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General Discussion

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Close range X-ray photogrammetry at Rolls-Royce

In order to analyse quantitatively the images obtained by using the Radiation Dynamics Super X, 8 MeV linear accelerator, Rolls-Royce have developed a system of close-range X-ray photogrammetry. In order to study the behaviour of components in motion, it is necessary to provide a flow of images from which specific events may be identified in a qualitative manner to allow a radiograph to be made for detailed measurement purposes. The use of real-time video techniques also allows the speed of an event or the rate of flexure of components to be determined, giving an indication of the nature of the force creating the movement. This may, for instance, be a thermal growth which may be slow or a pressure force which is likely to be more rapid in change. By using the Super X in the stroboscopic mode linked to engine speed, it is possible to identify eccentricity of compressor spacer rings. The video then allows the determination of the time when the ring becomes free and eccentric.

To quantify the engine movements identified by using the aforementioned techniques, it is necessary to produce a series of radiographs taken at intervals during an engine-running cycle. A statistical method was developed to extract the relevant dimensional information from the radiographic images. The equipment employed consists of a Ferranti X–Y coordinate measurement table, a cold-light illuminator, an optically magnified cross-sight and teletype, with a paper-tape punch, interfaced to the Ferranti measurement system. The cross-sight is positioned on the components of interest and the respective X–Y coordinates are recorded. The information is processed by using a computer program, the output of which provides data in an engineering format.

The main problem encountered when measuring from radiographs is the inherent unsharpness of the images. To overcome this problem each radiograph is measured by five different photogrammetrists and the average of these readings are then used, thus improving the precision of the measurement. By keeping a strict quality control during the production of the radiographs, the systematic error on any dimensions produced is maintained constant from radiograph to radiograph, for the same X-ray source alignment for a given engine. The dimensions measured from the radiograph of a static engine are taken from the dimensions measured from the radiographs of the engine at different running conditions. The change in dimension is the value retained for engineering purposes, and assuming a normal distribution, is correct within a 95 % confidence interval, based on the precision of measurement attained by the five photogrammetrists. Incorporated into the above method is a checking procedure which is used to eliminate gross errors. The quantitative information gained in this manner consists of orbital plots for compressor and turbine seals, nozzle guide vane leans, compressor and turbine rotor dishing and diametral expansions of rotors and casings. To improve the repeatability and precision of measurement a fast microdensitometer system has been developed within Rolls-

Royce. The system consists of a purpose-built X–Y coordinate and Quantimet 720 image analysis system.

The coordinate table has a stepping motor drive and a digital positional indication within ±0.0005 inches (0.127 μm). These coordinates are directly interfaced into our computing facility. The Quantimet system is video based, but includes a digitizing densitometer which can be calibrated in terms of optical density. This provides a density curve across the edge of the component to be measured and allows an objective decision to be made. A video-generated cross-sight is displayed on the monitor screen and the coordinate table is moved to cause the image of the edge to be measured to align with the horizontal line of the cross-sight. This ensures that the electronic and optical axes are kept constant and only the central portion of the field of view is needed. That is, the measurement is obtained from the movement of the X–Y coordinate table and the video part of the system is used as a null detector, which does not have to be calibrated dimensionally.

The Quantimet system is interfaced to a Texas Instruments microcomputer which allows more complex algorithms for determining the edge to be applied. Techniques for full image processing are currently being developed.

Close-range cold neutron photogrammetry at Rolls-Royce

The benefit of using subthermal neutrons in the range of approximately 0.004 eV was appreciated as the absorption coefficient for iron remains reasonably constant, except for the Bragg cut-off, whereas the cross-section for hydrocarbons such as oils and fuels increases considerably at lower neutron energy levels. The diversions between the two curves provide the necessary radiographic contrast for imaging oils and fuels. To test the usefulness of this technique, work was carried out at A.W.R.E., Aldermaston in the summer of 1975 on the Herald 5 MW research reactor. The work was carried out on the cold neutron radiographic facility with test objects.

Problems were experienced by Rolls-Royce in the oil system of the BS 360 Gem engine in the oil-scavenge system. Arrangements were made to use the 25 MW Dido reactor at Harwell, which has an external flight tube on the 6H hole. At a distance of 25 m there is a block-house which was used to house the Gem engine and the first successful radiography and fluoroscopy of a running gas-turbine took place on this site in November 1976. In both cases the cold neutron flux obtained was in the order of 2×10^5 cold neutrons $cm^{-2}\,s^{-1}$ and the luminance on the rear of the gadolinium oxysulphide phosphor was in the order of 10^{-7} ft-L.

While at the 6H hole, several radiographs were taken for research purposes comparing the images obtained of various thicknesses of oil and using various different oils. Step wedges and steel samples were also radiographed. The direct-image technique was used as the Gamma contamination of the beam from the 6H hole is very low. Much experience was gained also using engine modules of the exposure time needed for good clear radiographs. Some work was also done at a thermal facility 6HGR9, but there was found to be a rather high Gamma contamination and there was a constraint upon the maximum size of the object to be radiographed.

These tests raise several interesting questions which are now being tackled in a Rolls-Royce research programme. Neutron radiography in its applications to the gas turbine industry may well follow paths not yet taken by other researchers in this field: the results so far are very encouraging for the future.