a 5 conductor 30/0.25 mm 250 V cable for interconnection between the AMPLIFIER OUTPUT and the Exciter Head moving coil. Diagonal conductors in this cable should be connected together, one pair going to pin 1 and the other to pin 2 of the connectors. The fifth conductor is used for the Exciter Interlock signal and is connected to pin 3.

b) a 4 conductor (use diagonal conductors paired) 32/0.20 mm 750 V cable for the AC POWER EXCITER connection.

c) a 2 conductor 24/0.20 mm 250 V cable for the EXCITER TRIGGER connection.

The system is connected as shown in Fig.3.3 and details are given in the wiring diagram Fig.3.4 and the photographs Figs.3.5 and 3.6.

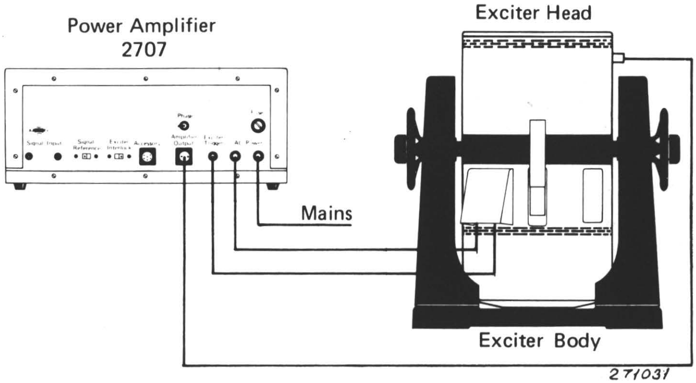

Fig.3.3. System Interconnections

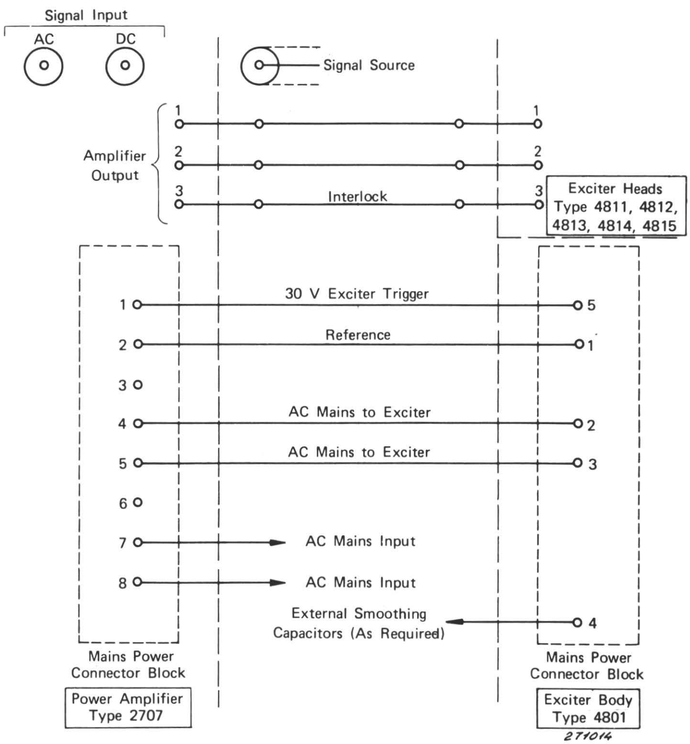

Fig.3.4. System Wiring Diagram

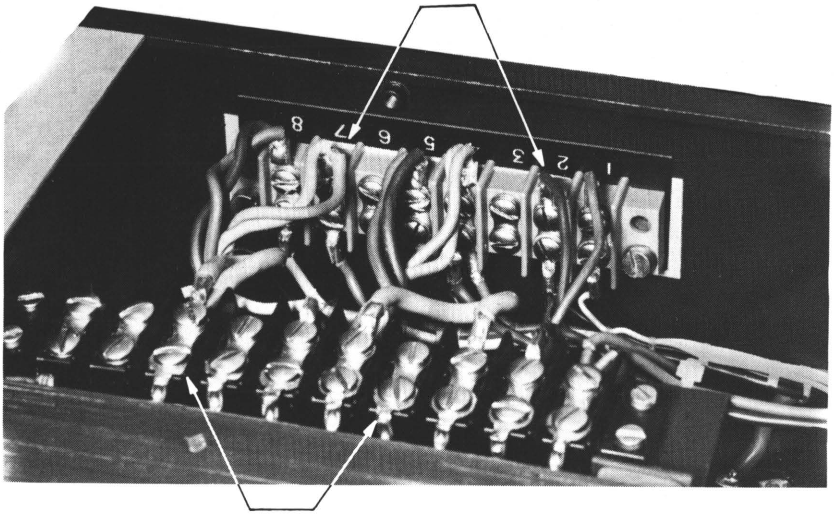

Fig.3.5. Amplifier Terminal Blocks

For use with shakers other than Type 4801, the manufacturer's wiring requirements must be followed. When so used the EXCITER INTERLOCK switch must be in the "Bypass" position.

3.3. NORMAL OPERATION

3.3.1. Set-up

After connecting the complete system and before applying power from the mains, ensure that the POWER switch on the amplifier is at "Off" and the AMPLIFIER GAIN is at "Reset". Set up the CURRENT LIMIT, and HEAD CONSTANT controls to the levels given on the plate affixed to each B & K Exciter Head. The HEAD CONSTANT control should then be locked. The DISPLACEMENT LIMIT can be set up at twice the expected test maximum but must not be greater than the Exciter's displacement capability. The displacement limits of B & K Exciter Heads are also on the above mentioned plate. Select the required OUTPUT IMPEDANCE. Operation in the "High" impedance mode keeps the generated force unchanged when changes occur in the test object, and therefore is particularly useful

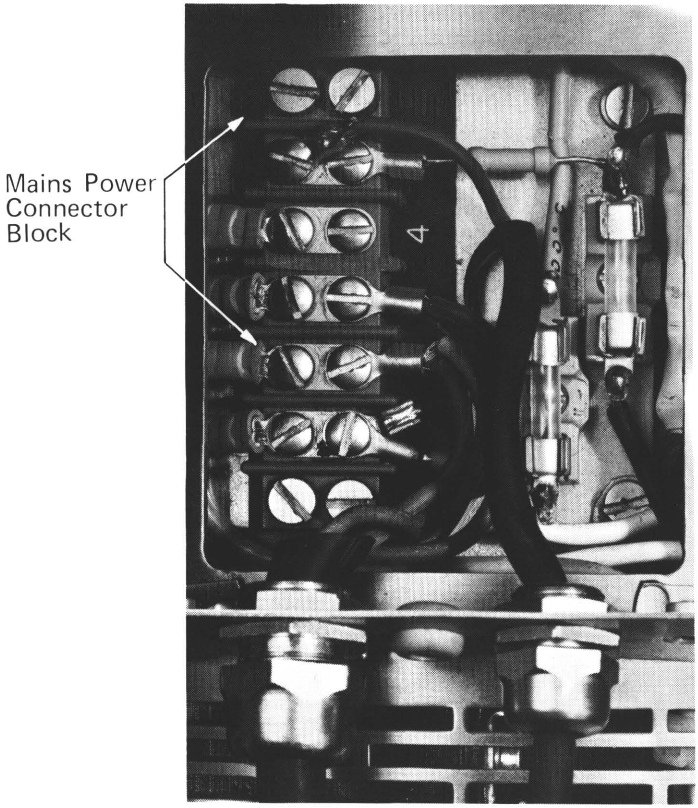

Fig.3.6. Type 4801 Exciter Body Mains Power Connector block

whenever the test is force-related. As examples, the single exciter fatigue testing of materials-test sample bars usually requires constant force, although the bar is deteriorating during the test. Also, when using more than one exciter to determine the resonant mode of a structure, constant forces of known phase and magnitude which are insensitive to changes in the structures are required.

The "Low" impedance mode keeps the voltage applied to the exciter independent of test object changes. The "Low" impedance mode provides the best acceleration waveform and is therefore preferable for most single exciter applications. "Low" impedance mode operation is useful for multiple exciters at low frequencies if the same motion is desired from each exciter, such as the use of one exciter to push and another to pull on a model of a bridge.

The CURRENT LIMIT circuitry operates with a 50 second time constant. This can be reduced to 2.5 seconds by removing an internal shorting link from printed circuit card ZL 0028 (Fig.3.9).

For non-B & K vibration exciters the allowable moving coil current must be ascertained from the relevant manufacturer and the CURRENT LIMIT control set accordingly, so that full protection is available.

Set the DIRECT CURRENT OUTPUT control to 5.0 and the AMPLIFIER GAIN control fully anti-clockwise to the "Reset" position.

On the rear panel set the EXCITER INTERLOCK to "In" for the B & K Type 4801 system and to "Bypass" for any other manufacturer's shaker. The SIGNAL REFERENCE control is set up as required, although normally this will be on "External". The PHASE switch can be "0°" or "180°" for single shaker applications and as dictated by circumstances in multiple shaker systems.

