SENTEK DYNAMICS

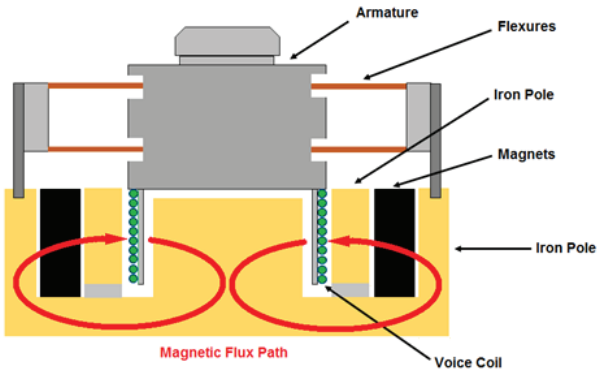
AN INTRODUCTION TO SENTEK DYNAMICS

VIBRATION TESTING SYSTEMS

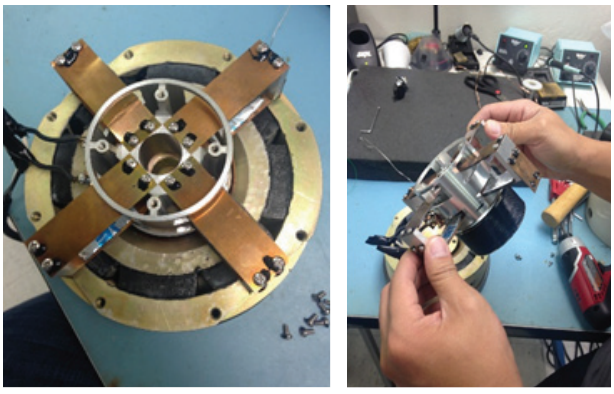
Whether you are shopping for your first shaker system, or just experiencing your first visit to the Sentek Dynamics Website, you may feel a little overwhelmed. We build a lot of different shaker systems! So let's spend a few minutes together to gain an overview and understanding of what is offered and why.

Firstly, all of our shakers are *electrodynamic* shakers. They rely on the same physical relationships that make a loudspeaker work. Basically, when a current passes through a wire that is in a magnetic field, a force perpendicular to the wire and to the magnetic flux is induced in the wire. The amount of force is proportional to the current, to the magnetic flux and to the length of wire in the magnetic field. We wind the wire around a cylindrical coil form that is part of the shaker *armature* and elastically suspend it in a radial magnetic field. This results in an axial force acting on the armature in proportion to the applied current. The suspension holds the coil concentric within the magnetic field. It allows the armature to move a limited distance axially relative to the shaker body. This limited distance is termed the shaker's displacement *stroke*.

Our smallest shakers use *permanent magnets* to provide the magnetic field. They employ simple elastic flexures as the spring-like suspension. These machines have a structure similar to a loudspeaker, but are far more robustly built. Typically, these shakers are used for *modal analysis* and provide an oscillating force to a structure that is supported by its own foundation. That is, they do not normally bear the weight of the item being tested. The force is frequently conveyed to the test object by a thin rod termed a *drive quill or stinger*, and the force is often measured by a force sensor mounted between the stinger and the device under test (DUT). If the DUT is light enough, it may simply be secured directly to the shaker armature for a whole-body shake. In this case, available shaker vibration stroke (a.k.a. peak-to-peak displacement) is surrendered to the *static deflection* of the shaker's suspension under the weight of the DUT.



Schematic representation of a permanent magnet shaker emphasizing the magnetic circuit and armature suspension. Radial polarized rare-earth magnets form a ring between two soft iron pole pieces, providing a radial flux through the armature's wound coil. Two sets of axially separated flexures center the armature in the gap while allowing axial stroke against a soft spring-rate. This configuration stiffly resists cross-axis translation and all rotations.



Left - Magnetic circuit elements and flexures. Right - Armature showing suspension flexure spacing and voice coil.

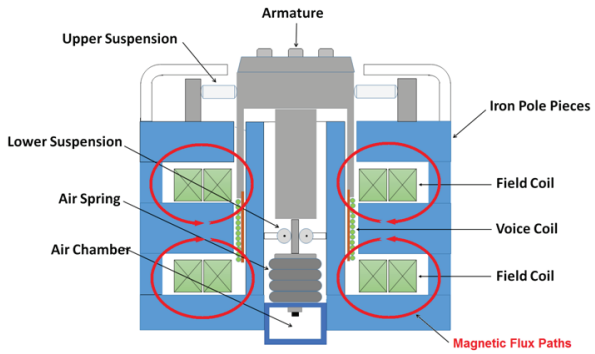
Two typical permanent magnet shakers, an MS Series on the left and a VT Series on the right.

