THE "MIRAGE" SENSOR IN A INDUSTRIAL ENVIRONMENT:

OPTICAL AND THERMAL LOSSES DETERMINATIONS

F. Charbonnier, F. Lepoutre, J.P. Roger,
D. Fournier, and A.C. Boccara
Laboratoire d'Optique - ER 5 CNRS
ESPCI, 10, rue Vauquelin
75005 PARIS - France.

A. Lemoine
DELAS (Groupe CGE Alsthom)
12-14, rue d'Alsace
92302 Levallois - France

P. Robert
SFENA
B.P. 128
86101 Châtellerault - France

INTRODUCTION

Since the first "Mirage" experiment run in the laboratory of ESPCI in 1979 [1], this method has been used by many other laboratories for the determination of optical and thermal properties and for non destructive evaluation [2] [3] [4].

Despite the fact that numerous applications deal with industrial problems, up to now there is no set up introduced close to a production line in a factory, to the best of our knowledge. Nevertheless, the technique is sufficiently reliable and mature, and its introduction in an industrial environment is now possible. In this paper we will describe two examples dealing with very weak thermal and optical losses determinations.

THE "INDUSTRIAL MIRAGE SENSOR"

The "Mirage" cell constitues the "heart" of the experimental set up. The sample surface is heated periodically by a modulated light beam and this sensor allows the measurement of the sample periodic temperature, through the deviation measurement of a probe beam crossing the heated area.

The cell derives from the realization we have described in ref [5], which was built for laboratory applications. Despite of its high sensitivity, this sensor required careful alignments of the sample and (or) of the probe beam. For industrial applications, we have chosen either to maintain tightly the sample surface at a fixed position with respect to the heating and probe beams (section 3) or to introduce an automatic positioning of the sample-probe beam distance (section 4). Moreover to avoid acoustic vibrations effects and specific noises, we have replaced the He-Ne laser by a diode laser coupled to a microscope objective. This last laser probe, despite of its larger noise level up to 200 Hz, is almost insensitive to acoustic and mechanical perturbations and exhibits less drifts associated to laser modes problems.

OPTICAL LOSSES DETERMINATION IN MIRROR COATINGS

Among the optical components which take place in the laser manufacturing, the mirrors play a major part. The dielectric coatings characteristics are especially important for laser-gyro performances , a typical absorption losses level being of the order of a few tens per million.

It was particularly important for SFENA company to use, close to a production line, a set-up allowing a fast, precise and sensitive measurement of absorption losses.

The compact mirage cell was designed in order to allow colinear mirage detection [6]. Colinear detection is possible as shown in fig. (1) because the multidielectric selective mirrors under test, highly reflective at He-Ne pump beam wavelength of 633 nm, are transparent at the wavelength of the laser diode probe beam (780 nm). The heat deposited in the coating diffuses into the substrate (i.e. silica), and the radial temperature gradient is probed within the bulk of this transparent substrate.

The modulation frequency was chosen in order to get a thermal diffusion length much larger than the coating thickness. So the signal only depends on the substrate thermal and optical parameters and is independent from the coating ones. The calibration is simply obtained by using a coating whose important absorption level can be measured directly by classical reflection-transmission photoelectric experiments.

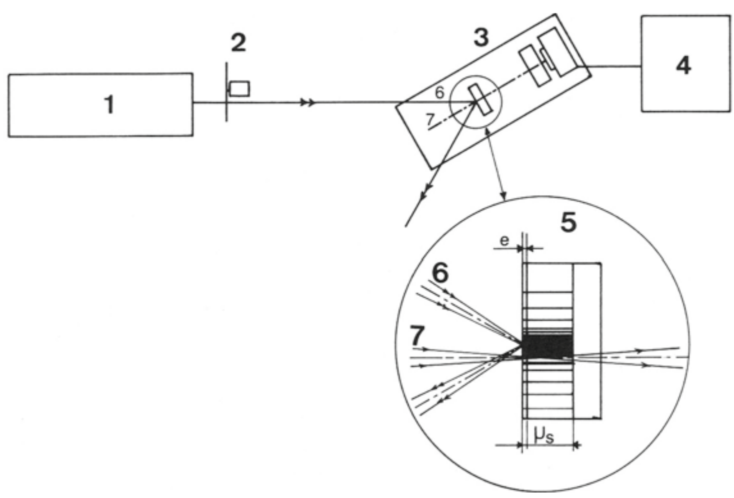

Fig. 1. Experimental set up of optical losses determination in coatings using the colinear mirage detection.
-1- 20 mW He-Ne pump laser.-2- Mechanical chopper.-3- Compact mirage cell.-4- Lock-in and microcomputer acquisition devices -5- Coating on substrate under testing.-6- Focused He-Ne pump beam absorbed and reflected by the coating.-7- Laser diode probe beam transparent for the coating and deviated into the substrat bulk.- The coating thickness (e) is much smaller than the thermal diffusion length (μ_s)-

On the one hand, in this mirage experiment, the signal increases linearly with the incident power of the pump beam ; on the other hand, the noise level, with a good laser diode can reach the photon noise of the position sensor at modulation frequency higher than 200 Hz. So that In our set-up, using a 20 mW He-Ne as pump beam, the signal equivalent to noise corresponds to an absorption level of one per a million.

