



Using MTS Shaker Tables (MAST) for Durability Testing of EV Batteries

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Proprietary Data

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MTS Systems Corporation Introduction and brief history

MTS has been a global supplier of high performance testing and simulation systems for almost 60 years
Operations span across Americas, Europe and Asia
Deliver technology and engineering expertise to produce high quality, innovative testing solutions for our customers

- 1966 – MTS founded as spin-off from Research Incorporated.
- 1967 - Moved to current location in Eden Prairie, Minnesota, USA.
- 1989 – Acquired Sintech, PC based screw driven test machines.
- 2008 – Acquired SANS, testing equipment company in China.
- 2014 – Acquired Roehrig Engineering, US based vehicle component testing company.
- 2018 – Acquired E2M Technologies B.V., EU based simulation and testing company.
- 2020 – Acquired R&D, Denmark, simulation and testing company.
- 2021 – MTS Systems Corporation acquired by Illinois Tool Works (ITW).

MTS has approximately 1,700 employees worldwide, including a network of ~400 field engineers and technical specialists



Materials >

1500
degree
Celsius

solutions for testing
high-temperature alloys,
composites, ceramics
and polymers

[Read the Article](#)



Aerospace >

20%
increase

in testing speeds using
state-of-the-art cross-
coupling compensation
technology

[Read the Article](#)



Automotive >

320
kph

flat-belt roadway enables
precise replication of
motorsports cornering
maneuvers

[Read the Case Study](#)



Civil Engineering >

1.32
million
pound

force capacity enables the
testing of very large
specimens all the way to
failure

[Read the Case Study](#)



Biomedical >

1
in 1,000
children

will need corrective
scoliosis surgery

[Read the Case Study](#)



Rail >

550
kph

test system enables lab-
based studies of high-
speed rail operating
environments

[Read the Article](#)



Energy >

56
MNm

overturning moment capacity
enables testing of the largest
wind turbine drivetrains

[Read the Article](#)



Rock & Geomechanics >

3x
stronger

concrete materials make it
possible to carry higher
loads

[Read the Case Study](#)



MTS Multi-Axis Shaker Table (MAST)

- MTS has delivered hundreds of MAST systems in the past 55+ years
 - » We have learned a thing or two . . .



Vibration Testing – History and Philosophy

- **Secure that your product will remain functional and secure during its usage cycle**
 - » What is an acceptable lifetime?
 - » How will it be used?
- **Different answers...**
 - » Depending on industry...
 - » Depending on targeted user groups

Vibration Testing – History and Philosophy

- **Military / Defense**

- » Vibration tests and standards developed during 1950's
- » Adapted by connected civil industries (Electronics, Transportation....)
- » Single direction or X, Y, Z separated

- **Aero**

- » Event base lifetime approach

- **Shipping**

- » Everything restricted by classification and roles.... –no testing

- **Automotive**

- » Lifetime defined by number of repeated events on a Test Track
 - ...for the complete vehicle, but broken down on sub-system and component level
 - Multi-axial

MAST Testing – Why?

- Why do customers perform multi-axial simulation tests of components/subsystems?
 - » To more efficiently and accurately reproduce road inputs
 - » In-phase DOF necessary to:
 - Validate durability life of vehicles, subsystems, and components
 - Ensure quality and reduce warranty expenses
- Advantages of testing in the lab:
 - » Consistency and repeatability of test inputs and test results
 - » Shortens vehicle development cycle:
 - Accelerate tests by eliminating non-damaging content
 - Perform test before full vehicle is available
 - Minimize delays due to weather, driver/vehicle availability

MAST Testing – What Tests?

- Durability Testing
 - » Reproduce acceleration time histories that represent a durability test
 - » Typically, up to 50 Hz
 - » Run until failure
 - » Accelerates vehicle development process
 - » Integration in Environmental Chamber
 - -40 to +100 deg C
- Noise and vibration Testing
 - » Lower amplitude tests
 - » Combination Time History and Sine Sweep
 - » Controlled, repeatable test environment
 - » Integration in Anechoic/Acoustic Chamber

MAST Testing – What Tests?

- Performance evaluation – Transmissibility
 - » Use Sine Sweep or Random as test method
 - » Typically, up to 50 Hz
 - » Allows engineers to get closer to test samples
 - » e.g., Ride Comfort of Seats
- Combination Durability and Transmissibility
 - » Durability 'ageing' of components combined with performance testing

MAST Testing – What Test Article?

- ***Battery Testing***
 - » ***BEV (Battery Electric Vehicle)***
 - » ***PHEV (Plug-in Hybrid Electric Vehicle)***
- Powertrain Mounts
- Fuel Tanks
- Radiators
- Seats
- Electrical Systems
- Instrument Panels
- Exhaust Systems
- *Seismic Applications
- *Transportation/Packaging Standards



MTS MAST Systems - Orthogonal

- 323.XX Series MAST Systems
 - » Variety of displacement & force capabilities
 - » Typical max. testing frequency 50 Hz.
- Standard Table Sizes
 - » 1.5 x 1.8 m
 - » 1.5 x 2.1 m
- Payload
 - » 500 kg
 - » 680 kg



MTS MAST Systems - Hexapod



Model 353.10

- 1 meter round table
- Up to 500 kg payload
- Up to 500 Hz control bandwidth
- Durability applications
- NVH applications
- Environmental chamber integration
- Anechoic chamber integration



Model 353.20

- 2 meter round or 2.2 meter square table
- Up to 1,000 kg payload
- Up to 150 Hz control bandwidth
- Durability applications
- Ride Comfort applications
- Environmental chamber integration
- Anechoic chamber integration



Model 353.50

- 2.5 meter square table
- Up to 3,000 kg payload
- Up to 100 Hz control bandwidth
- Heavy-duty Durability applications
- Seismic applications

