©M/RAD Corporation
71 Pine Steet
Woburn, MA 01801
888-500-9578 • 781-935-5940
Fax: 781-933 -7210
www.mradcorp.com • inquiries@mradcorp.com

# Technical Papers

## Principles of Operation of a Mechanical Reaction Shaker

By: Philip Marshall, President
Marshall Research and Development Corporation

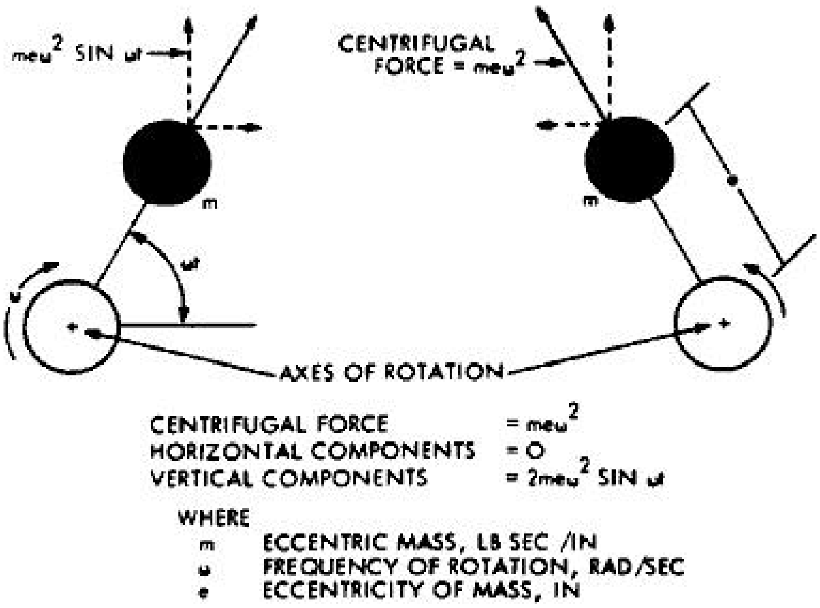
Mr. Marshall received his BME degree from New York University in 1954 and his SM in ME degree from MIT in 1955. He has been engaged in the shock and vibration business since graduation. -In 1967, Mr. Marshall founded Marshall Research and Development Corp. and is serving in the capacity of President of that Company.

### INTRODUCTION

The mechanical reaction shaker had - been developed to fulfill the growing demand for inexpensive equipment to perform vibration endurance testing over extended periods of time. A family of test specifications had developed from the findings of the Advisory Group on Reliability of Electronic Equipment (A. G. R. E. E. ) Office of the Assistant Secretary of Defense (Research and Engineering). MIL-STD-781B was developed from AGREE and specifies longevity tests of electronic equipment for time periods up to 2000 operating hours. These tests are normally performed at frequencies between 20 to 60 Hz and a fixed amplitude of 2.2g + 10% (1.0g for Navy applications) .

The philosophy behind AGREE testing is to determine statistically whether the tested production items will have satisfactory reliability over its operating life. Also to determine this fact before the equipment has left the manufacturer's plant. The AGREE test consists of a combination of temperature and vibration. Temperature is periodically cycled up and down and vibration is generally applied for 10 minutes out of every hour. The extremes of temperature and the level of vibration is not intended to fatigue the tested item but to expose latent defects such as cold solder joints which test acceptably when the equipment is new but are highly susceptible to early failure. The actual time duration of the test is a function of the failure rates experienced during the tests. For example, an extremely low failure rate may terminate the test early while a high failure rate will result in many more hours of testing until the failure rate falls into an acceptable category or the production lot under test is rejected. One does not have to be a statitician to see that the highest failure rates should be experienced early in the program when the most fragile defects will occur after which the failure rate should decrease. Moreover, if the tests were conducted over an extremely long period of time the failure rate should again increase because of fatigue considerations. Hence, the most favorable failure rates are achieved after some limited exposure to the tests. This initial test phase is called "burn in" and failures recorded during this phase do not count against the test item.