3.3.2. Switch-on

The POWER switch on the 2707 has three positions "Power Off", "Power On", and "Load On". In the "Power On" position, AC mains supply is applied to the amplifier and the field coil rectifiers in the Exciter Body. The moving coil is open circuit at this time otherwise the e.m.f.s induced in the moving coil by the sudden build-up of field would cause a severe transient at the Exciter table. The switch also ensures that the small switch-on transients due to the amplifier have had sufficient time to die away before the load is connected. To avoid damage to the test specimen, exciter or amplifier, a pause of one or two seconds duration must be made in the "Power On" position before switching to "Load On".

When the POWER switch is at "Power On", the Amplifier and Exciter Body cooling fans and the scale lamps are also energized. The meter indications should be zero.

Turn the POWER switch to "Load On". The meter indications of AC quantities will still be zero. Turn the RANGE A RMS switch to ± 10 A and either adjust the DIRECT CURRENT OUTPUT to give zero indication on the current meter or, using this control, centre the table in its vertical travel.

For manual testing set the signal source frequency to the desired value and increase the AMPLIFIER GAIN until the required test levels are established. For automatic sweep testing full instructions are to be obtained from the relevant instruction manuals.

3.3.3. Warning Lights

If the DISPLACEMENT LIMIT is set at less than twice the maximum test level, check that the Displacement circuitry does not trip at the low frequencies. Adjust the DISPLACEMENT LIMIT as necessary.

If any of the red front panel lamps light, determine the cause, and remedy the situation. Return the AMPLIFIER GAIN to "Reset" and recommence the run-up.

Should the CLIPPING lamp light, the signal level must be reduced until the light is extinguished. Full output voltage is available to 10 kHz and output voltage decreases in inverse proportion to frequency between 10 kHz and 100 kHz.

If the TRANSISTOR lamp lights during a test, monitor the voltage waveform and the vibration levels. If no degradation has occured and if the amplifier is operating reasonably below maximum rating, the test, if vital, can be continued. When the test is discontinued, turn down the AMPLIFIER GAIN control to the "Reset" position and the POWER switch to "Off". Remove the top-cover of the amplifier and check the fuses on the component board mounted to the fan-cooled assembly (Fig.3.8) and the power transistors mounted on the heat-sinks.

3.3.4. Fault Rectification

The schematic circuit diagram of the power output stage is given (Fig.3.7) and shows that the protection fuses can be checked in situ by measuring across each fuse in turn with an Ohm-meter. An un-blown fuse will indicate as a short circuit and a blown fuse as approximately 250Ω for the NPN transistors, depending on the polarity of the Ohm-meter connection.

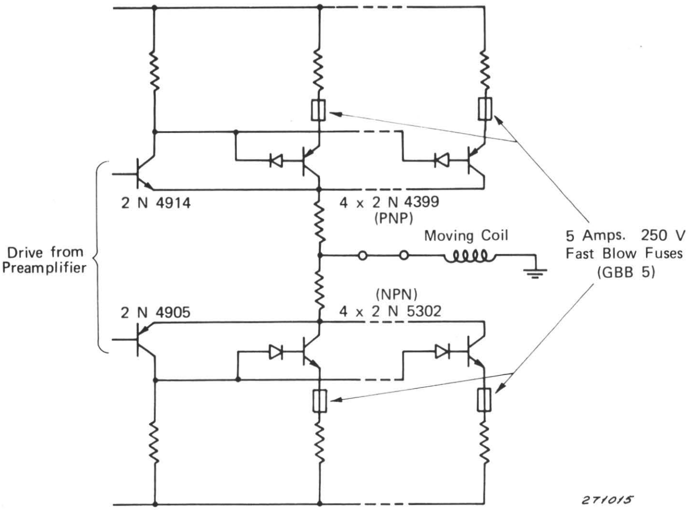

Fig.3.7. Schematic diagram of the Power Output stage

The fuses used are very fast acting and designed specially for use with semi-conductors. Any replacements used must be of a similar specification and such that for a current of 4 times their rated value of 5 A (i.e. for a current of 20 A) they will blow within 40 msec. and for a x 10 overload within 5 msec.

The power transistors should also be checked for damage, the most common mode of failure being a short circuit collector-to-emitter. A simple resistance check can be made by placing one lead of the ohm-meter on the power transistor case (collector) and the other on the relevant fuse-holder (emitter), with the fuse removed (Fig.3.8). Resistance readings depend on the polarisation of the ohm-meter and should be 200Ω or 1 kΩ for the NPN transistors and 200Ω–10 kΩ for the PNP transistors. Junction break-down will be indicated as a short-circuit.

The transistors are mounted in plug-in sockets and can be simply removed. The four power transistors mounted on the bottom of the heat-sink can be reached by removing the bottom plate of the amplifier case. Always ensure that the size of the base and emitter pins of the replacement transistors used is not greater than 1 mm ± 0.05 or the transistor holder will be damaged.

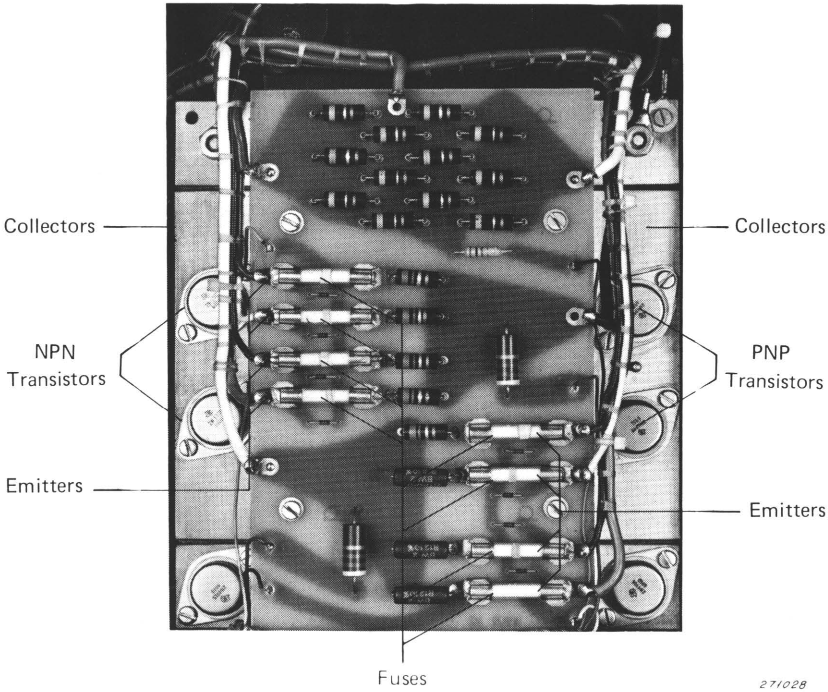

Fig.3.8. Transistor Protection Fuses

When replacing transistors a good thermal bond, using Heat Sink Cement, must be made with the surrounding heat sink.

After replacing any damaged components the test can be recommenced as previously detailed.

3.3.5. Stand-by

The amplifier can be left in a stand-by condition during the course of a test by switching the AMPLIFIER GAIN control to "Reset" and the POWER switch to "Power On". Note that it is not possible to remove the Head of a B & K Exciter when at stand-by because of the high standing magnetic field generated by the field windings.

At the end of a test the Amplifier is switched off by turning the POWER switch to "Power Off" with the AMPLIFIER GAIN in the "Reset" position.

3.4. CURRENT LIMIT TIME CONSTANT

The averaging time constant of the CURRENT protection circuitry can be reduced from the nominal 50 seconds to 2.5 seconds by removing the shorting link between the terminal pins on Card ZL 0028 (Fig.3.9).

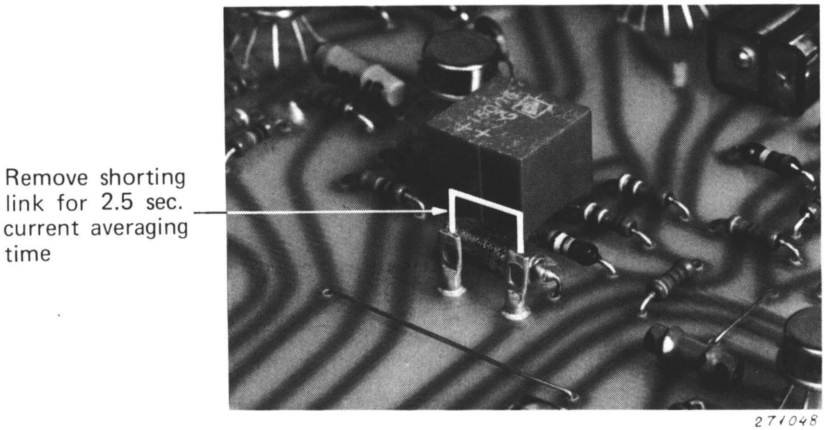

Fig.3.9. Shorting link to increase CURRENT averaging time constant

3.5. MULTIPLE EXCITER VIBRATION TESTING

Certain vibration applications require more than one Exciter to drive the test specimen. This type of connection is shown in the schematic diagram of Fig.3.10. To provide complete protection, a trip in any one Amplifier-Exciter combination must remove the input signal from all Amplifier-Exciter pairs in use. This is accomplished using the ACCESSORY sockets of the 2707s.

