Electronic Speckle Pattern Interferometry - ESPI

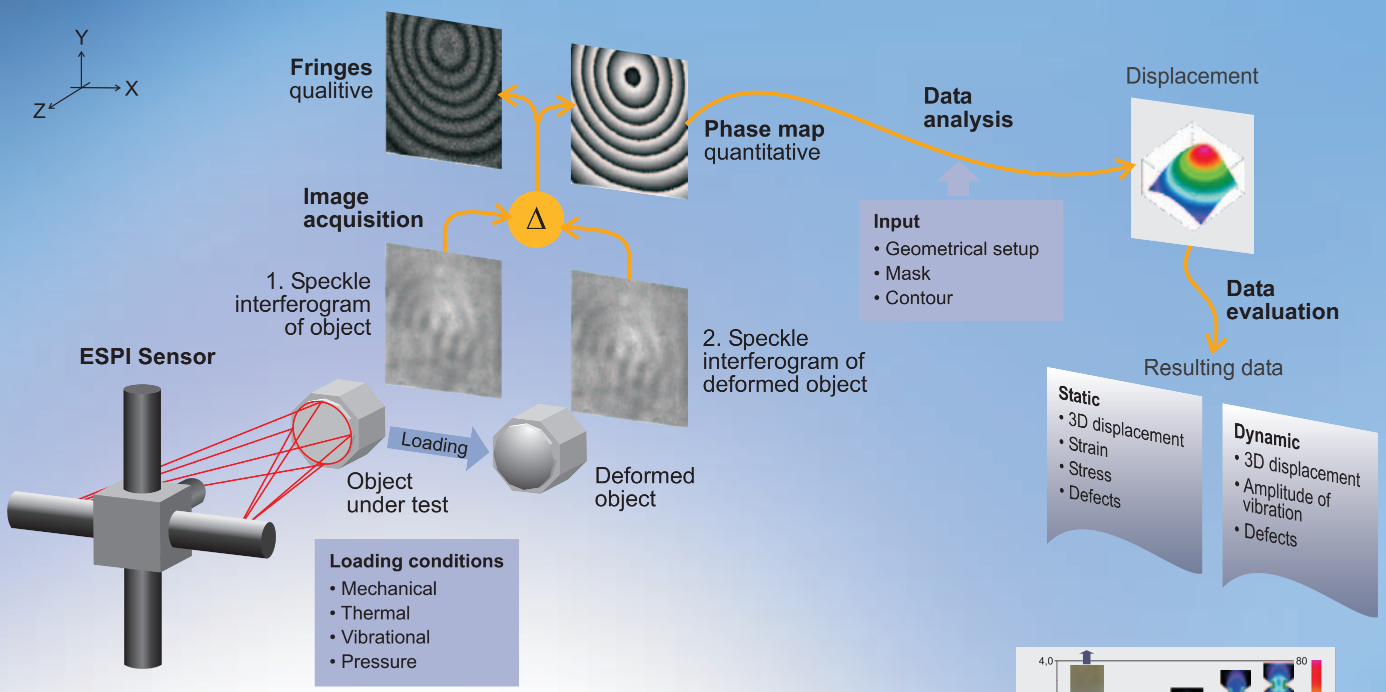
Introduction

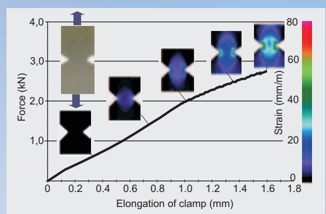
Electronic Speckle Pattern Interferometry (ESPI) is an optical technique which enables interferometric measurements of surface displacements on almost any surface and material. The non-contact and full-field measurement allows the calculation of the three dimensional distribution of the displacement and strain/stress of the object under test as a response to a mechanical or thermal loading.

ESPI has successfully been applied in many fields including automotive, aerospace, electronics and materials research, for the study of material properties, fracture mechanics, fatigue testing, NDT and dynamic behaviour of a variety of components.

