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Reliability Analysis on Solid Rocked Engine Vessel

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Abstract: *The solid rocket engine is widely used in missile. In order to expand the scope of attack, both iincrease specific impulse and decrease weight are become the research goal. In this paper, we take the vessel of solid rocket engine as research object, simulate the pressure of hydrostatic test, establish the finite element model of solid rocket engine vessel, solve the stress for any element in solid rocket engine vessel and find the maximum stress point by ANASYS, and then we solve reliability by the method of random analysis. According to this reliability, change the pressure which load on the inside of solid rocket engine vessel while insure reliability higher than the criticality. In this analysis, we can increase the pressure which loads the solid rocket engine vessel and we achieve the sensitivity of all parameters.*

Keywords: *solid rocket engine, shell, ANSYS, reliability*

1. Introduction

As the phase of fuel, rocket can be dividing into three types: solid rocket, liquid rocket and solid liquid hybrid rocket. Nowadays, most of missile employ solid rocket engine, because of the simple structure, easy maintain, quick response and so on, and this situation will still exist in the future. Reliability is the ability of a system or component to perform its required functions under sated conditions for a specified time. LIU P and ZHANG P [1] determined it was very difficult to solve the reliability in the past, with the development of computer technology, it is easier than before.

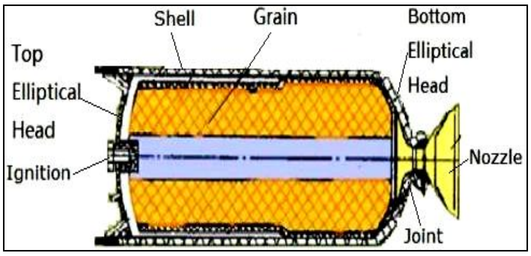
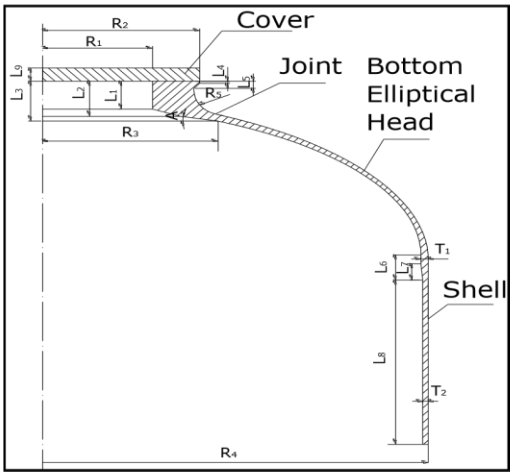


Fig.1 *Structure of solid rocket engine*

A typical solid rocket engine is shown in Figure1. Solid rocket engine has the following characteristics. ZHANG S and CAI H [2] determined the working time is short, the longest working time are not more than 10 seconds. The structure is simple; it is helpful to obtain high reliability. Solid rocket engine need to endure high temperature, high pressure, and another serious situation. After considering the characteristics of solid rocket engine, we counted and analyzed the solution, research the law of distribution from the viewpoint of probability theory. LIU F and ZHANG W [3] determined the reliability of vessel will influence the design of solid rocket engine, even influence the performance of solid rocket engine, in order to reach the reliability, we usually use the safety factor in the past. RUAN C [4] determined safety factor cannot measure the reliability; even bigger safety factor will lead to heavier weight, and then will result in lower specific impulse. Therefore, using the new method which is solving the reliability of solid rocket engine vessel base on the method of analysis design is significance. Particularly, we can obtain reliability by this method, verifying rationality of structure, and find the weak region. Moreover, the reliability is considered as theoretical basis to optimal design and develop new product.

Fig.2 *Simply structure of solid rocket engine vessel*



2 Methodology

2.1 Structure and parameters

Vessel is a very important component of the solid rocket engine. Solid rocket engine vessel consists of

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top elliptical head, shell, bottom elliptical head and the joint.

***Table 1.** Mean and deviation of parameters*

Symbol/Unit	Mean	Standard Deviation
R1/mm	57	0.1
R2/mm	81.5	0.117
R3/mm	91	0.117
R4/mm	200	0.153
R5/mm	12	0.06
L1/mm	17	0.06
L2/mm	21.4	0.07
L3/mm	24.3	0.083
L4/mm	1.3	0.033
L5/mm	4.3	0.04
L6/mm	15	0.06
L7/mm	10	0.06
L8/mm	100	0.116
L9/mm	8	0.05
T1/mm	3.8	0.04
T2/mm	2.9	0.033
A/℃	17	0.333
P/MPa	17	0.167
yies/ MPa	1750	72.6

