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Unconventional Methods of Non-Destructive Tests
Part 3.

Abstract: The article presents some testing methods applicable in the aviation industry. In addition to popular non-destructive methods, NDT methods used in the aviation industry (and discussed in the article) include optical holography or shearography. Structural materials used in the aviation industry as well as the importance of analyses, both at the manufacturing stage and during operation, require the performance of regular tests as a negligent approach to such activities could end up in a catastrophe.

Keywords: optical holographic tests, shearography, laminography, tap test, structural health monitoring (SHM)

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The aviation sector requires the vast application of non-destructive tests involving the use of special testing methods, including **acoustic, resonant, infrared, interferometric and Structural Health Monitoring (SHM)** methods [1]. The safety of aviation structures entails monitoring the condition of materials both at the manufacturing stage and during operation. Failures, if any, may have serious consequences, including an air crash. Non-destructive methods applicable in the aviation industry make it possible to assess the condition of modern materials used in aviation (including composites) and obtain information necessary for the continued operation of a given aviation structure.

Interferometric methods include the **holographic and shearographic** methods [1]. Information used in the above-named methods comes from the analysis of the interference of laser light reflected against a surface being tested. Optical holography has been discovered twice. First, in 1920 by Mieczysław Wolfke and, next, in 1947 by Dennis Gabor. However, it is Dennis Gabor (Nobel Prize winner in 1971) who is recognised as the inventor of holography. Ideas by Mieczysław Wolfke and Dennis Gabor were the same and concerned with the reconstruction (within the optical range) of images recorded using X-radiation (Wolfke) or obtained using an electron microscope (Gabor). Both inventors wanted to present the magnified spatial structure of materials [2].

Optical holography has found applications in medicine, biology and information technology (to store large amounts of data on holographic versatile discs (HVD). In turn, acoustic holography has been used in **flaw detection**. There are also research works aiming to apply holography in 3D films and TV. Rotating holographic mirrors are used to move laser radiation along the bar code in shop and supermarket check-outs [3]. Optical holography, more accurate than traditional photography, consists in the three-dimensional recording of

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	Holography	Photography
1	Recording of amplitude and wave phase	Recording of amplitude only
2	No need for optical systems	Object lens necessary
3	Sharp image within the entire depth	Sharp image within the object lens sharpness depth range
4	Spatial image – 3D	Flat image – 2D
5	Information about object image – recorded on the entire hologram	Assignment of object and image points
6	Positive image	Negative image
7	Recording requires coherent light	White light is usually used
8	Image is encoded	Image is readable directly
9	Highly complicated equipment	Relatively uncomplicated equipment
10	Information recording resolution above 1000 lines/mm	Recording resolution

images (Table 1). Photography only involves the recording of amplitude modulation, whereas holography is also connected with the recording of changes in the light phase (enabling the obtainment of more information about an object exposed to radiation).

Techniques used in optical holography include [3]:

1. interference of the reference beam with the beam reflected against the object;
2. interference of beam reflected against the object with a photo of an object before loading (with changes).

Figure 1 presents the principle behind the formation of a holographic image [3].

The holographic image can be obtained by illuminating an object using a defocused beam of monochromatic phasewise coherent light, i.e.

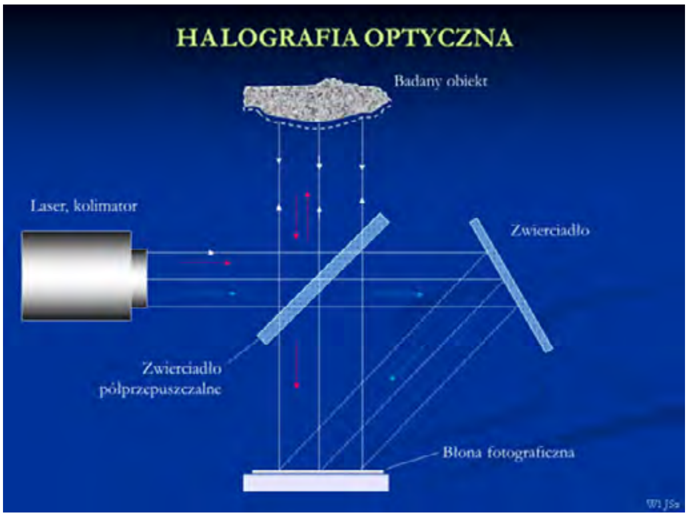

Fig. 1. Principle of halographic image formation [3]

