Advances in High Accuracy Measurement in Remote Visual Inspection

Abstract

This paper discusses recent developments in remote visual inspection (RVI) which have allowed the new generation of video borescopes to achieve significantly higher measurement accuracy, while allowing such measurement to take place quickly and easily without the need to change optical inspection tips. It explains how the optical metrology technique of phase shifting has been adapted by the development of a miniature projection system to allow the 3D visualization benefits of phase shifting to be transferred to RVI. By combining this patented projection system with high quality viewing optics and sophisticated, proprietary processing algorithms, it is now possible to view a full 3D map, or point cloud, of the surface under inspection and this is used in conjunction with measurement to obtain more precise information about the defect. Measurement simply involves the placing of cursors at selected positions on a normal full-screen image and information can be displayed in terms of a height/depth profile, a rotated image or as a conventional "white light" image. Immediate applications for the technology are in the aviation sector, especially for tasks such as tip-shroud clearance measurement. Applications in other sectors are envisaged as more customised probes are developed.

Introduction

Remote Visual Inspection (RVI) is a long-established inspection and non-destructive testing technique. Although conventional rigid borescopes are still widely used, video borescopes now account for most of the RVI tasks. They find application throughout the industrial and process spectrum and especially in the aerospace sector, where they are used to inspect airframes, APUs and engines. They are used as part of MRO routines, as well as by OEMs during engine build. They can be used to inspect for leaks, corrosion and surface cracking and to check internal gaps, as well as identifying the reasons for blockages and detecting foreign objects. With such a wide range of potential uses and requirements, it is not surprising that video borescopes have developed considerably over recent years.

Borescope Development

In its most basic form, an RVI system consists of a lens and illuminating light source, connected to a light transmitting extension, which ends in a viewing eyepiece. Designs have now progressed somewhat from these very basic endoscopes and today, fiber optics tends to be the light transmitting mechanism, while the human eye has been very much superseded by video devices. At the same time, there have also been significant improvements in the functionality of video borescopes with the introduction of on-board computing power. This has allowed borescopes to offer the capability to save and store video images in digital format. The capturing and storage of digital data was formerly achieved by floppy disc and videotape. This technology then advanced to include CD, DVD, flash media and solid-state memory cards, so that files could be transferred to a PC for further assessment or storage.

Sharing of inspection information is a vital part of any inspection procedure, especially in the aerospace sector, where safety and economics often require expert assessments of engine fitness-for-purpose. Consequently, the ability to share information is a feature, which has been particularly addressed in the latest generation of RVI instruments.

The latest video borescopes such as the XLG3 from GE's inspection technologies business , can allow total digital operation, in terms of data capture, data transfer and data management. This is possible because instruments such as the XLG3 feature PC-standard operating systems, with on-board CPUs. Their integral and intuitive image management software can create data folders, organize and delete files and create reports which automatically integrate saved images or video clips into a report document. Furthermore, text overlay and voice annotation can be combined with information, while multiple video stream outputs can allow simultaneous viewing by interested parties. Information sharing is now also further enhanced by the use of USB 2 devices for fast data transfer to portable memories and associated PCs. Connection to Internet lines and/or to support private network protocols is also a built-in feature.

Application Software

Introducing on-board PCs to RVI, has also allowed the introduction of a range of application software. For example, software is available to standardize inspection procedures to ensure consistency of both inspection and presentation of inspection results. Menu Directed Inspection (MDI) is a software solution that provides a guided inspection, where context is added automatically. When inspecting an engine, a drop-down menu will first allow an inspector to select the relevant manufacturer and specific engine. All the identification data relevant to the task (inspector, site, date etc) is then inputted before the inspector carries out the inspection, in the manner specified for that engine and component. The data image file is then tagged with annotations and filed within the borescope's data capture system. Finally, a hard copy report is produced with a convenient "click-to-report" feature.

Measurement Is Now Often Equally as Important as Detection

The measurement of flaws, discrepancies and clearances is nowadays often just as important as their detection and identification. To date, there have been three major measurement systems: comparison measurement; StereoProbe measurement and ShadowProbe measurement.

Comparison measurement is based on a known reference dimension in the inspection image, which is used to measure other objects in the same view and plane. (The reference dimension is often set in place by the instrument manufacturer or introduced with the probe.)

StereoProbe measurement uses a prism to split images, allowing the camera to capture left and right views with a precise angle of separation. The position of userplace cursors is then analyzed using a computer algorithm and a triangulation geometry is applied to obtain accurate measurements.

ShadowProbe measurement relies on a shadow triangulation of tip-to-target distance. A ShadowProbe projects a shadow across an inspection image and the position of the shadow in the image indicates the distance to the object. With this information, the ShadowProbe system can accurately calculate the size of userselected features or defects. Typical measurements afforded by these measurement methods are depth, length, area, point-to-line, multi-segment length and circle gauge.