Select one of the Amplifiers as the Master and the remainder as Slaves. Remove the shorting link between pins 4 and 5 on all the Slave amplifiers and, using external connectors and wiring, link pin 5 of each amplifier to pin 5 of every other amplifier.

The FET gates at the input to each amplifier are now parallelled and the gates' "on" bias is supplied from the Master Amplifier.

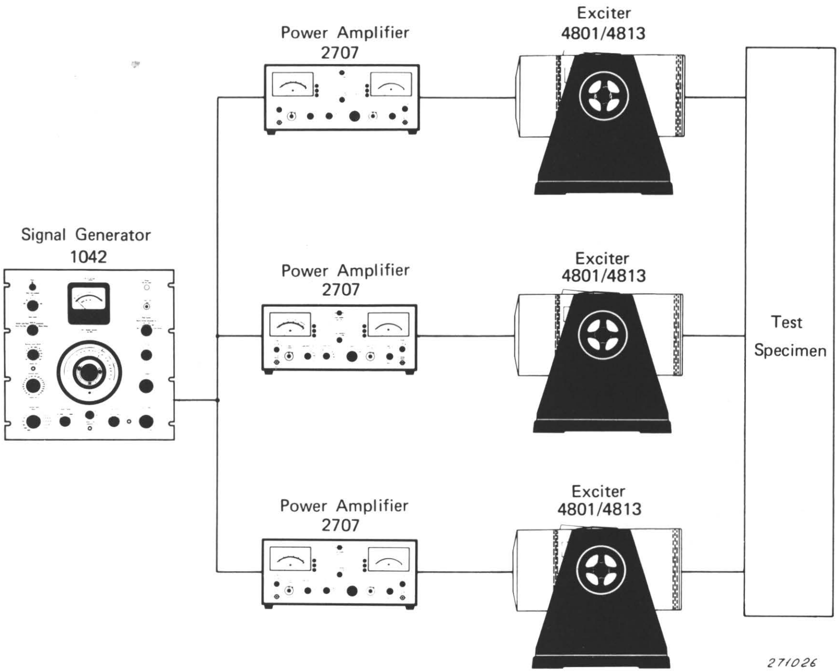

Fig.3.10. Multiple Amplifier-Exciter Operation. Single signal source

If any Amplifier-Exciter pair trips, the input and DC centring signals will be gated off from all amplifiers, but the only failure lamps lit will be the relevant lamp on the amplifier that initiates the trip. Thus the offending pair can be easily recognized and corrective action taken before continuing the test. Only the tripped amplifier requires to be reset before the test can continue, but ensure that the drive signal is re-applied gradually to the whole test set-up.

The OUTPUT IMPEDANCE can be chosen as detailed in section 3.3.1 for normal operation.

3.6. VERY HIGH OUTPUT IMPEDANCE

In the "High" impedance mode an even higher output impedance (for frequencies greater than 10 Hz) can be obtained by soldering a link across the two terminals on Card ZE 0067 (Fig.3.11). Typically, an output impedance increase of 10 dB may be obtained for frequencies greater than 100 Hz. The link must be replaced for operation in the "Low" impedance mode or the amplifier may oscillate.

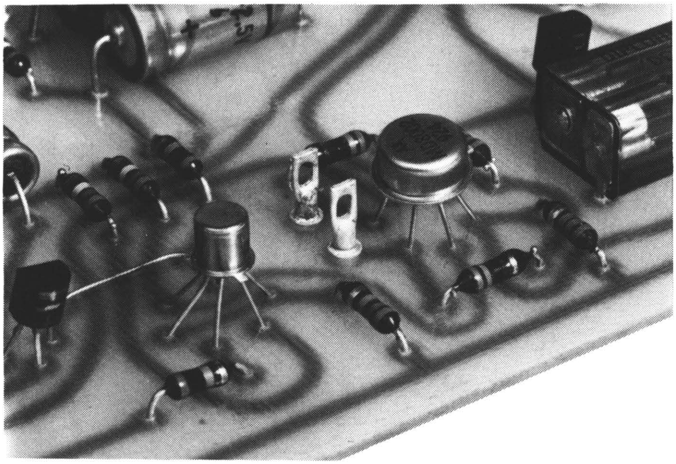

Fig.3.11. High Z Terminals. Card ZE 0067

3.7. REDUCTION OF BACKGROUND NOISE AT THE EXCITER TABLE

The field supply current is normally derived from a full-wave rectifier, and because of ripple some residual motion will still exist at the exciter table, even with no input applied to the amplifier. The ripple is at twice mains frequency (100 Hz or 120 Hz).

The residual motion of B & K systems with the Power Amplifier Type 2707, the Exciter Body Type 4801, and a matching Exciter Head is typically 70 dB below the motion corresponding to full force. This low level of background motion is insignificant for most applications.

An additional 10 to 20 dB reduction in the level of the residual motion (10 to 20 dB increase in dynamic range) can be achieved by connecting a 100,000 μF, 30 V electrolytic capacitor, by thick, short leads to the Exciter Body terminal block. This type of capacitor is polarized and must be connected positive to terminal 1 and negative to terminal 4 (Fig.3.12). Larger capacitors will further reduce the residual motion level.

Background noise can also be reduced by reducing the strength of the exciter field. With B & K exciters, this can be done by reducing the mains supply voltage to the Field Coil Rectifiers. For non-B & K exciters the manufacturer's instructions on reduced field strength operation must be followed.

3.8. OPERATION WITH REDUCED EXCITER FIELD

If operation is desired at very low vibratory levels, two methods are available to shift the dynamic range of the system to a lower range of acceleration levels:

a) A large mass can be added to the table. The same forces then cause smaller motions without reducing the dynamic range.

b) The mains voltage to the Field Supply can be reduced. Since the same current causes smaller deflections when the magnetic field is reduced, the background level is lower but the dynamic range is substantially the same. The amplifier mains voltage must remain at the nominal value.

Operation at levels in the 0.001 g range is very difficult. Very good instrumentation and a good seismic block system, to isolate the exciter from building motions, are essential.

A flexible means of providing reduced voltage operation is to wire a variable autotransformer in the power line to the exciter, providing a voltmeter to monitor the exciter mains voltage. An alternative method is to set the exciter transformers' primary taps for a nominal voltage greater than the actual mains voltage used. The preferred source of power is via the amplifier AC POWER EXCITER connector; thus avoiding the possibility of energizing the moving coil from the amplifier before supplying power to the exciter to establish moving coil cooling.

For the B & K Type 4801 Exciter Body the mains supply can be in the range −15% to + 5% from a nominal value selected by appropriate wiring of the transformers primaries. However, it is possible to operate the 4801 on voltages considerably below nominal, using the method outlined in the wiring diagram (Fig.3.12).

Reduction of the mains supply to an exciter field affects the HEAD CONSTANT and CURRENT LIMIT setting requirements, reduces the

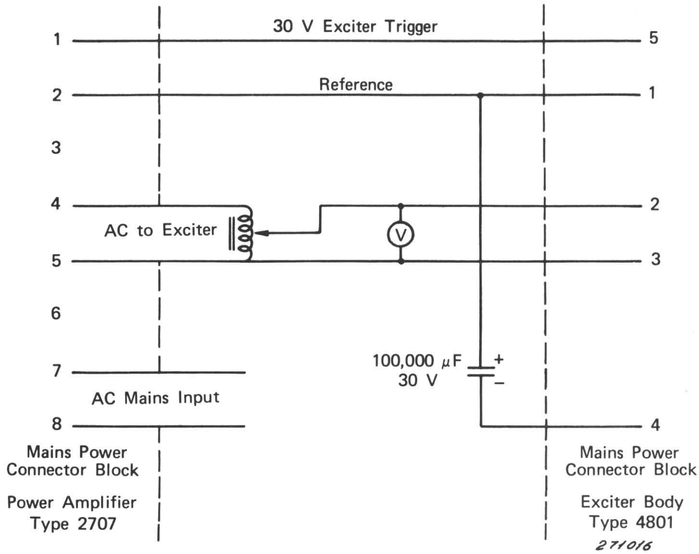

Fig.3.12. Special connections

effectiveness of the Exciter Interlock protective circuitry, the displacement capability and the available force.

Reduced mains voltage lowers the effectiveness of the exciter cooling, so the current to the moving coil must be limited to prevent its overheating. The amplifier CURRENT LIMIT control will provide this protection if

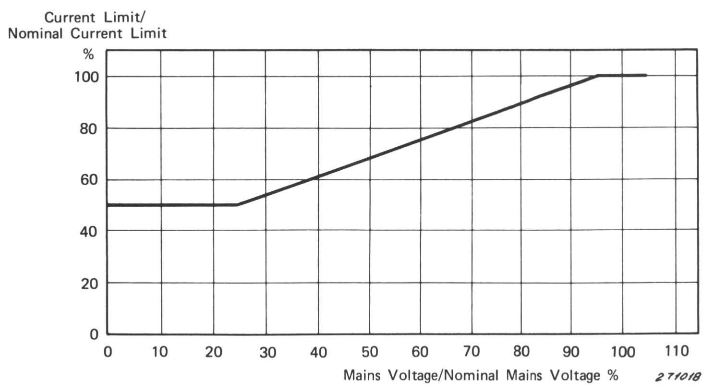

Fig.3.13. CURRENT LIMIT v. Mains Voltage

properly set, assuming the exciter cooling system is otherwise operating normally. The correct setting for the 4801 system of the CURRENT LIMIT is given in Fig.3.13.

