Development of a High Force Thermal Latch

William D. Nygren*

Abstract

This paper describes the preliminary development of a high force thermal latch (HFTL). The HFTL has one moving part which is restrained in the latched position by a low melting temperature or fusible metal alloy. When heated the fusible alloy flows to a receiving chamber and in so doing at first releases the tension load in the latch bolt and later releases the bolt itself. The HFTL can be used in place of pyrotechnically activated spacecraft release devices in those instances where the elimination of both pyrotechnic shock-loading and rapid strain-energy release take precedence over the near instantaneous release offered by ordnance initiated devices.

Introduction

Many different types of nonpyrotechnic spacecraft release mechanisms have been developed and qualified for flight. However, as Table 1 shows, there are no simple, resetable, 44500N (10,000 lbf) devices which offer slow strain energy release.

Table 1. Low Shock Release Mechanisms

Type	Maximum Force (N)	Slow Strain Energy Release	Resetable Without Disassembly	Complexity
motor driven	6,500	yes	yes	high
frangible link	40,000	no	no	moderate
memory metal	6,700	no	no	low
paraffin	4,450	no	no	low
thermal knife	700	yes	no	low

The use of fusible metal alloys as the working "fluid" for a rotary damper was presented in the 26 Aerospace Mechanisms Symposium. Therefore, the possibility of using a fusible alloy as the working "solid" in a release mechanism seemed somewhat credible and so a simple test was developed to determine the load carrying capability of a candidate fusible alloy as well as any potential difficulties in sealing the molten alloy against leakage.

Figure 1 shows the test setup. A Hollow cylinder of the solid alloy was machined and placed in the space between a double piston and one side of an internal ledge on the surrounding cylinder. The cylinder was threaded at both ends so that its attachment to the holder could be easily reversed after stroking. In this manner the device was easily reset without requiring compressive loading. An eutectic alloy of bismuth and

* Martin Marietta Astronautics, Denver, Colorado

tin was chosen for its melting point of 138°C which was well above normal spacecraft qualification test temperatures and yet not so high as to require a great deal of energy to melt. With only thermal conductance under consideration, aluminum was chosen for the cylinder to readily conduct heat to the fusible alloy, and titanium was chosen for the piston to block conductance away from the alloy. The cylinder was wrapped with nichrome heating tape and the whole device was placed in a creep rack which could apply up to a 21300 N (4800 lbf) load.

