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PREBUNCHING IN ELECTRON LINACS

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In trying to decide on what to do about bunching in injection cavities in our electron linac, we have studied the possibilities of using harmonic bunching. One would like to produce a sawtooth bunching voltage which presumably would produce perfect bunches in the small signal approximation.

The single fundamental bunching cavity is a first approximation to this, and a fairly poor approximation. We wished to find out how much improvement we could make by adding harmonics and determine the size of the large signal effects and the relativistic effects, since we're talking about 150 to 200 keV electrons. In fact, the relativistic effects (in particular the change of mass of the electrons) turn out, for electron bunching, to have a substantial effect on the bunching properties. It puts some really severe limits on the drift distances you must use.

We've taken the fundamental sawtooth shape and have done what is essentially a Fourier series expansion. We immediately get a great many parameters to put into the 7090. In order to have some place to start, we have taken a Fourier expansion of a sawtooth, and said that the phase and amplitudes of the harmonics are given by the expansion. Furthermore, if you do a large signal approximation to the bunching cavity, the transit time effect has a second harmonic contribution in it, which is at an unfortunate phase (such as to hurt you) and so one also would like to know how much trouble this causes.

We have worked out this program for our Linac, and if you plot the usual phase out versus phase in, you get the typical "s" shape diagram for phase bunching as shown in Fig. 1 for the fundamental (solid curve). Putting in the fundamental only, the best number you can capture into a typical electron linac is about 63% of the injected electrons. If you use the second

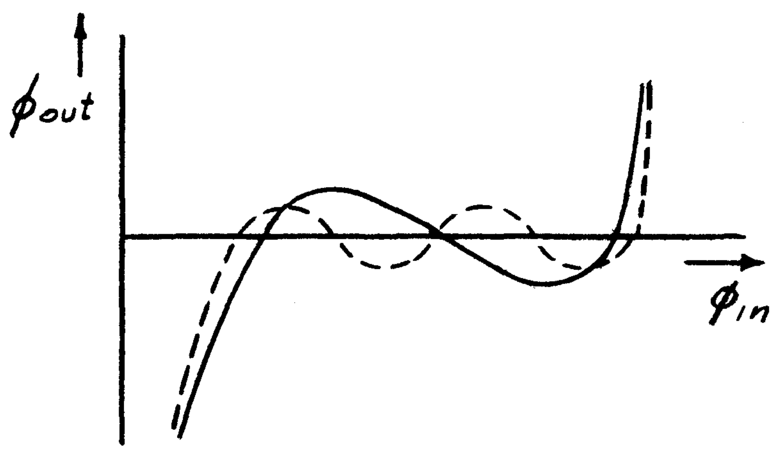

FIG. 1

harmonic, in the best case we've found, the second harmonic, put in properly (dotted curve), gives something like 89% of the injected electrons captured in the machine which is a substantial improvement. If you try to put in third and higher order harmonics, you're wasting your time, because it's very difficult to put in even the second reliably.

If you assume that the field is flat in the electron linac (which isn't a bad approximation, because the bunching occurs in a very short distance), it is possible to carry the entire analysis through from the front of the bunching cavity to the end of the machine analytically and to evaluate how good it is. For the particular case of adding in the second harmonic, in the best case, we were able to capture 89% of the particles and accelerate all of them to the end of the machine. About 84% of these were in a 1.6% energy band, and about 80% are within the 0.2% energy band. Thus a large fraction of the particles are within a very tight phase bunch. The particular point I wish to make is that the phase bunching using the second harmonic is considerably better than using only the fundamental.

BLEWETT: Can't you collect up to 70% with a first harmonic buncher?

LEISS: For the field gradient we have, about 63% is the best one can do with only the first harmonic, and by doing that you are already hurting your phase spread pretty badly, because to get the best spectrum you would want to be on a bunching factor of something like unity.

