IMPROVEMENTS IN THE CERN SYNCHROCYCLOTRON
OVER THE PAST THREE YEARS

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Measures introduced to improve the intensity of the CERN synchrocyclotron 5 to 6 times are described. The use of argon in the ion source gas, the use of a constant bias voltage across the central auxiliary dee, modulation of the amplitude of the r-f voltage, the use of a vibrating target, and other features are discussed. A program is presented for further experiments on the machine.

Over the past three years some improvement work has been done on the CERN synchrocyclotron. No substantial changes were made in the design of the machine proper, but the improvements do increase the synchrocyclotron intensity by a factor of 5 to 6 (Fig. 1), and the results of this work are of immediate interest, even if all the details are not definitively grasped. This report is needed right now since new and more fundamental improvements are being proposed for the immediate future.

Argon Added to the Ion-Source Gas

The ion source used for the CERN synchrocyclotron, a Penning type cold cathode source designed by R. Keller and L. Dick, operated on a hydrogen-helium mixture. News was received in 1961 that the intensity of the 150 MeV synchrocyclotron at Orsay (France) has been increased appreciably by the addition of trichloroethylene to the source plasma. Of course it would be undesirable to have $C_2HCl_3$ get into the chamber, from the standpoint of vacuum and chemical inertness, but this information still prompted the idea of using heavy inert gases, argon in particular. Since a gas mixture was already being used in the source, B. Hedin, who was in charge of this experiment, found no difficulty in replacing the helium with argon. The current maximum of the inner beam was obtained in an argon stream of $7 \cdot 10^{-3}$ torr \cdot liter/sec (15 $\mu$g/sec), a hydrogen stream of $15 \cdot 10^{-3}$ torr \cdot liter/sec (1.7 $\mu$g/sec), and in leakage of $14 \cdot 10^{-3}$ torr \cdot liter/sec (22 $\mu$g/sec). Gas flowrate was determined by the pressure increment sensed by an ionization pressure gage whose readings were correlated for the specific gas [1]. Two pumps of 12,000 liters/sec each brought about a vacuum of $10^{-6}$ torr in the chamber.

Optimum extracted-beam currents were attained at a lower argon flowrate. This indicates that the argon enhances radial particle oscillations while suppressing vertical oscillations.

The physical processes responsible for the argon effect in enhancing beam intensity remain somewhat obscure. Nevertheless, argon did increase the average beam intensity from 0.3 to 0.55 $\mu$A, so that the source has been using argon since 1961. The volume of the gas stream is not very critical; the source operates with somewhat greater stability on argon than it did on helium.
Previous reports [2] described stochastic acceleration experiments conducted at CERN by R. Keller, L. Dick, and associates. At first, it had been proposed to achieve stochastic acceleration of protons with the aid of an auxiliary dee (cf. Fig. 2) to comparatively low energies, then to accumulate protons at that energy and later accelerate them to full energy by the usual method. Tentative investigations showed that the full intensity would be roughly doubled, but that the equipment would have to be so complicated as to be exorbitantly expensive to operate. But careful attention to the results showed that maintaining a strictly constant voltage across the stochastic dee could also have an effect.

We made an attempt to study the effect of constant bias across the auxiliary dee with appropriate high-frequency decoupling. These investigations were carried out by L. Dick. We found that when the voltage across the stochastic (auxiliary) dee was of the same sign and almost the same magnitude as the bias voltage across the main dee, the internal beam intensity increased by roughly 50% to near 0.8 µA. The auxiliary dee probably alters the vertical focusing of particles in the region free of magnetic focusing. This focusing improves orbit stability and accordingly improves beam acceptance. It is perfectly clear that there is no reason to consider the existing geometry the optimal one, and the research now underway on the Joint Institute for Nuclear Research synchrocyclotron (Dubna phasotron, USSR) showed that proper siting of the stochastic dee and selection of proper bias level are highly effective measures [3]. The results of that work emphasize the need for a systematic review of electrostatic focusing.

Auxiliary-dee experiments have shown the possibility of extra-fine control of circulating beam intensity by bias voltage. This method provides improved reproducibility superior to the usual beam defining method, and has less effect on beam quality. When the auxiliary dee bias voltage polarity is switched, the intensity varies by as much as 1/10 of the peak value. Auxiliary dee bias has been in use since 1961 on the CERN synchrocyclotron.

**Modulating the R-F Voltage Amplitude**

While stochastic acceleration investigations were in progress on the CERN synchrocyclotron, Lawson at Harwell (Britain) was studying various cyclotron type machines designed for beam stacking at the center [4]. Russell [5] advanced a definitive proposal for stepping up the beam intensity of the 275-cm Harwell synchrocyclotron. In this latest plan for increasing the accelerating field at the initiation of the acceleration cycle, when current limiting is almost achieved, r-f voltage opposed in phase to the voltage across the main dee is impressed across the auxiliary dee situated at the center of the machine.

The high-frequency system of the CERN synchrocyclotron has been described in an earlier report [6]. As we see in Fig. 3, the accelerating voltage amplitude ranges from 5 kV at the beginning of the cycle to 25 kV at the end.