Holographic interferometry with photorefractive crystals : recent industrial applications.

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ABSTRACT

Photorefractive crystals allow in-situ dynamic holographic recording and indefinite reusability. Also they exhibit specific properties that other recording materials do not and which can be advantageously used in holographic interferometry. For 15 years we have been developing holographic interferometry techniques and devices with $Bi_{12}SiO_{20}$ (BSO) crystals. The dynamic behaviour of the latter allows a high degree of userfriendliness of holographic interferometry (like techniques based on electronic recording), together with higher resolution interferograms (no speckle noise - no need of filtering). In the past we already have presented a wide range of applications in metrology, NDT and vibrations measurement. Here we present recent industrial applications obtained with a device which is now commercially available. It has proven successful applications in highly demanding applications where high resolution was required

INTRODUCTION

A crucial element of Holographic Interferometry (HI) [1] is the photosensitive medium used for the hologram recording. If one generally considers that their principal figures of merit are the energetic sensitivity and the diffraction efficiency, other features such as the self-processing and the erasability/reusability of the medium can appear more important in their practical applicability to HI.

The PhotoRefractive Crystals (PRCs) [2] are interesting alternatives to other recording materials because they are self-developing in situ and indefinitely reusable. In these crystals charge migration appears, under the photoconduction effect, between illuminated and dark zones that result from the interference between the object and the reference beams. After trapping in crystal defects of the non illuminated zones, a local space charge field is created and modulates the refractive index through the linear electro-optic effect, yielding a phase hologram. This process is dynamic and reversible and can take place under thermal diffusion (diffusive regime), an external electric field (drift regime) or the photovoltaic effect (or any combination of these processes). Particularly, the PRCs belonging to the sillenite family, $Bi_{12}SiO_{20}$ (BSO), $Bi_{12}GeO_{20}$ (BGO) and $Bi_{12}TiO_{20}$ (BTO), have been studied for applications in HI because they are among the most photosensitive. The charge transport processes possible with sillenites are the diffusive and/or the drift regimes. The dynamic feature of holographic recording with PRCs meant that one can build holographic cameras that are as stand-alone and user friendly as other techniques based on speckle effect but here with higher image quality and lower noise level. The speckle is not present in the interferogram obtained by holographic interferometry while in speckle interferometry it is the main cause of low resolution of results obtained with that technique.
Also PRCs exhibit specific properties that other recording media do not. In particular the anisotropy of diffraction which consists of a rotation of the polarisation of the diffracted beam with respect to that of the direct (and transmitted) object beam. The crystal is said to act as a half-wave plate on the diffracted beam. A polariser is placed after the crystal for observing the interference between both the diffracted and transmitted beams.

Since the diffracted efficiency is very small in PRCs, the diffraction anisotropy allows equalizing both interfering beam intensities. Due to this the contrast *m* of interferograms can be set to almost the maximum (*m*=1), what explains the high quality of fringe pattern obtained.

In this paper we briefly present the photorefractive holographic camera and its principle of working. A further section is devoted to a review of recent applications that were carried out in recent projects and during routine industrial service.

PHOTOREFRACTIVE HOLOGRAPHIC CAMERA

In previous papers [4,5] we have presented the study of a breadboard holographic camera using a sillenite PRC. The aim was to build a transportable device capable of quantitative displacement measurement on relatively large scattering objects. Further developments were carried out to render this system more compact, keeping the same level of performances 6. The current holographic head is a cylinder of 25 cm length and 8 cm diameter (weight 1 kg). The laser light is brought by a singlemode optical fiber which was especially developed to allow 80% transmission over 5 meters for 5 W input power (patented). Its scheme and picture are shown in Figure 1.