Sentek Dynamics offers two series of permanent magnet shakers. The Sentek Dynamics' **MS** Series shakers are optimized for stinger attachment and are particularly recommended for *modal analysis*. The **MS** Series can tolerate a sustained DC bias current, and may be provided with an optional *automatic armature centering* (AAC) option allowing a DC bias to hold the stinger in tension when attached to a sensor mounted to a DUT. The **VT** Series allows stinger use, but also provides a small circular *load table* surface to support a small DUT; they are recommended for academic and general laboratory use. Smaller **VT** Series shakers feature slightly higher maximum operating frequency than their **MS** counterpart. Sentek Dynamics' permanent magnet shakers provide a maximum *peak sine force* of 20 N (4.5 lb) to 1000 N (224.4 lb) with strokes ranging from ±4 mm (±0.16 in) to ±12.5 mm (±0.5 in). They weigh between 2 kg (4.4 lb) and 62 kg (136.4 lb).

All **MS** and **VT** Series shakers come trunnion-mounted. The *trunnion* is a simple support-base structure that allows the shaker to be oriented horizontally or vertically (or at an angle in between). If desired, the shaker can be separated from the trunnion when a lower height vertical unit is needed or when you want to suspend an **MS** Series shaker using a bungee or other support. Various options are offered for these shakers including a cooling blower recommended for continuous operation at high power levels.

VT and **MS** Series shakers are fundamental tools for any noise and vibration laboratory. These small systems are completed by a matching Sentek Dynamics **LA** Series *linear amplifier*. They are typically employed with a *digital signal analyzer* (DSA) for modal analysis and other vibration characterization or with a *vibration control system* (VCS) and a control accelerometer for closed-loop product qualification shakes. The VCS or DSA provides the desired excitation signal as an input to the amplifier. In turn, the amplifier's high-current output drives the shaker's armature coil, vibrating the test object. The **LA** Series are true power amplifiers specifically designed to drive the low-impedance coils of the **MS** and **VT** Series shakers with high-fidelity. They provide high drive-current, low distortion, high signal-to-noise ratio and wide bandwidth. Five different **LA** Series amplifiers are available, providing 100, 200, 500, 800 or 1,500 VA output power. The LA-100 amplifier provides a built-in sine wave oscillator.

The remainder of our line consists of larger, more powerful vibration machines focused specifically upon environmental testing, wherein the device under test is attached directly to the load table of a shaker armature and the entire DUT is vibrated under control of a multi-channel VCS such as the Crystal Instruments Spider-81 or 80X Series. Systems of this type can reliably subject the test item to random, swept-sine or shock excitation profiles to match the requirements of virtually any military and/or commercial test specification.



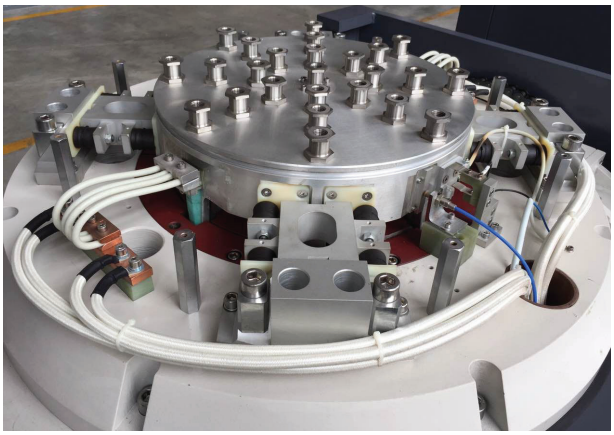
Schematic representation of an electromagnetic shaker emphasizing the magnetic circuit and the internal load support (ILS) suspension. Two flux paths sum at the voice coil location, reducing flux leakage near the DUT. The pneumatic spring of the ILS system provides a low stiffness with zero static deflection. A guidance system below the voice coil prevents an off-center DUT from rocking the armature.