Adjustment of the HEAD CONSTANT control on the amplifier front panel is necessary to maintain calibration of the DISPLACEMENT LIMIT protection (Fig.3.14 for B & K Type 4801). The circuit integrates the exciter moving coil voltage to obtain an analogue of displacement, and the proportionality between voltage and displacement depends upon mains voltage.

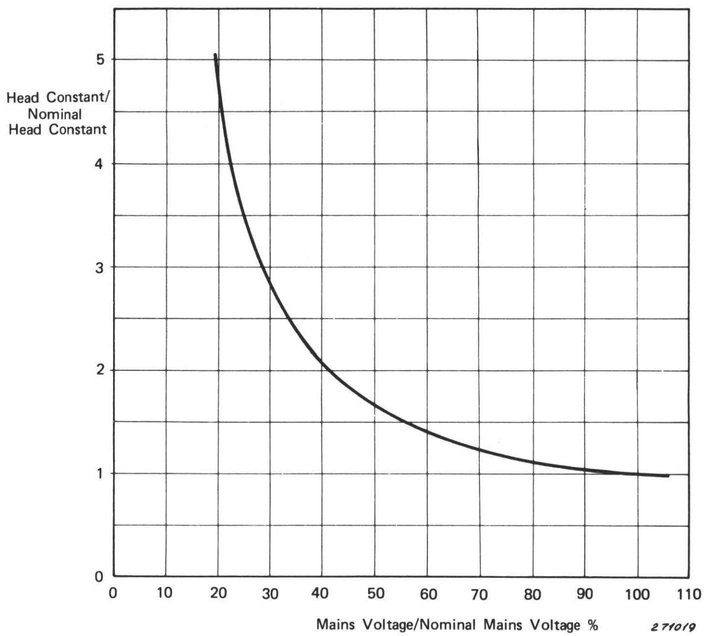

Fig.3.14. HEAD CONSTANT v. Mains Voltage

The Exciter Interlock protective circuitry will normally shut down the signal to the driver coil in the event of an exciter cooling system failure caused by power loss or a stalled motor. With reduced voltage this protective circuit must be by-passed, (EXCITER INTERLOCK switch to "Bypass") so the operator must check that the cooling is operating. Note that at voltages below 25% of normal, forced cooling is not required for either the moving coil or the exciter body components, so protection against cooling

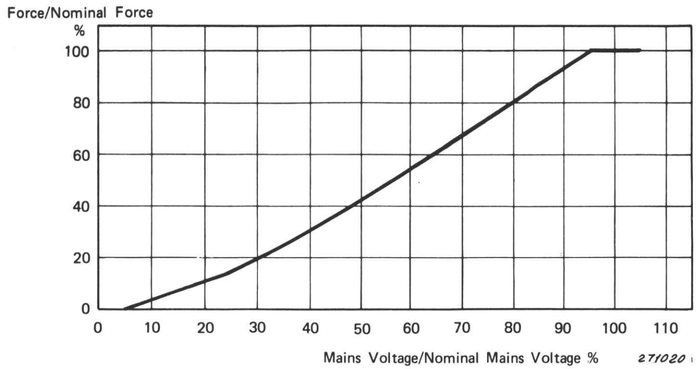

Fig.3.15. Force capability

system failure is unnecessary. The exciter field coils and field supply components will cool adequately at reduced mains voltage, and are still protected against cooling system failure by the thermostat on the rectifier heat sink.

The force capability of the exciter is reduced at low mains voltages. The force generated by the driver coil is proportional to the product of the flux density and the driver coil current. The lowered voltage reduces the field current and thus the flux density, and the useable moving coil current is reduced because of reduced cooling. See Fig.3.15 for typical Type 4801 force capability. Displacement capability is also reduced in the low frequency region where the force required to deflect the suspension is dominant over the force required to accelerate the moving mass. As well as lowered background noise at the table, low voltage operation may be required to reduce power demand from the mains, reduce heat dissipated from the exciter, etc.

For the 4801 Exciter Body the power input to the field supply at nominal mains voltage is about 1200 watts: this power is dissipated to the environment after the exciter has attained thermal equilibrium. The dissipated power can be reduced by operating at lower mains voltages, and can reasonably be approximated to:

$$\text{Power Dissipated} = 1200 \times \left[\frac{E_{mains}}{E_{nominal}}\right]^2$$

Thus operation at 70% of nominal voltage cuts the power to 600 watts: operation at 50% of nominal voltage reduces the power to 300 watts.

To summarize, the operating steps are:

a) Wire a variable autotransformer in the line supplying power to the Exciter Body.

b) Set amplifier controls:

CURRENT LIMIT and
HEAD CONSTANT as required by the new operating voltage
EXCITER INTERLOCK: "Bypass" position

c) Turn amplifier POWER switch to "On". Adjust (as necessary) the variable autotransformer for the desired mains voltage to the exciter.

d) Ensure that the cooling fan is working in the Exciter Body and then proceed as for normal operation.

3.9. EXCITER TRIGGER

The shorting-link between pins 1 and 2 of the ACCESSORY socket can be replaced by an external normally-closed pair of relay or switch contacts. When the contacts are opened the amplifier EXCITER protection circuitry will be triggered. The contacts could be controlled by a temperature overload thermostat of an environmental test chamber, a failure on the test specimen, etc.

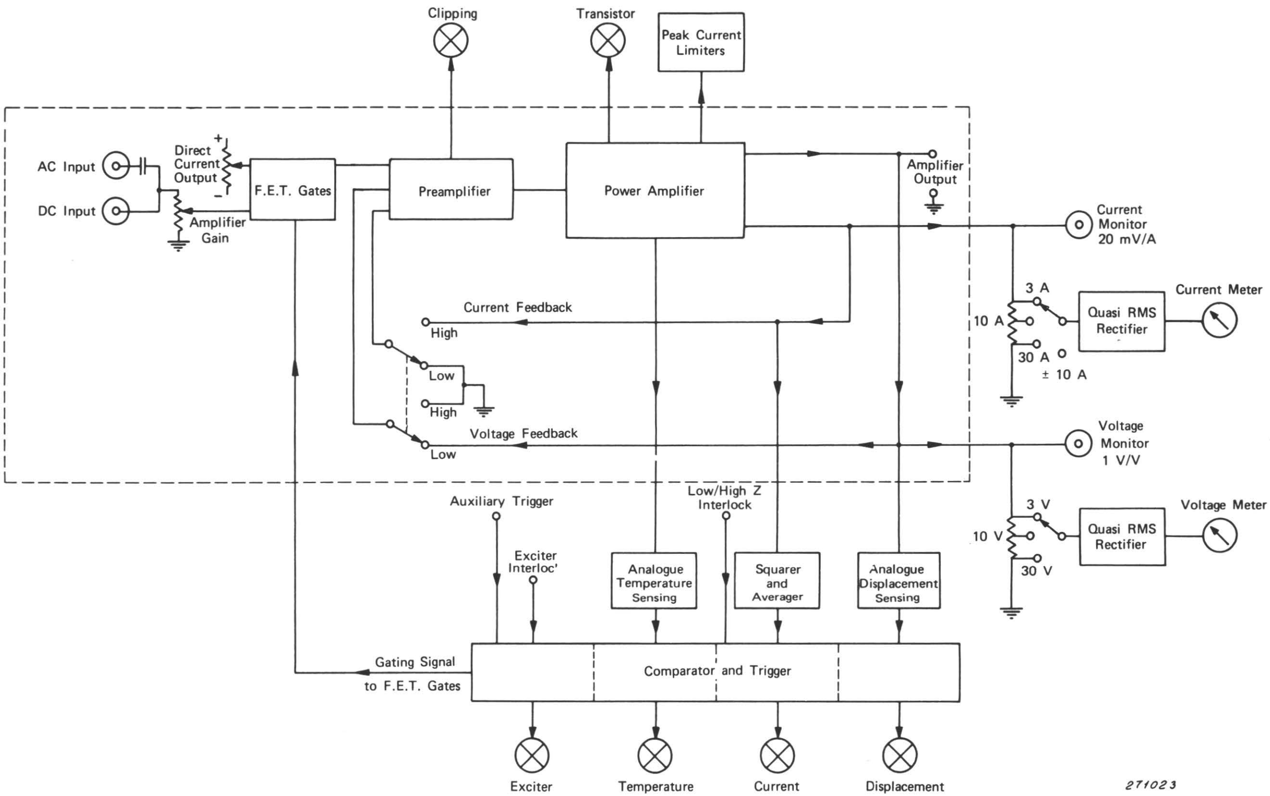

Fig.4.1. Block Diagram of 2707

4. DESCRIPTION

4.1. GENERAL

Vibration testing of large specimens or testing at high g levels requires a high power drive to the exciter. However, unless provision is made to avoid accidental mis-use of this power, considerable damage can be done to the test object, the shaker head or body, or even the amplifier itself. The block diagram (Fig.4.1) of the Power Amplifier Type 2707 shows that as well as power amplification, the instrument protects against electrical, mechanical and thermal overstressing. Facilities for waveform monitoring and continuous metering are also provided. Description of the circuit elements follows.

