Association of Metallurgical Engineers of Serbia
AMES

Scientific paper
UDC: 629.7.023.25

SPACE SHUTTLE SOLID ROCKET MOTOR (SRM) FIELD JOINT: REVIEW PAPER

S. Mohammad Gharouni*, Hamid M. Panahiha, Jafar Eskandari Jam

Composite Materials and Technology Center, MUT Tehran, Iran

Received 17.03.2014
Accepted 10.07.2014

Abstract

Due to Challenger space shuttle accident in 1986, significant research has been done concerning structural behavior of field joints in solid rocket boosters (SRB). The structural deformations between the clevis inner leg and the tang (male-to-female parts of joint), the sealing of the O-ring to prevent the hot gas in joints, has been neglected causing the failure of the vehicle. Redesigning the field joint in SRB engine by accurate analysis of dynamic and thermal loads and by design of insulator and good O-ring, the leakiness of combustion hot gases was eliminated. Some parts of field joint such as capture feature (CF) and its third O-ring, J-leg insulator and shim were added to redesigned field joint. Also, some adjustments in sealing system and pins were done to promote the efficiency of the field joint. Due to different experimental analysis on assembled field joints with default imperfections, redesigned joints operated well. These redesigned field joints are commonly used in aerospace and mechanical structures. This paper investigates the original and the redesigned field joints with additional explanations of different parts of the redesigned joints.
Key words: Field joint, Tang, Clevis, SRB, Capture Feature.

Introduction

One of the critical point in structure designing is linking in elements and aerospace structures which are depended on the whole weight of structure. Therefore, the designer tries to do his best to reduce the links. Composite layers which are used in aerospace industry have less links than still structures because they have an opportunity to be built in one level. However, concerning composite materials, linking design and the specific ways by which they are linked, are the main limits in designing. This research is a conclusion of deliberation on an important connection in aerospace structures which has been shown in an aerospace accident and now is rectified.

* Corresponding Author: Seyyed Mohammad Gharouni, s.m.gharouni@gmail.com

On 28th January, 1986, at 11:40 a.m. Challenger space shuttle (shown in Figure 1), has been blown up just 1 min after throwing from Kennedy space Centre in Florida and all 7 astronauts aboard were dead [1].

Engineers believe that the accident which led to subversion of Challenger space shuttle happened by link breaking in the right side of solid fuel rocket engine.

The failure of the O-rings of solid rocket boosters (SRB) makes the gases to leak and blasting **is** shown in Figure 2. All research was started from challenger event to find best structures for field-joints of SRB. A dynamic launch and flight load analysis confirms these reforms of field joints of SRB. Many research groups of NASA performed variety of analysis and examinations to redesign joints [2].

Figure 1. Challenger, the launching day. 1. External tank. 2. Solid rocket boosters [3].

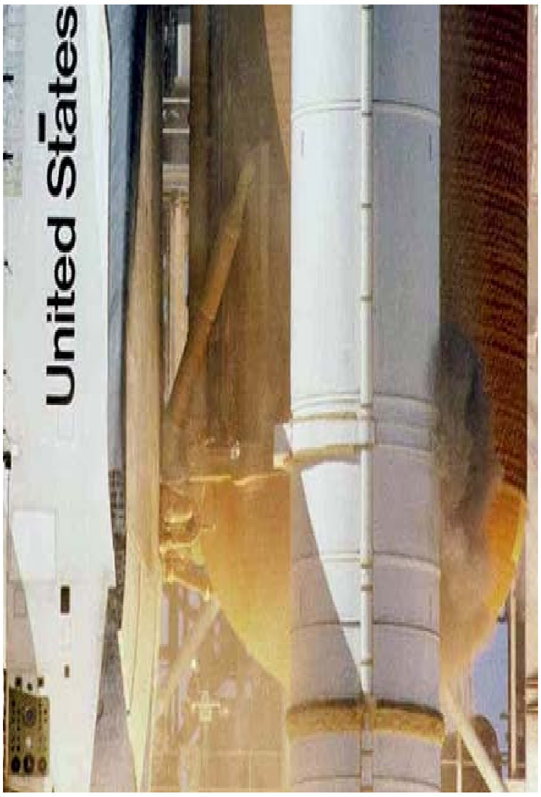

Figure 2. A portray from the fogs and smokes about the right field-joint of the booster of challenger shuttle (SRB) [4].

Field joints structures

Substructure system of SRB is mainly formed of shelters of the solid rocket motor (SRM) that consists of 4 main parts. Isolation engine of the rocket are assembled with the parts of field joints shown in Figure 3.

