Report 1

Combined environmental testing for equipment used on automobiles — Overview and test approach —

Jyuro Izumi*

Automobiles of the 1990's face societal demands such as conserving energy, promoting recycling, and preventing pollution, while at the same time they must respond to purchaser desires for improved safety and greater comfort and convenience. The complex control systems employed to meet these demands can only be discussed in terms of car electronics. The continued development of vehicle electronic equipment has led to an age requiring diagnostic systems, serial data transmission control, and information displays as well as data transmission to navigational and other equipment inside and outside the vehicle. This burgeoning use of vehicle-mounted electronic equipment has led to a diversity of mounting environments, so that sometimes even when the environmental endurance of an individual part is well understood, the results could change when the equipment is actually mounted on the vehicle. Some mounting sites are within the relatively benign environment of the passenger cabin, but the majority of parts are used in harsher environments, such as outside in low temperatures, or subjected to the high heat and humidity and the mechanical vibration of the engine compartment. To maintain the rated safety and performance for the long term in the environments where the parts are actually used, combined environmental testing is carried out on electronic equipment mounted on many types of vehicles, as well as for the machinery built into the electronic equipment. In this article, I would like to present some examples of the approach of combined environmental testing in which temperature, humidity, and vibration are combined to create the environments in which the parts are presumed to be used in the vehicle.

1. Introduction

There is a strong trend toward incorporating electronic control to attain the high performance and high functionality of today's automobiles. The greatest efforts in technological development are being poured into this field, and the functions of every type of control system are growing increasingly complex. Within this situation, we can note that:

(1) Customers are demanding more safety and comfort features, and safety and comfort equipment such as four-wheel drive, braking control, and traction control are becoming standard on many cars.

(2) Fuel consumption and exhaust gas regulations are becoming stricter, while at the same time the customer is seeking improvements in both driveability and general driving features, all of which requires higher level control.

With vehicle control systems relying on ever-more-sophisticated electronics, the reliability of the electronic control equipment has a major impact on the overall reliability of the vehicle.

In general, the usage environment affects the durability and operating characteristics of electronic devices and units. Therefore, when studying the developmental design and application of the equipment built into these devices and units, the crucial problems have become how environmental test items should be set with regard to actual usage conditions, and how to maintain practicality and requisite performance while keeping costs reasonable.

*Sales Engineering Department

2. The usage environments of equipment mounted on vehicles

The vehicle usage environment includes such factors as temperature, humidity, vibration, rainwater, weatherability, voltage fluctuation, and surge voltage. When considering temperature, we find that the vehicle itself is a source of heat production, and the temperature in the engine compartment gets up to around 100°C, it goes over 65°C in the trunk, and can hit 100°C at sites such as the instrument panel in the vehicle interior. With humidity, we find it is not limited to high humidity caused by rainwater. Sudden changes in temperature cause dew condensation, which reaches a maximum of 95 percent humidity in the trunk at 38°C. Next, turning to vibration, we find that the body shake vibration occurring while driving receives 2.2 to 4.4 G's of acceleration, and the engine vibration generates 20 to 40 G's of acceleration that affects the engine compartment.

3. The affects of temperature and humidity environments on vehicle-mounted equipment

3-1 Vehicle heat sources (engine compartment temperature conditions)

The major sources of heat in the vehicle are engine heat and friction heat from the braking and automatic transmission systems. Temperature conditions in the engine compartment are particularly severe in hot weather when driving in traffic jams or going uphill. Newer model vehicles have smaller ventilation openings to reduce air drag while at the same time having to cope with greater heat output due to equipment such as DOHC and turbochargers. The increased heat combined with the reduced ventilation means that temperatures of 80 to 120°C must be handled. Table 1 gives maximum temperatures for different areas of the engine compartment.

Table 1 Maximum temperatures at different areas of the engine compartment

Location	Maximum temperature
Engine coolant	120°C
Engine oil	120°C
Transmission oil	150°C
Intake manifold	120°C
Exhaust manifold	650°C
Alternator air intake	130°C

Quoted from "Vehicle electronics and reliability"

3-2 Cabin temperature while car is parked

When the car is parked under a blazing sun and the passenger cabin is shut tight, the car becomes like a sun room. The temperature climbs to around 110 to 120°C in the vicinity of the front and rear panels, which are exposed to direct sunlight. The temperature of the headlining and the area of the front and rear seats reaches 65 to 85°C. Table 2 gives maximum temperatures for different areas inside the passenger cabin.