4.2. INPUT CIRCUIT

The rear-mounted BNC input sockets are connected via the AMPLIFIER GAIN control and a FET gate to the preamplifier. The 2707 will accept either an AC coupled input (at the AC INPUT socket) or a direct coupled input (at the DC INPUT socket). The DC static centring signal from the DIRECT CURRENT OUTPUT control is applied to the preamplifier through a similar FET gate. The two gates are normally held open, but if the protection circuitry is activated the gates are closed and disconnect the preamplifier input from the static centring and amplifier drive signals. The gate controlling the static deflection signal is purposely made slow-acting so that large static offsets in table position are not transmitted to the test object as fast transients when the equipment is switched on or when the protection circuitry triggers.

The amplifier input impedance is minimum when the AMPLIFIER GAIN control is set for maximum gain, but is never less than 10 kΩ.

4.3. PREAMPLIFIER

The preamplifier consists of a balanced differential amplifier for inherent temperature stability, high common mode rejection and a simply set DC output level. This is followed by a high gain, large voltage swing stage, which is used to set the single dominant pole in the amplifier's high frequency response and to drive the power output stage. Thus, generous feedback can be applied to the circuit to optimize linearity while still maintaining a comfortable stability margin. Distortion curves are shown in Fig.4.2.

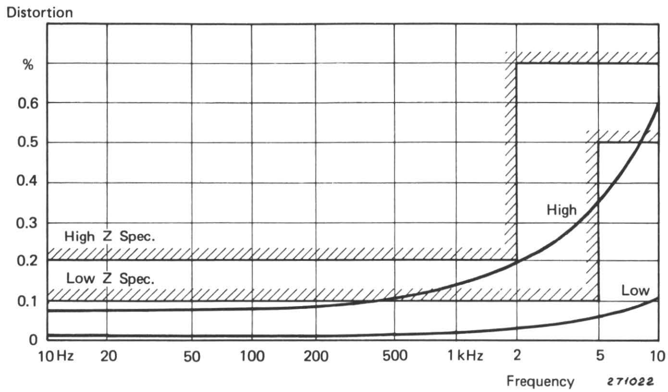

Fig.4.2. % Distortion. "Low" and "High" Impedance Modes

The type of feedback from the power amplifier is selected by the OUTPUT IMPEDANCE switch. In the position "Low", a fraction of the 2707 output voltage is fed back to the input. This gives voltage source characteristics (constant output voltage, very low output impedance) to the overall amplifier. If the OUTPUT IMPEDANCE switch is at "High" the 2707 has feedback proportional to the current flowing in the load. This gives current source characteristics (constant output current, high output impedance). However, at very low frequencies the feedback becomes a combination of both current and voltage feedback and the output impedance is reduced. At frequencies greater than 10 Hz an even higher output impedance can be obtained by inserting a shorting link when using the amplifier in the "High" mode (see section 3.6).

Graphs of output impedance variation over the frequency range, in "Low" and "High" impedance modes, are shown in Figs. 4.3 and 4.4.

Excessive signal levels at the input will saturate the amplifier and cause clipping of the output waveform. This will trigger the clipping detector in the preamplifier, which lights the yellow CLIPPING lamp on the front panel.

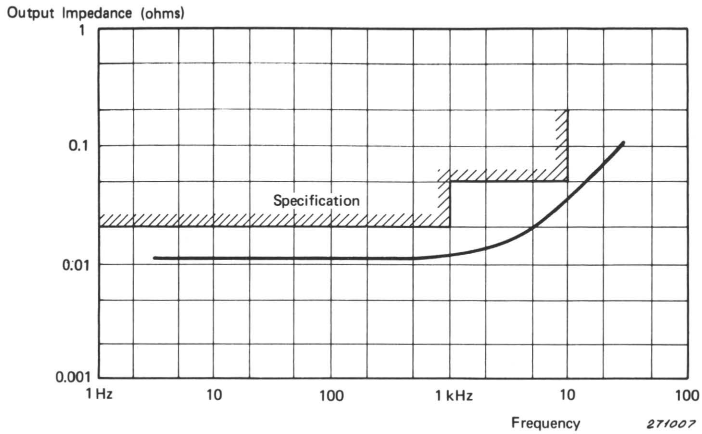

Fig.4.3. Output Impedance. "Low" Impedance Mode

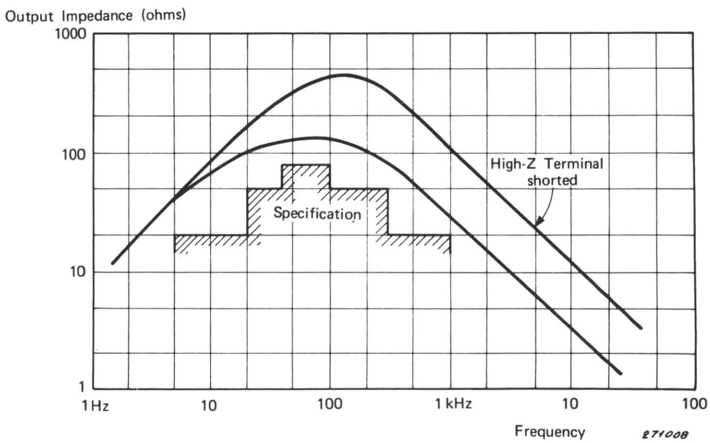

Fig.4.4. Output Impedance. "High" Impedance Mode

4.4. POWER AMPLIFIER

The power amplifier is a complementary connected stage operating in class B. The standing current is small, ensuring very low cross-over distortion. Each complementary half of the output stage is a special form of the Darlington connection, using complementary transistors, and having a very low output impedance.

The harmonic distortion of the 2707 is very low (Fig.4.2) mainly because of the separate power supplies to preamplifier and output stages, and the use of direct coupling.

The power output transistors (four NPNs Type 2N5302 and four PNPs Type 2N4399) are each protected by a fast-acting 5 A fuse. Power transistor failure resulting in a short circuit emitter-to-collector will blow the fuse and light the yellow TRANSISTOR warning lamp. The amplifier design is such that faulty output transistors do not affect the operation of the remaining output transistors.

Peak current limiting circuitry is arranged to provide limiting of instantaneous positive and negative output current peaks. The limiting value can be adjusted independently for positive and negative peaks. It is set up to limit at 40 A. Current limiting is indicated by the CLIPPING lamp.

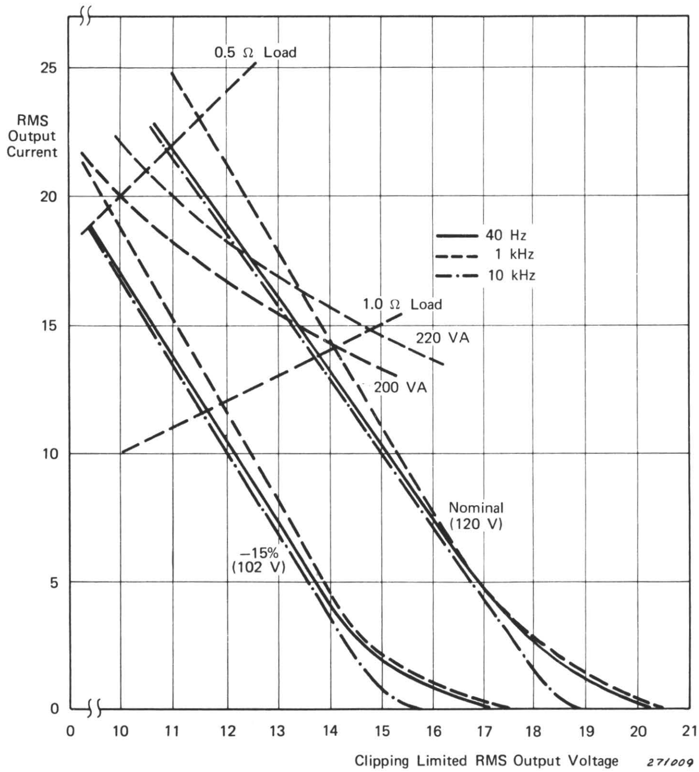

Fig.4.5. Clipping Limited Output

At nominal mains voltage the rated output of 220 VA is available for a range of load resistance from 0.5Ω to almost 1.0Ω (Fig.4.5). Operation with reduced mains voltage limits the unclipped swing of the output voltage. However, for a 0.5Ω load the full 220 VA is available down to approximately 90% of the rated mains voltage.

The unclipped voltage output depends on mains voltage, output current, and frequency. At nominal mains voltage, the output voltage is typically over 12 V for an output current of 20 A, rising to 18 to 20 V for lower output currents.

The rated load current is 22 A RMS over the range 40 Hz–10 kHz, 11 A RMS over the low frequency range (0.1 Hz–5 Hz) and 10 A at DC.

The small signal frequency response of the 2707 across a 0.5Ω load is shown in Fig.4.6. The high frequency response in the "High" mode is mainly determined by the load resistance. Amplifier gain is 5 Volts/Volt ± 1 dB in the "Low" impedance mode and 14 Amperes/Volt ± 2 dB in the "High" impedance mode.

