MOTOR CASE FOR ROCKET TRAJECTORY CORRECTION SYSTEM

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Abstract

This presentation describes the development of the composite, filament wound glass/epoxy motor case for the Guidance Rocket Motor (GRM).

The "design to cost" approach (DTC) for the GRM, including the segmented mandrel and integrated fitting/skirt assembly engineering concepts have been chosen.

The influence of the DTC on the general design of the case, its geometry, mechanical properties, and failure mode during pressure test are emphasized.

The GRM, as developed, was successfully tested and fount to meet the required specifications.

The principal stages of low cost manufacturing procedure, implemented at IMI's facilities, are briefly described.

1. Introduction

A Trajectory Corrected System (TCS) for the Multiple Launch Rocket System (MLRS) has been developed by Israel Military Industries (IMI), together with Lockheed Martin. According to the concept, the trajectory correction of the rocket is accomplished by the integration of a Guidance Rocket Motor (GRM) whose thrust vector varies according to in-flight parameters.

The GRM is located in the forward part of the rocket between the warhead and the nose cone, (Fig. 1).

This presentation describes the development of the composite, filament wound motor case for the GRM, as carried out at IMI.

The DTC has been chosen as a comprehensive process from development through production. It essentially influenced the base materials choice, internal geometry of the case, its mechanical properties, stress distribution under internal pressure, and failure mode.

Some interesting non-traditional phenomena have been observed in the behavior of the designed motor case.

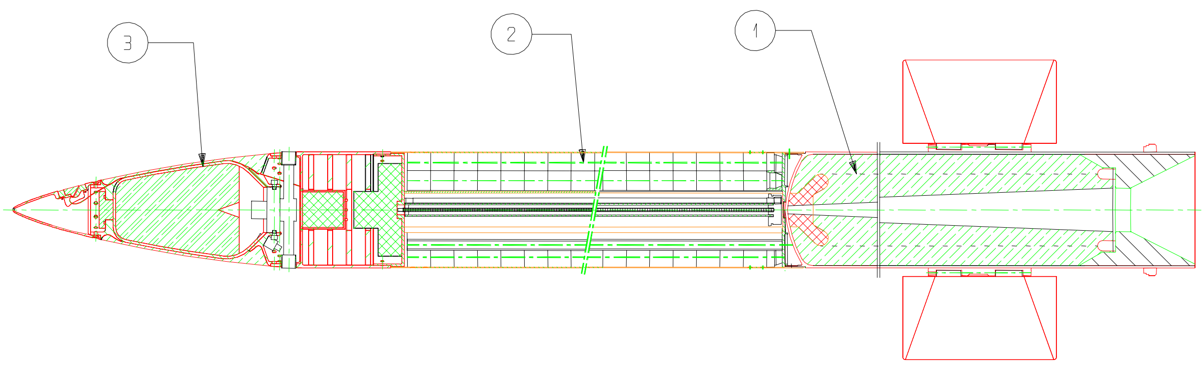

Fig. 1
Location of the GRM in the rocket body:
rocket motor (1), warhead (2), GRM (3)

2. Structural Specifications of the GRM case

The structural specifications of the GRM case were determined based on the overall MLRS Trajectory Corrected System operational requirements, structural design and aerodynamic characteristics. The most important of them are:

1. The external geometry of the motor case is determined by external contour of the rocket and can't be changed, see Fig. 2.

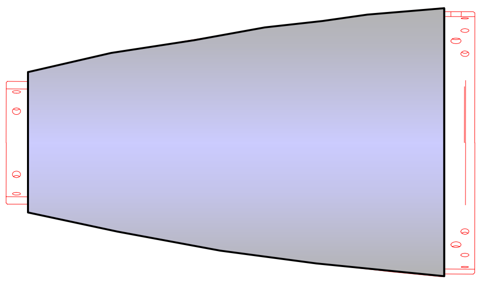

Fig. 2
External geometry of motor case

2. The internal volume of the case is given and determined by the internal ballistics of the GRM.
3. The test pressure of the case is 220 atm.
4. The burst pressure of the case must be at least 280 atm.
5. The external surface of the case must be kept smooth and without fiber/resin interface fractures after pressure testing.
6. The external surface of the case must survive the rapid rate of change of the temperature in the initial stage of the trajectory – 430º C over 10 sec – without any fractures.
7. The maximum strain in the composite envelope of the case during pressure testing must be less then 2%.

