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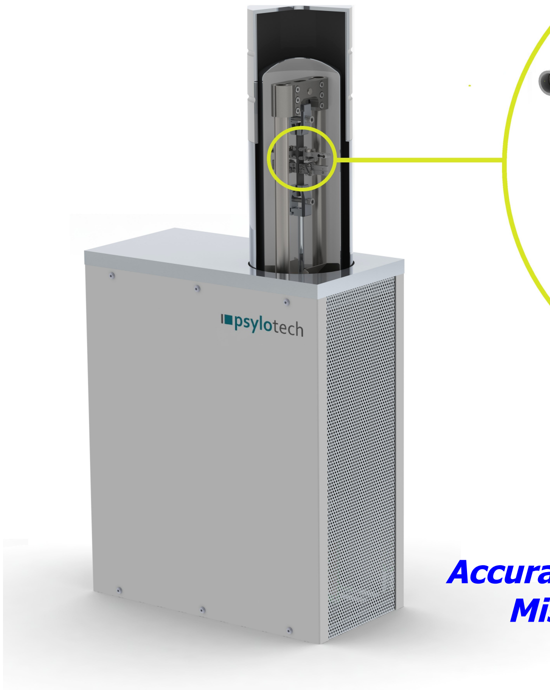
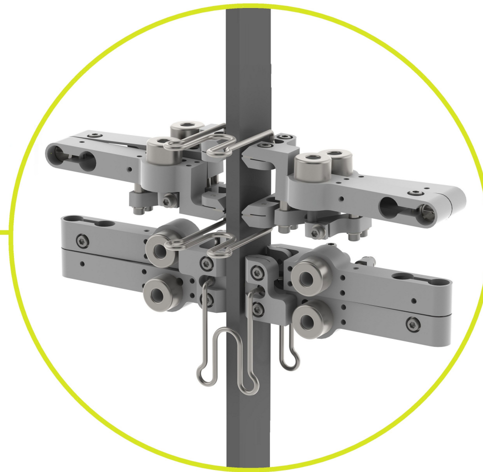
3D-DMA
Dynamic Mechanical Analyzer





Biaxial Extensometer

Accurate Material Property Characterization is Mission Critical for Structural Polymers.

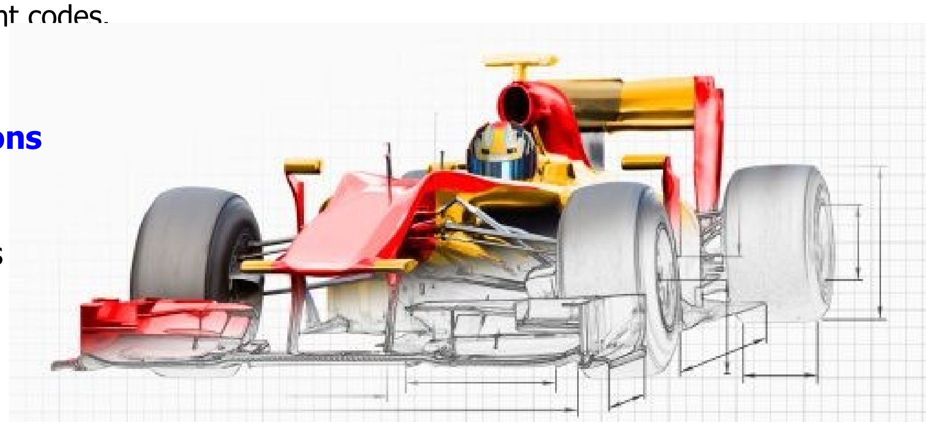
The Psylotech 3D-DMA is a universal testing machine specially purposed to measure the mechanical properties of *polymers*. It enables precise, accurate finite element analysis of viscoelastic materials. It is the *first* instrument of its kind to offer:

Local Strain Measurement on axially loaded specimens circumvents the substantial experimental errors associated with traditional beam bending specimens.

Dynamic Poisson's Ratio (ν*) and Young's Modulus (*E)** are concurrently measured, enabling determination of a viscoelastic material's full 3D mechanical property matrix.

