A breadboard holographic interferometer with photorefractive crystals and industrial applications

Photorefractive crystals (PRCs), and particularly those belonging to the sillenite family ($Bi_{12}SiO_{20}$ (BSO), $Bi_{12}GeO_{20}$ (BGO), $Bi_{12}TiO_{20}$ (BTO)), are notoriously promising recording media for holographic interferometry.[1] Classical plates are much more sensitive than PRCs, but they need chemical processing requiring liquid bridges when in-situ recording is required. Photo-thermoplastics have a sensitivity comparable to PRCs and they can be processed in-situ by electrical and thermal processes. However, though they can be erased, the number of exposures is limited. Sillenite PRCs are about 1000 times less sensitive than the others, but have the advantage of being self-developing and indefinitely reusable. One can envisage holographic cameras that, like speckle interferometers, do not require any external operation or manipulation, but here with the higher-quality measurement dynamics and lower noise levels that are typical of holographic interferometry.

At a first glance, these advantages are counterbalanced by the relatively weak sensitivity of sillenites. This difficulty, combined with a weak diffraction efficiency and optical dimensions of crystals limited to the cm^2, meant that experimental prototypes of PRC interferometers were confined to laboratories where powerful lasers were available. The recent availability of much larger, good-quality, sillenite crystals, powerful compact lasers, and sensitive, commercial CCD cameras, has allowed us to overcome these difficulties. Here we discuss an interferometer that was designed to be compact (on a breadboard), easily transportable, able to image objects of about 50×50 cm², and which made possible the taking of quantitative measurements.

The development and optimization of the system are already presented elsewhere.[2] Real-time holographic interferometry is performed: reference and object beams are incident onto the crystal for each exposure and the hologram is continuously recorded and read out. Once the object is deformed, an interferogram is observed and disappears slightly within a response time that depends on the crystal and illumination conditions. The instrument scheme is shown in figure 1. The ensemble surrounded by the grey line is completely included in a transportable casing ($80 \times 30 \times 20$ cm³). The laser is a compact, air-cooled cw DPSS YAG emitting 490 mW @ 532 nm. The crystal is a BGO doped copper grown by J-C Launay (University of Bordeaux) with a 29×27 mm² optical face. Typical working practice is to have a ratio of 200 between recording beams at the level of the crystal, with an object beam of at least 10 µW/cm². With a total intensity of 2 mW/cm², the response time is 9 seconds. This limits the use of the system in an only moderately stable environment. The quantitative measurement can be performed by phase-shifting[3] for sufficiently stable deformations, or by the spatial carrier technique with Fourier filtering, for the monitoring of dynamic deformations (one interferogram analysis).[4]
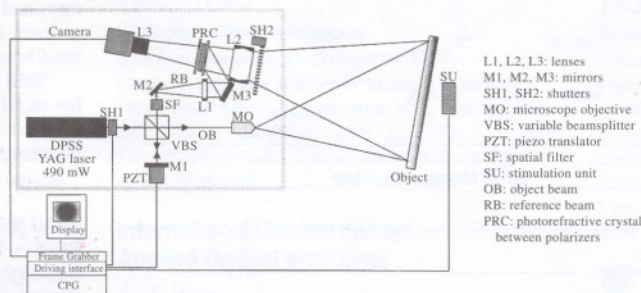

Figure 1. Scheme of the photorefractive holographic camera.

L1, L2, L3: lenses
M1, M2, M3: mirrors
SH1, SH2: shutters
MO: microscope objective
VBS: variable beamsplitter
PZT: piezo translator
SF: spatial filter
SU: stimulation unit
OB: object beam
RB: reference beam
PRC: photorefractive crystal between polarizers

A first application shown in figure 2 (a) and (b) is defects detection in composite panels. The observed area is 55×37 cm². After a hologram is recorded with the object "at rest", the object is heated and the interferogram is observed after relaxation. The phase interferogram (a) is obtained by phase-shifting and is further unwrapped and differentiated, clearly showing defects (b). Also, quantitative measurements of continuous deformations of large objects have been performed.[4] A new application of our system is the measurement of vibrations.[5] The technique used here is to record the hologram of the object at the rest and then excite it with vibration. Directly performed stroboscopic readout is synchronized with the excitation. The observed area is smaller than for other applications because less light is available at the CCD when the stroboscope is working. The object is set closer to the holographic head, so reducing the field-of-view (typically 25×25 cm²). Figure 2 (c) shows the phase map of a turbine blade vibration mode.

Provided the instrument is used in a moderately stable environment (merely a good relative stability between the holographic head and the object), measurement can be performed at high accuracies on relatively large objects.[2,3] To our knowledge, this is the first transportable holographic camera based on photorefractive materials and used in such varied applications. The present and future work of our group focuses on a compact head design, pulsed illumination experiments (for perturbed environments or analysis of transient phenomena), and near-infrared holo-graphic interferometry with semiconductor PRCs.

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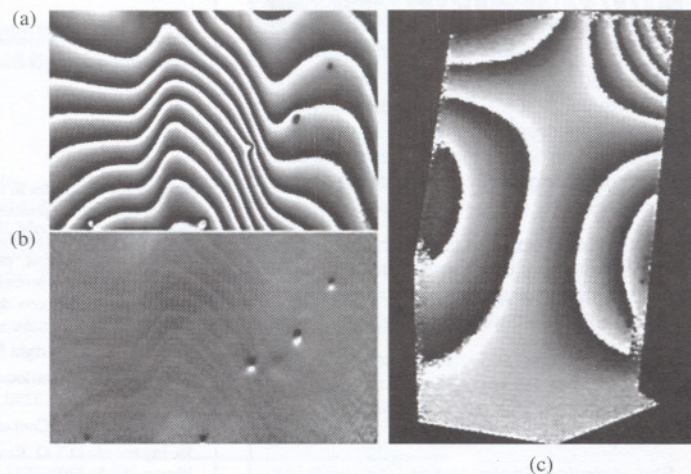

Figure 2. Industrial applications of the holographic camera. Defect detection in aeronautical composite panels. (a) Phase interferogram. (b) Differentiated phase for easy defect localization. (c) Vibration mode of a turbine blade (phase interferogram).