White Sands Test Facility

Task: Develop Critical Profilometers to Meet Current and Future Composite Overwrapped Pressure Vessel (COPV) Interior Inspection Needs

Figure 1
360-degree scan of COPV liner prior to autofrettage (at left),
and associated vessels shown with external instrumentation

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Objectives

The objective of this project is to develop laser profilometer technology that can efficiently inspect and map the inside of composite pressure vessels for flaws such as liner buckling, pitting, or other surface imperfections. The project will also provide profilometers that can directly support inspections of flight vessels during development and qualification programs and subsequently be implemented into manufacturing inspections to screen out vessels with “out of family” liner defects. An example interior scan of a carbon overwrapped bottle is shown in comparison to an external view of the same bottle (Fig. 1). The internal scan is primarily of the cylindrical portion, but extends about 0.15 in. into the end cap area.

Background

Current state-of-the-art borescope and videoscope inspections are used by COPV manufacturers and programs to evaluate interior surfaces for defects. These inspections sometimes miss the presence of ripples or buckles that result from liner anomalies, winding, and pressure cycling. Further, borescopes and videoscopes cannot quantitatively measure the changes that occur during autofrettage to ensure that bulging, excessive volume changes, pit growth, or other unacceptable defects do not occur. During vessel design and development it is very important to compare actual vessel mechanical response to model predictive response, and during manufacturing to compare the response of each vessel to nominal “in family” response. When ripples are noted in COPV liners, the profilometer will allow accurate evaluation of both the amplitude and periodicity of the defects and prediction of the resulting allowable cycles, and may possibly support rationale to continue to use COPVs with minor defects rather than replacing them.

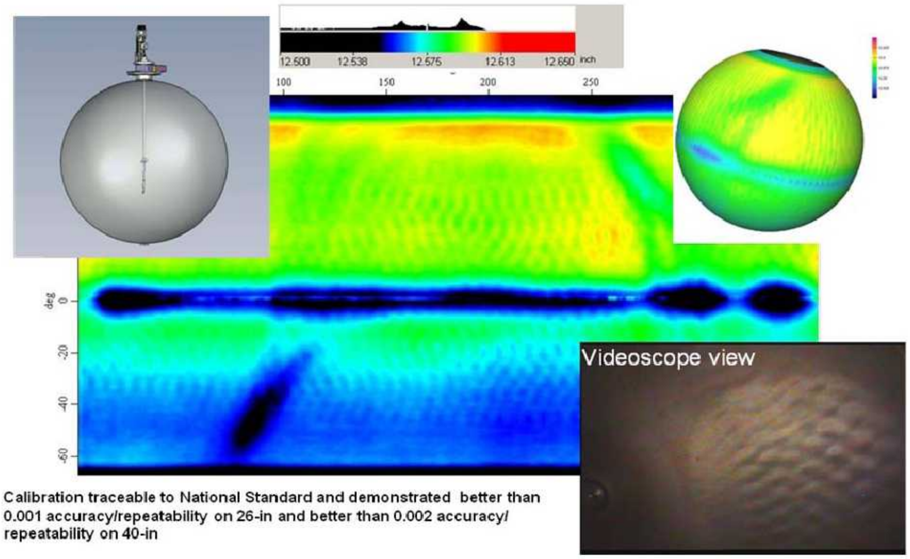
Approach

Prototype profilometers that were developed and used for evaluation of Space Shuttle Orbiter COPVs, and successfully aided in resolving a flight constraint, were further refined and upgraded. Of particular note were control software improvements to make the interface user-friendly. The existing system had limited capability to scan the interior of only spherical vessels, but measured surface profile accurately to within 0.001-in. in a ~ 26-in. and within 0.002-in. in a ~ 40-in.-diameter COPV (Fig. 2).

The new laboratory profilometer developed during this project added an additional translational axis so that cylindrical COPVs can be inspected. Further developments are now being pursued which, in addition to the cylindrical section inspection, will allow inspection of the ellipsoidal ends on cylindrical vessels. Development of a universal profilometer is planned. The universal profilometer is to be field-adjustable and able to support inspection and evaluation of a wide range of different COPV diameters and shapes, but will be limited to port sizes of 0.32 in. and larger.