Time domain moduli in an FEA compatible format. Psylotech provides subroutines to leverage the data in commercial finite element codes.

Automotive Applications
Composite Frames
Structural Adhesives
Nanocrystalline Metals
Tires and Belts
Seals



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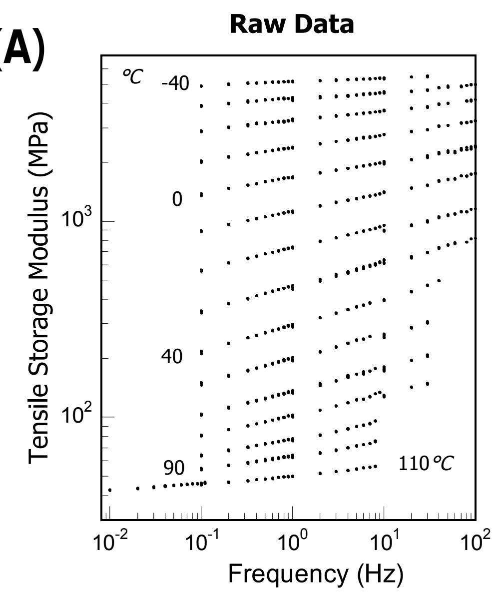
The Viscoelastic Modeling Process

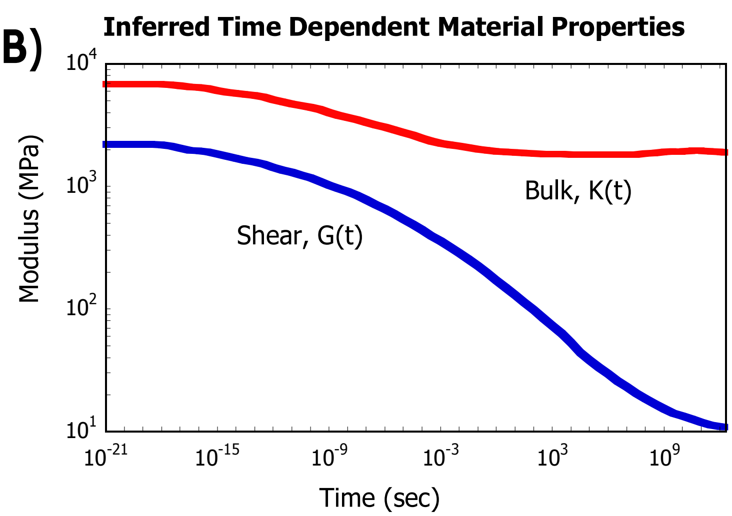
The mechanical properties of polymers depend on rate, history, temperature, pressure, solvent absorption, and internal damage. Reduced time constitutive models offer a powerful tool to quantify this complicated behavior. A reliable polymer constitutive model would enable effective finite element simulations to streamline polymer recipe customization, accelerate product development, and improve quality. Psylotech has developed enabling test equipment and advanced a proprietary reduced time theory.

In the modeling process, small strain, linear viscoelastic data are used to infer a polymer's large strain mechanical response. Isothermal frequency sweeps **(A)** are used to generate a master curve showing the material's mechanical response **(B)**. Those master curves are then integrated into a reduced-time, modified free volume model **(C)** to predict large deformation **(D)**. Predictions are shown for a strain-based, modified free volume model on a neat polyurethane adhesive. A thermodynamic state variable based model can also be used.

(A)



(B)

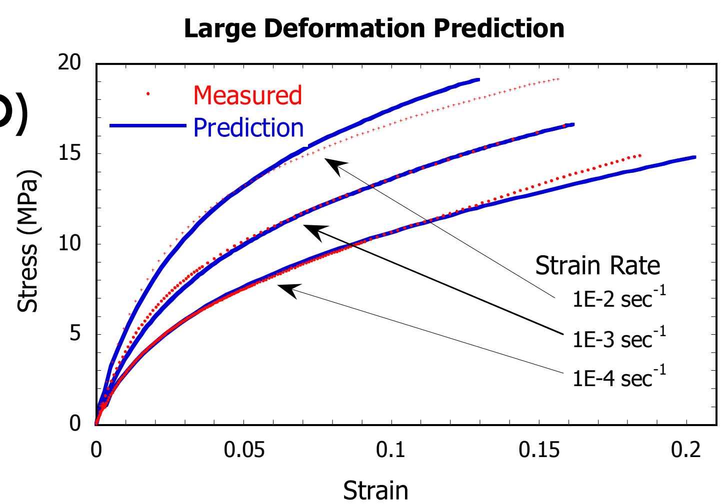


(C)

