

Foreseeing The Hidden Defects In Rocket Motor Hardware Through NDT- A Case Study

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ABSTRACT

The Solid Motor cases of 3.0 Meter class are fabricated through welding route using high strength Maraging steel material. Various Non destructive evaluation techniques like Liquid Penetrant Inspection, Radiography testing , Ultrasound testing are extensively used for the inspection and clearance of Rocket Motor Cases. Defect detection using Non-Destructive methods have been associated with its own inherent uncertainty or limitations regarding detectability of defects. Improving the probability of detection is a challenging task especially in the aerospace scenario since the acceptance criteria are rigorous and permissible defects sizes are so small. This paper gives the measures taken and overall improvements achieved in recent times regarding defect detection in rocket motor hardware made of maraging steels.

Keywords: Non-destructive Evaluation, Maraging steel

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1. INTRODUCTION

The solid motor cases for launch vehicles are realized through welding fabrication route and it entails a large amount of longitudinal and circumferential seam welding. The acceptance criteria used for clearing these weld joints are very tight requiring the need for rigorous Non-destructive Evaluation. This paper discusses the recent improvement implemented in NDE process & evaluation of the motor case weld joints.

Over the years, quality improvement efforts have been put in place to improve the detection and growth of defects especially of hidden types. This has led in reducing uncertainty and increased the probability of detection. An additional benefit of this effort is overdoing & superfluous testing could be avoided.

Paper covers the improvements achieved in the area of Visual, Liquid Penetrant, Radiography and Ultrasonic testing. Radiography and ultrasonic testing techniques being the mainstay in the detection of internal defects, these are dealt in detail. All the improvements are implemented in different work centres strengthening our confidence to realise hardware through indigenous sources.

2. Manufacturing Process- An overview

The Rocket Motor cases are being manufactured by various vendors of ISRO according to the stringent specifications and under the direct supervision of ISRO resident teams. It is fabricated using ultra high strength alloy steels like maraging steel using TIG welding process. Manufacturing of motor cases for launch vehicles involve a number of critical operations like aerospace quality welding, precision machining etc. The weld process parameters are closely controlled to ensure defect free weld seams.

The following NDT techniques are widely used for Weld Joint evaluation: Visual Inspection (VI), Liquid Penetrant Inspection (LPI), X-Ray Radiography testing & Ultrasound Testing (UT). UT is done only for motor cases made using Maraging steels.

The NDT of the welding process in fact begins before the actual welding process. The weld edges after groove preparation are subjected to 100% VI & LPI and the welding starts only after clearing the above tests. Then, after welding the seams are subjected to VI, LPI, RT & UT. The defects those are found unacceptable based on the above evaluation are subjected to repair according to approved weld repair procedure. After repair, the repaired zones have to undergo the same NDE protocol for getting cleared.

The final acceptance of the motor cases are based on the acceptance test i.e. Proof Pressure Test. After pressure test, the hardware weld seams will be subjected to one more round of thorough 100% UT evaluation.

The role of NDT not ends here. While storage also, the motor cases made of maraging steels are subjected to periodic 100% UT scanning of all weld joints, to monitor the health of the seams and find defect growth if any.

3. ND Evaluation and Acceptance Criteria for Weld Joints

The Weld Joint classification and NDE acceptance standards are internally evolved (within the Organization) and documented based on various applicable aerospace and international standards.

The internal standard for LPI is based on the standard ASTM E165 and the acceptance criteria are based on design requirements of Solid Boosters applicable to each material.

The weld joints are scanned using search units (UT Probes) of Normal beam and angle beams of 45°, 60° & 70° of specified frequency and characteristics. The acceptance criteria for Ultrasonic Testing are based on the standard AMS 2632. The UT reference block used for Angle Beam scanning of Weld joints is AMS G-Notch of size 1.3mm Deep X 2.5mm Long X 0.26mm Wide made on a block of similar thickness and same material (used for the actual hardware). For Normal beam scanning the reference reflector used is Ø2.0mm (FBH) Flat Bottom Hole block.

While scanning with Angle Beam probes, any indication having amplitude above 25% DAC with reference to the above reference is recorded. 50% and less is accepted for single discontinuity response whereas, 25% and less only is accepted for multiple discontinuity response. Multiple discontinuities are two or more indications separated by a distance equal to or less than 15mm. For linear discontinuity response also, 25% and less only is accepted.

In-house standard has been generated based on ASTM standards for the acceptance of weld defects in Radiographic Testing. The type of film recommended and has been in use was as per the standard **ASTM E 1815 Class-2** from reputed brands, for example Agfa D7 or its equivalents. The radiographic technique that has been in the practice ensures that it determines quantitatively the size of the defects equal to or more than 2% of the base metal thickness.

4. CASE STUDIES:

For the purpose of case study, rocket motor hardware fabricated in two major Vendors only are considered and they are identified as VR-1¹ & VR-2². Though fabrication is done at more than one work centre, the final acceptance test- proof pressure testing- is done by only one Vendor i.e. VR-2.

4.1. Case-1 In a particular segment of a Rocket motor case, a UT indication of amplitude 6% higher than the acceptance limit was observed during UT scanning after Proof Pressure Testing. The unacceptable indication was in the shell to forging joint. The above motor case was fabricated by Vendor VR-1 and completed all Quality protocols before despatching to Vendor VR-2 for Proof pressure testing.

