OPTIMIZING THE FERMILAB 15' BUBBLE CHAMBER NEUTRINO OPERATIONS WITH THE ENERGY DOUBLER

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At the present time (June, 1976), the Fermilab 15' Bubble Chamber neutrino program is running in a mode that takes only one picture per accelerator cycle. The beam spill required for this is typically a 20 μsec fast pulse of $1\text{-}2\times10^{13}$ protons at the end of the flattop with an accelerator cycle time of 10.5 sec. With the proposed doubler cycle time of 60 sec to continue to operate in this mode would slow down the picture taking rate a factor of six. A more efficient way to operate is to convert the chamber to a multipulsing mode, whereby multiple pictures are taken during the long accelerator flattop with the beam spill consisting of a series of millisecond spikes of approximately 1×10^{13} protons each. This is illustrated in Figure 1. The numbers used in the figures show a series of six spikes, two sec apart, each with an intensity of 1×10^{13} protons, placing a total intensity requirement of 6×10^{13}protons on the doubler.

Are these numbers reasonable? How fast and how many times can the chamber pulse? What is the desired number of protons on target per chamber pulse? What is the best cycle and intensity for the doubler to meet these requirements? The purpose of this note is to attempt to answer these questions.

First, how fast and how many times can the chamber pulse. The piston system with the fiberglass piston has operated in a physics run taking one picture with incident hadrons at the beginning of the flattop and one picture with incident neutrinos at the end of the flattop one second later. In a test run, the piston has operated as many as four times in a one second flattop. So the mechanical systems have the capability of pulsing once every 333 milliseconds. Another requirement is the minimum time needed to get rid of remnant tracks in the chamber. This is estimated to be approximately 150 milliseconds. The most serious limitation is the refrigeration capacity of the chamber itself. Presently installed refrigeration capacity is 6.6KW[1]. This handles a static heat load of 3-5KW and a dynamic heat load of 4,500 to 9,000 joules per chamber expansion. If the chamber operated with a 1 second repetition rate, for 10 sec and was off for 50 sec, the dynamic heat load would be .85-1.7KW average, for a total heat load of 3.85 to 6.7KW, just within the installed refrigeration capacity. Similar heat loads were handled during the mixed hadron-neutrino running mentioned previously. If the metal piston were used instead of the fiberglass one, additional heat loads of from 1.2KJ per expansion fore heavy neon, to 7KJ per expansion for deuterium[2] would be added, reducing the possible repetition rate for 10 expansions per doubler cycle for the heavy neon mixture and six pulses per doubler cycle for deuterium or hydrogen. In short, the 15' B.C. itself is capable of operating in a multipulse mode of from 6 to 11 expansions per 10 sec flattop, 60 sec cycle with no modifications.

What is the desired number of protons per bubble chamber expansion? All contemplated modes of running except wideband neon running can usefully utilize at least 10^{13} protons per bubble chamber expansion. Wideband neon running would have 1 event/picture with 5×10^{12} protons.

From these numbers and the arguments about refrigeration capacity it appears that the desired requirements are 10 or 11 expansions with 5×10^{12} protons/expansion for heavy neon running and six expansions with 10^{13} protons/expansion for hydrogen running per doubler cycle of 60 seconds.

What do these numbers and mode of operation imply for the targeting systems? At the present time, the main target system used for neutrino running of the 15' B.C. is the widebend horn[3]. This is a pulsed system with a horn current pulse width of 40μsec requiring a fast extracted pulse from the accelerator 20μsec in duration.

It is our understanding that multiple pulse extraction from the doubler is not possible with this small a width, but that multiple pulse extraction with 1msec widths may be possible[4]. Several studies have been made proposing various methods of stretching the horn pulse to 1msec[5,6]. CERN currently has under test, a transformer which will do this with a repetition rate of once each three seconds. An extension of the transformer technique to increase the rate to once each second is probably possible. Charging time for the capacitor bank is less than one second. Therefore, it appears possible to convert the wideband horn system into a system capable of multiple pulses with a one second repetition rate.