3. Influence of the DTC on the GRM case structure

Three principal ideas were used in the case design:

- application of low cost E-glass/epoxy composite for filament winding of the case envelope.
- choice of the segmented mandrel for production stage of the case, see fig.3.

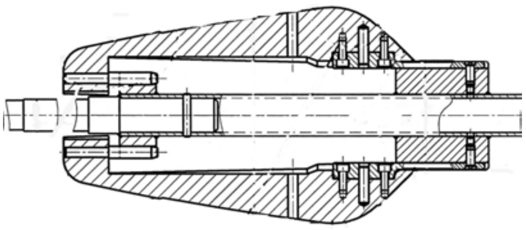

Fig. 3
The concept of segmented mandrel

- application of the integrated fitting/skirt assembly, see Fig. 4:

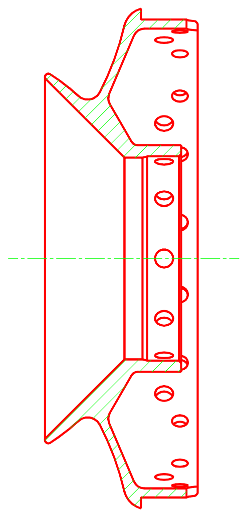

Fig. 4
An integrated fitting/skirt assembly

As a result of applying these ideas in the case design, the following additional problems in the case design were recognized:

- The pole openings of the case are relatively very large: the relation between aft/forward pole opening diameter to the maximal aft/forward dome diameter must be greater then 0.73 and 0.80 respectively.
- Only large winding angles may be realized on the mandrel surface.

4. The combined structure of the wound envelope and determination of the mandrel geometry appropriate to filament winding

To satisfy the temperature, pressure and external geometry requirements, the wound stack of case composite envelope was designed as combination of two structures. The first one is a base, strength bearing glass/epoxy wound structure, designed according to the pressure tests and strength requirements. The second one is a complementary external glass/flexible epoxy wound structure, which supplies an insulation for the base structure, provides a determined external geometry of the case (after machining) and maintains smooth case external surface during pressure test. A complementary wound structure couldn't essentially improve strength properties of the case as a result of machining operation that cuts its continuos fibers, and essential heating of the composite during rocket travel along its trajectory.

An appropriate contour of the mandrel was calculated to provide high quality winding process without slipping of the resin impregnated glass fibers. Special attention was paid to the geometry of fitting/skirt assemblies. These assemblies are mounted on the mandrel at the beginning of the winding procedure and must provide a free motion for the pay-out guide of the filament winding machine during winding in the fitting areas, see Fig. 5.

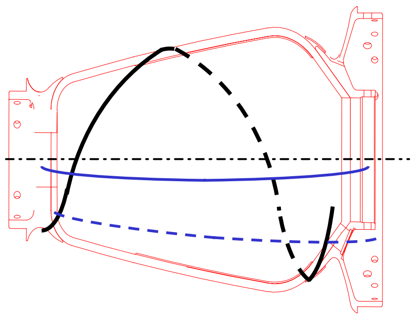

Fig. 5
Winding path on the mandrel

5. Designing and testing of the base strength bearing wound structure.

Within the framework of above mentioned geometric limitations on the case mandrel, the base structure was designed as a stack, containing four different wound layers in various combinations. All layers have large winding angles, and each stack has over-designed hoop strength. According to the results of strength analyses of the case, its failure must occur in the aft/forward dome areas near the fitting edges. For experimental corroboration of these results, three different stacks of base structure with minimal thickness were chosen and corresponding cases with base structures only were produced, During burst pressure tests of these cases, failures actually occurred in the aft/forward dome areas near the fitting edges, see Fig. 6,7.

Fig. 6
Aft dome failure of the base structure

Testing confirmed, that maximum longitudinal strains of the case were less then 2% during pressure test.

