Multi-axis squeak-and-rattle testing and servo motor shake tables

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Squeak and rattle testing is increasingly important as automobile customers demand quieter interiors and auto manufacturers require their Tier One suppliers to provide quiet and pre-tested components. These components include seating, instrument and side panels, lighting, steering columns, seat belts and retractors, air bags, rear view mirrors, sun roofs, and roof racks.

A unique design for an independent multi-axes vibration table, using programmable servo motors, has advantages in squeak and rattle testing. Servo motor tables can also be used for seismic, packaging, stress screening, road and aircraft simulation, and similar testing applications. These tables achieve the low-frequency long-stroke capacity of servo hydraulic systems, while having the convenience and relative quiet of electrodynamic vibrators. Application to squeak-and-rattle tests on an automobile seat are presented in this article, to demonstrate typical test requirements, and to illustrate servo motor table capabilities.

Squeak-and-rattle testing

Almost any component in the passenger compartment of an automobile can be the source of annoying "buzz, squeaks, and rattles." Squeaks and rattles are the third most common new car owner complaint (after power train and electrical problems). As customers ask for luxury and comfort over thousands of miles, car interiors have become more quiet and durable. Hence, greater effort must be made to eliminate squeaks and rattles. Noise sources acceptable in the past, masked by a generally higher passenger compartment noise level, have become the squeak-and-rattle issue of today.

Recent competitive forces require auto manufacturers to produce new products on a shorter cycle than before. Evaluation of seating noise performance, for example, can no longer wait for road tests on a nearly complete chassis. The seats must be developed and tested in parallel with chassis development. This requires the use of more realistic shake tables. These same competitive forces have also driven auto manufacturers to pass down noise and vibration engineering tasks (and risks) to their Tier One suppliers.

The Tier One suppliers must now obtain and develop noise and vibration expertise, either through the use of outside test laboratories or by installing appropriate equipment in their own facilities. For example, most automotive seating is manufactured by a handful of Tier One suppliers, rather than by the Big Three American auto manufacturers or their foreign competitors.

Unlike the military or nuclear power industries, there are few universally accepted regulations or specifications on how squeak and rattle tests are performed or the results interpreted. Methods differ significantly from one practitioner to another. Most tests involve placing the component on a single or multi-axes shake table and exposing it to sinusoidal, random, or prerecorded and edited road data. Often a jury of three persons listens to the component from a specified distance and "votes" as to whether or not a squeak or rattle is present. Attempts to quantify this detection procedure have met limited success and use.

Tests may be repeated after the component has been "driven" the equivalent of 20, 50, and 100,000 miles ("durability testing"). Edited road data, bearing only the higher level and damaging portions of typical road response, can age components at the equivalent rate of about 1,000 road miles per hour of testing. Hence, a durability test may require a

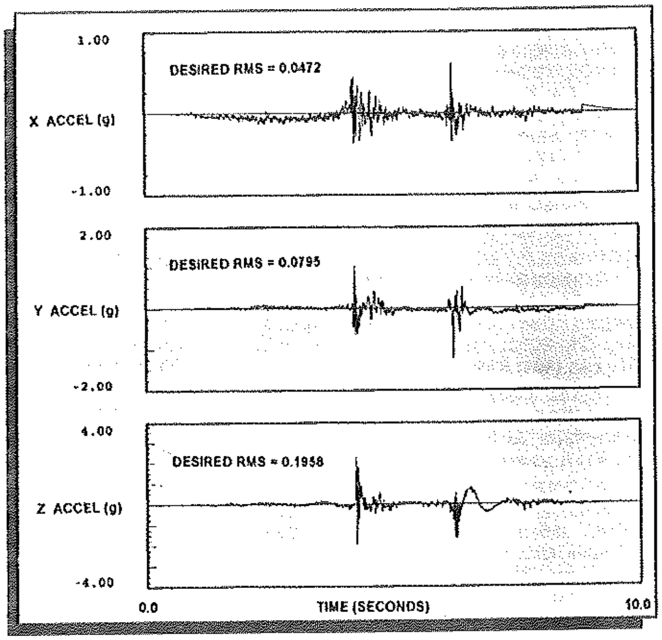

FIG. 2—Recorded triaxial motion of an automobile floor during actual curb impact. *(Courtesy Lear Corp.)*