$$\sigma_{ij} = g_o \int_0^t 2G(t'-\tau')\frac{\partial e_{ij}}{\partial \tau} d\tau + g_o \int_0^t 3K(t'-\tau')\frac{\partial \theta}{\partial \tau} d\tau$$

$$(t'-\tau') = \int_\tau^t \frac{d\xi}{a(T,p,\varepsilon_{ij})}$$

(D)



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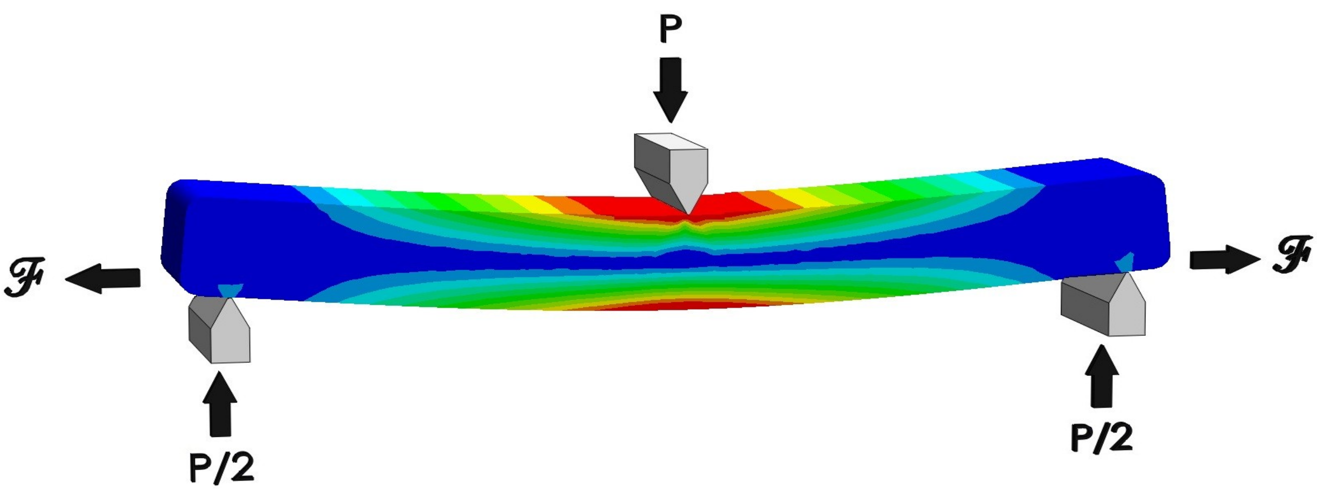
Uniaxial Testing

Psylotech's 500 *N* actuator enables uniaxial tension testing from the glassy through the rubbery region. An ultra-high resolution load cell accommodates small strain measurements under stiff, glassy conditions as well as soft, rubbery conditions.

Traditional DMA instruments rely on beam bending specimens so that low force actuators can test rigid, glassy polymers. However, beams specimens can introduce errors from strain rate variation, friction at the contact points, and local deformation at the contact points.



- <u>Strain rate variation</u> through the thickness and along the length. Considering viscoelastic properties are strain rate dependent, ignoring variance contributes to errors, particularly in the time domain. The colors in the figure represent different strain rates in bending, ranging from zero (blue) to the maximum strain rate (red).
- <u>Inaccurate boundary condition assumptions</u>: horizontal friction forces (𝓕) cause tension along beam axis, increasing vertical stiffness like a string on a bow. Frictional forces also falsely contribute to loss modulus measurement. Creep during test exacerbates friction contributions to error, reducing reproducibility.
- <u>Local deformation at contract points</u> contributes to displacement measurement and also increase frictional effects as the specimen creeps from offset loading.

