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Optics and photonics — Holography —

Part 2: Methods for measurement of hologram recording characteristics

Optique et photonique — Holographie —

Partie 2: Méthodes de mesurage des caractéristiques d'enregistrement holographique

Reference number
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information.

The committee responsible for this document is ISO/TC 172, *Optics and Photonics*, Subcommittee SC 9, *Electro-optical systems*.

ISO 17901 consists of the following parts, under the general title *Optics and photonics — Holography*:

— *Part 1: Methods of measuring diffraction efficiency and associated optical characteristics of holograms*

— *Part 2: Methods for measurement of hologram recording characteristics*

Introduction

A hologram is an optical device utilizing interference and applied in numerous fields. In order to know the exposure characteristics of materials on which the hologram is to be recorded, it is enough to initially record the hologram under common conditions and subsequently establish the numeral values representing exposure characteristics by measuring the diffraction efficiency. Though the hologram-related terms and the measurement method of critical evaluation parameters (diffraction efficiency, angular selectivity, wavelength selectivity) pertinent to optical characteristics are specified in ISO 17901-1, there is no stipulation as to the conditions concerning hologram recording or the way to calculate the numeral values. Therefore, the purpose of this part of ISO 17901 is to provide the terms and measurement method concerning the hologram exposure characteristics. This part of ISO 17901 does not intend to restrict manufacturing process.

Optics and photonics — Holography —

Part 2:
Methods for measurement of hologram recording characteristics

1 Scope

This part of ISO 17901 specifies the terms and measurement method concerning exposure characteristics (exposure characteristic curve, exposure at half-maximum, R-value, amplitude of refractive index modulation) for the hologram recorded by double-beam interference. The materials of hologram to be measured are not restricted to any particular ones. This part of ISO 17901 does not intend to restrict manufacturing process.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 15902, *Optics and photonics — Diffractive optics — Vocabulary*

ISO 17901-1:2015, *Optics and photonics — Holography — Part 1: Methods of measuring diffraction efficiency and associated optical characteristics of holograms*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15902, ISO 17901-1, and the following apply.

3.1
exposure
product of the laser beam irradiance and exposure time on the recording material surface, when the hologram is to be recorded on the recording material

Note 1 to entry: Exposure is represented in Joules per square meter (J/m^2) in the SI unit system, but may also be expressed in micro-Joules per square centimetre (μJ/cm^2) or milli-Joules per square centimetre (mJ/cm^2).

Note 2 to entry: If the object wave or reference wave enters the detector obliquely in the course of the measurement of the irradiance, the value of irradiance might not be measured correctly because of reflection on the surface of the detector. In such an event, it is enough to allow the object wave or reference wave to enter the detector in an approximately vertical direction to measure the radiant flux and then to divide the obtained value by the flux sectional area on the recording material surface.

3.2
exposure characteristics curve
<of the hologram> curve of measured values plotted with the exposure taken on the axis of abscissa and the diffraction efficiency taken on the axis of ordinate, which indicate the characteristics of hologram recording materials

Note 1 to entry: This curve is also called η -E characteristics curve.

3.3
exposure at half-maximum
<of the hologram> smallest exposure that can achieve 50 % of the highest diffraction efficiency in the exposure characteristics curve

Note 1 to entry: This term is a measure to indicate the sensitivity of the hologram recording material. The smaller the exposure at half-maximum, the smaller the light quantity required for hologram recording.

3.4
R-value
diffraction efficiency of the hologram that has recorded the interference fringes of a certain spatial frequency

Note 1 to entry: For the spatial frequency of interference fringes, the value measured in air is used.

Note 2 to entry: This is an index to indicate the resolution of a recording material in terms of the fine detail of the interference fringes identified spatially in the hologram. For the finer interference fringes, the recording material that can achieve the high R-value (diffraction efficiency) can be the recording material that ensures the high resolution in the hologram. For example, R (1000) is equal to 30 when the diffraction efficiency of hologram recorded with the spatial frequency of interference fringes being 1 000 lines/mm is assumed to be 30 %.

3.5
spatial frequency
<of the hologram> number of interference fringes per unit length

Note 1 to entry: This indicates the density of a periodic pattern of interference fringes and is expressed by the number of interference fringes repeated per unit length (lines/mm). This is proportional to the reciprocal of the spacing of interference fringes.

3.6
amplitude of refractive index modulation
<of the hologram> amount of modulation of the refractive index and equivalent to the contrast of interference fringes and the mean refractive index in the recording material of a phase hologram in which the phase is modulated according to the difference in the refractive indices of the recording material.

Note 1 to entry: This is an index to indicate the phase modulation capacity of recording material and expressed also in Δn.

