Piezoelectric shaker operating guide
Models F7, F7-1, D60L, D60H, D125L
January 30, 2006

Wilcoxon Research is requesting all users of the D60 Series* and D125 Series* piezoelectric vibration exciters (shakers) to verify they are being operated in a mode with the case electrically grounded.

Due to the high voltages used for the electrical drive signal, the case MUST BE grounded to a proper electrical safety ground connection.

For users operating either the D60 Series or D125 Series properly connected to an electrical safety ground, no action is required.

Users who operate either the D60 Series or the D125 Series in such a manner that the case is not connected to an appropriate electrical safety ground should CEASE OPERATION IMMEDIATELY and CONTACT WILCOXON RESEARCH directly.

For users operating either the D60 Series or the D125 Series ELECTRICALLY FLOATING or NOT PROPERLY CONNECTED to an electrical safety ground, IMMEDIATELY DISCONTINUE USE OR OPERATION and contact Wilcoxon Research IMMEDIATELY at: 1-800-946-2696 or +1-301-330-8811, request CUSTOMER SERVICE.

* Models that are identified as being in the D60 Series and the D125 Series are: D60-1, D60-1S, D60H, D60H-B, D60-M6, D60-M6B, D60-M8, D60L, D60L-1, D125H, D125L, D125L-10, and D125L-10, MOD
WARNING: OPERATION OF THE SHAKER IS SAFE WHEN THE INSTRUCTIONS IN THIS MANUAL ARE READ THOROUGHLY BEFORE CONNECTING TO THE POWER AMPLIFIER. PARTICULAR ATTENTION MUST BE PAID TO THE SAFETY SECTION OF THIS MANUAL.

WARNING: TO PREVENT FIRE OR SHOCK HAZARD, DO NOT EXPOSE THIS EQUIPMENT TO RAIN OR MOISTURE.

WARNING: LETHAL VOLTAGES ARE PRESENT IN THE WILCOXON AMPLIFIER AND MATCHING NETWORKS.

Safety section

The piezoelectric shakers can be safely operated when the instructions in this manual are carefully followed.

This section summarizes the safety considerations. Reminders, in the form described below, will appear in the detailed instructions to assure operator awareness of these safety considerations. Qualified personnel should operate and maintain this power amplifier only after becoming thoroughly familiar with this manual.

**WARNING:** This symbol is used in the instruction manual where operator safety must be considered. The instruction manual should be consulted and read carefully.

**CAUTION:** This symbol is used when caution is needed to prevent damage to equipment. It is used where careful attention to certain procedures described in the instruction manual is needed. This symbol is also used to emphasize procedures other than normal operating procedures.
Safety summary

1. Make sure that the power amplifier is properly grounded to a good earth ground.
2. Make sure that any piezoelectric shaker being driven is properly grounded to a good earth ground.
3. Disconnect the power cord at its source before connecting or removing any cables.
4. To reduce the risk of electric shock, do not remove the power amplifier cover. No user-serviceable parts are inside. Refer all servicing issues to Wilcoxon Research, Inc.
5. Do not attempt to operate a power amplifier without the protective covers secured.
6. All cables must be connected between the power amplifier, matching network, and shaker before electrical power is connected. Inspect for frayed or cut cables prior to operation.
7. Wear hearing protection when driving piezoelectric shakers at high levels and high frequencies.
8. Do not expose this equipment to rain or moisture.
9. Lethal high voltage may be present at any of the equipment connectors.
10. The Wilcoxon Research Model D125L Piezoelectric Shaker requires pressurization (minimum 1800 PSI) from a source of dry, inert gas. The shaker must be electrically connected to the matching network and power amplifier, or the shaker terminals should be shorted together, prior to pressurization or de-pressurization. Pressure must be applied or released slowly (1 minute) to prevent excessive voltages at the shaker connecting terminals. Use extreme caution when handling pressurized cylinders.
11. Use common sense and avoid haste!
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1.0 Product description

Wilcoxon Research piezoelectric shakers and tables are designed for use in the vibration test and analysis field. They utilize the properties of piezoelectric crystals for high level sonic and ultrasonic structural excitation. Conventional large electromagnetic shakers are limited to a frequency range of only several kHz while piezoelectric shakers and tables allow operation past 20 kHz. Wilcoxon Research’s largest piezoelectric shaker table, model D125L, surpasses the capabilities of a 3,000 pound (13,000 Newton) electromagnetic shaker at frequencies above 4 kHz. Piezoelectric shakers can be mounted on top of large electromagnetic shakers to provide both low and high frequency capabilities in one set-up. The F7 shaker is specifically designed to be mounted within the central core of either the Wilcoxon F4 or F10 electrodynamic shaker.

