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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Aircraft Structures Technical Memorandum 577

AN IMPROVED METHOD OF INVESTIGATION OF COMPRESSOR
BLADE FIT USING HOLOGRAPHIC INTERFEROMETRY

by

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**AN IMPROVED METHOD OF INVESTIGATION OF COMPRESSOR
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SUMMARY

An improved technique of application of double-exposure holographic interferometry has been developed and applied to investigate the effectiveness of bonding compressor blades into discs. The method enables the simultaneous observation of the small displacements of the blades from two directions when they are subjected to a small force.

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1. INTRODUCTION

Time lapse holographic interferometry is a technique which will detect and measure displacements of the order of a quarter of a wavelength of the laser source employed. The wavelength of helium-neon laser light is 632.8 nanometres. Thus displacements of a fraction of a micron can be measured. In this work, an improved method of recording the small displacements of ill-fitting compressor blades when subjected to a small force is reported. The technique described is an improvement on that reported by Rumble and Lawrie¹ as it records a radial and axial view of the blades at the same time. The resulting holographic views are therefore recorded for the same disturbing force and displacement. This technique has been used to assess the quality of fit of compressor blades in a compressor disc from a service aircraft, giving a more accurate and sensitive method than currently used routine inspection techniques. The previously used holographic technique¹ cannot record the two views of the disc simultaneously, takes twice as long and requires twice as many photographic plates as the method reported here. The improved technique is expected to enable the inspection of a complete disc with one hologram, and when applied with a pulse laser may provide an in-situ testing technique. The compressor blade problem and current inspection techniques have been discussed in depth by Glenny².

2. HOLOGRAPHY

Holography is a technique which has many scientific applications, and is now gaining acceptance in industry. It enables the recording of three-dimensional information about an object on a two-dimensional medium. Currently used methods of taking holograms rely on the recording the interference pattern which is generated when light from a coherent monochromatic source is split into two, (or sometimes more) beams, and they are recombined at the recording medium. One of the beams is reflected, or scattered from the object. As the source is coherent, the recombined beams interfere, and the resulting interference pattern is stored by the recording medium. The stored interference pattern can be used to reconstruct a three-dimensional optical field of the object. The light reaching the recording medium after reflection by the object is called the object or subject beam, the split off portion with which it interferes at the recording medium is called the reference beam. When recording a hologram, a point on the recording medium is illuminated by both the reference beam and light reflected by every point of the object's surface. Because the source is coherent, a point on the recording medium will be illuminated by light of constant amplitude and phase relative to the source. The amplitude and phase vary over the surface of the recording medium and are determined by the vector sum of the reference beam and the light reflected by each point of the object's surface. The recording medium linearly records the intensity of the resulting light falling on it. The pattern recorded is an interference pattern which can be thought of as a carrier wave (the reference beam,) linearly modulated by information about the object's surface (the object beam.) When reconstructed, each point of the recording medium is found to contain information about the phase and amplitude of light reflected by the whole of the object's surface, as viewed from that point on the recording medium. The most common recording media are photographic film or plate with very high resolution emulsions, photothermoplastics, photochromics, magnetic materials, or crystals.

3. HOLOGRAPHIC INTERFEROMETRY

Holographic interferometry is the interference of light from two holograms of an object at slightly different states in the case of time lapse interferometry, or interference between light from the object and its hologram in real time interferometry. The interference is usually produced by the superposition of the object and its hologram, or by the superposition of two holograms of the object. The resulting series of interference fringes can be used to measure the displacement of the object's surface. In real time holographic interferometry, the fringes are generated by the surface displacement that occurred after the hologram was taken. In double-exposure or time-lapse holographic interferometry, the displacement that occurred between the recording of the two holograms produces the fringes.

The technique used in the work reported here was double-exposure holography, where two holograms of the blades at different stress states were recorded on one photographic plate. The two holograms were records of the blade surface slightly displaced by the differing stress states. This displacement changed the length of the optical path between points on the surface of the blades and the recording medium. On reconstruction, the intensity of the hologram was modulated, which appeared as a series of fringes on the blade's surface. The resulting fringes provided a quantitative method of measuring the displacement of the blades. The displacement of the blades reported here was a combination of bending, and movement of the entire blade due to poor fit. The two components are easily separated.