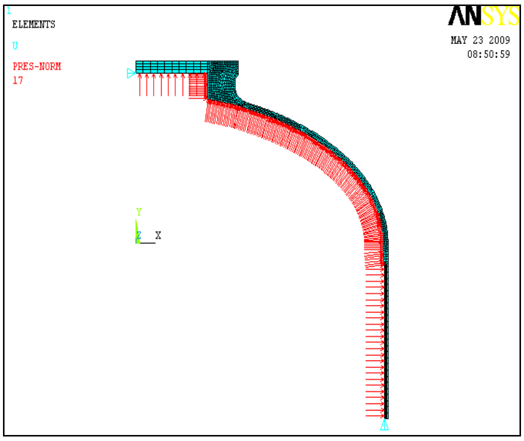

***Fig.3** Finite element model include mesh, constrain and pressure*

XIAO G [5] determined we can establish the complete model, it is not only necessary but also make the work more complicated. LI F et. al [6], ZHAO H et. al [7] and ZHANG L et al [8] determined the structure of shell is axisymmetric, the loading is also axisymmetric, and the top of elliptical head is stronger than the bottom of elliptical head, so the model of solid rocket engine vessel can be simplified, as shown in Figure 2. Mean and standard deviation of parameters are shown in table 1. Material properties of vessel are shown in table 2.

***Table 2** Material Property*

Vessel	
Material code	30Si2MnCrMoVE
Elasticity modulus	2.1×10^5 MPa
Poisson ratio	0.3

2.2 Preprocessing

The model was treated as the following steps. Firstly, we set Solid 82 as element type, input all the value of parameters (Table 1) and material property (Table 2). Secondly, we mesh the simple model. Cover and shell are belong to regular shape, so cover is divided into 10 x 4 meshes and shell is divided into 3 x 25. But elliptical head and the joint are not regular shape, so they are divided by free meshing. Thirdly, loading pressure on the inside of vessel and the pressure is 17 MPa. Finally, loading the constraint. One thing we loaded Y-direction constraint on the shell of cross-sectional area, because the shell is long enough, the extension of shell is negligible. The other we loaded X-direction constraint on the cover of cross-sectional area, because we used cover just in the pressure of hydrostatic test, the cover is big enough, the extension of cover is negligible. The Finite element model is as shown figure 3.

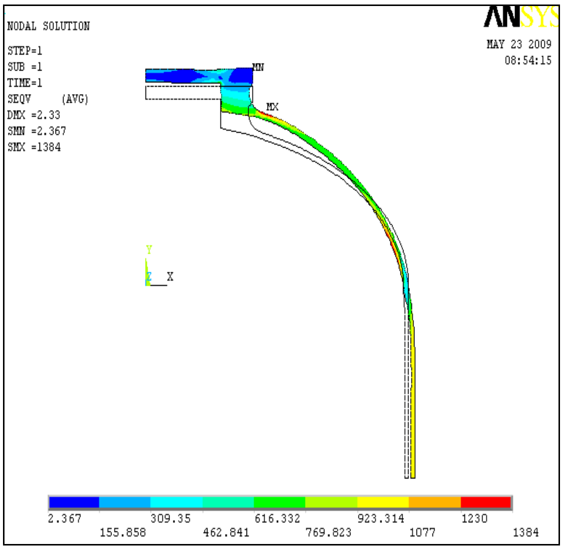

***Fig.4** Stress contour plot under 17MPa*

2.3 Solution

Solved and illustrated the solution by the figure 4. We can find two red regions. One red region arise on the outside of transition between joint and bottom elliptical head, here is the maximal stress region, the value of stress are reach 1384 MPa, so here it is the most dangerous region, the other weak point arise on the inside of transition between shell and bottom elliptical head, here is the second maximal stress region, it is also dangerous region.

2.4 Random finite element analysis

As everyone knows, accurate size never exist in the world, all the size has a range. If we think any size is correct, the finish size just in the range of size. So random selected all the size in their range on the basis of Table 1. We took the sample base on the parameters and the number of samples is 50,000. The number we took the samples is too big, the work of calculation is too hard, the number we took the samples is too small, the solution maybe not accurate, so the number of sample is 50,000. Of course, the number of solutions is 50,000, in other words, the number of maximal stress is 50,000. Into the Equation 1 to calculate, when yies is greater than or equal to maxstr, that is to say the value of Z is greater than or equal to zero, we think the solution is acceptable, otherwise is unacceptable. We can get the value of Z. ZHOU Z and ZHANG H [9] determined statistics used the method of Monte Carlo with Latin Hypercube and we can get the reliability.

$$Z = yies - maxstr \tag{1}$$

Where, yies - admissible stress;
Maxstr - maximal stress.

