PULSE STRETCHING IN A Q-SWITCHED RUBY LASER FOR BUBBLE CHAMBER HOLOGRAPHY

Gert G. Harigel
CERN, Geneva, Switzerland

ABSTRACT

During the first test of a modified in-line holography scheme in BEBC, heavy laser induced boiling was observed when using Q-switched pulses (≥ 20 ns, ≤ 3 J). This boiling spoiled the conventional pictures taken some 10 ms later. There was no boiling present when the laser was fired in the non-Q-switched mode (~ 1 ms) at the same energy, however this latter mode is unsuitable for holography, mainly due to the bubble movement and size variation during illumination. Our approach has therefore been to aim for an intermediate pulse duration. Consequently, a pulse stretching technique for a Q-switched ruby laser oscillator was developed at Columbia University^(*), which gives a fairly flat pulse of ~ 2 μ s duration with ~ 4 m coherence length. The cavity was followed by four amplifiers and they produce light energies up to 10 J for the holographic recording of particle tracks in a large volume (several cubic meters). The entire equipment was then tested during a technical run with the 15-foot Bubble Chamber at Fermilab^(**), and results obtained with various laser pulse durations will be discussed.

1. THE PROBLEM OF LASER INDUCED BOILING

Bubble chambers are made sensitive by a rapid mechanical expansion of the liquid. When pressures below the vapour pressure are reached, bubbles are created by local deposition of energy. In case of ionising particles, stopping delta-electrons produce hot spots which act as nucleation

(*) C. Baltay, M. Bregman, G. Harigel, M. Hibbs and A. Schaffer (Columbia University).

(**) H. Akbari (Tufts), H. Bjelkhagen, W.M. Smart (FNAL), P. Dingus (Berkeley), R. Michaels (Rutgers), P. Nailor (I.C. London) and R. Sekulin (Rutherford).

centers. There are also so-called parasitic bubbles created along uneven surfaces of the chamber walls. And the effect of light-induced bubbles has been known for over 15 years [e.g. refs 1-3]: spark gaps, nitrogen or ruby lasers were used in a variety of bubble chamber liquids, such as CF_3Br , Ar, N_2 , H_2 , and Ne/ H_2 mixtures. In a few instances it is desirable to produce such light-induced bubbles along the path of a laser beam (e.g. to make fiducial lines or sensitivity tests), however, they are a nuisance if conventional and holographic methods are used together to photograph particle tracks [4]. The general consensus is that these parasitic bubbles are created by absorption of light on micro-impurities. Arguments in favour of this hypothesis are:

- (a) no attenuation in the number of bubbles is observed over long distances (several meters) [3];
- (b) the range of sensitivity to light extends to liquid temperatures far below that for bubble creation along particle tracks [3];
- (c) the bubble nucleation does not depend on the wavelength of the light [2];
- (d) there is no obvious variation of bubble creation for various liquids with different ionization potentials [3].

There are three approaches to suppress bubble nucleation from laser light:

- (a) remove the absorbing micro-impurities by proper filtering techniques of the liquid (using successively filters from 5 μm down to, hopefully, 1 μm [5]);
- (b) reduce the overall energy requirement by increasing the film sensitivity by a combination of pre- or hypersensitizing and/or latensification (a factor of 5 could already be gained, maintaining the high resolution of holographic film [6]);
- (c) reduce the instantaneous power density by stretching the laser pulse, while maintaining its energy.

Only the last point will be discussed further.

Any solid state laser works preferentially in two ways:

- (a) normal or free-lasing, giving pulse durations of ~ 1 ms, consisting out some 15 to 30 spikes, each some 100 ns wide, depending on mode selection;

- (b) Q-switched lasing, where the light pulse is released by rapid opening of an electro-optic shutter, where the duration of the single pulse may vary between some 20 to 100 ns, depending on the cavity length and mode selection.

We want a stretched pulse, starting from a Q-switched laser. This goal can be obtained with three techniques: (a) by installation of non-linear materials in the cavity; (b) by lengthening the cavity and (c) by a feedback loop to control the switching of an electrooptic shutter.

Method (c) is best suited to our purpose, since we want to have a fairly long (several microseconds) and flat light pulse with small intensity variations. A practical upper limit for the pulse length is given by the bubble movement and by mechanical vibrations of the bubble chamber during the piston movement; however, its numerical value can only be found experimentally.

For the test described here we had stretched the laser pulse to $\sim 2 \mu\text{s}$ duration. This was a good step in the right direction. In the future we will try even for some 10 to 20 μs .

2. EXPERIMENTAL FEEDBACK CONTROLLED LASER SYSTEM

For the illumination of $\leq 10 \text{ m}^3$ of the fiducial volume of the 15-foot Bubble Chamber at Fermilab with a system similar to that described in [4], light energy up to $\sim 25 \text{ J}$ is needed [7]. This energy will be obtained with an oscillator stage followed by 4 amplifiers with increasing ruby rod and laser beam diameter (for the tests described here the maximum energy was $\leq 10 \text{ J}$). Since we expect no serious deterioration of the initial light pulse going through these amplifiers [8], we can limit ourselves to the description of the oscillator.

