AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

UCRL-JC-116184
PREPRINT

A Freon-Filled, Holographic Bubble Chamber as a High Energy Photon Burst Spectrometer

Peter G. Dendooven
University of Jyväskylä

Richard A. Lerche
Lawrence Livermore National Laboratory

This paper was prepared for submittal to the
10th Topical Conference on High-Temperature Plasma Diagnostics
Rochester, NY
May 8-12, 1994

April 26, 1994

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *ep*

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government thereof, and shall not be used for advertising or product endorsement purposes.

A freon-filled, holographic bubble chamber as a high energy photon burst spectrometer.

Peter G. Dendooven*, Richard A. Lerche

Lawrence Livermore National Laboratory, P.O. Box 5508 L-473,
Livermore, CA, 94550

A small holographic, freon-filled bubble chamber is being built to measure the energy spectrum of high-energy photons (energy above a few 100 keV) emitted in a short burst (less than about 1 ms duration). The photon energy is calculated from the scattered electron's energy and direction in the case of Compton scattering or from the electron and positron energies in the case of pair production. Electron and positron energies are determined from the curvature of the tracks in a magnetic field. The use of freon results in a large photon interaction probability. Holography combines good spatial resolution with large depth of field. The main concern for the holographic system is the minimization of the bubble image size, so as to maximize the number of bubbles visible in one hologram. A high energy photon burst spectrometer has several potential applications in Inertial Confinement Fusion research.

*Present address :

Accelerator Laboratory, University of Jyväskylä, P.O. Box 35, Fin-40351
Jyväskylä, Finland

I. Introduction

At present, a variety of x-ray and neutron spectrometers are used in Inertial Confinement Fusion (ICF) research. However, no such device for high-energy photons exists. We report here on the development of such a device.

Possible applications for such an instrument include :

1. the measurement of the high energy x-ray spectrum from ICF targets;
2. the yield measurement of neutron-less fusion reactions (e.g. $D + {}^3\text{He}$) by measuring the gamma-ray yield of the radiative capture branch of the reaction;
3. measurement of the alpha particle energy loss in deuterium-tritium targets through the secondary photons from the $\alpha + T \rightarrow {}^7\text{Li} + \gamma$ reaction¹;
4. measurement of the bremsstrahlung spectrum from high intensity pulsed electron and ion accelerators.

These applications require an instrument capable of detecting a large number of high energy photons (up to about 20 MeV) in a very short amount of time (sub-microsecond) in the presence of a large flux of background gamma rays and neutrons. In this article, we show that a holographic, freon-filled bubble chamber potentially meets these requirements.

First, the bubble chamber operating principle will be given. Then, we will discuss in some detail why a holographic, freon-filled bubble chamber can be used as a photon burst spectrometer. The final part is a more thorough discussion of the chamber design and the holographic aspect.

II. The bubble chamber operating principle

A bubble chamber is a track detector for energetic particles. The sensitive medium is a superheated liquid, i.e. a liquid at a temperature and pressure inside the stability region of the vapor state. This superheated state is created by the fast expansion of a liquid at a pressure above vapor pressure; resulting in a fast pressure drop, at constant temperature, to below the vapor pressure. The energy loss of an energetic particle traveling through the superheated liquid locally triggers the transition from liquid to vapor (boiling) : bubbles are formed along the particle's path. Photographing these bubble tracks allows one to deduce properties of the particles and their interactions in the liquid. More specifically, from the curvature of the tracks of charged particles in a magnetic field, their momentum can be determined.

III. Why a holographic, freon-filled bubble chamber ?

The choice of building a freon-filled, holographic bubble chamber as a photon burst detector is based on the following characteristics :

1. The use of freon gives the instrument a large intrinsic efficiency for high energy photons. For example, 20% of 4 MeV photons interacts in 10 cm of freon-115 ($\text{C}_2\text{F}_5\text{Cl}$). This freon is easy to use since there are no hazards control restrictions for the small amounts needed. It also

allows to operate the bubble chamber at a convenient temperature of between 20 and 60 °C.

2. Holography combines a good spatial resolution with a large depth of field, allowing a large number of tracks in one hologram. This improves the statistical quality of the photon spectrum and the dynamic range of the instrument.
3. In certain ICF applications, the photons are accompanied by a huge neutron flux, which will certainly fill the whole chamber with bubbles as it hits the chamber. Putting the bubble chamber some distance from the radiation source introduces a time-of-flight difference between photons and neutrons large enough to allow one to take a hologram before the neutrons hit.

IV. Chamber Design

Small holographic, freon-filled bubble chambers were used in high-energy physics in the early '80s²⁻⁵. The design of those chambers influenced our design. However, because of the different purpose, some operational features and the holographic aspect are quite different.

Figure 1 shows the bubble chamber design. The freon volume is about 350 cm³. The magnet coils in the figure only indicate the position of the magnet. The exact dimensions are not yet known. The chamber is made of aluminum. All sharp edges on the inside have been rounded, so as to avoid unwanted boiling to occur at these edges. For the same purpose, a silver coating is applied in order to make the surface finish smoother. We plan to use freon-115 (C₂F₅Cl), because it is easy to use and

has the most data about its use in bubble chambers available^{4,5}. The chamber is constructed for freon pressures up to 30 bar. The radiation enters the chamber through a 4 mm thick titanium window. The holography laser shines parallel to the magnet bore through two high quality BK-7 optical windows. In the following, several design topics are discussed in more detail.

