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HOLOGRAPHY IN THE FERMILAB 15-FOOT BUBBLE CHAMBER

E-632 Collaboration

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ABSTRACT

Holography in combination with conventional photography offers the possibility of measuring rare interactions with short lifetimes in large detectors. First experience has been gained with a modified in-line holographic technique during an exposure of the Fermilab 15-foot Bubble Chamber to a wide-band neutrino beam. Future plans for improvements are outlined.

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1. INTRODUCTION

Holography offers the possibility of photographing large volumes with increased resolution compared to that obtainable with conventional optics. This is of particular interest for the study of elementary particle reactions in gaseous or liquid detectors, where one searches for rare interactions with short lifetimes (short track lengths). Bubble chambers operated in neutrino beams at high energy accelerators are the most prominent examples of the application of this technique. The aim is to photograph bubbles in a volume of several cubic meters ≤ 1 ms after their creation, when they have grown to only $\sim 100 \mu\text{m}$ in diameter. These holograms then supplement the conventional stereo photographs taken some 10 ms later, when the bubbles have grown to diameters of $\sim 500 \mu\text{m}$. These two techniques complement each other and combine the advantages of a quick overall view, easy event recognition and track measurement in the conventional photographs, with the more detailed picture of the interesting event vertex region seen in the holograms.

The present paper describes the first trials with holography in the 15-foot Bubble Chamber at Fermilab during an exposure to a wideband neutrino beam with 800 GeV/c protons on the production target (Experiment E-632). Together with the 155,000 conventional 3-view pictures, 100,000 holograms were recorded simultaneously. The evaluation of these photographs is in progress. The technique will be further developed and used during an extension of this experiment. A beam dump exposure (Experiment E-646) is planned, where the highest possible resolution is needed for the detection of the tau-neutrino via tau-production and its very short decay lengths.

We limit ourselves here to a description of the one-beam holographic technique, which had been tested earlier in the Big European Bubble Chamber (BEBC) [1, 2]; aspects of two-beam systems can be found in refs. [3, 4]. Preliminary descriptions of measuring machines devised for analysis of holograms are given in refs. [5, 6].

2. THE EXPERIMENTAL LAYOUT

A hologram is formed by the interference of coherent light from a reference beam with the coherent light scattered by an object. In our case the objects are vapour bubbles with refractive index of ~ 1.0 in a liquid mixture of Hydrogen-Neon with an index of ~ 1.088 . We chose a modified in-line, Gabor-type set-up, where the object and the reference beam are combined. The laser beam enters the bubble

chamber through a small window at its bottom (fig. 1). This beam is then diverged by a specially designed aspheric lens such that only a small central part of the light goes through the liquid and through a window on the opposite side of the chamber onto the film to act as a reference beam. The other part of the beam illuminates the bubble chamber tracks within a conical volume. The intensity of this object beam at large angles increases to compensate for the decrease of the light scattered by the bubbles at large angles towards the film. Some elementary formulas, together with estimates based on experience in much smaller chambers, were given in ref. [1]. They comprise data on the optical resolution of such a system, the energy needed to illuminate a certain volume, the ratio of intensities of object to reference beam, and the required resolution of the photographic emulsion. Large coherence length of the laser beam also is required for our experiment.

The safety demands for the operation of non-explosion-proofed electrical equipment near a hydrogen area and the stray field from the bubble chamber magnet make it necessary to install the laser far away (~ 28 m) from the volume to be holographed. From the separate laser room the beam is guided through an evacuated underground pipe to the bottom of the chamber. Adjustable mirrors are needed for the beam transport. The beam is then spread with the light-diverging lens. This lens is positioned in the vacuum tank of the bubble chamber in front of a plane window, facing the cryogenic liquid (Ne/H_2 @ ~ 30 K). This lens has already been used during the experiment in BEBC (Big European Bubble Chamber at CERN) and is described in ref. [1]. It is designed for a 5 cm diameter, Gaussian-distributed, parallel beam from the ruby laser and it disperses the light over a cone with an half angle of $\sim 28^\circ$ within the bubble chamber's visible volume.

