PYROSHOCK SIMULATION USING THE ALCATEL ETCA TEST FACILITY.

Enrico FILIPPI
Alcatel ETCA s.a BP 4008 B-6000 Charleroi Belgium
Phone: +32 71 44 25 73, Fax: +32 71 44 22 00, E-mail: enrico.filippi@etca.alcatel.be

Hamien ATTOUOMAN, Prof. Calogero CONTI
Faculté Polytechnique de Mons, Service de mécanique rationnelle,
Boulevard Dolez, 31 B-7000 Mons Belgium
Phone: +32 65 37 41 80, Fax: +32 65 37 43 00, E-mail: conti@fpms.ac.be

ABSTRACT.

Today's Aerospace vehicles utilise numerous pyrotechnic devices to separate structural subsystems, deploy appendages and activate on-board operational subsystems. The firing of these pyrotechnical charges generates severe impulsive loads (so-called pyroshocks) that can cause failures in electronic components. There is a lack of computational techniques to predict the dynamic behaviour of complex structures when subjected to high frequency shock waves as well as a lack of damage and failure criteria for electronic equipment and so the projects must rely on testing to validate the design.

Alcatel ETCA has developed a pyroshock test facility dedicated to the testing of electronic units. The facility utilises a resonant test fixture assembly that is excited by a detonating charge or a mechanical impact. The test fixture assembly can be a simple plate, a beam, a double plate assembly or a more complex structure. The test item attached to the fixture is subjected to the direct shock wave and to the resonant response of the test fixture, which simulates the desired pyroshock. The test set up is checked and tuned versus the test specification by using a dummy of the test item. When the desired pyroshock is achieved, the nominal tests are performed on the test item.

Part I of this presentation describes the main characteristics of the test facility: test fixtures, excitation techniques, data acquisition, and data processing.

Part II presents some test results and details the effects of variables upon the induced shock response spectra. The main variables are related to the design of the test fixture (type, size, material) and the characteristics of the excitation (amount of explosive, location of explosive, and so on).

1. BACKGROUND.

1.1. Pyrotechnics [3] [14b].

Current launchers, payloads and spacecrafts utilise pyrotechnic devices over the course of their missions for the separation structural subsystems (e.g., booster, fairing or stage separation, clamp band release), the release of deployable appendages (e.g., solar panels or antenna's), and/or the activation of on-board operational subsystems (e.g., propellant valves).

Pyrotechnics are extensively applied because of their high efficiency:

- high energy delivered per unit weight,
- small volume,
- long term storable energy,
- controllable initiation and output energies,
- little initiation external energy required,

and despite a number of disadvantages:

- single shot,
- cannot be functionally checked before flight,
- impulsive loads (pyroshocks),
- safety issues,
- limited engineering approaches,
- some unexplained failures.

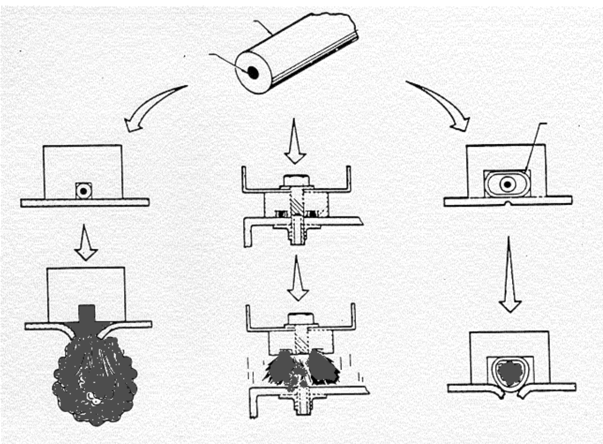

Figure 1. Mild detonating fuses (MDF).

Over 400 pyrotechnic components fly on each Shuttle mission. Some of them are used for each flight, the other one are ready for emergencies.

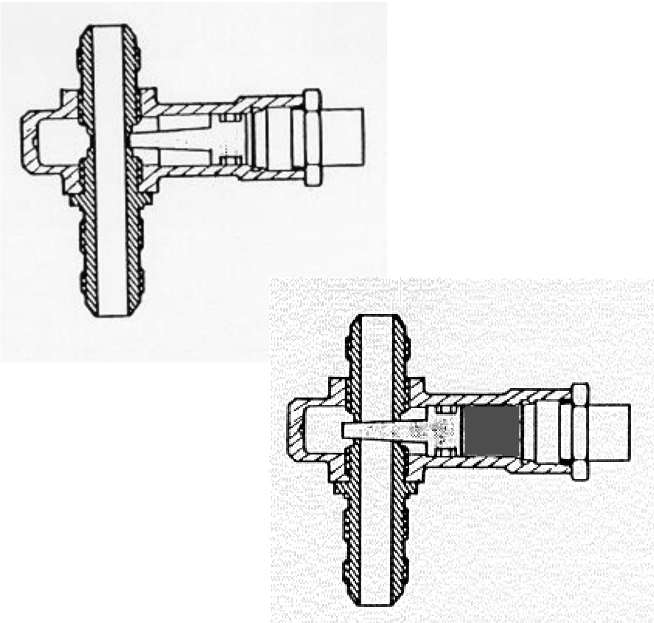

Figure 2.Pyrotechnically actuated valve (top view: before actuation – bottom view: after actuation).

Program	Number of installed pyrotechnic devices
Mercury	46
Gemini	139
Saturn	approx. 150
Apollo (CSM/SLA/LM)	314
Apollo (CSM/SLA) for Skylab	249
Shuttle	over 400

Table 1. Pyrotechnic Applications in Astronautics.

Pyrotechnics are also extensively used in aircrafts : F-4 (31 to 42), F-111 (315), F-14 (211), and F-15 (44).

A list of commonly used pyrotechnic devices, according to the severity of the shock-environment that they produce, follows:

a. Linear explosives in separation joints (Mild Detonating Fuse– MDF and Flexible Linear Shaped Charge - FLSC),
b. Separation nuts, explosive bolts,
c. Pin-pullers, pin-pushers,
d. Cable-cutters, pin-cutters, bolt-cutters.

The characteristics of the shock produced by these sources as well as the attenuation through various structural elements have been analysed by the Denver Division of Martin Marietta. Results are given in [13].

1.2. Ariane 5 BCS. Pyroshock ground tests.

During the development of Ariane 5, several full-scale separation ground tests have been performed. Alcatel ETCA has participated to some of them to check for the structural adequacy of CDC and BCS units.

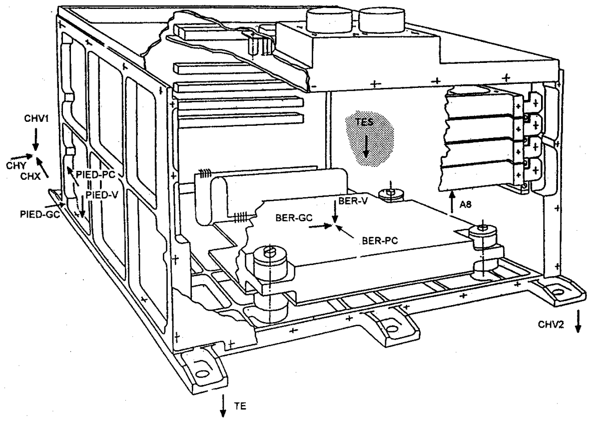

Figure 3. Ariane 5. BCS unit.