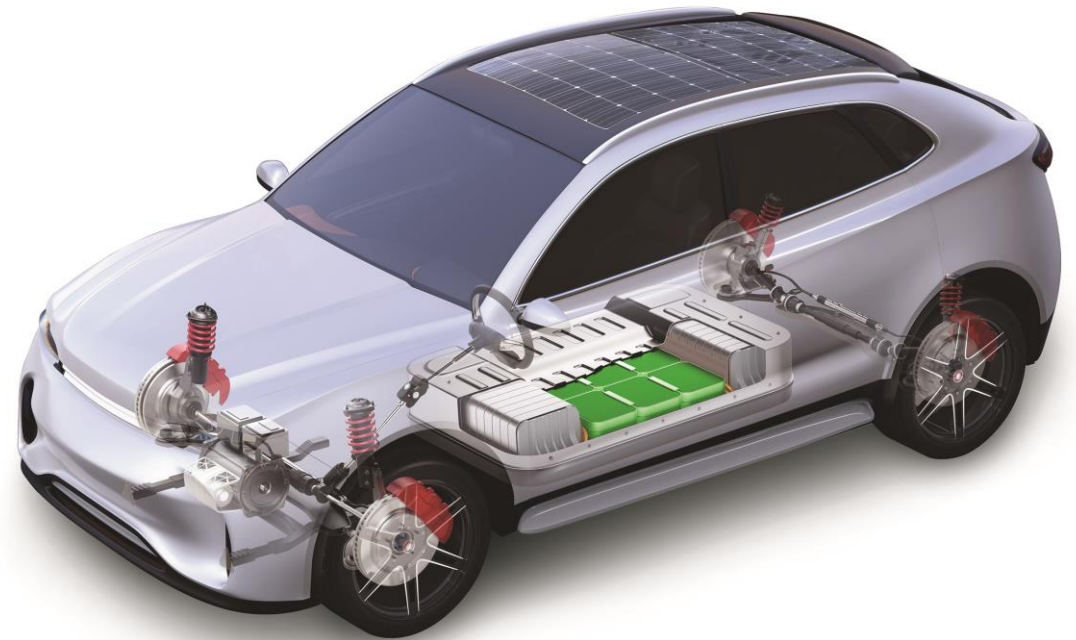


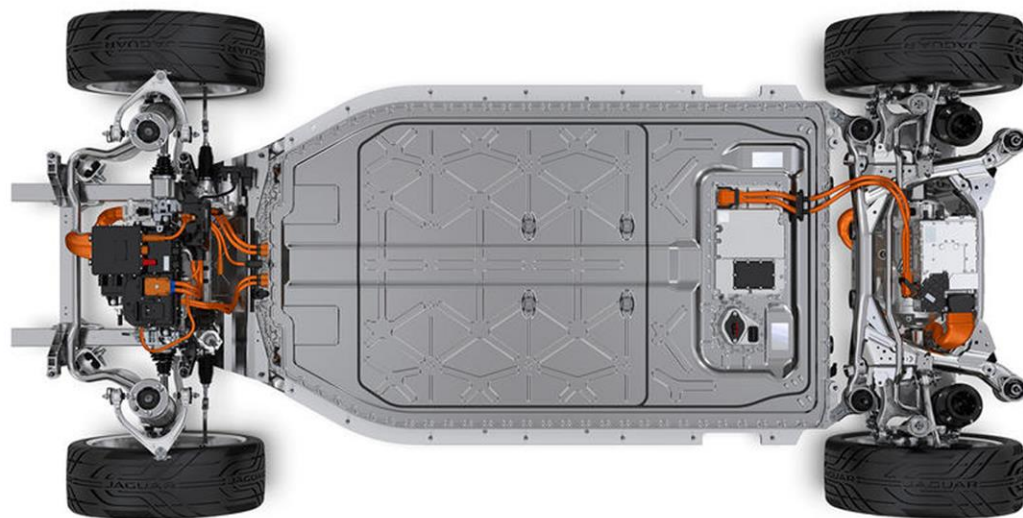
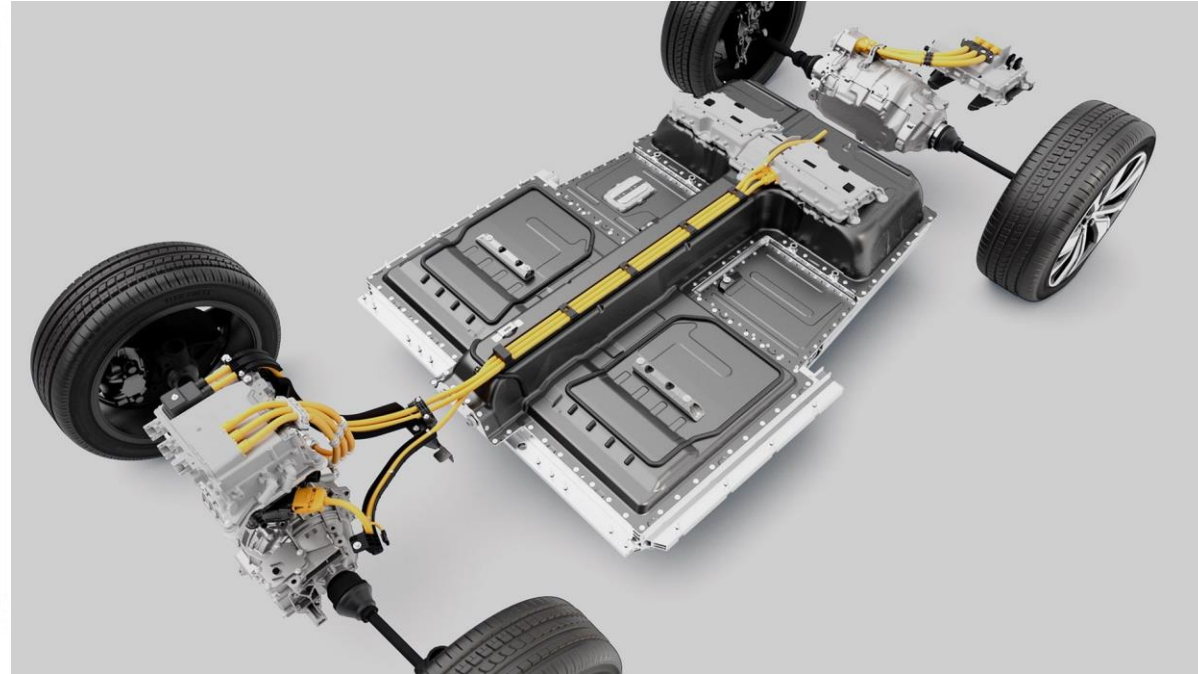
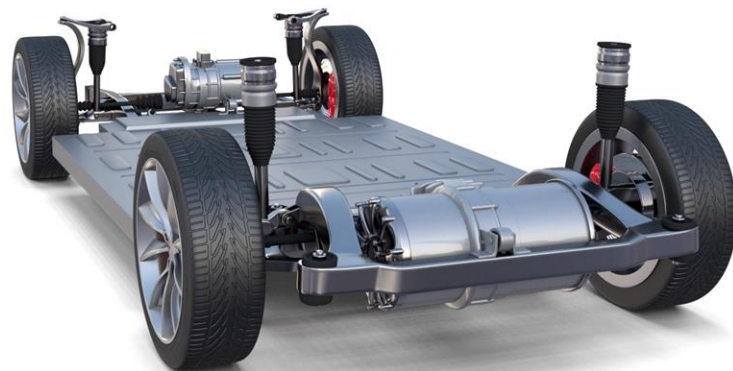
Model 354.20

