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Use of the

XYBION ISG - CAMERA

in the

RETRA-1000 TV- HOLOGRAPHY UNIT.

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THE UNIVERSITY OF TRONDHEIM
THE NORWEGIAN INSTITUTE OF TECHNOLOGY
DIVISION OF PHYSICS

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This report has been reviewed and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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A Xybion intensified CID-camera has been tested in the Retra 1000 TV-holography instrument. Apart from spurious oscillations in the amplifier chain, the camera - Retra combination was easy to use. Deformation and vibration fringe patterns of good quality were obtained both at room temperature and at object temperatures close to + 1500°C. The overall gain in light sensitivity was only marginal compared to standard video cameras. This somewhat unexpected result is due to the heterodyne recording in the holographic system where a strong reference wave with inherent low loss allows for detection of very low object intensities. The use of intensified cameras like the Xybion, is however, of interest for use in TV-holography due to the easy gating of the laser light which results in greater fringe stability and the possible attainment of very high object temperatures when combined with a pulsed laser.

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Use of the

XYBION ISG - CAMERA

in the

RETRA-1000 TV- HOLOGRAPHY UNIT.

Content of the report:

The practical installations of the XYBION camera into the RETRA - 1000 system was done by technical manager Hans Rechsteiner at Conspectum A/S, Trondheim.
Theoretical calculations and technical consultations are due to Dr. Gudmunn Slettemoen, Conoptica A/S, Klæbu.
The experiments and measurements were done by Dr. Jan T. Malmo and Dr. Eiolf Vikhagen, SINTEF Div. 19, Trondheim
The report was written by professor Ole J. Løkberg, The Norwegian Institute of Technology, Trondheim in consultations with the above mentioned.

The installation of the XYBION ISG - camera into the RETRA.

Problems and observations

The RETRA - is normally designed for use with a Bosch camera equipped with a standard Newicon tube. To test out the Xybion ISG - camera (hereafter called the ISG-camera), we had to remove the cover permanently. This did not cause any problems as the camera was coupled to the RETRA - interferometer by a specially designed fitting mechanism.

If a permanent installation of the ISG - camera is decided on, a new cover has to be made.

The reference branch of the interferometer was equipped with an extra variable sheet polarizer to reduce the intensity level of the reference wave.

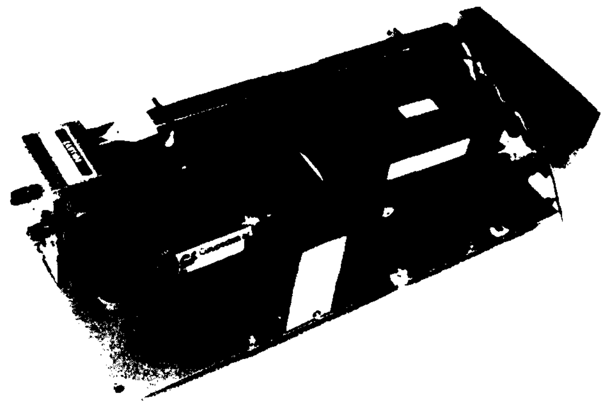


Figure 1.
RETRA 1000 with the ISG - camera.

Figure 1 shows the camera installed in the RETRA 1000 instrument. The extra polarizer could be controlled by the lower knob on the front panel.

Reflections of the reference wave in the camera target is normally a problem in TV - holography as the resulting interference patterns give reduced quality of the final fringe patterns. This problem is usually alleviated by cementing optical wedges with AR-coatings on the front part of the video-target. The ISG camera we used did , however, not pose any serious problems in that respect especially when the interferometer was used in the subtraction mode.
The biggest practical problem was caused by oscillation in the feed-back loop of

the camera amplification system. In some cases we were unable to regulate the camera back to normal behavior. We had to turn off the camera and wait a couple of minutes before proceeding. (Note that this feed back problems were also observed in normal application of the camera and had no relations to the particular use in the TV-holography set-up).

In order to reduce the background light we added an interference filter with a bandwidth of 2.5 nm.

In practical use we found the camera to give acceptable fringe pattern quality as will be documented later.

The camera also recorded the speckle field satisfactory.

The interferometric system.

To understand why the camera exhibits a different behavior when used in the TV-holographic system compared to normal viewing, we first take a brief recapitulation of the basic principles.