The set-up is reliable and the experiments can be reproduced within a few percents.

In practice, the sample holder can be easily removed from the mirage cell and its design defines a reference plane for the coating under test with a very good precision without mechanical adjustments.

It is important to note that it takes few seconds for the non specialist operator to put the sample in its holder and to get a numerical result from the lock-in and the microcomputer acquisition devices. Actually, after the coating operation each sample is systematically tested by this method which constitues the first in-line industrial application of the mirage detection.

Among all the methods that exist to measure optical losses with a high sensitivity, let us recall three principal classes:
The first ones are flying-time decrease measurements methods. These methods allow global losses measurement (Absoption + Transmission + Diffusion) and are limited in practice for high reflectivity mirors (>99%). But it remains delicate to make use of theese methods without precise and difficult optical adjustments. This situation is often incompatible with in-line sample tests after manufacturing.
The second ones are calorimetric methods. They allow absorption losses measurement but they take too long time to be compatible with industrial production requirements.
The third group of methods uses photothermal phenomenons. In this group, we have chosen the mirage detection for its simplicity and high sensitivity: the same absorption losses measurements are possible with a photoacoustic cell, for example, but in that case, sensitivity is smaller by one or two orders of magnitude than the one we have obtained.

THERMAL RESISTANCE LOSSES DETERMINATION IN TITANIUM HEAT EXCHANGER PIPES

The second application deals with the detection of very thin air slices in metallic systems. Some heat exchangers are built with titanium pipes made of two coaxial cylinders. When theese two cylinders are not enough tighted together, a residual air slice appears between them (see Fig. 2).

This defect decreases considerably the heat exchange efficiency. In our case, a thickness of 1 µm leads to a loss larger than 10 %. Practically the problem is to measure the thickness of the slice located approximately at 1 mm below the surface. The phase of the normal mirage deflection Φ_n have been calculated using the geometrical and thermal properties of the three dimensional problem (see Fig. 3). The different curves are related to the thickness of air slices varying from 0 to 1 µm by steps of 0.1 µm. Let us underline that these curves depend upon the distance z between the probe beam and the sample surface. For modulation frequency lower than 9 Hz this phase is strongly sensitive to the thickness of the air slice : a variation of 0.1 µm of this thickness induces a phase shift of about 1 degree. The compact bench previously described can easily detect such phase shifts (its experimental phase precision is of the order of 0.2 degree). On the contrary, at frequencies higher than 9 Hz, the phase shift of Φ_n is only sensitive to the distance z between the probe beam and the sample surface.

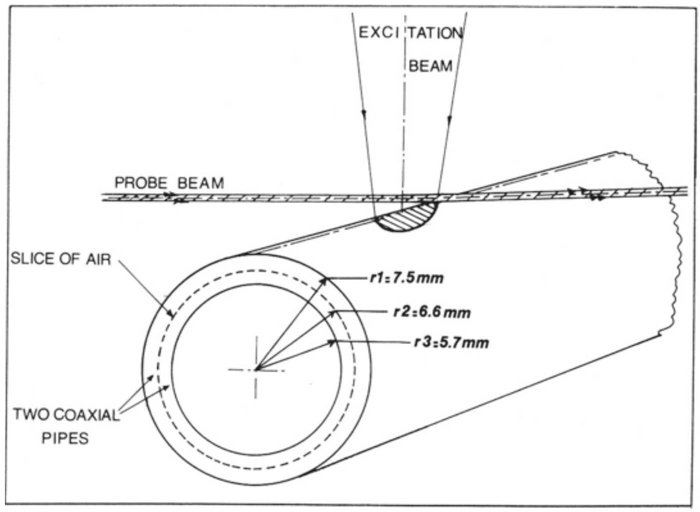

Fig. 2. Titanium pipes sample study with the disposition of the two beams of the Mirage detection.