- 2 meter round or 2.2 meter square table
- Up to 2,000 kg payload
- Up to 100 Hz control bandwidth
- Heavy-duty Durability applications
- Seismic applications

The Vehicle Market

- Global shift towards zero-emission electric vehicles
- Need for comprehensive vibration battery life cycle testing
- Driving requirements to support development of Battery Electric Vehicles and Plug-in Hybrid Electric Vehicles:
 - » High frequency solutions
 - » Higher payloads
 - » Larger platforms

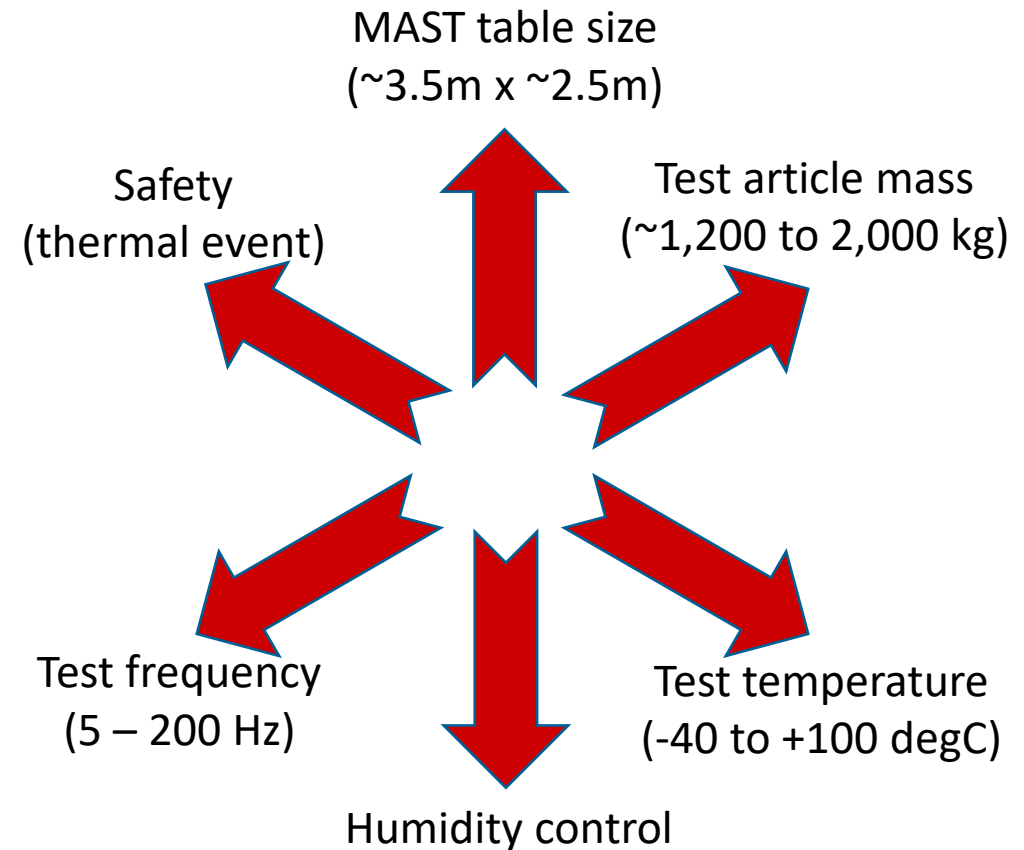




EV Battery Testing Requirements

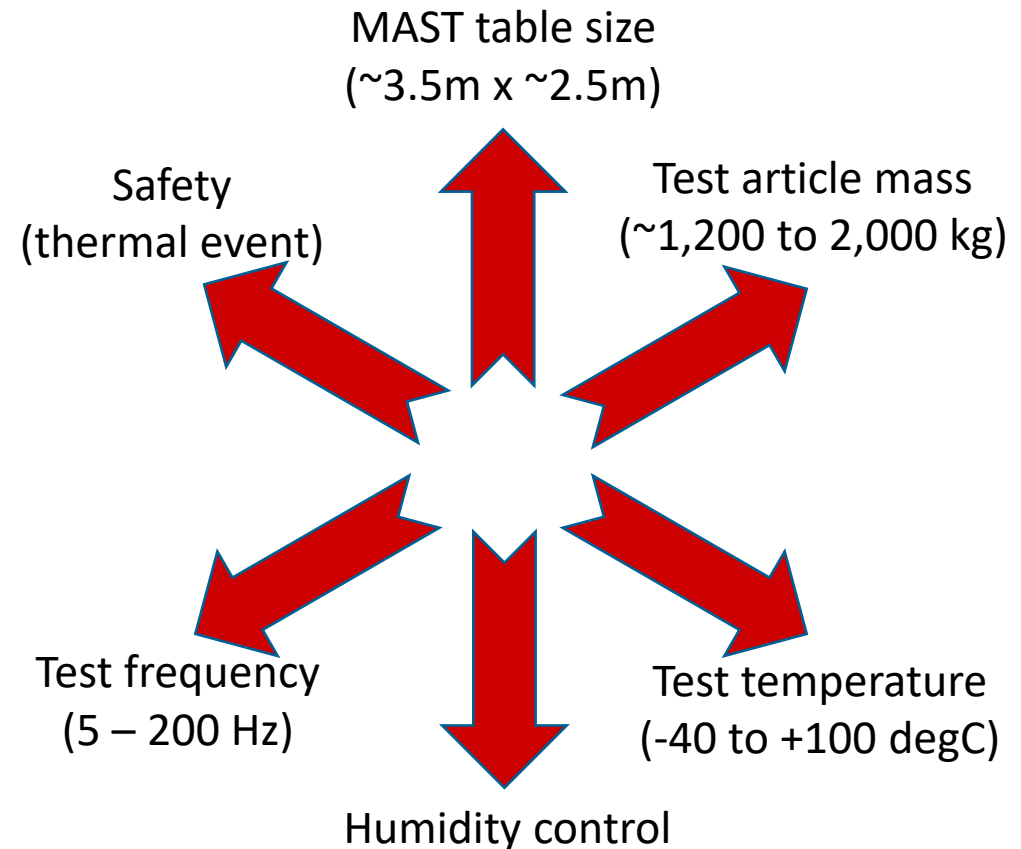
The challenge is to provide a MAST system to accommodate:-

- Large specimen footprint
- No resonant modes within range of test frequency
- Large test payloads
- Integrated with environmental chamber
- Integrated with Battery Management System
- Integrated with specimen monitoring & safety systems



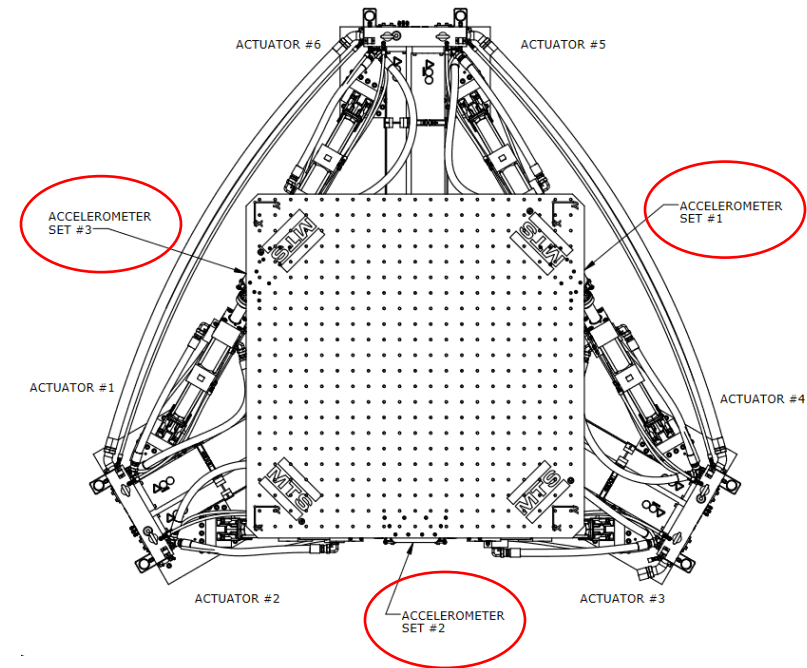
EV Battery Testing Requirements

- Physical size
 - » X, Y, Z (and center of gravity – need to consider overturning moment)
 - » Total mass (specimen + fixture)
 - » Component or sub-system
 - » Specimen Boundary Conditions
- Performance
 - » Acceleration, Velocity, Displacement, Frequency
 - » Road Load Data (RLD) or standard test protocols
- Testing standards
 - » (ISO, SAE etc.)
 - » Road Load Data
 - » SDOF or MDOF
- ***...often pulling in opposite directions!***



