SIMULATION OF PYROSHOCKS

U. von Wagner, N. Jüngel
TU Berlin, Institute of Mechanics
Einsteinufer 5-7
D-10587 Berlin
Germany

S. Ritzmann, A. Bäger
Astro- und Feinwerktechnik Adlershof GmbH
Albert Einstein-Str. 12
D-12489 Berlin
Germany

ABSTRACT

In commercial and scientific space programs pyroshocks are a fixed part of the test requirement for instruments and equipments. In the last years different test set-ups have been used to perform pyroshock tests.
Although there is a broad band of test experience, the state of the art for pyroshock testing is an experimental method and the set-up is defined primarily empirical. Therefore a better knowledge of the dynamic effects is the goal of a current study. The tasks of the study are in better understanding the shock initiation in the shock plate and the interaction of the shock plate with the test item. For this purpose experimental measurements and analytical calculations are used.
With the results of the study new test set-ups are to be investigated in order to develop a new test facility for pyroshock testing of instruments and equipment units.

1. INTRODUCTION

Pyrotechnic shocks or pyroshocks are transient motions of structural elements, assemblies, subsystems, or systems due to explosive loading induced by the detonation of ordnance devices incorporated into or attached to the structure.
A pyroshock is characterized by its high peak acceleration (300 g – 300 $*10^3$ g), high frequency content (100 Hz – 1 MHz) and short duration (10 µs to 10 ms), which is dependent on the source type and strength, structural type and configuration, and especially the distance from the source to the response point of interest.

For aerospace applications, explosive devices are generally used to separate structural subsystems, e.g. payloads from launch vehicles, deploy appendages, e.g. solar panels, or operational subsystems, e.g. propellant valves or magnetometer. Current spacecraft design often utilizes numerous explosive devices over the course of a mission.

Figure 1. Space component.

Figure 2. Satellite with solar sail.

2. FIELDS OF APPLICATION

Generally there are two categories of pyrotechnical devices: point sources, including explosive bolts, separation nuts, pin pullers and pushers, bolt and cable cutters and line sources, including flexible linear shaped charges (FLSC's), mild detonating fuses (MDF's), primer cords and others [1].

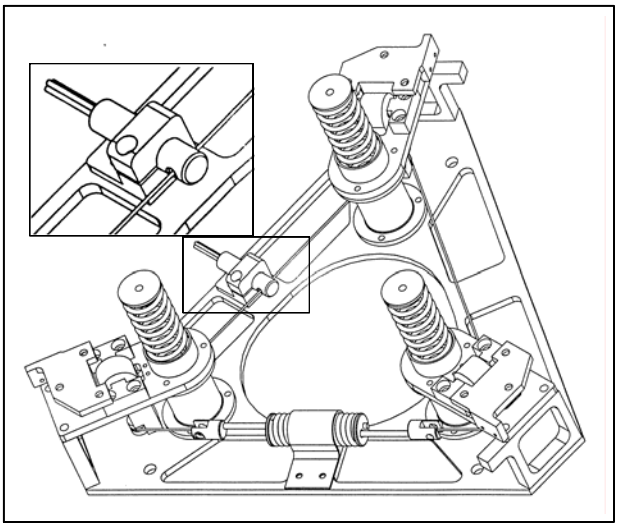

Figure 3. SSC micro satellite launch adapter with cable cutter.

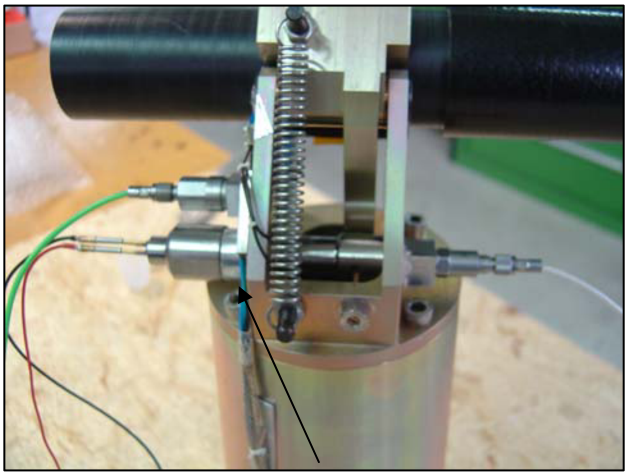

Figure 4. Deployment mechanism with explosive bolt.