Table 2 Maximum temperatures at different areas of the passenger cabin

Location	Maximum temperature
Top of the front instrument panel	120°C
Bottom of the front instrument panel	71°C
Passenger cabin floor	105°C
Rear deck	117°C
Headlining	83°C

Quoted from "Vehicle electronics and reliability"

3-3 Vehicle humidity environment

Most cars today come equipped with air conditioning, and when the doors are opened and closed, high humidity outside air flows in and tends to cause dew condensation to form on air-conditioned equipment. To take vehicle-installed audio equipment as an example, when a car has been parked in a cold area such as at a ski resort, the car is started up and the heater is turned on, blasting hot air from the engine compartment onto the audio equipment installed on the exterior of the front panel. The sudden change in temperature creates a gap between the panel temperature and the temperature inside the passenger cabin. Table 3 shows maximum humidity for different areas inside the passenger cabin.

Table 3 Maximum humidity at different areas of the vehicle

Location	Maximum humidity
Engine compartment (around engine)	38°C, 95%RH
Engine compartment (dashboard)	66°C, 80%RH
Passenger seats	66°C, 80%RH
Around both side doors	38°C, 95%RH
Around front dash panel	38°C, 95%RH
Floor sheet	66°C, 80%RH
Rear deck	38°C, 95%RH
Trunk	38°C, 95%RH

Quoted from "Vehicle electronics and reliability"

3-4 Examples of demands on electronic equipment by temperature environments

Temperature environments require that vehicle-mounted electronic equipment meet the following conditions.

(1) Operate normally at high and low temperatures.
(2) Operate normally during severe temperature increase or drop within a short period.

The ability to meet these conditions becomes crucial in environments that include such factors as severe temperature fluctuations and vibrations from starting up or stopping.

Example 1:

Starting up after having been parked under a blazing summer sun requires the ability to operate safely at 80 to 120°C. After driving 10 minutes, the air conditioner lowers the temperature to 15 to 20°C, and then the car is parked again and returns to the high temperature.

Example 2:

Starting the engine in the early morning in the dead of winter in a northern climate (about –30°C) requires the ability for all functions simultaneously to operate normally. After driving for 10 minutes, the engine compartment reaches 80 to 120°C, and the heater warms the passenger cabin to 20 to 25°C, then the engine is turned off and the temperature returns to minus 30°C.

3-5 Environments that vehicle electronic sensors must endure

Electronics sensors in vehicles are subjected to severe usage environment conditions in regard to such factors as temperature, humidity, vibration, high voltage surges, and power fluctuations. Malfunctions could lead to highway accidents, and so the equipment must have high ratings in safety and reliability.

Requirements for electronic sensors for vehicles include the following.

(1) Precision requirements are not particularly severe compared to other fields.

(2) Reliability and environmental endurance requirements are much more severe than in other fields.

Table 4 shows specifications and environmental endurance requirements for sensors with various applications.

The newest applications for sensors include measurements by two axis acceleration sensors to control the chassis, and measurements by three axis acceleration sensors to operate air bags.

4. Types of vibration and vibration characteristics that affect vehicle-mounted equipment

Noise and vibration in the passenger cabin come from many different sources of vibration. Fig. 1 gives an outline of the mechanisms that generate noise and vibration inside the passenger cabin.

These vibration sources can be classified according to the generating conditions and frequency bands. The broad classifications include engine vibration, gear noise, road noise, tire noise, and wind noise. Also, low frequency vibrations that become problematic with spring expansion and spring compression are mainly road vibrations. Vibrations can be considered random vibrations or shock vibrations (road bumps or sharp drops).

4-1 Vehicle noise that occurs while driving

(1) 1 to 2 Hz vibration (spring expansion body pitching and bouncing vibration)

During the large undulations on the express highway, or just after driving over a bump or a sharp drop, the body makes a continuous soft floating vibration. The oscillation frequency is determined by the natural frequency of the spring expansion.

