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“Rocket Motor Hardware Design and Structural Analysis”

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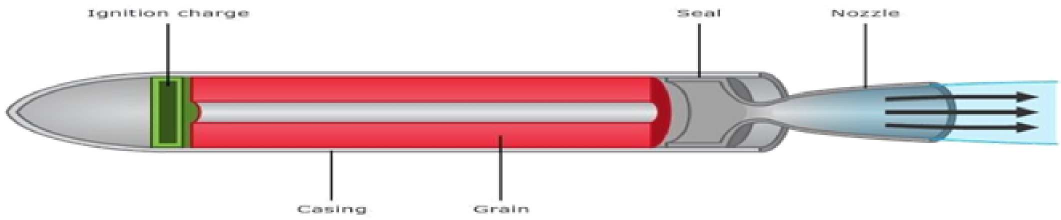
Abstract: *The rocket motor generally used for launching satellites and missiles. The motor consists the casing, nozzle, head end dome, propellant and igniters. The rocket motor hardware design is carried out generally with metals and composites materials*

In this project work literature survey carried out on the rocket motors. So the material selection is done and finally with suitable material, the rocket motor hardware is designed using ASME pressure vessel code. For the optimization point of view the hardware structural analysis is carried out using ANSYS package and weight is minimized. The structural analysis result comparison has carried out with test results.



I. Introduction

Rockets are a type of aircraft used to carry a payload at high speeds over a wide range of distances. Rockets are powered by a reaction type engine which uses chemical energy to accelerate and expel mass through a nozzle and relies on the principals of Sir Isaac Newton‘s third law of motion [1] to propel the rocket forward. Rocket engines use either solid or liquid fuel. They carry both the fuel and the oxidizer required to convert the fuel into thermal energy and gas byproducts. The gas byproducts under pressure are then passed through a nozzle which converts the high pressure low velocity gas into a low pressure high velocity gas. The thrust output depends on the mass flow rate of the fuel and the velocity of the ejected exhaust. [1]

Rockets are basically two types based on the fuel used in it. They are: chemical rockets and Solid rockets. Chemical rocket construction, working and design are very complex compared to solid rocket. The solid rocket itself can be designed as the integrated part of rocket. As in the sounding rocket and retro boosters and also they can be designed separately and installed into rockets and launch vehicles. Whereas, liquid rocket needs many separate equipment and pressure vessels to store the fuel and oxidizers. Solid rocket working is simple and easy to understand. The solid fuel is a mixture of fuel and oxidizer [2]. It has the property to burn instantly and continues to burn without stoppage. The exhaust is expelled through a nozzle and thrust is generated as a result.

1.1 Solid Rocket Motor:

Solid Rocket Motors serve as the propulsion back-bone for strategic and tactical missiles as well as satellite launch vehicles [2]. They impart required velocity to the vehicle at burn out of stage. The specification of rocket motor with respect to thrust versus time will be decided after detailed system study considering maximum allowable acceleration of the vehicle and burn out altitude from the point of view of dynamic pressure. Since most missions do not require sophistications of multiple restart and throttling operations, solid propulsion becomes overwhelming choice because of its inherent safety, high reliability, handling ease, simplicity, high density impulse minimum maintenance, packaging efficiency, effective system integration and low cost [3]. The solid rocket motors inherently have high reliability and lower costs because of the following reasons:

- Minimum number of components.
- No moving parts required to provide propulsive force.
- No complex electronic control systems for operation or diagnostics.

- No need for pressurized fluids which may leak or require venting hazardous gases.
- No maintenance of the rocket motor.

Many solid rocket motors use movable nozzles for steering or thrust vector controlling (TVC). These TVC systems can be operated with hydraulic, pneumatic or electromechanical systems. The solid rocket motors used in long range missiles and launch vehicles are fairly large in size compared to those used in tactical missiles and sounding rockets. The design principles remain the same irrespective of the size of the solid rocket motor. However, there is a vast difference in the aspects of design choices, performance prediction methods, analysis, choice of materials, manufacturing facilities, casting facilities, inspection, testing and qualification, handling, transportation and storage in case of development of large solid rocket motors compared to the smaller ones.

The most important difference between liquid propellant rocket and solid propellant rocket is that, it has no use of pressurized fluids. These pressurized fluids need to be stored in very low temperature named cryogenic fluids. Which is very uneconomical, hence solid rocket motor is the best choice for propulsion of entities to space.

The following figure shows the different components of a typical solid rocket.