Electrodynamic shakers can be used to perform these tests, however, their cost is considerably greater than the cost of a mechanical shaker which utilizes the centrifugal forces of eccentrically mounted masses on counter-rotation shafts to generate the vibratory forces. The following diagram illustrates how this arrangement works for a vertical shaker.

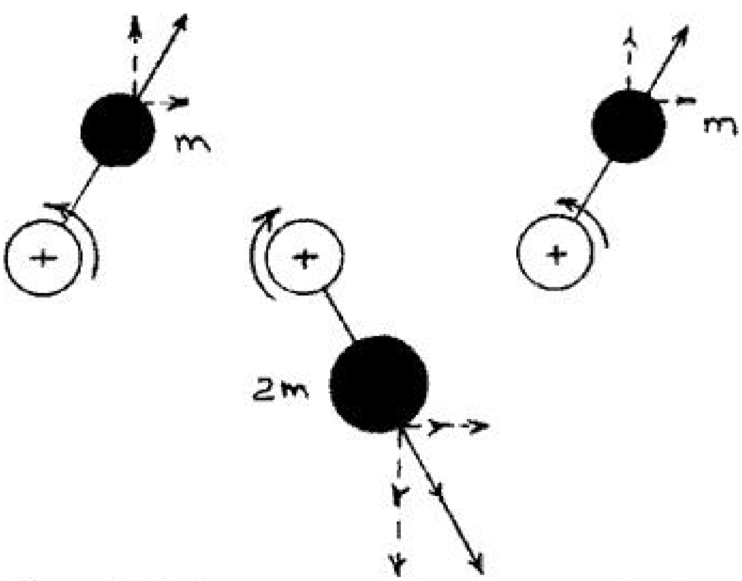



Note that the horizontal components of the forces cancel each other; thus, a pure sinusoidal force field in the vertical direction is generated. If the above mechanism is attached to a table and this combination, in turn, is supported on soft springs, the resulting amplitude of vibration of the table at any operating frequency is given by the simple relationship:

vibratory displacement (da) =

$$\frac{\text{2 x eccentric masses x eccentricity}}{\text{table mass}}$$

Hence, the amplitude of vibration may be varied simply by changing the eccentric mass or the eccentricity of this mass. Note that a mechanical shaker maintains a constant displacement over its frequency range for any given setting of the eccentric weights and test mass.

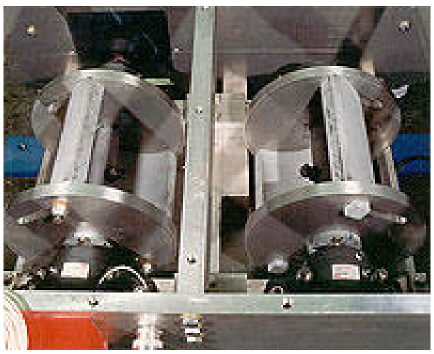



**Three Shaft Arrangement for Horizontal Vibration**

A vertical-horizontal shaker operates with three shafts instead of two as described above. The following diagram illustrates how the centrifugal forces are phased to produce either vertical or horizontal vibration. m this arrangement, the center mass is exactly twice the mass of each of the two outer weights. A machine is converted from vertical to horizontal motion only by changing the phasing of the outer two masses by 180 degrees with respect to the center mass.

## DESCRIPTION OF MACHINE

The basic configuration of the M/RAD mechanical shaker is shown in the photograph.



The table top is rigidly attached to the drive mechanism box which contains a pair of counter-rotating eccentric weights. The eccentricity of these weights determines the amplitude of vibration. Vibratory forces are generated by the centrifugal forces acting on the weights as they rotate about their respective shafts. The shafts are driven through a V-Belt from an electric motor. Frequency is adjusted either by adjusting the split pulleys with the machine at rest when the standard frequency drive has been selected, or with the ACI inverter which is supplied with an AC motor. The shafts are driven in opposite directions by a crossed timing belt arrangement to insure the proper phasing between the shafts. The drive mechanism box is supported on coil springs to isolate the vibratory forces from the foundation. The height adjusting and leveling mechanism is built into the base of the coil spring suspension. Access to the leveling adjustment is through openings in side panels of the machine. The shaker is normally provided with V-Groove casters to easily position the shaker in temperature chambers.