Solution was shown as figure 5, we can find the value of Z never lower than zero after 50000 times calculation. So, the reliability is 100% with the confidence level of 95%. Distribution of Z value was shown as figure 6. Process of sampling was shown as figure 7, we can see convergence has happened after calculating 12501 times, that means 50000 samples is enough.

```
Probability Result of Response Parameter Z
==========================================

Solution Set Label   = YLRQ11
Simulation Method    = Monte Carlo with Latin Hypercube Sampling
Number of Samples    = 50000
Mean (Average) Value =  3.8129122e+002
Standard Deviation   =  7.6981449e+001
Skewness Coefficient = -1.#IND000e+000
Kurtosis Coefficient = -1.#IND000e+000
Minimum Sample Value =  7.0498154e+001
Maximum Sample Value =  7.1640360e+002

The probability that Z is smaller than  0.0000000e+000 is:

 Probability  [  Lower Bound,   Upper Bound]
0.00000e+000  [ 0.00000e+000,  0.00000e+000]

NOTE: The confidence bounds are evaluated with a confidence level of  95.000%.
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Fig.5 *Solution of reliability under 17MPa*

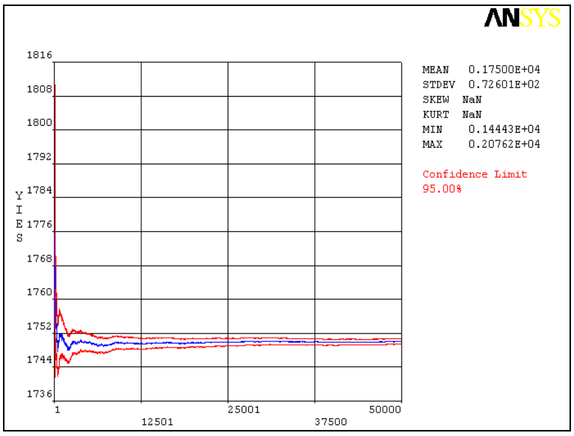

Fig.6 *Distribution of Z value with confidence level of 95%*

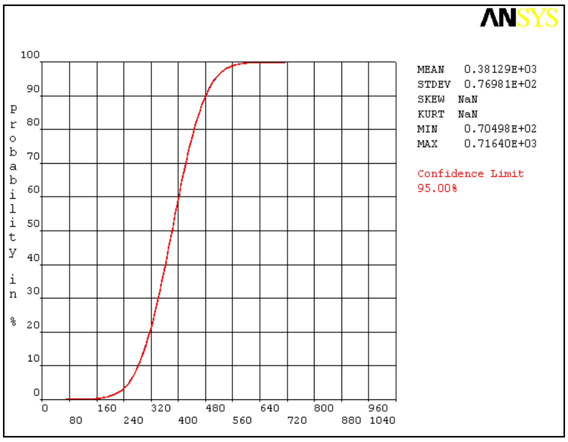

Fig.7 *Process of sampling*

The sensitivity Z value is shown in figure 8. The value of yies is the greatest influence on the value of Z, and the ratio of influence is about 55%. The second P which is the pressure of hydrostatic test is the second greatest influence on the value of Z, and the ratio of influence is about 8%. The third is parameter A and the fourth is parameter T1. The ratio of influence of other parameters is about 20%.

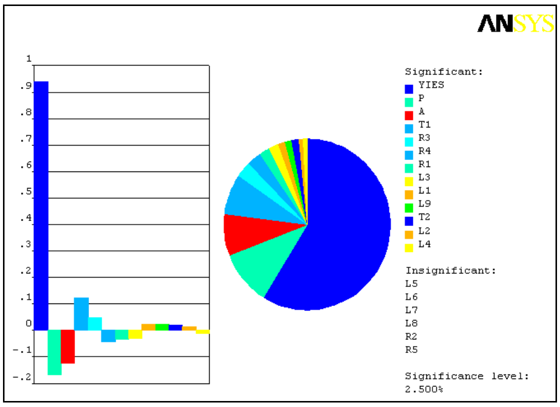

Fig.8 *Distribution of parameters sensitivity*

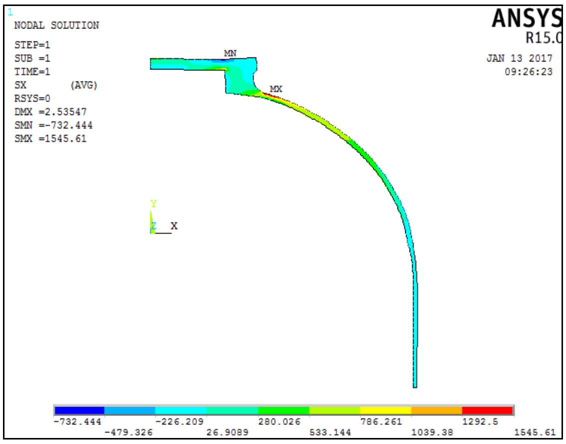

Fig.9 *Stress contour plot under 18.5MPa*

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Probability Result of Response Parameter Z
==========================================

Solution Set Label   = YLRQ11
Simulation Method    = Monte Carlo with Latin Hypercube Sampling
Number of Samples    = 50000
Mean (Average) Value =  2.6062051e+002
Standard Deviation   =  7.7217177e+001
Skewness Coefficient = -1.#IND000e+000
Kurtosis Coefficient = -1.#IND000e+000
Minimum Sample Value = -5.9021971e+001
Maximum Sample Value =  5.8810819e+002

The probability that Z is smaller than  0.0000000e+000 is:

 Probability  [  Lower Bound,  Upper Bound]
3.89298e-004  [ 3.01086e-004, 4.77510e-004]

NOTE: The confidence bounds are evaluated with a confidence level of  95.000%.

The probability is interpolated between:
Z=-7.7279489e-001 which has rank 19 out of 50000 samples
Z= 8.8808561e-001 which has rank 20 out of 50000 samples
```

