TMS THE MODAL SHOP, INC.
A PCB GROUP CO.

User Manual

Miniature Inertial Shaker

Model 2002E

"Helping you test, model, and modify the behavior of structures"

2002E

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Product Support

For answers to questions about 2002E, consult this manual. For additional product support, contact The Modal Shop at 800-860-4867 or 513-351-9919, 9 a.m. to 5 p.m. EST. If it is more convenient, fax your questions or comments to The Modal Shop at 513-458-2172 or email our sales staff at techsupport@modalshop.com.

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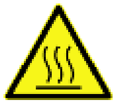

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1.1 General Description

The 2002E Inertial Shaker is a compact and lightweight force generator whose construction makes it equally well-suited for modal as well as general vibration testing on larger and more compliant test articles.

The generator has a single 0.141-in (3.58-mm) diameter mounting hole and a rugged internal suspension system which eliminates test fixture requirements for most testing applications. The 2002E can be operated in any orientation and is therefore easily positioned for modal applications above 20 Hz.

Reliability is assured through the use of the latest composite materials in the unique, inverted, armature coil design. The design provides excellent axial compliance with high lateral stiffness to eliminate internal alignment problems. When combined with a Modal Shop power amplifier, the system is unmatched for reliability, performance, and cost.

1.2 Technical Specification

The following are the performance and physical characteristics of the 2002E Inertial Shaker.

Note: The user should be aware that the following specifications assume no amplifier or other system limitations.

Parameter:	**Specification:**	
Rated output force:		
Sine force		
Natural cooling, pk	2.0 lbf	(9 N)
Forced air cooling, pk	4.0 lbf	(18 N)
Random force:		
Natural cooling, RMS	1.4 lbf	(6.2 N)
Forced air cooling, RMS	2.8 lbf	(12.5 N)
Shock force (20 ms pulse), pk	4.5 lbf	(20 N)
Low-frequency force	$0.012\ f^2\ (0.35 - d)$ f=freq. Hz, d=disp. in pk-pk	
Maximum Displacement, pk-pk	0.35 in	(8.9 mm)
Maximum Velocity, pk	70 in/s	(1.78 m/s)

Maximum Acceleration	
Resonant sine, pk	100 g
Peak shock, pk	27 g (bare table)
Frequency range	20 - 3000 Hz

Physical characteristics:

Dynamic element mass	0.33 lb (0.15 kg)
Resonances:	
Reaction mass (nominal)	10 Hz
Structural	3500 to 4500 Hz
Rated armature current (max.)	
Natural convection, RMS	1.1 A
Forced air cooling, RMS	2.2 A
Generator mounting	0.141 in (diameter through hole)
Stray magnetic field	< 15 gauss at 1in (2.54 cm) distance
Generator weight	0.56 lb (0.25 kg)
Generator dimensions	2.00 in (50.8 mm) diameter x 1.5 in (38.1 mm) long
Generator cooling	3.5 CFM at 5 psi forced air cooling recommended for continuous operation above 1.0 lbf

Environmental conditions:

Ambient temperature	40 ˚F to 100 ˚F at 85% RH max. (4 °C to 38 °C)
Force derating (> 100 ˚F)	Reduce 1% per 1 ˚F ambient air temperature >100 ˚F (17.2 °C)
Altitude	< 6562 ft (2000 m)

Installation and Operation

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2.1 General

Installation of The Modal Shop's 2002E Inertial Shaker involves unpacking, preparing the equipment, and readying it for operation. This must be preceded by selection of an appropriate location and preparation of the same.

2.2 Site Selection and Preparation

The location in which the generator is to be mounted should be one basically free of airborne particles of foreign matter, but especially those that are of a ferromagnetic or other metallic nature.

Warning: Consideration should also be given to the maximum sound pressure level produced during normal operation. This value is dependent upon the test frequencies and acceleration levels as well as the specimen and its mounting acoustic characteristics. Sound pressure levels, which require the use of protective earpieces, can be present during testing. Sound pressure level should be measured or calculated by the equipment user both at the operator's position in normal use and whatever point 3.2 ft (1 m) from the equipment has the highest sound pressure level. Hearing protection should be provided as necessary.

A power amplifier and signal source will also be required for operation. These can be in the form of The Modal Shop's power amplifiers or compatible equivalents.

If additional cooling is desired for maximum shaker performance, a clean, dry compressed air source should be secured and routed to the test location prior to start-up.

As for the shaker itself, the physical location of its installation is restricted only by the lengths of the interconnecting cables and hoses. Position the unit such that access to the cables and/or hoses is not restricted.

2.3 Unpacking and Handling

At the time of arrival, check the equipment against the packing list to make sure that the shipment is complete. Inspect all packages for shipping damage and check for loose, broken, and/or damaged components.