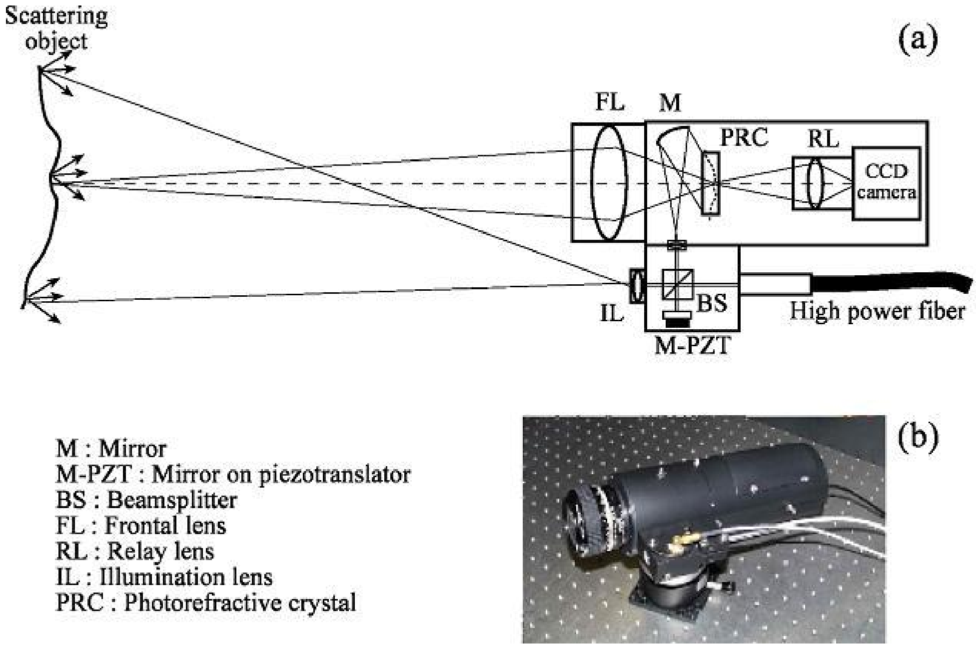

Figure 1. Compact holographic camera, scheme principle (a) and picture (b)

The working principle is the following. Both recording beams (reference and object) are continuously incident on the crystal. The recording of the hologram takes place under the response time of the photorefractive effect. The latter is mainly driven by the reference beam intensity that can be tuned. The response time to use depends mainly on the external conditions under which the holographic camera is utilized but generally its value ranges from 5 to 10 seconds if a moderately stable environment is considered (few external vibrations and air turbulences, no need of vibration compensated optical table). This response time being the same at the recording and the readout, it must not be too short in order to allow a proper use of the phase-shifting process during interferograms capture [4,5]. Once the readout is complete and the first hologram erased, the instrument is ready for a new hologram recording and measurement. The repetition rate of the measurement sequence obviously depends on the response time.

This system is adapted to quasi-static measurements (with application of phase-shifting) or to dynamic events (with single frame analysis, such as Fourier transform with fringe carrier addition) [5]. Numerous examples of applications have been shown in the detection of defects, impacts, delamination [5,7]. Also pure displacement metrology can be performed: CTE measurement [6], comparison with finite element modelling (FEM) [8], among others. A review of these past works can be found in reference 7. Vibration mode shapes can be measured by stroboscopic readout [9]. It is sufficient to add an acousto-optic modulator at the laser output and to synchronize it to the sinusoidal excitation of the object.

What is remarkable with our technique is the high quality of fringes and the resolvable density of fringes. This allows an extended range of measurement: we can resolve interferograms with 5 pixels/fringe. The smallest measurable values have been calibrated too: the accuracy is typically 10 to 15 nm, mainly limited by the external perturbations but not by the photorefractive erasure [5]. The observable area depends on the illumination laser power. A good rule of thumb is that we reach this level quality on a 50x50 cm^2 white coated object illuminated with 400 mW.

RECENT APPLICATIONS

The system presented above is used at both the Centre Spatial de Liege (CSL) and the start-up company Optrion. The approach of CSL is to use it as a tool for various projects (related to space but not limited to) and to insure new developments of the sensor in function of applications, as well as implementation in new applications, with specific utilization or testing constraints. On the other side, Optrion commercializes the device and uses it in routine service for industry.