To view the holographic interferogram it must be reconstructed by illuminating it with a source of coherent light. Two three-dimensional images are produced with spatial dimensions and locations identical to the object in its undisturbed and disturbed states. The images interfere with each other producing a fringe pattern which is a series of contours of constant surface displacement superimposed upon the hologram of the object. The fringes are spaced one half a wavelength of optical path length apart, which corresponds to displacement of the surface of one quarter of a wavelength of the laser source.

4. EXPERIMENTAL

The holograms reported in this work were taken using a Radiation Research Pty. Ltd. 15mW helium-neon laser model LXH15 with a wavelength of 632.8nm. The compressor disc, and optical components were mounted on a 2440mm by 1220mm Newport Corporation Research Series vibration isolated optics table. The optical layout used incorporated a front surface mirror, to simultaneously record an axial and a radial holographic view, recorded for the same perturbing force. The optical arrangement is shown in Figs 1-3. Figure 4 shows a close-up of the compressor disc, film plate holder, and front surface mirror, and Fig 5 a plan view.

The perturbing force used to produce the displacement of the blades was applied by clamping adjacent blades together with a modified wooden clothes peg. The first hologram of the double exposure pair was recorded with the peg attached, and the peg was removed to record the second hologram. This procedure produced a hologram of a pair of adjacent blades for each exposure. To test the reproducibility of the loading force a number of holographic interferograms of a pair of blades was made. The resulting fringes appeared to be identical, indicating consistent loading.

The holograms were recorded on Agfa Holotest 8E75HD 4 by 5 inch holographic plates. Four double-exposure holograms were recorded on each plate, one in each corner. The ratio of the light intensity of the reference beam to the intensity of the light scattered from the compressor disc was two to one. Exposure time for the holographic plates varied, due to variations in laser output power, but was approximately 3 to 12 seconds.

The plates were developed in Kodak D19 developer at 20C until the optical density was judged to be one when viewed under a green safelight. The plates were bleached using the procedure detailed by Hariharan³ to produce a phase hologram with a higher diffraction efficiency than the amplitude hologram which results when a fixing process is used.

The holograms were reconstructed using the helium-neon laser, and photographed with an Olympus OM4 camera, fitted with a Zuiko 65-200mm lens set to 65mm, and mounted on a 25mm extension tube. The film used to record the holograms was Kodak Technical Pan film 2415. Exposure time was typically one second at f/8, and the film was processed in D19 developer for four minutes which gave maximum fringe contrast. The photographed holograms were printed on Ilford grade 2 glossy photographic paper, developed in Ilfospeed paper developer.

5. RESULTS

Photographs of reconstructed double-exposure holograms are shown at Figs 6-7. Figure 8 is a photograph of a reconstructed hologram of a well-fitting blade adjacent to a ill-fitting blade. The poor quality of the fir-tree image of the lower blade is due to physical damage of the blade sustained during evaluation using other techniques. The disc is a test specimen, not a component from an aircraft. The blades in Fig 7 are of a good fit, as can be seen by the small number of fringes on the root of the blades, on both the radial and the axial views. The ill-fitting blades depicted in Fig 6 have a higher fringe density due to the greater amount of movement of the blades in the disc. The fringes that can be seen near the base of the blades in Fig 7 are due to bending. They are most easily seen at the base of the blades, as the amount of deflection there is smaller than at their tips. The fringes exist near the tips, but their density is so great that they cannot be resolved by viewing the photograph by eye, and they are broken up by laser speckle, which also gives the photographs a grainy appearance.

A photograph of the disc, blades and front surface mirror viewed from the film plate is shown in Fig 9. Each hologram contains an end-on view, and a side-on view of the blades at the same state of perturbation. The view on the right side of Figs 6-9 is a radial view reflected in the front surface mirror. It should be noted that the fringe patterns for the two views in Figs 6-8 differ although there is correlation between them. This difference is due to both the directions of illumination of the blades, and the viewing directions being different, resulting in different sensitivity vectors for the two views, even though they were recorded on the same hologram at the same time.

