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M SU Superconducting Cyclotron

R.F. note #9

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Alex J. Riedel

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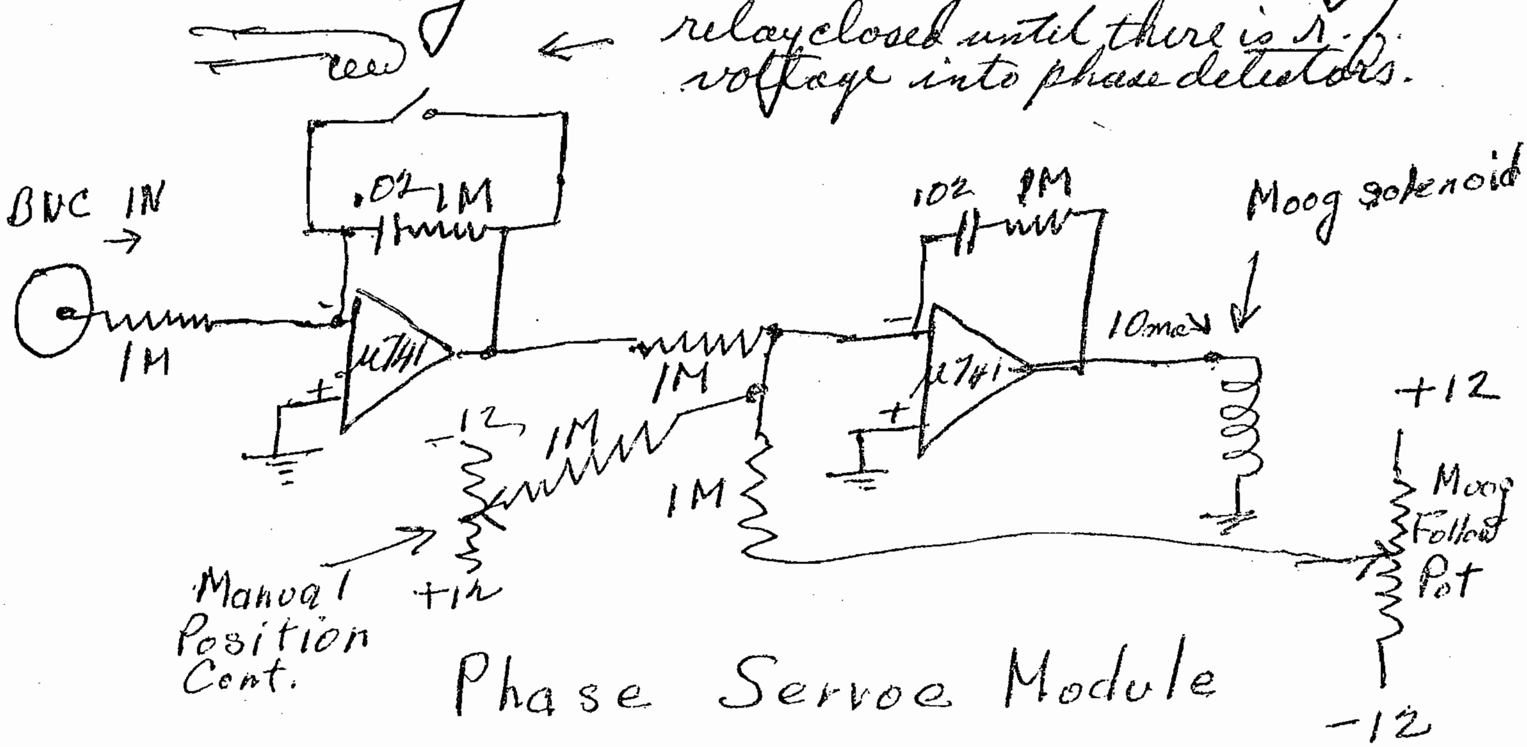
1. Moog Hydraulic actuators for the hi-Q model.
After a few false starts, Dave Birkit demonstrated that we have three hydraulic actuators which work completly satisfactorily as position servos ~~for~~ to actuate the Jennings Vacuum Condensers, the fine tuners of the model. The hydraulic pressure required is 500 psi, and the performance is characterized by a single integrating time constant.

The dc open loop gain is 10^5 and at 0.00015 Hz starts falling off by a factor of ten for each decade, achieving unity gain and 45° $\Delta\phi$ at 15 Hz, continuing to fall at 6db/octave until 60 Hz where the time constant of the Moog valve adds another 6db/octave. The phase shift is 180° at 50 Hz, but the closed loop is stable and damped because the gain there is 1/5.