Eight BCS units flight on each Ariane 5. Some of them are located in the VEB (Vehicle Equipment Bay) and the other ones in the EAP's (boosters). They are part of the self-destruction systems. They transmit through relays the destruction orders. These relays are mounted on a structure that is shock isolated by means of silicon rubber parts. The suspension has been designed to act as a low pass filter in order to prevent relay chatter or transfer. The translational modes of vibration have a frequency of about 100 Hz; there is very little coupling with the rotational modes of vibration.
The results of two separation tests are shown here after (fairing separation and main stage separation).

		Fairing separation		
		Time	SRS	
		g_{max}	g_{max}	frequency (Hz)
Equipment bay (close to BCS)	X	150	770	2800
	Y	95	330	2000 - 5000
	Z	95	500	4800
BCS unit (close to relays)	X	33	150	250
	Y	15	60	210-1200-2500
	Z	13	61	300-2800

Table 2. Ariane 5- BCS. Fairing separation. Acceleration levels.

		EPS-EPC separation		
		Time	SRS	
		g_{max}	g_{max}	frequency (Hz)
Equipment bay (close to BCS)	X	253	900	2500
	Y	130	540	4200
	Z	140	350	4200,9000
BCS unit (close to relays)	X	54	120	3200
	Y	25	85	2300
	Z	18	55	300-700-1900

Table 3. Ariane 5. BCS. EPS-EPC separation. Acceleration levels.

The test results show the filtering effectiveness of the isolation device.

Typical measurements are shown hereafter.

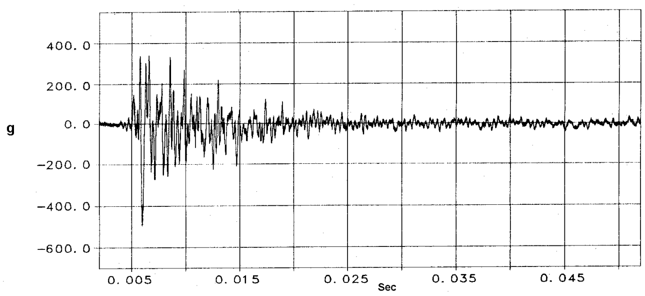

Figure 4. Ariane 5. VEB structure (close to a BCS). Acceleration time history.

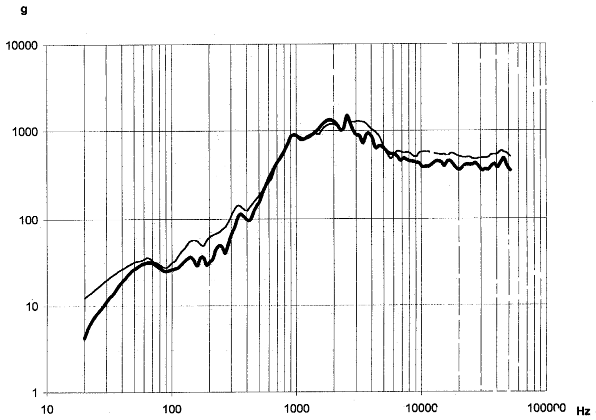

Figure 5. Ariane 5. VEB structure (close to a BCS). Positive and negative SRS's.

This example has shown some typical Ariane 5 pyroshocks and one way to protect shock sensitive components against them.

1.3. Stress wave propagation [20].

Pyrotechnic devices generate compression, flexural and shear shock waves that travel at the sonic velocity within the transmitting material. All these waves propagate through the structures, they are reflected and transmitted through the interfaces and they excite the structure mode shapes. The pyroshock experienced by the electronic units combines direct shock waves with a duration of a few µs with the structural response of the carrying structures with a duration of ten's of ms.

1.4. Pyroshock levels [1].

The numerous reflections and recombinations produce pyroshock levels that vary according to the distance from the source and the complexity of the carrying structure. They are broadly divided into three categories depending on the distance from the pyroshock generation device:

a. <u>Near-field pyroshocks (direct shock wave):</u>
- peak accelerations much higher than 5000 g
- substantial spectral content above 100 kHz
- locations lower than 15 cm from intense source (line source), lower than 3 cm for less intense source (point source)

b. <u>Mid-field pyroshocks (direct shock wave and structural modal response)</u>
- peak accelerations between 1000 g and 5000 g
- substantial spectral content above 10 kHz
- locations between 15 cm and 60 cm from line source, between 3 to 15 cm from point source

c. <u>Far-field pyroshocks (structural modal response)</u>
- peak accelerations below 1000 g
- spectral content below 10 kHz
- locations above 60 cm from line source, above 15 cm from point source,

Some authors consider the mid-field environment to be part of the far-field.[2].

1.5. Pyroshock induced failures.

There is a lack of data concerning pyroshock induced failures in electronic units. The authors have experienced the following ones: relay chatter and transfer, relay failure, ferrite failure, crystal failure, bond fracture and bearing damage.

C.J. Moening paper [14] reports some failures experienced during ground shock testing:
- Relays and Switches
  - chatter and transfer
  - permanent damage
- Crystals, ceramics, brittle epoxies, glass diodes, wire leads
  - cracks and breakage
  - loss of seals
  - bond fractures
  - shorts
- Particle contaminants in piece parts
- Deformation of small, lightweight structural elements.

Pyroshocks rarely damage structural members.

C.J. Moening also reports 85 pyroshock induced flight failures to compare with 3 vibration induced flight failures. That does not mean that the pyroshock environment is most severe that the vibration environment but simply that the pyroshock environment is not so well in hand than the vibration environment is Pyroshock tests are performed during the qualification tests of some units, there is no acceptance tests on flight hardware.

1.6. Shock Response Spectrum.

The most widely used technique for quantifying pyroshock is the Shock Response Spectrum (SRS). The SRS is a method of reducing the time-history to compare shock motions, to design equipment to withstand shocks, or to formulate laboratory tests simulating environmental conditions. The SRS is viewed as a measure of the damage potential. A SRS is a plot of the maximum response experienced by a single degree-of-freedom (SDOF) system, as a function of its own natural frequency, in response to an applied shock. For pyroshocks, the shock spectrum is calculated from the measured pyroshock time-history applied as a motion of the SDOF system foundation. The response may be expressed in terms of acceleration, velocity, or displacement; these amplitudes may be absolute or relative to the motion of the foundation. For pyroshocks, the maximum absolute acceleration is generally used; the maximum absolute positive and negative acceleration responses are also used to check for the measured data quality.