Because of the high frequency content, many small elements resistant to random vibration are susceptible to Pyroshock induced failure. Particular examples of Pyroshock induced failures include cracks and fracture in crystals, ceramics, epoxies, glass envelopes and others.

3. STATE OF THE ART OF PYROSHOCK SIMULATION

In the last years different test set-ups have been used to perform pyroshock tests [2]:

- Pyroshock performed with impact pendulum hammer (figure 5)
- Pyroshock performed with freehand hammer (figure 6)
- Pyroshock performed with bolt shot device (figure 7)

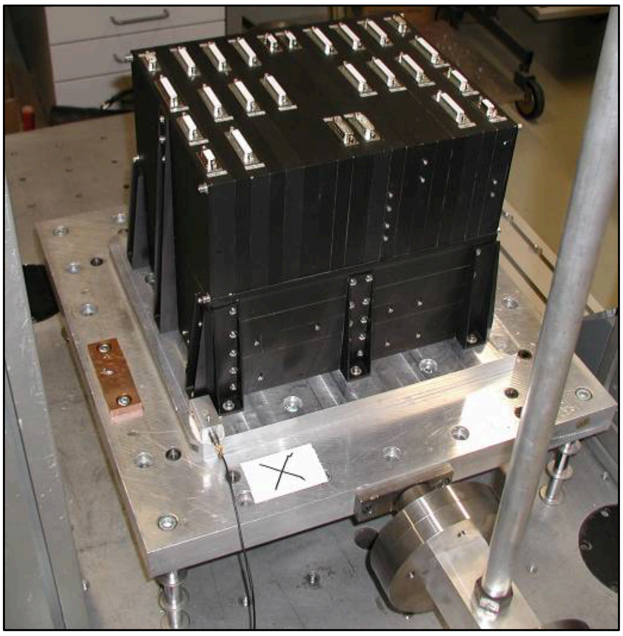

Figure 5. Pendulum hammer on an E-box (DLR).

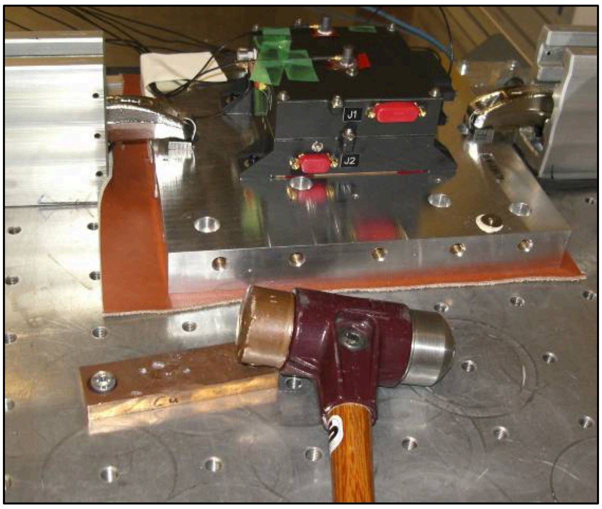

Figure 6. Freehand hammer on a MPS E-box [3].

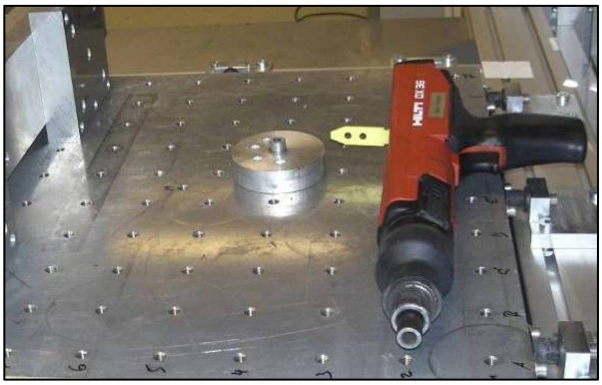

Figure 7. Bolt shot device.