For the layout of the cavity we used various elements from a KORAD K-1000 Ruby Laser System, given to us by Columbia University's Radiation Laboratory. Fig. 1 shows the geometrical arrangement. The length of the cavity is chosen to be 100 cm, similar to the layout described in [8]. In order to keep the cavity as simple as possible we extract the light needed for the feedback loop through the rear 85% reflector rather than from a beam splitter placed inside. The outgoing 15% of the light passes through a ruby amplifier to give sufficient intensity and flexibility for the operation of the feedback electronics. After only some 30 cm path length (1 ns delay) the light hits a 45 mm diameter photodiode (ITT FW114A), which controls via the electronic circuit (fig. 2) the Pockels cell. The lower part of the circuit serves to adapt the trigger to the KORAD power supply. We choose a KD*P Pockels cell (Quantum Technology, model QK-T)

with a low quarter-wave voltage (2100 V) and low capacitance (6 pF); the connecting wires were kept short to minimize the stray capacitance of the circuit. A 200 Ω load resistor R was employed as shown in fig. 2. The Pockels cell was switched on initially by means of a Krytron switch (type KN6B). To operate the system the Pockels cell was biased to the lowest quarter-wave voltage thereby preventing laser action. On firing the Krytron tube the Pockels cell bias falls to zero and light amplification begins. The switching time of ~ 1 ns determined by the load resistor and the Pockels cell capacitance, is insignificant compared with the pulse built-up time of about 100 ns. The 2 M Ω isolation resistor prevents C_2 from being charged by the power supply during the laser pulse duration but is low enough to keep the Krytron conducting.

Measurements of the output pulse made with a cone calorimeter showed that between 80 and 90 per cent of the energy of the Q-spoiled pulse is retained in the extended pulse.

In order to obtain good coherence length the oscillator stage was equipped with a temperature stabilized output etalon ($< 0.1^\circ\text{C}$). A 2 mm aperture was used to obtain the TEM_{00} -mode. We did not yet have any polarizer in the cavity. The coherence length was measured holographically behind the first amplifier: it varied between 2 and 4 m.

A variety of typical stretched pulses is shown in the oscilloscope pictures of fig. 3. There is always a small overshoot at the beginning of the pulse, which is enhanced by the amplifiers. Often we have the beating of two or more cavity modes, and the fine structure has frequencies of some 150 MHz (Note that this beating is removed with improved mode selection; i.e. long coherence length).

3. BOILING TESTS IN THE 15-FOOT BUBBLE CHAMBER

With the set-up described above three modes of testing were performed: Free-lasing, Q-switched, and stretched pulses. These laser pulses at various energies, were injected into the track sensitive bubble chamber during its pressure minimum. Conventional photos were taken ~ 10 ms after the laser pulse. Fig. 4 shows photographs for the three kinds of pulses at a given energy. The amount of boiling was then estimated by measuring the height of the bubble cone from the light diverging lens, and was plotted for Q-switched and stretched pulses against $(\text{energy})^{1/2}$ (fig. 5).

We can conclude that an early terminated free-lasing pulse is of no interest for our application, since light comes out in spikes and may not be coherent. The pulse stretching shows obvious advantages over the

Q-switched pulse, reducing the level of boiling by a factor of ~ 7 , going from 120 ns to 2.2 μ s. At this long pulse duration holograms of good quality of cosmic rays were taken. Since we intend to go to higher laser energies to illuminate larger volumes of the chamber, a further extension of the pulse duration to some 10 to 20 μ s is desirable and will be attempted; any decrease in the quality of the holograms, caused by excessive vibration and bubble movement, will determine its upper limit.

4. CONCLUSIONS

Pulse stretching with a feedback system in a ruby laser, similar to that described in [8], helped to reduce parasitic boiling inside the bubble chamber. Still longer pulses are desired and can be obtained. A commercial laser with good quality beam is essential. The pulse stretching technique is also of interest for other applications, in particular if one wants to transport higher energy laser pulses through mono- or multi-mode fibers for two-beam holographic techniques [9].

REFERENCES

- [1] R.C. Stamberg and D.E. Gillespie, J. Applied Physics 37 (1966) 459.
- [2] F.H. Poesposoetjipto and E. Hugentobler, Helvetica Physica Acta 43 (1970) 203.
- [3] G. Harigel et al., Nucl. Instr. & Methods 88 (1981) 517.
- [4] H. Bjelkhagen et al., Nucl. Instr. & Methods 227 (1984) 437, and G. Harigel, these proceedings.
- [5] W.M. Smart, private communication.
- [6] H. Bjelkhagen, Holographic recording materials and the possibility to increase their sensitivity, CERN/EF 84-7, 23 March 1984.
- [7] M. Hibbs and W.M. Smart, Laser dispersing Lenses for holography in large bubble chambers (unpublished).
- [8] R.V. Lovberg, E.R. Wooding and M.L. Yeoman, IEEE Journal of Quantum Electronics, Vol. QE-11, (1975) 17.
- [9] H. Bjelkhagen et al., Nucl. Instr. & Methods 220 (1983) 300, and private communication.

FIGURE CAPTIONS

Fig. 1 Geometrical layout of the oscillator, pulse stretching components and amplifiers (schematic):

oscillator: R - Ruby rod, PC - Pockels cell, RM - Rear mirror, MS - Mode selecting aperture, OE - Output etalon;

feedback loop: AO - Amplifier, M1, M2 - Mirrors, PD - Photodiode, E1 - Electronic circuit (details in fig. 2);

amplifiers: A1, A2, A3, A4 - Amplifiers, BE - Beam expander, M3 - Mirror.

Fig. 2 Pulse stretching: the electronic circuit.

Fig. 3 Four typical oscilloscope traces of stretched pulses, time scale 200 ns division.

Fig. 4 Conventional photographs of laser-induced boiling, taken 10 ms after injection of laser pulses, at comparable energies: Q-switched, pulse-stretched, free-lasing.

Fig. 5 Amount of laser-induced boiling (height of bubble cone) as function of laser energy for Q-switched and stretched pulses.

Fig. 1

Fig. 2

Fig. 3

Q-switched

~ 120 ns

1000 mJ

Pulse-stretched

~ 2.2 μ s

1000 mJ

Free-lasing

~ 1 ms

700 mJ

Fig. 4

Fig. 5