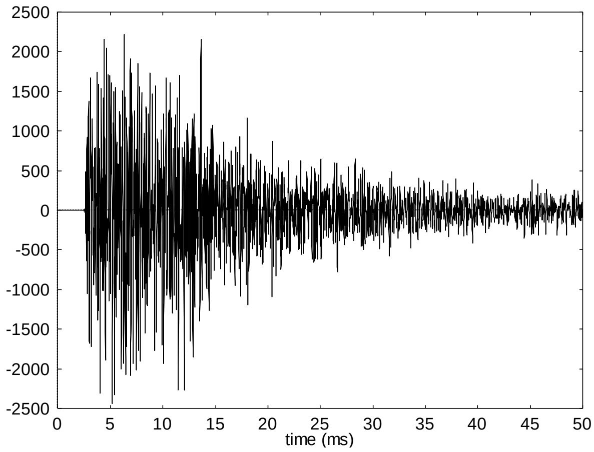

Figure 6a. Acceleration time-history for a pyroshock.

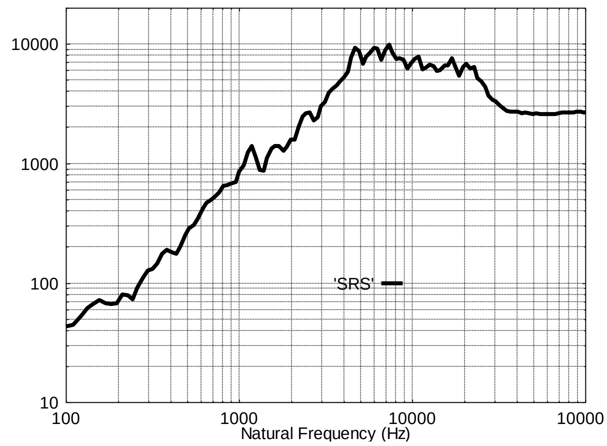

Figure 6b. SRS of a pyroshock. The SRS is calculated from the Fig.6a inset acceleration using a 5 percent damping ratio (dynamic amplification Q = 10).

The absolute acceleration is related to pseudo-velocity or relative displacement by the following relationship:

$$\omega^2.\delta = \omega.v = a$$

for non damped systems with:

- ω = resonance angular frequency,
- δ = maximum spring deflection (maximum relative displacement)
- v = maximum pseudo-velocity
- a = maximum absolute acceleration

On the extreme left of Fig.6b corresponding to low-frequency SDOF systems, the response approaches an asymptote corresponding to the value of the maximum ground displacement (or velocity depending on the excitation characteristics). For very high-frequency SDOF systems, the spring is very stiff; therefore, when the ground moves, the spring forces the mass to move in the same way the ground moves, and the mass must have the same acceleration as the ground at any time. The SRS plot asymptotically approaches the maximum ground acceleration line on the extreme right-hand side of Fig.6b. This is used to check the SRS calculation.

1.7. Shock testing facilities [6].

A variety of test facilities are used for pyroshock testing.

a. Conventional machines.

In all cases, however, conventional drop test machines, where the test item is mounted on a table that free-falls against an arresting device, should never be used. Such machines subject the test item to a large net velocity change, which produces a shock with substantial low frequency energy that can damage the test item in a detrimental way meanwhile pyrotechnic devices generally produce little or no net velocity change.

Conventional electrodynamic shakers can not simulate adequate SRS's because they are limited in amplitude (300g's) and in frequency range (up to 3 kHz). Some shakers have a special construction allowing them to reach 5000 g's. They are sometimes used but care has to be taken in order them not to generate a time-history that looks like a vibration instead of a pyroshock. Such system tend to act on the dynamic amplification factor in order to get high amplitudes in the SRS while maintaining low amplitude time domain excitation. These electrodynamic shakers are unable to provide sufficient excitation above 5 kHz.

b. Impact devices.

Several test facilities use metal-metal impacts. They utilise a fixture (simple plate, beam, Hopkinson bar, 3-D shell) that is shock excited into resonance by a mechanical impact from a dropping mass, a fired missile, a pneumatic piston, or a pendulum. The MIPS (Mechanical Impact Pyro Shock) simulators are well described [8]. They require a fair amount of trial-and-error tests to achieve the required spectra. In order to improve such kind of process, some systems use a tuneable resonant test fixture impacted by a pneumatic device [7]. They adjust the test fixture fundamental frequency in order to produce typical pyroshock simulations with knee frequencies.

c. Pyrotechnic devices.

Several types of ordnance devices exist. They use a flat plate [12] [15] [18] or a double plate [19] excited by an explosive charge (ordnance device). The magnitude and the shape of the required SRS are controlled by the size/location of the explosive material and the location of the test item on the plate. The advantage of this technique is its ability to achieve high accelerations and high frequencies and to generate transient excitation along all axes at the same time.

1.8. Pyroshock Test Specification.

The SRS is the most commonly used technique for pyroshock test description. Acceleration values are specified from a low frequency limit of a few hundreds of Hertz to a high frequency limit of 25 kHz (launchers) or 10 kHz (spacecrafts). The amplitudes vary widely depending on the test specification. There is a requirement for each of the three orthogonal axes. Common tolerances are ±6dB for frequencies < 3000 Hz and +9dB/-6dB for frequencies > 3000 Hz. Sometimes they are tighter but in such a case they are much difficult or impossible to achieve especially in the in-plane directions.
Some specifications require that the SRS positive and negative curves must be close to each other (for example 3 dB). Sometimes there are additional requirements on acceleration pulse decay and peak velocity.

Some examples are given in Fig.7.

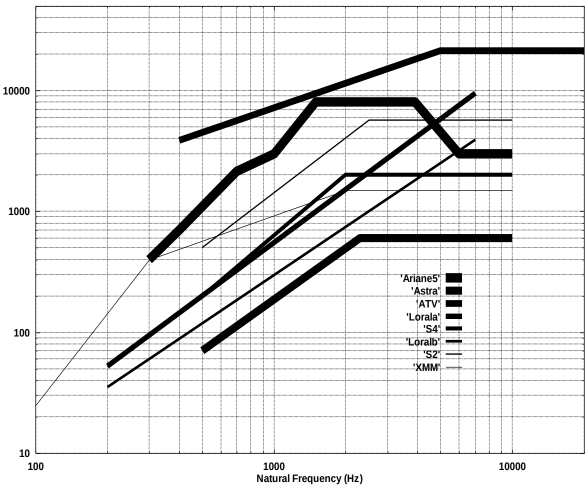

Figure 7. Specified Pyroshock Spectra. Out-of-plane direction.

Some specified SRS's have an increasing amplitude with frequency; some others do not, they have a knee frequency with a constant acceleration above this frequency.