In spite of this broad band of test experience, the state of the art for pyroshock testing is an experimental method and the set-up is defined primarily empirical. Therefore a better knowledge of the dynamic effects is the goal of a current study.

4. MODELING OF PYROSHOCK SIMULATION

The tasks of the study are in better understanding the shock initiation in the shock plate and the interaction of the shock plate with the test item. For this purpose experimental measurements and analytical calculations are used. The principal aim of these investigations is to get knowledge about how to produce predictable and reproducible pyroshock simulations. An additional goal is the realization of shock response spectra due to customers' desires. With the results of this study test set-ups are to be investigated in order to develop a new test facility for pyroshock testing of instruments and equipment units taking into account the essentials mentioned before.

4.1. 1-D Approach

As a first analytical approach the 1-D wave propagation in a rod due to mechanical impact is investigated. A cylindrical rod made of aluminum (length: 1m, diameter: 20mm) that is initially at rest is struck by a rigid sphere (steel, diameter: 100mm). At the end of the rod the velocity and the acceleration are measured by a laser vibrometer and an accelerometer. This experimental set-up is sketched in figure 8. An alternative way to create the impact is the use of a pendulum hammer.

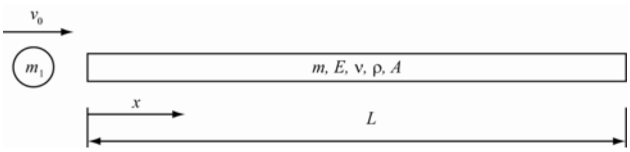

Figure 8. Impact of a sphere with rod.

A simulation of the impact is run with MATLAB, using both St. Venant`s contact theory and the Hertzian contact theory described in [4] by Hu, Eberhard and Schiehlen. A comparison of measured velocity and acceleration time histories compared with simulated ones is shown in figures 9 and 10 respectively.

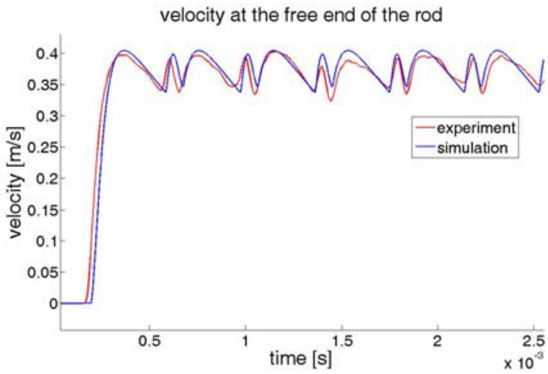

Figure 9. Velocity at the free end of the rod.

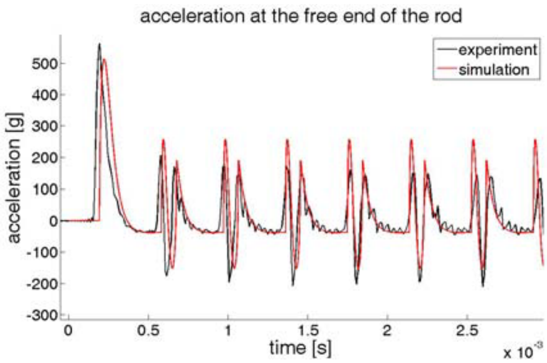

Figure 10. Acceleration at the free end of the rod.

The acceleration signal is used to calculate the shock response spectrum (SRS) described e.g. in [5]. The SRS is not equal to the classical Fourier spectrum but also gives a description of frequency contents of a signal and is the standard description of pyroshock properties. It applies the measured acceleration time history as a base excitation to an array of virtual single-degree-of-freedom systems. The natural frequency of each single-degree-of-freedom system is equal to the frequency sampling point in the SRS, where the actual SRS value is given by the maximum amplitude of the response acceleration.

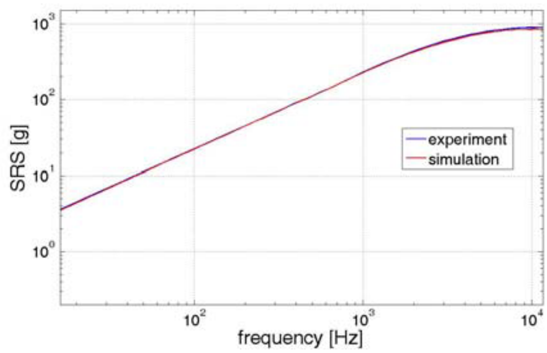

Figure 11. SRS of acceleration time history in figure 10.