The bubble growth rate and the number of bubbles per cm of track length depend on the temperature and final pressure of the freon. A good control over these parameters is therefore essential for the controlled operation of the bubble chamber.

The operating temperature of the chamber will be somewhere between 20 and 60 °C. It is controlled by a temperature stabilized water bath/circulator (stable to within 0.01 °C) connected to 4 parallel water circuits drilled inside the chamber walls. The freon temperature is monitored with a platinum thermistor inside the chamber.

During operation, pressure will drop from 20-30 bar to 5-10 bar in 5-10 ms. The pressure is measured by a fast (μ s reaction time) transducer inserted directly into the freon. The pressure is regulated by a piston acting on the freon. The piston is connected to a fast servoactuator/servo valve (flow rate of 5 GPM in 3 ms). The servo valve is controlled by a feedback from the freon pressure transducer. The pressure to operate the servo valve is supplied by a hydraulic power unit.

The magnet is a split-pair solenoid with an iron shroud. The coils are made of water-cooled hollow-core copper conductor. It will provide a field of at least 1.5 T throughout the chamber.

The operation of the bubble chamber in an ICF experiment requires two triggers. The expansion mechanism (servo valve) is triggered 5-10 ms

before the arrival of the radiation of interest. The trigger time of the hologram laser depends on the specific experiment.

V. Holography of the bubble chamber

Holography has been used to record bubble chamber tracks before. Because of the different applications for the chamber described here, the holographic aspect is very different. Our situation resembles more the holography of a spray of droplets, fog, aerosols, etc. The following is an overview of the requirements for the holographic system for a bubble chamber to be used as a photon burst spectrometer. We will end this section by suggesting a solution that meets all requirements.

When the photons are accompanied by an order of magnitude larger neutron flux, the neutrons hitting the bubble chamber will most likely fill it completely with bubbles. Therefore, a hologram has to be taken before the neutrons arrive. A few meters flight path results in a time-of-flight difference between photons and 14 MeV neutrons of 50 to 100 ns. At this time, the bubbles will be very small. An extrapolation to lower freon temperatures of bubble growth rate measurements from ref. 5 suggests a diameter of 1 micron can be reached after 50 ns. These bubbles will scatter little light. The contrast problem associated with this necessitates the use of a two-beam holographic recording scheme.

The photon energy is determined from the curvature of the electron tracks in a magnetic field. Since the electrons can travel in any direction, a good spatial resolution in all 3 directions is important. For electron energies above about 2 MeV, the relationship between the magnetic field

strength (B , in T), curvature radius (ρ , in cm) and electron energy (E , in MeV) is, to a very good approximation, given by $B \rho = 0.334 E$. So, the relative error in energy is as large as the relative error in curvature radius. For a 1.5 T field, a 1 % electron energy uncertainty requires the measurement of the curvature radius with an accuracy better than 45 (220) micron for a 2 (10) MeV electron. The uncertainty in the electron energy due to the statistical variation of the electron stopping process will be larger than 1 %. So, as far as the electron energy resolution is concerned, the determination of bubble positions with about a 100 microns accuracy is good enough.

It is important to see as many tracks as possible in a single hologram, thus the need for maximizing the bubble density (the number of bubble visible per cm^3). The bubble density increases as the bubble image size during replay decreases, so the minimization of the bubble image size is very important. We estimate that at least several thousand bubbles per cubic centimeter will have to be recorded.

Because of the large number of bubbles in one hologram, the analysis will have to be highly automated. This analysis includes : finding the bubbles and measuring their coordinates (focusing), linking the bubbles into tracks and measuring the track curvature. Software from high-energy physics might be used for this.

A holographic particle image velocimetry system that fulfills the requirements listed above has been developed at the University of Illinois⁶. It has been shown to image 10^6 0.5 to 1 mm oil droplets in an air volume of 36 cm^3 (about 3000 droplets/ cm^3). The droplet images are ellipsoids 100 to 700 micron long and 15 to 30 micron in diameter. The

droplet positions can be determined to within 10 micron. This shows that the holography required for the bubble chamber can be done.

Acknowledgments

We gratefully acknowledge the assistance of John R. Reed and Robert L. Horton in the design of the bubble chamber. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

References

- ¹Peter G. Dendooven, R. Paul Drake, Michael D. Cable, J. Appl. Phys. **74**, 3638 (1993)
- ²M. Dykes, P. Lecoq, D. Güsewell, A. Hervé, H. Wenninger, H. Royer, B. Hahn, E. Hugentobler, E. Ramseyer and M. Boratav, Nucl. Instrum. Meth. **179**, 487 (1981)
- ³E. Ramseyer, B. Hahn and E. Hugentobler, Nucl. Instrum. Meth. **201**, 335 (1982)
- ⁴A. Hervé, K.E. Johansson, P. Lecoq, P. Olivier, J. Pothier, L. Veillet, G. Waurick and S. Tavernier, Nucl. Instrum. Meth. **202**, 417 (1982)
- ⁵J.L. Benichou, A. Hervé, K.E. Johansson, P. Lecoq, P. Olivier, J. Pothier, G. Waurick, E. Wiatrowski, Roosen, S.P.K. Tavernier, G. van Beek and Williams, Nucl. Instrum. Meth. **214**, 245 (1983)
- ⁶D.H. Barnhart et al., "Phase conjugate holographic system for high resolution particle image velocimetry", to be published in J. Appl. Optics

Figure caption

Figure 1

Design drawing of the bubble chamber. The holographic plate collects the light scattered perpendicular to the laser beam.

DATE
FILMED

6/15/94

END