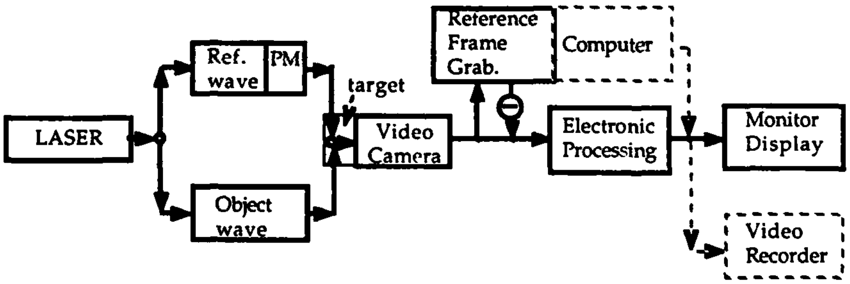


Figure 2.
Basic elements of the TV-holography system.

A flow diagram of the system is shown in figure 2. The laser used in our experiments was a 5 mW He-Ne laser with wavelength 632.8 nm. The light from the laser is divided into two interferometric branches. In the object branch, the laser light illuminates the object and the reflected light is imaged to the target of the video camera. (The target is here the primary light-sensitive target). The reference branch is a spherical wave made to emerge from the exit aperture of the imaging system in the object branch. The two waves combine or interfere on the target of the video-camera. The camera transforms the image - interferogram

to a video-signal which can be treated in several ways.
In the simplest mode - the signal is sent through the (analog) electronic processor and the processed signal is subsequently displayed on the monitor. This mode is used for vibration analysis. The demands for beam uniformity in the reference beam is quite severe.

For deformation testing a reference hologram (video - frame) is stored in the frame grabber and subtracted from the frames recorded by the video - camera.

The difference signal is subsequently processed and the monitor displays the difference as sinusoidal fringes. Due to the subtraction process the optical noise is minimized, but the demands on system stability is greater.

The processing can also be performed by the computer, which will increase the quality of the fringe pattern and allows for alternative ways of displaying the fringe information.

Interferometric recordings compared to conventional incoherent image recordings.

It is important to point out the difference in recording by means of coherent (interferometry) and incoherent light.

Indicating the object - and reference field respectively as E_{obj} and $E_{ref.}$, we have the following expression for the camera exposure in TV-holography:

$$I = | E_{obj} + E_{ref} |^2 = I_{obj} + I_{ref} + 2\sqrt{I_{obj} I_{ref}} \cos\varphi \qquad (1)$$

Our information is contained in the last terms, the first two terms can be considered noise which we try to eliminate in the processing stage.

We see from this equation that we can increase our signal by increasing the intensity of the reference wave. In this connection it is important to note that the light loss in the object branch is far greater (in the range of 10^6) than in the reference branch. Therefore the major (about 95 %) part of the light from the laser is used to illuminate the object, while the remaining light is usually further reduced before illuminating the target. As a consequence, the intensity of the reference wave is easily increased to saturate the target without reducing the available light in the object branch.

In ordinary imaging, the exposure of the video-target is as follows:

$$I = | E_{obj} |^2 = I_{obj} \qquad (2)$$

In this case the signal to noise ratio can be expressed as:

$$\left(\frac{S}{N}\right) = \frac{I_{obj}}{N\text{ (various contributions)}} = \frac{I_{obj}}{\sqrt{\sigma_s^2 + \sigma_f^2 + \sigma_{amp}^2}} \qquad (3)$$

where σ_s is the shot noise, σ_f is thermal noise and σ_{amp} is amplifier noise. With ordinary CCD's and vidicons, the last two contributions in the noise terms - are usually dominant. Due to the electronic pre-amplification of the incoming light, the ISG - camera is far better than ordinary cameras for imaging purposes with incoherent light, and it works close to the shot noise limit as given by σ_s.

In the TV - holography set-up we have to look at the information which as mentioned is contained in the last term of equation 1 - the cross-interference term. We find the signal-to-noise ratio as:

$$\left(\frac{S}{N}\right) = \frac{2\sqrt{I_{ref}\, I_{obj}}}{\sqrt{\sigma_s^2 + \sigma_f^2 + \sigma_{amp}^2}} \tag{4}$$

As we explained, the exposure is dominated by the reference intensity I_{ref}, and therefore the shot noise term σ_s will be close to proportional to the square root of I_{ref}. Therefore, by increasing I_{ref} we can make σ_s arbitrarily large and the shot noise term can be made to dominate compared to the other noise contributions.