2. ALCATEL ETCA PYROSHOCK TEST FACILITY DESCRIPTION.

2.1. Test facility description.

The facility utilises several resonant test fixtures that are excited either by a detonating charge or a mechanical impact (dropping mass, air gun, pneumatically driven piston, or sledge hammer). The test fixture can be a simple plate, a double plate, or a more complex structure. The test item attached to the fixture is subjected to the direct shock wave and to the resonant response of the test fixture which simulate the desired pyroshock. The test set-up is checked and tuned versus the test specification by using a dummy test item in a trial-and-error process. When the desired pyroshock is achieved, the nominal tests are performed on the test item.

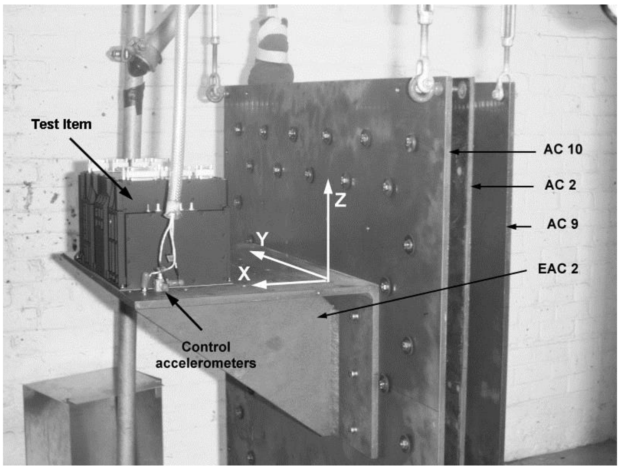

Figure 8. Alcatel ETCA Blast room for ordnance excited pyroshock tests.

The main parts of the test facility are the test fixture, the shock generating devices, the data acquisition system and the data analysis system.

2.1. Test fixtures.

A number of test fixture assemblies have been developed to simulate the variety of specified pyroshock environments. They are assembled from the plates and structures defined in table 1. Additional test fixtures are developed to match the requirements better and better and/or to speed up the process. The choice of an adequate test fixture is the most important parameter in this trial-and-error process. More than 1000 firings have been performed. The results are part of a pyroshock data base. At the beginning of a new test campaign, a computer program scans the data base to look for the test results closest to the specified spectra. The search criteria is based on a least square sense with adjustable weighing factors for frequencies and directions.

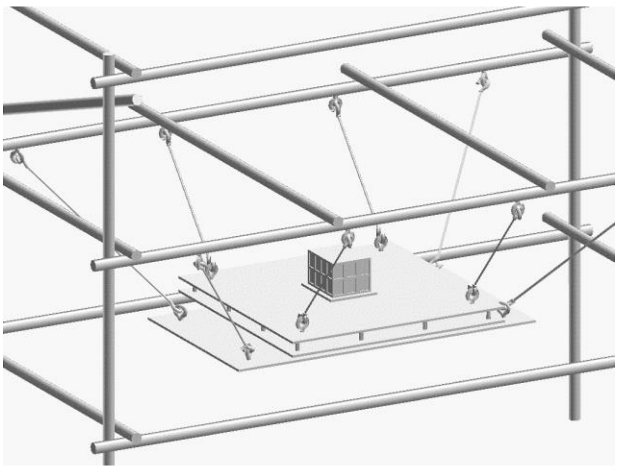

Figure 9. Test Fixture Assembly.

The supporting structure is made of steel pipes and special holding devices; it can be easily modified to any test fixture.

2.2. Shock generating devices.

a. Mechanical impact.

A variety of impact devices are available including:
- projectiles fired by an air gun,
- dropping masses,
- sledge hammer (Fig.10a),
- and pneumatic piston (Fig.10b).

The impact device hits a small plate ("anvil") attached to the test fixture.

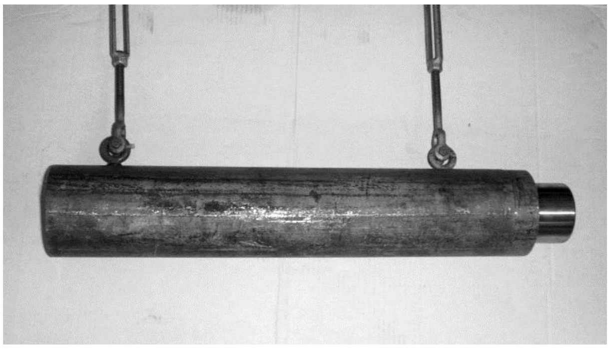

Figure 10a. Sledge hammer.

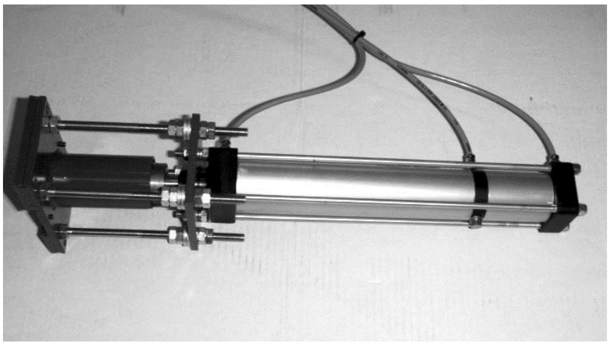

Figure 10b. Pneumatic piston.

The magnitude and shape of the resulting shock are controlled by the following parameters:
- test fixture (type, material),
- impact direction (// or ⊥ to test item mating plane),
- weight of the impact mass,
- impact device speed (air pressure, drop height)
- distance from impact point to test item,
- anvil material,
- hitting tip material,
- damping control (rubber, …).

For several practical reasons, the hitting tip material is harder than the anvil material.

b. Explosive.

The test item is mounted to one side of the test fixture. The explosive charge is usually attached to the backside or the edges of the test fixture (contact explosion). It can also be mounted on a second test fixture not in direct contact with the primary test fixture (non-contact explosion). A detonating cord (10 g/m) and non-electrical (NONEL) detonators are used. The detonating cord length can vary from 0 to 1m. The explosive charge propagates at about 7km/s, so that the cord will complete its detonation in less than 0.1 μs. The explosive is unconfined. NONEL detonators are used for safety issues but also because they generate less electromagnetic pulse than electrical detonators. This is especially important when operating electronic units are tested.

The magnitude and shape of the resulting pyroshock are controlled by:
- test fixture (type, material),
- contact or non-contact explosion,
- location and size of the explosive charge,
- explosive charge mounting details,
- location of the test item on the test fixture,
- damping control.

2.3. Data Acquisition.

The basic instrumentation consists of:
- piezoelectric accelerometers: Endevco 7255, PCB350B02
- signal conditioner: PCB power supply
- piezoresistive accelerometers: Endevco 7270A-M4
- DC amplifier: Endevco Model 136
- analog low-pass anti-aliasing filter: Elliptic DIFA
- analog-to-digital converter: Nicolet BE 490-XE
- computer : PC.

Tape recording is not used because of its low dynamic range and poor operational performances.