As a shaker becomes larger, it becomes less-and-less feasible to use permanent magnets to derive the fixed reference flux. Environmental test shakers derive their magnetic field from electromagnetic coils excited by a fixed DC current. As in permanent magnet designs, these axially-wound coils act in consort with soft iron pole pieces to focus a radial flux field through the armature's voice coil, which is driven by a variable current to induce vibratory motion. A pair of axial coils is used to minimize the magnetic leakage near the load table (top of armature). By using two additive flux paths, the strong driving radial field (and the flux gap in which the voice coil moves) are positioned lower within the iron body of the shaker. This greatly reduces the stray magnetic flux passed through the DUT and control instrumentation.

These shakers are designed to vibrate small to large and heavy objects. For this reason, their suspensions incorporate an *internal load support* system (ILS) using an *air-spring* to support the weight of the device under test while the armature remains centered in its stroke range. These bladder-like pneumatic springs are filled with shop air. A pressure between 0.2 and 0.6 MPa (29 to 87 PSI) will maintain the armature in the center of its stroke range for any tested mass up to the specified *maximum static payload* of the system. On any Sentek Dynamics shaker, shop air may be added manually through a Schrader ® valve while monitoring the armature position against a mid-position gauge. With the optional automatic armature centering (AAC) module the armature mid-point position is maintained automatically. An over-travel interlock prevents the armature from moving outside of its designed stroke range by interrupting the drive signal from the amplifier until the necessary corrections are made.

For shakers providing over 3kN (660 lb) force, the AAC option performs two centering functions. *Static centering* automates the pressure control of the ILS; change the static payload on the load table and the ILS valves more or less air into the air chamber connected to the air-spring, changing the internal pressure to hold the armature's vertical position fixed. *Dynamic centering* provides "fine tuning" of the armature's center position (in response to temperature change, for example) while a test is running. This is accomplished by adding a DC bias to the voice coil signal. The AAC option is particularly desirable in operations where items of significantly different weight are tested frequently.

The ILS acts like a soft mechanical spring with a preload applied at its reaction end to balance the weight of the DUT. The required operating pressure is proportional to the weight of the DUT (and fixtures) being tested. The stiffness of the air-spring is also directly proportional to the spring's internal pressure and inversely proportional to its internal volume. Hence, the natural frequency of the loaded armature-on-suspension is constant, regardless of the attached payload. The extra volume of the air chamber connected to the air spring softens the resulting spring rate resulting in a lower *table resonance frequency* and expanding the usable frequency range of the shaker.

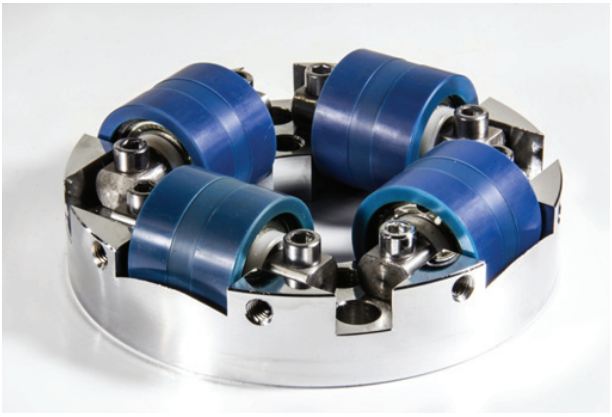


Above - "Roller-truss" upper suspension used in shakers with up to 51 mm (2 in) stroke has four elastomeric elements;

Left - Rolling link "dog bone" used in longer stroke machines is entirely metallic.

While flexures are no longer needed to support the weight of the bare armature, structure is required to hold it concentric with the pole pieces forming the flux gap. This is accomplished by using suspension elements above and below the voice coil. Depending on the stroke (displacement) of the shaker the armature is centered with elastomeric elements or with metallic rolling contact guides. The lower-suspension surrounds a square-post attached to the armature with four elastomeric rollers. All elements of these suspension systems are adjustable for wear and can be readily replaced.

Lower suspension square guidance post sitting on air-spring over air chamber and base attachment plate. The post is held to the armature by a screw.



Lower guide rollers that surround the guidance post are retained by a ring that is secured to the inner pole piece.

Larger, more powerful shakers give off more heat. Cooling of the shaker becomes essential, particularly for extended operation at high-force levels. Sentek Dynamics' shakers providing less than 65 kN (14,300 lb) of force are air-cooled by a remote blower. Room-temperature air is drawn into the shaker through a shroud surrounding the load table. This air passes through the magnetic gap, cooling the voice coil and the field coils as well as extracting heat from the iron structure. The air is drawn to a plenum chamber at the bottom of the shaker and out through a flexible duct to the blower. The blower may be mounted outside of the workspace to minimize noise and re-circulated heat. An interlock prevents shaker operation if the blower is not drawing sufficient air through the shaker.