As a conclusion, we can therefore say that in ordinary imaging - only the ISG camera is close to shot noise limitation - while in interferometry - most cameras can be made to work close to the shot noise limit. We see that how close to the shot noise limit a camera can be made to work , depends on how much the reference intensity can be increased before the camera saturates. The maximum intensity is defined by the dynamic range D of the camera.

We will now make a more stringent analysis of the problem.

Camera performance in TV-holography.

We refer to equation 16, p.469 in chapter 8 - Basic Electronic Speckle Pattern Interferometry by Løkberg / Slettemoen - presented in "Applied Optics and Optical Engineering" vol. X (eds. Wyant & Shannon), where the signal - to - noise ratio for TV - holographic set - up used in the subtraction mode is given as:

$$\left(\frac{S}{N}\right)^2 = \frac{4\,\gamma_{12}^2}{(1+r)\left(1+\frac{1}{r}\right)}\left(\frac{<I>\,g}{\gamma_e}\right)^2 \text{ (subtraction mode)} \tag{5}$$

where:

γ_{12}	is the degree of resolution of the crossinterference term
r	is the ratio between the reference and object wave intensities
$<I>g$	is the maximum signal from the camera (the saturation point)
γ_e	is rms. electronic noise

If we enter the performance parameters for the ISG-camera, which we suppose to be shot noise limited and data for a representative, ordinary camera, we get the following analytical expression for the ratio between the signal -to - noise:

$$\frac{\left(\frac{S}{N}\right)_{ISG}}{\left(\frac{S}{N}\right)_{camera}} = \sqrt{\frac{\eta_{ISG} \cdot F_{ISG} \cdot n_{camera}}{\eta_{camera} \cdot F_{camera} \cdot D_{camera}}} \qquad (6)$$

In this equation we have the following parameters:

η_{ISG}	- the quantum efficiency for the ISG - camera
η_{camera}	- " " " ordinary camera
F_{ISG}	- a fill factor, includes gating, fiberoptic fillfactors etc.
F_{camera}	- "
n_{camera}	- rms. number of noise electrons
D_{camera}	- the dynamics of the camera, that is: (maximum signal/ rms. noise)

If we insert representative numerical data for e.g. a Newicon camera into the equation, we get the following result:

$$0.5 \le \frac{\left(\frac{S}{N}\right)_{ISG}}{\left(\frac{S}{N}\right)_{camera}} \le 4 \qquad (7)$$

From the numbers in equation 7 we again draw the conclusion that the ISG - camera does not result in any dramatic improvements when it is used in a TV - holography set- up. Ordinary video - cameras may perform equally well.

TESTRESULTS.

SERIE 1. Lower interferometric detection limit of ISG vs. a CCD-camera.

The tests here were performed with the object at room temperature and with a 2.5 nm, interference-filter in front of the object lens to block background light. The roomlights were turned off, but no other precautions regarding stray light suppression were attempted.The light from the object was suppressed by combining various neutral density filters.
A United Detector Technology S 371/262 photodetector was used to measure the light level. The numbers given in this report refer to the direct output from the detector according to the producer. The size of the detector was 6.63 mm x 6.63 mm, which leads to a conversion factor of **2.28x** used when quoting the light levels or the irradiance (irrad.) in **nW/cm^2**.

The RETRA - 1000 instrument was used in its subtraction mode to record real-time fringes. A Pulnix CCD - camera was used as reference camera in the RETRA.
The test object used was a stable steel plate with no surface preparation. Its size was 50 mm x 10 mm x 1 mm. The illumination area was about 100 mm in diameter. The fringes pattern were obtained by tilting the mirror in the illumination path as this gave more repeatable patterns.

The end results is documented in the picture series on the next pages.

Figures 3 a -b represent the normal light level on to the camera (object light measured to 2.8 nW) where no density filters have been placed in the object branch. As we see comparing figs. 3 a and b, there is no noticable difference apart from a slightly larger noise contribution in the dark fringes of the ISG-recording
In figures 4 a - b the light level in the object branch has been reduced to about 70 pW, that is by a factor of 1/40. The fringe contrast is lowered, but still surprisingly good. Again there is no large difference between the two cameras, but this time the ISG camera has a slightly better image.