The piezoelectric accelerometers have been developed for pyroshock measurement purpose. They include a built-in mechanical filter to prevent the high frequency high acceleration peaks to reach the active crystal and create noise and zero shift. They also include a built-in low pass electronic filter. The accelerometers are directly screwed on the test fixture through their integral stud. The electrical connecting wires are soldered to the accelerometer terminals in order not to have an electrical connector close to the shock source and so to eliminate any connector induced noise. For ordnance tests, the accelerometers are protected against the direct airborne shock wave by means of a special device. The connecting cables are not attached to the test item or to the structure but directly carried away from the accelerometer in the opposite direction from the shock source.

2.4. Data Analysis.

Pyroshock measurement is a big challenge for several reasons: the peak acceleration is unknown, the test is sometimes a one-time experiment (stage separation or prohibitively expensive to repeat). So it is necessary to carefully select the transducers and to set all gains to a conservative value in order to avoid accelerometer overloads, impulsive noise or amplifier saturation. In practice, the useful dynamic range is much less than the maximum dynamic range. Zeroshift is the most common consequence.

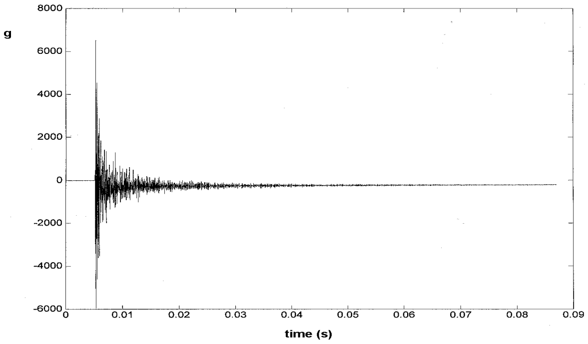

Figure 11: Acceleration signal with zeroshift.

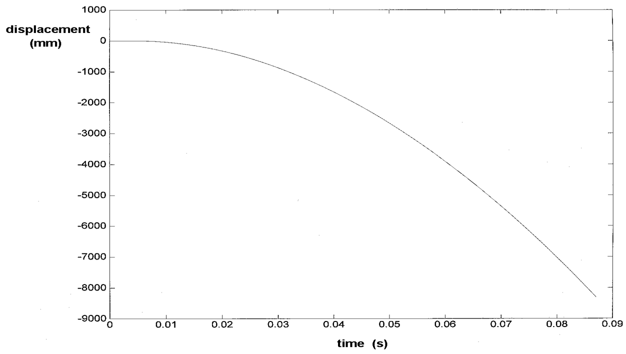

Figure 12b: Displacement.

In a pyroshock testing facility, the expected peak acceleration value is known from the previous trials as well as frequency content . So the dynamic range can be adjusted to improve the signal to noise ratio as much as possible. This information is also used to check for accelerometer selection. Nevertheless, once the accelerations have been acquired, the data must be examined to insure its quality. At least three steps are necessary for the data validation:

- visual inspection of the time history
- velocity/displacement validation,
- positive versus negative SRS validation.

a. Visual inspection of the time history signals.

Common anomalies are described in [10]. They include zeroshift, asymmetry between positive and negative values, spikes, drop out, saturation and so on. The data has to be visually checked for that.

b. Velocity and displacement computation.

The acceleration time history should be integrated to obtain velocity and displacement time histories. These plots emphasize zeroshift and spikes. Fig.12a and 12b give the velocity and displacement computed from the Fig.11 acceleration signal. Due to zeroshift, the results do not have physical meaning.

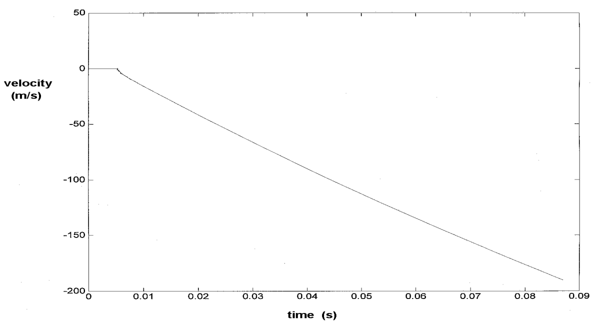

Figure 12a: Velocity.

c. Positive and negative SRS's.

Positive and negative SRS's of Fig.11 acceleration time history have been computed. These two curves are the plot of the maximum positive and negative absolute acceleration responses of the SDOF systems. They are of course enveloped by the maximum absolute response curve. They are used to check the SRS measurement quality as well as the validity of the pyroshock test simulation. Zeroshift creates significant differences between the two curves.

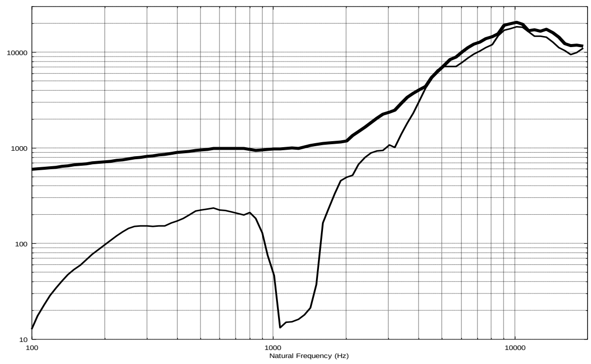

Figure 13. Positive and Negative SRS's.

Both velocity/displacement validation (Fig.12a and 12b) and positive/negative SRS's (Fig.13) computation show zeroshift in the Fig.11 signal.

A signal that has successfully passed through this entire process is supposed correct.

c. Analysis of the hidden zeroshift.

The signal of figure 11 is the superposition of the real acceleration signal and a decaying function. This function has been extracted by a classical curve fitting technique. Two functions have been tested (polynomial function and a sum of decaying exponentials). Both give nearly the same result. The result of the polynomial curve is shown in Fig.14. This signal has been removed from the original data and shown in Fig.15. New velocity and displacement have been computed (Fig.16a and 16b) as well as positive and negative SRS's (Fig.17).

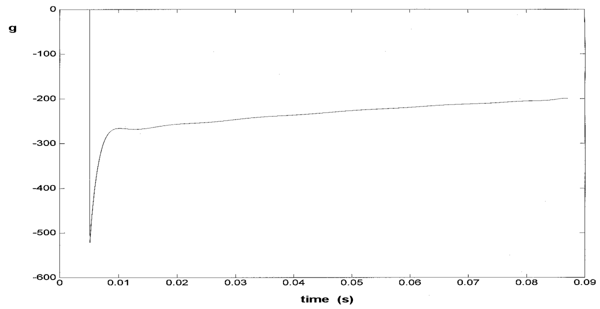

Figure 14. Hidden zeroshift shift (polynomial curve fit).

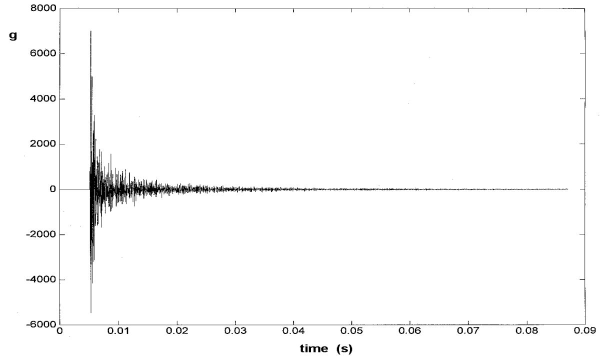

Figure 15. Recovered acceleration time history.

