# A SYNCHRONIZATION PULSE FOR THE PRINCETON-PENNSYLVANIA ACCELERATOR

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Summary. The basic synchronizing pulse in the P.P.A., tying the injection pulse and the R.F. to the magnetic field, is derived from the total current flowing through one of the Accelerator magnets. This pulse is generated in a biased toroidal coil wound on a supermalloy core, by the magnetic field H(t) created by the magnet current in a coaxial conductor.

This method has provided us with a synchronization signal pulse with excellent long term stability and very little time-jitter. Part of the time-jitter may be attributed to the variations of dH/dt at the time of the reversal of the magnetization of the core due to variations of $I_{min}$ in the magnets.

A method has been developed to effectively cancel out the dH/dt effect in the supermalloy core.

Introduction. In the Princeton-Pennsylvania Accelerator as in all other synchrotrons, the magnetic field is the independent variable and the injection and R.F. programs are servoed to it. The time at which the magnetic field has reached the proper value to initiate injection must be derived from the magnetic field directly or from the currents which go to the magnets. Other synchronization signals may then be derived from either B(t), I(t) or the proton beam itself.

In our accelerator we have chosen to derive our first synchronization pulse from the current going into one of the magnets and the other synchronization pulses are optionally switch selected from pulses derived from either the current or a signal produced when the proton beam strikes an electrode at a preset radius.

Since the current to the magnets is very close to a biased sinusoid,

$$I = 700 \text{ Amp DC} + 674 \text{ Amp}[1 - \cos 2\pi 19 \text{ sec}^{-1} t]$$

and injection takes place about 300 to 400 microseconds after the minimum, it is clear that small variations in the minimum current (a small difference of two large quantities) will produce non-negligible changes in the I(t) (and the corresponding B) at the time I and B have the proper values for injection. Thus, a scheme was developed to measure the value of dB(orbit)/dt, at the time $B \sim B$ (injection) and then modify the injection program. Part of this program compensates for the dependence of the coercive force of ferromagnetic materials on dH/dt.

Approach. Assume two conductors are wound toroidally on a ferromagnetic material with a very small coercive force ($H_c$). Then, as a current increases through one coil and the associated field increases from zero to beyond $H_c$, one would detect a large induced emf on the other as the magnetization is reversed in the core. The larger [I(t)] is, the larger will be the induced emf. If this induced emf is observed in an oscilloscope whose X-axis sweep is related to I, then the display shows a "peak" at the moment I passes through the value corresponding to $H_c$. This behavior is useful since the ratio of instantaneous value between the induced emf's during reversal as compared to the rest of the cycle may be about a few times $10^5$.

Now, assume that a third winding is added to the toroidal system and a D.C. current flows through it. This current will add (or subtract) a constant magnetic field to the time-varying magnetic field, advancing (or retarding) the time at which the varying current will reverse the magnetization. Thus, if the time-varying current is periodic, we see that the phase at which the reversal takes place may be controled by a biasing D.C. current. The actual manner of applying this technique is described in the procedure below.

If we have

$$I = I_{DC} + I_{AC}\,[1 - \cos \omega t]$$

biasing current, $- I_{bias}$, and we assume $H_{coercive} = 0$, then the peaks will occur at $t_o$; when the total current equals zero, e.g.,

$$I_{bias} = I_{DC} + I_{AC}\,[1 - \cos \omega t_o]$$

and

$$\omega t_o = \arc\cos\,(I_{AC} + I_{DC} - I_{bias})\, I_{AC}^{-1}$$

If $\omega t_o \ll 1$, then

$$\omega t_o = \sqrt{2\,(I_{bias} - I_{DC})\, I_{AC}^{-1}}$$

The coercive force may be thought of as an additional current which tends to delay the "peak", if the effective coercive force is given by $H_c = H(I)$ and $I = I(H_c)$, then

$$\omega t_o = \sqrt{2[I_{bias} + I(H_c) - I_{DC}]\, I_{AC}^{-1}}$$

and recall that $I(H_c)$ is a function of the previous magnetic history and dH/dt. This second order effect was canceled out by the scheme of advancing slightly the "peaking" time and adding a delay proportional to dB(orbit)/dt at that time.

Procedure. The total current of magnet #13 was made to flow through a shorted coaxial line, see Figure 1; this structure was chosen to permit the use of magnetic shielding around the peaking core. Since high potentials to ground may exist in case of a fault in the magnet power supply system, the assembly was housed in an evacuated

* Supported by the U. S. Atomic Energy Commission

container later filled with carefully dehydrated transformer oil. Since the power part of the central conductor, where the peaking coil assemblies are coaxially mounted, is only 0.32 inch in diameter, 1 inch long, and it must stand 850 Amp. r.m.s., the assembly is forcibly oil cooled.