A first example of application is full-field displacement metrology within a European Space Agency funded project. It consisted in refining finite element modelling (FEM) of satellite structures through comparison with full-field displacement metrology. The satellite mock up parts were made in various materials (aluminium, CFRP, honeycomb,...). Also different mounting strategies between parts were considered. Various solicitations were performed on these structures: thermal, mechanical and combination of both.

Figure 2 shows one of the set-up and results obtained in the characterization of a representative satellite cubic structure made by assembling different panels together. Various measurement techniques were used in addition to the holographic camera. Figure2(c) is an interferogram of one of the panel after heating.

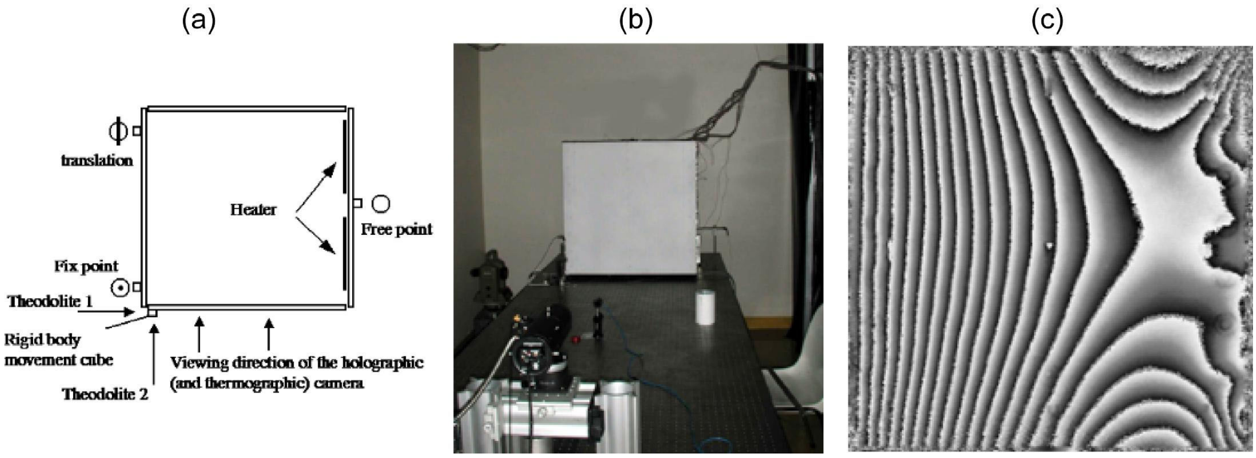

Figure 2. (a) Sketch of object (simplified cubic satellite structure mock up) with main measurement methods, (b) test bed (hologaphic camera in front), (c) interferogram due to heating of one part.

Among the numerous results obtained, the one shown in Figure 3 was quite surprising and easily shows the capability of our technique in term of high interferogram resolution. The global deformation of a sandwhich structure has been measured when undergoing heating on the back side. The skin is to thin that one observes the underneath honeycomb. The high resolution capability of the technique allows observing such detail that was not predicted by FEM.

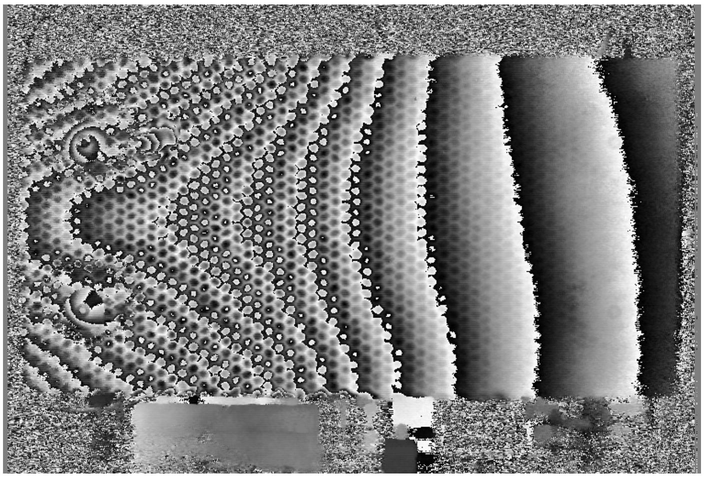

Figure 3. Interferogram of a sandwich structure (honeycomb+CFRP skins) undergoing thermal change