Fig. 7
Forward dome failure of the base structure

One of three tested stacks with maximum burst pressure as 296 atm was chosen as a base structure for final case version. This structure contains a stack of seven layers, built from follow combination of four wound layers, see Fig. 8.

6. Designing and testing of the complementary wound structure

The general purpose of complementary wound layer is to supply an appropriate solution for specification items: 1,5 and 6. Glass/epoxy composite provides good possibility for a machining process to achieve the given external contour of the case. It is also able to survive high temperature peaks over few seconds as required by item 6.

It was found, that epoxy resin system, used in the base wound structure, leads to appearance of the external fractures during pressure testing, see Fig. 9.

To satisfy the demands of item 5, a more flexible epoxy system was specified relative to the epoxy system of the base wound structure.
The compatibility of two resin systems was specially tested and proven. So both structures of the case are wound one after the other in the same continuous winding procedure, and are cured simultaneously.

A pressure testing program for externally machined case, wound with both structures, was performed. It was noted, that complementary wound structure after machining doesn't influence the value of the burst pressure, or the failures location.

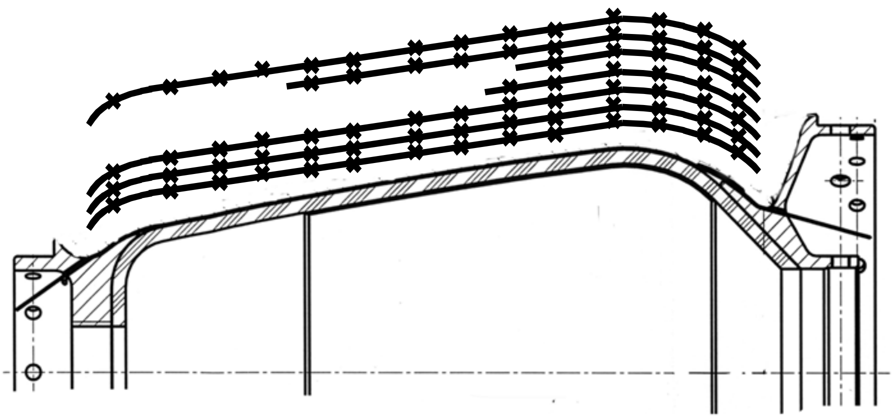

Fig. 8

As before, during burst pressure tests, failures occurred in the aft/forward dome areas near the fitting edges.

Fig. 9
An external fractures in the fiber/resin adhesion during pressure test

Fig. 10 shows the machined motor case, wound with flexible epoxy system in the second structure after pressure testing. No fiber/resin adhesion fracture of the external surface of the case was found after visual inspection.

7. Manufacturing procedure of the case

According to the DTC, a low cost manufacturing procedure was designed and implemented at IMI's facilities. The general flow chart of manufacturing procedure is represented in Fig. 12, Stations 1-6.

It begins with production of the rubber insulation layer on the mandrel surface and attachment of the integral fitting/skirt assemblies, (Station1). After that, filament winding is performed for two mandrels simultaneously, (Station 2). As a first step of winding procedure all mandrels are wound with base structure layers. Then resin system is changed to a flexible one and all mandrels are wound by complementary structure layers. The winding procedure of the complementary structure is shown in Fig. 11.

Fig. 10
Developed motor case after Pressure test

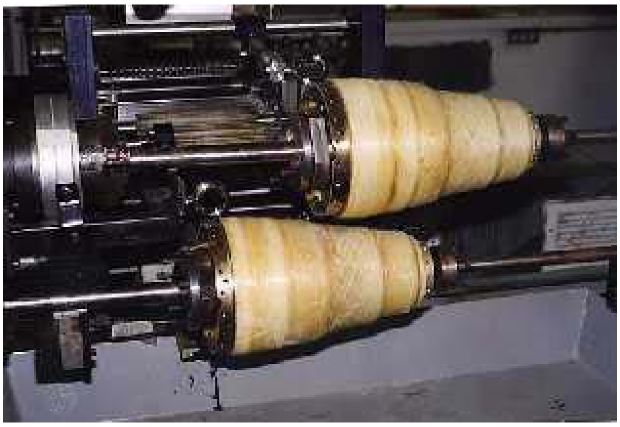

Fig. 11
Winding of the complementary structure

After finishing the winding and curing procedures, (Station 3), the mandrels are disassembled, their segments are removed from the cases and each mandrel is assembled once more to continue case procession, (Station 4).