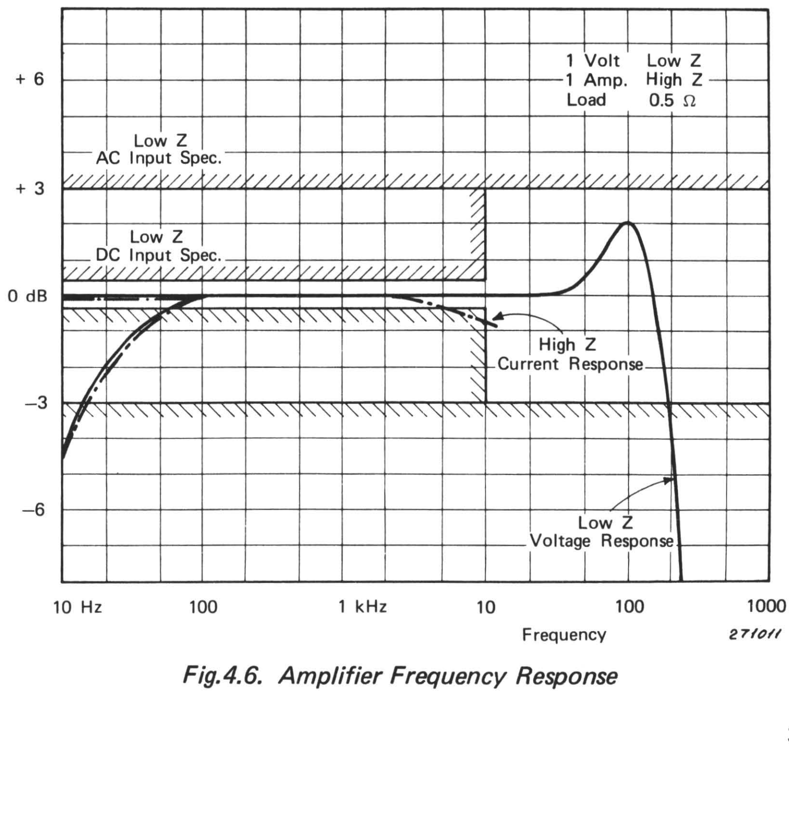

Fig.4.6. Amplifier Frequency Response

4.5. PROTECTIVE CIRCUITS

The 2707 is protected by fast-acting Silicon Controlled Rectifiers (SCR's) which, when triggered, turn-off the two FETs at the input, thus disconnecting the drive and DC centring signals. Each triggered SCR also lights a lamp which gives an indication of the reason for equipment shut-down.

Overload protection is provided against excessive coil drive current (CURRENT), shaker table displacement (DISPLACEMENT) and amplifier temperature increase (TEMPERATURE). Activation of the exciter head/ body protection will trigger the EXCITER circuitry.

To reset the amplifier, the AMPLIFIER GAIN control must be reduced and turned fully anti-clockwise to the click-position marked "Reset". This opens the anodes of all protection SCR's. Increasing the gain once more returns the amplifier to its normal operating condition with the protection circuitry again enabled.

4.5.1. Current

A front-panel control (CURRENT LIMIT) is used to pre-set the RMS output current (including the DC component) at which the CURRENT circuitry trips. The limit can be set anywhere between 2 A and 24 A.

The squared and averaged value of the voltage across the current feed-back resistor is compared to a reference. If the reference level is exceeded the CURRENT SCR will be triggered, turning on the red front-panel lamp labelled CURRENT and disconnecting the system inputs. The time-constant of the averaging circuitry is 50 sec., matching the minimum thermal time-constant of the Exciter Heads used with the B & K Exciter Body Type 4801. This permits short-term current overload and means the shaker system can be used in a pulsed mode. The averaging time-constant can simply be reduced to 2.5 sec. if a "snap-action" current trip is required (see section 3.4) or if a non-B & K exciter is to be used.

Interlocking ensures that any attempt to alter the OUTPUT IMPED-ANCE switch when the amplifier is delivering power to its load will trip the CURRENT protection circuitry.

The Exciter Head moving coil is not connected to the amplifier until the three-position POWER switch is at "Load On". When switching on the system, a short pause in the "Power On" position gives the field time enough to build-up to its final value. This delay in switch-on will prevent large and possibly damaging surges being transmitted to the object under test.

If the amplifier is switched from "Off" to "Power On" when the AMPLIFIER GAIN is not at "Reset", the CURRENT trip circuitry will be triggered. This prevents transients being transmitted to the exciter load if the input to the amplifier is still connected.

4.5.2. Displacement

The front panel control DISPLACEMENT LIMIT is used to pre-set the peak-to-peak level of shaker table displacement at which the DISPLACEMENT circuitry trips. The control is continuously variable and can be set anywhere between 0.1—2.0 inches (2.5—50 mm).

With sine wave excitation the wide band performance of electro-dynamic shakers can be summarized by the asymptotic plot of acceleration against frequency (Fig.4.7.a). At low frequencies (up to approx. 20 Hz), acceleration is limited by the available table displacement between end—stops. The maximum attainable velocity is determined by the maximum amplifier output voltage and dynamic loss effects in the mounts and other suspension parts. The velocity limitation usually falls within the freqeuency range 20—200 Hz. Above about 200 Hz the maximum acceleration available depends on the driving coil current and the moving mass. The regions of constant velocity and constant displacement are shown in Figs.4.7.b and 4.7.c.

Since the amplifier output voltage is proportional to the table velocity over the frequency range where full displacement is attainable (and since velocity is the first derivative of displacement), integrating the output voltage will give a signal proportional to the table displacement. The constant of proportionality (termed the "Head Constant") depends on the dimensions of the driving coil, number of turns, field flux density, etc. and is electrically set-up using the HEAD CONSTANT control. The numerical value of the Head Constant is stamped on each Exciter Head of the B & K shaker system.

The logarithmic plot of displacement against frequency (Fig.4.7.c) shows that displacement falls off as frequency increases. The gain/frequency characteristic of the displacement sensing circuitry is arranged to match the

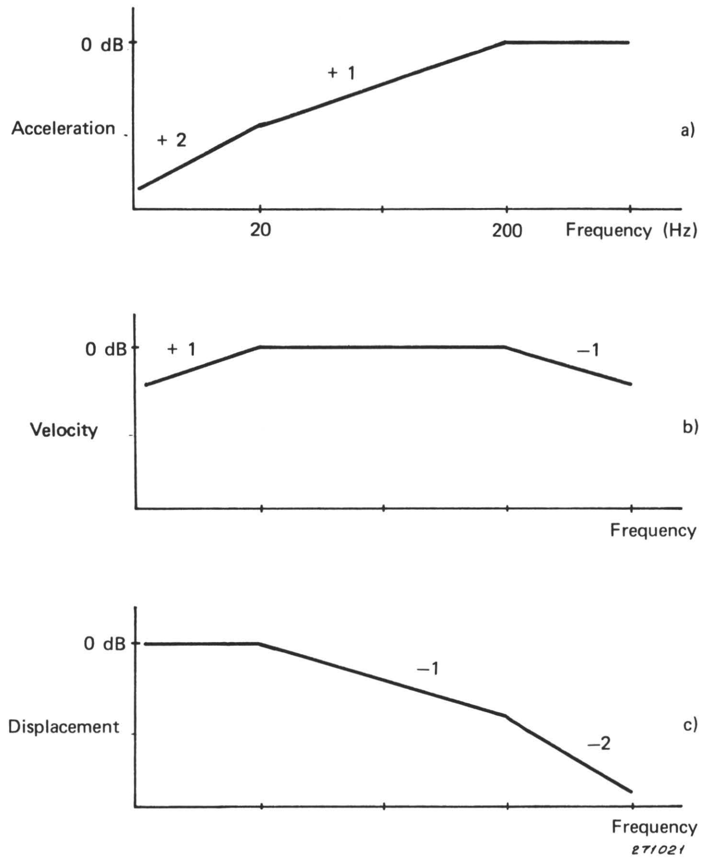

Fig.4.7.a *Acceleration v. Frequency*
Fig.4.7.b *Velocity v. Frequency*
Fig.4.7.c *Displacement v. Frequency*

displacement fall-off slope of a typical shaker system and includes a margin of safety. Below 1 Hz, and above the constant displacement region the gain is suppressed to give good noise rejection. The DISPLACEMENT LIMIT control adjusts the overall gain level of the displacement sensing characteristic, high gain corresponding to low displacement limits. The circuit provides protection for both positive and negative displacement peaks.

However, the sensing circuit is AC coupled and thus takes no account of any DC centring current flowing. For a heavy specimen the DC current is generally used to offset the static deflection of the flexures to re-centre the table, thus the full displacement capability is unaltered. When the DC centring signal is used to give a static displacement to the test specimen, the mean table position will not be at the centre of travel. This offset is not accounted for by the displacement sensing circuitry and must be kept in mind when setting the DISPLACEMENT LIMIT control.

4.5.3. Temperature

Abnormal load conditions, failure of the heat sink cooling fan, or high ambient temperatures could result in output transistor junction temperatures in excess of design limits, and subsequent transistor failure. To prevent damage to the output transistors under these conditions the TEMPERATURE SCR will trigger, removing the inputs and lighting the red front-panel lamp labelled TEMPERATURE.