In figures 5 a - b the light level is about 40 pW or a total reduction of 1/70. The fringe contrast is further lowered, but still it would be no problem to interpret fringe patterns at these contrast levels. The two cameras are equal in performance.

Figures 6 a - b represent object light level 24 pW - total reduction 1/116. The fringe pattern recorded by CCD-camera is hardly recognizable, while the ISG - camera produces a noisy, but interpretable recording.

Figures 7 a - b, object light level 6 pW - reduction 1/470. With great imagination we might identify 4 faint fringe across the ISG-recording. Note that the pattern which seems to be recorded by the CCD is not interference fringes , but an electronic noise pattern.

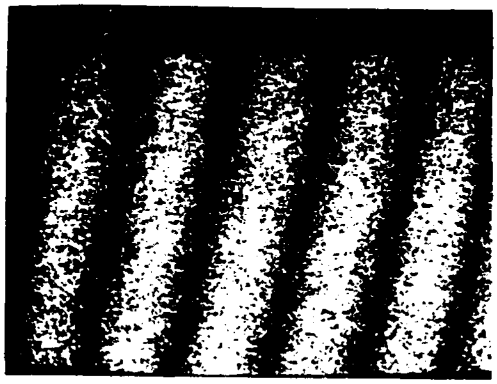


Fig. 3 a. ISG - 2.8 (6.37)nW(/cm2) irrad.

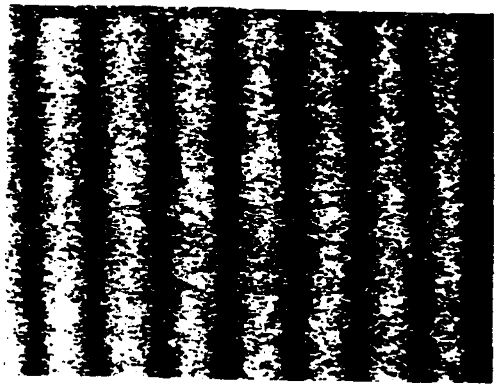


Fig. 3 b. CCD -irrad. as in 3a)

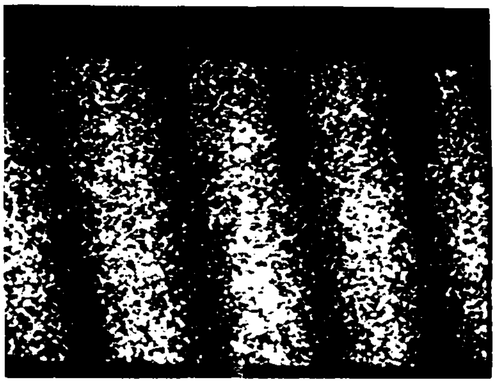


Fig. 4 a. ISG - 0.07 (0.16) nW(/cm2)

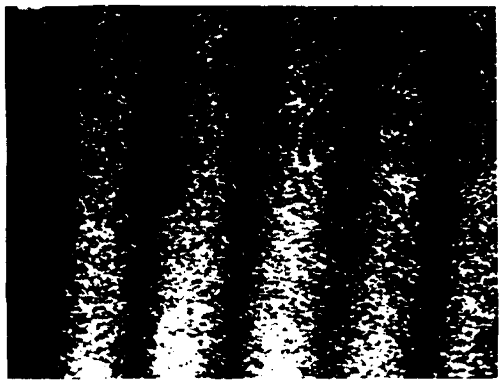


Fig. 4 b. CCD -irrad. as in 4a)

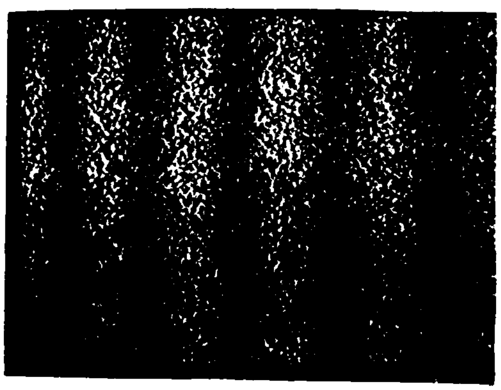


Fig. 5 a. ISG - 0.04 (0.09) nW(/cm2)