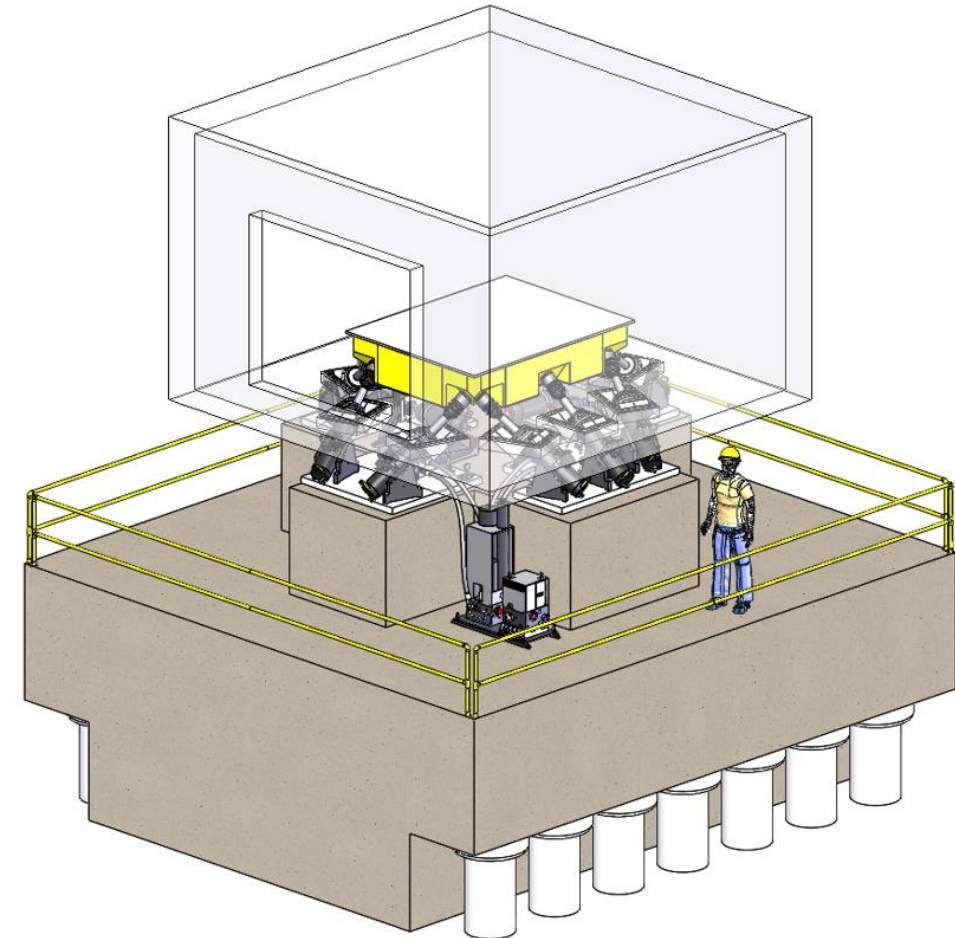
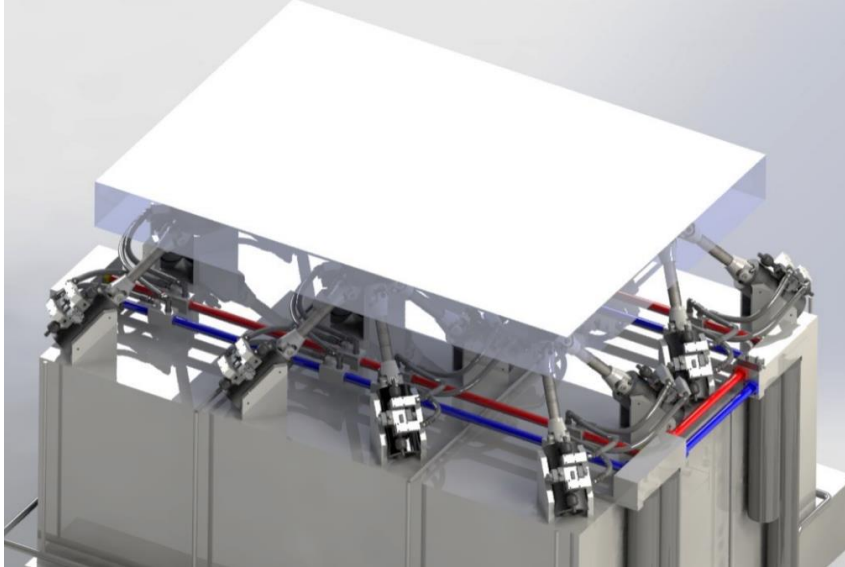
System Design

- The standard 354.20 MAST bandwidth with a maximum payload of 2000kg is quoted to be 100Hz
 - » Time history replication with content up to 100Hz using RPC or other MTS compensators.
 - » The limiting factor in the 100Hz bandwidth is a flexible table mode
 - » The flexible table mode is observed by the accelerometers that MTS uses on the MAST table for 6DOF control, which are placed near the actuator connections on the outer edge of the table.
 - » ...and the table is not big enough for test specimen.



System Design

- MTS advanced actuator performance simulation
- Actuator and strut design for >200 Hz operation, mode-free
- Finite element analysis for fatigue resistant table design
- Modal analysis of table for >200 Hz, operation, mode-free
- Draws on MTS experience of MAST and Seismic Test Systems



