고체 추진기관 선진국 기술 동향에 관한 연구

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A Study on the Advanced Technology of Solid Rocket Propulsion

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ABSTRACT

Recently, due to the enormous cost for sending a satellite into an orbit, small and more reliable satellites have been more demanded. An introduction of new binders(HTPB, GAP) and new oxidizers made great improvements of the large thrust modulation. In order to make cost reduction, one prefers to the low melting temperature thermoplastic propellant reforming the manufacturing process dramatically. Solid propellant rockets have been had a problem of the injection accuracy into orbit, but PBS(Post Boost Stage) using a liquid mono-propellant improves the injection accuracy. This paper also gives the direction of the advanced nozzle materials and the motor case.

초 록

최근에 인공위성을 궤도에 올리는데 막대한 비용이 들어가므로, 소형이면서 좀 더 신뢰도가 높은 인공위성이 요구되어 왔다. 추진제의 새로운 바인더(HTPB, GAP)와 산화재(CL20, ADN)의 발명은 로켓의 추력을 다양하게 하는데 많은 기여를 했다. 제조 공정을 획기적으로 변화시키는 낮은 온도에서 녹는 열가소성 추진제는 비용을 상당히 절감시켰다. 인공위성을 궤도에 정확하게 안착시키는데 어려움이 있었던 고체 연료 로켓은 액체추진제를 사용하는 PBS를 상단에 추가 설치함으로 정확도를 증진시켰다. 이 논문에서 또한 선진화된 노즐재료와 연소관에 대해서도 방향을 제시한다.

Key Words: launch vehicles(발사장치), thermoplastic propellant(열가소성 추진제), self-check system(자동 점검 시스템), solid propellant rockets(고체 추진제 로켓)

1. Introduction

During last a couple of ten years, many spacecrafts were developed, but because of relatively high cost and long duration required for development and manufacture of those large spacecraft, the launch has not been performed very often. These spacecrafts will not survive as it is. Thus the engineers should focus on the development of more small satellites with lower cost and shorter development time and seek for more frequent launching. Conventional solid rocket motors functioning is pre-defined by its

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subsystems design and remains difficult to modulate during operation. Indeed, the design of the motor case, nozzle and propellant grain determine once for all motor's thrust law and answer to specific low extensible operational requirements.

The advanced launch vehicle aims at a simple system configuration and satisfaction of various users requests flexibly. The configuration should be designed considering the balance of the target cost and the system requirement. Generally speaking, it is not always easy because performance and cost are naturally two competing indexes. The key to success is in the research into toe subject of sensitivity to launch performance. The first stage motor is relatively expensive mainly due to its relatively large size. Despite this, its sensitivity to the entire rocket for launch capacity is not so high. Thus the first stage motor can be considered reasonable to utilize the cheap but medium performance. On the other hand, the second and third stage motors have significantly high sensitivity to the launch performance though they are inexpensive due to their relatively small scales. A rapid improvement and an increase of the rocket performance are brought by the introduction of the composite propellant and composite materials. In this paper, it suggests the optimization of a advanced motor case.

2. The injection accuracy into orbit

The recent solid rocket is aiming to achieve injection accuracy equal to liquid propellant launch vehicles. For this purpose, new strategies are adopted in its upper states. Post boost stage(PBS) mounted in the upper stage is one of those strategies. The PBS is speed adjustment stage that a small liquid engine is installed. As a result, the accuracy of trajectory can be increased to as high as that of liquid propellant rockets.

3. The recent nozzle material

Carbon/carbon or carbon-silicon carbide are used for 3,000°K high temperature resistant materials. Carbon layers stitched together to manufacture carbon preforms. Those preforms are cut in billets and densified with pyrocarbon or pyrocarbon and silicon carbide(SiC). Resin impregnation is used to reduce material porosity and thus gas permeability for some parts used as valve manifolds or external valve bodies. Resistance to erosion and oxidation is given through a final SiC coating on nozzle seats that needs to be protected against oxidation and ablation.

Fig. 1 Nozzle seat made by C/C-SiC

4. The solid propellant

Throughout the 50 years history of the solid rocket launchers, the research and development were executed only to increase the payload capability and orbital accuracy. The cost and the efficiency of the launch system have not been seriously considered. Recently, an introduction of new binders(HTPB, GAP) and new oxidizers(CL20, ADN) made great improvements of the propellant. The main specific features are metal free (or more generally providing solid or liquid particle free gas) formulations in order to avoid mobile parts plugging and crippling erosions, energetic binders and highly oxygenated plasticizers in order to maximize the propellant specific impulse and compensate the lack of metallic charges, highly energetic oxidizers also to increase the specific impulse, high pressure exponent in order to provide extensive thrust modulation. Historically, the performance and the manufacturing process of the solid propellant improved significantly by the introduction of the composite propellant and it made more powerful and larger solid propellant rockets into reality. This almost established the solid rocket technology and enabled all solid rocket launchers to conduct even planetary explorations.