The heating effect of the drive current is a function of both current and frequency. The drive current in the useable frequency range, as limited by the TEMPERATURE circuitry, is shown in Fig.4.8. The TEMPERATURE protective circuitry is calibrated to trigger at 14 A RMS load current, at a frequency of 5 Hz, in an ambient of 25°C (77° F). This gives a trip margin over the rated output current, thus allowing the shaker system to be operated at higher temperatures than 25°C. A rise of 20°C (36° F) ambient temperature reduces the tripping current by about 10% (i.e. to 12.6 A).

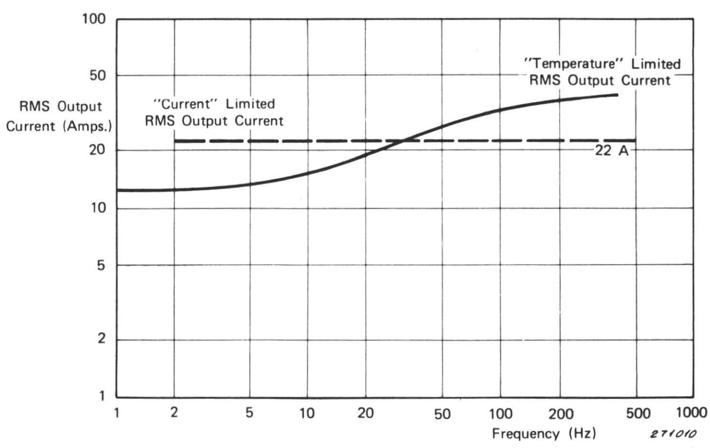

Fig.4.8. Output Current as limited by TEMPERATURE protective circuitry

At DC, output currents up to 18 A can be obtained without the temperature trip operating but the output transistor heat-sink thermostats will close at 88°C (190° F) and trigger the TEMPERATURE protective circuitry.

4.5.4. Exciter

The EXCITER protection circuitry is triggered by:

a) Failure of fuses protecting the cooling fan or field windings,

b) Activation of the Exciter Body over-temperature thermostat (the thermostat is set to close at 99°C (210° F)),

c) Attempted operation with the Exciter Head separated from the Exciter Body,

d) Opening of an external pair of contacts connected to the shaker system using the ACCESSORY connector.

4.6. METERING AND MONITORING

The meter rectifiers used have a quasi-RMS characteristic. This gives correct reading for sinusoidal and Gaussian distributed signals.

4.6.1. Voltage Metering

The output voltage of the 2707 is applied to the meter via a three-position range selector switch. The ranges available are 3, 10 and 30 V RMS. From the range selector the signal is applied via a unity gain isolating amplifier to the quasi-RMS rectifier. The output of the rectifier drives the VOLTAGE METER.

4.6.2. Current Metering

The voltage across the current feedback resistor is applied via a range selector switch (3, 10, 30 A RMS and ± 10 A DC) to a voltage amplifier with a gain of approximately 50. The measuring amplifier's output is rectified, again using a quasi-RMS rectifier, and drives the CURRENT METER. For Exciter Head centring using the DC OUTPUT control, the drive coil current can be monitored with the CURRENT METER on the ± 10 A DC range. A DC offset signal is applied to the meter to give the centre-zero display.

4.6.3. Monitoring

Two oscilloscope or external meter take-off points have been provided, one as a Current Monitor (20 mV/A) and the other as a Voltage Monitor (1 V/V).

5. USE WITH OTHER INSTRUMENTS

5.1. FREQUENCY SWEEP VIBRATION TESTING

Sine wave testing is a powerful laboratory tool during equipment development and can be used not only to detect resonance, but also for extended testing at the known resonances (dwell testing) and for testing by sweeping through a band of frequencies.

Sweep testing requires the exciter to be fed with a sinusoidal drive signal, at a pre-determined rate of change of frequency (sweep rate). Resonances in the test object and exciter system mean that the power supplied to the exciter is frequency dependent and must be automatically decreased or increased. This is usually done by the compressor amplifier within the signal source, the time constant (regulation speed) of which must be selected according to the expected Q-values of the system resonances.

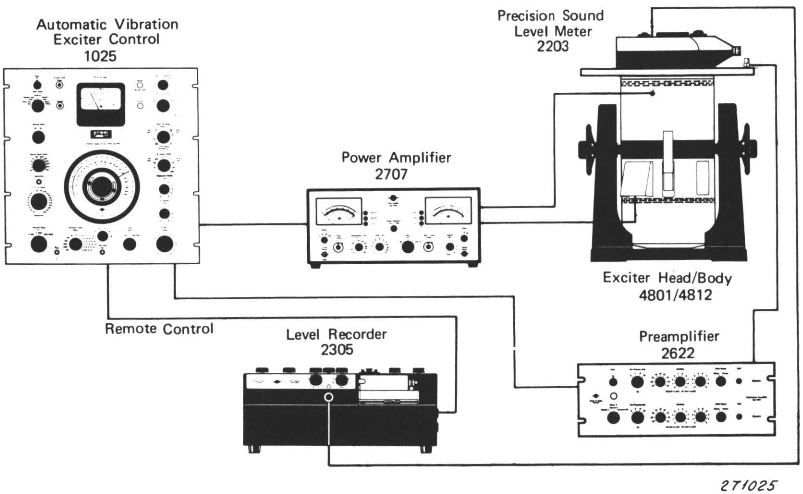

Fig.5.1. Measuring set-up for investigation of vibration sensitivity of the Precision Sound Level Meter Type 2203

A test of this type was carried out on the B & K Precision Sound Level Meter Type 2203 to determine the effect of vibration on the output. The test set-up is shown in Fig.5.1 and consists of an Automatic Vibration Exciter Control Type 1025 driving the Exciter Body/General Purpose Head Type 4801/4812 combination via the Power Amplifier Type 2707. The Sound Level Meter signal output with first microphone and then dummy load connected were recorded using a Level Recorder Type 2305 and are shown in Fig.5.2 and curves I and II.

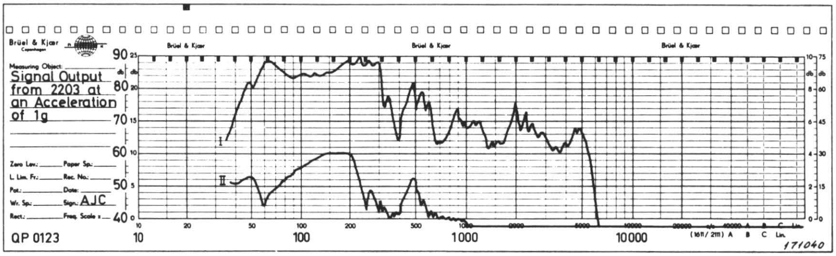

Fig.5.2. Output signal of 2203 (dB re 2 x 10^{-5} N/m^2) with a table level of 1 g RMS. Curve I is obtained with the microphone in place, while the curve II is obtained with the microphone substituted by an equivalent impedance which is sound and vibration insensitive

5.2. SWEEP RANDOM TESTING

Wide-band random frequency testing can be very expensive because of the equalization filters required to shape the test frequency spectrum to comply with the specifications set. An economic alternative to wide band testing is sweep random testing. It consists of one or more narrow bands of noise, sweeping (or dwelling) according to a detailed test programme and emphasizing various important frequency regions.

The test arrangement shown in Fig.5.3 is set up for two such bands. The Sweep Random Generators Type 1042 drive the Power Amplifier Type 2707 and the Exciter Head/Body combination Type 4812/4801, via isolation transformers. Each generator sweeps back and forth in a different frequency band. The associated Heterodyne Slave Filters Type 2021 ensure that the compressors are fed with the feedback signals they require for correct operation independent of spurious accelerometer and table resonances, and of the other generators' signal.

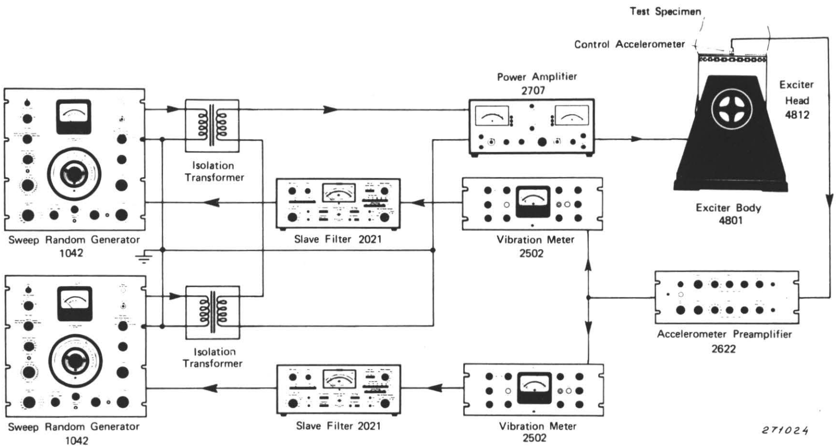

Fig.5.3. Example of test arrangement for multiple sweep random testing

The number of narrow band generators necessary to perform the proper test will depend upon the number of important frequency regions.