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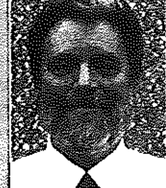

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***George Howard** is the Computation Division Director at ANCO Engineers. He has 27 years' experience in the dynamic analysis of structures subjected to hydrodynamic, thermal, seismic, impact, and operating loads, and is the author of numerous papers on these subjects. He performed the structural calculations for the design of ANCO's servo motor driven tables and helped develop the data analysis programs for its control. He holds a PhD in nuclear engineering and structural analysis from UCLA and is a member of the ASME.*

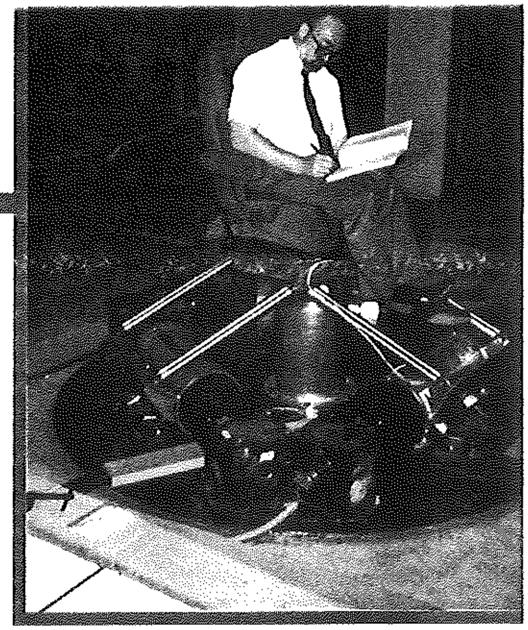

FIG. 1—The independent triaxial servo motor shake table used in this study.

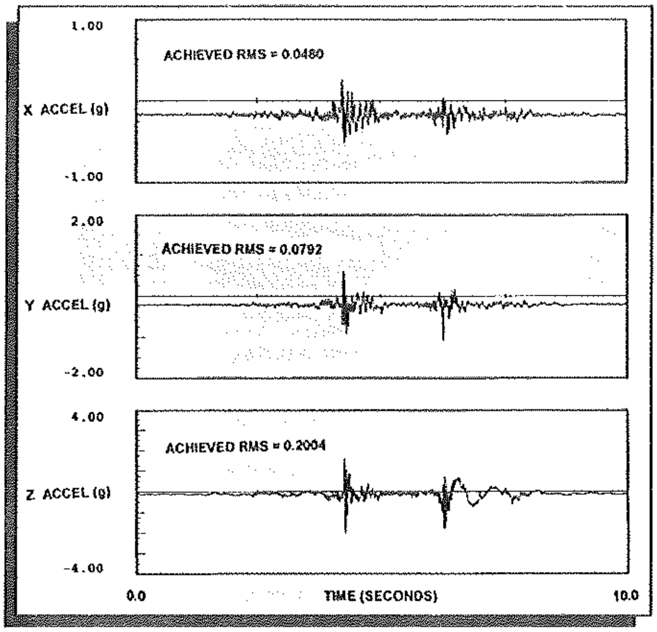

FIG. 2—The achieved motion of an automobile floor during the example test.

hundred hours of shake table time. Tests may be conducted in a temperature, humidity, and solar chamber.