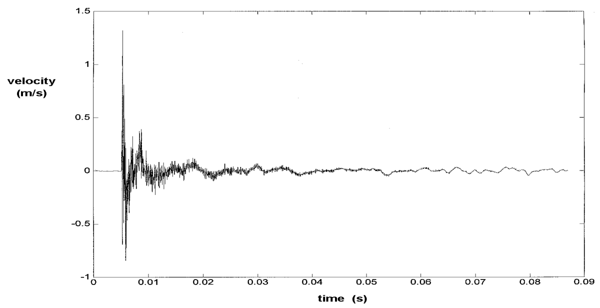

Figure 16a. Velocity from recovered time history.

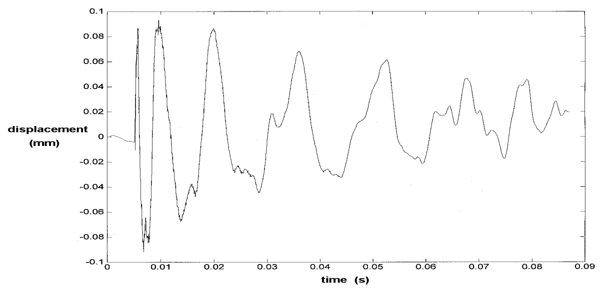

Figure 16b. Displacement from recovered time history.

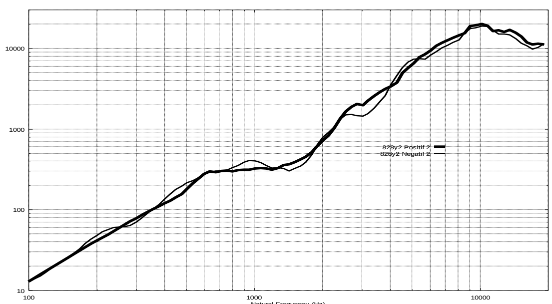

Figure 17. Positive and negative SRS's of the recovered signal.

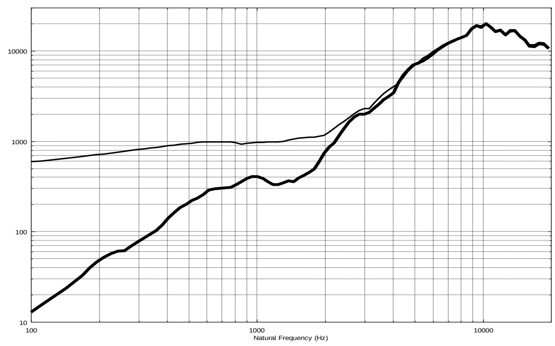

Figure 18. Corrected SRS versus original SRS.

The results clearly show that zeroshift causes serious errors in the shock response spectrum results. In this example, less 7% of error in time domain gives more than 1 order of magnitude of error in the SRS low frequency range.

This type of procedure could be used to recover data. More investigations are needed before to apply it.

The subject has been analysed by some authors (Smallwood [17]). Such a correction will of course necessitate very good engineering judgement; because it is very difficult to know how credible is the data just after the saturation occurred. The best solution is of course simply to reject the data and perform another test but this is not always possible. In that case, it is better to correct instead of pursuing with bad SRS data. This is especially true when the data is used for the definition of a test specification. When recovering, both signals (original and recovered) should be processed and documented in the test report.

2.5. Repeatability.

The test has to be repeatable when all the control parameters are the same. This is of primary importance. The difference between two test results has to be much lower than the test tolerances in at least three cases:

a. from test to test to allow the trial-and-error process but also to allow the performance of additional tests when several firings at the same level are requested,
b. after dismounting of the dummy and mounting of the test item,
c. after entire dismounting of the test fixture.

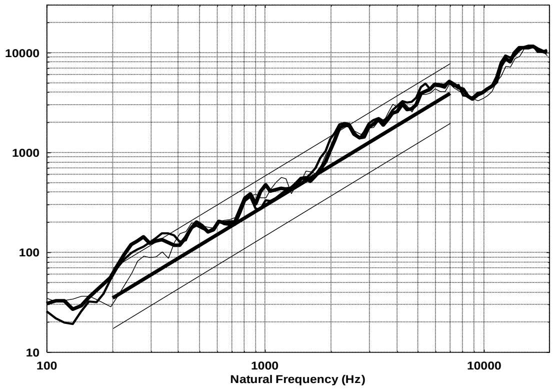

Figure 19. Ordnance Excited Pyroshock Tests.
Test repeatability according to requirements a and b.

Requirement (a) and (b) are almost always achieved. Requirement (c) is often achieved but, in some cases, additional adjustments are needed.

The test repeatability is much better with steel test fixtures than with aluminium structures.

3. EFFECT OF SOME PARAMETERS.

For mechanical impact, the main parameters affecting the shock amplitude, shape and direction have been previously described. Detailed information is given in [4] and [9].

In ordnance tests, the main parameters are the type of test fixture assembly, the location and size of the explosive charge, the explosive charge mounting details, the location of the test item on the test fixture and the damping control. Hereafter, three of them are discussed.

3.1. Effect of the type of test fixture.

The type of test fixture is the most important parameter to succeed in the trial-and-error process. It allows to cover a wide area of the SRS diagram above 1500 Hz.

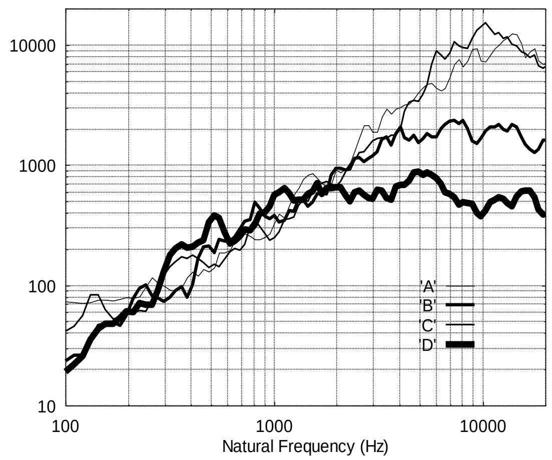

Figure 20a. Effect of the Test Fixture Set-up.

3.2. Effect of contact/non-contact explosion.

The explosion generates both airborne and structure-borne loads. Usually, the explosive is directly attached to the test fixture and both loads act together. In some cases, the explosive is attached to a second test fixture located at some distance of the first one. That allows to decrease the high frequency content close to the test item.

3.3. Effect of the explosive location.

The explosive location modifies the spectral content as well as the amplitude as shown on Fig.20c. However, this parameter is mainly used to equalise the relative amplitude and shape of the SRS's measured in the three directions.