(2) 2 to 15 Hz full body trembling up and down vibration

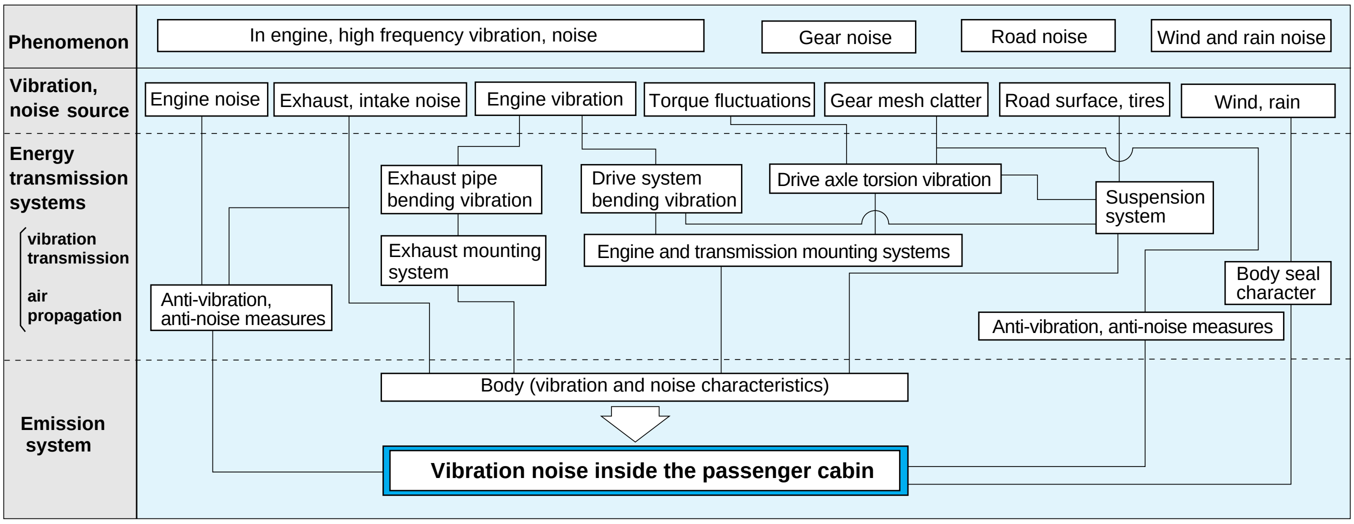
This vibration occurs when driving over a continuously uneven surface, or just after driving or a major bump or sharp drop. It is amplified by spring compression resonance, engine rigid body resonance, and body elasticity resonance, and transmitted to the seats, steering wheel, and the floor.

(3) 15 to 30 Hz rough vibration that is transmitted to the driver

When driving over a continuously rough road surface, the vertical and longitudinal road surface stimulation is transmitted without being dampened by the suspension system.

Table 4 Specifications and environmental endurance requirements for sensors with various applications

		Home use	Measurement use	Airplane use	Vehicle use
Precision		Several %	0.1 to 1%	0.1 to 1%	1 to several %
Environmental endurance	Operating temperature	–10 to 50°C	0 to 40°C	–55 to 70°C	–40 to 120°C
	Vibration	Up to 5G	1G	0.5 to 10G	2 to 25G
	Source voltage fluctuation	±10%	±10%	±10%	±50%
	Electromagnetic environment	Good	Good	Good to Worst	Bad
	Saltwater	No	No	Yes	Yes
	Water	Yes	No	Yes	Yes
	Muddy water	No	No	No	Yes
	Gases	No	No	No	Yes
Reliability (failure rate)		—	—	(Max. 10^{-9})	10^{6} km (10^{-9})



Quoted from "Vehicle technology handbook tests and evaluation" chapter 6

Fig. 1 Diagram of mechanisms generating vibration noise inside the passenger cabin

4-2 Low-frequency engine vibration while driving

The vehicle engine suspension system has a rigid body resonance of 10 to 30 Hz. That vibration phenomenon is exhibited in various forms. Body vibrations occur when starting or idling, and shock and body longitudinal hiccup vibrations occur due to sudden changes in engine torque when accelerating or changing speeds.

(1) Engine shake (7 to 20 Hz)
Engine resonance and rigid body vibration of the body create low-frequency vibrations in the coupling system of the engine, body, and suspension. This is called engine shake.

(2) Idling vibration (20 to 50 Hz)
During idling, low-frequency vibration occurs in the floor, seats, and the steering wheel. Trembling up and down vibration causes 20 to 35 Hz low-frequency vibration with four cylinders and 30 to 50 Hz low-frequency vibration with 6 cylinders. Swaying up and down vibration occurs at 5 to 10 Hz due to uneven combustion. The main cause of swaying up and down vibration is engine roll vibration.

4-3 Vibration characteristics of the suspension system

The vibration characteristics of the suspension system differ from static characteristics. Anti-vibration rubber largely relies on displacement and frequency, and has poor vibration transmission characteristics at the high frequencies and low displacement that become a problem with road noise. With coiled springs, a steep peak appears at high frequency and the spring constant becomes high. At the shock absorbers, the characteristics become nearly the same hysteresis dampening as the anti-vibration rubber.

The suspension system transmits various types of vibration, but the main ones are as follows.