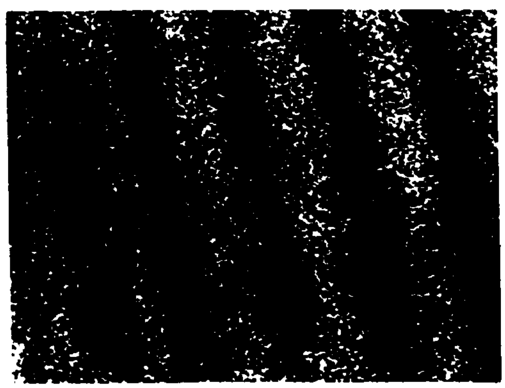


Fig. 5 b. CCD -irrad. as in 5a)

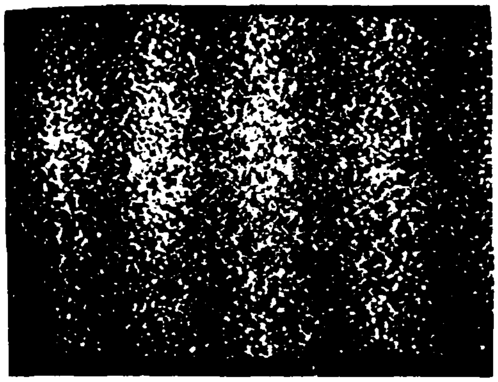


Fig. 6 a. ISG - 0.024(**0.055**) nW(/cm^2)

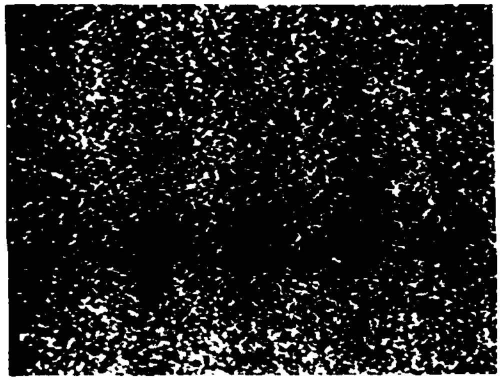


Fig. 6 b. CCD - irrad.. as in 6a)

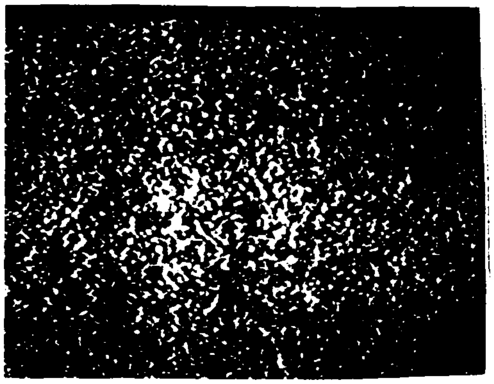


Fig. 7 a. ISG - 0.006(**0.014**) nW(/cm^2)

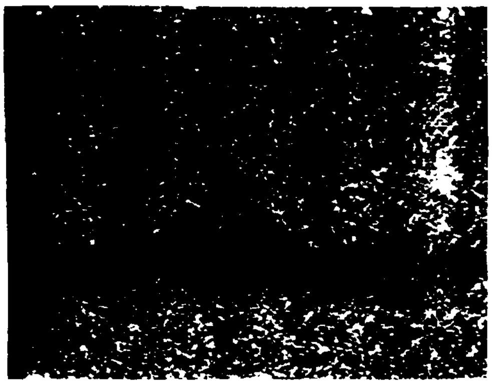


Fig. 7 b. CCD -irrad. as in 7a)

SERIE 2: ISG-Recording of vibrations at elevated temperatures.

The test object was a tungsten plate size: 50 mm x 10 mm x 0.05 mm.

The plate was heated in air by a DC-current sent through it. Its temperature was monitored and measured with a high precision pyrometer.

Vibrations were induced in the plate by sound using a loudspeaker with high directional properties.

To improve the fringe quality a continous frame - subtraction was effected by the FM 60 frame grabber. The fringes were documented using a Hasselblad camera with exposure time of 15 sec. to get an effective averaging.

The ISG camera recorded the vibration patterns of the plate with no problems up to the maximum temperature used in our experiments - about +1200°C.

Figures 8 a and b represent typical vibration patterns recorded by the ISG-camera. In figure 8 a the temperature is about +800°C, frequency of vibration 1260 Hz. Figure 8 b shows the same mode at + 1150°C, the black areas are oxidation crusts formed during the documentation.

