Fermi National Accelerator Laboratory

FERMILAB-Pub-87/80
2125.000

High Rate Operation of a Warm-Liquid Ionization Chamber*

D.F. Anderson,
Particle Detector Group
Fermi National Accelerator Laboratory
Batavia, IL 60510 USA

R.A. Holroyd
Department of Chemistry
Brookhaven National Laboratory
Upton, NY 11973 USA

R.C. Muñoz
CERN-EP
Geneva, Switzerland

May 1987

*Submitted to Nuclear Instruments and Methods A.

FERMILAB-PUB-87/80
May 1987

High Rate Operation of a Warm-Liquid Ionization Chamber

D. F. Anderson[1],R. A. Holroyd[2], and R.C. Muñoz[2,3]

(Submitted to Nuclear Instruments and Methods A)

Abstract

The effect of positive ion build-up at high rates in warm liquid ionization chambers is considered. Measurements made with TMS indicate that warm liquids can operate at SSC particle fluxes.

---

1) Particle Detector Group, Fermi National Accelerator Laboratory, Batavia ,IL 60510 U.S.A.

2) Department of Chemistry, Brookhaven National Laboratory, Upton, NY 11973 U.S.A.

3) Now at CERN - EP, Geneva, Switzerland

1. Introduction

More and more attention is being paid to the instrumentation problems that will be encountered at the proposed Superconducting Super Collider (SSC) with its center-of-mass energy of 40 TeV, a luminosity of $L=10^{33}$ $cm^{-2}s^{-1}$, and an interaction rate of 10^8 s^{-1}. Among the proposed detectors for calorimetry are liquid ionization detectors using liquid argon, LAr, or the warm liquids, such as TMS or 2,2,4,4,-TMP [1].

It is easy to calculate that at SSC intensities, even at shower maximum in the calorimeter, that recombination will not be a problem[2,3]. We estimate that at a flux of 10^7 particles $s^{-1}cm^{-2}$ through a 2 mm thick gap filled with TMS and with a collection field of 10^4 Vmm^{-1} that only about 1% of the charge will be lost to recombination.

A more serious problem at high rates in warm liquid filled ionization chambers has to do with the spatial redistribution of the charge liberated. This problem, which causes a change in the signal pulse height, will be discussed in the following sections.

2. Charge Redistribution at High Rates

In liquids, the positive ions have a very low mobility. For organic liquids at room temperature the mobility is on the order of $5x10^{-4}$ $cm^2V^{-1}s^{-1}$[4] ($6.12x10^{-4}$ $cm^2V^{-1}s^{-1}$ for LAr)[5]. Thus, for an electric field of 10^4 Vcm^{-1} the positive ion drift velocity is only 5 cm s^{-1}. At high rates there can be a substantial space charge which distorts the electric field in the chamber. The net result is that the electric field increases near the cathode and decreases near the anode.

For liquids that obey the Onsager relation[6], such as the warm liquids of interest, the number of electrons liberated per unit length by a low ionizing particle can be written in the form:

$$\frac{dn}{dx} = k_1 + k_2 E, \qquad (1)$$

where E is the electric field and k_1 and k_2 are constants dependent on the liquid used, the temperature, and the rate of ionization of the particle. The charge liberated in the gap from the particle is given by:

$$Ne = \int \frac{dn}{dx} dx$$

$$= \int_0^d k_1 dx + \int_0^d k_2 E(x) dx \,, \qquad (2)$$

where N is the number of electrons liberated and e is the charge of an electron. This can be solved noting that the voltage drop across the gap is:

$$V_o = \int_0^d E(x) dx, \qquad (3)$$

We can evaluate eqn. (2) to get:

$$Ne = k_1 d + k_2 V_o. \qquad (4)$$

Thus, within the accuracy of the Onsager relation, the amount of charge collected in a warm liquid filled ionization chamber depends only on the potential across the gap, and not on the details of the internal electric field.