A typical low-force air-cooled shaker system.

The **H, P** and **E** Series shakers are our most powerful offerings, providing peak force ratings from 65 kN (14,300 lb) to 400 kN (88,000 lb). These large shakers are all water-cooled. The armature is wrapped with a flat cooling tube and the body cylinder has cast-in water passages. Each system is provided with a cooling unit which passes the heat generated within the shaker into a flow of outside water. Each cooling unit is sized to match the shaker and incorporates two heat exchangers, two pumps and a single divided tank for distilled water. Two internal closed-loop cooling circuits provide distilled water to the armature and to the field coils.

One heat exchanger and pump supplies water to the armature circuit; the other heat exchanger and pump supplies water to the field circuit. An outer circuit passes the extracted heat from the inner circuits to a facility raw water source, typically from a remotely located chiller. Water pressure in the armature and field circuits is monitored by sensors as is the facility raw water pressure. If any values surpass their respective settings, the system alarm will sound and the amplifier will shut-off.

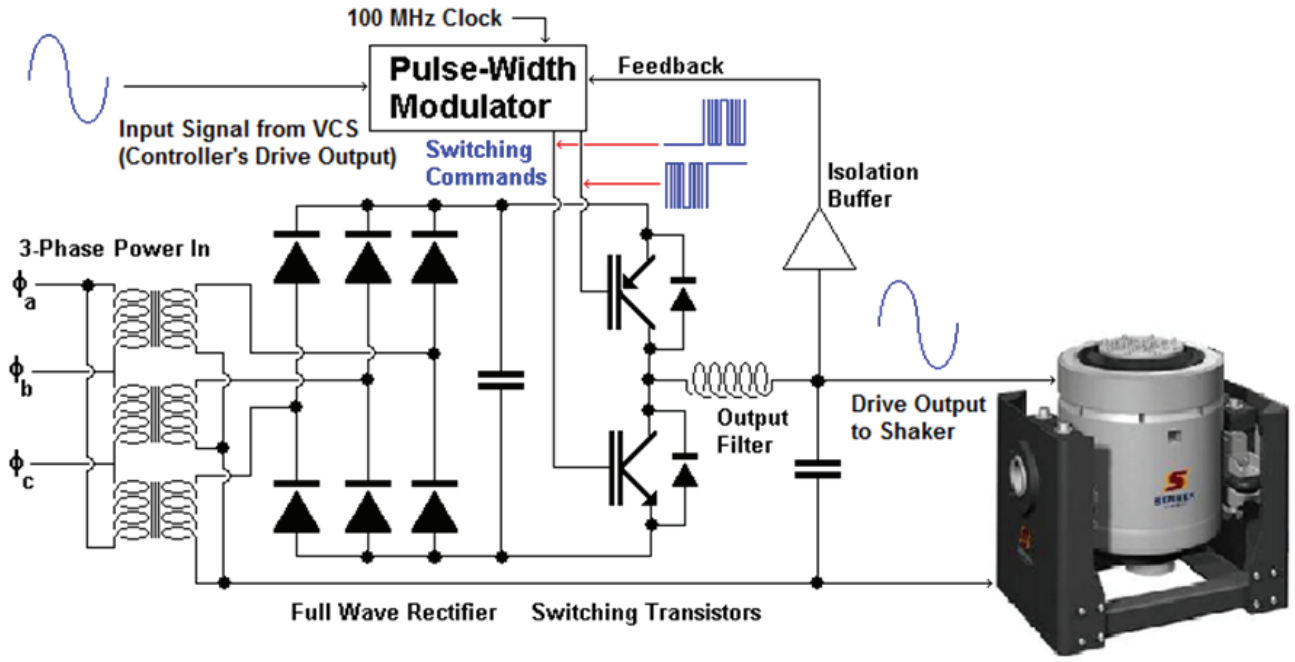
A typical high-force water-cooled system including a shaker and mono-base slip-table with air isolation mounts.