4 Symbols and abbreviated terms

NA Numerical aperture of objective

λ Laser wavelength in air (µm)

η Diffraction efficiency (%)

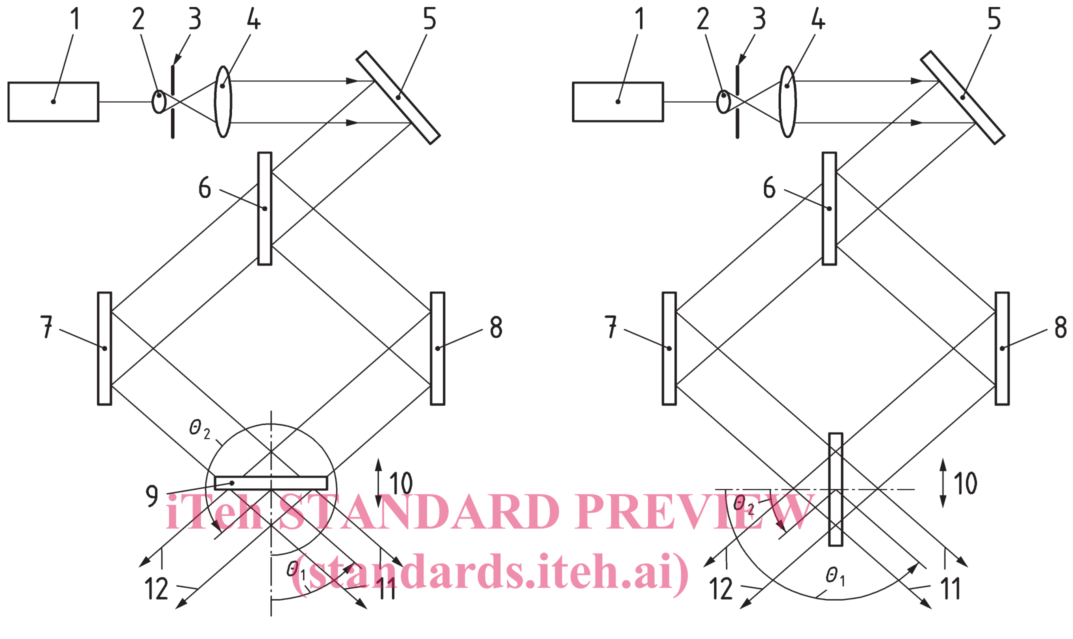
T Thickness of hologram (µm)

θ'_B Bragg diffraction angle (angle inside the hologram) (radian)

5 Principles

Holograms are recorded through mutual double-beam interference of plane waves. Examples of hologram recording optical systems are shown in Figure 1. The measurement is made of the diffraction efficiency of each hologram according to any one of measurement methods specified in ISO 17901-1:2015, 6.5. The exposure characteristics curve, exposure at half-maximum, R-value, or amplitude of refractive index modulation is derived from the relationship between the measured diffraction efficiency value and exposure conditions.

To derive the exposure characteristics curve or exposure at half-maximum, multiple holograms are recorded while changing the exposure and the diffraction efficiency is then measured for each hologram. To derive the R-value, one or multiple holograms are recorded while adjusting the incident angle of double beams in such a manner that the interference fringes with specific spatial frequency are obtained and subsequently, the diffraction efficiency of each hologram is measured. To derive the amplitude of refractive index modulation, the diffraction efficiency is measured according to any one of measurement methods specified in ISO 17901-1:2015, 6.5. Finally, the amplitude of refractive index modulation can be obtained from the Formula (2) or Formula (3) described in 6.8 to substitute values of the wavelength of light used for the measurement of diffraction efficiency, volume of the hologram, double-beam incident angle, mean refractive index of hologram, and the measured diffraction efficiency.



a) Transmission hologram **b) Volume reflection hologram**

Key

1 laser
2 objective
3 pinhole
4 collimating lens
5 mirror
6 half mirror
7 mirror 2
8 mirror 3
9 hologram recording material
10 holder
11 reference wave
12 object wave

Figure 1 — Example of optical arrangements for hologram recording

6 Measurement methods

6.1 General

The exposure characteristics (exposure characteristics curve, exposure at half-maximum, R-value, and amplitude of refractive index modulation) as specified in this part of ISO 17901 are measured as follows on the basis of the diffraction efficiency as specified in ISO 17901-1. It should be noted that, according to this part of ISO 17901, the exposure characteristics during a hologram recording is derived by measuring the diffractive efficiency of holograms recorded through double-beam interference of plane waves.