The comparison of experimental and calculated SRS in figure 11 shows a very good coincidence. This fact could be observed for multiple experiments in ranges of acceleration amplitudes significant for pyroshock approaches.

4.2. How to influence the SRS conventionally

As stated above, the aim is to produce desired SRS given by customers. So the question arises, how to influence the SRS characteristics. Therefore, the following parameters are varied in simulations: mass of the sphere, the diameter and the elastic modulus of the sphere. Figure 12 shows corresponding results to be compared with the SRS in figure 11. As a result it can be stated, that the elastic modulus varies the SRS in the high frequency range (in our experiment for frequencies >1 kHz) while the mass of the striking sphere mainly influences the low frequency range (<1 kHz). For real experiments, mass and surface diameter of the contact area of course can be varied in a wide range. In contrast to this, the elastic modulus of course is fixed by the material used. The graphs in figure 12 also show that the possibilities to "raise" desired spectra are somewhat limited. Therefore a mechatronic device for pyroshock simulation will be sketched in the following section.

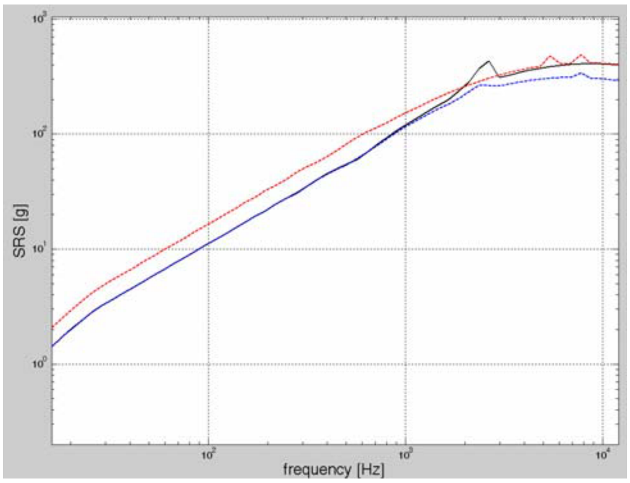

Figure 12. Variation of SRS:
original SRS (black); sphere with increased mass (red); sphere with reduced elastic modulus (blue).

4.3. Mechatronic pyroshock device

As an alternative energy source an electrodynamic shaker was used for a pyroshock simulation set-up. Corresponding SRS results are shown in figure 13, where a control was used giving spectra boarder lines by the red curves. The blue line shows the realized SRS. It can be clearly seen that there are some deviations to the desired spectrum in the low frequency range as well as in the high frequency range. The main deficiency of this method is the deviation in the high frequency range. Of course it is well known, that electrodynamic actuators are mainly to be used in a mid frequency range which enables a sole use of an electrodynamic actuator only for very low acceleration amplitudes. One big advantage of a mechatronic device is of course, that almost arbitrary electrical excitation signals can be produced promising also a high performance in producing desired SRS.

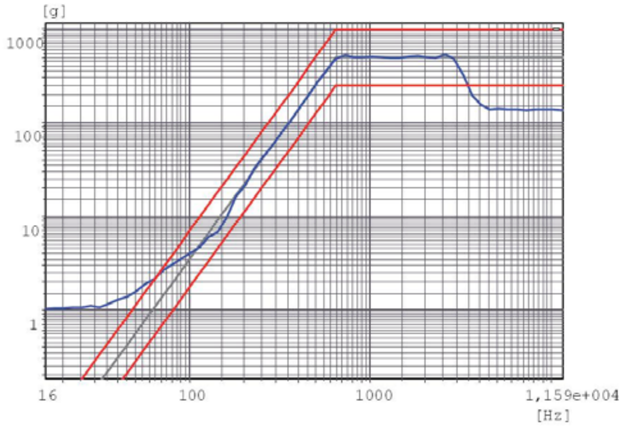

Figure 13. SRS produced by shaker.