The amplifier for an electrodynamic shaker is actually a system that performs multiple functions, including:

- Amplify the drive signal from an external vibration controller and apply it to the shaker's voice coil
- Provide a constant DC current to the shaker's field coils
- Provide 3-phase power to the blower
- Facilitate safe and orderly start-up and shut-down of the shaker system
- Monitor safety interlocks and respond appropriately and rapidly to any "trips"
- Display the status of the system
- Maintain armature mid-point position under static and dynamic conditionals (with optional AAC)

Sentek Dynamics **PA** Series amplifiers are air-cooled and modular. The shaker voice coil is driven by a digital (Class D) switching amplifier. This switching amplifier is comprised of multiple 12 kVA power-modules working in parallel, driven by a separate DC source. Each module is comprised of two independent 6 kVA sub-modules. This modular construction provides excellent load-sharing between all of the T-channel MOSFET switching transistors involved and simplifies field maintenance and power upgrades. MOSFET switching at 100 kHz provides excellent resolution, linearity and fidelity. **PA** Series amplifiers up to 480 kVA are available. All exhibit greater than 90% efficiency, minimizing the heat thrown off by amplifier cabinet. Sentek Dynamics can provide replacement amplifiers for older systems produced by other manufactures.

A PA Series amplifier – the control center of your shaker system



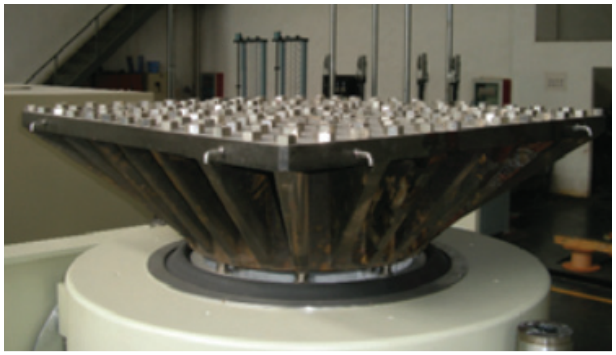
Functional representation of a Class-D switching amplifier. The low-voltage analog Drive input from the VCS is amplified to a high-power level and applied to make the voice coil move.

The **PA** Series amplifier cabinet serves as the central wiring point. It is powered from a three-phase source (typically 480 VAC) and provides power to all remaining elements of the shaker system. It also houses the **SCU-200** main control panel which serves as a central control point with system status readouts. Interlock sensors assure that the armature position, all voltages, currents, temperatures and blower air-flow (or cooling water parameters) are within normal limits before allowing a test to commence. Any parameter that goes out of range during a test initiates a trip readout and an automated emergency shut-down. An Emergency Stop button is also provided. The optional SA-**100** remote control panel is available, providing full system control and readout at a remote location.

Every Sentek Dynamics shaker comes with a mating trunnion base. A trunnion (from the old French *trognon* or trunk) is a cylindrical protrusion used as a cannon's mounting and/or pivoting point. This mounting base allows the shaker to be operated in vertical or horizontal orientation (for use with a *slip table*). The trunnion base supports the shaker at two pivot points, much like a cannon. It is provided with locking bolts to affix the shaker in either orientation. The shaker/trunnion interface is provided with pneumatic isolators to minimize floor vibration. Other isolation options, such as air-isolation feet, pads and mounts are also available. Shakers delivering 6 kN (1320 lb) force and greater can be provided with a motorized gearbox to rotate the shaker.

Optional motorized gearbox for shaker rotation.

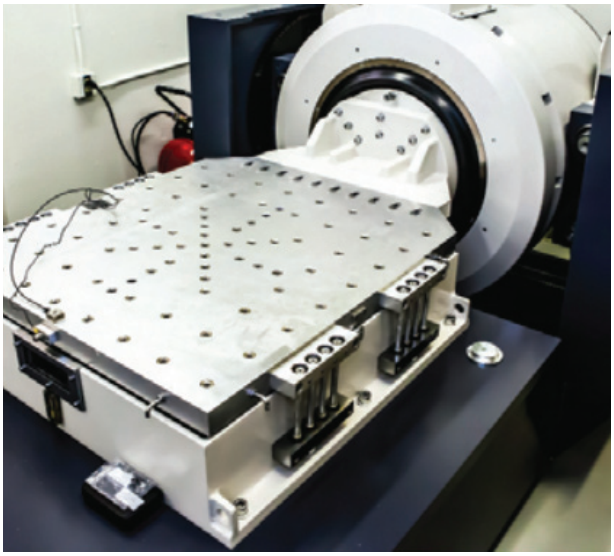
Vibration tests conducted in the vertical direction are quite common and normally demand nothing more than a shaker system of the proper size. Specifications that require the DUT to be qualified in two or three mutually perpendicular directions can be executed in sequence, rotating the specimen between runs. Alternatively, special fixtures may be used to test 3 (or a multiple of 3) examples simultaneously with one facing X, a second facing Y and the third facing Z. In some instances, the size of the fixture may be too large to fit on your shaker. This problem can be solved (at the cost of increased non-DUT mass) with a *head expander*, a larger platform that is bolted to the shaker's load table. Sentek Dynamics can provide both custom fixtures (Cube, L-type and T-type) and head expanders for new or existing systems.