The M/RAD shaker has been designed so that all amplitude and frequency adjustments can be made with the shaker in the chambers. All parts of the machine mechanism are accessible for service by removing either the access panels or the top plates.

To adjust the height of the shaker, raise the coil spring suspension by turning nut 51 counterclockwise in four places through the openings in the side panel of the base of the machine. This adjustment should be made with the shaker on the track so that the proper height to match the chamber can be established. There is approximately a 2 inch adjustment in the shaker height. Once the shaker is leveled and adjusted to the desired height, lock nut 51 in place by jamming with nut 52.

## OPERATION

### Amplitude Control-Vertical Shaker

The amplitude of vibration is controlled by changing the eccentricity of the rotating masses about their respective shafts. Before any adjustments are made in the shaker, push the stop button on the manually operated safety switch on the front on the shaker to prevent accidental start of the shaker.
The shaker cannot be turned on when the stop button is depressed. Remove the two safety covers (7) to expose the amplitude control screws (19). Loosen slightly the two lock nuts (18) on the guide screws, but do not remove. With a wide blade screwdriver turn the adjusting screw clockwise to increase the eccentricity or counterclockwise to decrease the eccentricity. A scale is attached to the mechanism which indicates the eccentricity of the mass directly. Both masses must be set identically. The thread on the mass adjusting screw has been selected to provide 1/16 inch movement of the mass for each revolution of the screw. Tighten the lock nuts (18) after the mass eccentricity has been set and replace the safety covers before operating the shaker.

The displacement amplitude of vibration is independent of frequency and a function only of the vibrating mass (∑W) and the eccentric moment (w e) as given by the following equation:

$$DA = \frac{2\ w\ e}{\sum W} \qquad (1)$$

where:
DA = peak to peak displacement amplitude, in.
w = total of eccentric weights, lbs.
e = eccentricity of center of gravity of mass from center line of shaft, in.
W = total vibrating weight (shaker and payload), lbs.

Equation ( 1 ) has been plotted in a nomograph. The weight of the shaker (including the insulated top) is provided on the Specification page. Add to this weight the weight of all test items and fixtures. Enter the nomograph with this total weight and read the moment of the eccentric weights at the desired displacement amplitude. Divide the moment answer from the nomograph by the weight of the eccentric masses to compute the eccentricity setting in inches. A vibration nomograph is also provided to convert vibration amplitudes specified in g units to displacement in inches. Note that the displacement reading of the vibration nomograph is a vector quantity and must be multiplied by 2 to convert to a peak to peak displacement for use in the eccentric mass computation.

For example, assume the shaker weighed 750 pounds, the eccentric weight is 30 pounds, the specimen weight is 350 pounds, and the desired test is 2. 2g at 35 cps. From the vibration nomograph, the vibration displacement amplitude is 0.035 inches (double amplitude) . Enter the moment nomograph at a total weight of 1100 pounds (750 + 350) and read a moment of 19 inch-pounds. Therefore, the eccentricity is set at (19 divided by 30) 0.64 inches.

The rotating masses are factory aligned to each other to within 5 degrees. Adjustments are provided so that this error shall never exceed 5 degrees when replacement parts are used.

### Amplitude Control - Vertical/Horzontal Shaker

The vertical/horizontal shaker has three parallel shafts. The eccentricity adjustments of all three masses in this shaker is computed and made in the same manner as described in the preceding section.

To operate the shaker in the horizontal direction the three arrows on the front end plates of the eccentric mass assembly should all be aligned in the same direction as shown → → →. To operate this shaker in the vertical direction, rotate both the two outer eccentric mass assemblies 180 degrees with respect to the center mass assembly so that the arrow alignment is ← → ←. The vertical/horizontal shaker was designed with its center of gravity below the line of action of the force vectors when operating in the horizontal mode. However, test specimens will alter the location of the center of gravity and crosstalk will be experienced. The M/RAD AGREE shaker is provided with counterweights to minimize this cross-section however, cross-motion is permitted during AGREE tests.