Fig.10 *Solution of reliability under 18.5MPa*

2.5 Optimal design

The reliability is 100% under 17 MPa with confidence level 95%, we can find the minimum value of Z is about 70 MPa by Figure 6. That means the vessel is reliable or safe but conservative. After trying numerous times, finally we raised the pressure of hydrostatic test and reach 18.5 MPa. Using the same method to solve, the solution is shown as Figure 9. We also fine two red regions; the location is the same to arise the two red regions under 17MPa. But the maximal stress is reaching 1545.61 MPa.

$$Z = yies - maxstr \tag{2}$$

We use the equation (2) to estimate reliability in the conventional method. If Z is greater than or equal to zero, we think the vessel is reliability, otherwise it is not reliability. Notes, n is equate to 1.2, Z is not more than zero under 18.5 MPa. So this solution was unacceptable in the past, but it is shown as Figure 10, we can find the range of failure rate is from $3.01086e^{-004}$ to $4.7751e^{-004}$. So the range of reliability is from 99.952249% to 99.9698914% with confidence level 95%.The reliability is also can be accepted.

3 Conclusions

- Solid rocket engine vessel is reliable or safe under 17MPa, but is conservative. Under the acceptable reliability, we can increase the pressure and reach 18.5 MPa. It is very important for the specific impulse of solid rocket; it is a base for expanding the scope of attack.
- We can find which parameter is serious influence reliability of solid rocket engine vessel or not. It is theoretical base for optimal structure of solid rocket engine vessel.
- By comparing the method of random analysis with conventional method, we can find the method of random analysis is significant for designing solid rocket engine vessel.

References

[1] LIU P and ZHANG P, "The Technologies of Reliability Assessment of Solid Rocket Motors", Journal of Solid Rocket Technology, 25 (1), PP. 1-4, 2002, DOI:10.3969/j.issn.1006-2793.2002.01.001

[2] ZHANG S and CAI H, "Bayesian Approach of Performance Reliability Assessment of Solid Rocket Motors", Journal of Solid Rocket Technology, 26, (4), PP. 9-11, 2003, DOI:10.3969/j.issn.1006-2793.2003.01.006

[3] LIU F and ZHANG W, "Research and Realization of the Reliability Design System for Solid Rocket Motor", Aeronautical Computer Technique, 35 (1), PP. 48-50, 2005, DOI:10.3969/j.issn.1671-654X.2005.01.013

[4] RUAN C, "Technical Problems for Tactical Missile Solid Rocket Motors", Journal of Solid Rocket Technology, 25 (2), PP. 8-12, 2002, DOI:10.3969/j.issn.1006-2793.2002.02.002

[5] XIAO G, "Reliability Assessment of Solid Rocket Engine Based on Converted Information", Journal of Xi'an Jiao Tong University, 33 (7), PP. 33-36, 1999, DOI:10.3321/j.issn.0253-987X.1999.07.009

[6] LI F et. al, "Application of Finite Element Analysis Software ANSYS to 3-D Modeling of Rocket Engine", Applied Science and Technology, 31 (10), PP. 59-60, 2004, DOI:10.3969/j.issn.1009-671X.2004.10.022

[7] ZHAO H et. al, "Numerical Simulation Computation of Plastic Flow of A Working Solid Rocket Motor Case", Journal of Solid Rocket Technology, 26 (4) PP. 38-40, 2003, DOI:10.3969/j.issn.1006-2793.2003.04.011

[8] ZHANG L et. al, "Establishment of Mechanical Model of High-speed and High-acceleration Solid Rocket Engine Case", Journal of Air Force Engineering University (Natural Science Edition), 4 (1), PP. 19-21, 2003, DOI:10.3969/j.issn.1009-3516.2003.01.006

[9] ZHOU Z and ZHANG H, "Performance Deviation Calculation and Reliability Evaluation of Solid Rocket Motors", Journal of Solid Rocket Technology, 26 (3) PP. 35-38, 2003, DOI:10.3969/j.issn.1006-2793.2003.03.011