Piezoelectric shakers consist of three main components: the head or table, the compliant piezoelectric stack, and the reaction mass.

Below the fundamental resonance frequency of this system, the output for a given input voltage is based upon the displacement. For example, if the displacement is 1 micron per 1,000 volts input, then a sine wave of 1,000 volt, peak, will produce an acceleration of:
- 4g peak at 1 kHz, or
- 100g peak at 5 kHz

The acceleration of the table is proportional to the square of the frequency times the displacement.

Above the fundamental resonance frequency, the output for a given input voltage is based upon the force. The force generated by the piezoelectric shakers can be up to:
- 2,000 Newton peak (800 Vrms), using the F7 model
- 50 Newton peak (800 Vrms), using the F7-1 model
- 3,000 Newton peak (1,500 Vrms input), using the D60 models, and
- 13,000 Newton peak (1,500 Vrms input), using the D125L model

The output of the shaker, when a typical test specimen is attached to the shaker or table, is dependent on the mechanical impedance of the specimen.

- At anti-resonances, maximum impedance, the displacement of the table is minimum, but the specified force is delivered, provided that the impedance of the base mass is sufficiently high.
- At the resonances, minimum impedance, the shaker or table acceleration must be limited to the maximum specified levels for the individual shakers or tables. The blocked force output curves (graphs on the product data sheets) refer to the force developed against a mass of infinite impedance and show typical frequency response, which vary between shakers.
- Wide fluctuations in force output are present at very high frequencies. These shakers can be used as a source of structural excitation above 60,000 Hz.

Wilcoxon Research will match shakers to a common first resonance frequency by special order.

Piezoelectric shakers present a capacitive (reactive) load to power amplifiers, therefore the electrical impedance decreases with increasing frequency. A large power amplifier is required to drive a shaker at maximum voltage to its maximum frequency. Smaller amplifiers may be used to drive the shaker at maximum output at lower frequencies. Optimum operation over a range of frequencies requires the proper impedance matching network between the power amplifier and piezoelectric shaker.
1.1 Piezoelectric reaction shakers

Piezoelectric reaction shakers are compact, lightweight shakers that utilize the expansion and contraction properties of piezoelectric crystals to generate sonic and ultrasonic structural excitation. These portable, reaction-type shakers generate large dynamic forces to very high frequencies used for structural excitation in vibration research and testing. These shakers can be stud-mounted directly to structures in any position, without external support or critical shaft alignment problems. The F7 piezoelectric vibration generator mates with the F4 or F10 electromagnetic vibration generators to extend the frequency range down to low frequencies, detailed on the specification sheets.

The F7 has an impedance head with two transducers, a force gage and an accelerometer, which measure the force applied to the structure (force gage) and the resulting vibratory motion (accelerometer). The transducer signals can be fed into either the read-out equipment or into signal conditioners. The base was designed to yield a minimum mass below the force gage.

Examples of applications for these instruments include biomedical research, production testing, mechanical impedance studies, high frequency vibration research, and other applications for which structural excitation over a wide frequency range is required.

1.1.1 Model F7 piezoelectric shaker

The F7 piezoelectric shaker is compact and lightweight for structural excitation, and produces large dynamic forces to high frequencies. The N7FS matching network is designed for use with the F7.

The F7 is supplied with an impedance head that contains a force gage and internal high impedance accelerometer, to monitor the force applied to the test structure and the resultant motion, respectively. The impedance head, a titanium cylinder, mounts concentricity within the F7, and calculates the mechanical impedance of the structure.

1.1.2 Model F7-1 piezoelectric shaker

The F7-1 piezoelectric shaker is compact and lightweight for structural excitation, and produces large dynamic forces to very high frequencies. The N8HFS matching network is designed for use with the F7-1.

The F7-1 is, typically, used without an impedance head and produces higher frequencies than the F7 piezoelectric shaker.

1.2 Piezoelectric shaker tables

Piezoelectric shaker tables are designed for use in the vibration test and analysis field. They utilize the properties of piezoelectric crystals for high level sonic and ultrasonic structural excitation. They produce more force than the piezoelectric reaction shakers and are not, generally, supplied with an attached impedance head for measuring the force or acceleration imparted to a test specimen.

Piezoelectric shaker tables consist of three main components: the table, the compliant piezoelectric stack and the base mass. Below the fundamental resonance frequency of this system, the output for a given input voltage is displacement controlled. Above the fundamental resonance frequency the output is force controlled.
The output of the shaker with a typical test specimen attached to the table is dependent on the mechanical impedance of the specimen. At anti-resonances (maximum impedance) the displacement of the table is at a minimum, but the specified force is delivered, provided that the impedance of the base mass is sufficiently high. At the resonances (minimum impedance) the table acceleration must be limited to the specified levels.