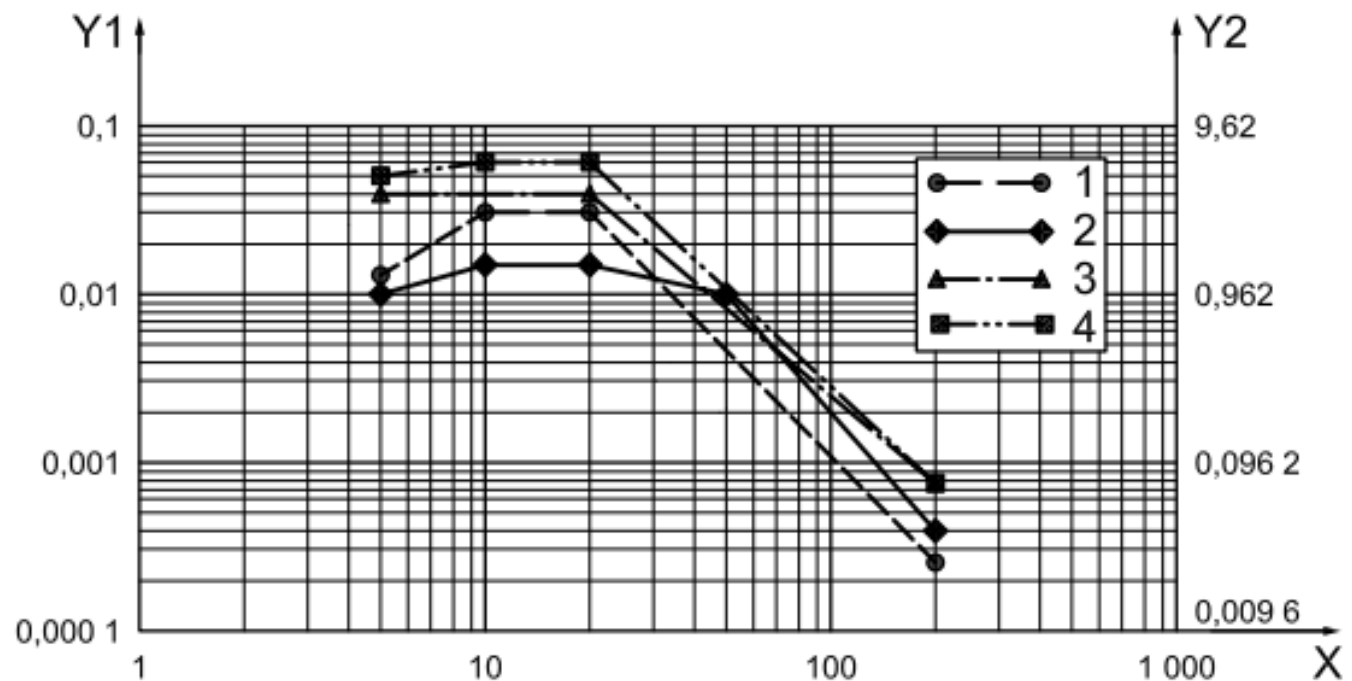
Vibration Test Standard – ISO 12405

■ ISO 12405 Battery Specification

- » Power Spectral Density (PSD) Vibration profiles in X, Y and Z; 5-200Hz
- » Typical vibration test description (as used by electrodynamic test system)

Key

- X frequency (Hz)
- Y1 power density (g^2/Hz)
- Y2 power density (PSD) ($m/s^2)^2/Hz$)
- 1 PSD horizontal longitudinal X
- 2 PSD horizontal transverse Y
- 3 PSD horizontal transverse Y
- 4 PSD vertical Z



Vibration Test Standard – ISO 12405

■ ISO 12405 Battery Specification

- » Power Spectral Density (PSD) Vibration profiles in X, Y and Z; 5-200Hz
- » The test shall be performed in accordance with IEC 60068-2-64:2008, Tables 20 to 23, or according to a test profile determined by the customer and verified to the vehicle application
- » The vibration test shall be performed in a sequence of all three spatial directions, if not otherwise agreed between the customer and supplier, starting with the vertical direction (Z), followed by the transverse direction (Y) and, finally, with the longitudinal direction (X)

Table 20 — Values for PSD_horizontal_longitudinal_X

Frequency Hz	PSD g ² /Hz	PSD (m/s ²) ² /Hz
5	0,0125	1,20
10	0,03	2,89
20	0,03	2,89
200	0,000 25	0,02
r.m.s	0,96 g	9,42 m/s ²

Table 21 — Values for PSD_horizontal_transvers_Y

Frequency Hz	PSD g ² /Hz	PSD (m/s ²) ² /Hz
5	0,04	3,85
20	0,04	3,85
200	0,000 8	0,08
r.m.s	1,23 g	12,07 m/s ²

Table 22 — Values for PSD_horizontal_transvers_Y Passenger_compartment_bottom

Frequency Hz	PSD g ² /Hz	PSD (m/s ²) ² /Hz
5	0,01	0,96
10	0,015	1,44
20	0,015	1,44
50	0,01	0,96
200	0,000 4	0,04
r.m.s	0,95 g	9,32 m/s ²

Table 23 — Values for PSD_vertical_Z

Frequency Hz	PSD g ² /Hz	PSD (m/s ²) ² /Hz
5	0,05	4,81
10	0,06	5,77
20	0,06	5,77
200	0,000 8	0,08
r.m.s	1,44 g	14,13 m/s ²