A commercially available holographic ruby laser system (JK Laser System 2000) was used. Its oscillator has high mechanical stability, is equipped with two intracavity etalons, which are thermally locked into the cooling system of the ruby rod to ensure maximum mode stability. Nominal operating values of the JK 2000 System are a 30 J Q-switched pulse of 30 ns duration, which is obtained by the oscillator, followed by three amplifiers. The repetition rate (under conditions described later) was one pulse every 8 s with an energy per pulse of ≤ 8 J.

3. EXPERIMENTAL RESULTS

A detailed analysis of the holograms and of the conventional photographs is in progress. Therefore some of the following statements have, for the moment, a more qualitative character.

As had been shown in a previous experiment [1], Q-switched or free-lasing pulses are not suited for our application:

- (a) a very short pulse produces excellent holograms, but gives rise to considerable boiling in the bubble chamber liquid thereby affecting the quality of conventional photographs and even making them unusable,
- (b) a millisecond pulse is so long that mechanical vibrations, bubble movement and growth wash out the holographic fringe pattern completely, may produce still some boiling due to its spiky structure, and furthermore may not provide reliably the necessary coherence length.

It can be assumed that this boiling is created by absorption of the laser light on micro impurities. This hypothesis is favoured by experimental observations from various other experiments:

- (i) no attenuation of boiling in a parallel beam is seen over long distances,
- (ii) the sensitivity to light occurs at liquid temperatures far below the region of particle track sensitivity,
- (iii) the effect is wavelength independent, and
- (iv) there is no drastic variation for various liquids with different ionization potentials.

Three approaches were made to suppress the laser-induced boiling: reduction of (i) the number and size of absorbing objects, of (ii) the overall energy needed and of (iii) the power density. The first objective was dealt with by recirculating the bubble chamber liquid during stand-by periods successively through 5, 2 and 0.5 μm filters [7]. The second needed the increase of film sensitivity, without loss of resolution, by special development techniques, where we gained a factor of 5 [8]. Probably the most effective measure was to reduce the power density by stretching of the laser pulse in time.

We developed a feedback circuit, which gave us initially enough flexibility to adjust the duration of the pulse over a wide range. An additional prerequisite was a long coherence length (up to several meters). These requirements could be met exceedingly well with our stretching circuit [9, 10], which gave fairly flat pulses, with little overswing at the beginning, adjustable from $\sim 2 \mu\text{s}$ to $100 \mu\text{s}$, and a coherence length in excess of 8 m. The maximum obtainable energy of the JK Laser varies with the above conditions, but is typically less than 8 J with a stability of $\pm 10\%$, and the repetition rate is ~ 1 pulse in 8 s. A supplementary behaviour for some test purposes is a "Q-switched" pulse with 220 ns FWHM duration and a coherence length ≤ 1.5 m.

For our experiment the expansion sequence was three pulses at 10 s intervals, followed by a 40 s pause, dictated mainly by the operation mode of the accelerator. The particle beam pulse was approximately Gaussian in time with a FWHM of ~ 1 ms.

During most of the physics run the laser pulse duration was adjusted to either 40 or $18 \mu\text{s}$. This reduced the macroscopic boiling in the bubble chamber to such an extent that it was barely visible near the entrance of the beam into the liquid and did not affect adversely the evaluation of the conventional photographs. The delay of the laser pulse in respect to the passage of the beam was ≥ 1 ms. The smallest bubble tracks holographed and replayed with good contrast had diameters of $\geq 150 \mu\text{m}$.

Two additional problems, which reduced the quality of holograms during the run, are discussed below.

Some object beam light goes through multiple reflections off the chamber walls and eventually reaches the holographic film. This was discovered to be an important limitation on the amount of laser light that could be sent into the Bubble Chamber. This parasitic light is superimposed upon the reference beam, but provides no information to the hologram. In order to obtain the correct exposure on the film, the laser energy was lowered, reducing the useful information content of the hologram. Warm (empty) chamber tests showed that excellent holograms could be obtained by putting an 1 inch diameter aperture in front of the diverging lens, which reduced the object beam energy to about 0.6 J. Unfortunately this also reduced the half-angle of the illuminated cone inside the Bubble Chamber to $\sim 20^\circ$, resulting in a $\leq 1 \text{ m}^3$ holographically visible volume.