In the event of shipping damage, notify the agent of the delivering carrier and obtain a full report of the irregularity. Have this signed by the agent before accepting the shipment.

2.4 Installation Procedure

The installation of the generator is a simple process which only requires attention to a few details and can be accomplished as follows:

1. Prepare a single #6 (or M3) threaded hole in the axis of the desired force on the test object with a 0.5-in diameter minimum flat surface for the force generator mechanical interface.

2. Rotate the force generator to the optimum position for cable and hose connection and fasten it to the test object using a single #6 non-ferrous screw (brass or non-magnetic stainless steel is recommended). A washer must be used under the head of the mounting screw with a 0.375-in minimum outside diameter.

Caution! Do not tighten the mounting screw head into the threaded center shaft hole. Permanent damage to the force generator's center shaft and mounting surface can result if the mounting screw is not supplied with an appropriate washer.

3. If cooling air is to be used, a 1/8-in (3.2-mm) diameter hose should be attached, using appropriate adaptors, to the hole in the generator housing.

Caution! If forced air cooling is not used, ensure that the cooling airport is plugged in with the included 1/8-in (3.2-mm) long screw and gasket to prevent dirt infiltration into the unit.

Warning! Shaker surface may become hot to the touch after prolonged use.

Caution! Do not screw any fitting or screw into the cooling port that protrudes more than 0.09 in (2.3 mm) into the generator's body. Permanent damage to the body/coil assembly may result from the use of too long a cooling fitting or block-off screw.

4. Cooling air for maximum generator performance must provide for the required flow rate. If a 1/8-in (3.2-mm) inside diameter hose is used, approximately 5 psi (0.34 bar) will be required for each foot (30 cm) of cooling hose used, plus 5 psi for the drop at the generator. For a 10-ft (3-m) hose, set the pressure regulator to 55 psi (3.79 bar).

5. The drive cable should now be connected to the power amplifier.

Warning: To prevent electrical shock, shut the system power amplifier off and disconnect its power cable to ensure that there is no power coming from the power amplifier before connecting the shaker drive cable terminals.

There are two wires in the cable which are to be connected as follows:

2002E Label	Amplifier Connection
+	(O) Output (plus)
-	(R) Return (minus or ground)

Fuse Requirements:

The shaker drive cable fuse requirements are as follows:

Force Rating (lbf pk)	**Fuse Specification**
2	1 1/4 in Fuse, 1 A, Fast Blow, 250V
4	1 1/4 in Fuse, 2 A, Fast Blow, 250V

The in-line fuse holder should be checked to ensure that the proper size fuse is installed and functional.

6. With an appropriate signal source properly connected to the power amplifier, the generator is now ready for operation.

2.5 Operation

The 2002E Inertial Shaker is designed to provide a force output proportional to the input drive from a power amplifier and faithfully reproduce the waveform within the specified level and frequency bandwidth limits. It is important to note that the generator and amplifier combination, whether operated by a manual or closed-loop control system, will react directly to an input either intentional or accidental. Great care must be taken to avoid damage to the drive coil or internal suspension components. Damage can be caused by transients in the supply waveform or by exceeding the displacement and/or acceleration limits. To prevent such potential damage, please observe the following cautions during operation:

Caution! If the generator is being controlled manually through the frequency range, approach low-frequency resonances slowly. Mechanical test object resonances can have very large amplification factors and can force the generator's displacement level to exceed its displacement limit.

Caution! Always reduce the power amplifier output to zero before switching the oscillator or control system to a different range. Switching before reducing the power amplifier gain to zero could result in a transient, which would exceed the generator's acceleration or displacement limits.

Caution! Make sure that the maximum displacement is not exceeded at the low frequency end of the range. Exceeding the displacement will cause the reaction mass assembly to strike the mechanical stop with an impact that could exceed the acceleration limit.

Caution! Observe that the maximum drive current is not exceeded and that the proper cooling air flow is maintained since overheating and possible coil damage can occur. Refer to subsection 1.2 for rated drive current and cooling air flow specifications.

Warning! If the generator is used in a manner not specified by the manufacturer, protection provided by the equipment may be impaired.

Warning! Generator surface may become hot to the touch after prolonged use.

Principles of Operation

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3.1 Description

The 2002E Inertial Shaker incorporates a double-ended magnet structure to provide the high-level magnetic field which surrounds the drive coil assembly. The reaction mass assembly is suspended and centered in the magnetic gap by a pair of high-compliance compression springs and a linear bearing assembly. The reaction mass assembly is guided by a lightweight center shaft which ensures linear motion over its entire stroke.

The reaction mass assembly consists of a cylindrical magnet and pole piece assembly and linear roller bearing. The drive coil assembly is a copper coil bonded to the generator's body to minimize the overall weight and maximize the structural stiffness. The drive coil is positioned around the magnet pole pieces and is positioned in the air gap in the magnetic structure. The coil springs provide axial support for the reaction mass assembly in all force generator mounting positions.