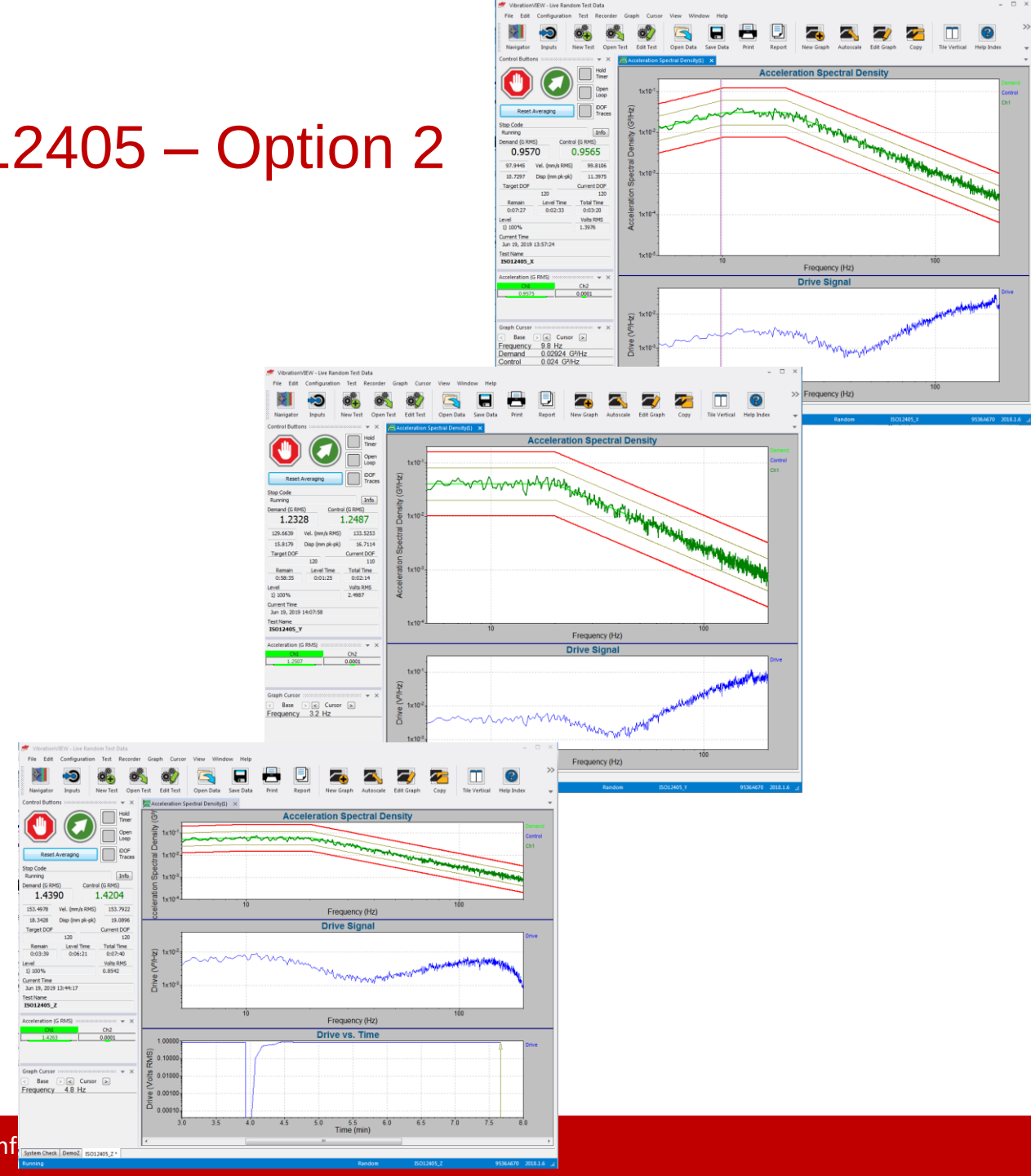
Vibration Test Standard – ISO 12405 – Option 1

- ISO 12405 Battery Specification with max payload; 2,000kg – **Time History Replication in RPC Connect**
 - » A Gaussian time history was created based on the ISO 12405 Specification with content from 5-200Hz in three translation degrees of freedom: Longitudinal (X), Lateral (Y), and Vertical (Z)
 - » RPC was used to iterate to the desired profiles to show the capability of the table to reproduce time histories in 3 degrees of freedom simultaneously
 - » Successful results were achieved with less than 3% RMS error after 6 iterations with conservative gains