The fringe pattern is generated by the phase difference $\delta\phi$ between the wavefronts reaching the observer. Referring to Fig 10, the optical path difference between the source and observer for a small displacement $\underline{d}$ is given by

$$\begin{aligned}\delta\phi &= \underline{d} \cdot (\underline{k}_2 - \underline{k}_1) \\ &= \underline{d} \cdot \underline{K}\end{aligned}$$

where $\underline{k}_1$ and $\underline{k}_2$ are the propagation vectors of the incident and reflected light and have a magnitude $|\underline{k}_1| = |\underline{k}_2| = 2\pi/\lambda$, and $\underline{K} = \underline{k}_2 - \underline{k}_1$

$\underline{K}$ is called the sensitivity vector.

When $\delta\phi = \pi, 3\pi, 5\pi \dots (2n-1)\pi$ destructive interference occurs and dark fringes are generated.

For $\delta\phi = 2\pi, 4\pi, 6\pi \dots 2n\pi$ constructive interference results in bright fringes.

The sensitivity vector has the same direction as the component of displacement of the object that is viewed on reconstruction, and is determined by the geometry of the optical arrangement. The sensitivity vector for a typical hologram is depicted in Fig 10. Movement of the object normal to the sensitivity vector results in minimum interferometric sensitivity and generates the lowest fringe density. The sensitivity vectors for the radial and axial views are illustrated in Figs 11-12.

6. DISCUSSION

Comparison of the side and end views shows that there is reasonable correlation of the fringe patterns which indicates that either view may be sufficient to detect badly fitting blades. Work is continuing to enable a quantitative correlation of the fringe patterns in the two views, so that the end view can be used to detect badly fitting blades, or to identify those that require more detailed evaluation. This may enable all the blades in a disc to be tested with one hologram, instead of requiring typically sixty holograms as is now the case. The method described here requires half the holograms needed previously¹, and produces two views with identical loading on the blades which the two hologram per blade method cannot do. In the earlier method, a complete change in the optical set-up was required to record the side and end views. This resulted in a considerable delay between the taking of the holograms of the two views. As it is inefficient to rearrange the optical set-up for each pair of blades, in the past all the holograms of one view were taken, then those of the other. The typical delay has been several days, during which time some parameters may have changed making the reproducibility of conditions for a pair of blades less likely.

The use of a pulse laser, and a suitable method of simultaneously loading or exciting all the blades is being investigated, and if successful, should enable a complete compressor disc to be tested with one hologram. This would be a major step towards an in-situ testing technique. A single hologram method would have to be of an axial view to see all the blades. Fewer fringes are generated in the end view than the radial view. However the application of a larger disturbing force, or applying it axially would compensate for this reduced sensitivity.

Although the method reported can be used to measure blade displacement, only the number and density of fringes have been used to evaluate quality of blade fit, and no attempt has been made to quantify the movement of the blades. The criterion for deciding if the blade fit was within acceptable tolerances has been to compare the fringes with those of blades which have been classified using other evaluation techniques. It should be possible to quantify the disturbing force and fringe properties and evolve a quantitative criterion for the quality of blade fit.

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3. Hariharan P. Optical Holography. Principles, techniques and applications. First edition. Melbourne: Cambridge University Press 1984