(1) Both perpendicular and horizontal vibration are caused at the tires by uneven road surface.
(2) Torque fluctuation occurs during braking at the braking friction surfaces.
(3) Rotation vibration occurs due to static and dynamic unbalance at the rotating sections, from the engine to the tires.
(4) High-frequency vibration of 400 Hz to 1 kHz occurs during gear meshing in the transmission and differential.
(5) High-frequency vibration from 1 to several kHz is caused by self-induced vibration of braking friction surfaces.

4-4 Vibration characteristics of the steering system

Just as in the suspension system, most vibration affecting the steering system does not act directly on the steering system, but is amplified in the tires and suspension system. Other vibration phenomena include power steering vibration, kickback due to uneven road surface, and dynamic unbalance of rotating parts such as the wheels and the braking system.

(1) Low-speed shimmy*1 is generated by self-induced vibration accumulating within the steering system, and occurs at the low vehicle speeds of 20 to 60 kilometers per hour. Displacement is large, and the shimmy has a greater tendency to occur in worn tires or tires with low air pressure.
(2) High-speed shimmy*1 is mainly caused by static or dynamic unbalance of the tires on the wheels. Other causes include disk wheel eccentricity, the wheel not being vertically plumb, and non-uniformity*2 of the tires. Unbalance of the tires on the wheels causes peak vibration in the vicinity of 10 Hz to 30 Hz. Displacement is small, but with worn tires or low air pressure in the tires, displacement becomes large.

*1 Vibration in the direction the steering wheel turns caused by unbalance or non-uniformity in the front tires is called "shimmy".
*2 Unevenness in tire weight, internal rigidity, or dimensions is called "non-uniformity".

(3) Kickback occurs when driving on a bad road surface causes both vertical and horizontal vibration to the drive tires. That vibration is transmitted to the tie rods, causing the steering wheel to turn suddenly. This vibration occurs in the drive wheels on front-wheel-drive cars, giving a greater tendency for longitudinal changes in force than with rear-wheel-drive cars.

(4) Tire vibration factors seen from the characteristics of static springs, include vertical springs, lateral springs, longitudinal springs, and torsion springs. Longitudinal stiffness is strongly related to actual vibration, and becomes harder roughly in proportion to the increase in air pressure. Natural tire frequency results from the fact that an elastic body filled with air has an individual vibration mode. The natural frequency of radial tires is around 90, 110, 135, and 160 Hz, while that of bias tires is around 140 and 155 Hz.

We have looked at suspension and steering systems in regard to vehicle vibration characteristics affecting vehicle-mounted equipment. Fig. 2 shows related vehicle vibration and noise classified according to source input and source frequency.

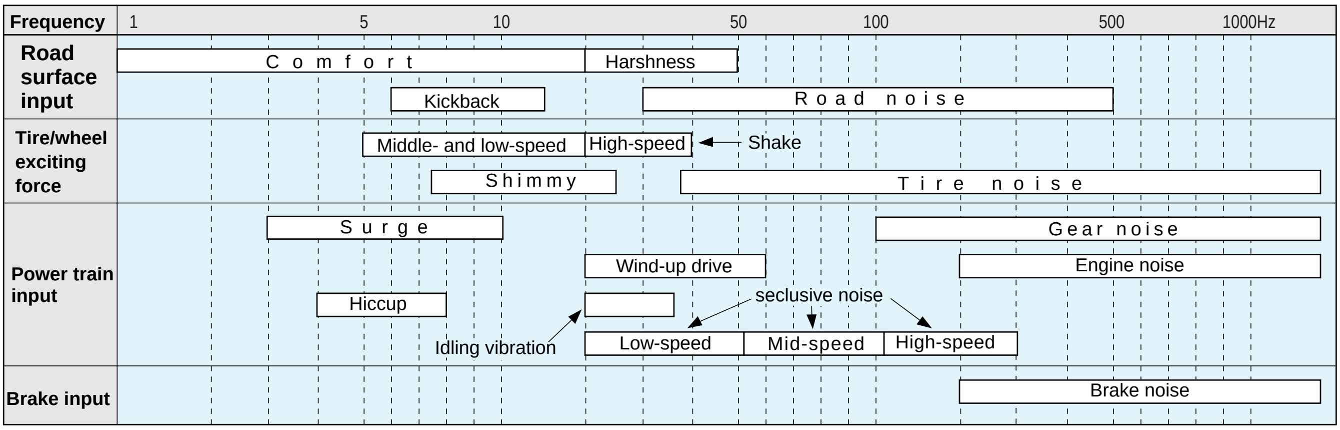


Fig. 2 Vibration sources and input to the suspension and steering systems

4-5 Elastic vibration and vibration noise of the vehicle body

Many types of vibration and noise can be sensed while driving. Vibration is transmitted to the passenger cabin from the controlling force generated by the engine drive and the power transmission equipment as well as vibration from the road surface while driving. Table 5 shows elastic vibration in the vehicle body and related vibration phenomena.