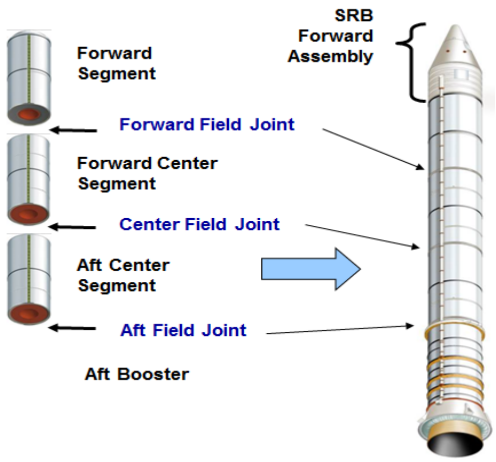

Figure 3. Field-joint in the solid fuel rocket booster (SRB) [5].

The main field joints and redesigned joints in boosters consist of a male-to-female connected joint between two cylindrical shells that are joined together by pins to be shelters of the fuel motor (SRM). The diameter of booster is 3.7 m (12 foot) and the length of 9.1 m (30 foot). The male-to-female parts in joints are considered as tang and clevis that are joined together [6].

The most important varieties considered in field-joints are discussed in the following text.

Capture Feature (CF)

The most important characteristics of these joints are their ability of capture feature (CF) that is a limitation for the maximum deflection between tang and clevis (Figure 4). This feature is an inseparable character of tang in the male-to-female parts of field-joints as shown in Figure 5 and in the abnormal situations when the isolator does not work properly it serves as a thermal isolator in the combustion procedure.

Figure 4. CF on the base of tang [7].

According to Figure 4, CF provides interference fit in the inner clevis part and movement of the tang part is minimized related to two O-rings based on the clevis part. In this case the sealing capability of the primary and secondary O-rings is enhanced.

By a good interference fit, the tertiary O-ring in the capture feature in contact with inner surface of clevis part is locked against the inner surface of the clevis inner leg and does not move during motor pressurization. However, due to the possibility of damage during motor assembly, associated with an interference fit, the tertiary O-ring seal is not relied upon as a primary sealing mechanism in the redesigned joint. The results show that the addition of CF for redesigning of joint significantly decreases the variations of O-ring flaw [8].

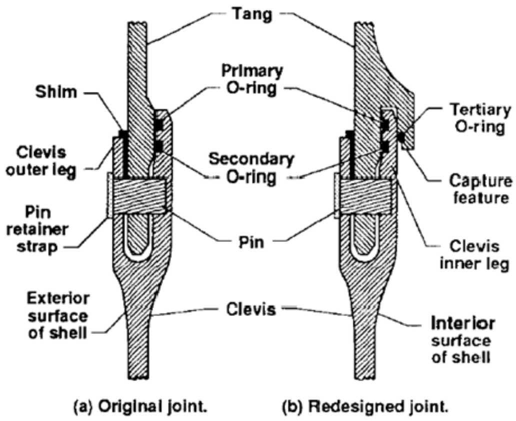

Figure 5. Comparison of the main field-joint and the redesigned one with CF [6].

O-ring

The redesigned inner face of the clevis is machined to improve the sealing system and the third O-ring is added. The compression of both the primary and secondary O-rings was increased by increasing the O-ring diameter by 0.010 inch from the pre-Challenger configuration, and the O-ring grooves were winded by 0.005 inch to prevent four wall contact by the O-ring [6].

Rubber O-rings are used to provide a pressurized sealing at the same time of the engine work. The efficiency of the O-ring in preparation of the sealing is dependent on the relative displacement of parts of joints near the main O-ring.

According to Figure 6, if the bush does not work as a shelter for field-joints, the pressure on the tang and the two-sides of inner leg of clevis penetrates to sealing O-rings.

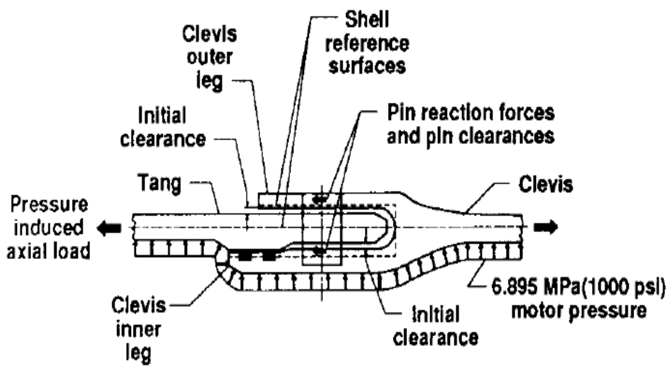

Figure 6. The pressure on inner faces in field-joints without Bosch [6].

