

HOLOGRAPHY WITH NON-COHERENT LIGHT

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A new technique of making holograms with non-coherent light has been demonstrated using continuous-spectrum white light zirconium arc source. Such a technique, employing diffraction gratings as beam splitters and beam deflectors, allows easy control of the modulation transfer function so as to produce low-pass, band-pass or high-pass characteristics by simply changing the position of either one of the gratings or the recording plane.

Many various efforts [1-5] have been made toward the production of high-quality holographic image with light of low coherence. The purpose of these efforts has been either (1) the improvement of the resolution from an available limited-coherence light source, in order to adapt such potentially useful sources as multi-line gas lasers, injection lasers, light emitting diodes, dye lasers, cathode ray tubes, gas discharge tubes, or X-ray sources to holographic systems, or (2) the avoidance of highly coherent light, which aggravates the artifact problems.

Leith and Upatnieks [2] demonstrated a configuration that reduced off-axis coherence requirements to those of in-line holograms. Later Katyl [4] demonstrated that coherence requirement may be reduced further. However, all previous techniques employed lenses and prisms or lenses and gratings, and thus are restricted in the aperture available. In such systems the modulation transfer function of hologram cannot be controlled easily.

We have devised systems employing diffraction gratings as beam splitters and beam deflectors: one of these configurations is shown in fig. 1. Such systems, as shown in previous analysis [5], have no limitations on object size, hologram size, or number of fringes generated. Moreover, in such systems we

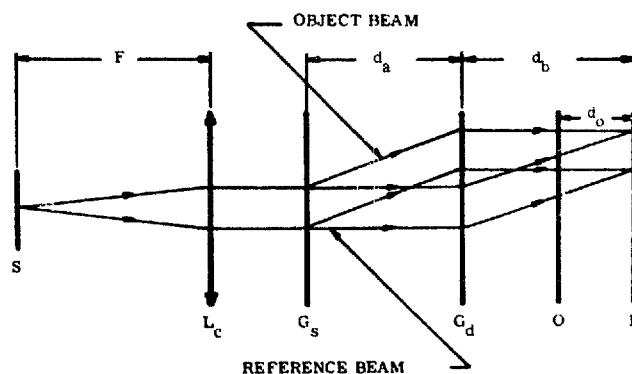


Fig. 1. Holographic system based on grating-interferometer. S is the source, L_c is a collimating lens of focal length F . G_s is the grating used as beam splitter, G_d is the grating used as deflector, O is the object plane and H is the hologram recording plane.

can adjust the modulation transfer function so as to produce low-pass, band-pass or high-pass characteristics by simply changing the position of either the grating G_s or the grating G_d ; also the same effects can be obtained by changing the position of recording plane H. Even though, in practice, there is a limitation on attainable resolution from a source of given coherence, the coherence requirement can be reduced con-

siderably. The classical limit of hologram resolution for a given coherence is no longer true in this new system. This technique can in principle be applied to such non-visible waves as electron beam, acoustic wave, microwave, or X-ray.

The important property of the grating-based interferometers is that they form broad-source, achromatic fringes; even with an ordinary flash light very high contrast fringes can be generated. Therefore, this system can use broad-source white light in both the processes of hologram construction and reconstruction, with a resultant reduction of the artifact noise.

Here we report some experiments on hologram formation and reconstruction with non-laser light sources. The detailed theoretical analysis and further discussions on various applications will be reported later.

The system used is shown in fig. 1, where gratings G_s and G_d have the same spatial frequency. If we neglect the effect of source size and assume uniform intensity distribution over the spectrum range of $\lambda_0 - \Delta\lambda \leq \lambda \leq \lambda_0 + \Delta\lambda$, the modulation transfer function is given by²

$$H(\beta) = \text{sinc} [(d_0\beta^2 + K_0)\Delta\lambda] \quad (1)$$

where

$$K_0 = (d_b - d_a)f_0^2 \quad (2)$$

f_0 is the spatial frequency of the gratings G_s and G_d , d_0 is hologram-object distance and β is spatial frequency of the object. Letting $\beta = d_0\beta^2\Delta\lambda$ and $K_0 = K_0\Delta\lambda$, we have plotted $H(\beta)$ as a function of β for various values of K_0 in fig. 2.

Fig. 3 shows the effect of source spectral width on resolution, and how adjustment of K_0 can compensate for the broadened source spectrum. At the top is shown the original object, with letters 0.5 mm in height. Also, we show images from holograms made with the green line of the Hg source (the Hg series) and with the white light of the zirconium arc source (the Zi series). The value of K_0 increases from a to c. For Hg(a), the value of K_0 is less than 0, which is a rather unfavorable case. For Hg(b), $K_0 = 0$, which, as described in ref. [5], gives a passband equivalent to conventional, in-line holography. In Hg(c),

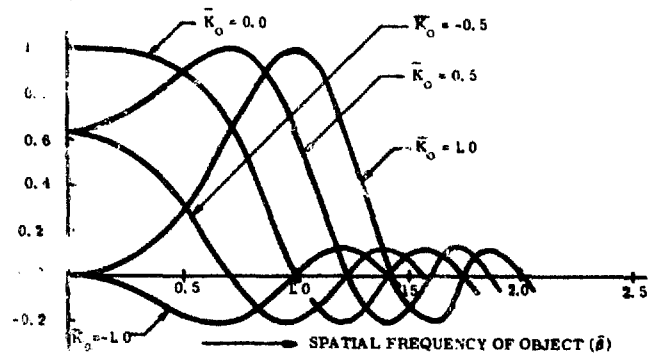


Fig. 2. Modulation transfer function as a function of β for various values of K_0 .