The beam profile, as measured on burn paper, deteriorated substantially on its 28 m path from the last amplifier to the diverging lens. There it showed a hot outer ring with a more or less homogeneous energy distribution in the central part. A preliminary remedy for this unacceptable beam shape (the dispersing lens was designed for a Gaussian-like spatial beam distribution, TEM₀₀-mode) consisted in increasing the beam size at the dispersing lens (with the telescope located just after the laser) such that the hot ring, containing ~ 80% of the energy, could be cut out by the 1 inch aperture in front of the lens.

The quality of the holograms varied throughout the run. We outline a few possible reasons for these instabilities.

While the spatial distribution in the central 1 inch diameter of the laser beam at the dispersing lens was approximately flat, it still contained sharp local variations in the intensity. Slight movements of the beam position (perhaps due to vibrations) and small output energy changes of the laser might account for some of the variations in the hologram quality.

While the multiply reflected light problem was small during the empty chamber tests, provided the laser energy entering the chamber was less than ~ 0.6 J, the liquid in the chamber during the physics run may have changed this. The refraction change at the laser entry window causes a different distribution of the object beam light and small random variations of the liquid optical index occur due to temperature differences. With expansions, the predominate heat source is on the bottom of the chamber, near the laser entrance, while heat removal is by the main heat exchanger at the top of the chamber.

The varying appearance of holograms also may be attributed to some extent to minor changes of the operating conditions of the Bubble Chamber, in particular those of the piston stroke and/or expansion ratio during each expansion.

4. FUTURE DEVELOPMENTS

The objective for future development work consists primarily in the increase in visible volume, but also in improvements of the laser beam instrumentation and survey to guarantee the reproducibility of good quality holograms. To achieve these goals, various hardware modifications are envisaged.

A new dispersing lens is being designed for a flat incoming light distribution, which serves at the same time as a bubble chamber window. It will illuminate a cone with an half-angle of 30° . More energy ($\sim 10 \text{ J}$) will be sent into the chamber, which is needed to illuminate a larger conical volume ($\leq 5 \text{ m}^3$). The flat surface of this lens is in direct contact with the liquid and has a sufficiently large diameter so that the energy density per unit area should be low enough to prevent excessive heating effects.

Parasitic (multiple) reflections of laser light will be reduced by catching the object beam after it has crossed the chamber once. This will be done by installing venetian blind baffles on the portion of the chamber wall hit directly by the illumination beam.

The laser beam profile underneath the dispersing lens will be substantially improved by an optical relay system, which transfers the beam of the light from one plane to another, maintaining both position and angle of all rays, so that the profile remains essentially flat. To suppress the remaining diffraction pattern, originating from the spatial filter in the oscillator, a soft aperture might be used instead of a hard one.

Detailed studies of the effect of vibrations, bubble growth and its influence upon holography have been performed [11], demonstrate that laser pulse durations between about 3 to 8 μs are best suited to satisfy two diverging demands:

- (a) pulse durations long enough to minimize parasitic boiling visible on the conventional photographs and to suppress micro-bubbles which, if present at all during the pulse, deteriorate the reference beam, and
- (b) durations short enough to minimize vibration and bubble growth effects.

With this new equipment in place, further search for optimum chamber operating conditions (temperature and expansion ratio) will be made.

5. CONCLUSIONS

Considerable progress in the development of a modified one-beam holographic system for the 15-foot Bubble Chamber since its first tests in BEBC has been made. Many remaining problems are now understood so that various components in the laser

beam layout can be redesigned. The ultimate aim is to photograph holographically bubble tracks with a resolution of $\geq 100 \mu\text{m}$ in $\sim 5 \text{ m}^3$ of the fiducial volume with good contrast.

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Fig. 1 Layout of the holographic system for the 15-foot Bubble Chamber