Pressure Vessels:

A pressure vessel is a leak proof container to hold fluids at high pressures. They are used in almost all the industry

es, ranging from Nuclear Power generation, Beverage Industry to Aerospace industry. In fact, there is no sector that does not use a pressure vessel. Hence, they are ―fundamental component in sectors of great industrial importance.‖ And they could be of any shape ranging from a soda can to the arbitrary shaped fuel tanks in airplanes. The most used geometric shapes of pressure vessels are cylindrical and spherical, Fig 1.4 and

Problem description:

This study is to design a retro-booster containing a fixed nozzle, cylindrical pressure vessel and tori-spherical dome of total length 299mm and cylinder diameter of 58mm. The length of nozzle is 50mm and throat diameter is 14mm of width 2mm. The internal working pressure is 150kg/cm2 and FOS of 1.5 on ultimate tensile strength of the material.

Material of the retro booster is chosen to be 15CDV6. As alloy 15CDV6 which is a low carbon steel, this combines high yield strength with good toughness and weld ability. This alloy finds many applications in the aerospace and motorsports industries in such components as roll cages, pressure vessels, suspensions and rocket motor casings.

Scope of the study:

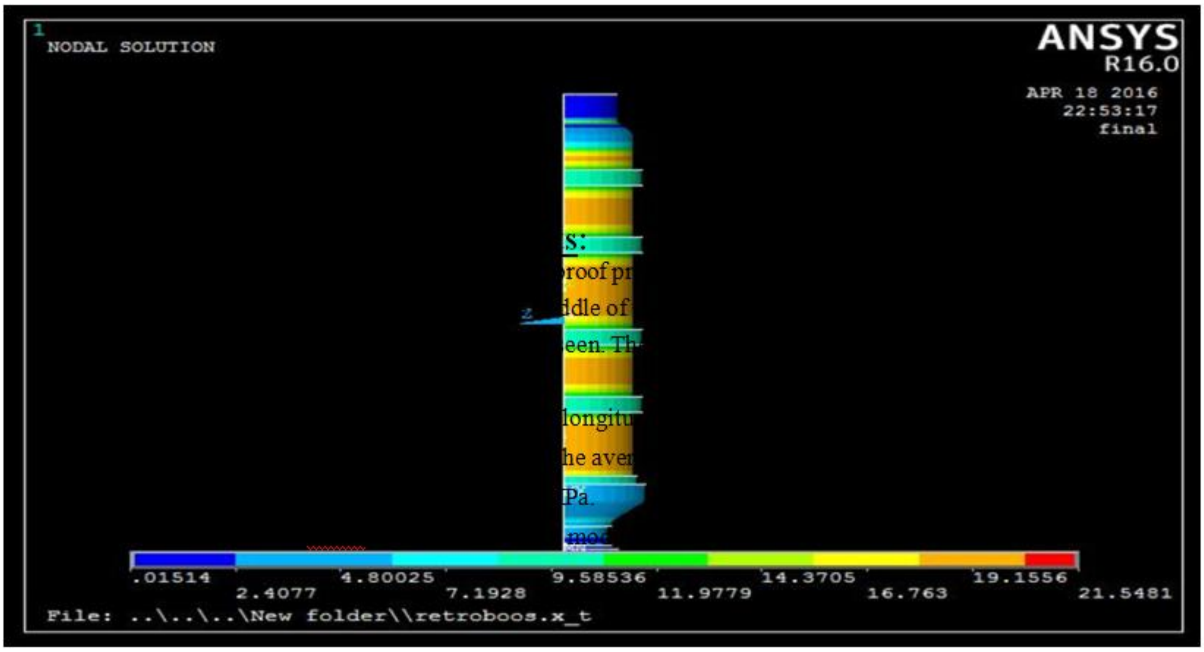
Retro-boosters find its use in many aerospace applications as discussed above. More than just designing the retro-boosters, this study involves the design procedure of pressure vessels and their components. Pressure vessels are most widely used equipment in almost all industries as pressure holding capability is the most important aspect in every machine or device. Pressure vessels are everywhere ranging from a soda can to fuel tank in an aircraft. The procedure and guidelines for pressure vessel design is very important for all design engineers. This study mostly deals with the pressure vessel design procedure and FEM for analysis and decision making.

