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An innovative method for Measurement of Insulation thickness of Fired Solid Rocket Motor

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Abstract

Thermal insulation system of a typical case bonded solid rocket motor consists of polymeric ablative material which is bonded on to the inside surface of the metallic / composite motor casing. A further coat of thin layer of liner is applied followed by the propellant which is cast in-situ. During the firing, insulator provides thermal insulation against high temperature combustion process inside the rocket chamber. Design of the insulation system is a complex job involving crucial assessment of ablative regression of the exposed insulator. Propulsion system designers carry out series of actual motor firings for monitoring the adequacy of thermal insulator. The design is validated by actual measurement of insulation thickness in unfired and fired rocket motor. Thereby fast and reasonably precise measurement of insulation thickness at various locations along the length and periphery of motor is of paramount importance in these experiments.

Rocket motor was positioned on a lathe machine. Measurements were carried out using a suitably positioned dial gauge mounted on a boring bar which was further secured on the tool post. A mirror arrangement was also fitted at one end of the boring bar (near the dial gauge) to enable fast and easy read-out from the open end of the rocket motor. Methodology to carry out the measurement was developed and readings were taken at various positions along the length and periphery of the rocket motor. Comparisons were made with the readings and generally observed erosion (ablation) profile. The measured profile of the eroded (ablated) insulation was in line with the usually observed trend.

Author(s) of this paper faced a number of engineering challenges which were overcome using simple and effective concepts and ideas which are discussed in this work.

Keywords: Solid rocket motor, thermal insulation, ablation, measurement

INTRODUCTION

Thermal insulation system of a typical case bonded solid rocket motor consists of polymeric ablative material which is bonded on to the inside surface of the metallic / composite motor casing. A further coat of thin layer of liner is applied followed by the propellant which is cast in-situ (refer figure 1 **[1].** During the firing, insulator provides thermal insulation against high temperature combustion process inside the rocket chamber.

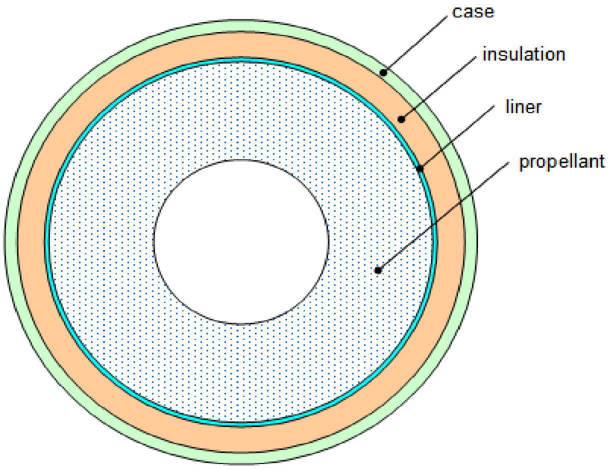

Figure 1. Cross section of a typical solid rocket motor [1]

Measurement of insulation thickness of rocket motors is a challenging task in terms of accuracy and repeatability. General Engineering or advanced **[2-8]** methods are often employed with associated limitations, in terms of complexity, sophistication although with sufficient accuracy. However, general engineering methods are largely limited by the accessibility inside the motor**.** The problem becomes even more pronounced in case of longer motors (or with higher length to diameter ratio). In order to overcome this problem, a novel idea was conceived by the author(s) that culminated into design of a set-up. The set-up utilizes a conventional lathe machine for mounting the motor (on the chuck) which enables circular manipulation of the motor. The measurement head is mounted on the tool post. The measurement head consists of a sufficiently long bar, with the dial gauge mounted at one end. On the other end, a light source along with a mirror is positioned as shown in sketch. The dial gauge stylus contacts the insulation surface and directly reads the available thickness at that location (by difference between the initial reading set at ‘0’ on reference surface). Easy and convenient reading of the dial gauge is made possible by using the specially designed mirror arrangement which reflects light and forms the image, visible to the user.

Several readings were taken for a rocket motor and contour maps were drawn depicting the ablation of insulation thickness at various zones providing key inputs to designers. Such detailed measurements were otherwise not possible using conventionally available instruments or methods. This technique was also utilized for gaining better understanding of thermal insulation performance of a tactical missile propulsion system.