K_0 is about 1, which yields a decidedly high-pass characteristic, at the expense of loss of lower spatial frequencies, and a resulting poor signal to noise ratio.

For the Zi series, we have holograms formed with continuous-spectrum white light. Zi(a) shows the $K_0 = 0$ case. In Zi(b), we have K_0 about 0.6, which we judge to be a good compromise between edge sharpening and preservation of the higher spatial frequency content. Zi(b) is overall better than Zi(a), and shows that this technique permits rather good holograms to be produced in completely white light. For Zi(c), $K_0 = 1$, and the comments made about Hg(c) apply here.

From these experimental results, we conclude that the attainable control of the modulation transfer function can increase the hologram resolution considerably, and that as long as a light source having wide spectrum is of reasonably small size, it could find useful applications in holography.

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References

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² A similar equation was given in ref. [5], but the exact derivation will be given in a future paper.

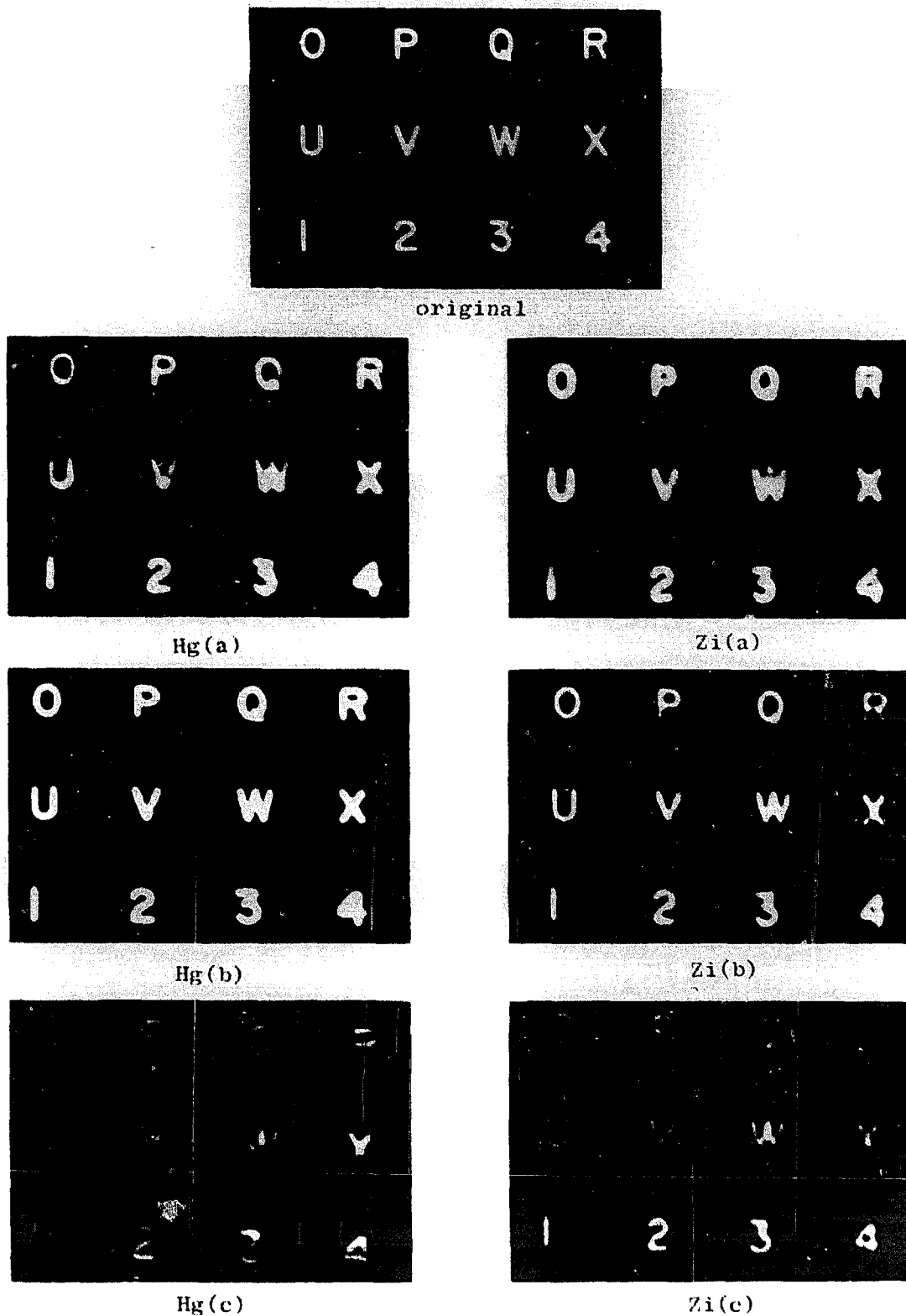


Fig. 3. Images produced from holograms made in the system shown in fig. 1 to show the effect of spectrum width of light source and the effect of the modulation transfer function on the resolution of holographic imagery. f_0 is 200 lines/mm, $d_a = d_b = 55$ mm, $d_0 = 25$ mm and the height of letters is 0.5 mm. The source size (diameter of pinhole) is 150 microns and $F = 240$ mm.