Figure 7 shows the distribution of pressure due to the shelters when the initial O-ring seals the joint and the first O-ring collapses**,** and the second O-ring seals the joint, respectively.

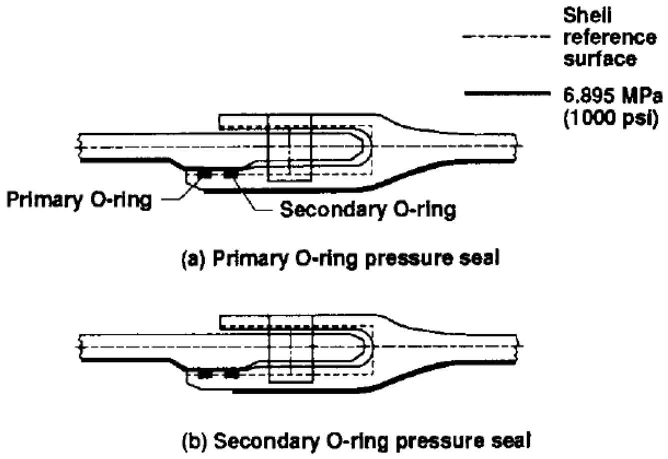

Figure 7. The comparison of the sealing of primary and secondary O-rings in original joint [6].

The flaw which occurred in the bound-line of insulators can propagate to CF O-ring in the direct current. In the case of collapsed line, CF O-ring can be the next obstacle for the entrance of the gas. The third obstacle is interference fit with steal shelters, whereas the primary and secondary sealing O-rings are the fourth and fifth obstacles, respectively.

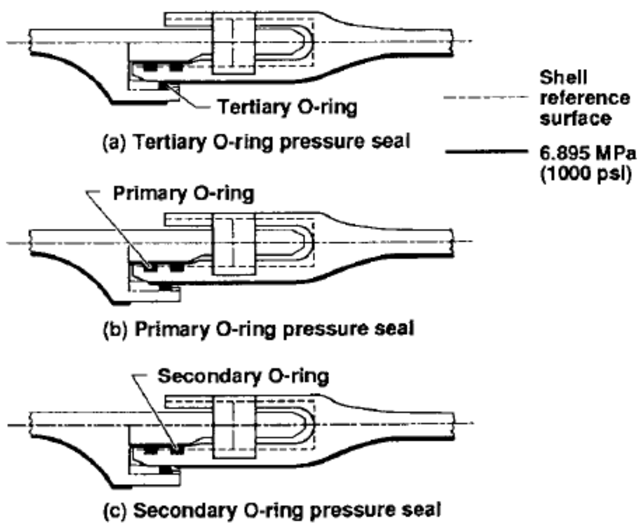

*Figure 8. The comparison of the sealing of primary, secondary and tertiary O-rings in redesign**ed** joint [6].*

Insulators

The inner insulator in the space shuttle redesigned SRM field-joint for thermal isolation steal shelter and the sealing of the O-ring is used. The material of these insulators is made of Acrylonitrile Butadiene Rubber (NBR).

Unvented design is a choice to prevent the entrance of gases of hot cham**b**er into the inner parts of the joints. In this design the hot gases of the motor are banned to reach the sealed O-ring. According to Figure 5, the insulator on the **t**ang part consist**s** of pressure flaw in the shape of J leg. This part is for the convergence of the tolerances of the insulator in contacts, in the situation of the thermal shrinkage and expansion after assembling of the field-joint.

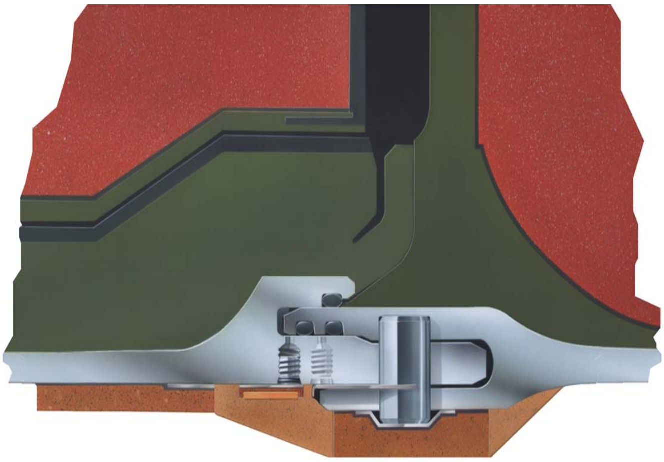

Figure 9. Insulators besides each-other and on the inner face of the field-joint [7].