Another example of full-field metrology is shown hereafter. It consisted of characterizing the behavior of space-borne laser bench (developed by a major European space company) with respect to mounting and gravity constraints. Figure 4(a) shows the ensemble of the test bed with the space laser bench lying horizontally and the holographic camera observing it from the top. A first test consisted in screwing the top of the bench on the remaining part. A hologram is taken when parts are in contact. Then a dynamometric screw driver is used to lock the screws, providing and effort on the bench top. Finally the readout is performed and shows the deformation of the laser bench top (Figure 5(a)). Another test was the simulation of gravity effect by a controllable pressure in the middle of the bench provided by a mechanical arm (Figure 4(b)). The corresponding interferogram is shown in Figure 5(b).

(a) (b)

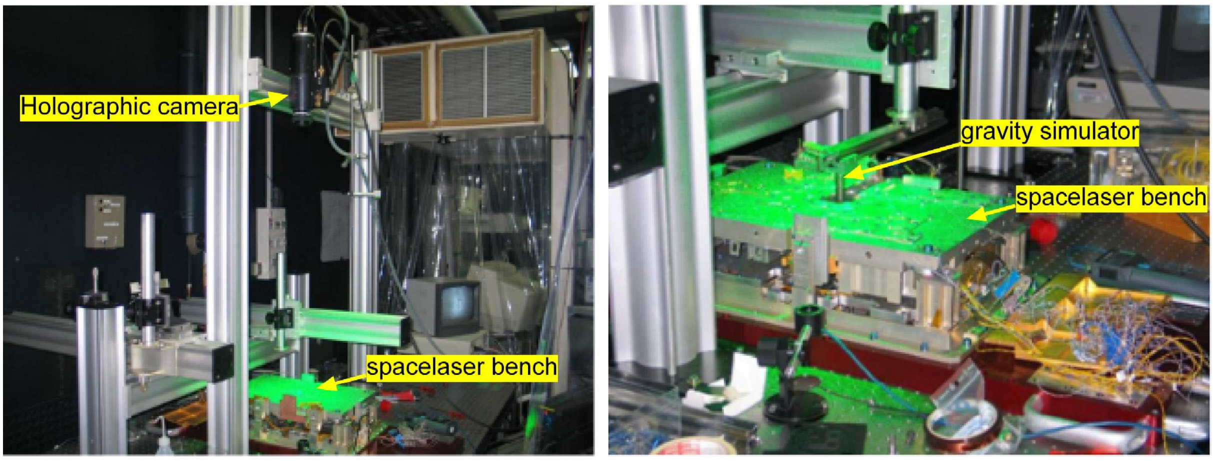

Figure 4. (a) Overall test bed with the holographic camera and laser bench displayed, (b) detail of structure under test with gravity simulator