Development of a miniature laser sensor that can be inserted through COPV end ports as small as 0.25 in will also be planned if adequate funding is found. Although this miniature sensor would allow COPVs with smaller ports to be scanned, the resulting smaller diameter probe may have a shorter range and would likely be more susceptible to vibration issues. The project team is also pursuing funding to develop a miniaturized local area scanner that can be attached to the end of a videoscope in order to permit more accurate measurement of internal pits and voids in both COPVs and other smaller components.

All profilometry tools developed under this project are being designed with user-friendly control and data acquisition system interfaces, and physical calibration standards that are traceable to the National Institute of Standards and Technology (NIST).



Calibration traceable to National Standard and demonstrated better than 0.001 accuracy/repeatability on 26-in and better than 0.002 accuracy/ repeatability on 40-in

Figure 2

Laser profilometry of the COPV interior surface quantifies liner buckling that is not inspectable by other methods and mirrors physical observation

Customers

The direct customers for this task will be the Space Transportation System, International Space Station, Constellation or "Flexible Path" vehicles, "Flagship" mission vehicles, In-Space Propulsion/Planetary programs, and other endeavors related to NASA's Space Exploration Initiatives. Indirect customers are all other space flight systems employing COPV technology. The results developed could be used across NASA, DOD, and commercial aerospace applications.

Metrics

Progress in state-of-the-art profilometer development shall be reported on an annual basis and peer reviewed by NASA Nondestructive Evaluation Working Group (NNWG) members. A comparison shall be made to the original project plan and schedule, providing a measure of project progress. Additionally, the NASA Engineering & Safety Center (NESC) Composite Pressure Vessel Working Group is a stakeholder, and this proposal has their expressed endorsement.

Products

At least four separate profilometers will be produced (six are desired):

1. Operational developmental unit for 26 and 40 in. liners, interfaceable to existing thruster profilometer instrumentation (COMPLETE)
2. Operational developmental unit for ~ 6.2 in. cylindrical liners (COMPLETE)
3. Operational developmental unit for larger cylindrical liner with ellipsoid ends
4. Operational field-adaptable profilometer for a wide range of COPV sizes and shapes

Needed, but currently unfunded:

5. An operational laser profile scanning system for small COPV liners with 0.25 in. threaded ports (technology available, but requires additional funding)
6. Operational miniature local area scanner to be interfaced with commercial videoscope (technology available, but requires additional funding)

Status

A new laboratory profilometer was developed which added an axis of translation to permit examination of cylindrical vessels to the existing spherical vessel inspection device. The new profilometer was been developed for vessels with diameters of 5.9 to 6.5 in. Since development, the unit has been successfully used on dozens of COPVs manufactured for the NNWG stress rupture test project (40 have been tested), the NESC autofrettage test project, and the NESC plastically responding liner testing (Fig. 3). Fig. 4 depicts how changes in vessels before and after autofrettage can be evaluated. Fig. 5 is a 3-D view of displacements before and after autofrettage to help visualize changes in the vessel. Fig. 6 demonstrates the ability of this profilometer to image and measure pits in the inner surface.

The profilometer was shipped to the General Dynamics facility in Lincoln, Nebraska in December 2009 and used to inspect International Space Station stress rupture test articles in the 5.9- to 6.5-in.-diameter range.

An articulated sensor system is also being developed to allow inspection of COPVs with ellipsoidal heads. This unit has been designed and is currently in fabrication, and is expected to be tested in August 2010. The first target vessel for this new profilometer design is a 20-in.-diameter vessel ~ 55-in. in length that is to be used on the Orion vehicle.

Figure 3

WSTF and Laser Techniques Company personnel evaluate a COPV for the NESC Plastically Responding Liner Project