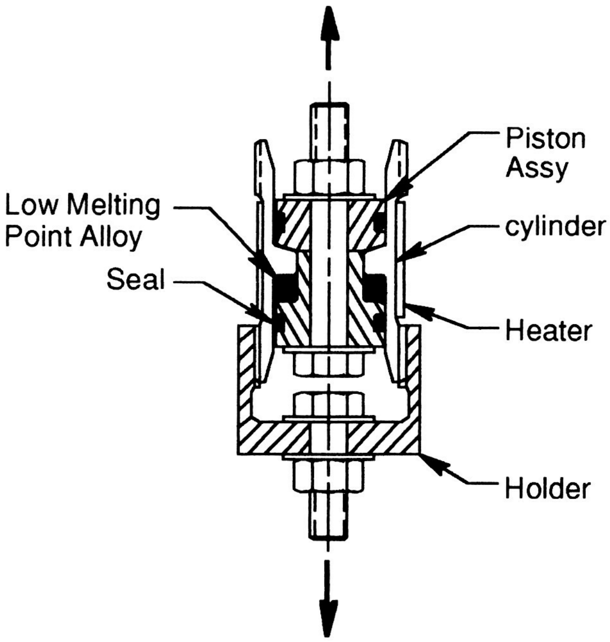

Figure 1. Initial Test Setup

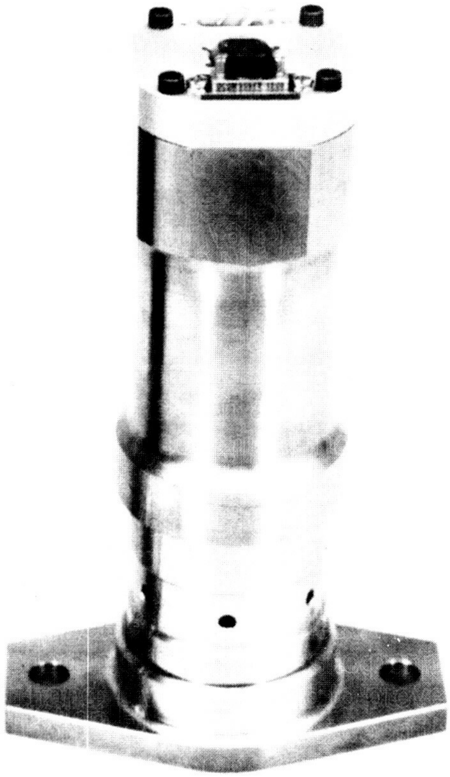

Figure 2. Development Unit

Initial results were promising. The assembly would stroke when heated with only a 20 pound applied force and would apparently hold 21,400 N (78.6 MPa internal pressure) at temperatures up to nearly the 138°C melting temperature of the alloy. The time to stroke was approximately 9 minutes with an input power of 30 Watts. The o-ring seals appeared to work as desired. Next, an elevated temperature (70°C) creep test was initiated which immediately showed that the piston was moving 50 microns (.002 inch) per day. Upon disassembly extrusion of the alloy in the 64 micron (.0025 inch) radial clearance between the piston and cylinder could be observed.

The solution to this problem was first to eliminate the clearance at non-operating temperatures with an interference fit between the piston and cylinder; and second, to choose materials with a large difference in coefficient of thermal expansion (CTE) so that there would be a radial gap or orifice for the alloy to flow through at the operational or melting temperature of the alloy chosen. A new piston was fabricated from Invar 36 with a nearly zero CTE (1.1μ inch/inch/°F) with a room temperature interference of 25.4 microns (.001 inch) at the cylinder dia and 12.7 microns (.0005 inch) at the throat dia. This arrangement worked very well including a 30 day creep test at 70°C with only a 5 micron (.0002 inch) total movement.

Materials

After an attempt to increase internal pressure by simply increasing the throat dia. of the piston lead first to yielding of the original 6061 cylinder and later to the fracture of its "beefed up" 7075 replacement (upon heating), it was realized that greater attention had to be paid to material selection--in particular high temperature yield strength--and that a finite element model of the piston and cylinder would be required to accurately predict stresses and deflections. The finite element analysis showed that the piston and cylinder deflections were counteracting the interference fits. Which meant that stiffness was also a critical parameter. Table 2 lists the primary material candidates according to CTE and other key parameters

Table 2 Material Properties

Material	Coefficient of Thermal Expansion 10^{-6} m/m/°C	Thermal Conductivity W/m/°C	Modulus of Elasticity 10^4 MPa	Yield Strength (20°C) MPa	Yield Strength (200°C) MPa	Yield Strength after cooling MPa
6061-T6	24.5	173	6.8	276	207	248
7075-T7651	24.3	164	7.1	469	193	276
2219-T87	23.9	145	7.2	386	221	338
2618-T61	22.9	156	7.4	372	283	377
W2F.20A-T6	19.3	122	10.4	420	310	
17200-AT	17.5	119	12.8	972		
17-4 PH	11.0	19	19.6	1172	1006	
Ti-6AL-4V	9.4	9	11.0	931	648	
Inco 902	7.6	15	18.6	931		
Invar 36	2.0	10	14.1	276		

2219-T87 aluminum was chosen for the cylinder for its availability and its strength after exposure to high temperatures. This exposure comes mainly from reheating to reset the device during ground test. W2F.20A-T6 which is 2618 aluminum reinforced with Al_2O_3 also looks very promising with its high modulus and high CTE. Inco 902 or Ni-Span-C which is an iron-nickel alloy like Invar but with much higher strength so it was chosen for the piston in spite of its higher CTE.

Development Unit

Figure 2 is a photograph of the development unit. This device has successfully completed 28 functional cycles (18 of which were at the 44500 N level), a 3 axis random vibration test (16.5 Grms),and a 4 cycle thermal-vacuum test (-40°C to +65°C).