Four phase servoe modules are being constructed by the electronics shop. These will not only be used on the model, but on the final r.f. system as well. Below is a sketch showing what they are.



Phase Servoe Module

2. Electronics.

A nice package of circuit diagrams and pc. flimsies ~~were~~ from DCI in France was awaiting me on my arrival at MSU. Basically these are copies of proven circuits first developed at FNAL and Princeton. They are:

A. An electronic phase shifter nee FNAL

B. Phase detectors nee PPA

C. Amplitude servo nee Princeton Cyclotron.

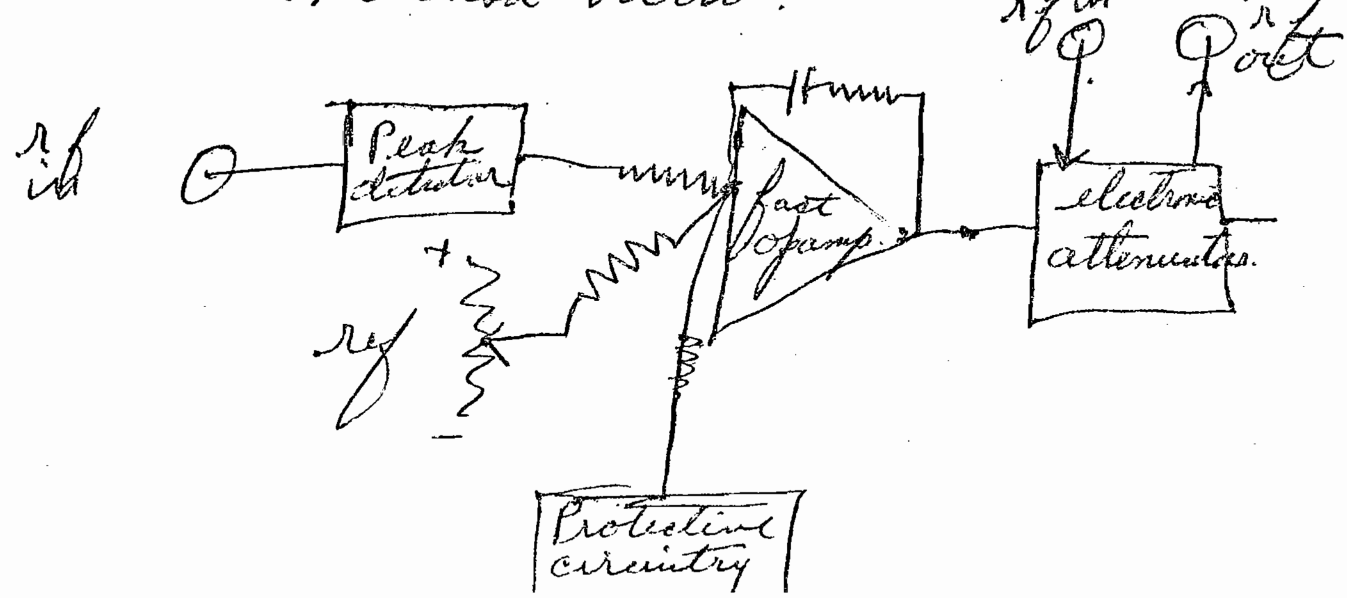
But all now have a ~~fre~~ French flavor added. Only very small modifications need be made to get the French out.

The electronics phase shifter, which can also serve as a manual shifter, employs a 20 section lumped constant delay line employing varicaps as the capacitors. We use Zener diodes as varicaps because they are cheaper than varicaps by a factor of 20 or so, and equally ~~both~~ satisfactory. Tests at Orsay showed that ± 50 ns ~~delay~~ variable delay caused only a 10% VSWR in the 50 ohm line and this should cause no trouble. A single width module contains two of these, and we are building two modules. These will be used on the hi-Q model and on the final r f system.

A phase detector module contains 4 phase detectors of the balanced modulator type. This will be satisfactory for the hi-Q model tests, but I envisage employing a different type of phase detector for the final r.f. system. This will be discussed in r-f note #10.

