THE EVOLUTION OF AUTOMOTIVE VIBRATION FIXTURING

by Tony Araujo

The principal vibration testing capabilities in common use today largely evolved from the early requirements of the aerospace industry. Standard test protocols, random vibration, single axis testing, and combined temperature and vibration testing were developed in response to the reliability testing needs of the early Gemini and Apollo space programs. The use of electronics in mobile applications was still in its infancy and the need to deploy highly reliable systems in space applications drove the testing industry to develop better tools with which to simulate the new end-use environment.

While vibration testing using shakers has been around since World War II, these early shakers were limited to 85 Hz and were more suited to examining the fatigue properties of structural components. Engineers knew that significant vibration energy could be present at higher frequencies and that electronics were more susceptible to these frequencies, but they couldn't test them until electrodynamic shakers became more common. To ensure that their device under test (DUT) experienced the energy present at these higher frequencies, aerospace testing methods stressed the necessity of vibration fixturing, which delivered high transmissibility throughout the test frequency range.

The common use of electronics in autos only started to take hold in the 1970s, and back then it was largely isolated to engine control units as a response to meeting more stringent pollution controls. Consequently, nearly all automotive vibration testing in this era was performed below 100 Hz. With the increasing use of electronics in vehicles to control various body systems with individual ECUs—especially since the 1990s and particularly today with electric vehicle and autonomous vehicle applications—the automotive industry has come to recognize the benefits of vibration testing at higher frequencies using electrodynamic shakers.

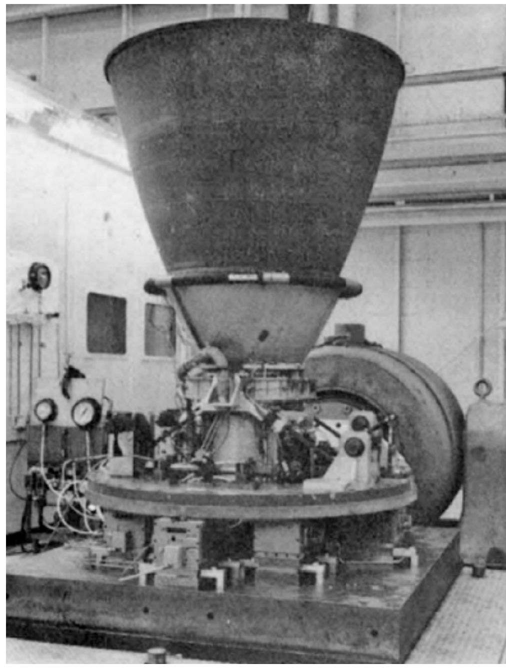
While the automotive industry, like aerospace, recognizes the need to test electronics at higher frequencies, many automotive engineers—trained in the era of low-frequency testing or still using specifications based on these early applications—fail to understand the impact which the vibration fixture can have in magnifying or attenuating higher frequency vibration energy in their vibration tests.

This article describes how the industry got to this point and how segments of the industry are leading the adoption of qualified vibration fixturing as a necessary requirement of high-frequency vibration testing.

The early days of vibration testing

Vibration is a relatively young field of study. The first college course devoted to the study of vibration was only introduced in 1928. While vibration has been recognized for nearly a century as a critical environmental factor for which the designer has to accommodate, it's only since the 1960s and the advent of electrodynamic shakers that the modern practice of vibration testing really evolved. Before this period, the mechanical vibration machine technology that was available limited the frequency range to 85 Hz. Indeed, the variety of machines and the very specific vibration environments each machine was attempting to simulate made it very difficult to compare test results between laboratories.

The WWII period introduced the concept of qualification testing on equipment prior to use, and the period after the war saw the rapid development of new vehicle and weapon technologies. Vibration fixtures for the early low-frequency vibration test machines could be counted on to be resonance-free, even though they were only designed for strength. Unless they were very large fixtures, the dynamic response of the fixture was not a major test consideration. After the war, the lower (<100 Hz) and usually periodic frequency domains of propeller-driven aircraft began to be replaced by the higher frequency (100 Hz to 2000 Hz) random vibration environment produced by jet and rocket engines.