According to Figure 9, the bound-line of the J shape joint can be considered as the first obstacle against the deficiencies. Due to motor's pressure to the J shape leg of the joint in contact with the clevis insulator, the sealing system of the joint is increased. Also a sensitive adhesive to pressure is added to J shape joint to reach reliability of remaining the J shape joint in contact with the insulator on the clevis. This was done in order to increase the fuel temperature before launching and pressure on the insulator faces [8].

Pins

Every SRM field joint is joined by the pins. Metal pins in rows, in the holes of clevis and tang, hold the joint together.

Increasing length of the pin with holder width-band can increase the reliability factor and these bands cause better holding of pins. Every pin has a few holes to ease the procedure of assembling. All 180 pins are machined in the equal sections and are located in a circle manner on the clevis and tang for both original and redesigned joints [1].

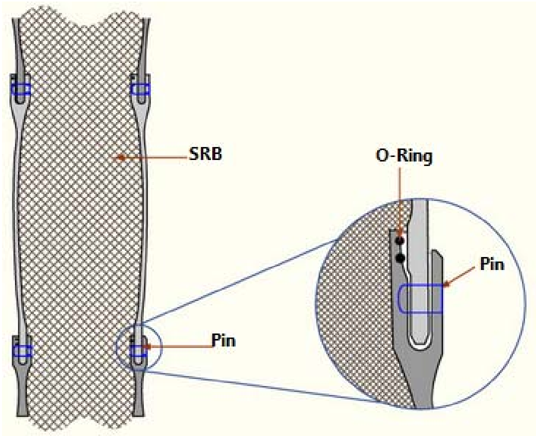

*Figure 10. Pins based on **t**ang and **c**levis [4].*

The filler volume

Definitions:

V_1 =between CF O-ring and the head of CF tip,

V_2 = between CF and primary O-ring,

V_3 =between the head of the CF and adhesive bond,

V_2A =in the CF O-ring groove chamber.

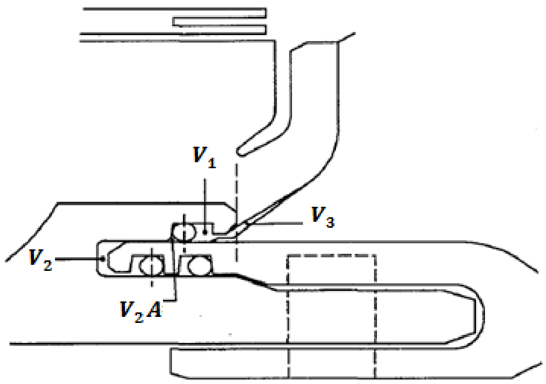

Figure 11. Volumes of the fillers on the field-joint [8].

The most important and more useful of the filler part is V_2. The filler is carbon powder which is located on the tip of clevis as shown in Figure 11, between primary O-ring and tang and is used to reduce the free volume between CF O-ring and the primary O-ring. V_2 filler is located between 8 parts that are separated with 2 inch grooves and uses 0.65% of the free volume and limits the hot gas in the leakage situations to prevent entrance to J shape joint [2].

Shim

The metal shims between the tang and the outer clevis arm are used to control the space between two parts to limit the increasing of growing flaw in primary and secondary O-rings in the pressure and sealing system. Some research is done to investigate the effects of the thickness of the shim on decreasing of the space between tang and pin with respect to the hole of pin. According to the Figure 12, in the first case there is no space between the hole of the pin and tang, but in the second case the shape of the hole of the pin is conical and by increasing the thickness of the pin the space between tang and pin will be decreased.

