Ultrasonic and Acousto ultrasonic evaluation of polyimide pipes and its interface for Indian cryogenic rocket stages for space launch vehicles

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Abstract

Polyimide pipes are used in the cryogenic stage to carry Liquid Hydrogen/Oxygen from tanks to engine and other sub-systems. Polyimide pipe is a layered structure consisting of multiple layers of polyimide film. For welding the pipes to the tankages, metallic end adaptors are provided at the ends. Hence there are many interfaces present in the product. Non-destructive evaluation is essential to assess the health of interfaces and also ensure minimum thickness availability. Ultrasonic methods using various frequencies, transducer configuration and scanning techniques are developed by the authors and implemented. All these methods are implemented prior to acceptance testing. Digital ultrasonic equipment with special sharp pulse/echo shape is selected for getting high accuracy. After acceptance testing re-inspection is done and compared with the results before acceptance test. To prevent thermal energy leakages from ambient to inside pipe, special way low density foams are moulded over the polyimide pipes. The bond between this foam and polyimide is also checked using special audible frequency sound transmitters. This paper details the developmental activities, standardization work and implementation work done by authors.

1.0 Introduction

Polyimide pipes are used in the cryogenic stage to carry Liquid Hydrogen/Oxygen from tanks to engine and other sub-systems. They have many advantages compared to metals. They are light weight, chemically and thermally stable, have good mechanical properties, and retain good properties even at low temperature. Polyimide pipe is a layered structure consisting of multiple layers of polyimide film. For welding the pipes to the tankages, metallic end adaptors are provided at the ends. Hence many interfaces are available in a pipe like polyimide-polyimide and metal-polyimide. To meet the functional requirement, there should not be any delamination within the layers especially near to the ID. Also, bond between end adaptor and polyimide is to be ensured. Even though pipe is subject to various pressure and leak checks, there was no NDT method available to assess the health of the interfaces and also to ensure the minimum thickness requirement with high accuracy. Initially studies were conducted on specimen level by sending sound at various frequencies and studying responses. As the evaluation demanded high level of accuracy, a digital ultrasonic equipment with special sharp pulse/echo shape was selected for systematic experimentation. Methodology was developed, standardized and implemented on actual product.
2.0 Brief studies on specimen level

To study the ultrasound characteristics of polyimide material, laminate specimen of different thickness were made. Inputs of various frequencies were sent to these specimens and their responses studied. Pulse echo mode of inspection was adopted. After arriving at the optimum frequency, velocity of sound in the material was estimated. Ultrasound velocity was found in the range of 1600-1700m/s and minimal variation between batches. To simulate defect/delamination, intentional defect was created on a specimen at a known depth. Focussed delay probe was used for inspection. Depth of delamination could be captured from the reflected echo from the defect.

The back wall echo is the measure of thickness of the specimen. Hence feasibility of the methodology was established on specimen level.
3.0 Ultrasonic evaluation of polyimide pipe and its interfaces.

The pipes have interface between metal and polyimide, polyimide to polyimide, polyimide to composite tapes. Pipes have varying thickness depending on operating pressure and other design requirements. For accurate thickness measurement, sharp pulse is required. Hence a digital equipment with sharp pulse was selected for the purpose. Pulse echo mode of inspection with focussed delay probe was adopted for polyimide region. At the end adaptor region, both through transmission and pulse echo methods were used. Further, to detect debond between adaptor and first layer of polyimide, inspection was carried out from ID of pipe.

![Fig 4 :Polyimide pipe UT inspection](image1)

![Fig 5 :Good bond signal over adaptor](image2)

![Fig 6 : Delamination signal over adaptor.](image3)

Through transmission mode inspection was also carried out over end adaptor since fibre reinforcement is given over adaptor region before acceptance test and pulse echo mode of inspection cannot be done. Normal sound transmission over adaptor (through transmission mode indicates good bond.)
Above figure shows the comparison of signals during inspection of adaptor from ID side. When debond is present between metal and polyimide, multiple reflection occurs within adaptor indicating sound is not transmitted to the polyimide interface. When bond between polyimide and adaptor is good, sound leaks into polyimide region resulting in attenuation.

In summary following types of inspection were standardized and implemented for polyimide pipe. The following inspections were carried out using pulse echo mode

i) Thickness mapping (including over end adaptor)
ii) Delamination detection in polyimide region from OD

iii) Delamination detection from OD over end adaptor

iv) Debond detection between polyimide-adaptor interface from ID of end adaptor

Through transmission inspection methodology was adopted over end adaptor. All these methods are implemented prior to acceptance testing. After acceptance testing re-inspection is done and the acceptable existing delaminations and debonds are monitored. Results were compared with radiographic observations and found to be matching. Accuracy of +/-0.05 mm could be achieved in thickness measurement and delaminations of minimum size 3mm diameter could be detected.

4.0 Acousto Ultrasonic evaluation of insulated polyimide pipes

To prevent thermal energy leakages from ambient to inside pipe, special low density foams are moulded over the polyimide pipes. Foam being a porous and very low density material, conventional NDT methods cannot be used. Inputs of various frequencies were sent to specimens of this material and responses were studied. Material responded well to audible frequencies. Special probing systems were designed for further experimentation. For simulation of actual product, cryofoam half pipe specimen with intentional defect was created and trials were conducted with specimen bonded over polyimide. The void region will act as a debond area when sound is passed through it and the signal recieved from there will be entirely different from signal recieved from a region without void. When there is no defect, sound gets weakened when approaching the interface and if bonded, part of the sound pulse get dissipated relatively at higher rate and thus reflected sound will be relatively less, compared to defective region. When there is a debond, sound pulse get dissipated relatively at lower rate and thus reflected sound will be relatively more, compared to good region, resulting in a high amplitude signal. Amplitude and width of recieved signals varies depending on the size of defect. If calibrated, at known input conditions amplitude of signal received give a measure of size of defect.
When there is a debond/void in the foam, there is an acoustic impedance mismatch due to presence of air. Comparitively higher reflection occurs in the presence of defects. Hence higher amplitude of received signal is observed. When the interface bond between polyimide-metal is good, the sound leaks from the foam to the polyimide interface. Hence, due to sound attenuation, amplitude of received signal is less. Insulated pipes are inspected for full surface area. Defective regions are marked. Defect sizing is done based on the amplitude of received signal.

5.0 Conclusion

Ultrasonic evaluation of critical interfaces of polyimide pipe has been made possible by ultrasonic testing. Methodology was developed, standardized and has been successfully implemented on polyimide pipes for flight use. The method is time saving and insitu evaluation is also possible. The method has been proved to be a good alternative to radiography.