▲ **Figure 1.** Early high-force electrodynamic vibration machine.
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The advent of the space programs of the 1960s coincided with the introduction of high-powered electrodynamic shakers which were capable of performing vibration tests up to 2000 Hz and higher. With the newfound ability to replicate a high frequency spectrum, this higher frequency vibration testing capability quickly became the norm for qualification testing in the aerospace industry. These new machines made it easier to promote inter-laboratory test repeatability. A lot of this testing was also being driven by necessity to increase the reliability of all the new electronic systems that were being introduced.

Early on, aerospace engineers recognized that these new higher-frequency domains would require a thorough understanding of the vibration fixture—the interface between the shaker table surface and the individual attachment points on the DUT. Without any pre-existing standards for fixture performance, many questions about vibration fixture design needed to be answered. Should we replicate the impedance of the actual in-service mounting? Where should we monitor the vibration input into the DUT? What is acceptable performance?

The evolution of MIL-STD-810 paints an accurate picture of the changes in vibration fixture design philosophy. In 1962, the standard indirectly defined fixture performance was, "The test item shall be installed… by its normal mounting means directly to the vibration exciter table, or by means of a rigid fixture capable of transmitting the vibration conditions specified herein," and, "The vibratory acceleration levels or DAs of the specified test curve shall be maintained at the test item mounting points. For large items where there is a variation of the vibration level between mounting points, the minimum input vibration shall be that of the specified test curve." Crosstalk (transverse) motion was limited to 100%, regardless of frequency.

Today's aerospace testing laboratories find fixture performance has been much better defined in the current version MIL-STD-810H and fixture modal survey or resonance search of the vibration fixture is required before any testing is performed.

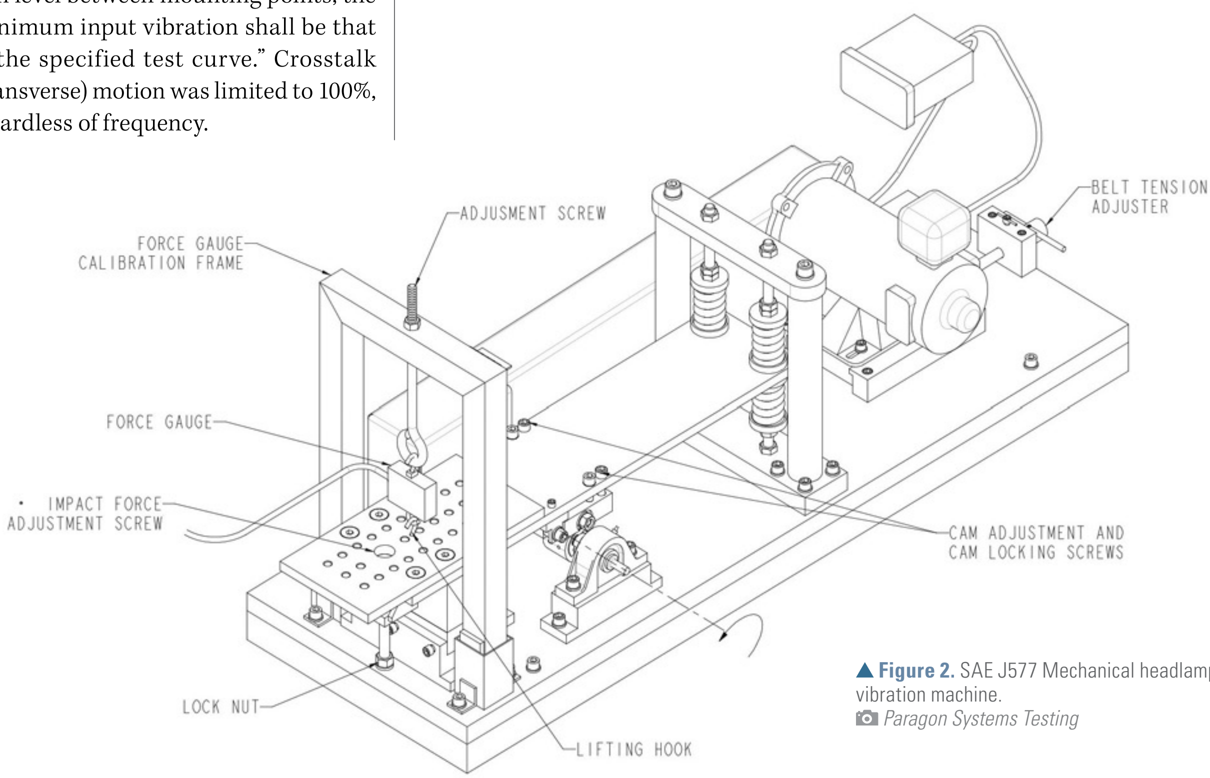
Vibration testing in the automotive industry