### Frequency Adjustment - AC Motor Drive

CAUTION: Before any adjustments are made, push the STOP button on the safety switch on the front of the shaker to prevent accidental start of the shaker while being adjusted.

Shakers driven by an AC motor are provided with three split pulleys labeled A, B, and C respectively. The frequency range and orientation of these pulleys is shown in the following table. Pulleys must not touch oil cups when being installed.

### PULLEY ORIENTATION

| Motor Shaft | Drive Shaft | Frequency Range (approximate) Hz. |
|---|---|---|
| A | B | 20 - 30 |
| B | A | 29 - 41 |
| C | A | 40 - 60 |

To adjust the speed range or to change pulleys, first loosen the nuts holding the motor under the shaker, and slide the motor so there is slack in the V-Belt. Next, adjust the pulleys within the speed range per the above table. To increase frequency make the diameter of the pulley on the motor shaft larger and the pulley on the drive shaft smaller.

To decrease frequency make the pulley on the motor shaft smaller and the pulley on the drive shaft larger. After the adjustments are completed, pull the motor to take up any slack in the V-Belt and retighten the nuts supporting the motor. Reset the start button for automatic operation. NOTE: The shaker may be operated remote from the temperature chamber and controlled with the START and STOP buttons on the safety switch which is also an approved motor starter containing thermal overload protection. CAUTION: Shakers must never be operated at accelerations greater than 5g or R .1 inch (da), whichever is less. Extreme care must be exercised when operating the shaker above 30 Hz that the acceleration limits are never exceeded or the shaker will be damaged.

### Frequency Adjustment - DC Motor Drive with SCR Control

The frequency may be adjusted over the entire operating range of the shaker without changing pulley sizes. The frequency adjustment is made on the control box by turning the speed control knob clockwise to increase and counterclockwise to decrease frequency. The control box also has a two-pole circuit breaker, a tachometer, and a light that indicates the presence of power in the panel. In the case where the shaker is not ordered for use in conjunction with an environmental chamber, a separate control switch is provided. However, the shaker is normally turned on and off by command signal from the chamber. CAUTION: Before any adjustments are made inside the shaker, place the circuit breaker in the off position.

### GENERAL CONSIDERATIONS

The shaker is provided with friction dampers located inside the base cover to limit the transient motion of the shaker during start and stop as the shaker frequency passes through the resonant frequency of the spring suspension. EXTREME CARE must be exercised if the shaker is to be operated at or near the suspension resonant frequency (3 - 6 Hz) that the shaker displacement amplitude does not become excessive due to resonant build-up.

The center of gravity of the test specimen shall be located as close to the center of the shaker as possible. Eccentricity of the test specimen will result in non-uniform motion across the table top.

All bolts and studs have been treated with LocTite at final assembly. After 500 hours of operation check the torque on all the bolts and studs in the tightening direction only. Torque values are given in the following table.

### Suggested Maximum Fastener Torque Values

| Bolt Size | Torque ft-lbs |
|---|---|
| 1/4 | 6.0 |
| 5/16 | 12.0 |
| 3/8 | 19 |
| 7/16 | 29 |
| 1/2 | 40 |

If any fasteners are loose, remove to apply I Tite and reinstall with the proper torque.

### LUBRICATION

Grease lubricated bearings should be lubricated every two months of operation. Oil lubricated bearings should be checked weekly.

### TIMING BELTS

To change the timing belt remove top plate from shaker and loosen at the timing belt end only, the inside bearing stop bolt on one shaft Next, loosen the nuts holding that shaft's bearing at the timing belt end and slide the bearing toward the center of the machine. Remove the old belt and replace the new belt taking note not to change the direction of the twist in the belt. Retighten the stop bolts and bearing nuts and replace the top of the shaker.

*Delivered at an Environmental Equipment Maintenance Clinic under the auspices of the Environmental Equipment Institute at the Institute of Environmental Sciences annual meeting, Boston, Mass., April 14, 1970.*