A head expander fitted to the armature's load table increases mounting area.

Horizontal testing is best addressed with a *slip table*. The table is driven by a shaker rotated on its trunnion to the horizontal and connected by a *driver bar*. We offer these tables in a variety of standard (square) sizes from 300 mm (12 in) to 1500 mm (60 in). We can also provide custom sizes. Two families of Sentek Dynamics slip tables are offered. The cost-effective **LST** Series features a magnesium slip plate guided by V-groove bearings gliding on a low-pressure oil film over a precision-ground granite slab. They are compact, having an integral hydraulic pump, reservoir and filter. **LST** slip-plates are very suitable for testing light objects with their center-of-gravity (CG) close to the plate; a lawn mower deck, for example.

The more capable (and more expensive) **HST** Series use T-slot bearings and high-pressure oil provided by an external hydraulic power supply and oil cooler. They offer far greater resistance to over-turning



Slip table driven by horizontal shaker through driver bar.

and are thus suitable for testing heavier specimens with a CG well above the slip plate; think telecommunication equipment racks.

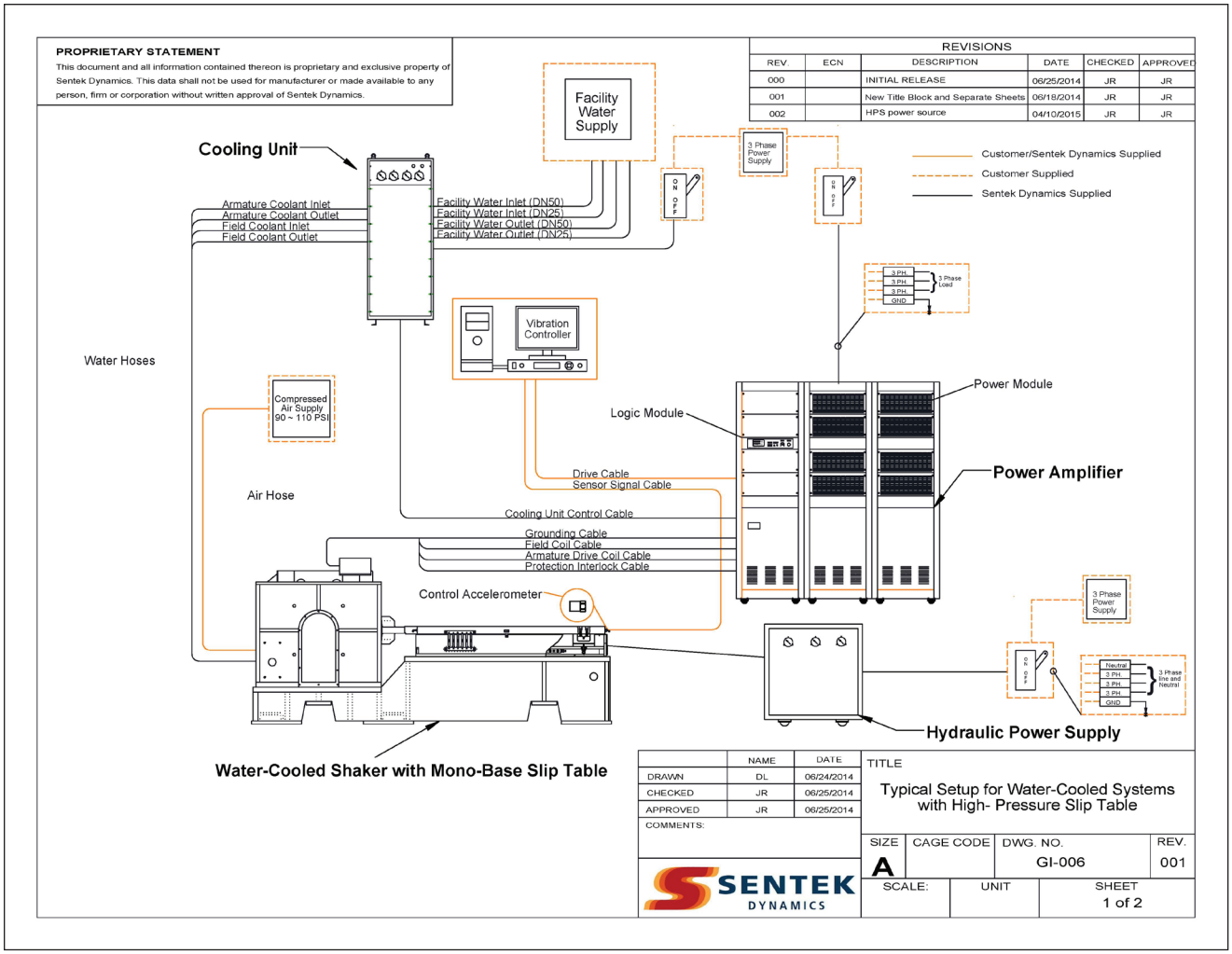
Both the **LST** and **HST** Series can be delivered as independent components that can be driven by any vertical shaker in your laboratory. Leveling feet on the steel support platform simplify alignment. This arrangement offers excellent equipment flexibility and allows the use of a legacy shaker from any manufacturer. A more convenient solution is to order your shaker and slip table in a *mono-base*. In this configuration, the shaker and slip table share a common steel base that enables rapid conversion between horizontal and vertical operation. Exact alignment of the shaker to slip table is guaranteed – just flip the shaker 90° and everything slips smoothly together. This is the right answer for a new facility purchase.