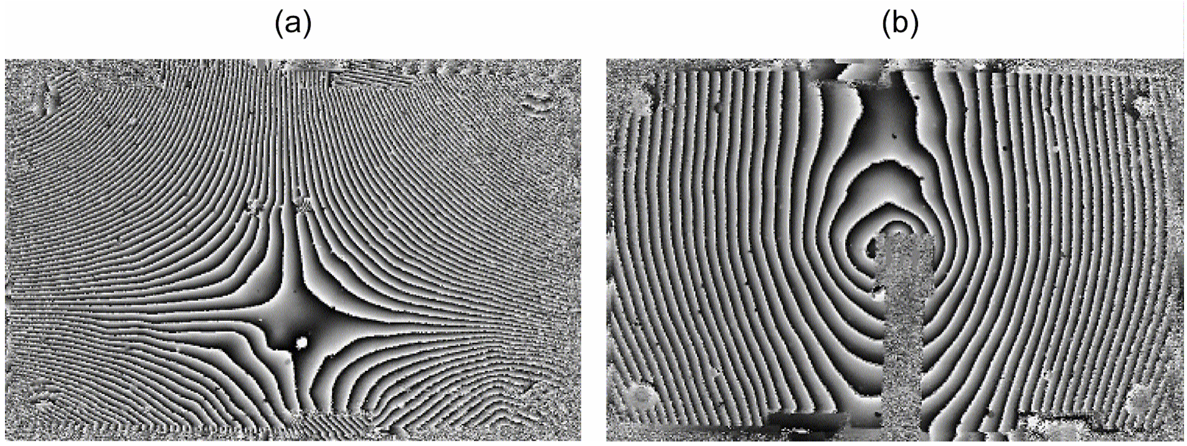

Figure 5. (a) Interferogram of the deformation of the laser bench top after locking it to the rest with a dynamometric screw driver. (b) Interferogram of the deformation due to simulated gravity effect

The largest number of applications for Optrion is the one of vibration measurement and comparison with FEM, mainly in the field of aircraft engine manufacturer. In the past we already have shown some examples of turbine blades which were undergoing sinusoidal vibration and observed with stroboscopic readout. We will not show here a catalog of results obtained on single blades over the last years. However, a more demanding and recent application is the one of stator segment composed of successive blades attached one to another. Figure 6(a) shows the test bed with the object under test, its holder and the holographic camera on top, Figure 6(b) shows a detail of the object in its mounting tool, Figure 6(c) shows the stator segment.

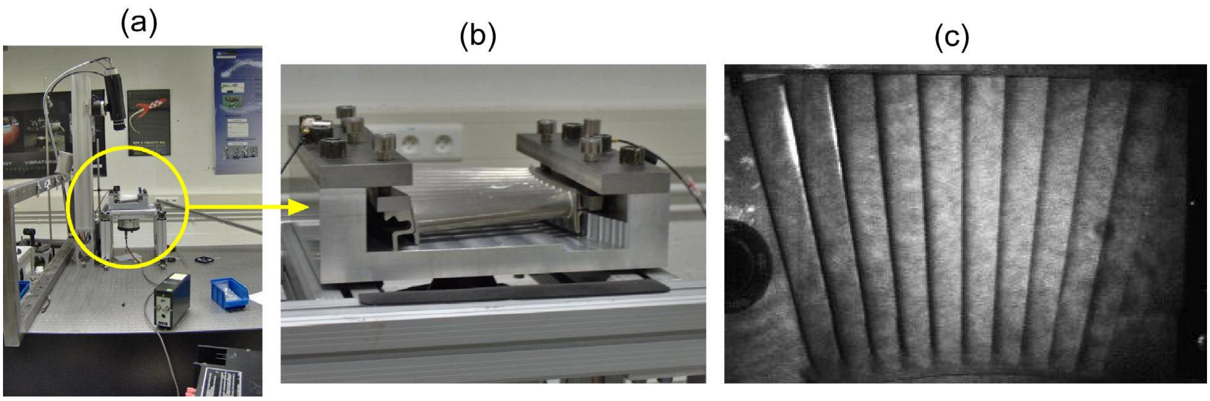

Figure 6. (a) Test bed with the stator segment in its mounting tool and small shaker below. (b) detail of the object and mounting tool. (c) image of the stator segment.

A hologram of the object is recorded at rest. Then it is sinusoidally excited by a small shaker. A stroboscopic readout is performed in synchronization with the excitation. The opening time is such that a stable interferogram is observed when the object vibration is at its maximum (object appears not moving for a short time). Typical duty cycles (ration opening time/period of vibration) are 10-15%. A first part of the test consists in scanning the frequency. The modes appear and disappear around the resonance. After some time, the photorefractive crystal is erased due to the readout. The vibration is stopped and a new reference hologram recorded and then the test can be continued. Once a resonance mode is found, again a new hologram recording is performed and readout when vibrating at the frequency previously found. Phase-shifting is applied and provides interferograms such as shown in Figure 7. One can note also the high quality of fringes obtained without any kind of filtering. It is worth to mention also the exotic behavior of such assembly, with similar displacement of all the blades at some frequencies and completely different at others.