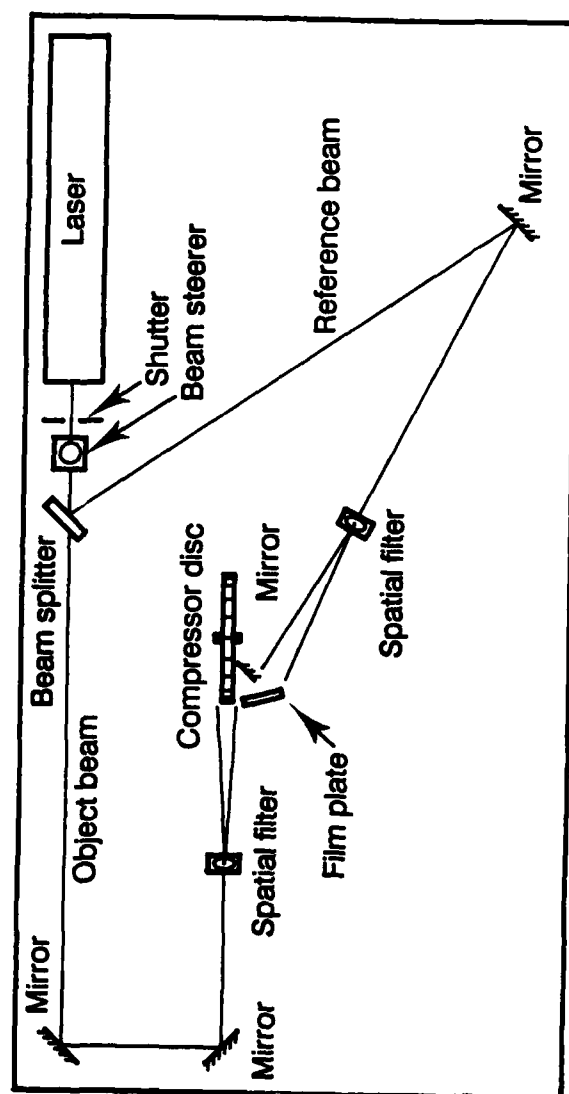


FIG. 1 OPTICAL ARRANGEMENT FOR RECORDING AXIAL AND RADIAL VIEWS SIMULTANEOUSLY

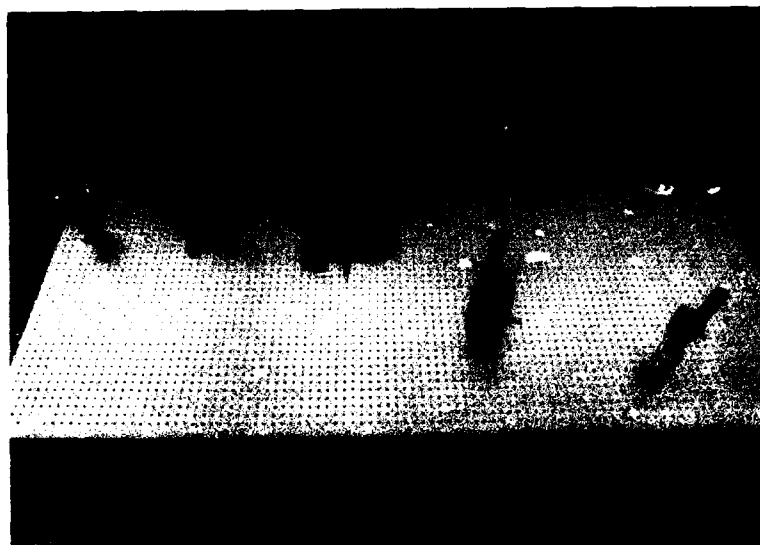


FIG. 2 PHOTOGRAPH OF OPTICAL TABLE AND OPTICAL
ARRANGEMENT



FIG. 3 PHOTOGRAPH OF OPTICAL ARRANGEMENT