Adoption of electronics in the aerospace industry in the 1950s and 1960s, and the new high-frequency vibration environment that these systems were required to operate in, drove the industry approach to vibration fixture performance. In contrast, during the same time period, the automobiles of the same era used very little, if any, electronics. Vibration tests—when they were performed on automotive components—were also limited to the lower frequencies provided by electromechanical vibration machines.

As in aerospace, the automotive industry developed special-purpose machines to simulate the automotive vibration environment. One of the earliest of these vibration machines was developed to perform testing of automotive lamps. The test machine and method were originally defined in 1940 in SAE J577 and performed fixed displacement testing up to 60 Hz. However, unlike the aerospace industry, which moved quickly to more modern vibration machines, the automotive industry was much slower in making the switch. In fact, the mechanical headlamp vibration test machine is still specified in FMVSS 108 as the only recognized machine for this purpose.

The original slow pace of electronics adoption in automobiles has been replaced today by an explosion in electronic applications for road vehicles. While ABS brakes and airbags are considered "mission-critical" applications for electronic controls—where the consequences of failure of an ECU are serious—they don't compare to the consequences of an autonomous transport truck losing control on a congested highway.

While electronics in critical applications are now in common use throughout a modern vehicle, the adoption of modern vibration testing methods have not kept up the same pace. Many automotive manufacturers have embraced the current state-of-the-art vibration test methods to tailor test methods for individual applications. But many automotive test



▲ **Figure 2.** SAE J577 Mechanical headlamp vibration machine.
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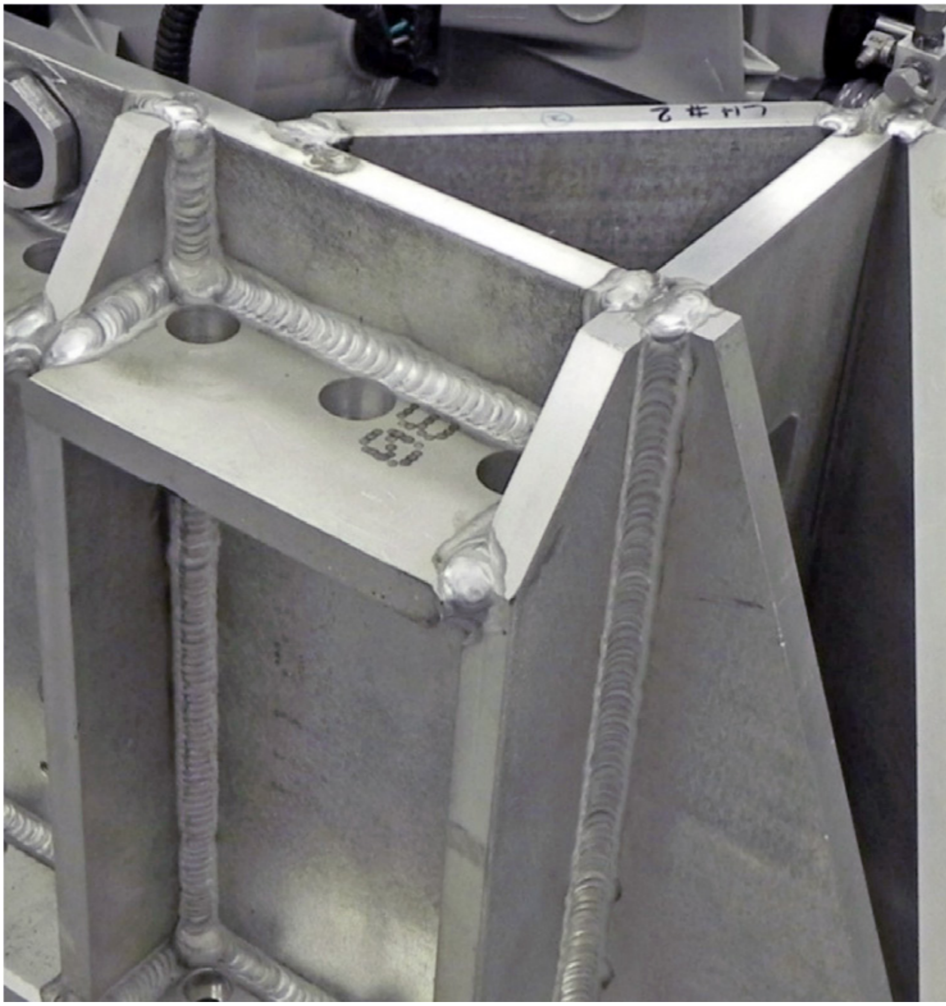
methods are still partly based upon the legacy 85 Hz era of electromechanical vibration machines.