The authors of the actual paper see an alternative method for getting high acceleration amplitudes in high frequency range in using piezoceramic actuators. Piezoceramic actuators can be specified by containing high dynamic forces but only small displacements. Figure 14 shows a corresponding experimental set-up, where a "self-made" piezoelectric staple actuator at the down-side of an aluminum plate is used for exciting shock accelerations.

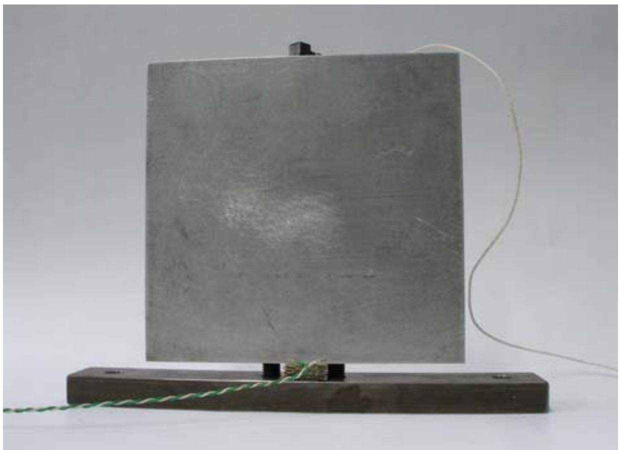

Figure 14. Piezoceramic actuator at bottom-side of a plate.

The corresponding SRS in figure 15 makes clear, that high acceleration levels are obtained (only) in the high frequency range. A promising pyroshock simulation set-up therefore can be seen in combining shaker and comparable small piezo actuators as used in the experiment described. Nevertheless, commercially manufactured piezo staple actuators show a much higher performance then the "self-made" used in the experiment. Comparing force-displacement characteristics of commercial piezo stacks with those calculated in the simulations for the conventional method in section 4.1 clearly show that there is the perspective to cover a wide range of SRS tests by using piezoceramic actuators for shock excitation.

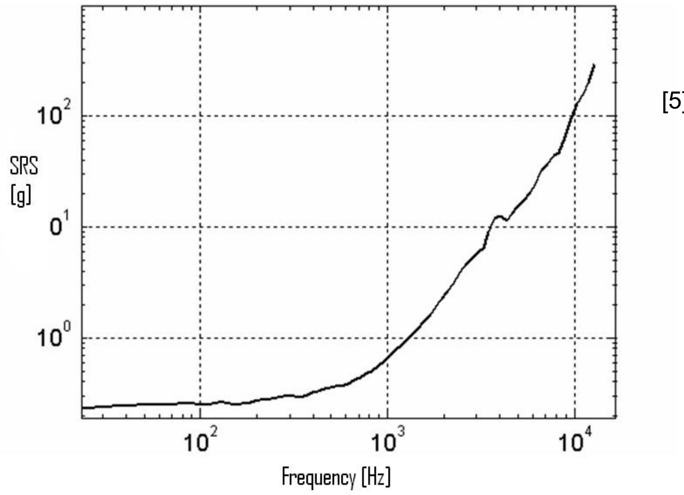

Figure 15. SRS produced with piezoceramics.

5. CONCLUSIONS

Pyroshock simulation is of rising interest in commercial and scientific space programs. In the last years different test set-ups have been used to perform pyroshock tests.

Although there is a broad band of test experience, the state of the art for pyroshock testing is an experimental method and the set-up is defined primarily empirical. The aim of the study is to produce predictable and reproducible acceleration time histories with shock response spectra (SRS) defined by customers.

Simulated SRS for 1-D longitudinal wave propagation are very close to those measured in the experiment. Hence good results in a 2-D model are expected. The problem of conventional pyroshock simulation by a striking sphere or pendulum is that the “raising” of desired SRS is somewhat limited. Therefore a mechatronic test device using piezoceramic actuators or a combination of piezoceramics and a shaker is introduced, which is promising extensive possibilities to create desired SRS.

With the results of the study new test set-ups are to be investigated in order to develop new conventional and mechatronic test facilities for pyroshock testing of instruments and equipment units.

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