Figur 8 a.
Vibration pattern at + 800°C, freq. 1260 Hz

Figure 8b.
As fig. 8 a., but at + 1150°C

SERIE 3: DeformationTesting by ISG.

The test parameters and object were the same as in the vibration experiments we reached slightly higher end temperatures - about +1450°C. The temperature distribution was quite uneven and the temperature cited was not measured at the warmest position.

Figure 9 a and 9 b shows deformation fringe patterns recorded at respectively +1150°C and +1450°C. The fringe quality is acceptable.

Figure 9 a.
Deformation pattern at + 1150°C

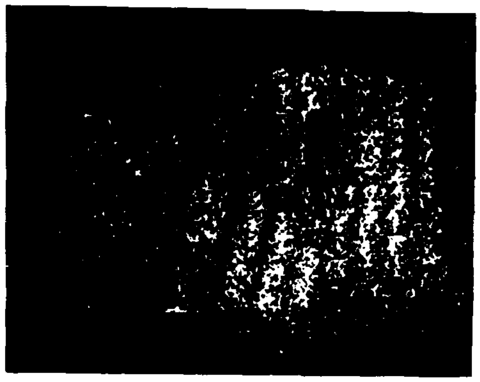


Figure 9 b.
Deformation pattern at + 1450°C

SERIE 4. Fringe recording of a larger hot object with ISG.

In this experiment an electrical heater plate of diameter about 150 mm was used - the observed area was 100 mm in diameter.
The experimental parameters were otherwise unchanged.

Deformations fringe patterns were clearly observed up to the maximum attainable temperature + 800°C.

Figure 10 shows a typical example.

Figure 10.
Deformation of 150 mm hot plate at + 800°C

SERIE 5. Measurements of the background radiation level.

Finally we measured the background radiation as a function of temperature. The 2.5 nm. interference filter centered at 632.8 nm was used which means that we measure background radiation in this wavelenght window. The remaining experimental parameters from *SERIE 1* experiment were unchanged.

Temperature (oC)	Background radiation nW(/cm2)
20	0.00 - **0.00**
820	0.05 - **0.11**
910	0.09 - **0.20**
940	0.12 - **0.27**
1010	0.19 - **0.43**
1070	0.38 - **0.80**
1150	0.42 - **0.96**
1400	2.35 - **5.35**

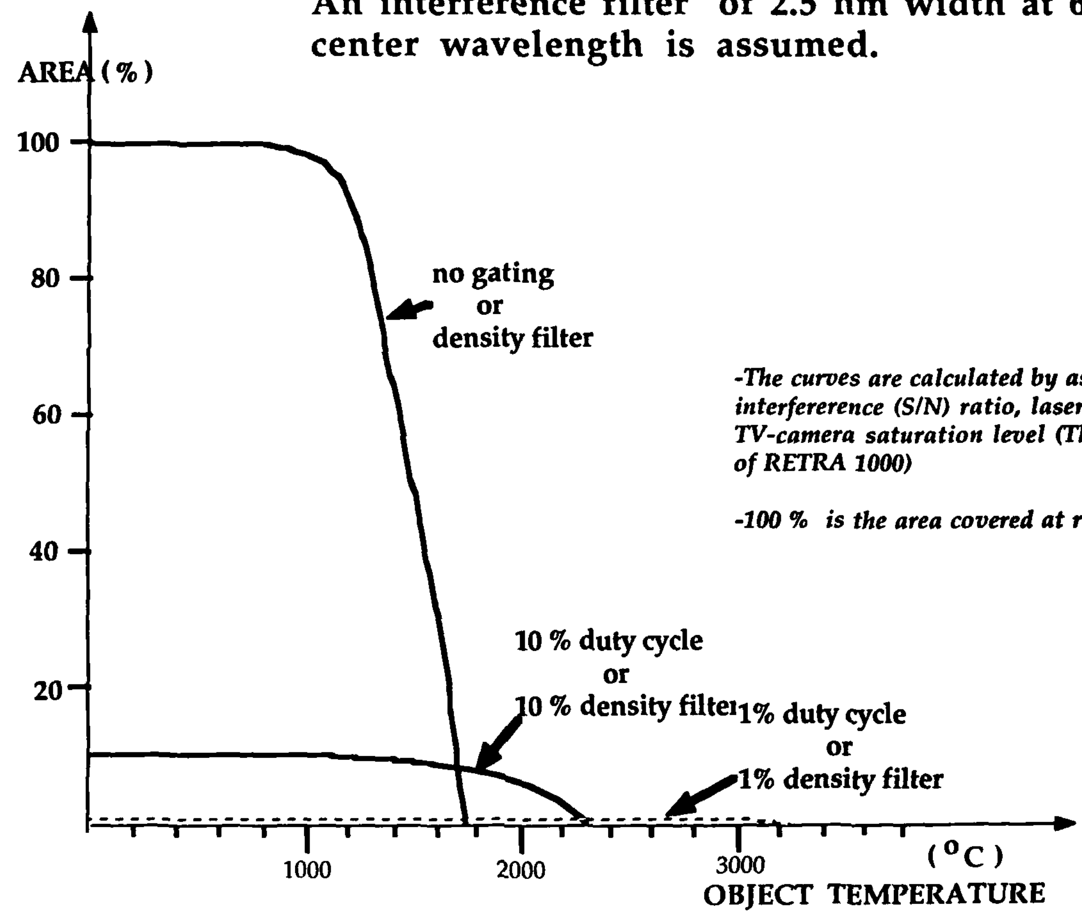
We should note that the temperature values must be considered mainly as an indication of the change in background radiation and should be used with great care. They are uncertain due to formation of oxidation crusts which change the radiative properties of the surface. For example the large increase in value from 1010 to 1070 followed by a smaller increment from 1070 to 1150, is probably caused by attempts to remove the oxidation crusts. In addition the electrical heating of the sample is known to give an uneven distribution of heat across the surface with corresponding temperature differences. Finally, the image of the object did cover only a fraction of the detector surface.