Wound cases are machined to receive a determined external contour, (Station 5), after which each one is subjected to the pressure testing, (Station 6).

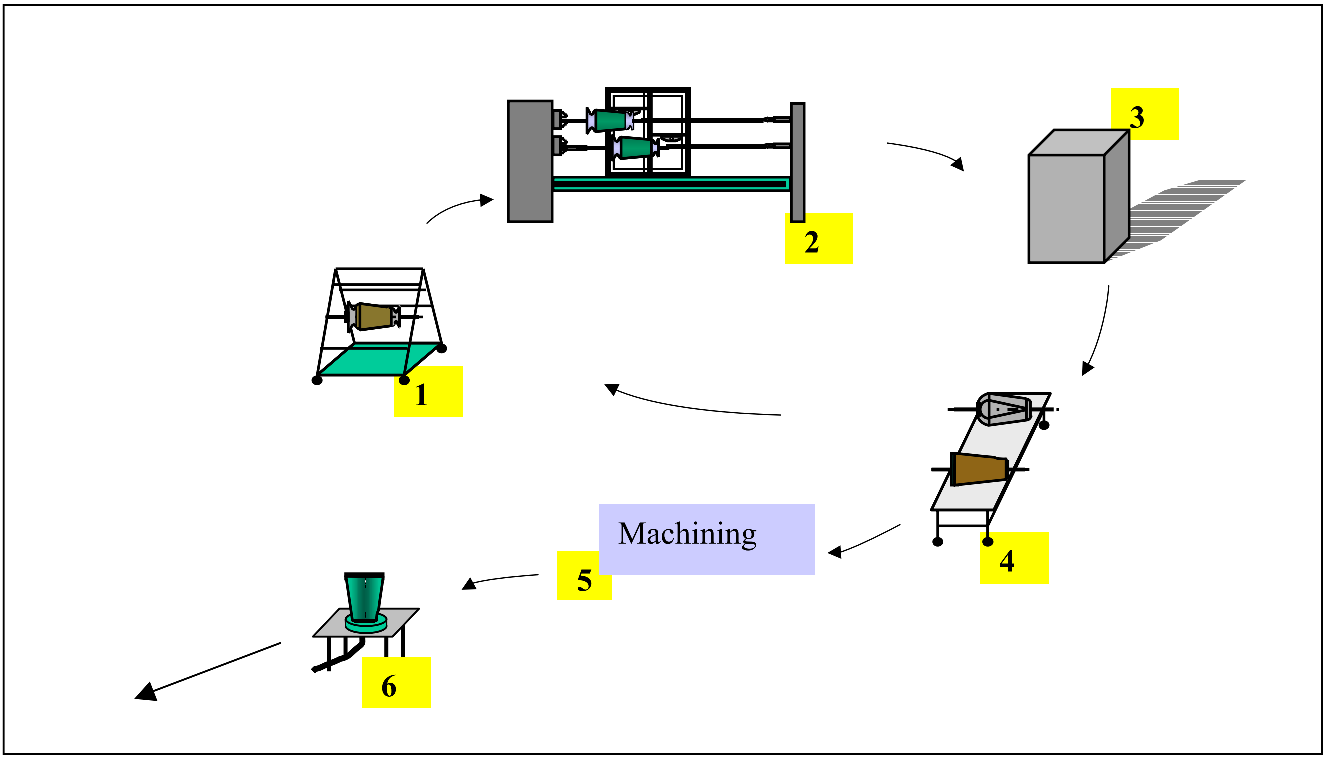

Fig. 12
Flow chart of manufacturing procedure:
Station 1 - mandrel preparation for filament winding,
Station 2 – filament winding, Station 3 – curing procedure,
Station 4 – disassembling and assembling of the mandrels,
Station 5 – machining of the case,
Station 6 – pressure test of the case.