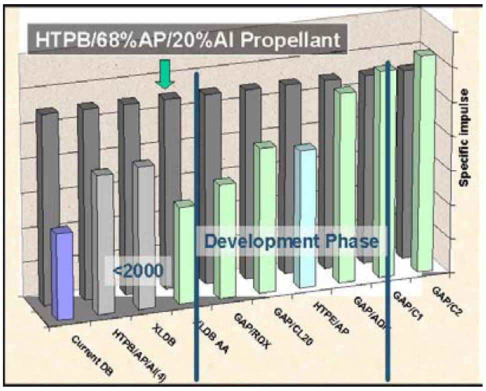

Fig. 2 Metal free propellant development road map

However, the high price of rockets for the manufacturing process of large scale and low utilization frequency converts to the one of small scale and high frequency for a significant cost reduction. The current manufacturing process of the solid propellant consists of; the stir mixture of a binder (HTPB), an oxidizer(ammonium parchlorate; AP) and aluminum powder with the mixer; and molds them into the motor case. Then, the whole motor case is heated so that the elastomer becomes stiffened. This final process, heat stiffening, is a one way reaction that makes the entire process become a quite sensitive no return process and cannot be stopped once started. Therefore, the manufacturing facilities, even the mixer, become gigantic although their utilization rate is very low, leading to an inefficient facility and labor skill cost. To reduce the cost, an innovative concept of the manufacturing is introduced. It has a reverse nature to the conventional composite propellant; thermal elasticity and low melting temperature that can make an evolution in the solid propellant. This propellant remains solid at room temperature while it melts when heated at a relatively low temperature of below 100°C and it is most important this nature is a two way reaction like a chocolate bar. Now that the manufacturing process can be intermitted between mixing and molding, the chocolate bar type small pieces of propellant can be mixed by a laboratory scale small mixer and can be produced continuously day and night. Finally, they can be stored in a stock house, thus raising utilization rates of the mixer up to 100%. Then, the final loading of the propellant into a motor case can be easily done by melting pieces of propellant bars and molding them into motor case at an automatic mass production style. In this way, the manufacturing process can be converted to one of a much smaller scale and high utilization frequency, leading to a reduction of personnel expenses. As it is natural that the resin melts at high temperature, there can be many candidates potentially. The LTP consists of AP, aluminum powder and thermoplastic binder, which is currently a combination of Butadiene elastomer, Plasticizer and bonding agent. This innovative concept leads to a significant cost reduction based on improving the manufacturing process.

5. The motor case

The motor case is composed of an in-plane layers, hoop layers, unidirectional layers, dummy layers, forward and aft skirts and forward and aft boss. The unidirectional layers for transmission of axial load and the hoop layers for reinforced of circumferential direction are wound in cylinder. The forward and aft skirts that unite upper and lower stage structures are made of CFRP for weight saying, and attach-ring is not adopted. The dome openings are reinforced by high strength aluminum alloy bosses, which interface the closure and nozzle. High strength CFRP was developed in cooperation with the material maker aiming to improve performance and to reduced the cost of Carbon/Epoxy prepreg. The filament winding method of a composite case divides into two categories; in plane winding method and helical winding method. The in plane winding method is unsuitable for the motor with a large aspect ratio while the forward and aft domes openings diameter is adjusted to a different value. On the other hand, the helical winding method can correspond also to the motor with a large aspect ratio, but the forward and aft domes openings diameter should be the same. The dome openings are installed bosses, which interface the closure and the nozzle. It is preferable to reduce the bosses for lightening the motor case. The size of the aft boss is decided depending on the interface size of the nozzle holder. The size of the forward boss is decided depending on the size of the shaft of the case mandrel used when the case is manufactured. The diameter of a forward mandrel shaft is reduced as much as possible for lightening. As a rusult, the upper round type motor case adopts in plane winding method from almost globular it, the forward and aft domes opening diameter different. The dome openings are reinforced by wafer.

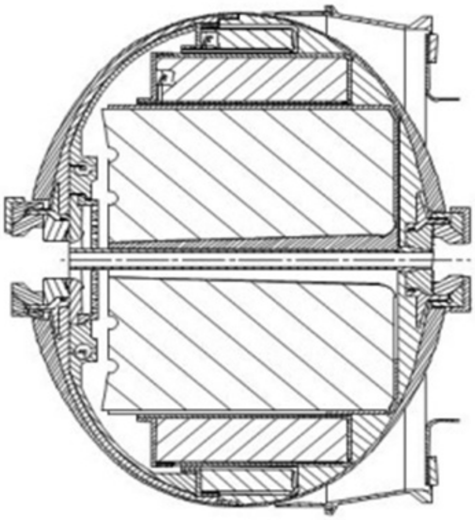

Fig. 3 The spherical type motor case

The hoop layer does the role to reinforce the cylinder in weak in plane layers to inner pressure, and it is made of CFRP the same as the case. As for the cure method of the motor case, autoclave method and oven cure method are mainly used. Each method is a process of manufacturing of general FRP product. Oven cure method can reduce cost of manufacturing, because a process of bagging is unnecessary.

The skirt is bonded to the cylinder of motor case. An interface of the skirt and case is composed of the dummy layers and rubber. The dummy layers are made of CFRP, and it is processed to suitable shape for bonding the skirt.

The bosses are made of aluminium alloy in consideration of balance of the cost and the performance. It is a design principle to allow boss plastic strain in proof pressure. The bosses evaluate by result of elastic plastic analysis, and are aiming at lightening.

6. Summary

Because of the enormous cost for launching a big satellite, small and more reliable satellites have been more demanded. For the thrust modulation of a launcher, new binders(HTPB, GAP) and oxidizers made great improvements. Because the low melting temperature thermoplastic propellant made the manufacturing process simple dramatically, the manufacturing cost was down. An introduction of PBS(Post Boost Stage) using a liquid mono-propellant improves the injection accuracy. This paper gave the direction of the advanced nozzle materials and the motor case.

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