Comparing these measurements with the results from *SERIE 1*, we find that at 1400oC the background radiation is at the same level as the normal laser illumination from the instrument, allowing us to make acceptable recordings well within the dynamic range of the camera. We should remember again that under normal interferometric recording the refererence wave is much stronger than the object wave and the added background radiation results only in a bias-level which is hardly of any consequence as long as we are recording within the dynamic range of the camera.

To reach significant higher temperatures, we have to increase the coherent illumination level of the test object. This is either done by concentrating the illumination on a smaller part of the test object or increasing the laser power. The total irradiance on the target is reduced by a density filter in front of the objective lens or chopping the camera.

The next page shows a graph of the attainable temperatures using this technique. The graph shows the area covered by TV-holography as a function of object temperature. The area is normalized to 100% which corresponds to operation at room temperature. The values are based on an emissivity factor of 0.4 .

Area covered by TV - holography as a function of temperature.
An interference filter of 2.5 nm width at 633 nm center wavelength is assumed.



-The curves are calculated by assuming constant: interfererence (S/N) ratio, laser power and TV-camera saturation level (The Newicon tube of RETRA 1000)

-100 % is the area covered at room temperature

CONCLUDING REMARKS.

As a conclusion of our experiments and investigations, we find that regarding:

Installation

The Xybion - camera , when installed in the RETRA 1000 TV-holography instrument, could be used for recording both vibration and deformation fringe patterns.

Light sensitivity

Both theoretical calculations and practical experiments , show only a marginal gain in sensitivity by replacing the conventional camera in the RETRA with the Xybion..

Practical use

In practial use, the Xybion-camera regulates itself very well after the light level and apart for some disturbing oscillations, it was easy to use also at high temperatures.

Gating

The Xybion - camera has a "built-in" gating mechanism. To reduce the background light level at higher temperatures when using at CW - laser, the gating process and the density filters are equally useful.. We should note that the Xybion camera will be very interesting to use in combination with powerful pulsed lasers like the YAG-laser. In this case very high temperatures will be reached.

Interferometric stability

The gating feature of the Xybion camera can be used to stabilize the fringe pattern to reduce the effects of unstabilities. We can achieve similar stabilization by mechanical"chopping", electrical gating is however a more practical method.

The use of RETRA at high temperatures.

The RETRA proved again to be be very well suited for high temperature measurements. If it is desired to do recording of larger objects, we suggest either the use of a conventional video camera with a strong CW-laser like the Argon laser or use the gating feature of the Xybion camera in combination with a pulsed lasers like the YAG -laser.

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