1.2.1 Model D60H piezoelectric shaker table

The D60H piezoelectric shaker table is designed as a base-mounted shaker table for vibration testing at frequencies up to 50,000 Hz. It is useful for structural excitation for modal analysis and device testing. The D60H is not supplied with an impedance head. The N8FS matching network is designed for use with the D60H piezoelectric shaker table.

The standard D60H piezoelectric shaker table has seven (7) bolt holes for mounting test specimens. The central hole is a 10-32 NF threaded, 0.38 inches (9.6 mm) deep mounting hole. Surrounding the central mounting hole are six (6) 1/4-28 NF threaded, 0.5 inches (12.7 mm) deep mounting holes, equally spaced around a 1.614 inch (41 mm) diameter circle.

1.2.2 Model D60L piezoelectric shaker table

The D60L piezoelectric shaker table is designed as a base-mounted shaker table for vibration testing at frequencies up to 20,000 Hz. It is useful for structural excitation for modal analysis and device testing. The D60L is not supplied with an impedance head. The N8FS matching network is designed for use with the D60L piezoelectric shaker table.

The standard D60L piezoelectric shaker table has nine (9) bolt holes for mounting test specimens. There is no central hole on the standard shaker. There are six (6) 1/4-28 NF threaded, 0.5 inches (12.7 mm) deep mounting holes equally spaced around a 1.61 inch (40.9 mm) diameter circle. Set within this same circle are three (3) 10-32 NF threaded, 0.48 inches (12.2 mm) deep mounting holes equally spaced around a 1.614 inch (41 mm) diameter circle.

1.2.3 Model D125L piezoelectric shaker table

The D125L piezoelectric shaker table is designed as a base-mounted shaker table for vibration testing at frequencies up to 20,000 Hz. It is useful for structural excitation for modal analysis and device testing. The D125L is not supplied with an impedance head. The N8FS matching network is designed for use with the D125L piezoelectric shaker table.

The standard D125L piezoelectric shaker table has ten (10) bolt holes for mounting test specimens. The central hole is a 3/8-16 NF threaded, 0.75 inches (19 mm) deep mounting hole. There are six (6) 3/8-16 NF threaded, 0.75 inches (19 mm) deep mounting holes, equally spaced around a 3.0 inch (76.2 mm) diameter circle. There are three (3) 10-32 NF threaded, 0.48 inches (12.2 mm) deep mounting holes, equally spaced around a 3.5 inch (89 mm) diameter circle.

A static source of inert gas (nitrogen is recommended) with a minimum of 1,800 psi (124 Bars), is required to pressurize the D125L for the static pre-load on the piezo-ceramic stack. The gas must be connected to the pressure fitting on the side of the shaker through a 1/4 inch high pressure hose and a 1/4 inch x 37° flare swivel fitting (7/16-20 threaded coupling).
WARNING: When the D125L is being pressurized, lethal high voltage can be generated at the connection terminals of the D125L shaker. The shaker electrical leads should be shorted together during pressurization and de-pressurization to prevent a shock hazard.

1.3 System components

1.3.1 Model F7 piezoelectric shaker system

The F7 piezoelectric shaker system comes complete with the F7 piezoelectric shaker, the Z7 impedance head, all input and output cables, a mounting stud, and a spanner wrench. The impedance head of the F7 requires a Wilcoxon model CC701 charge converter for each high-impedance transducer monitored. See section 1.5 for more information.

1.3.2 Model F7-1 piezoelectric shaker system

The F7-1 piezoelectric shaker system comes complete with the F7-1 piezoelectric shaker, all input cables, a mounting stud, and a spanner wrench.

1.3.3 Model D60H piezoelectric shaker table

The D60H piezoelectric shaker table comes with an R7-7M-J59-12 input cable.

1.3.4 Model D60L piezoelectric shaker table

The D60H piezoelectric shaker table comes with an R7-7M-J59-12 input cable.

1.3.5 Model D125L piezoelectric shaker table

The D60H piezoelectric shaker table has an integral input cable with a special high-voltage BNC connector to mate with the N8FS. A high-pressure hose is supplied for pressurization of the crystal stack.

1.4 Matching networks

CAUTION: If you attempt to operate a piezoelectric shaker without a matching network, you risk serious damage to the output stage of the power amplifier used to drive the piezoelectric shaker.