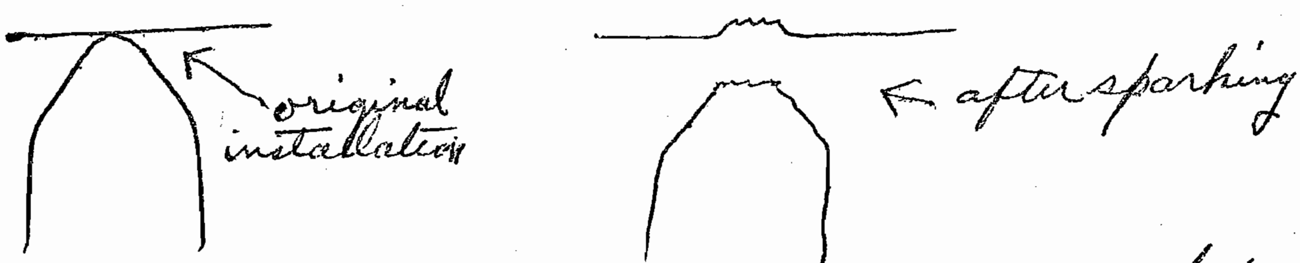
Finally, 4 modules each containing an amplitude regulator will be built. To the original Princeton circuit the French added a wire wrapped card containing a D-A converter for computer control. However this saturated the space and made debugging almost impossible. So we are deleting the D-A converter. When we need it, it can go into a separate module. This makes sense ~~b~~ because for our final 3 ϕ operation we will need 3 regulators ~~for~~ but only 1 D-A. I will be sending W Herder a new diagram for the amplitude regulators.

The significant features of the regulator are sketched below.



3. <u>Finger Tests</u>

At the end of the previous stint at MSU (reported in Note #7) results were inconclusive because of vacuum problems and foil destruction. When the 1 ~~mill~~ mil cu foil was installed, and the water leak in one of the water hoses fixed, the apparatus could safely go up to 100 amps without destroying anything but the finger! It was found that it was very easy to destroy a finger. A destroyed finger, observed under a microscope revealed that the hemispherical finger was flattened and jagged on the edges and the ground surface was cratered, as below



It took several runs to realize that great care must be taken while running up the current to detect the very first flash of light from the PM, because after this first flash the finger would have been destroyed in a Hi power setup, but in this test the contacts simply welded together and were capable of going up to much higher currents before more sparking occured. Thus it was established that the first incidence of sparking occured at about 5 amps even though subsequently one could go up to 60 amps or higher. Many runs were made where the test was stopped at the first incidence of sparking (~ 5 amps), and the finger & mating surface were removed and inspected under a microscope. The flattening and cratering were always as in the previous sketch.

So we mounted one of the silvered spring fingers of the type used at Chalk River in the test set up and lo and behold it was unbelievable that at 10 amps no sparking was observed! The finger was remove & inspected. It was in its pristine condition. This was repeated at 20 amps. Same. So finally the current was increased until sparking occured. This was at 40 amps and on removal for inspection still no damage was discernable. Amazing. The pressure was about 1/2 oz compared to 16 oz for my cu fingers. The test was repeated using the next size larger finger, the type we will use on the hi-Q model, and again sparking did not occur until 40 amps.

So we repolished our cu finger, now with a 1/32" diam hemisphere and silver plated it and the opposing surface and set the pressure at 400 gms. Sparking initiated at 60 amps and led to cratering and flattening as before.

All this is very interesting. It seems that a logical decision to make is to use the commercial contact fingers in our walking short. But due to the importance of reliability in this short further tests are in order, especially to determine the importance of the contact surface. Perhaps it should be silver plated; maybe gold plated; maybe have a rhodium flash. We plan on investigating these matters. D. Cole is acquiring materials and know how to plate our fingers and mating surfaces with these elements.

4. Report on a one day visit to Chalk River.

Because the Chalk River superconducting cyclotron is similar to ours, and because they are much further along with the construction of their r f system it seemed like a good idea to visit them to glean some usefull information. As would be expected, the Chalk River people were very cordial and informative. Their superconducting coil winding was almost finished (only 2 coils of some 20 remaining to be done). They were expecting the yoke & pole faces in about a month. They have an elaborate cryogenic laboratory where they can conveniently make various tests. At this time they were redesigning the coil lead-ins because their first design is unsatisfactory. Their problem here is greater than at MSU because of the current being a factor of 3 greater

I was amazed to find that there is a large group still working on the CW Linac. At present they are trying to get a 100 KW about 6 ft long 200 MHz linac running, using double ended triodes of the type used at CEA. Obviously they have a large group of experienced and competent power r f people. But none of these are working on the SC cyclotron.