The peaking cores were chosen subject to the following criteria and compromises: a) the cores ought to have a small diameter to increase H and dH/dt, at times of the order of 300 - 350 microseconds after $I_{min}$ (as close to $I_{min}$ as 1/2 Ampere turn), but there must be adequate insulation between the coil and the central conductor, b) the radial width of the ferromagnetic core must be small to minimize the peaking time interval from $H$ $(= 2I/r) = H_c$ at the inner radius of the core until it reaches that value on the outer radius of the core. Finally, a 4T-7428-S1 core was chosen. This core consists of 0.001 inch thick supermalloy tape, .500 inch I.D., 30 turns thick, 0.125 inch high. The nylon case has an I.D. of 0.425 inch. The 0.001 inch supermalloy tape has the smallest effective coercive force for reversing fields of large dH/dt.

The bias winding consists of 100 turns of AWG #34 wire, insulated with heavy formvar.

The bias winding is also used as the pick-up winding as shown on Figure 2. The constant current power supply delivered from 200 to 300 mA (the current at the bias of interest is about 265 mA), with a dynamic output impedance greater than $10^5$ ohms at frequencies of upto 100 Kc. The induced emf peak was detected by a tunnel diode discriminator circuit which had to be shielded carefully from external noises. Three stages of isolation were placed between it and the users. The standard synchronization pulse sent to all users is + 10 V, 2 microseconds wide, and it is available at 75 ohm and 50 ohm levels.

The correction for the variation in the effective coercive force by the dH/dt at the time of the reversal of the magnetization was made by reducing the bias current somewhat, then measuring the value of dB/dt in the magnet at "peaking" time and adding a delay proportional to dB/dt.

Results. In the actual set-up, there are three identical cores, power supplies, discriminators, etc.; if one displays on an oscilloscope the sum of two of these pulses after having adjusted their respective currents so that, on the average, these pulses superpose, then the r.m.s. displacement of these pulses is well below 1/2 microsecond.

Since $\dot{B}$ at injection time is of the order of 50 Kgauss per second, the timing jitter is of the order of 20 milligauss. The temperature of the oil containing the peaking core assembly is closely controled. Thus a long term stability of about ten milligauss is obtained, most of which can be ascribed to the constant current supply. This could definitely be improved as soon as it would appear worthwhile.

This pulse has been used for a large variety of purposes, the most noteworthy being:

a.) Turning on the Van de Graaff ion source and initiating the injection process. A flag pulse (from a beam flag on the edge of the vacuum chamber) which appears approximately 10 microseconds after this pulse is then used for Van de Graaff programming.

b.) Regulating the synchrotron field for a given dB/dt (50 KG/sec) at the time of this pulse.

c.) Sampling and holding the DC value of the R. F. program.

d.) Serving as reference (at present) for a 1024 pulse train used for general timing. This pulse and the bias current determining its setting are monitored and controled from the console by the operators. The overall reliability has proven to be excellent. The only electron tubes in the system, the pass-tubes in the constant current supplies even though viewed with suspicion at the beginning, have given a minimum of trouble.

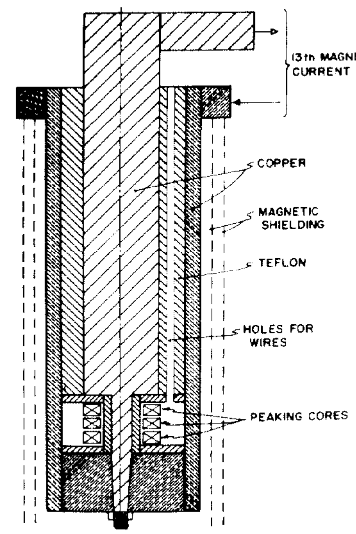


Fig. 1. This sketch shows the assembly for the peaking core. The coaxial current conductor was wrapped with a magnetic shield (conetic AA) and forcibly oil cooled.

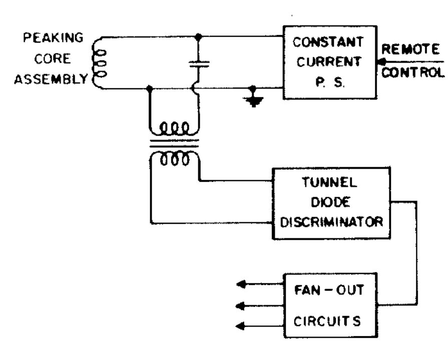


Fig. 2. Sketch of the electronics associated with the peaking cores. All the circuits use transistors except for the use of pass-tubes in the constant current power supplies.