AND BEAM PATH



FIG. 4 CLOSE UP PHOTOGRAPH OF COMPRESSOR DISC AND COMPONENTS

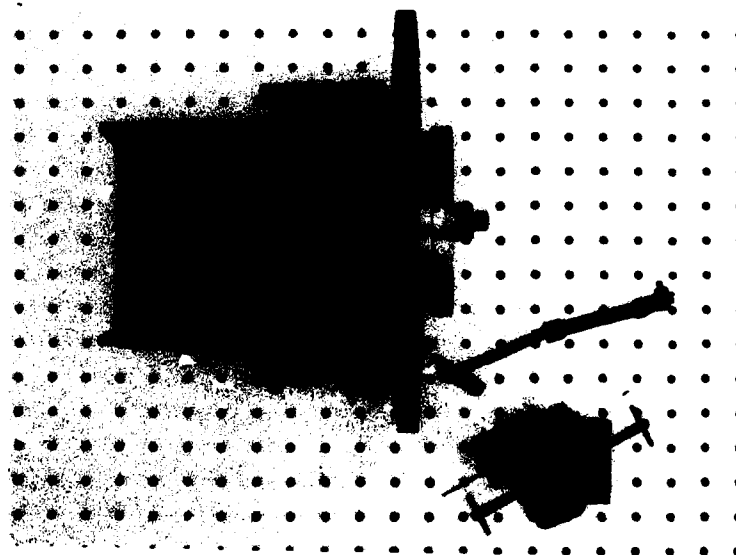


FIG. 5 PHOTOGRAPH OF PLAN VIEW OF DISC, MIRROR, AND FILM PLATE HOLDER

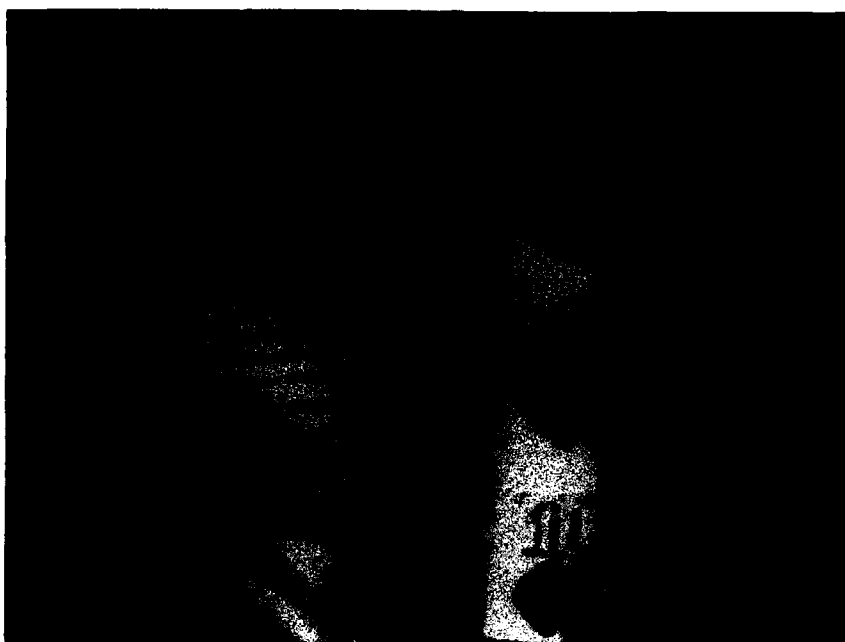


FIG. 6 PHOTOGRAPH OF RECONSTRUCTED HOLOGRAM OF