FEATURES

- The technique is non-contact and gives full-field information on almost any surface and any material
- Object contour and displacement is measured, strain and stress is calculated
- All three components of displacement and contour can be measured with a compact sensor head
- Static loading (e.g. tensile test) as well as dynamic events (e.g. vibrations) can be investigated
- Using high resolution CCD cameras, resolution in the sub-micrometer and micro strain range are possible
- Results are similar to Finite Element Analysis



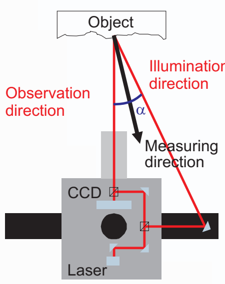


Strain fields for different loads in tensile test (notched aluminium sample).

Principles

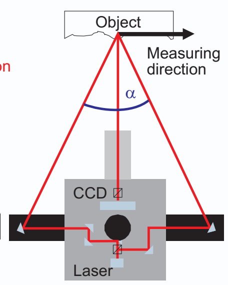
The illumination of a rough surface with coherent laser light and subsequent imaging using a CCD camera generates statistical interference patterns, the so-called speckles. Like a fingerprint, these speckles are inherent to the investigated surface. Superimposing a reference light, which is split out of the same laser source, on these speckles results in an interferogram.

When the object under test is loaded, e.g. by mechanical means, and the surface is deformed, the speckle interferogram also changes. Comparing an interferogram of the surface before and after loading will result in a fringe pattern, which reveals the displacement of the surface during loading as contour lines of deformation. These qualitative fringe images are of low contrast and noisy due to the presence of the speckles. A procedure called phase shifting takes a series of speckle images for each surface state and calculates a quantitative phase map. In contrast to the fringe images this phase map furthermore contains quantitative and directional information which can directly be transformed into a displacement value.



ESPI setup for out-of-plane measurement

$$d = \frac{N \cdot \lambda}{1 + \cos(\alpha / 2)}$$



ESPI setup for in-plane measurement

$$d = \frac{N \cdot \lambda}{2 \cdot \sin(\alpha / 2)}$$

d = displacement, N = number of fringes
λ = wavelength, α = illumination angle

3D information

In order to measure all three displacement components u, v and w, measurements should be performed in x, y and z directions. The z component of displacement is measured in an out-of-plane configuration, the x and y components in an in-plane arrangement. Modern sensors integrate all arrangements and allow one to toggle in milliseconds.

For static tests the three displacement directions are measured in series. In dynamic applications however, all sensitivity directions are acquired in parallel.

The resolution of the displacement is determined by the wavelength of the laser employed and the geometrical arrangement. Typical values are down to 50 nm.

Strain/stress

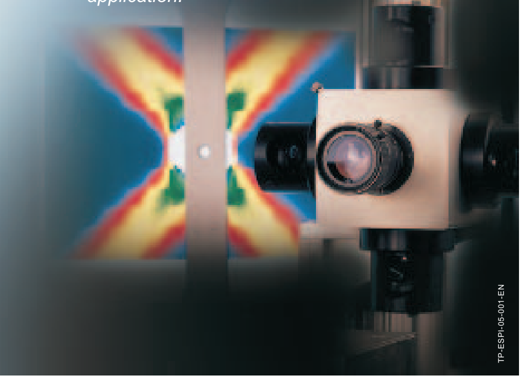
The strain within the object due to a mechanical or thermal loading is calculated from the three dimensional displacement field. Therefore for nonplanar objects the contour is also measured. With known material parameters (Young's modulus, Poisson's ratio) the corresponding stress components in the linear elastic region are calculated from the strain components.

Applications

The full-field nature of the results allows an accurate and easy determination of material parameters and the identification of highly stressed areas. In contrast to conventional methods e.g. strain gauge, scanning vibrometer, ESPI systems combine an unsurpassed density of measuring points with very high sensitivity and a dynamic range up to several hundred kHz.

Typical applications utilize not just a single measurement but a sequence of measurements, so that the user can follow the evolution of displacement/strain during loading.

3D ESPI sensor in tensile test application.



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