3D Phase Measurement - an advanced measurement and imaging system

Even with the current range of measurement techniques, measurement remains the most difficult aspect of using video borescopes. Operators must be highly trained and practiced to obtain reliable and repeatable results. This expertise level has been addressed as RVI is now professionalized as an official NDT discipline and is a module within ASNT's TC1A Level-III testing and certification process.

However, significant advances have been made recently in improving the accuracy, repeatability and ease-of-use of video borescopes when carrying out measurement tasks, with the development of 3D Phase Measurement, which is now available with GE's XLG3 instruments.

3D Phase Measurement is based on an existing optical metrology technique known as Phase Shifting. This generally involves sequentially projecting three or more line patterns onto a surface, capturing on camera an image of each pattern on the surface and then processing the pattern images using triangulation to produce a 3D map of the surface. With 3D Phase Measurement, the videoprobe projects sinusoidal phase shadow patterns onto the surface. These patterns are then analyzed using specific algorithms and a 3D surface map is generated from the X, Y and Z coordinates of the point cloud which is created.

Unlike conventional stereo, shadow or laser-based measurement systems that operate on a point-by-point basis, 3D Phase Measurement processes the image data to generate a full 3D map of the viewed surface before beginning the measurement process itself. The user can then simply place measurement cursors on a normal, full screen image without the point matching, shadow identification or dot selection steps that can be challenging with other measurement techniques. Areas where measurements cannot be made, because of shadowing or excessive distance to object, are clearly indicated by a red overlay.

3D Phase Measurement imagery also provides a great deal of information about a flaw. For example, with a dent, the operator can perform an initial depth measurement by placing three cursors outside the area of the dent to establish a reference plane and then placing a fourth cursor within the dent reference plane in a position where the greatest depth would seem to be located. If the point cloud is then viewed, the system will indicate the location of the measurement cursors, focus on the region around the measurement and can optionally color code this region, using a depth scale relative to the reference plane. This can assist in more precise measurement by indicating whether or not the cursors or appropriately placed around the dent and if the fourth cursor is in fact at the deepest point.

The versatility of 3D Phase Measurement imagery is also demonstrated by fact that the 3D map can also be rotated, zoomed and viewed to provide further information on the shape of a defect and the location of the measurement cursors. The system also has the facility to provide a Profile View of the defect. This is achieved when the user positions cursors on either side of an area of interest and the 3D Phase Measurement system draws a line between them. Profile View is then selected and a cross section of the part along that line is displayed, helping to visualize the shape of a pit or crack or corrosion area. While working in Profile View, the user can move a cursor to obtain accurate and fast measurement of depth at points along the cross-section relative to the reference surface. This profile can then be graphically displayed regardless of viewing angle.

Features for Increased Productivity

The 3D Phase Measurement system relies on the fitting of a patented, precision, miniature light projection system into a detachable optical tip. One major advantage of this is that the same probe can be used both to view and to measure. This offers significant productivity benefits, as using stereo and shadow can be time-consuming as well as requiring expertise. For example, with stereo measurement, it is first necessary to spot the defect using an optical tip. This tip must then be replaced with a stereo tip, the defect must be re-located, the image is frozen, the cursors are matched and the measurement is taken. With 3D Phase Measurement, the defect is located, the image is frozen and measurement is carried out. There is no need to change the tip. Greater ease of use means fewer operator mistakes and more repeatable and accurate results.

Auto Tip Detection is another productivity feature allowing the probe to identify the attached measurement tip and provide the relevant calibration information, which is stored in the system memory.

Important, Immediate Applications

An important application of the new technology is the measurement of aircraft engine tip to shroud clearance. Aircraft engines, and other axial flow turbomachinery, are typically designed to minimize the radial gaps between the blade tips and the blade housing or shroud. Gaps between tips and shrouds can reduce efficiency by allowing gas or air to leak into the downstream stages. Consequently, it is very important to check this clearance, both during manufacture and also during service as the gap changes during engine operation. (High operational rotating speeds and high temperatures can cause radial elastic growth of blades, as well as thermal expansion of the shroud.)

Historically, one method of measuring tip/shroud clearance has involved inserting a thin metal rod into an axially drilled bolt and attaching this assembly to the fan case so that the end of the rod is positioned where the blade tips should be. After the engine has been operated, the amount of wear on the rod is measured. Obviously, this is not a high accuracy technique and its execution often generates problems such as the liberation of metal from the rod, which can cause damage to the engine.

3D Phase Measurement now offers a simple, non-contact and high accuracy technique for measuring tip to shroud clearance.

Conclusions

There have been many advances in Remote Visual Inspection since its early days. Easy-to-implement, innovative RVI measurement techniques using 3D Phase Measurement is the latest development and can provide fast, accurate results with more comprehensive imaging improvingquality control during manufacturing. This allows smarter more efficient in-service inspection.

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