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Dynamic Poisson's Ratio

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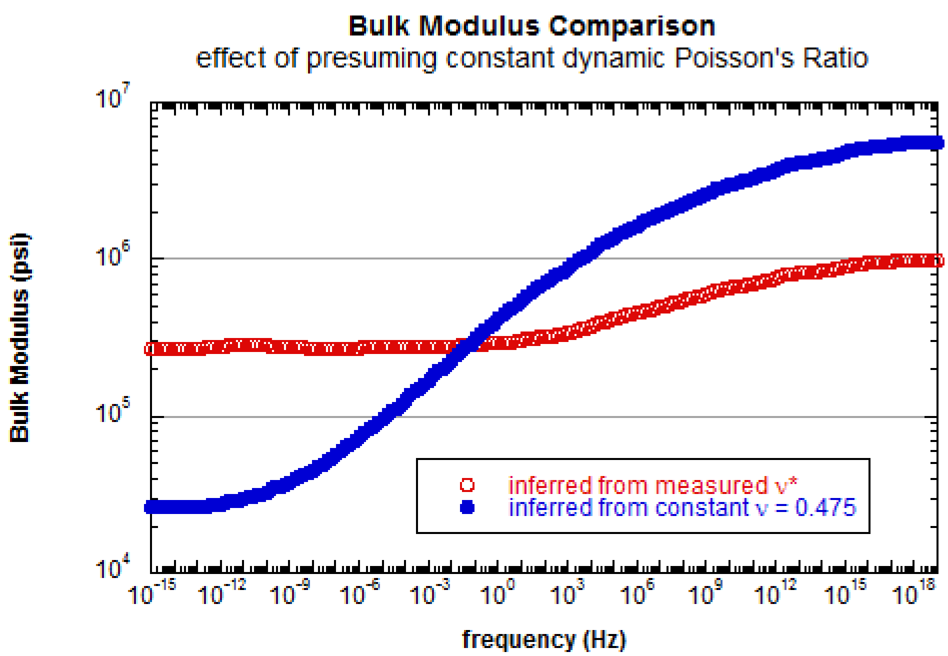
Adhesives

The 3D DMA measures Dynamic Poisson's ratio (ν^*) concurrently with dynamic Young's Modulus (E^*). In producing the data, the sample for both measurements experiences the same temperature, strain and processing history. For isotropic materials, the power of measuring both ν^* and E^* is that any mechanical property can be inferred from these two properties, resulting in the full three dimensional mechanical property matrix. For anisotropic materials, specimens can be tested in multiple directions to determine the property matrix.

Traditional dynamic mechanical analysis typically presumes constant Poisson's ratio over a range of temperatures. This assumption can lead to significant errors when modeling dilatation strains, as is evident by comparing viscoelastic bulk modulus inferred from E' plus constant and measured Poisson's ratio (see plot). It is well known that Bulk modulus remains relatively constant over a material's frequency response, similar to the red curve. Ignoring dynamic Poisson's ratio gives a 10x fluctuation over the frequency range, implying 10x error in the dilatational component of an FEA model.