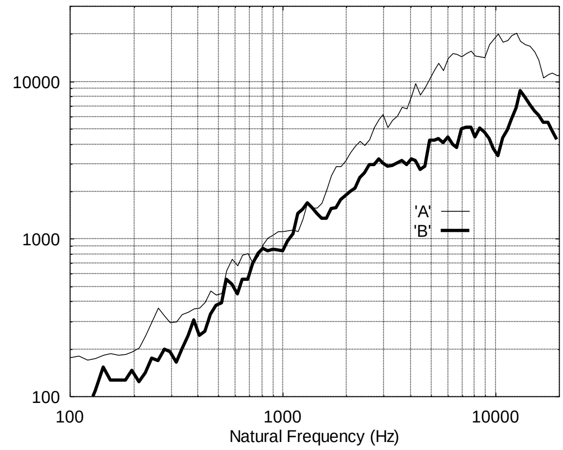

Figure 20b. Effect of Contact/Non-Contact Explosion.

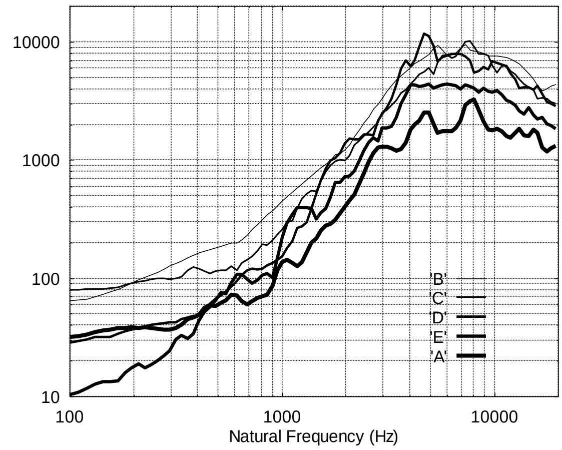

Figure 20c. Effect of Explosive Location.

3.4. Explosive testing: advantages/disadvantages.

Explosive testing is more difficult to implement than mechanical testing due to numerous safety issues but it has a number of advantages:

- it generates high accelerations and high frequencies,
- one firing gives excitation in all directions,
- the impact location can be easily modified,
- the pyroshock levels experienced by the test item through its fixation points are more uniform than the levels obtained with mechanical impacts.

Unfortunately, it has a number of disadvantages :

- numerical simulation is very difficult.
- the decreasing of the amplitudes at high frequency is more difficult to achieve.
- the ordnance test generates dust.

3.5. Some case histories.

More than 1000 firings have been performed for the qualification of about 40 units. In most cases, an explosive charge has been used.

The main concern of the test lab is to achieve the required spectra without over or under-testing. The out-of-plane requirement (Z axis) is usually easily obtained. The problem often comes from the in-plane directions (X and Y axes) especially in the low frequency range i.e. under about 3 kHz. Flexural test fixture vibration modes (Z axis) simulate the specified pyroshock environment better than in-plane fixture mode shapes. So to improve the test results, 3-D test fixtures are preferred.

Two ordnance test results are shown hereafter (tests A, B).

In each test, the two SRS plots are the result of one firing. In ordnance tests, it is possible to meet the requirements in all directions at once when an appropriate test set-up has been defined.

In most cases, the Z axis response has the highest amplitude compared to X and Y axes whatever the test fixture, the type and location of the excitation device except when the fundamental bending mode shapes of the test fixture assembly act in the test item in-plane direction (Fig.21e).

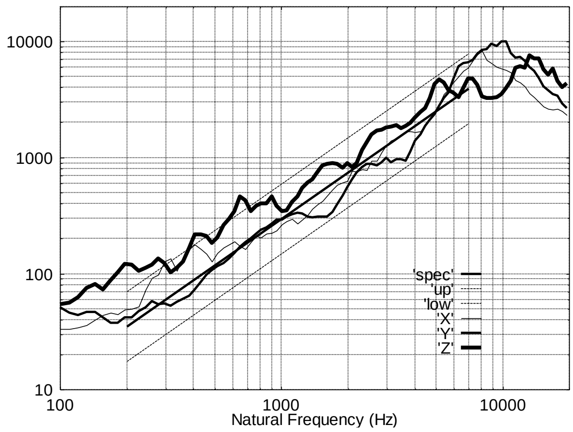

Figure 21a. Unit A.

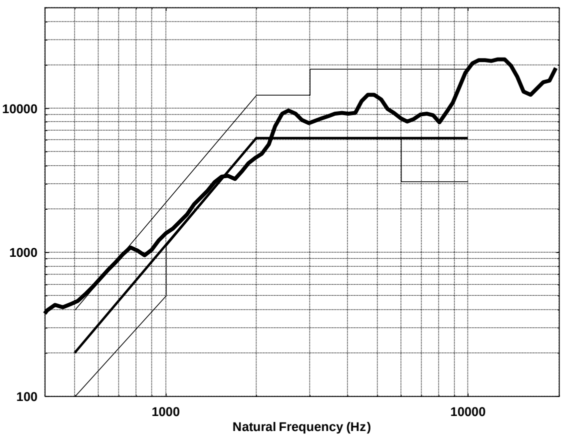

Figure 21b. Unit B. Out-of-plane direction.

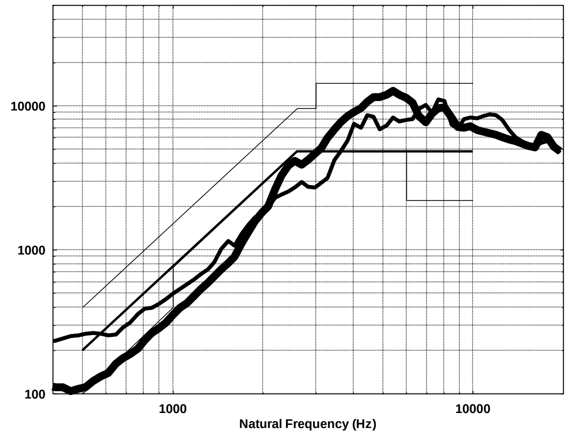

Figure 21c. Unit B. In-plane directions.

A large variety of SRS shapes has been simulated. Examples are shown in the Fig.21d.

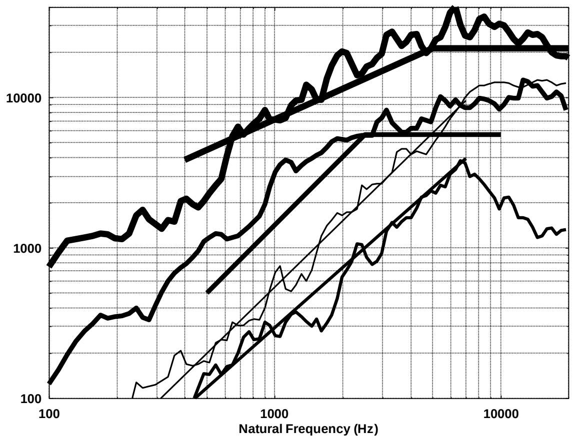

Figure 21d. Matching of some specifications. Out-of-plane directions.