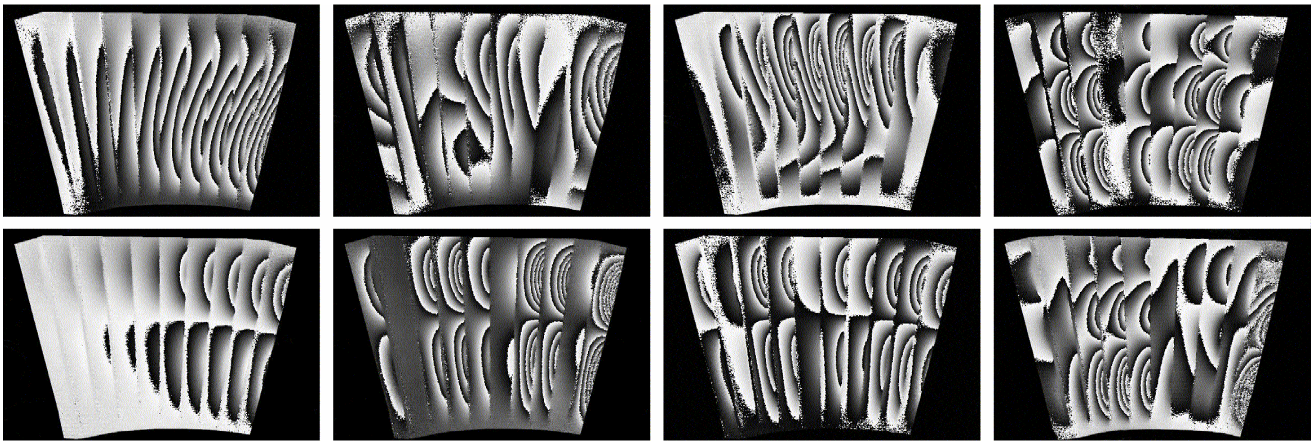

Figure 7. Interferograms of a stator segment obtained at different resonance frequencies.

A last example of application is the search of defect and cracks in various elements used by the Hydroquebec company. Radiatiors and capacitors were tested outside laboratories. The radiator was lying on the floor (Figure 8(a)) and the camera observed deformation due to change in pressure of the oil circulating into it. Figure 8(b) and (c) shows interferograms on zone of interest "a" taken when pressure is changed.

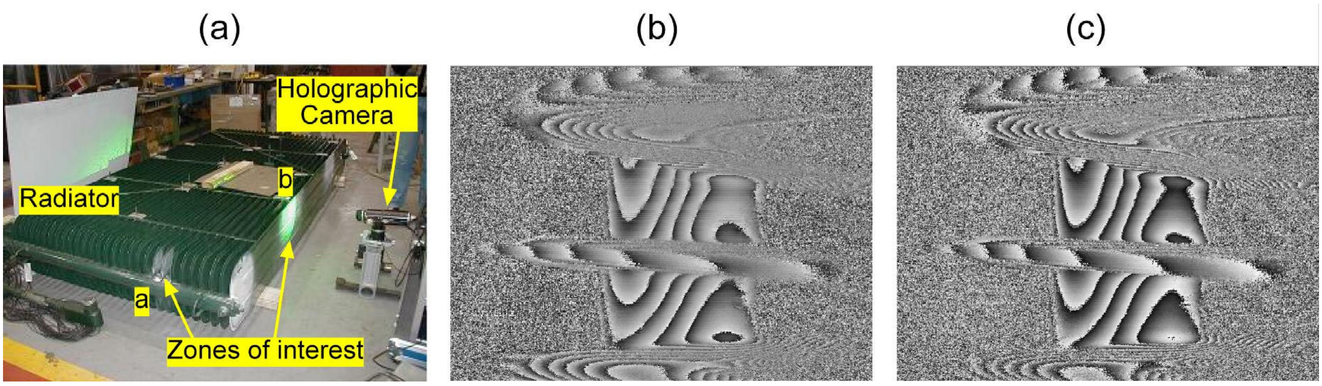

Figure 8. (a) Test of a radiator at Hydroquebec plant in Montreal area.