One other point worth mentioning is that on a prototype of our linac we did some experiments to try to understand how important the Q in the bunching cavity was, because we were worried about self-excitation of the cavity. The Q of the cavity we used was somewhere between 1,000 and 2,000. If you look at the accelerated beam (current against time) during a beam burst, you would like to have something like Fig. 2a. We were observing sometimes very strange structures, as shown in Fig. 2b. We were able to demonstrate that

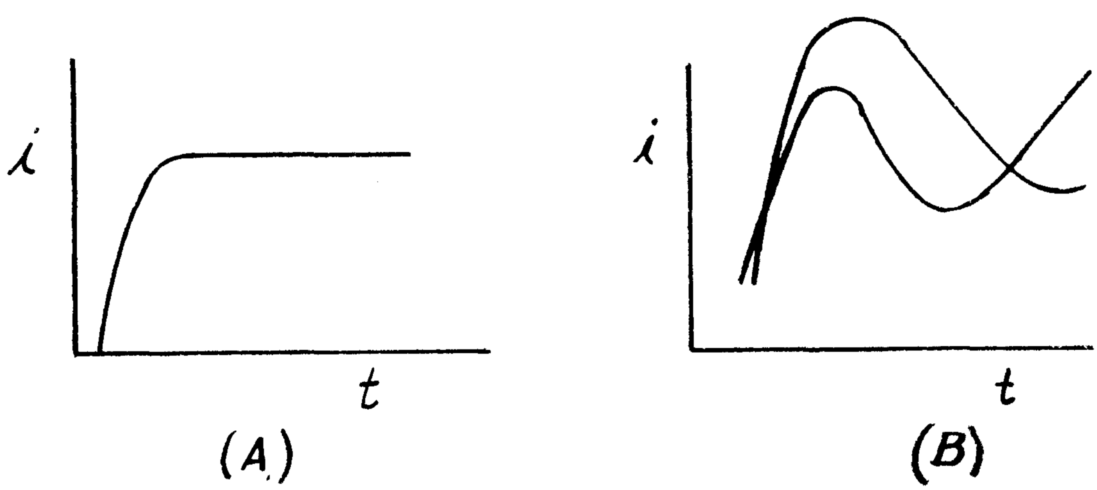

FIG. 2

these effects are caused by random noise in the unbunched injected beam exciting the bunching cavity. This was done by disconnecting the bunching cavity drive source and changing the tuning. This pattern just moves all over the place as a function of the tuning, and so clearly it is self-excitation of the cavity. This is a klystron-type cavity, and we eliminated these effects by taking the tuning stub off, and by loading the cavity. We had to pull the Q down to about 100 before we got rid of self-excitation problems. I don't know if this is observed in proton machines, but it certainly is a very noticeable thing in electron machines.

QUESTION: Where was the buncher powered from?

LEISS: In this particular case, it was coming from the rf drive source. We're now taking it from the first klystron. This is just a phase stability problem.

WHEELER: How do you plan to introduce the second harmonic in the buncher? Would you use two separate cavities?

LEISS: I think that if you use a klystron-type cavity, you have to do it in two cavities. Actually, what you would do is to put the second harmonic cavity in front of the fundamental. There is a distinct advantage to putting this harmonic cavity first, because it has a smaller signal. We have shown that it is important to get these two cavities as close as possible. When you include large signal effects, you get unavoidable phase shift difficulties if you don't get them as close as possible. We've tried to think of a way to get the two in the same cavity, but we don't know how.

BLEWETT: Are you worried about the problem of preserving phase through a frequency doubler?

LEISS: Yes. If you build a high-energy proton linac you have to do the frequency doubling anyway and also have to preserve the phase, so you have the signal available to you.

BLEWETT: This is rather reminiscent of some work that was done at Argonne and published in a report by Roland Perry. (To PERRY.) Are you in the process of actually building a multiple harmonic buncher?

PERRY: Yes, we are. We have the cavities built and ready to go on the line, but not actually installed. We have the rf system which Livdahl mentioned, which is presently not quite completed.

LEISS: In the electron case we have an additional problem because we really have to worry about de-bunching quite a bit. In the electron case, the velocity modulation has a very substantial influence on the final phase bunching of the beam. One shouldn't just look at phase, but also at the velocity modulation that occurs.

HUBBARD: I'd like to mention one novel approach to this problem that is being thought about by the RF Engineering group at Berkeley. They are trying to design a single cavity in which the next mode up is a harmonic of the fundamental; therefore, they can actually drive it with two frequencies.

LEISS: We can see how they can build the third harmonic in, but we don't see how they can build the fundamental and the second harmonic in the same cavity and get the field flat across the aperture.