For the wideband horn, the beam on target per bubble chamber expansion is set by two criteria: the event rate in the bubble chamber and the abiltiy of the target to survive the instantaneous power dumped into it by the beam. For the heavy neon fill as previously stated $5x10^{12}$ protons per expansion would seem optimum for the event rate. For hydrogen 10^{14}protons per exposure would seem optimum; however, it is questionable whether any target could survive that intensity in 1 millisecond[7]. At the present time, we are experiencing target failures in both Al and Al_2O_3 water cooled passive targets with beam intensities of $1.0\text{-}1.5x10^{13}$ protons in 20 microseconds. Stretching the beam pulse to 1 millisecond and spinning the target so that the beam physically hits different material within that time will surely raise this limit; however, it is doubtful that any target can be made to survive 10^{14} protons per expansion. $2\text{-}5x10^{13}$ protons per expansion is most probably the upper limit for reliable operation of the target.

The second target system that might be used is a narrow band system, either another pulsed horn or a dichromatic train made of conventional magnets. For either of these systems, the ability of the beam dump to survive the instantaneous beam poer is the limiting factor. $1x10^{13}$ protons per expansion is a reasonable upper limit for reliable operation.

Other proposed target systems for neutrino running, such as the sign-selected bare target for antineutrinos and the triplet for neutrinos, will run into similar problems. Therefore, from the viewpoint of the target system $1\text{-}2x10^{13}$ protons per expansion is a reasonable desirable intensity.

Thus far, we have confined our discussion to utilization of the doubler with the proposed doubler cycle time of 60 seconds and an intensity of $5\text{-}6x10^{13}$ protons per cycle and demonstrated how the 15' bubble chamber neutrino program could usefully utilize the entire intensity of the doubler within that cycle with only a minimal change to the wideband horn. Another question we might ask, is what is the optimal doubler cycle and intensity that the 15' bubble chamber could use to increase the physics(i.e. picture) output. Under the proposed mode of bubble chamber operation of 11 expansions in 10 sec and off for 50 sec the total heat load on the chamber refrigeration system could be as high as 6.7KW just matching the installed capacity. If this refrigeration capacity were increased to 10KW, the chamber itself could increase its expansion rate to 31 expansions per 10 sec flattop, 60 second cycle. However, it is doubtful that the wideband horn could pulse at this rate. A more likely limitation for the horn is once per second, a limitation imposed by the transformer and charging time. The doubler has a proposed single turn injection beam of 5×10^{13} protons at 100 GeV/c. If we are to utilize 30 or more expansions on the bubble chamber per cycle, multi-turn stacking will be necessary to achieve the desired intensities. The purposes of illustration, we have adopted the following set of parameters: 1. 15' bubble chamber with 10KW refrigerator and plastic piston, 2. wideband horn capable of 1 sec repetition rate, 10^{13} protons per firing, 3. injection into the doubler 5×10^{13} protons at 100 GeV/c, 4. three sec cycle for present main ring injection, acceleration to 100 GeV/c, and injection into doubler, 5. 24 sec rise and fall time of the doubler. Given these parameters, Table 1 shows possible doubler intensities, cycle times and chamber output in pictures per day.

TABLE I

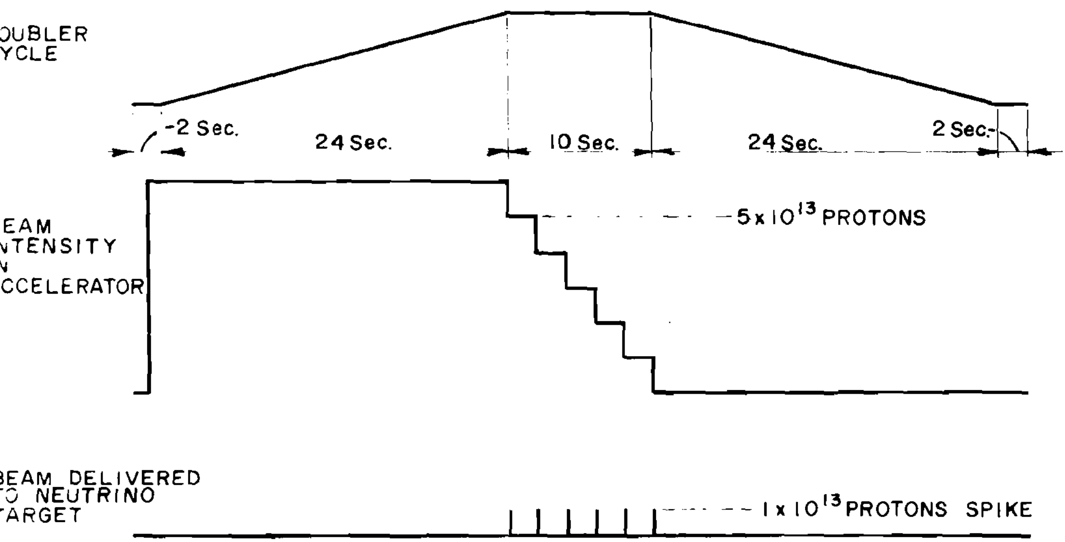
BUBBLE CHAMBER OUTPUT IN PICTURES PER DAY
AS A FUNCTION OF DOUBLER INTENSITY AND CYCLE TIME

