PYROTECHNIC SHOCK WORKSHOP

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DESIGNING ELECTRONICS FOR PYROTECHNIC SHOCK

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The following are comments made at a Pyrotechnic Shock work session. Experience with testing and designing spacecraft electronic equipment for pyrotechnic shock are described.

I would like to start by outlining my experience. Almost all the electronic equipment (black box) I have worked on has been for our own spacecraft. Most of which are small rugged assemblies with no moving parts. The test levels that are imposed on these typical spacecraft electronic equipment range from a peak shock spectrum of 1000 g's starting at 1000 Hz up to 17,000 g's starting at 4000 Hz. The shock spectra for drop-tower shock tests for piece parts usually are in the 1500 g to 5000 g range. I will talk about my experience in designing this type of equipment for these levels. The design spectrum and the test method, because the test method is just as important to me, if not more so, than the absolute level of the environment. I must design differently for a Drop tower, for a "ringing plate" or for an actual pyrotechnic on a spacecraft, even for the same spectrum. The test method makes a big difference, whether I pass or fail the test, so the test level and the test technique must be considered together.

My experience in shock testing piece parts has run mainly with the drop-tower. I have not failed any piece: parts such as transistors or flat packs up to shock levels of 5000 g's. I therefore expect success in the 2500-5000 g region. But, relays and crystals are a different story; here failures usually begin to occur in the vicinity of 2500 g's so the 2500-5000 g area usually becomes a gray area. The lowest shock test level, however, where I have experienced parts failures was around 800-900 g's during a shock test on a relay. This gives you an idea of the region that I am concerned with. Most of the relays used in our equipment can withstand shocks up to 2500 g's; this is our standard relay. Twenty-five hundred g's is the beginning of a gray area where the shock resistance of shock designed relays and crystals becomes marginal.

My drop-tower shock testing experience with electronic equipment has been with fairly small units. Structural failures of the mounting feet have occurred in the region of 2500 g's. I, however, have not tested any units to those high levels on drop testers.

I have also had considerable experience using a shaker as a shock simulator for units. In this case, no structural failures have occurred at 2500 g's on quite a number of units. However, crystals in a unit and a small microswitch with a gold bonded wire have failed at this level. In addition, numerous relay transfers have occurred in one unit, and a relay suffered some permanent internal damage. Therefore 2500 g's shock is the failure threshold for this type of spectrum using a shaker shock test. This raises the question what shock levels would units without these piece parts endure? I have tested units without these sensitive parts to levels of up to 5000 g's, at 3000 Hz, without any structural failures. This means the structural failure level was above 5000 g's at 3000 Hz. But 5000 g's at 3000 Hz works out to a number of approximately 1.5 using the velocity type frequency relationship, so I was up to a number of 1.5 without a structural failure, but I was just marginally failing crystals and other sensitive parts down in the 0.8 region.

I have also had experience testing on a structure which simulated the actual spacecraft structure. Everything passed at 2500 g's. I even had the same unit in this test that failed the 2500 g shock test on the shaker. I didn't even get relay chatter. In addition we have actual spacecraft test firing, where we fired the real pyrotechnic devices, e.g., bolt cutters, pin-pullers and the like, no failures have occurred at any time. Levels as high as 7000 g's have been measured near a TWT. Most levels however are well below the 2500 g TWT specification I had for the simulator. Overall therefore extrapolating from this experience I expect the failure threshold to be reasonably above the 2500 g peak. .

Another technique was the "ringing plate." I have rested a few units up to 4500 g's without failures. I must point out however, that there were no sensitive parts in those units. The highest test level I have ever reached was 18,000 g's during a shock test on one unit. The only structural failure, if I can call it that, was some screws became loose after several test runs. I didn't fail piece-part leads, circuit boards, or basic structure. Again, there were no particularly sensitive parts. From this limited experience for our spectrum Shapes, structural failure of units seem to be above 4500 g's.

Why am I having this inconsistency in trying to develop my failure level? One answer is that one test method, for the same shock spectrum is substantially worse than another. I therefore would have to compare the failure criteria against the test method. I believe that shock tests on a rigid fixture on a shaker, would, on a peak spectrum, differ in severity by a factor of approximately five. That is, if the failure level on a rigid fixture is 0.8 times the frequency then the same equipment would pass at a level of 4 times the frequency on a simulator or on a real structure. Failures might even occur at a lower level, 0.6 times the frequency, if the tests are conducted on a drop tester.