3.2 Theory of Operation

A force generator transforms electrical current into mechanical force for the purpose of vibration testing. The generator consists of a magnet structure reaction mass and a drive coil and body assembly. Force is generated on the body by interaction between current flowing in the coil and the magnetic field in which the coil is positioned. An alternating current in the coil will produce an alternating force at the same frequency.

The drive coil and the force-transmitting structure comprise the body assembly. The reaction mass assembly is supported in the body by a center shaft and linear bearing and a pair of high-compliance coil springs. This suspension allows movement of the reaction mass normal to the force generator's mounting surfaces.

The magnet structure is designed to provide extremely high-flux densities in the coil gap and yet have low leakage flux density outside of the force generator. The high flux density provides a high ratio of force to current.

The force generated in the drive coil is always defined by the following equation:

$F=K_1\ BL\ I\ (2.54)^2$

F = the force generated in the armature coil
K_1 = a physical constant (0.885×10^{-7} in English system of units)
B = the magnetic flux density (gauss) in the gap
L = the length of conductor (in inches) in the gap (coil circumference x number of coil turns)
I = the armature current

Whenever a conductor is moving in a magnetic field at the same time that current is flowing through the conductor, there is an interchange of power between the electric circuit and the mechanical system associated with the motion of the conductor. This is true in the case of a force generator. Neglecting the voltage drop across the electrical impedance of the armature coil due to the flow of current through it, a voltage will be generated in the coil that is directly proportional to the velocity of the coil.

$E_B = K_2 BLv (2.54)^2$

E_B = the back-voltage generated in the coil
K_2 = a physical constant (10^{-8} in English system of units)
B = the magnetic flux density (gauss) in the gap
L = the length of conductor (inches) in the gap
v = the velocity of the armature coil (in/s)

Where E_B is the back-voltage generated in the coil; K_2 is a physical constant (10^{-8} in English system of units); B is the magnetic flux density (gauss) in the gap; L is the length of conductor (in inches) in the gap; and v is the velocity of the armature coil (in/s).

3.3 Formulae

To effectively utilize the 2002E Inertial Shaker for specific vibration testing applications, it is useful to review the formulae which describe the physical principles of force generator operations. Some of these formulae define the capabilities of the generator while others describe the physical relationship between the operational parameters of acceleration, velocity and displacement.

Defining generator capabilities:

Fr = M • A/q (Fr = W • g/q)

Where:

Fr = vector force, resonant, *(lbf)*
M= total moving mass (generator dynamic weight + weight of specimen), *pounds*
A = vector acceleration, gravity units *(g is a unitless multiple of gravity)*
q = resonance quality, *no units (q is a unitless ratio of damping)*

Example:

Find the force required for a sinewave resonance search of 5 g pk maximum to be performed on a specimen of 1.5 pounds and an expected resonance q of 10.

Fr = M • A/q (F = W • g/q)
Fr = (specimen mass + generator dynamic mass) • A/q
Fr = (1.5 + 0.33) lbs • 5g pk/10
Fr = 1.83 lbs • 5g pk/10
Fr = 0.915 lbf pk

Caution! Although this calculation determines the force required, the maximum displacement and velocity must also be determined before proceeding with the test.

Describing the relationships between acceleration, velocity and displacement:

$\mathbf{V = \pi\ f D}$	Where;	**V** = velocity in in/s pk
$\mathbf{V = 61.44\ g/f}$		**D** = displacement in in/pk-pk
$\mathbf{g = 0.0511\ f^2 D}$		**f** = frequency in Hertz (Hz)
$\mathbf{g = 0.0162\ V f}$		**g** = acceleration in gravity units

All of the relationships for sinewave testing can be derived from the formulae shown.

Defining the random acceleration levels:

$$\mathbf{g\ RMS = [\Delta f\ (g^2/Hz)]^{1/2}}$$

Where; Δ**f** = bandwidth (f_2-f_1), in Hz
g^2/Hz = acceleration spectral density
g RMS = root mean square acceleration

This formula will provide the total root mean square (RMS) acceleration level for a flat random spectrum. For shaped spectra, a more lengthy calculation is required.

Maintenance 4

4.1 General

The 2002E Inertial Shaker is designed to provide trouble-free service for long periods of time when operated within the performance limits set forth in subsection 1.2 and in an environment which is free of excessive dust, metallic particles, and other potentially harmful materials.

The only maintenance that should be performed on a routine basis, outside of replacement of worn or damaged components, is the cleaning of the air filters. If operational problems are suspected, consult the factory for troubleshooting hints or return the unit along with a brief description of the problem for service.

Warning: To prevent electrical shock, shut the system power amplifier off and disconnect its power cable to ensure that there is no power coming from the power amplifier before beginning maintenance procedures.