NUMBER OF INJECTIONS	DOUBLER INTENSITY	CHAMBER EXPANSIONS	CYCLE TIME	DYNAMIC HEAT LOAD ON CHAMBER	PICTURES PER DAY
1	5×10^{13}	5	55 sec.	0.82KW	7854
2	1×10^{14}	10	63 sec.	1.43KW	13714
5	2.5×10^{14}	25	87 sec.	2.56KW	24827
10	5×10^{14}	50	127 sec.	3.54KW	34015

The most striking result shown in Table 1 is the vastly increased output in pictures per day obtained when stacking is used to increase the doubler intensity. For a doubler intensity of 5×10^{14}, over four times as many pictures could be obtained. This cycle is shown in Figure 2.

Conclusions:

In order to maintain the present picture rate of the Fermilab 15' bubble chamber, it will be necessary to convert the chamber to a multipulsing mode during the long doubler flattop, utilizing 10^{13} protons per expansion. With no modifications to the chamber itself, and only minimal modifications to the wideband horn, this proposed mode of operation is possible. A vastly better picture output can be obtained if the doubler intensity were increased to 5×10^{14} protons and the chamber refrigeration was improved to 10KW, enabling up to 50 pictures per doubler cycle to be taken. We believe this latter case should be adopted as the long term goal with the former case serving as the interim goal.



igure 1: Proposed Spill Structure on Neutrino Target

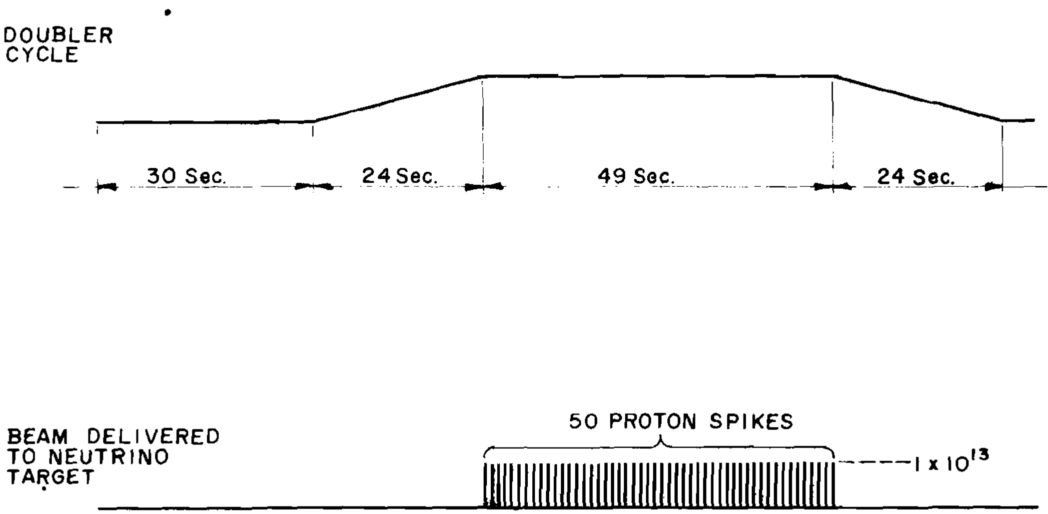


Figure 2: Optimal Spill Structure on Neutrino Target

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