DETAILED CONCEPT AND SYSTEM LAYOUT

The components and sub-components of the novel system is shown in the schematic view in figure 2.

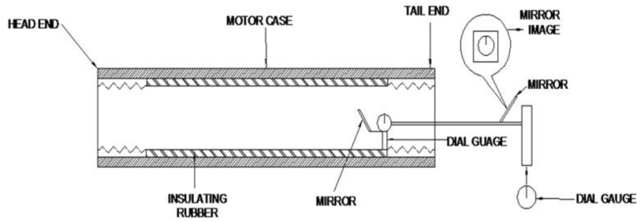

Figure 2. Schematic representation of measurement of insulation thickness of fired solid rocket motor

The components / instrument used for measurement of insulation thickness are

(i) Centre Lathe Machine Spec. LB 17 x 3000 mm

(ii) Dial gauge ((Qty-2 Nos),

(iii) Plain Mirror –Sizes (Qty-2 Nos)

(iv) Steel Rule- 1000 mm length

(v) Boring Bar length 2000 mm long

The system was developed taking into account the length of the fired motor, internal diameter of the motor, suitable dial gauge and plain mirror. The General Arrangement (GA) of the system has been described. Figure 2 shows the general components and layout of the same in the machine.

SET UP AND OPERATING PROCEDURE

1) The arrangement is mounted on lathe (HMT make / Model LB-25 x 3000 mm) as shown in Fig-3.
2) The one end fired motor is mounted on head stock – chuck and other end held with the help of steady rest.
3) Mounting of Motor on lathe is calibrated with the help of dial gauge.
4) Boring bar of length 1 meter is used for holding the one dial gauge with mirror attachment in one end.
5) Other end of Boring bar is held in tool post, at the tool post one more dial gauge is mounted for calibrating the tool post with boring bar.
6) The dial gauge is mounted on boring bar and has to and fro motion inside the motor with the help of periscope arrangement.
7) Inside diameter of Motor is calibrated with zero with the help of dial gauge mounted on boring bar. Then the probe of dial gauge is touched with the insulation and takes measurement at different position across length and diameter.
8) The thickness of insulation directly can be seen with the help of dial gauge fitted inside the motor (on mirror).

Figure 3. Rocket Motor mounted on Lathe

MEASUREMENT OF INSULATION THICKNESS AND DISCUSSION:

A general step-by-step process is as follows;

(a) Truing (circular alignment) of Rocket Motor:

The Rocket motor was mounted and holds on chuck on the lathe machine and truing operation has been done by using dial gauge as shown in Figure 4

Figure 4. Truing of Rocket Motor on Lathe

(b) Attachment of boring bar, dial gauge, plane mirror:

A mirror is placed to facilitate measurements from otherwise difficult to access locations as shown in Figure 5

Figure 5. Attachment of boring bar, dial gauge, plane mirror

(c)Measuring thickness of Insulation thickness

The Figure 6 A and 6 B shows a typical process still wherein the reading is being taken.

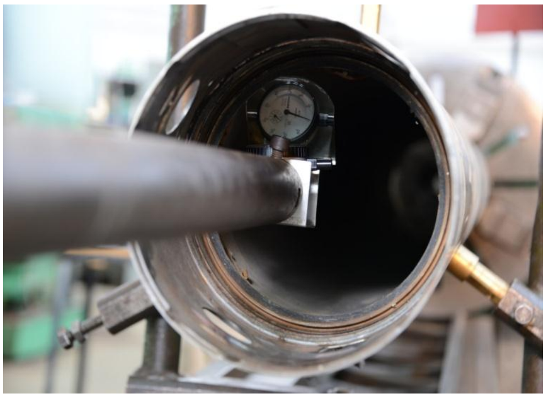

Figure 6 A. Measurement reading being taken at a given location

Figure 6 B. Measurement reading being taken at a given location

RESULTS AND DISCUSSION:

The insulation thickness has been measured at different location viz. lengthwise and angular. The details are summarised in the table no. I. Measurement results are shown in the Figure 7 below

Table I: Measurement station locations

Distance (axial)	Angular positions (degrees)
Measurement stations located at every 10 mm starting from 300 mm to 700 mm from head end.	0 / 360
	45
	90
	135
	180
	225
	270
	315