As we have seen, body vibration is related to many types of vibration and noise. Propelled by the movement for safer and lighter vehicles that can be recycled, developmental research for new synthetic materials and body construction is flourishing.

Table 5 Elastic vibration and vibration noise in the vehicle body

Vibration and noise phenomena	Elastic vibration in the body	Related vibration phenomena
Shake (front)	Body primary flexural resonance (5 – 30 Hz)	Rigid body vibration in the engine suspension system, front spring compression resonance, steering system vibration
Shake (lateral)	Body construction primary torsional resonance (30 – 50 Hz)	Tram road resonance of the rear chassis, lateral seat vibration
Idling vibration	Body construction primary torsional resonance (30 – 50 Hz)	Rigid body vibration in the engine suspension system, vibration in the exhaust pipe system
Hiccup vibration	Frame construction primary flexural resonance (– 10 Hz)	Torsional primary vibration in the drive system
Acceleration/ deceleration vibration	Body primary torsional resonance (5 – 30 Hz)	Rigid body vibration in the engine suspension system, primary and secondary vibration in the drive system
Low-speed seclusive noise	Passenger cabin floor body resonance (30 – 50 Hz)	Rear suspension wind-up resonance, pillar of air resonance
Mid-speed seclusive noise	Panel sectional vibration (50 – 100 Hz)	Elastic vibration in the rear suspension system, torsional fourth-level vibration in the drive system, pillar of air resonance
High-speed seclusive noise	Panel resonance (100 – 200 Hz)	Drive train vibration, pillar of air resonance
Road noise and harshness	Resonance from all of the above	Vibration in the tires and suspension system

4-6 Characteristics and nature of vibration and noise generated from the drive train

Table 6 shows the results of classifying vibration and noise in the drive train according to generating phenomena.

The sources of vibration include gear meshing, torque fluctuations due to angle, and unbalanced rotating parts in the power transmission system. The vibration wave pattern from the engine’s dynamic unbalance and torque fluctuation due to operating conditions is classified as random wave, random on random, and sine on random. Testing vibration transmitted from the power transmission system requires a high-level vibration controller that can analyze and reproduce actual vehiclevibration.

Table 6 Phenomena generated by causes in the drive train and their characteristics

Vibration source	Phenomena generated	Frequency range
Engine torque fluctuations	Surge (vibration)	2 – 10 Hz
Clutch misalignment	Judder (vibration)	2 – 10 Hz
Driveshaft angle	Acceleration vibration (vibration)	10 – 20 Hz
Engine torque fluctuation	Wind-up (vibration, seclusive noise)	20 – 50 Hz
Unbalanced rotation	Wind-up (vibration, seclusive noise)	20 – 50 Hz
Engine torque fluctuation	Drive train torsion (seclusive noise)	50 – 80 Hz
Driveshaft angle	Drive train torsion (seclusive noise)	50 – 80 Hz
Engine complete rotation inertia	Power plant/driveshaft bending vibration (seclusive noise)	100 – 200 Hz
Hypoid gear meshing force	Power plant/driveshaft bending vibration (differential noise)	400 Hz – 2 kHz

5. *Approach of combined testing for vehicle-mounted equipment*

Reliability testing for vehicle parts and environmental endurance testing are fully considered and set according to the established JASO-D001 “General rules of environmental testing methods for automotive electronic equipment” of the Japanese Automobile Standards Organization. However, the diverse environmental conditions in which vehicle-mounted equipment is used, as represented by the recent boom in RV’s and minivans, has brought a corresponding increase in the types of vehicles introduced to meet the many different user purposes, and so when the identical part is installed at a different location, operating conditions can undergo major changes.

Lately, the Environment Simulation Test (EST) has become more widely used. The EST uses MIL and IEC standards as references. Increasingly, combined environmental testing is being used to determine reliability and endurance of vehicle-mounted parts as well as to evaluate the parts. Combined environmental testing considers the effects of the temperature and humidity environments of the individual vehicle-mounted parts as well as the vibration and vibration characteristics of the vehicle type and the driving conditions.