the laser light beam. The beam is split into two parts, one of which illuminates an object being tested, whereas the other one is the reference beam. The interference of light reflected against the object and that of the reference beam is recorded on a light-sensitive photographic film [4]. The reproduction of the object in the form of a three-dimensional apparent image requires the re-illumination of the photographic plate. If, on the same photographic film, images of an object not loaded and loaded with forces are recorded, the comparison of interference lines of obtained images could enable the formulation of conclusions concerning changes of the object subjected to tests. Even small changes of the dimensions and shape (e.g. triggered by stress concentration in an area of imperfection) of the object are clearly visible in the holographic image. In the aforesaid manner, a film referred to as a hologram is obtained. The film, observed at magnification is a system of bright and dark points (fringes). On a fragment of a (photographic) plate it is not possible to see a sector of a photographed object [4]. If the plate is cut into two parts, each of them creates a larger fragment of an image. In extreme cases it is even possible to obtain two images with a lower number of details. Commonly known multi-layered reflection holograms have the spatial system (many layers) of diffraction grating. Such a multi-layered system, functioning as reflecting diffraction grating, forms a holographic image visible in non-coherent (e.g. white) light.

Figures 2 and 3 present examples of holographic images. The analysis of an image provides information about an imperfection (surface deformations).

Presently, optical holography finds applications in the precise visualisation of deformations triggered by stresses, e.g. in the detection of stress concentration resulting from the assembly/fixing of two elements (e.g. engine block and head), the detection of incomplete fusion in laminated materials, adhesive-bonded joints and in multi-layered electronic boards as well as the detection of thermally-triggered deformations (cast body stubs of computer discs) and the non-contact analysis of vibration (e.g. aero-engine turbine discs) [3, 4].

In the **shearographic method**, images are obtained as a result of a beam reflected against the surface of an object. The method, involving the use of coherent light and coherent sound waves, provides information about the quality of various materials in **non-destructive tests, deformation measurements and vibration analysis**. Tests require the use of shearographic cameras and the illumination of an objected using a divergent monochromatic light beam. A dedicated software programme identifies surface deformations with interferometric resolution [4]. Changes are determined by moving two images and results are presented on a monitor. Shearography uses a test object itself as a known reference; it shears an image and creates a double image as well as superimposes two images, where the shearing image represents the surface of a tested object in the non-loaded state. As a result, the method is significantly less sensitive to external **vibration and noise** [4]. A material undergoes a deformation under an insignificant load. The inhomogenous quality of the material generates the non-uniform movement of the object surface. A new sheared image is recorded in a loaded state and, next, it is compared with an image recorded before loading. If there is any discontinuity, it will be detected.

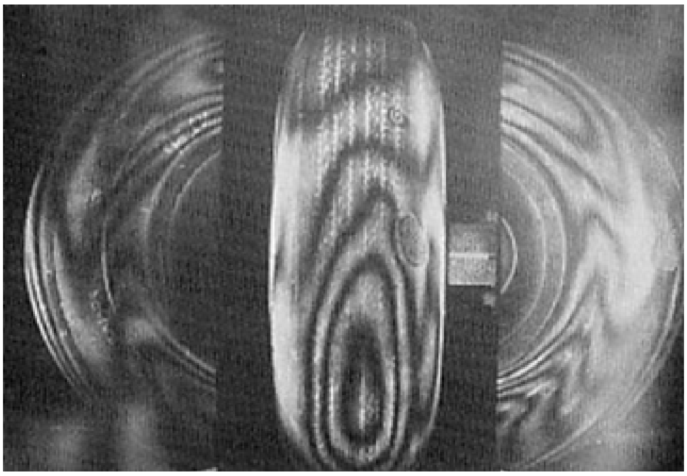

Fig. 2. Tyre in two states of deformation triggered by internal pressure [3]

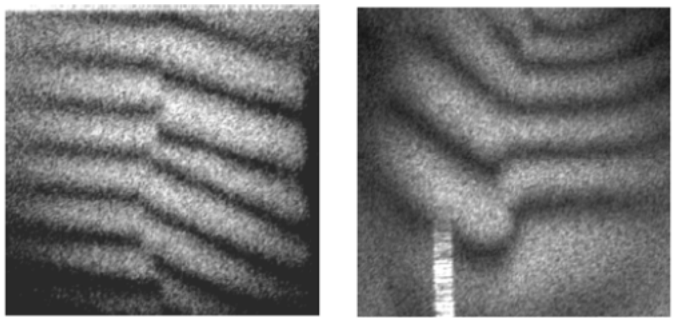

Fig. 3. Discontinuity of fringes on the fracture line; thermally triggered surface deformation [3]