Typical frequency ranges of interest are two-50 Hz, although some tests extend to more than 100 Hz. Typical maximum input motion required are ±2 inches, 20 inches per second, and three g. Many tests are performed with single-axis electrodynamic vibrators. However, there is an increasing interest in multi-degree-of-freedom tables to achieve realism and avoid over testing. Good time history reproduction is usually required—about five percent error in RMS value, and 10 percent reproduction of acceleration peaks. To enable the investigator to hear squeaks and rattles, the table and laboratory should not exceed about 60 db self noise.

If unacceptable squeaks and rattles are found, a variety of engineering fixes are available. These include decreasing or increasing gaps, changing material type, application of elastomeric or woven materials to impacting or rubbing components, or introduction of additional noise insulation or sound-absorbing materials.

Triaxial servo motor table

The independent triaxial servo motor table used in this study is shown in Figure 1. The table uses six servo motors, grouped in three pairs by three torque tubes. The torque tubes serve to prevent table pitch, roll, and yaw.

The servo motors act directly on the torque tubes, which are attached to the table with six arms using rod ends. A control Pentium PC serves to transform the desired orthogonal motions of the table (surge, sway, and heave) into the required independent rotations of the torque tubes. A constant force air cylinder under the table supports the table and test object dead weight and relieves the servo motors from the need to support this dead weight. The air cylinder reacts against the polished bottom of the table with a slip plate.

In this configuration, peak table displacement of ±5 inches and peak table velocity of 100 inches per second are achievable. With a payload of 200 pounds, peak table acceleration is in excess of three g. The table can test payloads up to 800 pounds. The table has good fidelity up to 50 Hz, and excitation capability to 200 Hz. The table can apply sine, sine sweep, sine beat, random, and previously measured and edited time histories to any axis, sequentially or simultaneously. ➔

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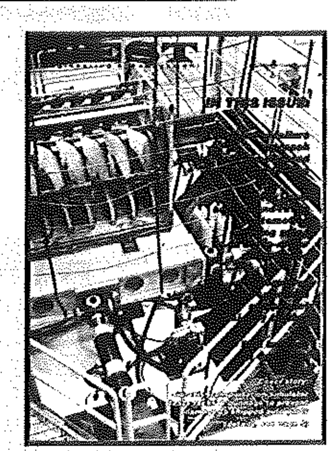

A giant commercial six-axis transportation simulator testing facility, built by Control Power-Reliance, Troy, Michigan, duplicates all the complex motions involved in the transportation path of car parts and other valuable components. The seismic vibration machine is capable of shaking, rattling, and rolling fixtures and parts weighing up to 15,000 pounds. Its initial application involved developing data to improve racks and containers used to transport various automotive parts.

Servo motor shake table (continued)

Servo motor driven tables can suit a variety of purposes. The triaxial table described herein can operate with six axes of independent motion (surge, heave, sway, pitch, roll, and yaw) by removing the torque tubes. Servo motors can be connected in series to achieve higher torque (acceleration); longer arms can be used for greater displacement and velocity; shorter arms can be used for greater acceleration; smaller servo motors reduce system size and cost; orthogonal orientations of the servo motors are possible; eight or more independent axes can be implemented. Hence, the technology of servo motors applies to almost every area of motion-base simulation and testing.

The table actuators are Parker 5500A hybrid servo motors. They have a flat torque-to-speed curve and smooth rotation at slow speed, and an external rotor needing no speed reducer. They produce 370 foot-pounds torque at 0.0 to 1.5 rps, with 30 arc-second positioning accuracy. In typical configurations, these drives can produce up to 1,000 pounds of linear force, with up to a ±5 inch stroke. These servo motors are highly reliable, having been developed for robotics and assembly-line applications such as welding stations in automobile manufacturing. Their normal maintenance time is after 20,000 hours of continuous operation.

The table is controlled with a closed-loop analog servo controller. In addition, a frequency domain iterative digital batch equalization is performed. This equalization uses a transfer function measurement, inversion, and drive signal correction procedure. Analog feedback is provided by three rotary displacement transducers on the torque tubes. Three orthogonal accelerometers are used to verify table motion. This control system is similar to those used for servo hydraulic systems. Software packages for table equalization are available from several suppliers.