Next we should compare the test method and requirements with spacecraft flight data. For most tests we have enveloping techniques, margins are imposed, the shock wave is correlated at the mounting feet, and the test fixture or plate is fairly rigid. All of these differences produce a much more severe shock test than the actual spacecraft environment. As a result the actual margin is really higher than specifying agency thinks it is imposing. Likewise the design should consider these tests differences when evaluating the test damage potential.

Now to a new topic. How do I design the unit to resist pyrotechnic shock? First, I must recognize the basic failure mode. Let's review the structural failure mode first. I have not experienced any structural failures in the 5000 g region on a unit that was designed to resist random vibration levels at approximately 0.3 to 0.4 g^2/Hz at the first fundamental resonant mode of the unit. For example, on one program we have a shock specification of 4500 g's and a random vibration environment where the PSD is 0.4 g^2/Hz at the resonant frequency region of the unit. We will design the structure to pass the random vibration test, and we expect the same design to structurally pass the 4500 g pyrotechnic shock requirement. Our design criteria is to design for the random vibration, don't design for pyrotechnic structural loads.

Now let us consider the failure modes of transistors and diodes. I don't expect those parts to give me trouble. So nothing unique needs to be done. But, when relays, crystals, or switches are present, I begin to worry, and I don't trust a 4500 g level. In this case failures might be avoided by selective use of available parts and by providing out the available parts with their own special shock tests. In the past we have had to use parts for electrical reasons, and we did not find their shock resistance was acceptable hard mounted. We therefore, as one example, have isolated those parts, e.g., crystals and big power relays within the unit itself. We have developed compliant mounting for alumina substrates. They are shock resistant to above 5000 g's.

This is another possible failure mode. The position accuracy of frictionally held items can be affected. (After yesterday's talk I will refer to this as the zeroshift problem.) Parts held in place by friction, such as a helix in a traveling wave tube, can shift, and they will detune the circuit. This is similar to the failure mechanism with accelerometers discussed yesterday. The sock range where this occurred in my experience was 2500 g's or above.

To summarize my comments, I do not feel most of my problems with failures are true shock design problems. In jest, it can be said "there is nothing wrong with this unit that a change in spec would not fix." For most of my designs, as far as structure is concerned, I design for random vibration and I will structurally pass the shock tests. Next, we must get to the electrical engineer to design out electrical performance failure mechanisms if possible. An example would be to allow a relay to chatter without it being a failure. A crystal can have some noise without it being a failure. Fortunately these piece part abnormalities are not normally failure mechanisms for spacecraft because in the application of that equipment most of the equipment does not need to function during shock.

We also often work with the manufacturers of crystals relays, and the like, to modify parts so that they can pass the environment.

Frequently the part specification does not give the true fragility of the part, but is only indicative of the test level verified. As an example, we had one relay especially designed for us, which was modified from an existing design. The manufacturer maintained the identical specification and just changed the number. We now have two different parts, with the same basic electrical and mechanical specifications, but substantially different capabilities. We have found by our own tests that there can be a big difference between parts, which is information we use in design. In some cases, we have had to shock isolate parts when we have not been able to get the parts up to the level we want. There are however limitations to isolation systems. These include, unacceptable change in crystal electrical characteristics, increased thermal resistance, and volume limitations. When we must isolate we have almost exclusively, isolated the one part within the unit itself, and not the whole unit.

There are other design techniques which I also use. As an example; I have gone the route of making my structure and using as many joints as I can to get up to critical part.

If friction is important to the performance of the part, then we try to eliminate as many frictional joints as we can by bonding or some other kind of locking device that can hold the part in place. And finally, when we work with the spacecraft layout, those units which we expect to be shock sensitive, we try to locate them further from the shock source. Our shock source, in almost every case is a point source, not the zipper type, so we have been able to take advantage of preferred locations to some degree. This effectively completes the comments I've prepared for this presentation, I however would also like to address some of the points made by Chuck Moening of Aerospace this morning.

Chuck stated that a comment made by contractors is "The shock environment is too short to cause failure, a three minute vibration test is more severe." I'd like to relay my experience. For my shock tests I've not had structural problems but there are other potential problems such as relays or crystals, therefore the statement is partially true.

The next comment he hears from contractors is "Our electronic equipment will be reduced to scrap, if exposed to pyrotechnic shock levels of several thousand g's." My response is I expect typical spacecraft equipment to be capable of meeting shock levels on actual spacecraft structure, exceeding 5000 g's. I expect I can also get up to 5000 g's without failure on "ringing plates" used for unit testing.