The impedance presented by the piezoshaker will decrease almost linearly with increasing frequency. However at the shaker system's resonant frequency, the impedance is real and extremely low. In order to get maximum displacement at low frequencies, and consequently maximum acceleration levels, the voltage must be amplified. The matching networks prevent damage to the power amplifiers at resonance.
Note: If a constant voltage independent of frequency is generated, such as constant displacement, then the acceleration and force outputs will increase with the square of the frequency, up to the resonance of the piezoshaker (i.e. at 40dB per decade).

The impedance matching network normally consists of a step-up transformer and an output tap switching arrangement. A variety of output voltages are then available to maximize the voltage delivered to the piezoshaker at different frequencies. Due to the capacitive nature of the piezoelectric shaker, the output impedance of the power amp, and the impedance transformation of the matching network’s transformer, the voltage at the piezoelectric shaker rolls off at a rate of 20dB per decade, after the corner frequency (exactly like an RC filter). As the voltage switch setting on the matching network is switched from highest to lowest, the bandwidth of the system will increase.

In general, the piezoshaker can be operated at lower frequencies with the matching network switch in its highest voltage position. The relatively low load (high impedance) of the piezoshaker at low frequencies is not demanding and the power amplifier can maintain the high voltage swing for maximum shaker output, however as the operating frequency increases, lower output voltage taps become more efficient. The greatest power requirements for the power amplifier will occur at the corner frequencies of the matching network and shaker system and at the resonant frequency of the shaker.

CAUTION: The piezoshakers can be damaged by internal heat build up when run at high levels for extended periods. This is due to the dielectric loss tangent of the piezoceramic material that generates heat. When driven at high power levels this heat buildup will raise the temperature of the piezoceramic to the Curie temperature were it will depolarize itself. Please contact WR for assistance when extended high output testing will be performed.

CAUTION: Reduce power to minimum prior to changing switch settings.

The N7FS matching network, which powers the power the F7 piezoelectric shaker, connects to the power amplifier and provides selectable maximum voltage outputs of 100, 200, 300, 500, and 800 Vrms.

The N8FS matching network, which powers the D60L and D60H shaker tables or the D125L piezoelectric shaker, connects to the power amplifier and provides selectable voltage outputs of 300, 450, 800, 1150, and 1500 V rms.

The N8HFS matching network, which powers the F7-1 piezoelectric shaker, connects to the power amplifier and provides a maximum voltage output of 360 Vrms.

1.5 Optional accessories

Accessories available from Wilcoxon Research for these systems include power amplifiers, a high-pressure supply hose, mounting hardware, and cables.
Model F7 piezoelectric shakers requires one or two Wilcoxon model CC701 charge amplifiers to monitor the impedance head. Refer to the Wilcoxon Research catalog for product numbers and ordering information.

2.0 Initial system setup

The piezoelectric shaker, independently, does not have any operating controls or settings. It functions as a part of a total system for vibration excitation. This system should be installed according to the following instructions.

CAUTION: Complete all of these instructions before operating the shaker system.

2.1 Checking components

After carefully unpacking the shakers and any accessories, inspect all external parts for visible damage to the shaker or connectors. If there is damage, file a claim with the carrier who transported the system. Retain the shipping containers and packing material for use in case reshipment is required.

CAUTION: Do not drop the shaker. The Piezoelectric shaker operating element is a piezoelectric ceramic. The mechanical shock from dropping could fracture the ceramic. If space permits, it is recommended that a thick piece of protective material, such as foam rubber, be wrapped around the periphery to prevent accidents.

Ensure that you have all components of the purchased system.

2.2 Mounting instructions

The mounting surface of the Z7 impedance head must rest flush against the test structure to maintain transducer sensitivity.

The F7-1 has no impedance head, but should rigidly contact the surface of the structure under test to ensure adequate vibration energy transfer. The F7-1 is mounted using the 1/4-28 UNF tapped hole in the center of the base, and four equally spaced 10-32 UNF tapped holes on a one-inch circle.

The D Series shakers tables have mounting hole patterns for attaching test structures to the table. A thin layer of grease between the shaker table face and the test object can improve the mechanical energy transfer.

Be careful not to dent the mounting surface of the shaker when attaching it to the test structure.
2.3 Connect the power amplifier

Wilcoxon Research power amplifiers are purchased and packaged separately from shaker products. Refer to the operating guide supplied with the power amplifier for connection instructions. If using a power amplifier other than one supplied by Wilcoxon Research, Inc., follow that manufacturer’s recommended procedure for installation and operation.

2.4 Connect the matching network

Wilcoxon Research matching networks are purchased and shipped separately from shaker products. Refer to the operating guide supplied with the matching network for connection instructions.