The actuation times were 450 seconds from -40°C and 225 seconds from +65°C with 138 Watts of input power. The development unit used a redundant element foil heater which could be safely operated at the 200 watt level out of vacuum.

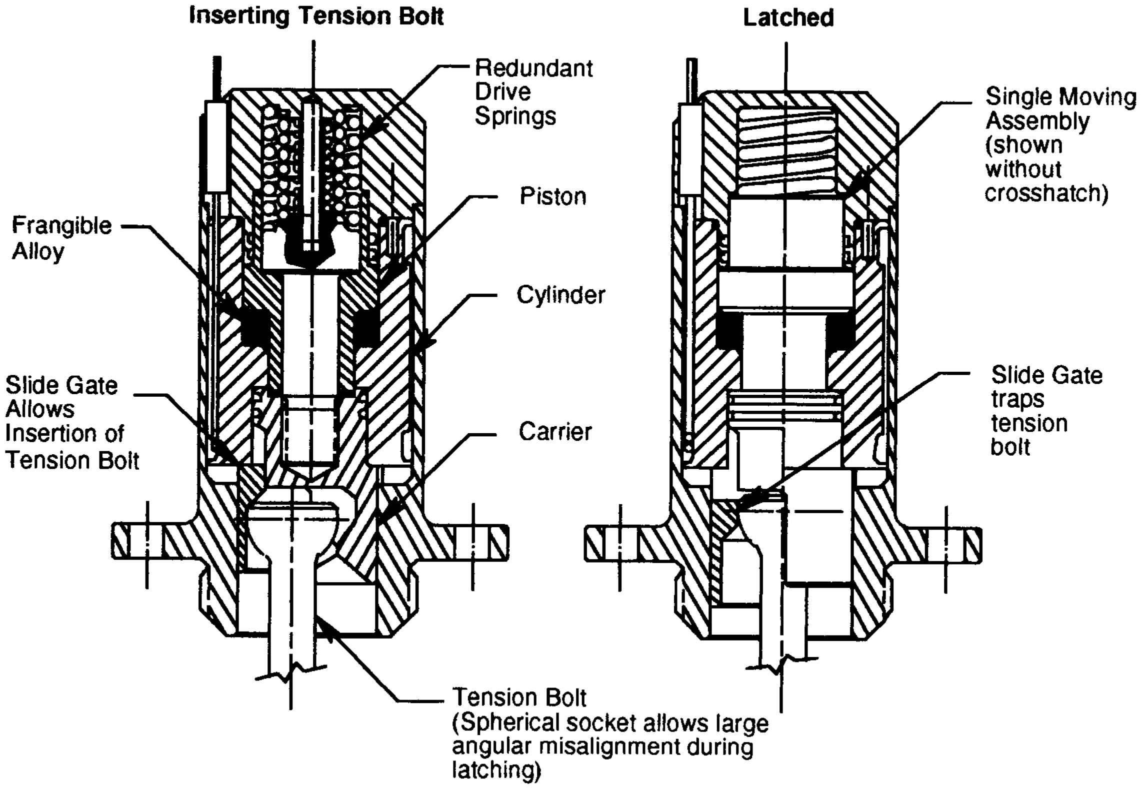

Figure 3 HFTL Cross Section

Two interesting phenomena occurred with the development unit. First, the behavior of the alloy changed from that of a eutectic or single melting point mixture to that of a noneutectic mixture with a slushy stage from 138°C to 175°C. Apparently, when liquefied under stress a lower melting temperature phase is forced out first leaving a non eutectic mixture behind. While too vigorously resetting the mechanism some of this non eutectic mixture was forced by the Teflon o-rings which allowed its composition to be investigated. Second, while the device will hold 44500 N at room temperature and at 65°C has a creep rate of only 145 microns/year (.0057 inch/year) it will stroke 1.4 to 1.7 micron per cycle if cycled between 65° and -40°. This may be a stress relieving phenomenon.