The method is less susceptible to the movement of a rigid body, which is an impediment when testing and detecting discontinuities in holography. Unlike a holographic image, where fringes are proportional to the movement of the surface, fringes observed in a shearographic image represent surface inclination. Shearography can be used successfully in tests of composites, adhesive-bonded joints and materials provided with thin coatings as well as in the detection of delamination or the presence of gas pores and material inclusions [4]. Shearography is used in the automotive, aviation, aerospace and shipbuilding industries, in windfarm power generation as well as in the production of tyres and in the protection works of art. The advantages of shearography include the possibility of testing large areas (up to 1 m² per minute), non-contact properties, relative insensitiveness to environmental disturbance and the obtainment of good results when testing honeycomb-structured materials (which pose a significant challenge for traditional non-destructive testing methods).

Interferometric techniques can be used in operational aircraft tests. A significant advantage of interferometric techniques is the possibility of testing large one-sidedly accessible surfaces without the necessity of removing them. To increase the sensitivity of the measurement method, the process of real-time phase shift is used in sensors. The interferometric sensor features a stepped mirror shifting the reference beam, which is next processed applying the best adjustment algorithm and used to present information on a real-time basis. The principle of the formation of a shearographic image is presented in Figure 4.

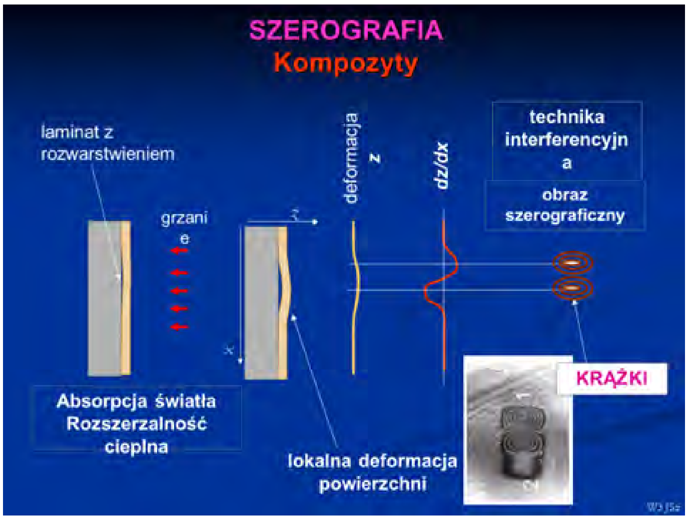

Fig. 4. Formation of a shearographic image illustrated with an example of composite testing [3]

Fig. 5. Shearographic image [3]

Fig. 6. Shearographic test with infrared radiation heating [3]

Fig. 7. Shearographic test of a rocket airframe [3]

Figures 5, 6 and 7 present an image after a shearographic test and the practical application of the test.

Laminography, a technique similar to computed tomography, is used in stratified tests of elements, where planes of interest are located near one another [5]. The principle of laminographic testing is presented in Figure 8.

There are two methods in which the source of X-radiation and the radiation detector (film) are moved in relation to each other, i.e. rotation and displacement. The first method involves the synchronous movement of the source and the film, whereas the second method involves the parallel movement. The advantages of laminography include the possibility of testing objects having several planes lying close to one another and the fact that the making of a laminograph requires a considerably lower number of radiograms. As a result, the obtainment of a three-dimensional image is significantly less time-consuming [5].

Tap test is a method used in tests of composite materials. The method, highly subjective and dependent on skills of a person performing a test, consists in tapping (using a special hammer) and listening to sounds. The size of a defective area is based on **sounds and their pitch**. An advantage of the method is the possibility of detecting discontinuities located near the surface (e.g. incomplete adhesive bonding or delamination). The detectability of discontinuities decreases along with greater depths. There are works going on aimed to make the method automatized [1]. Figure 9 presents a tap test device.

Structural health monitoring (SHM) is an optical method involving the use of optical fibres providing information about the pressure or temperature-triggered loading of a given structure. Piezoelectric sensors are located inside a container, whereas the system makes it possible to monitor elements along the entire length of optical fibres and to test large areas. Applied sensors contain vacuum chambers and gas chambers. Piezoelectric sensors react to the flow of gas to the vacuum chamber, triggered by the fracture of a structure and the breaking of the connection between the vacuum chamber and the gas chamber. An area subjected to tests is located directly under the sensor surface [1]. Figure 10 presents an exemplary SHM method-based test 10.

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