~~But~~ C. B. Bigham is, ~~as~~ among other things, in charge of the r f system. Undoubtedly this is the first accelerator where the r f will be the first thing finished. The stems are finished as well as the sliding short. The pole face copper liners are finished and while I was there they were pounding copper on steel dee forms to make the dees. All detailed designs are complete and it looks like they should have all the r f built in a month or two. They are building a steel tank ~~to~~ just for the purpose of testing the r f system in vacuum independent of the magnet. I did not find out how far along this item is.

Meanwhile they are using an air λ/4 tunable resonator ~~that~~ has the same Rs as one final structure to test their control & regulation circuitry. For peanuts they were able to get a 20 KW surplus commercial transmitter to power this resonator.

The transmitter is fed to the resonator via a 30Ω 6" commercial transmission line where it is capacitively coupled to the high voltage end of the resonator in such a way as to terminate the line. They use an RCA directional coupler in the line and phase detect the incident voltage with a loop signal picked up from the anulus of the sliding short. In this design this line plus the water cooling for the anulus is brought out through the center of the two push rods for the moving short.

The output of the phase detector is then amplified and drives a d.c motor which moves the push rods through conventional rubber and teflon sliding (chevron) seals employing a double pumping scheme. The criteria for adjusting the variable coupling capacitor is to minimize the reflected power ~~as~~ from ~~[illegible]~~ another directional coupler. They seem very happy with the performance of all this. For amplitude regulation they use a variable attenuator and their goal is ± .1% which they have achieved. The electronics for the final system exists.

Meanwhile they have ordered from Continental Electronics the ~~[illegible]~~ final transmitter of 100 KW for 300 K$ which includes all power supplies and preamplifiers. They only need one transmitter covering the frequency range 30 to 60 MHz

The orbit people are concerned that the radial variation of voltage of the two dees supported by a single stem will not be equal, due to mechanical asymitries arising from the extraction electrodes mounted within one of the dees. Therefore they have cut holes in the iron facing each dee at the outer radius and will mount a capacitor divider there to monitor each dee voltage. Then under each dee, where there is a convenient 5" hole thru the magnet, will be a variable capacitor to ground whose position will be adjusted to equalize the dee voltages and thus eliminate a first harmonic force on the orbits. The mechanical arrangement to adjust these capacitors via dc motors is very complicated.

We discussed the merits of using hydraulics for doing this (as this capacitor in principal is the same as the fine tuning capacitor we propose for the MSU cyclotron, which we plan to control via hydraulics) as well as for controlling their magnetic field trimming rods. Their position is that no one there is familiar with hydraulics so they never considered using this technique!

Their schedule is have the cyclotron assembled with r f system and measured magnet in about a year and that in about two years it will be disassembled and moved to its final site near the injector tandem.

4. Calculations

R.F. note # 8 outlined instructions for writing a program to calculate the 3 ϕ operation problem, and we would have made such a program except that it seems that maybe we can use the existing ECAP program. ECAP is a very sophisticated program (18K core required) which, because it can do anything, is not very flexible, especially for print out. However Birkett has arranged to dump the output into a holding file and then use another simple program to accept that file as data and print out only usefull information. But there is an intrinsic problem in ECAP: it refuses to place a vector in the 3rd quadrant. However, we were able to deduce where it belonged by making reflections etc and thus get some useable results. The results agree very well with those from the model as reported in RF note # 7. We tried only one case: one dee was detuned by 1 part in 3Q. This resulted in amplitude and phase assymetry, but the departure from the correct phase for the detuned dee was much greater than the phase error of the other dees.

5. Plans

Further work will be done using ECAP to permit us to come up with precise information on the degree of orthogonality of the adjustment of phase and amplitude of the 3ϕ system. Then we can put the real circuit into ECAP, i.e., the couplers, transmission lines and transmitter circuits, so that the real circuit can be simulated.

Hi-Q MODEL

It is hoped that the Hi-Q model will be completely assembled and ready for test by Aug 1, 77. The electronics necessary to perform tests on it will probably not all be ready by this time, but considerable testing can be done using only the three solid state transmitters which have yet to be put into the shop. But these are trivial and can easily be ready by Aug 1.

Finger Test

We propose to keep the finger testing apparatus alive until Aug 1, 77.

Synthesizer. Specifications for a special synthesizer could be written now but it seems reasonable to first: write a note delineating a Conceptual Design for Control and Regulation of the R.F. System. I propose to write this during the next week. Then various people can study it and after it is amended we can proceed with the synthesizer specifications, ~~and~~ the transmitters and the power supplies.

Thus by Oct 1, '77 perhaps we can have a total design which is almost final.

Now I will tend my garden