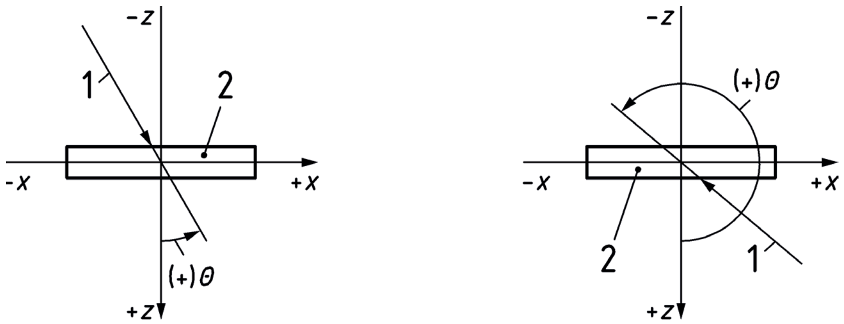
6.2 Definition of the Coordinate System

The axis of coordinate and the angle of wave are defined as follows.

a) The recording material (or hologram) plane shall be the *xy*-plane while the axis vertical to the plane shall be the *z*-axis.

b) For the *z*-axis, the advance direction of the object (or reconstructed) wave shall be positive.

c) As shown in Figure 2, the angle of incidence, θ, is formed between the *z*-axis in positive direction and the extension of the incident wave; the positive symbol indicates a counter-clockwise direction).



a) Wave advancing in the +*z* direction **b) Wave advancing in the –*z* direction**

Key

1 light wave

2 recording material or hologram

Figure 2 — How to establish the coordinate system and wave angle in measurement of exposure characteristics of hologram

6.3 Hologram recording environment

Hologram recording shall be made inside a dark room at stable room temperature and humidity and under conditions with thorough countermeasures against mechanical vibration and air turbulence.

For example, mechanical vibration can be prevented by mounting all of the equipment, including a laser, on a vibration-isolation optical table. In order to prevent air disturbance, the whole optical table may be enclosed in the plastic cover or blackout curtain to shut off the air flow from the air conditioner, etc. When the laser is of either air-cooling or a water-cooling type, due care should be taken on air turbulence or vibration generated from the laser itself.

6.4 Measurement device and apparatus

The optical system as shown in Figure 1 shows an example of an optical system that can be used for the measurement of the exposure characteristics of hologram recording materials. This system consists of the following components:

NOTE Refer to Annex A for the recommended assembly procedure and stability confirmation method for the hologram recording optical system, Annex B for the hologram recording procedure, and Annex C for the relationship between the spacing of hologram interference fringes of double-beam interference based hologram and the incident angle of object (and reference) waves.

a) Laser

The laser should ensure high temporal stability of the output (for example, ±5 % or less in output fluctuation over 30 min).

b) Objective

An adequate objective to be selected should be the one capable of expanding the beam diameter so that the irradiance of the laser beam irradiating the collimating lens becomes approximately even within the effective diameter of the collimating lens (for example, the magnification of ×10 to ×40).

c) Pinhole

The pinhole to be used should have the adequate hole diameter (for example, 5 approximately 25 μm) relative to the laser wavelength and the objective focal length.

NOTE The theoretical formula for the beam diameter, *d*, at the focal point of the objective is given by Formula (1). The value twice as large as the value given by Formula (1) can be used as a rough standard for the pinhole diameter.

$$d = \frac{4f\lambda}{\pi\omega} \approx \frac{4\lambda}{\pi\, NA} \quad (1)$$

where

f is the focal length of objective (μm);

ω is the beam diameter of incident light (the width at which the beam intensity becomes $1/e^2$ of the maximum value (μm);

NA is the numerical aperture of objective.

d) Collimating lens

Lens as attached to the lens mount which has its spherical aberration corrected relative to the wavelength of the laser to be used.

e) Mirror

The mirror should have a sufficiently high surface flatness (for example, better than the wavelength level of about 1/10). The stage on which the mirror is to be mounted should be capable of fine motion of rotation and tilting and is best achieved using a micrometre controlled mount.

f) Half-mirror

The half mirror should be capable of achieving the reflected light/transmitted light ratio of 1:1.

NOTE Such half-mirrors include, for example, those with multi-layer derivative or chromium coating, those shaped like wedges with the wedge angle of 1 deg [=π/180 (rad) to avoid interference noise caused by backside reflection, and those provided with the anti-reflection coating.

g) Test-piece holder

The holder should be capable of moving within a range approximately equal to the test piece size while holding the hologram recording material. In this situation, the holder should have anti-vibration characteristics.

Removal or attachment of recording materials has to be done in a dark room and therefore, the holder should be configured to enable easy removal and attachment. For example, the holder may be an edged metal frame of a size approximately equivalent to the test piece (a frame with a width of about 10 mm, and matte-black coated), with the test piece clamped with leaves (clamps).

h) Detector

The detector should have a sufficient dynamic range and responsivity to the light intensity to be measured and should have been calibrated.