For further analysis, when the radiographs (of stage before Heat Treatment) of the particular spot were reviewed (by VR-1) subsequently, a very faint indication was observed at the respective zone which was most unlikely to catch the eyes of even an experienced interpreter. But, from that it is hard to make out if it was Lack of Fusion or not. This RT was done with usual Agfa **D7** film conforming to ASTM Class-2. As a salvage action, the spot was repaired and subjected to ND Evaluation and cleared.

In view of the above, the entire RT procedure was reviewed and improvements are implemented at the work centres. One of the major changes implemented is in the class of film used. Instead of ASTM E-1815 Class-2 films, Class-1 type is suggested i.e. Agfa D4 or its equivalents, since Class-1 is having better Detection Quantum Efficiency (DQE). DQE depends on film Graininess (σ_D -related to noise) and Gradient (G- related to signal). Minimum Gradient G is 4.1 at $D^3=2$ above D_0^4 and 6.8 at $D=4$ above D_0 for Class I and is 3.5 at $D=2$ above D_0 and 6.4 at $D=4$

¹ Name not disclosed because of strategic reasons.

² Name not disclosed because of strategic reasons.

³ D-Optical density

⁴ D_0 -Fog and base density

above D₀ for Class II . Indeed it was an expensive proposition, but quality always takes precedence to cost.

This corrective measure or improvement was reviewed afterwards, and found to be very effective and satisfactory in curtailing such lapses in RT film reviews.

- 4.2** Case-2 In a few number of maraging steel motor cases fabricated by vendor VR-1, unacceptable UT indications were observed in the post Pressure test mandatory UT scanning. This has created an alarm, therefore was subjected to serious investigation and brainstorming to identify the root cause.

Finally, it has been concluded to be due to a 'simple reason' i.e. operator fatigue. Scanning of each weld seam is done minimum 7 times before heat treatment stage i.e. using three different angle probes as described and then with Normal probe. With each angle probe, the seam is scanned both in longitudinal and transverse direction. Thus it adds up to 7 times. In subsequent stages like post ageing Normal probe is not used. Thus, the UT operators performing the scanning works continuously even without break in order to fulfil the tight schedule requirements. This has practise has eventually lead to more operator fatigue and loss of concentration. Naturally, the effect of fatigue come to surface only in later phases i.e. mostly during scanning with 70° probe.

To overcome the above, two sorts of measures were implemented. One is Periodical qualification of UT operators for Motor case scanning jobs. The pre-requirement of a UT operator is he should be Level-II qualified according to ASNT or ISNT scheme and must have minimum two years experience. The VSSC qualification scheme involves theory and practical scanning test and finally a viva voce. Thus, structured qualification program was planned and implemented. Then to reduce fatigue related issues, inspectors are forced to take a half hour rest after every two hours of scanning. A separate logging scheme is made for strict implementation.

After the implementation of the above, subsequent re-examinations of the weld joints by an approved third party agency has revealed that all the recordable level and other indications were completely captured and the issue was settled.

- 4.3.** Case-3: Hardware Design Changes implemented for augmenting UT Scanning:

This case study is an excellent instance of the level of significance given to ND evaluation in motor case fabrication, i.e. even a design modification of a hardware interface is done to facilitate UT scanning without any hitch.

A motor case of 3.0Meter class consists of three types segments viz. the Head End, Middle & Nozzle End. They joined together gives full motor case. The tongue and groove is normal interface used for joining the motor case segments. The tongued and grooved rings (known as TR & GR) are provided with radial holes to put shear pins. The TR and GR are forgings and they are welded to the Shells using circumferential seams. A pre-machined TR forging is shown in the figure.

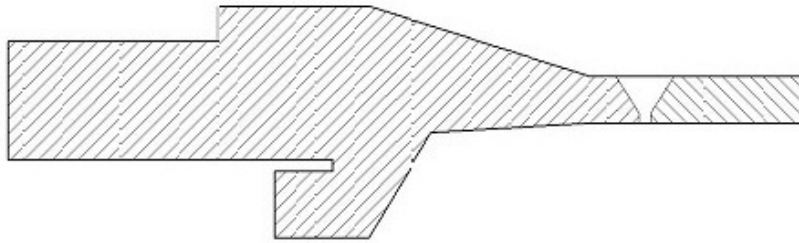


FIGURE 1

As per the UT scanning protocol, longitudinal angle beam scanning of the cir-seam weld joint has to be done from both sides i.e. from both shell side and forging side. And it has to be done from half skip to 2 skip distance for all the three angle probes viz. 45, 60 & 70°. But, owing to the taper on one side, even for a 45° angle probe scanning at one and half skip distance was found impossible. Therefore, UT scanning from the forging side had been waived till recently just due to unfeasibility.

Meantime, various ways were explored to include this joint also under full UT protocol since it was a critical one, and finally change of forging design was the only option found left out. So, it has been decided to remake the forging with adequate straight portion to facilitate unhindered UT scanning of the critical cir-seam joint. Thus, all Class-1 weld joints of the motor case are brought under full NDE protocol.

5. CONCLUSION

In fact the above improvements implemented in NDE system are not minor or insignificant but, it is part of continual system updating program undertaken by the Quality Control Team in the Motor Case area. The primary objective is to reduce the likelihood of defect missing due to human factors or method limitations, thus systematically improve the probability of detection; since presence of any unacceptable defect (due to size or orientation) in the weld seam of the hardware is simply unaffordable for aerospace application.

6. REFERENCES

- (1) *Inspection reports of a large number of motor case segments from Vendors VR-1 & VR-2.*
- (2) *VSSC- NDE documents for Motor case weld joint evaluation.*