2.5 Electrical connection instructions

1. Make sure that the AC line receptacle used for the power amplifier is properly grounded to a good earth ground.

![WARNING: Do not operate the system without proper grounding.]

2. Decrease the power to minimum before changing the matching network switch positions.
3. Before making any changes in electrical connections, turn the signal input level to minimum and turn the power amplifier main power switch to off.
4. After the shaker system and its components are properly connected and mounted to the test specimen, connect the accelerometer and force gauge outputs in the impedance head to the proper signal conditioners and to the readout device.

![CAUTION: Powering systems supplied by Wilcoxon Research are designed to prohibit exceeding the maximum input voltage. If another powering system is used, do not exceed the maximum input voltage to the piezoelectric shaker.]

5. The following table indicates the cable types and connections for Wilcoxon Research power amplifiers, matching networks, and piezoelectric shakers. Consult this table for guidance on cable and equipment connections.

Table 3.5 – Interconnecting cables

<table>
<thead>
<tr>
<th>Piezoelectric shaker</th>
<th>Cable from power amplifier to matching network</th>
<th>Matching network</th>
<th>Cable from matching network to shaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>F7</td>
<td>R22-22-J9B-5</td>
<td>N7FS</td>
<td>R4-4M-J9-10</td>
</tr>
<tr>
<td>F7-1</td>
<td>R22-22-J9B-5</td>
<td>N8HFS</td>
<td>R4-4M-J9-10</td>
</tr>
<tr>
<td>D60L</td>
<td>R22-22-J9B-5</td>
<td>N8FS</td>
<td>R7-7M-J59-12*</td>
</tr>
<tr>
<td>D60H</td>
<td>R22-22-J9B-5</td>
<td>N8FS</td>
<td>R7-7M-J59-12*</td>
</tr>
<tr>
<td>D125L</td>
<td>R22-22-J9B-5</td>
<td>N8FS</td>
<td>Integral, high voltage BNC*</td>
</tr>
</tbody>
</table>
* Note: The D Series shakers also have a screw terminal on the shaker, where additional ground wire should be attached between the shaker and matching network, for increased safety.

2.6 Model Z7 impedance head connection

The Z7 impedance head is an integral part of the F7 piezoelectric shaker. It contains a piezoelectric accelerometer and a piezoelectric force gauge. The output from these high impedance, charge-mode sensors is from two 10-32 coaxial (Microdot) connector jacks on the periphery of the transducer. They are marked “A” for acceleration, and “F” for force.

3.0 Operation

The vibration generating system is ready for operation only after it has been thoroughly checked for proper electrical connections. Select a suitable location for the system, such as a sound isolated room, because the shaker may generate a considerable amount of sonic output.

**WARNING:** It is recommended that the operating personnel use hearing protection.

The following steps are suggested for operation of the vibration shaker system:
1. Make sure the oscillator amplitude control is set to minimum or to off.
2. Adjust the matching network amplitude setting to minimum output.
3. (Optional, depending on your system configuration.) Turn on the vibration monitoring system consisting of the accelerometer and its associated output-measuring or display instruments.
4. Turn the oscillator on and set the frequency dial to the low end of the desired frequency range of the test sequence.
5. STAND CLEAR OF THE SHAKER DURING OPERATION.

**WARNING:** The D125L shaker face is pre-loaded by the high pressure nitrogen. NEVER place any portion of your body directly in line with the shaker face.

6. Set the amplifier power switch to on.
7. Slowly increase the setting of the signal generator amplitude control until the shaker generates the desired vibration level or until clipping of the power amplifier output occurs.
8. (Optional, depending on your system configuration.) It is recommended to use a monitoring system to monitor the amplifier output to prevent overdriving the shaker.
9. Continue the test by changing the oscillator frequency dial and adjusting the amplitude control to attain the desired vibration levels.
10. When using a matching network, higher vibration levels can be obtained. First, turn the signal generator amplitude output to minimum. Next, increase the output voltage of the matching network as required.
11. Repeat steps 9 and 10 above to conduct additional testing.
12. When the test sequence is complete, turn down the signal generator amplitude output and then turn the matching network to minimum.
13. Set the power amplifier power switch to off.
4.0 Technical assistance

4.1 Technical assistance

For technical assistance, please contact Wilcoxon’s Product Manager at 301-330-8811, fax to 301-330-8873, or email to wilcoxon.techasst@meggitt.com.

4.2 Customer service

To obtain a return goods authorization number, please contact customer service at 301-330-8811, or fax to 301-330-8873.
Appendix – Mounting surfaces

D60H bolt hole pattern

D60L bolt hole pattern

D125L bolt hole pattern