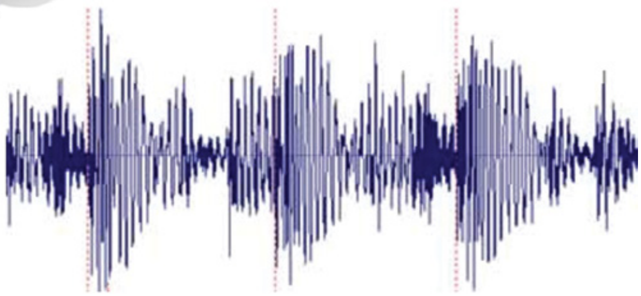
Reducing NVH through refined powertrain measurement



NVH characteristics are among the most important factors consumers use to judge a vehicle's quality.

The C1000 vastly simplifies measuring the mass matrix of heavy, odd shaped engines and powertrains.

By Scott Zagorski

Accurate measurements of vehicle centers-of-gravity and inertia are vital for helping NVH engineers further improve their dynamic vehicle models—and thus improve performance and safety. Specialized vehicle test machines are used for NHTSA's New Car Assessment Program (NCAP) and new variations are entering service for the subsystem level. One of them is the C1000, developed by **S-E-A Vehicle Dynamics** headquartered in Columbus, Ohio.

As the smallest of S-E-A's Vehicle Inertia Measurement Facility (VIMF) product line, the C1000 was developed to finally simplify the decades-old issue of measuring the mass matrix of heavy, odd shaped engines and powertrains. The resulting data is crucial to NVH engineers and is now much easier to obtain.

"For decades, automotive engineers have been suspending extremely heavy engines to measure their inertia. We would regularly hear clients lament that the process was labor intensive and produced results that were not easily repeatable," noted company director Gary Heydinger, Ph.D and PE. He explained that the C1000 was conceived "to make [engineers'] work day easier and provide results they can trust"—with consistent, repeatable fidelity.

Reliable data and the end customer

Most consumers won't purchase a new vehicle without a test drive. Not only is it their one occasion to evaluate the cabin features offered by the manufacturer, but also their sole opportunity to experience the vehicle's ride performance. Does the suspension deliver a good balance of compliance and accurate roadholding? Or is it too floaty—or too hard? As part of this naturalistic evaluation, the combined noise and vibration is immediately apparent when assessing the feel of a vehicle.

Noise control, however, is not just about making cars quieter for a more relaxing ride, but about enhancing the overall cabin experience. NVH characteristics are high among the factors consumers use to judge a vehicle's quality.

What causes NVH, and more importantly, how is it mitigated? One source is the engine, where vibrations are generated and then travel through the engine mounts, into the structure, and through the car seat into the driver. Alternatively, vibrations from the same source can take a similar path through the structure to become acoustic noise when it is amplified by the cabin. Optimizing these factors is therefore of utmost importance for the overall experience of a vehicle.

Engine mounts play a crucial role in a vehicle's comfort, while protecting the engine from excessive movement and forces due to low frequency road and high frequency engine excitations. This has led to significant interest in computer-aided predictive techniques for NVH, such as a frequency response function (FRF) model of a vehicle to evaluate the optimum types and locations of engine mounts. Others use finite element (FEM) and multi-body dynamic modeling, or a combination of them, to tune their mounts to achieve specific objectives.

In these models, an engine block is modeled as a rigid body attached to the neighboring parts to study how to reduce the transmitted vibrations to the occupants. Engineers need to know the mass matrix of the engine with a high level of accuracy to best evaluate the system computer models.

Saving testing time

S-E-A's C1000 measures the complete inertia matrix: mass, center of gravity location (X_{CG}, Y_{CG}, Z_{CG}), and all moments and products of inertia (I_{XX}, I_{XY}, I_{ZZ}, I_{XY}, I_{YZ}, I_{XZ}). These quantities are imperative in studying engine vibrations, calculating the torque roll axis (TRA), and in determining the