ILL-FITTING BLADES



FIG. 7 PHOTOGRAPH OF RECONSTRUCTED HOLOGRAM OF
WELL-FITTING BLADES



FIG. 8 PHOTOGRAPH OF RECONSTRUCTED HOLOGRAM OF
ONE GOOD AND ONE BAD BLADE

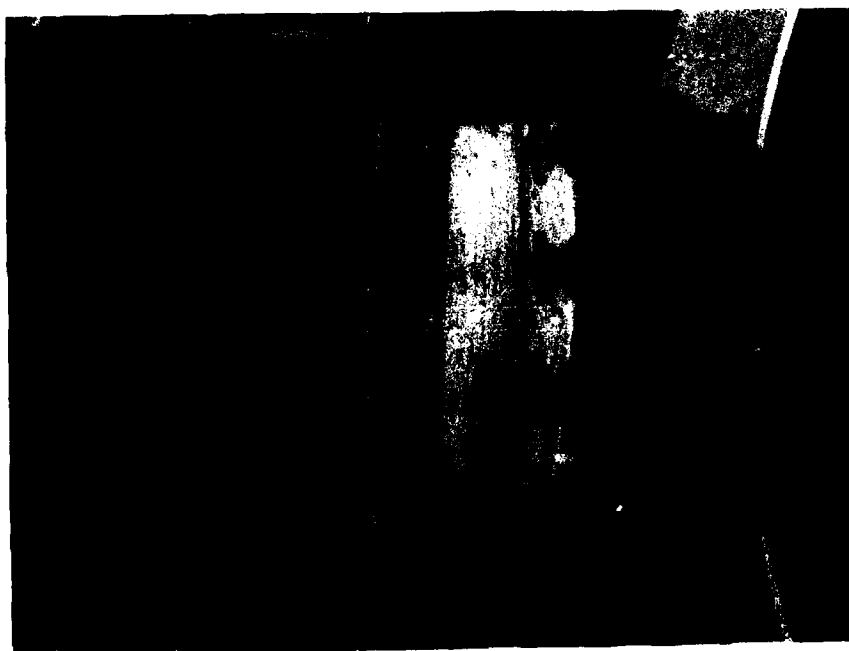
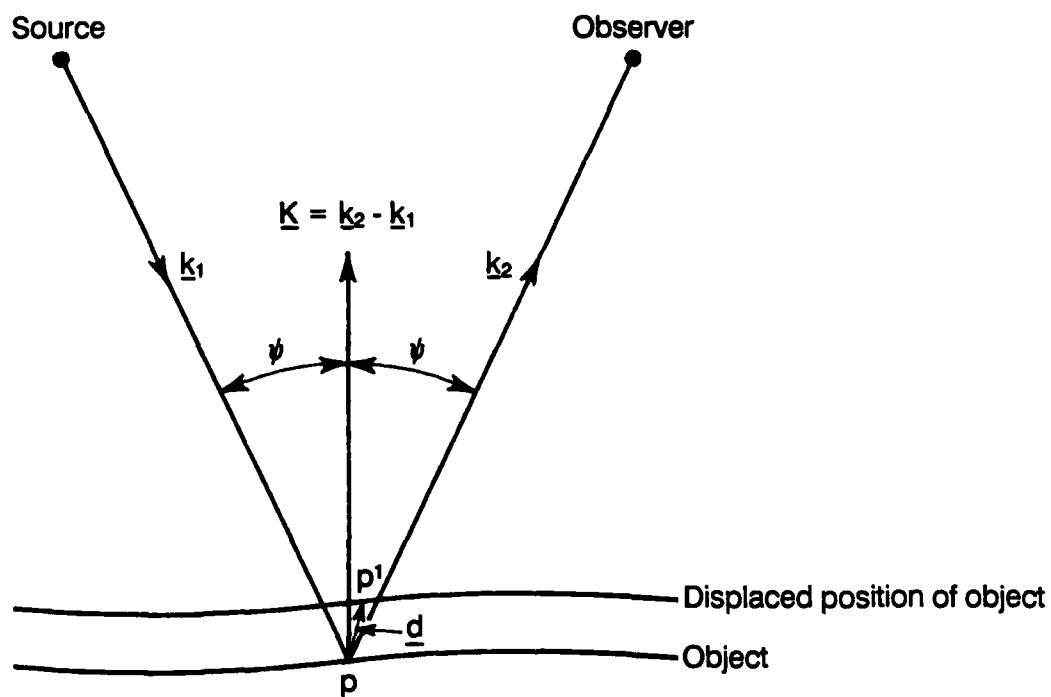