 - » X, Y, Z axes tested sequentially



Vibration Test Standard – ISO 12405 – Option 2

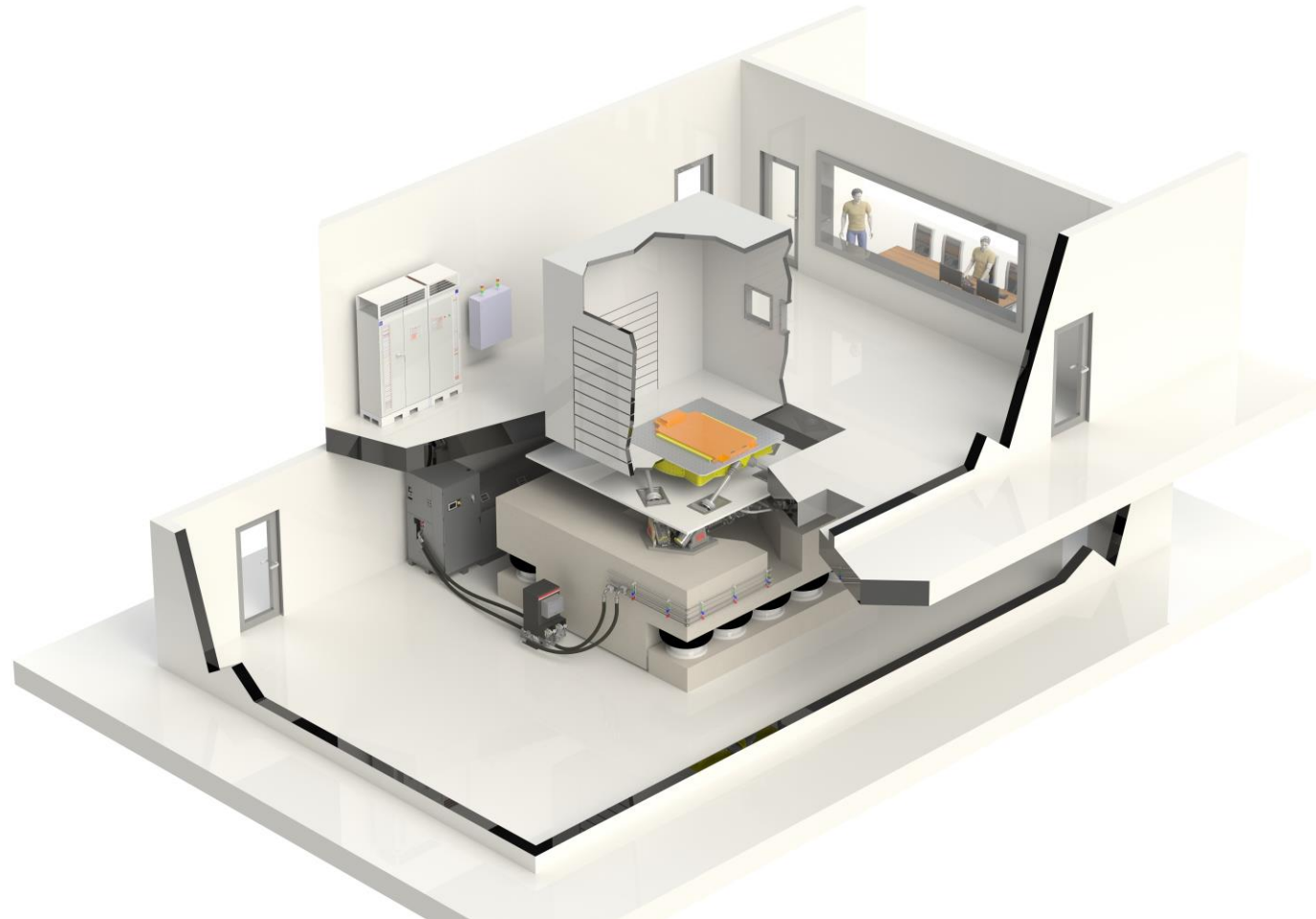
- ISO 12405 Battery Specification with max payload; 2,000kg – **PSD Testing using 3rd party Vibration Controller**
 - » Vibration Controller send drive command to MTS MAST Control System through external input +/- 10V
 - » Feedback from triaxial accelerometer directly to Vibration Controller
 - » Vibration controller adjust drive command passed on feedback from accelerometer
 - » X, Y, Z axes tested sequentially