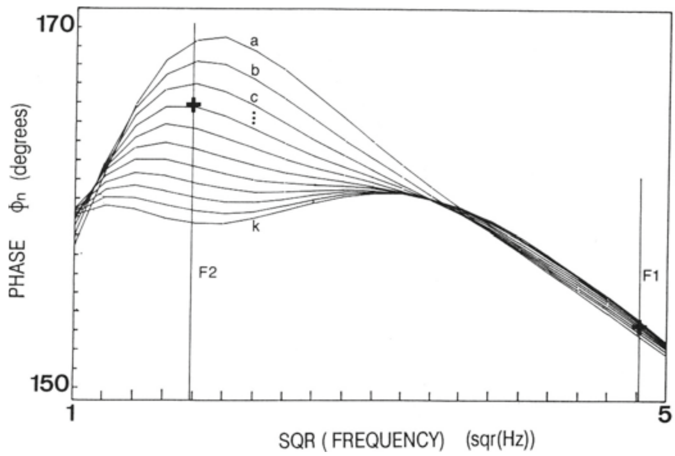

Fig. 3. Titanium pipes characterization: Phase of the normal Mirage deflection versus the square root of the frequency.
The different curves are deduced from calculation of the phase for different thicknesses of the air slice:
- curve a corresponds to 0 micron, curve k corresponds to 1 micron, step between each curve: 0.1 micron
F1 and F2 represent the square roots of the modulation frequencies used for the test.For instance the two experimental points (+) correspond to a 0.3 micron thick air slice.

Experimentally the measurements are performed for each point on the pipe at two modulation frequencies.

- Firstly at $f \approx 25$ Hz, the measurement phase of Φ_n is used to determine the distance z, between the probe beam and the sample surface.

- In the second step, the modulation frequency is decreased down to 3 Hz. With the knowledge of the distance z, the measured phase shift can be compared with theoretical calculation and finally gives the thickness of the defect.

For reasons of simplicity and time saving, only the theoretical results, calculated at a given distance $z = z_o$, are stored in the computer memory, so that the phase measurement must be performed at this specific distance z_o. To achieve this experimental condition, the mirage bench can be displaced with respect to the sample . At $f \approx 25$ Hz, the measured phase (which depends only upon the distance z) is compared to the one related to the distance z_o and the bench is moved until these two values become equal.

The machine (Fig. 4) is totally automatized. The pipe is heated by the light beam (≈ 1 W) of an iodine lamp modulated successively at $f \approx 25$ Hz and $f \approx 3$ Hz. The results appear on the screen as images in false colors or experimental points on the theoretical curves. The complete quantitative test takes less than 2 minutes per point.

To detect small slices of air inside a metal, at least two methods are possible: Eddy currents and ultrasonics. Comparative measurements with theese two probes and the mirage cell were done at the manufacturing plant, where Eddy currents and ultrasonics are both currently used in production quality control. It is important to note that the mirage detection has appeared fastly to be the quantitative standard of the comparative test as well as for the precision and the repeatibility of the measurements. Moreover, the thermal theoretical modelisation of the defect measurement remain simpler than electromagnetic or stress and strain modelisation. For all theese reasons the mirage detection was introduced not to replace other methods, but because, it was particulary well adapted to the defect geometry and to the physical phenomenon concerned: heat exchange tested with heat probe.

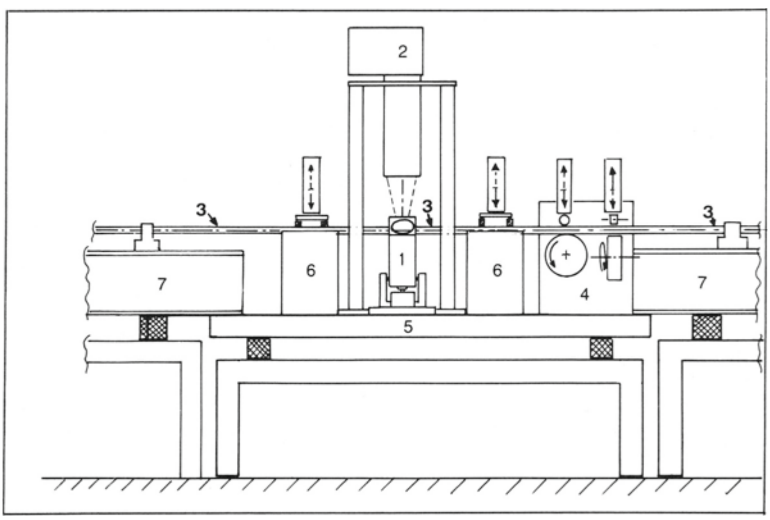

Fig. 4. Central part of the machine for the test of titanium pipes :
-1- Mirage block cell
-2- Modulated iodine lamp
-3- Titanium pipe under testing
-4- Mechanical system for automatic displacement of the pipe
-5- Marble
-6- Flanges
-7- Rail to sustain the pipe

CONCLUSION

The systems we have described before were chosen among other solutions, first because they present the qualities required for industrial testing, they are :

- non destructive (with such low power pump)
- reliable and highly sensitive
- automatic and robust
- insensitive to environment perturbations

Secondly, they present two specific qualities : they are elementary to use and quantitative.

This choice of the mirage effect by high technology industries proves that our method is now an actual industrial N.D.E. tool.

ACKNOWLEDGMENT

We would like to thank S.T.C.A.N. from French National Navy for constant encouragement and financial support allowing to realize the machine described on section 4.

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