However, the pulses recorded in the external circuit (per electron) depend on where the electrons are liberated, the contribution of each electron to the signal being proportional to the fraction of the distance across the gap that it drifts. Since the positive ions increase the electric field near the cathode, more electrons will be produced there and correspondingly fewer near the anode. Therefore the average distance drifted by the electrons increases with increased positive ion accumulation. Hence, one would expect the signal pulse height to increase with increased rate, not decrease as in familiar systems.

3. Experimental Setup

The hypothesis that the pulse height would increase with increased positive ion density in warm liquid was tested with a cell filled with TMS. The TMS used had an electron lifetime of 6 μs. This cell contained an ionization gap 1 mm thick and 1.77 cm^2 in area. To produce the ionization in the cell, 60 ns wide x-rays pulses from 1.9 MeV electrons impinging on a tungsten target in a Van de Graaff generator at Brookhaven National Laboratory were used. Since the rate of the Van de Graaff was limited to 197 s^{-1}, the intensity rather than the rate of x-ray pulses had to be varied to increase the space charge. This is somewhat of a problem since at an electric field of 10^4 Vcm^{-1}, there will only be the ions from 4 pulses in the gap and half that number at $2x10^4$ Vcm^{-1}. Even with this handicap we were able to demonstrate the effect in question.

A second problem that had to be faced in the measurements was the amount of charge in the pulses. The pulses that we studied had charges that ranged from about 40-500 pC. This was too large for any available amplifier. Eventually the cell was simply connected with about 10 m of coaxial cable to a spectroscopy shaping amplifier, with a 4 μs shaping time constant. The pulse height was measured with a Canberra Series 35 pulse height analyzer.

4. Experimental Results

The first step in the calibration of our measurements was to convert the current from the tungsten target of the Van de Graaff to a charge deposited in the test cell. Figure 1 shows the cell current as a function of target current for four different collection voltages. From the Onsager relation one would expect , for a given target current, that the cell current at different collection voltages to go as[8]:

$$\text{current} \propto [1 + 0.608 \times 10^{-4}\, E(\text{Vcm}^{-1})]. \qquad (5)$$

This relation was supported by our current measurements. Also, over the range of cell currents measured, there was no sign of recombination.

The pulse height as a function of target current, for four collection voltages are shown in Fig. 2. The straight lines are extrapolation from the first few data points at low target currents. The deviation from linearity at the higher currents is obvious, with about a 15% excess in height at the highest current and collection voltage. The upper scale of this figure gives the equivalent particle flux in units of 10^6 $s^{-1}cm^{-2}$. The conversion was taken from the cell current to target current relationship from Fig. 1.

It should be noted that in the measurements made at 2000 Vcm^{-1} the cell contained only the positive ions of 2 pulses at one time. It is likely that the observed effect would be larger if the pulse rate were higher. Also, the cell gap is only 1 mm. The effect of positive ions will increase if larger gaps are used. Finally, this effect will decrease for such liquids as 2,2,4,4-TMP with its lower electron yield.

5. Discussion

One can see that the pulse height increase for a 1 mm cell filled with TMS does not become significant until the particle flux reaches about 10^7 $s^{-1}cm^{-2}$. From an estimate of the particle flux that one would expect at shower maximum at the SSC in a uranium-warm liquid calorimeter (see appendix), this condition would be met at the SSC at about 1 m and 2 m at 12° and 7.5° respectively. We believe that this effect depends on the gap thickness

squared, and thus a cell with a 3 mm gap will see this effect at about 10^6 $s^{-1}cm^{-2}$. But, neglecting the question of rate capability, these estimates do indicate that warm liquid calorimeters can work in particle fluxes as high as those that will be encountered at the SSC.

It should be noted that because the charge collected as a function of collection voltage does saturate in LAr, the distortion of the electric field in the gap may result in a loss in the total number of electrons collected. This would result in a decrease in pulse height at very high charge deposits. There is evidence, however, that this effect is not seen, even at very high rates[9].

Acknowledgement

R.A. Holroyd and R.C. Muñoz were supported by the U.S. Department of Energy, Division of Chemical Science, Office of Basic Energy Science under Contract DE-ACO-76CH00016.