5-1 Vibration excitation wave form of combined environmental testing

Below is a classification of vibration wave forms, which are necessary for reproducing and evaluating actual driving conditions. The vibration machine generally used is the electrodynamic single axis air-cooled type.

Excitation wave form

- Sine wave
  - Fixed frequency sine wave
  - Slow sweep frequency sine wave
  - Step sweep frequency sine wave
- Wide band wave
  - Steady wave
    - Random wave
    - Sine on random wave
    - Random on random wave
  - Non-steady wave
    - Classical shock
    - Shock on random wave
    - Shock response spectrum
    - Actual driving wave form

In evaluating excitation wave forms, sine waves have greater excitation energy, while random waves, if they are made in a qualified power spectrum, are closer to the usage environment. Control is usually achieved through digital control diffusion, permitting easy testing of sine, random, and shock waves. Usually, in slow sweep frequency sine waves, the acceleration level is fixed for the vibration frequency range and the frequency axis, and there are a number of patterns with two or three phase values changed. Fixed frequency sine waves are used for resonance point endurance testing, and random wave testing is beginning to be used for parts directly affected by engine vibrations and vibrations from the road surface when driving.

More recently, testing is changing from using single direction vibrations to three-way vibrations (vertical, longitudinal, and lateral), with a three axis vibration shaker sometimes being used. In reproducible evaluation testing for sound disruption of vehicle-mounted audio equipment, the simultaneous three axis vibration shaker is said to be effective in reproducing actual driving vibration wave patterns.

5-2 Representative examples of combined environmental testing

5-2-1 Random wave test conditions

Findings on vibrations induced at the installation site have shown that they are different from the three way total m/s^{2}rms value, they require vertical and horizontal testing, and they vary with different vehicle types. Combined testing is possible through simultaneously adding temperature and humidity conditions to these vibration test conditions.

Table 7 Representative examples of random wave testing

Vehicle type		Installation site	Vibration direction	Total value	Vibration frequency
12 V systems	All	Dash panel, floor, center console	Vertical Lateral Longitudinal	31.9 m/s^{2}rms 27.4 m/s^{2}rms 26.8 m/s^{2}rms	15 – 500 Hz
24 V systems	All	Dash panel, floor, center console	Vertical Lateral Longitudinal	21.5 m/s^{2}rms 6.5 m/s^{2}rms 15.9 m/s^{2}rms	

Testing time: 2h

5-2-2 Sine wave test conditions

Table 8 Representative examples of sine wave testing

	Vibration frequency	Cycle	Vibration acceleration	Vibration direction and time
12 V systems	15–60 Hz	20 min.	43.2 m/s^2	Vertical, 4 h Lateral, 2 h Longitudinal, 2 h
24 V systems	33 Hz	—	66.7 m/s^2 (3 mm)	Same as 12 V systems

All without current

Table 8 shows generally used official test patterns as vibration test conditions for spring expansion. In more recent vibration generating machines, the use of a longer stroke (100 mmp-p) and switching amps has increased the maximum vibration speed (200 cm/sec), making 43.15 m/s^2 (79 mmp-p) possible at 5 Hz, and testing has become possible at near the body resonance point. Combined environmental testing can be performed by simultaneously adding temperature and humidity conditions from both inside and outside the passenger cabin to these vibration conditions.

5-2-3 Combined test cycle

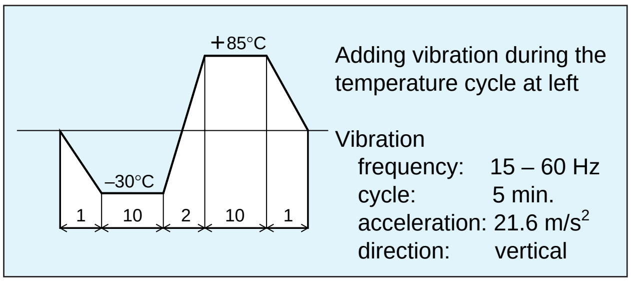


Fig. 3 Representative example of combined testing

Fig. 3 is a cyclic test that can be applied to test patterns for combined testing such as that used to test front panel displays and car navigation LCD displays used inside the passenger cabin. Combined testing of the air bag assembly unit inside the steering wheel and the front passenger side air bag unit adds RT (23°C) to longitudinal and lateral vibration testing. Vibration frequency is widened in the 5 to 100 Hz range, and the acceleration value is changed in each direction of vibration. In this way, for evaluation testing of vehicle-mounted equipment for new cars coming onto the market, by using the differences in vibration and vibration transmission characteristics during driving, combined testing is being performed simultaneously for vibration and temperature for equipment in three way installation conditions.