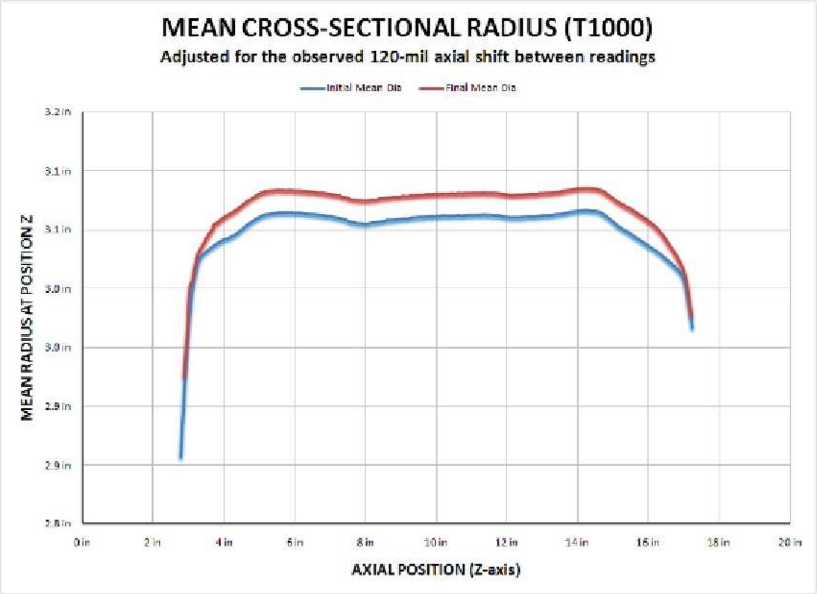


Figure 4

Plot of average diameter changes in an NESC T1000 autofrettage carbon vessel before and after autofrettage

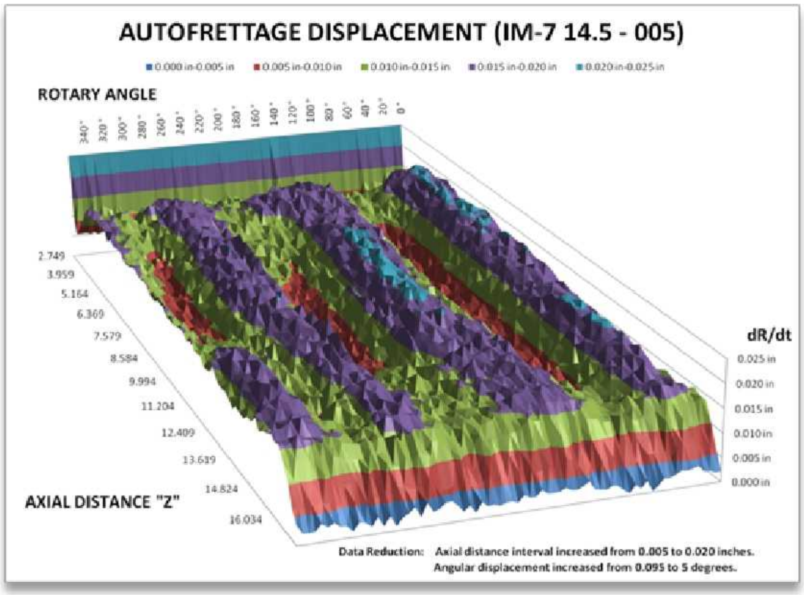


Figure 5
3-D view of displacement, before and after autofrettage

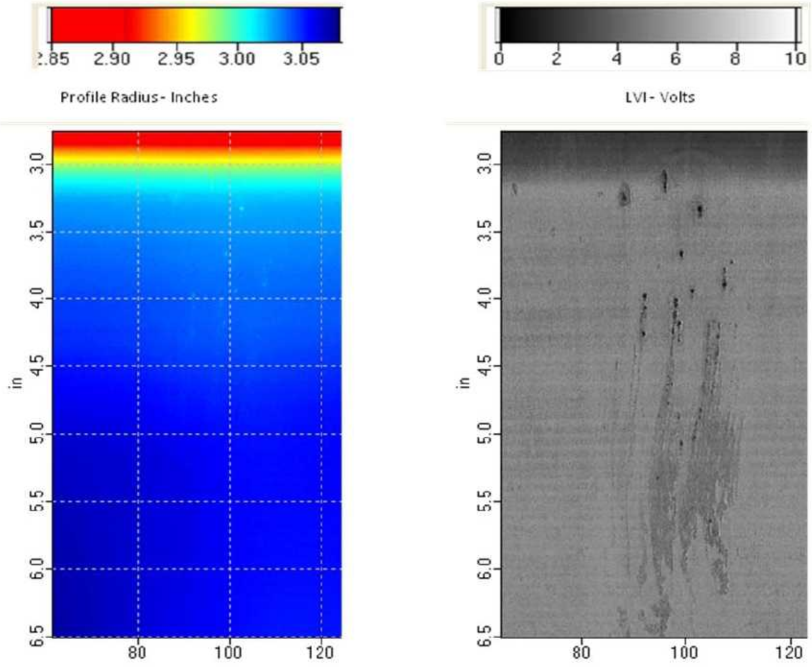


Figure 6
Scan Parameters: Close-ups of pits measured at a depth of 0.005 inches