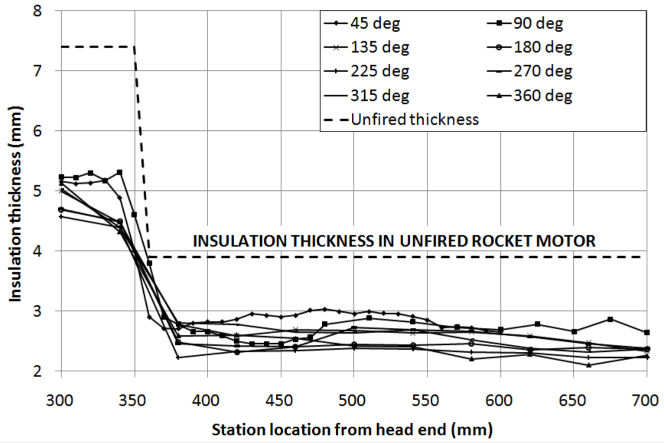

Figure 7. Variation of insulation thickness at various stations

The insulation thickness was kept high at locations near the head end and nozzle end in order to account for higher intensity of thermal environment in these locations. The same was evident from the measurements carried out in these locations.

Insulation thickness was found to reduce to the extent of 50-80% and more pronounced reduction was noticed at the mid section owing to lower initial thickness as shown in figure 8. Adequacy of insulation design is greatly dependent on the reduction of insulation thickness **[5-6].** As the insulation is a thermal barrier, pronounced reductions can lead to increased heat transfer leading to undesirable results or even system failure.

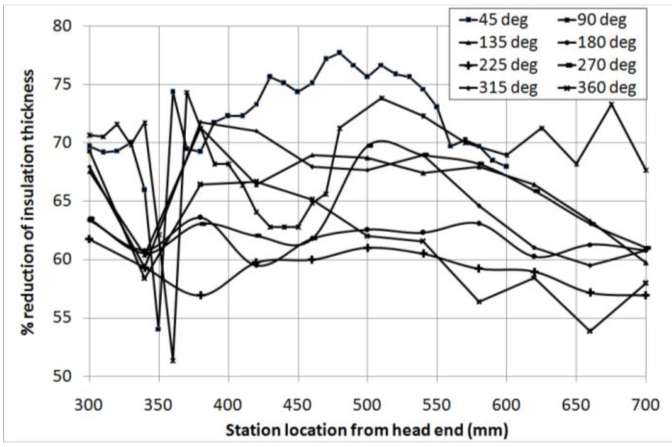

Figure 8. % reduction in insulation thickness at various stations

An abrupt change in trend for the insulation erosion was noticed at locations beyond 340 / 360 mm from head end where the initial insulation thickness gradually reduces from 6.1 to 3.9 mm. This decrease in reduction of insulation thickness can be attributed to changes occurring in flow dynamics and ensuing decrease in heat transfer coefficient. Erosion was found to be the low at this location owing to the fact that the insulation thickness reduces gradually and not abruptly as shown in the Fig 7. The measurement station resolution of 10mm is not sufficient to capture the gradual reduction of insulation thickness leading to the apparent trend.

An anomaly was noticed in the measurement results at angles of 45 & 90 deg locations. In these angular positions, the reduction in insulation thickness was minimal particularly in the region close to the head end. This can be attributed to circularity tolerance either in the metallic motor hardware or the insulation. Differences in relative bulk temperature of free stream air around the motor at different angular locations during the firing can also lead to such differences in insulation reduction as a result of varying heat transfer rates.

In order to ascertain the accuracy of the devised method, direct measurements of remaining insulation thickness can be made by physically cutting the motor. However, this was not possible in the present case due to certain limitations. Alternatively, other methods such as ultrasonic [2], using thermocouples [7] or plasma capacitance gage (PCG) method [8] may be utilised for comparative studies. Precision during these measurements was found to be within ±0.1mm which is acceptable.

CONCLUSIONS

The system was successfully developed and fabricated addressing features such as simplicity of design and compliance to good engineering practices. The insulation thickness of rocket motor has been measured and the results / trends corroborate design features and are in agreement with the theory. However, the accuracy of the devised method can only be ascertained if a standard reference is available for the same. Precision in measurements was also found to be within the acceptable limit. Notwithstanding the same, these inputs are crucial in design of an efficient insulation system for modern high performance solid rocket motors.

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