5-3 Degradation testing and accelerated stress testing at actual conditions of equipment mounted inside the passenger cabin

Reliability testing and endurance evaluation testing of electronic equipment for automobiles require long testing times. While maintaining conformity for developing electronic parts and developing vehicles for use in diverse areas, reducing testing time is vital, and means are being sought for accelerating stress testing. Accelerated stress testing consists of applying more severe stress than the conditions in the usage environment or than the maximum rating. This test combines two or more environmental factors and accelerates physical degradation in a short time to efficiently estimate the life of parts and products.

The specifics I would like to present here are the published results of collecting and investigating electronic equipment that was mounted on vehicles that had been scrapped by major domestic vehicle manufacturers. This report evaluates the life of the valuable solder joints.

(1) None of the electronic equipment had any problems at all with electrical contact, but visible cracking had occurred in the vicinity of the lead pin in one section, and the fracturing was a model of granulated thermal fatigue fracture.
(2) Areas with cracking were limited to those in close proximity to the lead pin and soldered fillet sections around substrate holes.
(3) Areas with cracking were not the result of peeling off from the lead pin interface, but rather occurred within the solder itself.
(4) To hypothesize the mechanism of degradation, stress is repeatedly applied to the soldered joints, tin (Sn) spreading occurs, and progressive roughening occurs in the α layer, with minute airholes developing in the crystal grain boundary in the interface between the Pb-rich α layer and the Sn-rich β layer, causing a decline in destructive stress.

From the details obtained from the above investigation, a field model type was used to measure life under actual conditions of use, and a method of evaluating the soldered joint life of vehicle-mounted electronic equipment was published. In the future, we anticipate promoting testing of single assembled parts due to the necessity of accelerated life testing stemming from the demand for reducing development lead time.

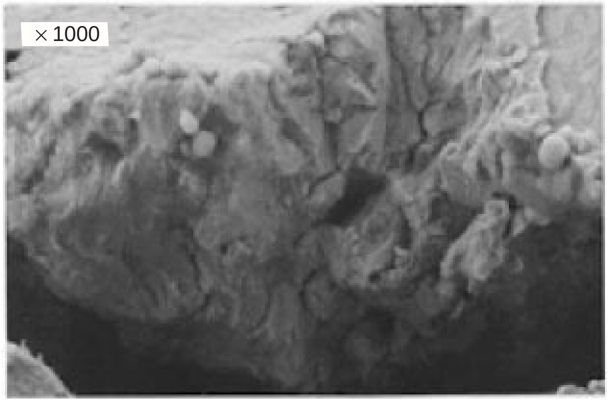


Photo 1 Cracking fracture

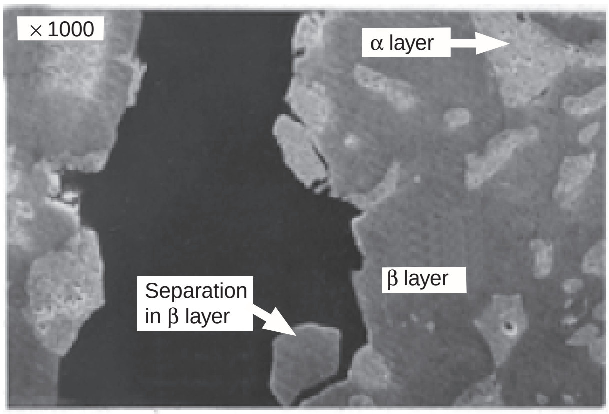


Photo 2 Magnified cross-section of cracking section

5-4 Test results at the vehicle test site and defect results in the market

In addition to environmental simulation testing indoors using combined environmental testing equipment, each manufacturer road tests vehicles for evaluation by actually driving them on a test course at the test site.

At this point, I would like to present examples comparing the results at the testing site with the actual failure rates in the market.

Fig. 4 shows a comparison of the defect rate in the market and the defect rate due to driving on bad roads at the test site. The failure rate in the body and steering systems is higher at the test site than in the market, but the failure rate for the engine, brakes, transmission, and electrical systems is much higher in the market than at the test site. Each test requires further analysis of the failure details.

Fig. 5 shows an example of looking for the correlation between the failure data in the market and the endurance test results at the test site. There is a uniform relationship between the failure rate and driving distance at the test site from 2700 miles to 30,000 miles, but in the market the relationship between the failure rate and the driving distance from 5,000 miles to 18,000 miles is lower than that at the test site, while above 20,000 miles it is higher. This seems to show that the endurance test methods at the test site require further study.