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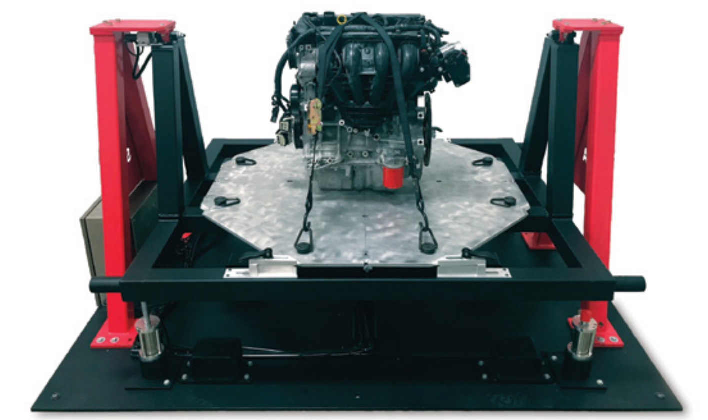
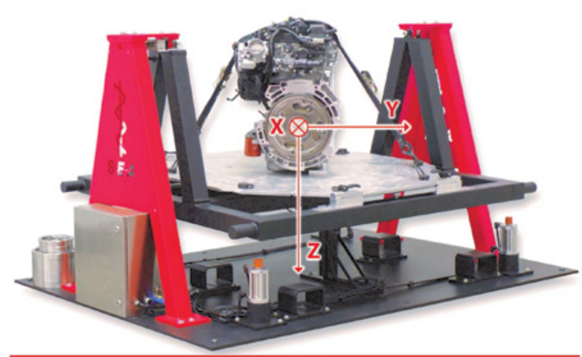
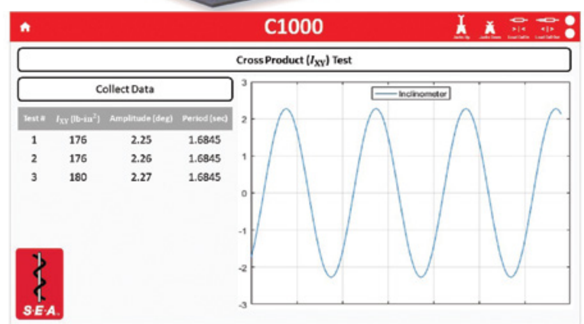


On the C1000, the test plate rests on a bearing, allowing it to rotate relative to the pendulum.





The platform is shown rotated 45° for an IXY product test. During testing, the software captures the period of oscillation of the pendulum.

placement of engine mounts. A key feature of the C1000 is that the engine, once placed on the test table, is never reoriented during the test process. This reduces the testing time to an hour or less. Previous inertia test methods were inefficient, requiring up to five reorientations, separate CG measurements, and several days to complete.

Below is a sample data set output from the C1000. The machine measures the CG of the system (X_{CG}, Y_{CG}, Z_{CG}), which is then adjusted based on the desired reference point of the engine ($X_{ref\text{-}CG}$, $Y_{ref\text{-}CG}$, $Z_{ref\text{-}CG}$):

	INCH	MM		lb_m-in^2	kg-m^2
X_{CG}	0.03	0.8	I_{XX}	19,951	5.839
Y_{CG}	0.06	1.5	I_{YY}	13,835	4.049
Z_{CG}	-13.1	332.2	I_{ZZ}	11,002	3.220
$X_{ref\text{-}CG}$	10.6	268.0	I_{XZ}	155	0.045
$Y_{ref\text{-}CG}$	-0.2	-5.6	I_{YZ}	2,107	0.617
$Z_{ref\text{-}CG}$	-4.6	116.3	I_{XY}	177	0.052

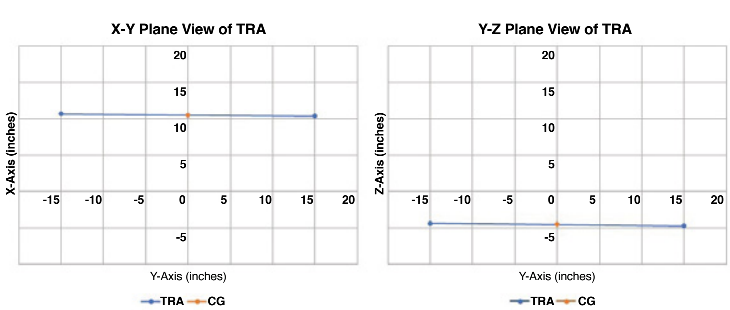
The unit was designed with test time and accuracy in mind. Like S-E-A's VIMF, this machine is robust and repeatable. If you place a known fixture on it today, then again in five years, the same result within about 2 millimeters would be expected.

The physical principles are as old as Isaac Newton, although modern electronics and software aid the process. The C1000 uses a stable pendulum arrangement to obtain the CG location, two moments and one product of inertia. The test plate rests on a bearing allowing it to rotate relative to the pendulum. The third moment is measured using the torsional spring method, while the final two products of inertia use the torsional spring method combined with a load cell.

For a typical passenger vehicle engine, accuracy is on the order of 2.5 mm for CG, 1-2% for moments of inertia, and products of inertia are 2% of the smallest moment of inertia.

With this equipment, NVH engineers can input reliable and repeatable data into their vibration models to determine the optimum engine mount locations. Getting the locations correct early in the process saves time and money, the company claims, while the end result improves the entire vehicle experience for the driver and passengers.

"S-E-A has always provided customized testing solutions. Our products have helped to establish standards when there is no standard, and our Vehicle Dynamics specialists continuously innovate by using cutting edge technology to develop new and unique test equipment and methods," commented Dan Buss, the company's global sales director.



The mass matrix data is used to determine the slope of the TRA, to ensure the engine mounts are properly aligned with the inertia of the engine.

Author Scott Zagorski, Ph.D, PE, is a mechanical engineer who has been performing vehicle testing/vehicle dynamics for 15 years. He has been with S-E-A for four years.