Appendix

Estimate of Particle Flux at Shower Maximum
in an Electromagnetic Calorimeter at the SSC

In order to estimate the particle flux at shower maximum in a uranium-warm liquid calorimeter at the SSC, we first assume that the interaction rate is 10^8 s^{-1} and that there are 6 charged particles per unit rapidity[10] and 60% that number in π^os. Thus, we have:

$$3.6\ \pi^o\ /\ \text{unit}\ \eta \rightarrow 7.2\ \gamma\ /\ \text{unit}\ \eta\ . \qquad (6)$$

If we assume that the average P_T is 700 MeV/c the average γ energy distribution will be:

$$< E_\gamma(\theta) > = \frac{< E_\pi(\theta) >}{2}$$

$$= \frac{350\ \text{MeV}}{\sin\theta}\ . \qquad (7)$$

The electron-positron multiplicity at shower maximum, N_e, for these gammas is given by[11]:

$$N_e = \frac{0.3y}{\sqrt{\ln y - 0.31}}\ , \qquad (8)$$

In eqn. (7) y is the total track length in the calorimeter which can be approximated by:

$$y \approx < E_\gamma(\theta) > \left(\frac{Z}{550\ \text{MeV}}\right)$$

$$\approx 0.17 < E_\gamma(\theta) >\ , \quad \text{(for uranium)} \qquad (9)$$

where Z is the atomic number of the converting material in the calorimeter. Combining eqn.s (7) and (9) we get:

$$y \approx \frac{59}{\sin\theta}$$

Using the above assumptions, the flux of particles into an area of 1 cm^2 at shower maximum and at a radius r from the interaction region in a uranium calorimeter at the SSC is given by:

$$F(\theta,r) = \frac{7.2N_e10^8}{2\pi r^2 \sin\theta} \frac{d\eta}{d\theta},$$

$$= \frac{7.2N_e10^8}{4\pi r^2 (1-\cos\theta)}. \qquad (10)$$

Figure Captions

Fig. 1 Cell current as a function of target current for four collection voltages.

Fig. 2 Pulse height as a function of target current and as a function of equivalent particle (electron-positron) flux for four collection voltages.

References

1) SSC Central Design Group, LBL, Report of the Task Force of Detector R and D for the Superconducting Super Collider, SSC-SR-1021, June 1986.

2) T.K. Sham and R.A. Holroyd, J. Chem Phys. **80** (1984) 1026.

3) G. J. Hine and G.L. Brownell, *Radiation Dosimetry* (Academic, New York,1956) p.165.

4) A.O. Allen, M.P. De Haas, and A Hummel, J. Chem Phys. **64** (1976) 2587.

5) C.R. Gruhn and R. Loveman, IEEE Trans. on Nucl. Sci., **NS-26** (1979)110.

6) L. Onsager, Phys. Rev. **54** (1938) 554.

7) W.J. Willis and V. Radeka, Nucl. Instr. and Meth. **120** (1974) 221.

8) R.A. Holroyd and D.F. Anderson, Nucl. Instr. and Meth. **A236** (1985) 294.

9) Joey Houston, Michigan State University, private comunications.

10) M.G.D. Gilchriese, Proceedings of the 1984 Summer Study on the Design and Utilization of the Superconducting Super Collider, June 23-July 13, Snowmass, Colorado, p.491.

11) C. Fabjan, from *Techniques and Concepts of High Energy Physics-III,* T. Ferbel, ed. (Plenum Pub. Corp., 1985).

