a brighter future for SYNCHROCYCLOTRONS?

By Robert T. Siegel

On February 6, a group of physicists, accelerator specialists, and interested observers met in Williamsburg, Virginia, to discuss for two days the recent past and immediate future of that venerable accelerator, the synchrocyclotron. This conference on high-energy cyclotron improvement, held at the College of William and Mary, was intended to provide opportunity for a pooling of information which might help determine the extent to which new experiments with 100-800-MeV protons (and their secondary particles) will be possible in the next few years. In this "intermediate" energy region, the synchrocyclotron still reigns supreme, as it has since the Berkeley 184″ machine first demonstrated the success of the phase-stability principle of McMillan and Veksler in 1946. Few changes have been made in any of these machines since they were built, and "one μamp" is still the standard guesstimate of internal proton currents for most of them. Recent events have caused a rustle of activity directed toward greater internal beams, more efficient extraction of protons, and more efficient utilization of secondary-particle beams.

For example, the CERN machine has suffered the indignity of a complete physical check-up during the past three years. Everything from antianemia injections of argon into the hydrogen stream at the ion source to carefully programmed cardiac modulation of the rf system has been tried. The inevitable arteriosclerosis of radioactivity build-up on the internal components has been studied, and detailed recommendations have been made on materials to be avoided and preferred (graphite) for minimization of this type of background. The internal proton beam has been raised from 0.4 μA to 1.6 μA during this period, and experimental work with a full-scale model of the central region of the machine may yield further increases. These efforts at CERN are characteristic of those at many laboratories where programs which do not include major modifications to the machine structure have been in progress.

The standard Le Couteur regenerative extractor has generally brought about 5 percent of the internal beam into a well-collimated external proton flux. A good example is McGill's 98-MeV, 0.02-μA external beam occupying such phase space (1-inch milliradians horizontally, 2-inch milliradians vertically) that it has been focused into a 0.001-in^2 area far (50 ft.) from the machine. The problem of increasing the extraction efficiency to obtain greater proton flux in a more accessible beam, and also to reduce the induced radioactivity of the machine, remains a challenge. Only the Tokyo (60-MeV) machine has succeeded in this endeavor, with 50 percent extraction efficiency achieved at $n = 1$, whereas all other regenerative systems operate inside $n = 0.2$. No larger machine has shown enough beam at $n = 1$ to make this method practicable.

The efficient use of secondary beams has been greatly enhanced by the development of the pion-muon channel, invented at CERN and improved in a recent design executed at Chicago. These arrays of focusing magnets trap pions near the machine and convey them (and a portion of their decay muons) to the experimental areas with an intensity twenty times that obtained from a pipe of the same aperture. It is clear that other such devices may also prove useful, since only about 10^{-4} of the mesons produced at an internal target ever reach an experimental apparatus.

An important improvement of synchrocyclotrons has been the "unbunching" of the proton beams,

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which spreads the time distribution of the particles over a longer period than that characteristic of the beam during the acceleration process. Briefly, the circulating beam is "stacked" at a certain radius by suddenly turning off the rf, and the beam is then slowly moved into a target or extraction system. This may be accomplished either by moving a target into the beam mechanically, or by "stochastically", (i.e. slowly), accelerating the beam for the last few inches of its radial motion with an additional rf electrode system. The latter method has become more popular because of mechanical problems with rapidly vibrating targets, and because the "stochastic" method can be used with extracted proton beams. The most efficient system described is that at Carnegie Tech, where 65 percent of the total internal beam is drawn onto a target with a 50 percent duty cycle, including rf fine structure.

When it comes to major modification of the machines, the physicists are often loath to surrender time for this purpose. But at Rochester a complete rebuilding of the rf system two years ago has resulted in a 5-μA internal beam instead of the previous 1 μA, principally because of the increased dee voltage and dee aperture, and everyone there seems happy with this result. Perhaps the fact that the accelerator experts were the physicists themselves made it easier to schedule this renovation.

But still the nagging question exists: What has limited synchrocyclotron beams to a few microamperes? For the first time a quantitative explanation may be appearing in the form of a straightforward theory of space-charge effects near the ion source which has been developed by K. R. MacKenzie (UCLA). He has shown that the onset of magnetic focusing occurs suddenly, at a radius r_m, and that a larger current can be brought to this radius by (a) increasing rf voltages, and also modulation rates, (b) improving electric focusing by dee "feelers", and (c) by improving magnetic focusing, perhaps with iron cones or more complex forms at the center of the magnet. His formula, which includes all focusing effects, has experimental verification from Berkeley, and provides hope that 100 μA may yet be attainable. The Orsay 160-MeV machine (built by Philips) uses high (20-kV) dee voltages to yield 20 μA with an otherwise conventional machine, providing further support for his ideas.

As K. R. Crowe suggested in his summary talk, the lid may finally be off the 1-μA ceiling, and synchrocyclotrons will hopefully be able to sustain intermediate-energy research until a new generation of accelerators comes into being.