The arrangement can be extended to include more generators whenever required. In this way capital investment required to perform adequate random vibration testing is reduced to a minimum and a very flexible test system is obtained.

5.3. MULTIPLE-EXCITER VIBRATION TESTING

Testing of large specimens can involve many problems in the design of a suitable fixture. These problems are reduced if multiple-exciter systems are used. A two-exciter system is shown in Fig.5.4. The test specimen is large and may have independent and different resonant frequencies causing irregular overall motion. Thus, four feedback control accelerometers are used, and the Control Signal Selector Type 4410 allows the control signal to be selected. It can choose any channel, the highest, the lowest or the average of the channels. If the test specimen was a dead mass, a single accelerometer feedback could be employed.

The signal source used is a Sweep Random Generator Type 1042 driving into Power Amplifiers Type 2707. Each Power Amplifier drives an exciter Head/Body combination. Either the Mode Study Head Type 4814, the Big

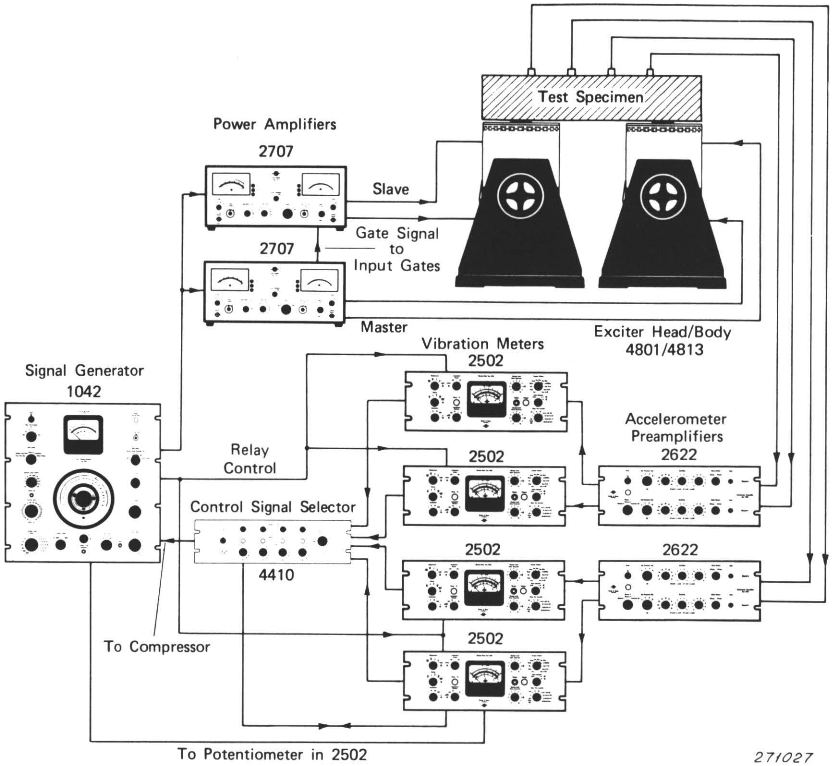

Fig.5.4. Multiple Exciter Testing

Table Head Type 4813, or the General Purpose Head Type 4812 can be used.

Before the Control Signal Selector, each feedback signal is normalized and amplified in one channel of an Accelerometer Preamplifier Type 2622 and a Vibration Meter Type 2502. The 1042 controls the Meter time constant, the stabilizing relay and the cross-over frequency. If more than the single cross-over frequency available here is required, the Vibration Programmer Type 4411 could be added to give up to 5 cross-overs.

Two signal generators, each with separately controlled compressors, could be used if the generators were connected in the "Master-Slave" mode (ref. Application of B & K Equipment to Mechanical Vibration and Shock Measurements, section on Vibration Testing).

6. SPECIFICATIONS

Power Output Capacity:	220 VA into 0.5Ω exciter or resistor load	
Voltage	10 V RMS	DC to 10 kHz
Current	10 A	DC
	11 A at and below	5 Hz
increasing to	22 A	40 Hz to 10 kHz

Frequency Range:

Full capacity	40 Hz to 10 kHz
Reduced capacity	DC to 40 Hz
	10 kHz to 100 kHz

Frequency Response: (typical, small signal, "Low" impedance mode)

DC Input	DC to 10 kHz $< \pm 0.5$ dB
	DC to 100 kHz $< \pm 3.0$ dB
AC Input	15 Hz to 100 kHz $< \pm 3.0$ dB

Output Phase: Selectable in-phase (0^{o}) or anti-phase (180^{o}) referred to input.

Input Impedance: $>$10 kΩ

	"Low" Impedance	"High" Impedance
Gain (at 1 kHz)	5 V/V ± 1 dB	14 A/V ± 2 dB
Output Impedance:		
	$<$0.02Ω DC to 1 kHz	$>$20Ω 5 Hz to 1 kHz
	$<$0.05Ω 1 kHz to 10 kHz	$>$50Ω 20 Hz to 300 Hz
		$>$80Ω 40 Hz to 100 Hz
Harmonic Distortion:	0.1% 20 Hz to 5 kHz	0.2% 100 Hz to 3 kHz
(full capacity)	0.5% 20 Hz to 10 kHz	0.7% 20 Hz to 10 kHz
Noise and Hum:		
(below full output)	not less than 85 dB	not less than 75 dB

DC Stability: <50 mV drift for:
+ 5% to −15% variation of mains supply from nominal,
10°C to 45°C variation in ambient temperature

Direct Current Output: not less than ± 2 V
Available at AMPLIFIER OUTPUT terminals.
Variable by a front panel control.

Metering: Quasi-RMS rectifier circuits indicate Current and Voltage output. Correct for sinusoidal and Gaussian inputs.

	Voltmeter	Ammeter
Scales (FSD)	3 V, 10 V, 30 V RMS	3 A, 10 A, 30 A RMS ±10 A DC
Response ±2%	20 Hz to 10 kHz	±2% 20 Hz to 5 kHz ±5% to 10 kHz
Accuracy (at 1 kHz)	±2% of FSD	±4% of FSD

Protection: Input signal is removed and an indicator lamp is lit when the following parameters exceed pre-set limits:

Exciter Displacement — limit adjustable
Moving Coil Current — limit adjustable
Power Transistor junction temperatures
Heat sink temperature
Exciter fuse failure, cooling failure, attempted operation of Exciter Head separate from body.

Front panel indication is provided when the following occurs:

Output signal clipping
Power transistor fuse blown

AC Power Input Requirement 700 VA at full output
100, 120, 127, V RMS ±5% 50 to 60 Hz
200, 220, 227, V RMS ±5% 50 to 60 Hz
240, 247, 254, V RMS ±5% 50 to 60 Hz

Approx. 80% of full output voltage capability down to −15% of nominal mains supply.

Dimensions:	Height 17.7 cm (6.96 inches) Width 43.0 cm (16.9 inches) Depth 50.0 cm (19.7 inches) excluding connectors
Weight:	27.9 kg (61.4 lbs)

ACCESSORIES SUPPLIED:

1 x JP 0035	BNC 75Ω connector
1 x JP 0308	3 pin connector (Cannon Type WK–C3–32C)
1 x JP 1005	6 pin connector (Cannon Type WK–6–32C)
1 x VF 0020	4 A/250 V Mains Fuse
2 x VF 0021	8 A/250 V Mains Fuse
16 x VF 0022	5 A GBB 5 Transistor Fuses
2 x VS 1274	Bulbs for Scale Lamps
2 x GV 0833	Mounting Brackets to 19 inch Rack System
6 x YQ 0096	Screws (for Mounting Brackets)
6 x YO 0439	Washers (for Mounting Brackets)

B & K INSTRUMENTS:

ACOUSTICAL....
Condenser Microphones
Piezo-Electric Microphones
Microphone Preamplifiers
Microphone Calibration Equip.
Sound Level Meters
(general purpose-precision-
and impulse)
Standing Wave Apparatus
Tapping Machines
Noise Limit Indicators

ELECTROACOUSTICAL....
Artificial Ears
Artificial Mouths
Artificial Mastoids
Hearing Aid Test Boxes
Telephone Measuring Equipment
Audiometer Calibrators
Audio Reproduction Test Equip.

STRAIN....
Strain Gauge Apparatus
Multipoint Panels
Automatic Selectors
Balancing Units

VIBRATION....
Accelerometers
Accelerometer Preamplifiers
Accelerometer Calibrators
Vibration Meters
Magnetic Transducers
Capacitive Transducers
Vibration Exciter Controls
Vibration Programmers
Vibration Signal Selectors
Mini-Shakers
Complex Modulus Apparatus
Stroboscopes

GENERATING....
Beat Frequency Oscillators
Random Noise Generators
Sine-Random Generators

MEASURING....
Measuring Amplifiers
Voltmeters
Deviation Bridges
Megohmmeters

ANALYZING....
Band-Pass Filter Sets
Frequency Spectrometers
Frequency Analyzers
Real-Time Analyzers
Slave Filters
Psophometer Filters
Statistical Analyzers

RECORDING....
Level Recorders
(strip-chart and polar)
Frequency Response Tracers
Tape Recorders

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