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MASTER

PRELIMINARY STUDIES ON ACCELERATOR DEVELOPMENT PROGRAM*

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PRELIMINARY STUDIES ON ACCELERATOR DEVELOPMENT PROGRAM *

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Introduction

The studies undertaken were aimed at obtaining a preliminary understanding of the Abramyan type accelerator. There are many questions involved in designing a high intensity accelerator using this technique. Some questions such as the spark gap or the beam dynamics of the accelerating tube require an extensive effort, but the resonant transformer principle and the beam induced voltages can easily be studied using models.

ABRAMYAN MODEL

A scale model of the accelerator proposed by Abramyan was built as shown in Figure 1a. A simplified schematic representation of this accelerator is shown in Figure 1b.

Figure 1a

Figure 1b

*Work performed under the auspices of the U.S. Atomic Energy Commission.

The primary consisted of four turns 1/8" x 1/2" aluminum strip and the secondary consisted of 8 bundles of 10 each #20 wire. The primary winding was adjustable with respect to the secondary so that the coupling coefficient could be varied. The self resonance of the primary and secondary was well above 100 KHz. The resonant frequencies of the primary and secondary were made equal by adding capacitors C_1 and C_2 (Fig. 1b). Under these conditions the relationship between the primary and secondary voltages is as follows¹

$$V_2 = V_1 \sqrt{\frac{L_2}{L_1}} e^{-t/r} \left[\sin \frac{\omega_0}{2} \left(\frac{1}{1-K} + \frac{1}{1+K} \right) t \right] \left[\sin \frac{\omega_0}{2} \left(\frac{1}{1-K} - \frac{1}{1+K} \right) t \right]$$

For the case where $K = 0.6$ and Q is relatively high the peak voltage is reached at the second halfwave and is

$$V_2 = V_1 \sqrt{\frac{L_2}{L_1}}$$

For our case:

$$L_2 = 2.88 \text{ mH}$$

$$V_2 = V_1 \sqrt{\frac{2.8810^{-3}}{3.010^{-6}}}$$

$$V_2 = 31 V_1$$

$$L_1 = 3.0 \text{ } \mu\text{H}$$

Measured voltages

$$V_2 = 170 \text{ V}$$

$$\frac{V_2}{V_1} = 28.3$$

$$V_1 = 6 \text{ V}$$

Close agreement exists between calculated and measured voltages. See Figure 2 for picture of primary and secondary voltages as a function of time.

¹E. A. Abramyan, IEEE Transactions on Nuclear Science, Vol. NS-18, No. 3 June 1971 Neil, V. K. LLL Engineering Note 110

Traced from Oscilloscope
Photograph

In order to make an accelerating structure out of this module one of the gaps would have to be shorted out uniformly around the circumference so that the electron beam sees only an accelerating field. The spark gap itself is the subject of another study. The resonant transformer method for voltage step-up limits the repetition rate of the accelerator to a few hundred kilohertz. This limitation occurs because of self resonances of the secondary transformer. It was found that the coupling coefficient and the resonant frequencies of primary and secondary were not critical in obtaining the high voltage step-up.

ACCELERATING CAVITY MODES

It is a well known fact that any accelerating structure or non-accelerating for that matter, is excited by the beam's leading edge as it passes through the cavity. These induced fields are a function of the cavity geometry beam current and risetime. The beam induced fields have the effect of modulating the beam itself, accelerating and decelerating it depending on signal polarity. The energy spread produced is undesirable and must be known so that a correction can be applied. This modulation effect was observed in the Astron accelerator and also in the 120 MHz buncher system.²

²R. K. Cooper, V. K. Neil, L. L. Reginato, B. H. Smith, Proceedings of APS, March 1973, UCRL-74288.
R. K. Cooper, V. K. Neil, UCID-16667.

In order to study the Abramyan cavity excitation at low levels without actually installing it in the beam line, the structure shown in Figure 3 was used.

Figure 3

It consists of two tapered lines of 50Ω impedance so that a good match is maintained up to the cavity. Gap B was shorted to represent spark gaps which have fired and removed the decelerating fields. The inner conductor simulates a hollow electron beam. A 10 Ampere hollow beam of 0.5 ns risetime was simulated by using a mercury pulser. Of interest here is the self electric field generated at a gap A which subsequently modulates the trailing portion of the beam. Figure 4 shows the gap voltage induced by the 10 A beam. The time domain display shows several discrete discontinuities. The peak induced voltage is 120 V and the detectable discontinuities.

Figure 4

(2 way travel time) are at 2 ns and 6 ns. A frequency domain study of the cavity helps to locate the different resonant discontinuities (Figure 5) from zero to 500 MHz.

Figure 6

Figure 6a

Figure 6b

The different discontinuities on time domain can be linked to the physical dimensions of the cavity. The 2 ns corresponds to the open ended radial line (point C); the 6 ns is about the two way travel time to the shorted gap (point B); there is another discontinuity associated with the circumferential mismatch (point D).