A significant advantage of servo motor actuators is their low noise. In squeak-and-rattle testing, conventional table hydraulic noise can interfere with the test. For example, the typical noise level on a multi-axes servo hydraulic table is 75 to 80 dB. To perform squeak-and-rattle testing, the noise level just above the table top typically needs to be under 60 dB. On a servo hydraulic table, elaborate methods are needed to reduce the 75 to 80 dB to 60 dB, and reducing the noise below 60 dB is nearly impossible.

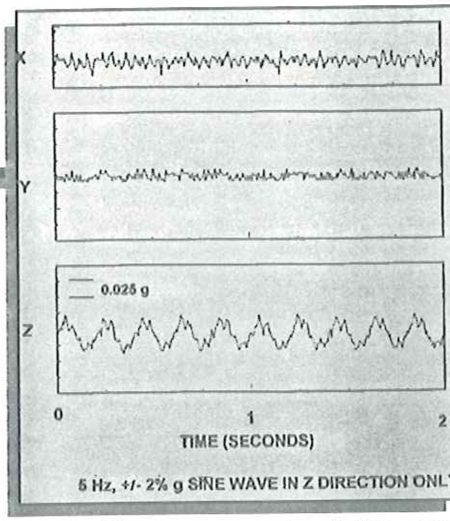

FIG. 4—The servo motor table performance when reuested to produce a 0.02 g, 5 Hz, sine wave in the vertical (Z) direction only.

Measurements made on ANCO's servo motor shake table indicate a noise level of about 60 dB without any acoustical insulation. The noise is reduced to less than about 50 dB with minimal acoustical insulation around the servo motors.

Testing example

Squeak-and-rattle testing involves the repeated exposure of the component to a

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variety of different extreme road conditions. These conditions include curb impacts, cobblestone roads, bumps, rough and rutted roads, etc. Figure 2 shows the recorded triaxial motion of an automobile floor during an actual curb impact (courtesy of Lear Corporation). The major response is vertical (Z direction) at about three g, but there are also significant longitudinal (X) and transverse (Y) motions (0.5–1.0 g). This motion represents the desired motion of the table with the automobile seat during this example test. Figure 3 shows the achieved motion. The waveforms are quite similar. The RMS values agree to better than three percent, and the significant peak values agree to better than 10 percent.

Multi-axes tables can also be used to perform modal tests of components using sine-sweep or random excitation. For example, most seating has a first mode of vibration in the 10 to 15 Hz range involving the longitudinal and pitching motion of the seat back. Evaluation of the resonant frequency, damping, and non-linear trends of this mode is key in seating evaluation.

Hence, a requirement for tables performing modal testing is the ability to reproduce low-level as well as maximum response. Some tables have difficulty, for example, in achieving a 0.02 g sine signal if the table must also achieve 4.0 g. Figure 4 shows the servo motor table performance when requested to produce a 0.02 g, five Hz, sine wave in the vertical (Z) direction only. The noise superimposed on the sine wave, and on the cross axes (X, Y) is less than 0.01 g. Much of the noise is accelerometer electrical noise at these low levels as the table had 50 g full-scale accelerometers at the time of this test.

Conclusions

Squeak-and-rattle tests are increasingly important to a growing number of auto and auto-component manufacturers. The paucity of uniform specifications and the vagaries of the human ear mean that squeak-and-rattle testing is still a combination of science and art. There is significant variation on test conduct and in the vibration levels used. New shake tables, controllers, and software are providing increasingly sophisticated and convenient tools, which can help provide more realistic and uniform testing standards and procedures.

Servo motors are reliable, quiet, and easily integrated prime movers that have numerous applications in vibration testing systems. The advent of larger and more sophisticated servo motors, control systems, and software opens up the field of application and allows servo motors to take their place alongside servo hydraulic actuators and electrodynamic vibrators.

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