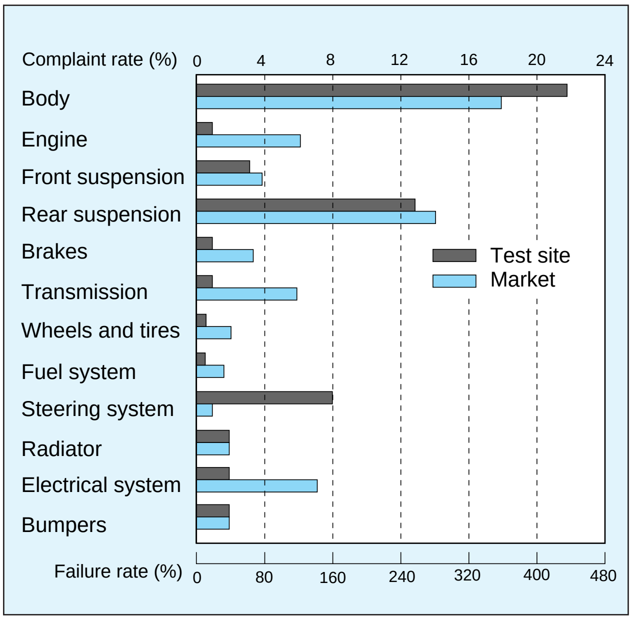


Fig. 4 Comparison of defect rates in the market and defects rates in bad road driving at the test site

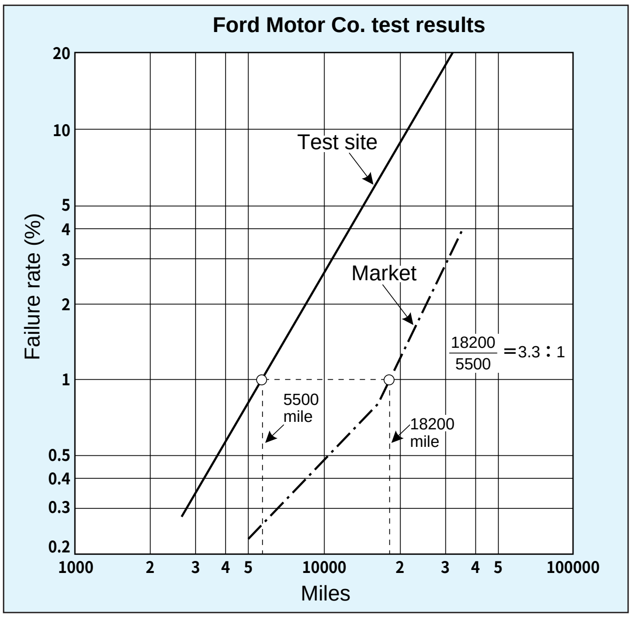


Fig. 5 Correlation between market failure data and endurance test results at the test site

6. In conclusion

In this article, I have discussed temperature and humidity conditions applicable to combined enviro-nmental testing for vehicle-mounted equipment and examined driving vibration and vibration characteristics. I have also presented test examples and discussed the most recent trends in testing.

Vehicle-mounted equipment now coming onto the market is facing demands for accelerated evaluation testing, including product life-cycle testing, to shorten the time period between the development and the marketing of a product. Both the past field data and the current evaluation data are used to carry out logical evaluation tests. However, to reproduce the defects that occur in the market, combined tests need to be based more closely on the types of applications for which the products are used.

Joining the combined test chamber with a single-axis vibration shaker makes it possible to create more test systems according to individual applications, but this does not completely satisfy the need for reproducing field data.

Advances in digital controllers have made it possible to reproduce a variety of unidirectional single-axis vibration wave forms on the vibration table, but the three axis vibration method comes much closer to reproducing the usage conditions in the field.

Progress has brought continued improvements in three axis vibration test equipment, and systems newly introduced to the market are now capable of reproducing the range of vibration frequencies to which vehicle-mounted equipment is subjected. However, a number of problems remain that need to be addressed to perfect combined three-axis vibration test systems.

Those problems include:

(1) Maintaining the moving construction for the vibration table inside the test chamber without three way restraint while attaining a perfect seal at the junction between the vibration shaker and the test chamber.

(2) Improving the work of placing and removing specimens on the vibration table in the test chamber in the limited amount of space and operating surface.

If the environmental test equipment manufacturers can solve the above problems in relation to combined multi-axis vibration tests while maintaining the performance of the single axis combined test, they will be able to introduce a combined three axis tester on the combined test market by combining temperature and humidity with three way vibration. This delivers new prospects for combined environmental testing.

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