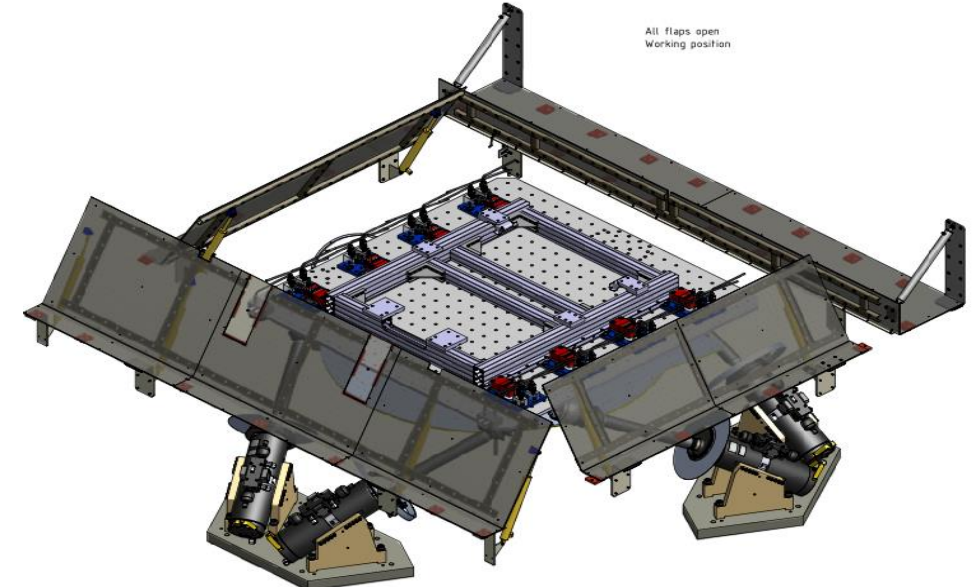
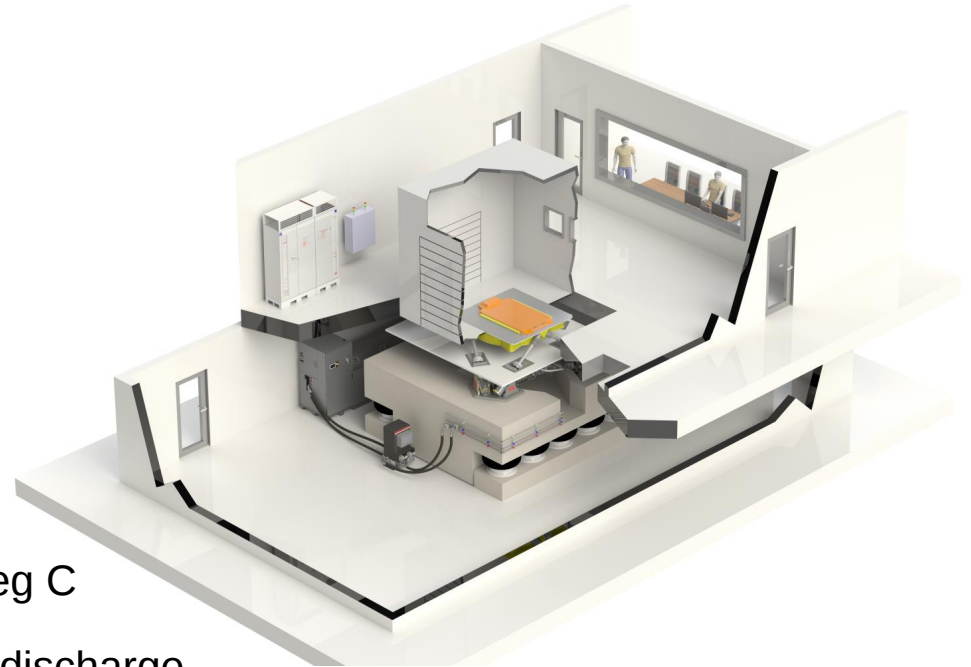
EV Testing Total Solution

- MTS works with partners to provide turnkey testing solution



Battery Turnkey Offerings

- Vibration motion platform from MTS
- Isolation Mass
- Environmental Chamber
 - » Typical temperature range is -40 deg C to +100 deg C
- Battery Management Systems (BMS) – battery charge/discharge
 - » Battery Power and Cooling, Quick disconnection System
 - » Specimen Monitoring System or Customer Supplied
 - » Pallet for specimen fixture
 - » Hydraulic clamp element
 - » Pit cover flaps inside the climate chamber
 - » Winch system
- Safety PLC Monitoring System



Thank you for your attention!