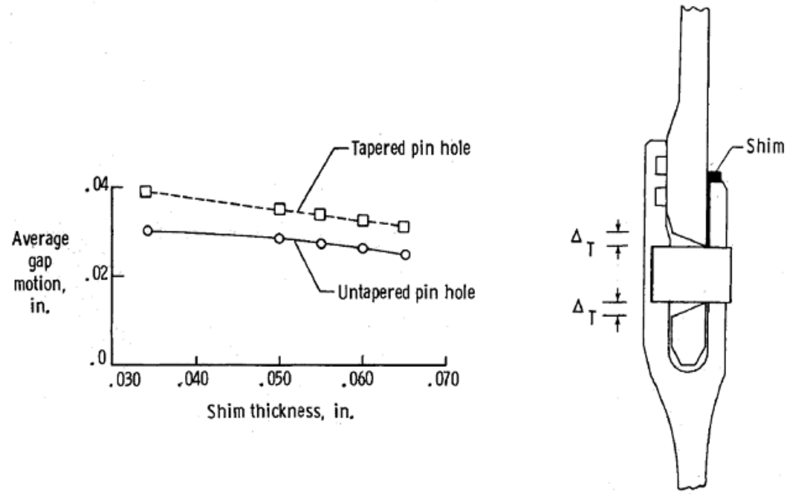

Figure 12. The effect of shim's thickness on the space between tang and the pin with respect to the hole of the pin [9].

Leak Check Port

According to Figure 13, leak check port is used to investigate the primary O-ring in order to check the sealing system of redesigned joint [2, 7].

Leak Vent Port

According to Figure 13, leak vent port is used to release the air between the CF and initial O-ring [2, 7].

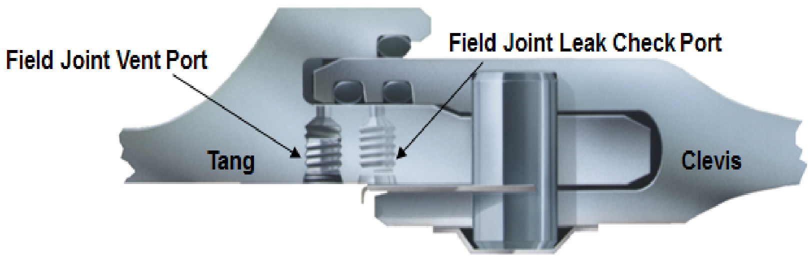

Figure 13. The leak check port and the leak vent port in the field-joint [7].

Conclusions

The most important features that are added or changed on the joints and their effects in comparison to old joints are investigated. Redesigned field joints are widely and safely used in solid rocket motor industry. Application of these redesigned field-joints confirms their reliability. Some new and additional investigations such as vibration analysis on the joints should be done to complete more information on theirs behavior.

References

[1] N.F. Knight, Jr., R.E. Gillian, and M.P. Nemeth, Nonlinear Shell Analysis of the Space Shuttle Solid Rocket Boosters. ed. Springer Series in Computational Mechanics, ed. Springer Berlin Heidelberg. Vol. 1990. Number of 305-326.

[2] W. Harkins, Solid Rocket Motor Joint Reliability 1999.

[3] N. Allman, et al., *The Challenger Space Shuttle Disaster Report*.

[4] http://www.ahrtp.com/RSS-JSfeeds/Shuttles_Challenger_Columbia_Tragedies.html#.UyHc1oVRBK4.

[5] Solid Rocket Booster Processing. ed., ed. Nasa: Kennedy Space Center, Florida.

[6] N. Michael and A. Melvin, Axisymmetric shell analysis of the Space Shuttle solid rocket booster field joint. ed. Structures, Structural Dynamics, and Materials and Co-located Conferences, ed. American Institute of Aeronautics and Astronautics, 1989.

[7] D. Ruddell, D. Holt, M. Yates, B. McQuivey,V. Call, Vacant, Metal Components and Seals. ed., ed. ATK THIOKOL.

[8] M. Perry, et al., Journal of Propulsion and Power. 7(2): 1991 p. 139-145.

[9] W.H. Greene, N.F. Knight, and A.E. Stockwell, Structural behavior of the space shuttle SRM tang-clevis joint [microform] NASA technical memorandum ; 89018. National Aeronautics and Space Administration, Langley Research Center Hampton, 1987.

[10] M. A and R.A.Y. W, Space Shuttle Solid Rocket Motor Program. ed. Joint Propulsion Conferences, ed. American Institute of Aeronautics and Astronautics, 1991.

[11] D. Vaughan, The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA. University of Chicago Press, 2009.

[12] N.F. Knight, Preliminary 2-D shell analysis of the space shuttle solid rocket boosters [microform]. National Aeronautics and Space Administration, Langley Research Center: Hampton, 1988.

[13] D. Garecht, *Space Shuttle Production Verification Motor-1 (pv-1) Static Fire*, Brigham City, Thiokol Corp., Space Operations , 1989.