With an off axis beam many higher order modes of the radial line can be excited. Some can have circumferential variations or Z axis variations. For our case where the cavity was excited symmetrically only the main modes are detectable. For an accelerator with 10 ns current duration, the most undesirable effects are those of the 2 ns ringing. Some effort was made to eliminate this mode. Symmetric resistor loading at gap A dampened mainly the low frequency modes; the 2 ns ringing was only slightly affected. Next, gap A was loaded with ferrite (ceramag 11) 1" thick, 6" I.D., and 28" O.D.; under these conditions, the radial line behaved more like a lump LC system with a ringing frequency of 14 MHz (Figure 6a, b). The high frequency ringing was completely attenuated by the ferrite and the induced voltage of the low frequency mode was about 120 V.

INDUCTION LINAC CAVITY

High intensity electron accelerators in the 5 MeV and 1 kiloamp range presently in operation are of the induction type. The Astron accelerator has 300 ns pulse width and uses silicon steel cores while the ERA accelerator having a 40 ns pulse width uses ferrite cores.

The effect of beam induced fields in the accelerating cavities exists in both of these structures. With some small modifications, the Abramyan model was used to study these effects. The modified cavity was again adapted to our tapered 50 Ω transmission line to simulate beam effects (Figure 7). The gap voltage induced by a 10 A beam pulse is shown in Figure 8a, b.

Figure 7

Figure 8a

Figure 8b

As expected, the first reflection as shown in Figure 8b is the same as it was in the Abramyan cavity. The other mode which is easily detectable from the time domain display is a 10 MHz one. The ferrite at the shorted end acts as a lumped inductor while the gap AC is a distributed capacitor, the combination resonates at 10 MHz. In an effort to attenuate the 2 ns reflections, microwave absorbing material 4" I. D. and 12" O.D., 1" thick, was installed at gap A. Except for a single 1 ns reflection the signal developed at the gap contained only the 10 MHz frequency mode (Figure 9). By increasing the

Figure 9

pulsed current signal risetime from 0.5 ns to 4 ns, the only mode excited was the 10 MHz one (figure 10); this kind of self field could be compensated by the

Figure 10

driving signal. Unfortunately, the solution of locating microwave absorption material in vacuum and at the highest field point is not a feasible one. Other more suitable materials with similar properties could be used.

Some attenuation methods could be applied at places away from the high electric field and out of the vacuum region. An attempt was made to build a radial line transition to obtain the characteristic impedance of a plane wave from inner to outer diameter and attenuate the induced fields at this point (Figure 11).

Figure 11

Figure 12a

Figure 12b

The unattenuated signal is shown in Figure 12a while Figure 12b shows the results with the addition of microwave absorber material. The low frequency mode has gone from 10 to 11 MHz.

The single reflection 3 ns wide is larger in amplitude than the multiple reflections observed for the non-tapered case. Microwave absorber material improves the situation somewhat. The induced gap voltage for this case has increased because the wave impedance as seen by the pulse at the gap has increased.

In trying to minimize the gap voltage induced by the beam, a distributed capacitor of 1800 pf was installed at the gap (Figure 13a). This was an effort in trying to reduce the impedance as seen by the wall current at the gap. The added gap capacitance lowered the resonant frequency of the main mode and reduced by a factor of five the amplitude of the 2 ns reflection (Figure 13b). By lowering the main mode frequency, the induced gap voltage after 10 ns is also lower. The 2 ns ringing is still not acceptable, however, the effects of the gap capacitance are clear.

DISCUSSION

The information was obtained over a relatively short period of time by using 1/2 scale model of an actual accelerating module. This was intended to be a zero order study to obtain a preliminary understanding of the kinds of problems which have to be solved when an actual 10 KA beam will have to be accelerated. Some of the solutions which were tried in the model are not acceptable for a final accelerating cavity, however, they do indicate the way to go.

The Abramyan technique of resonant transformer charging an accelerating gap works very well. The circuit is quite simple and the component values not critical. It offers the advantage of low voltage primary capacitor and a single switch to generate the high secondary voltage. The repetition rate of this system is essentially unlimited (i.e. hundreds of KHz).

The voltage gain per accelerating module approaches the spark over limit of the gap. One of the drawbacks of this type of accelerator is the spark gap which shorts out the decelerating field. This spark gap is a difficult one because it must fire simultaneously around the periphery at about eight places so as not to side-kick the beam.

One further drawback of this type of accelerating module is the fact that the beam induced voltages at the gap are worse than those of an induction type cavity. This is due to the multiple reflections generated when the wave front reaches the primary and the secondary windings of the resonant transformer.

In the two existing 5 MeV accelerators, the Astron and the ERA, self-induced fields are not much of a problem. These accelerators are not too bothered by the induced field because the beam currents are below 1 KA and beam risetime is in the tens of nanoseconds.

For the accelerator being considered, 10 KA and sub-nanosecond risetime, the induced voltages would be unacceptable. Studies performed on the model indicate that the low frequency mode induced would not be a problem because it would be a well behaved sinusoid small in amplitude and easily compensated by the Blumlein terminations. Of main concern would be the high frequency reflections. Some of the solutions tried in eliminating these reflections showed some promise but a practical solution will require much more extensive studies with a real cavity and beam through it.

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