Now there is only one matter to be resolved. Which Sentek Dynamics shaker is right for you? This is never a simple question to answer, but one catch phrase will serve you well: "Bigger is better!" Whether you are talking about the maximum force rating, the maximum acceleration rating, the stroke, the load-table (armature) diameter, the maximum payload, usable frequency range or your facility budget, more is always better. Tomorrow's testing specifications will demand more from your shaker than yesterdays. There is nothing less comfortable than than being a "can do" guy with a "must do" mission and a "can't quite make the spec" facility.

	L Series	M Series	T Series	H Series	E Series	P Series
Peak Force (kN)	1 - 10	15 - 65	30 -54	65 - 160	200-400	80
lb	220 - 2,200	3,300 - 14,300	6,600 - 11,880	14,300 - 35,200	44,000 - 88,000	17,600
Peak Accel (M/S2)	490 - 980	784 - 980	588 - 784	980	980	1470
g	60 - 100	80 - 100	60 - 70.9	100	100	150
Stoke (mm)	25 - 51	51	100	51	51	51
in	1 - 2	2	3.9	2	2	2
Table Diam (mm)	110 - 240	280 - 445	445	445 - 640	640 - 860	445
in	4.3 - 9.5	11 - 17.5	17.5	17.5 - 23.6	23.6 - 32.3	17.5
Max Payload (kg)	70 - 200	300 - 1,000	500 - 800	1,000 - 2,000	2,000	800
lb	154 - 440	660 - 2,200	1,100 - 1,760	2,200 - 4,400	4,400	1760
Freq Range (Hz)	5 up to 5,000	5 up to 3,000	5 up to 2,300	5 up to 2,500	5 up to 2,200	5 up to 2,500
Cooling Method	Forced Air	Forced Air	Forced Air	Water Cooled	Water Cooled	Water Cooled
Models Available	5	7	3	5	3	1

We currently catalog 24 standard electromagnetic shakers grouped into six series. The fundamental performance metrics are summarized in the table above. Use it to home in on the system that's the right size for your needs.

When first approached, selecting a shaker for a particular test or set of tests can be a daunting task. You may also need to spend precious facility dollars for upgraded electrical service, air-conditioning, lift-and-transport facilities, improved lighting or high-quality shop air. Planning a new laboratory is an old problem. We can help you with both issues – please visit http://www.sentekdynamics.com to contact one of our Application Engineers or just to peruse more detailed information about these fine products.



Typical setup diagram for a Sentek Dynamics shaker system; a high-force water-cooled Shaker with companion slip-table in a mono-base is illustrated.

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