These latter methods are completely silent on the issue of vibration fixture performance because it was largely a non-issue with low frequency tests. It's not uncommon for a testing laboratory to receive an automotive component from a client for vibration testing to a 5 Hz to 2,000 Hz spectrum, where the vibration fixture consists of a simple steel tube space frame which must be clamped to the shaker table surface. Steel tube fixtures are economical to fabricate and readily configured for three-axis vibration test deployment, but they are not known for their rigidity over 85 Hz.

When a vibration test method that has a 5 Hz to 2,000 Hz spectrum doesn't define the dynamic performance requirements of the fixture or the necessity of monitoring test levels at specific product mounting locations in the way a 5 Hz to 85 Hz test would in the past, the vibration engineer can't do much more than expose the fixtured sample to the vibration test spectrum using a single accelerometer mounted to the shaker surface. An experienced vibration test engineer will do this with the knowledge that the test sample may be both over-tested and under-tested over significant portions of the test spectrum. But because fixture performance and monitoring locations are not defined in the test method, the engineer is simply controlling the test level at the interface between the fixture and the vibration table surface.

Vibration is an area of study not covered in detail by many engineering programs. The knowledge required to design vibration fixtures is an even rarer skillset. So, it stands to reason that most engineers who will end up reading a vibration test report produced under these conditions will not recognize that the test sample may not have experienced the full effect of the vibration test described in the method.

If the test sample failed the vibration test, there will likely be further investigations which may then pinpoint the fixture as the reason for the failure. However, a more likely outcome is that the product designer will respond to a sample failure by spending time and resources redesigning a product that was overtested because of fixture resonances.



▲ **Figure 3.** Detail of state-of-the-art vibration fixture.
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And if the product passed the vibration test? At first glance, this this might seem to be a more benign outcome. After all, the product engineer can now get on with the next phase of product deployment. But, without any knowledge of the fixture's effect on the test, an undertested product may be released to production with the potential for a future field failure and recall.

The future of automotive vibration testing

During the first decades of electronics deployment into automobiles, the consequences of a sample failure were not that consequential. If your radio or power windows stopped working, an automotive manufacturer might face a bill for the repair costs. In the coming era of autonomous vehicles, where electronic systems will be in complete control of a vehicle, the consequences of a failure are more serious. Automotive safety recalls have cost manufactures billions of dollars. To avoid this potential in the future, automotive engineers need to recognize what aerospace engineers have known for decades—namely that understanding vibration fixture performance is a critical requirement of any high-frequency vibration test. EE

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