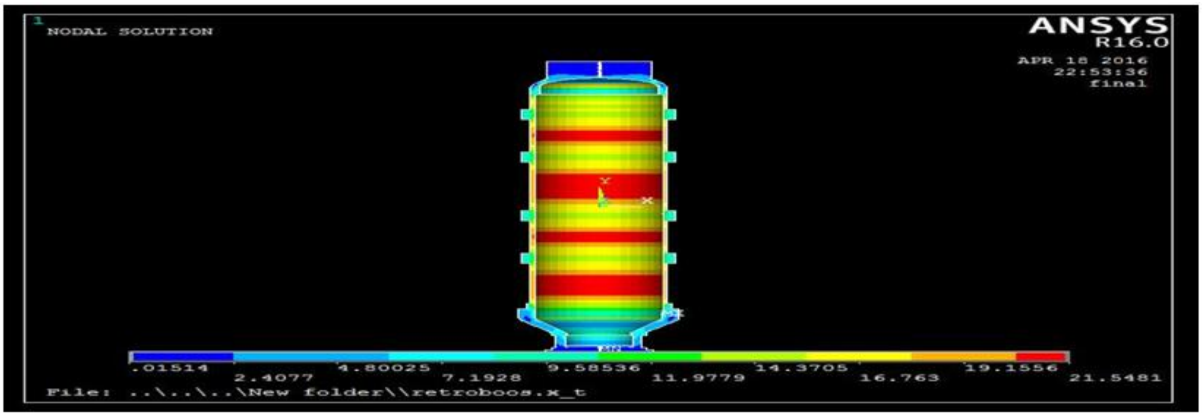
II. Theory Of Design

Design Procedure:

Pressure vessels as components of a complete plant are designed to meet various requirements as determined by the designers and analysts responsible for the overall design.

The first step in the design procedure is to select the necessary relevant information, establishing in this way a body of design requirements, as shown in Figure 3.1. Once the design requirements have been established, suitable materials are selected and the specified design code will give an allowable design or nominal stress that is used to dimension the main pressure vessel thickness. Additional code rules cover the design of various vessel components such as nozzles, flanges, and so on. Following these rules an arrangement of the various components are finalized and analyzed for failure. Most of the types of failure relevant to pressure vessel design are stress dependent and therefore it is necessary to ensure the adequacy of the stress distribution and check against different types of postulated failure modes. The proposed design is finally iterated until the most economical and reliable product is obtained.





III. Test Results:

The rocket motor casing was subjected to proof pressure test. The proof pressure value is 225kg\cm2. During the test the strains were monitored in the middle of the shell. The calculated stress is 20kg\mm^2. From Analysis obtained maximum value of 25kg\mm^2 is seen. They fairly assured each other. For the optimization in the burn is desirable.

In the theory of thin pressure vessels, the longitudinal stress of cylinder is always half the value of hoop‧s stress. We can see that in the figures and as the average value of the longitudinal stress is 9.5 MPa and is nearly half average value of hoop‧s stress of 20MPa.

Finally, the von mises stress of half solid model of the pressure vessel is shown the figure below.

In the design of pressure vessels safety is the primary consideration, especially for nuclear reactor pressure vessels, due the potential impact of a possible severe accident. In general however, the design is a compromise between consideration of economics and safety. The possible risks of a given mode of failure and its consequences are balanced against the effort required for its prevention; the resulting design should achieve an adequate standard of safety at minimum cost. Safety cannot be absolutely assured for two reasons. First, the actual form of loading during service may be more severe than was anticipated at the design stage: abnormal, unpredictable loads inevitably occur during the pressure vessel‧s lifetime. Second, our knowledge is seldom adequate to provide a qualified answer to the fracture of materials, state of stress under certain conditions, and so on.

IV. Conclusion And Future Scope

The solid rocket motor casing is basically a pressure vessel. In this study we designed the case structure with the ASME standards and explored ways to model and validate the modeled structure. We explored the standard way of structural designing using FEM. The cylindrical pressure vessel with end nozzle and end tori-spherical dome was modeled and analyzed in ANSYS to check if it has structural integrity. Since, the obtained thicknesses with ASME standards are very difficult to fabricate, we rounded off those thicknesses to thickness which are easy to manufacture. Hence we paid a penalty by not using the material to its full potential. Disadvantage of which is that, we have extra mass for the structure and mass is a very important aspect to consider in aerospace applications. To tackle this, we can change the material used to some aluminum alloy of low strength and low mass. Otherwise, the structure is highly efficient.

Future Scope

Now as we have done the stress analysis to predict the validity of the retro motor, similarly many other analyses like, fracture analysis, thermal analysis, buckling analysis and modal analysis can be done to further validate this structure.

There is a scope of optimizing the structure by using several other fracture tough alloys like AA 6061 and Ti6Al4V. Or by reducing the thickness, we may reduce the mass of the structure.

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