The next contractor statement Chuck has received is "The predicted shock levels are much too high or too low." Yes, definitely, both are true sometimes. Another comment from contractors is "Avionics equipment doesn't fail at shock levels below 1000 g's. We are wasting money testing equipment to such levels. Let's delete the test required." My comment is, possibly, if you are judicious with your use of that statement. If you have designs which are tested to reasonable random vibration levels and that do not have the shock sensitive parts, or if you have instituted a program to test those parts, and just select those parts which will survive, then I believe that the statement would be true. Experience is that when these criteria are met then testing the unit at normal 1000 g's spectrum have not given me any information.

The next contractor statement that Chuck has received is "We have never had a flight failure due to pyrotechnic shock, let's delete the test requirement and submit a cost savings." My comment is, Yes, if you have done the proper steps ahead of time and on a selective basis, then I think you can delete some shock test requirements on select programs and on selected types of units. But, not across the board! There are potential shock design failure modes such as relays or crystals. Another failure Chuck discussed was contaminants and the third area was the wire leads and the cracked glass. Chuck also said these occur at shock levels in the range of 3000 and 6000 g's. We however have not experienced any failures of wire leads at this level. I don't have experience with glass, but relays and crystals have failed in this range.

The problem with contaminants is an interesting one. I don't look at contaminants as a shock failure problem. I don't even like to have it in the same category. This is a workmanship problem and a parts problem: it's not a unit shock design problem. I have run into this problem a number of times. We therefore must combat the problem in assembly and not by a qualification shock test. Shock, however can be useful in acceptance testing, but only as part of a series of tests where vibration follows shock. The unit then must he monitored for intermittents during vibration to determine if the shock broke a contaminant lose.

Mr. Moening: Is it your standard practice to use passivation parts?

Mr. Luhrs: Passivation is good practice and is used any and every place where the electrical performance allows it. There have been cases where the electrical performance has not allowed it. I did have one case where a passivated part failed. Two leads coming into the part were so close together that even a small contaminant was able to short across the leads even though we had passivated it.

Mr. Windell (Admiralty Research): I am having a problem with your statement as I understand it, that the test methods supposedly had normally the same spectrum. When you say spectrum you are talking about the shock spectrum. Have you taken into account that the shock spectrum ignores the phase, it throws away phase information? Did your different tests actually have different phase relationships? Was that why you were getting different failure modes?

Mr. Luhrs: You have input phase relationships. When I perform tests on a rigid structure, all of the feet are correlated and the inputs are correlated. When I test on the "ringing plate" I do not have input phase correlation, I do not have the same environment at the same time, I do not have the same impedance matching. So these differences mean that the effect of that shock is different for different test techniques although "I have met the "spec".

Mr. Windell: I would just like to suggest there is a different spectrum involved.

Mr. Luhrs: I have discussed that with Chuck Moening on more than one occasion. We never came to an agreement on that one.

Mr. Windell: You have spoken about the failure of component parts, relays and the like; in general did the failures correlate with resonant frequencies of component parts?

Mr. Luhrs. On the relay, yes. On the crystal, no. The crystal was a brittle fracture, so I would say that it is reacting to the very high frequency ring. The relay has a yoke going around it to support the mechanism. It is that resonant frequency mode that causes the failure. When it rings, it causes motions, and the contacts chatter.

Mr Van Ert (The Aerospace Corporation): I know TRW is one of those people who use this practice; there is a list called the Program Approved Parts Substitution List. Are those parts that can be substituted without supposedly altering the qualification status of the hardware? Are those parts tested, or is there some way of their being validated so that we know we are not substituting a shock sensitive part for a nonshock sensitive part?

Mr. Luhrs: We selectively put the pyrotechnic shock test requirements on relays, crystals, and the like. We do not do it now across the board. As an example, small capacitors and resistors, generally speaking, do not have a pyrotechnic shock requirement. I therefore can substitute parts, which are sensitive, where both have been tested. Parts which are not sensitive are not tested therefore can also be substituted since there is no concern with their capability.

Mr. Silvers (Westinghouse): We are very interested in that comment you made about losing the battle if you get loose particles inside your integrated circuits or components. I think you said, by some sort of procedure, either a sampling procedure, or a qualification procedure you could assure yourself you didn't have this type of workmanship problem. What is that procedure?