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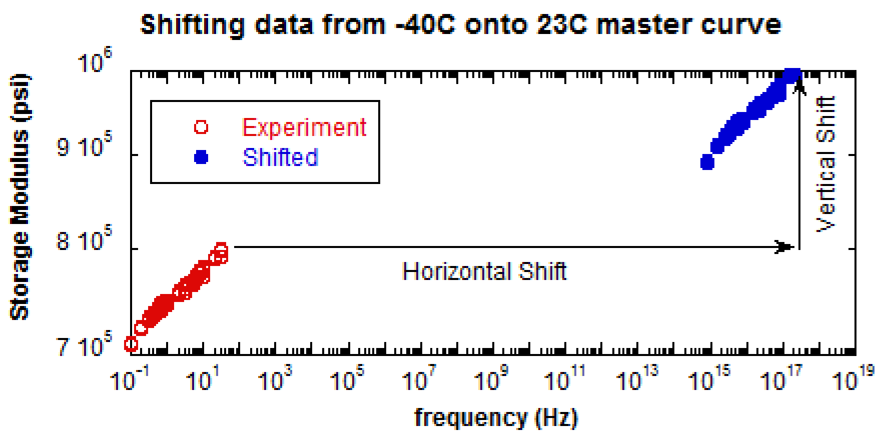
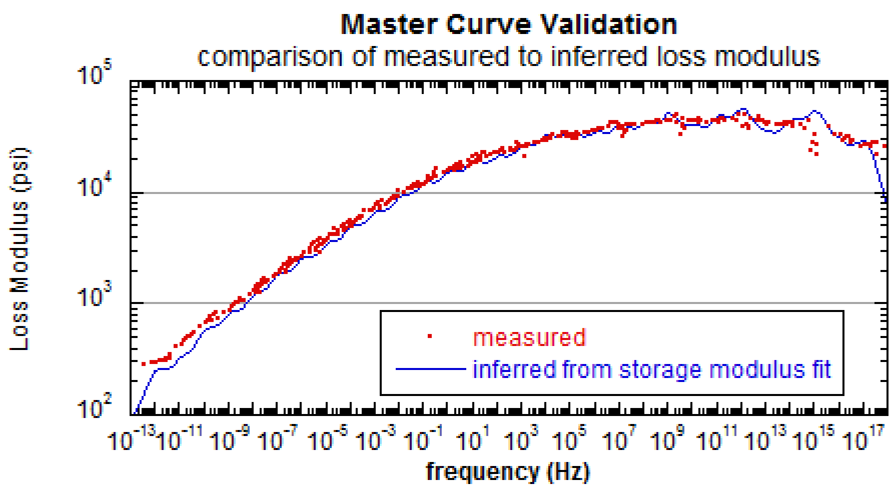
Post Processor

A Windows™ based post processing software is included with the 3D DMA. When generating master curves, the software calculates both horizontal <u>and</u> vertical shifting factors (see figure below). Traditional DMA's pass over vertical shifting, which can be acceptable when data is displayed on log-log plots. However, it can lead to 20% error, which is a problem for finite element analysis.



The post-processor also ensures ν^* and E^* shifting factors match. Further ensuring self-consistency, storage modulus is used to infer loss modulus. The inferred function is then compared to measured E'' (see plot below). Performing this exercise on data produced from traditional DMA's reveals inconsistencies in data sets.



Finally, the post-processor converts frequency domain data into time-domain Prony Series readily compatible with finite element analysis.

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Microscoping Sensors

Civil Engineering
Polymer Rebar
Polymer Modified Concretes
Earthquake Damping Materials
Structural Retrofits

Psylotech sensor technologies were specifically invented to address the unique needs of dynamic mechanical analysis of polymers. Load cells and extensometers offer high sensitivity, typically providing 400 mV/V sensitivity, rather than the 2 mV/V common to strain gauged alternatives. Stronger signal and comparable noise mean 100x higher resolution of measurement changes.

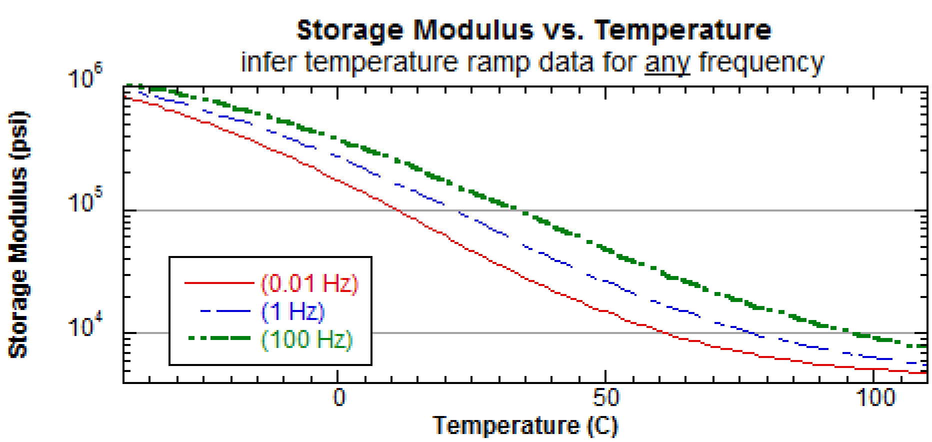
Microscoping™ load cells have sufficient full scale range to accommodate high forces in polymers' low temperature glassy regime. They also have the sensitivity to measure low force perturbations when the specimen is tested in the rubbery regime. Conventional strain gauge load cells specified for testing rigid glassy polymers operate beneath their noise floor when testing the rubbery regime under small strain sinusoidal amplitudes.