Qualification Unit

Based on desire to simplify the HFTL design plus decrease the operating time (which in turn decreases the total energy required to operate the device) the following changes were incorporated into the qualification unit's design. First, the tension bolt and carrier were changed to MP35N from 17-4 and beryllium copper so that the whole device could be downsized. Second, the foil heater was replaced with a cable heater which can deliver up to 400 watts input power with both circuits powered (see figure

4). Third, a frangible alloy of lead and bismuth with a lower melting point of 124°C has been chosen to replace the tin-bismuth alloy used in the development unit. Concerns have surfaced associated with the phenominum of liquid metal embrittlement (LME) and in this reguard, most tables show liquid tin to be more of a concern than liquid lead when in the presence of aluminum. In the new design the choice of anodizing vs. nickel or chrome plating for LME protection will be investigated. On the piston side of the problem, a central bolt which never comes in contact with the frangible alloy provides tensile backbone for the mechanism. Finally, a spring loaded slide gate was added to the design which allow easy insertion of the tension bolt prior to tensioning.

Figures 3 and 4 show the internal workings of the qualification design which should be somewhat selfexplanatory. The drive springs are incorporated so that even if the tension load in the bolt goes to zero, the drive springs will over come the o-ring drag and completely stroke the piston/latch. The device is reset by first reheating the alloy to liquefy it and then pushing the carrier and drive springs back to their initial position with a tool that mounts the HFTL housing.

Conclusion

The HFTL is a simple one critical movement device which can hold and gently release large tension loads. This capability comes at the expense of a somewhat large power requirement but one that is well within the capabilities of the batteries on today's large spacecraft.

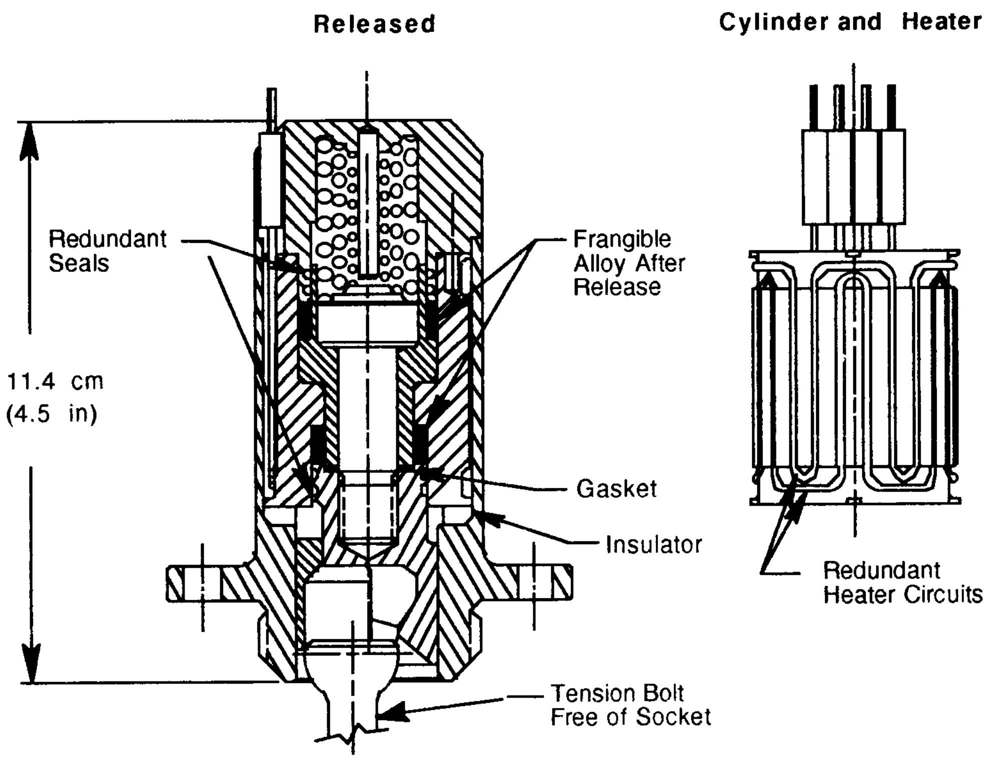

Figure 4. Released Configuration