FIG. 9 PHOTOGRAPH OF DISC AND MIRROR VIEWED FROM
FILM PLATE



$$|\underline{k}_1| = |\underline{k}_2| = 2\pi/\lambda$$

FIG. 10 TYPICAL SENSITIVITY VECTOR FOR A HOLOGRAM

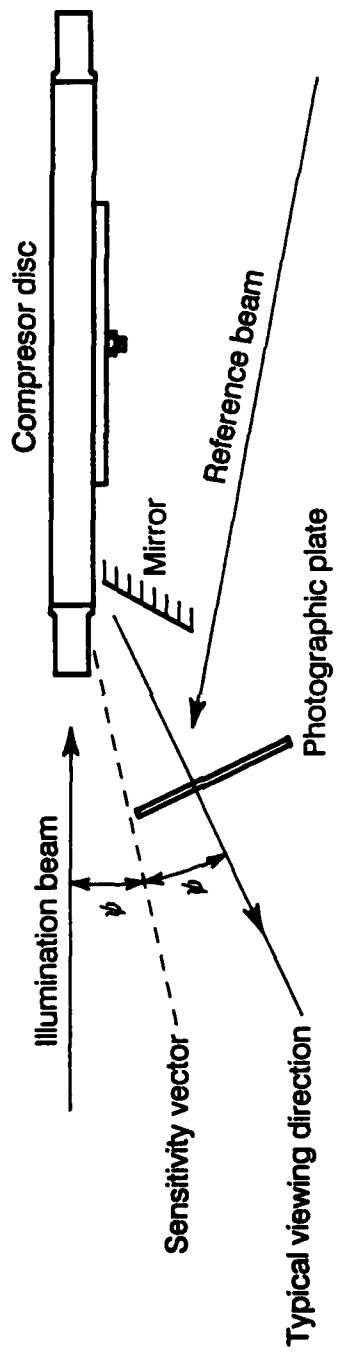


FIG. 11 TYPICAL SENSITIVITY VECTOR FOR RADIAL VIEW

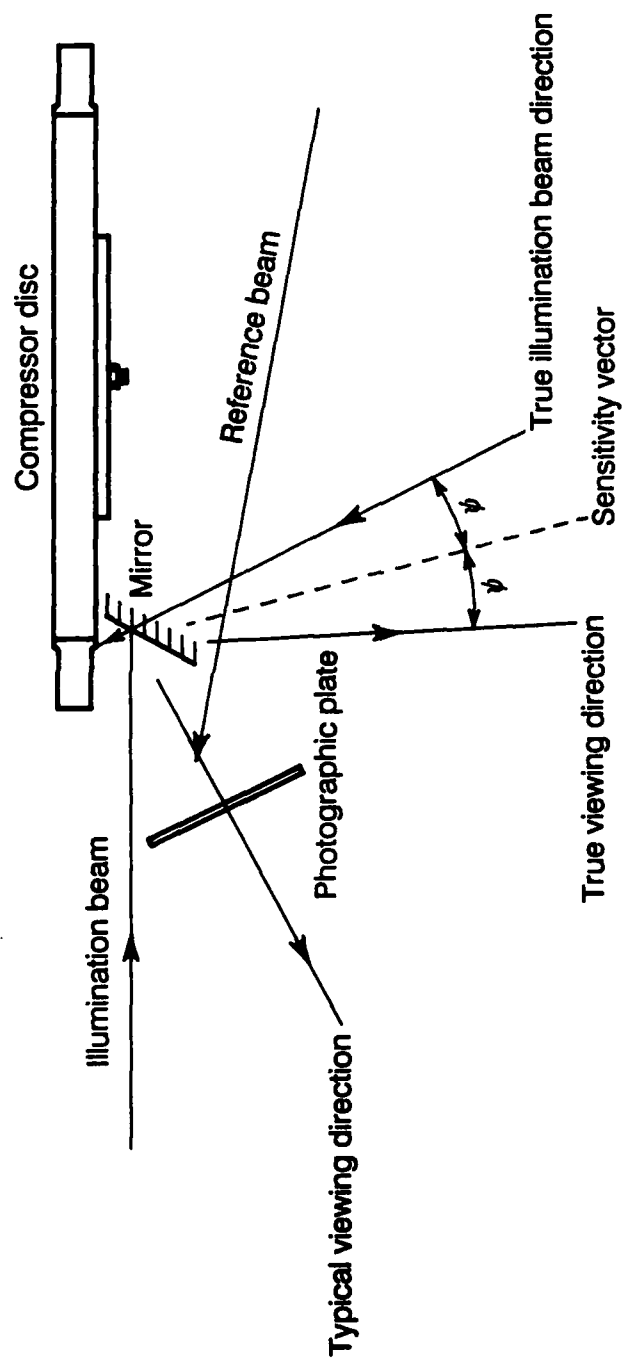


FIG. 12 TYPICAL SENSITIVITY VECTOR FOR AXIAL VIEW