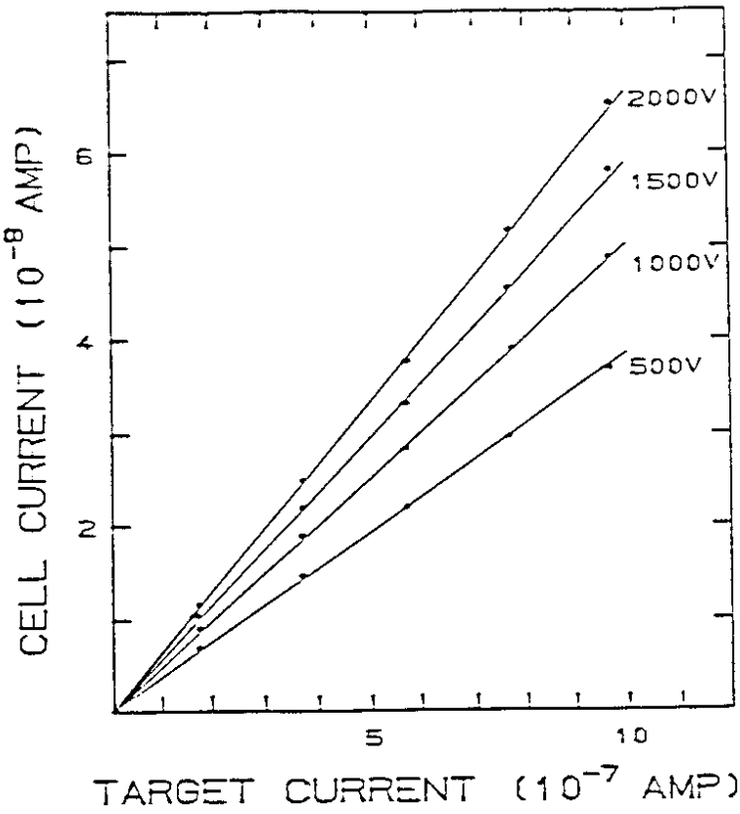

Figure 1

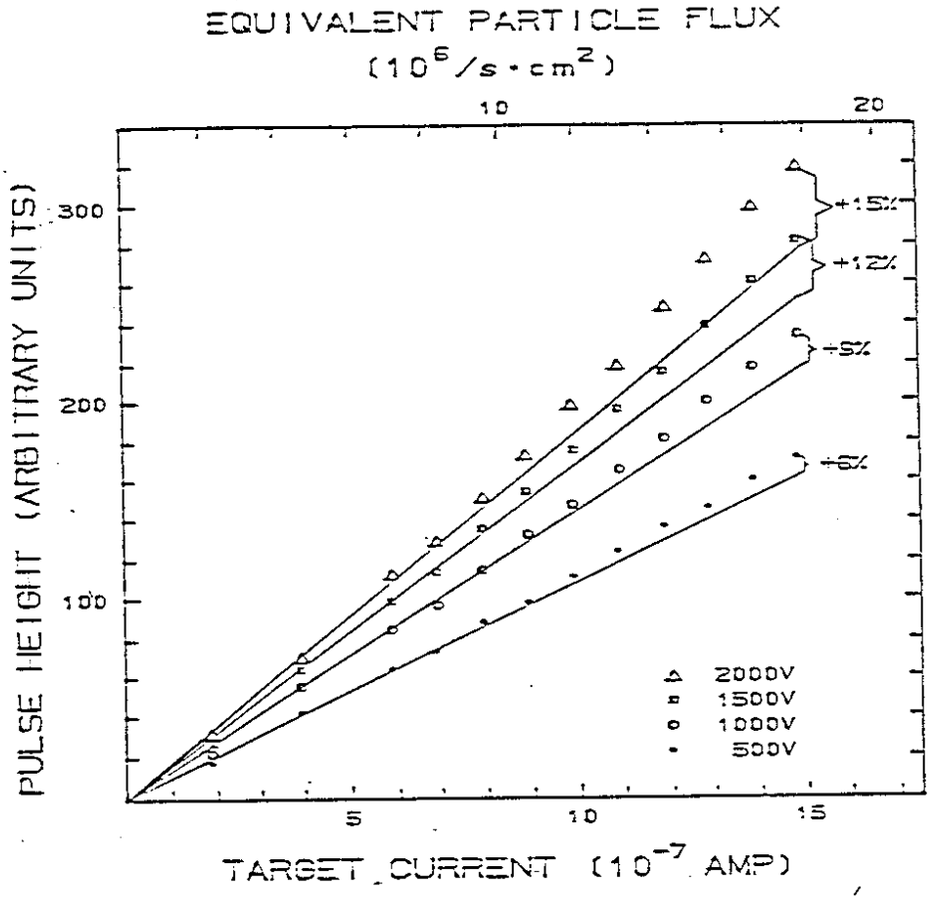

Figure 2