4.2 Cleaning Air Filter

If the generator is operated in a relatively dust-free environment, the air filters (located at each end of the generator inside of the spanner holes) should not need cleaning for a period of approximately 500 hours of operation. If cleaning is deemed necessary, please proceed as follows:

Using a small vacuum cleaner, adjusted for the minimum suction, gently vacuum the filter holes on each end of the generator.

4.3 Inertial Shaker Disassembly and Repair

The 2002E Inertial Shaker is designed with no moving coils, current flexures or other normal user serviceable components and therefore it is not recommended that the unit be disassembled in the field. If a reaction mass bearing problem is suspected and the unit cannot be returned to the factory for adjustment, the following disassembly guide can be used to inspect the reaction mass assembly. There are four subassemblies to the shaker. These are the magnet/reaction mass assembly, the drive coil/body assembly, and the end caps and center shaft assembly.

The Inertial Shaker is disassembled as follows:

1. Disconnect all wiring and cooling hoses to the unit.

2. Using an appropriate pin spanner at each end of the Inertial Shaker, unscrew the ends of the Inertial Shaker and pull the center shaft and the two coil centering springs out of the unit.

3. Remove the reaction mass from the body carefully. The magnet will be pulled to one side of the body/coil assembly and will require some force to eject it.

Caution! Do not use any tools to pry the magnet/reaction mass assembly from the body. The coil assembly is quite thin on the inside and easily damaged. It is recommended that the reaction mass assembly be removed using only strong, gloved hands.

4. Inspect the interior components of the unit.
    a. Inspect the inside diameter of the Inertial Shaker body for any signs of rubbing.
    b. Inspect the rubber coating on the shaft for signs of excessive wear or degradation.
    c. Assure that the two circular bearing shafts are properly seated in the brass housing and that all six (6) bearings roll freely.

5. If any of the above are in evidence, reassemble the unit and return it to the factory for repair.

The Inertial Shaker is assembled by reversing the disassembly steps above.

1. Manually tighten the end caps to center the magnet/reaction mass in the center of the body assembly before tightening the end caps with the spanner wrench.

2. The shaft must be flush with or below the surfaces of the end caps when fully tightened.

Return for repair:

If the shaker is damaged, it is recommended that the entire unit be returned to the factory for repair. Call for an estimate of turnaround time and shipping instructions. Spare parts are usually in stock and the repair can be completed within a week or two. For shipping the unit to The Modal Shop, use the box and packing foam in which the unit was originally shipped.

Outline Drawing

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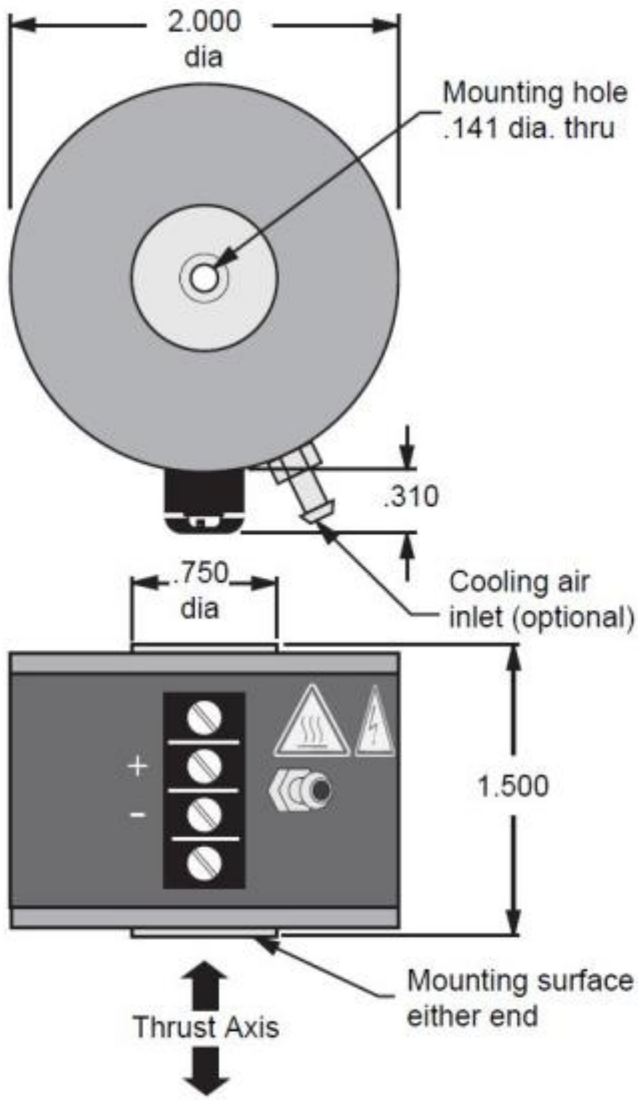

*Dimensions in inches