Psylotech's light weight extensometers provide mechanical and bending compensation for axially loaded specimens. Their Microscoping™ functionality enables them to accurately measure small mechanical strain perturbations while still accommodating large thermal strains. Thermal strains can be two orders of magnitude larger than mechanical strains over the temperature range of a typical experiment.

Advanced Temperature Control

The 3D-DMA's environmental chamber is a vacuum insulated Dewar, providing low thermal mass, fast response time, and improved energy efficiency. Forced convection accelerates the time to reach uniform, steady state temperature. The test temperature is controlled from a platinum resistance thermometer clamped directly to the specimen surface, accounting for specimen self-heating during cyclic loading.

For temperature ramp tests, specimen temperature varies through the thickness. Considering viscoelastic properties vary with temperature, ignoring this effect contributes to errors. Psylotech recommends isothermal frequency sweeps. Temperature ramp tests can be inferred for any frequency through post-processing (see plot below).



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Closed Loop Control of Strain, Load or Displacement

As a universal test system, Psylotech's DMA linear motor is separate from the transducers. The system accommodates any sensor in the feedback loop. Some DMA's are native load controlled, where testing soft samples can rely on a measurement near the sensor resolution. Other DMA's are native displacement control, and are prone to uncontrolled vibration for rigid samples. Control flexibility for closed loop control of strain, load or displacement avoids either of these problems.

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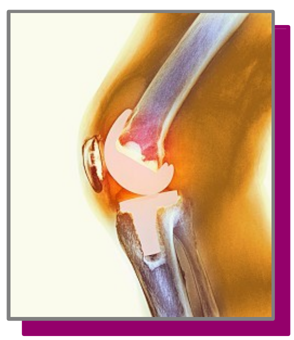
Directional Drilling Motors
PVC Pipeline lifetime prediction
Joint Durability

Medical Implants
Synthetic Cartilage
Polymer Stents
Orthopedic Implants
Biodegradable Lattices
Artifical Heart Valves



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Golf Clubs and Balls
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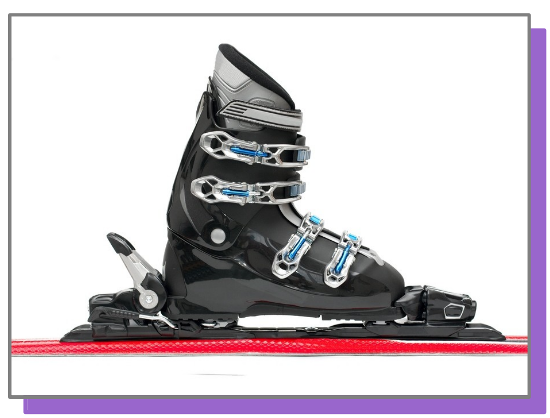

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Specifications

Force

Capacity	500 N
Resolution	250 μN

Stroke

Range	100 mm
Resolution	50 nm

Strain

Range	±25%
Resolution	1 με
Extensometer mass	15 g

Specimens

Test Geometries	Tension (recommended), compression, Arcan mixed-mode, Arcan shear, 3 & 4 point bend
Tensile specimen dim.	12.5 x 3 x 125 mm

Frequency Range	0.0001 to 100 Hz
Temperature Range	-150 to 200 °C **(**300 °C without Extensometers**)**
Isothermal Stability	±0.1 °C
Liquid Nitrogen interface	3/4″-16 JIC male

Power Requirements	120V (240V) dedicated 20 amp (10 amp) circuit + separate power for control PC and monitor
Laboratory Grounding Bar	Recommended

Footprint	40 x 20 cm