Another test consisted in detecting cracks and defects in capacitors. Here thermal loading was used and the object was in the same environmental conditions than the radiator. Figure 9(a) shows a typical capacitor,**Figure 9** Figure 9(b) and (c) show different the deformation of different parts. The hologram is recorded at rest and the interferogram is obtained after heating and thermal relaxation a few tens of seconds later.

The last examples show that despite its relative sensitivity to external perturbations (due to the relatively long exposure time of 5 to 10s), the technique can be used provide the set-up is in a quiet place. In some cases, the quality of fringes is not good, although sufficiently to be used. But it is worth to mention that these examples have been obtained out of optical laboratory conditions.

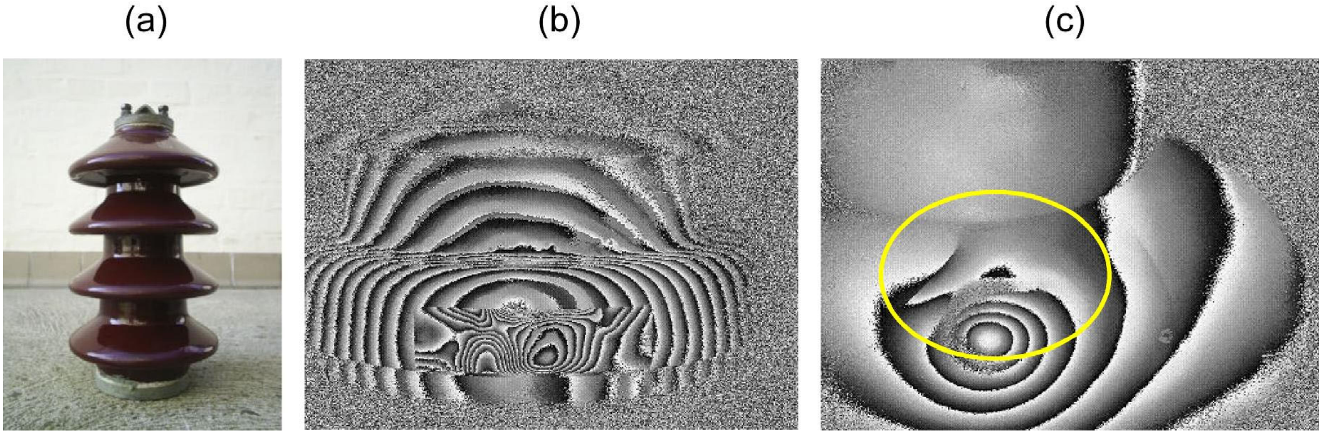

Figure 9. (a) A typical capacitor. (b) and (c) Interferograms obtained after heating. (c) shows a crack whereas (b) shows differential behaviour of different parts.

DISCUSSION - CONCLUSIONS

We have presented a photorefractive holographic camera that allows performing classical holographic interferometry (no speckle) but with a self-processable in situ recording medium which can be erased and reused rapidly. The device can be used by engineers for metrology, NDT and vibration mode shapes observation.

The varied types of applications shows that industrial use of holographic interferometry is not reserved to speckle based systems. Indeed our technique is userfriendly and does not need hologram recording media replacement and external processing. Moreover, one of the trademark of our technique is that is allows very good quality of fringes without needing any kind of filtering.

Various applications have been shown in the past and we have presented here more recent ones. Most of the results were obtained in routine service, either in a lab or on site. It must be noted that moderately stable environment have generally to be considered. However it is not a mandatory requirement, the only condition required is a relative stiffness between the object and the holographic head.

Some examples shown here were obtained in areas that are not specifically devoted to holographic measurements. However, in those cases results are not always necessarily of optimal quality, even sometimes the level of perturbations prevents holographic recording. In order to cope with more unstable environments, some specific phase locking techniques have been demonstrated already [10] and will be implemented in the future aboard the holographic camera.

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