New Optical Methods of Moiré Fringe Multiplication

Three simple optical methods are introduced to increase the sensitivity and accuracy of moiré analyses by an order of magnitude or more

by Daniel Post

ABSTRACT—Photographs or other replicas of relatively coarse specimen screens can be analyzed with sensitivities corresponding to screens of many thousands of lines per inch (lpi). Moiré fringe multiplication is accomplished by collecting specific groups of diffracted beams emanating from two moiré screens in series. Three methods are described and multiplication by factors as high as 30 are demonstrated. Sensitivity and accuracy are increased by the fringe-multiplication factor. Usefulness of full-field mechanical differentiation techniques is extended to cases of correspondingly lower strains. These fringe-multiplication methods apply to both bar-and-space screens and transparent diffraction gratings.

Introduction

The moiré method offers a superb means of determining displacement fields of stressed bodies. Most often, however, strains and stresses must be determined, and this requires differentiation of the displacements. Unfortunately, differentiation is an inherently inefficient process. Displacement fields must be known to much better than ordinary engineering accuracy in order to derive strain fields with acceptable accuracy.

When strain-induced displacements are very large, sufficient data are available to effect satisfactory differentiation. Otherwise, strain determination has been difficult. The answer suggested here is amplification of the moiré effect by simple optical means, so as to increase the sensitivity of moiré experiments by an order of magnitude or more.

The deformation of a moiré screen on a specimen exactly matches the deformation of the specimen—and this remains true regardless of the frequency of lines in the screen. It is the sensitivity with which this deformation can be measured by the conventional moiré method that depends upon screen frequency. Nonconventional methods of analyzing the deformation of moiré screens are presented here, wherein the deformation of relatively coarse screens can be measured with unprecedented sensitivity and accuracy.

Moiré literature has evolved with redundant terminology. In strain analysis, arrays of closely spaced rulings on the specimen and analyzer have been called "screens." In other areas of metrology, they have been called "gratings." Screens imply rulings comprised of alternating opaque bars and transparent spaces, or else nonreflective bars and reflective spaces. In the alternate terminology, bar-and-space rulings are called "amplitude gratings." Rulings consisting of closely spaced grooves in transparent or reflective materials are called "phase gratings." Since moiré technology in strain analysis has now evolved to include use of phase gratings, it appears appropriate to unify the terminology by adapting the term "grating" for all types of regular, closely spaced rulings. This terminology will be used in the present paper.

Basic Optical System

Let the experimental data be obtained in the form of a deformed grating on a transparent plate. For convenience, this grating may be

![Fig. 1—Basic optical system for moiré fringe multiplication](image-url)
graph, (b) a contact print or (c) a replica of the specimen grating in the deformed (strained) state. The specimen grating would usually be of the amplitude type, in the form of a grid (orthogonal linear rulings), although phase gratings are also applicable. The deformed specimen grating is mated with an analyzer, which may be an amplitude or phase grating, and inserted in a collimated path of monochromatic light, as shown in Fig. 1.

An array of images of the source appear in the focal plane of the decollimating lens. Each source image contains all rays that emerge from the pair of gratings in a specific direction. Guild shows that sets of rays emerge in a preferred direction after experiencing diffraction at the two gratings; he defines each set of essentially parallel rays as an “r-group.” Rays that follow diffraction orders $a$, $r-a$ at the first and second gratings, respectively, comprise an r-group; $r$ and $a$ are positive and negative integers, including zero. Light from each r-group is converged by the decollimating lens to a discrete region in its focal plane. The separation

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![Image](image_url)

Fig. 2—Fringe multiplication by Method I. Gratings: grille 500 lpi and grid 500 lpi; transmittance $T = 0.5$ (width of space + width of bar plus space)

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<thead>
<tr>
<th>Pattern</th>
<th>Multiplication factor</th>
<th>Sensitivity equivalent, lpi</th>
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<tbody>
<tr>
<td>a</td>
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<td>500</td>
</tr>
<tr>
<td>b</td>
<td>3</td>
<td>1500</td>
</tr>
<tr>
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