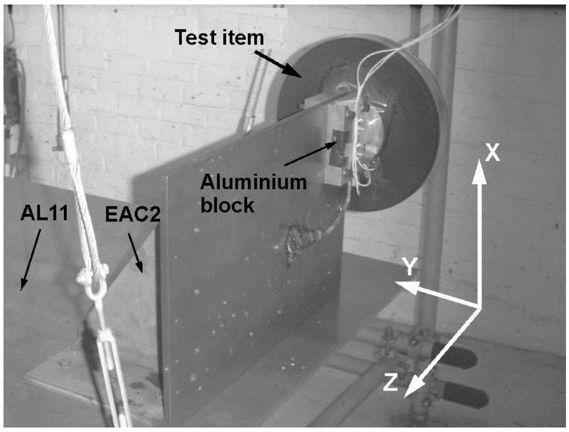

Figure 21e. Test setup for in-plane excitation.

4. HOPKINSON BAR.

The main concerns with the previously described test devices are cost and delay due to the amount of trial-and-error required.

Devices that use resonant test fixture and mechanical impact eliminates much of the trial-and-error described before. They have been extensively described [2], [6], [7]. A resonant test fixture is designed such that it's first mode of vibration has a frequency at or near the SRS knee. This can be obtained with plates in bending or bar excited in longitudinal modes (Hopkinson bar).

The drawback is that these devices are dedicated to a typical test requirement that exhibits a characteristic "knee" where the spectrum changes from a raising slope to a constant amplitude.

The frequency of a bar longitudinal mode shapes are given by:

$fn = n * c / 2 * L$

where $n = 1,2, 3, ...$
c = compression wave speed ($c^2 = E/\rho$)
L = bar length
E = Young's modulus
ρ = mass density

The main characteristics of our Hopkinson bar are:
- dimensions: 250mm x 250mm x 1400mm
- St50 steel
- mass: about 700 kg
- longitudinal natural frequencies: 1860 Hz, 3720 Hz, ...
- available surface for test item fixture: 250 x 250 mm.

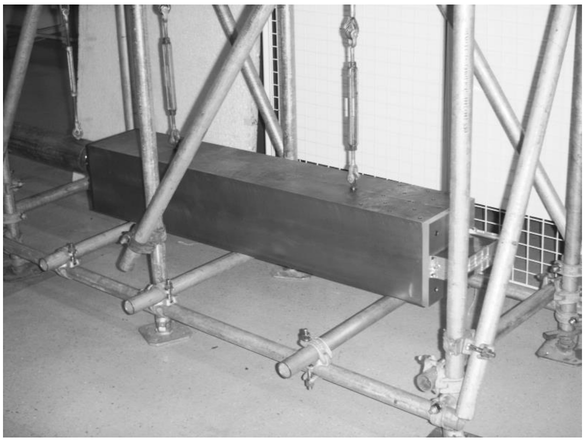

Figure 22. Hopkinson Bar.

This test fixture simulates an SRS with a knee frequency at about 1860 Hz when it is excited in such a way that the first mode shape is dominating. If this mode shape participates nearly alone, the SRS falls at higher frequencies. In order the SRS to be flat, the 2^{nd}, 3^{rd} , ... mode shapes must be excited as well.

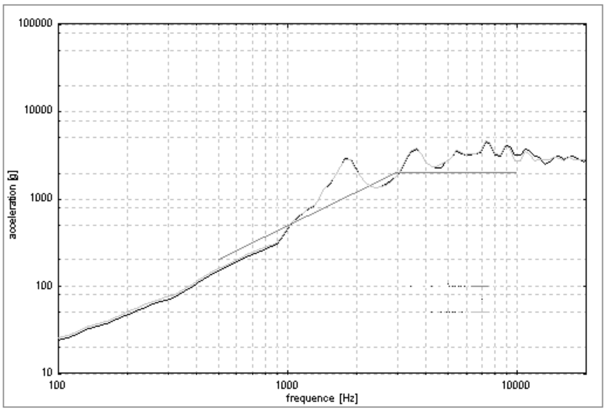

Figure 23a. Hopkinson Bar Test Results. Several modes are excited.

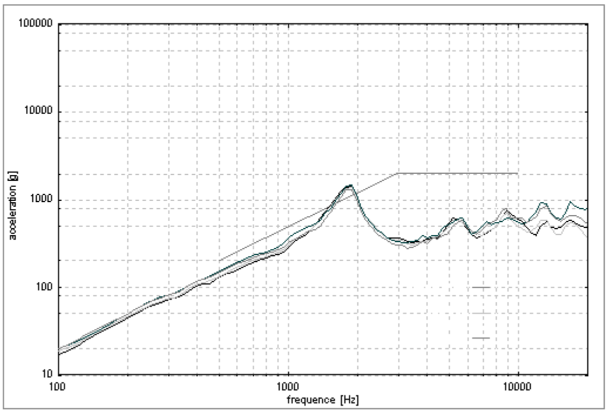

Figure 23b. Hopkinson Bar Test Results. First mode dominates. .

Once the adequate excitation method has been selected, minimal experimental adjustment is required to attain the specified SRS. The parameters are

- impact mass,
- impact speed
- impact duration (by using various shock programmers)
- fixture damping (clamps are attached to the fixture)
- clamp position (relative to the nodes of the desired mode)

The impact duration together with clamp location determine the relative participation of the different mode shapes to the bar response. The duration should be one half the period of the desired mode and the clamp should be located at the nodes of the desired mode.

Some additional damping is needed because the fixtures have very little damping of themselves and resonate for hundred of milliseconds instead of the expected tenth of milliseconds.

The response of this heavy test fixture is not influenced by the test item mass and so a test set-up can be used for a variety of test items.

One disadvantage of this method is that the excitation at the test item interface is in-phase from point-to-point.

For practical reasons, the test item is attached to an intermediate fixture such as a square plate. A steel plate gives better results than an aluminium plate (the input is less altered).

Several excitation techniques have been tried (air gun, pneumatically driven piston, sledge hammers). The best results have obtained with a heavy sledge hammer.

9. CONCLUSION.

The Alcatel ETCA pyroshock test facility provides a versatile capability for shock testing of electronic units according to a wide range of test specifications to be met in the three directions. The test facility has already been used successfully for the qualification of about 40 units.

Achieving the desired Shock Response Spectrum in the direction normal to the test item mating plane does not require too much trial-and-error because of the accumulated experience and data base (more than 1000 firings).

In the directions parallel to the test item mating plane, the requirements are much more difficult to achieve when the acceleration is flat above a knee frequency and the amplitude requirement is the same in all directions.

The Hopkinson bar concept should help to perform much cheaper tests but its “damage potential” has still to be demonstrated. As a first step, it will dedicated to the evaluation of small shock sensitive components (relays, magnetic components, ceramics, glues).

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