2.2 The Rotary Capacitor: Tuning Acceleration

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The orbital frequency of the protons in the synchrocyclotron decreases during the acceleration because of the relativistic increase of the mass of the particles and the radial decrease of the magnetic field required to focus the outwardly spiralling particles. The decrease of orbital frequency calls for a large frequency sweep of the accelerating electric field (this being the potential difference between a D-shaped metal box, called the Dee, and the grounded vacuum chamber). The Dee is located in the magnet gap where it covers about 150° of the orbital plane. The particles experience the accelerating field at the entrance and exit of the Dee. The required modulation of the radio frequency (RF) accelerating field from 30 to 17 MHz was initially obtained by means of a vibrating capacitor, the so-called tuning fork (Fig. 2.3) [11].

The synchrocyclotron (SC) was designed [11] to provide an average internal proton current of 1 μA at 600 MeV. In 1967 an improvement programme [12] was initiated to increase the current to 10 μA and improve the beam quality. Amongst other measures it was decided to raise the accelerating voltage from 20 to 30 kV and the repetition rate from 54 Hz to 500 Hz. The latter required a modification of the RF system: the tuning fork had to be replaced by a rotating capacitor, a device used in other synchrocyclotrons at that time. Figure 2.5 shows the layout of the new RF system [12, 13]. The acceleration time was 1.4 ms.

The power oscillator feeds the system through the constant value coupling capacitor C_{CL} and two rotary capacitors, for coupling (C_{cos}) and modulation with respect to earth potential (C_{mod}), both synchronized on the same shaft. Their capacitances vary as a function of the azimuthal position of the shaft. The function of C_{cos} is to present a constant load to the power oscillator, which provides 180 kW peak. The transmission line formed by the stub and the Dee has a carefully designed tapered impedance distribution to achieve the required variation of the resonant frequency for practical values of C_{mod} while keeping the voltage across the capacitors at acceptable levels.

The rotary capacitor C_{mod}, which the team affectionately dubbed Rotco (the old term for capacitor being condenser), consists of an aluminium alloy rotor of 1.5 m diameter rotating on a cantilevered shaft between earthed stator blades. It is driven by a variable speed motor and rotates in vacuum at speeds of up to 2600 revolutions per minute (rpm). Both rotor and stator blades are shaped and tapered to provide the required variation of capacitance. All blades are water-cooled and designed in such a way as to avoid mechanical resonances (Fig. 2.6).

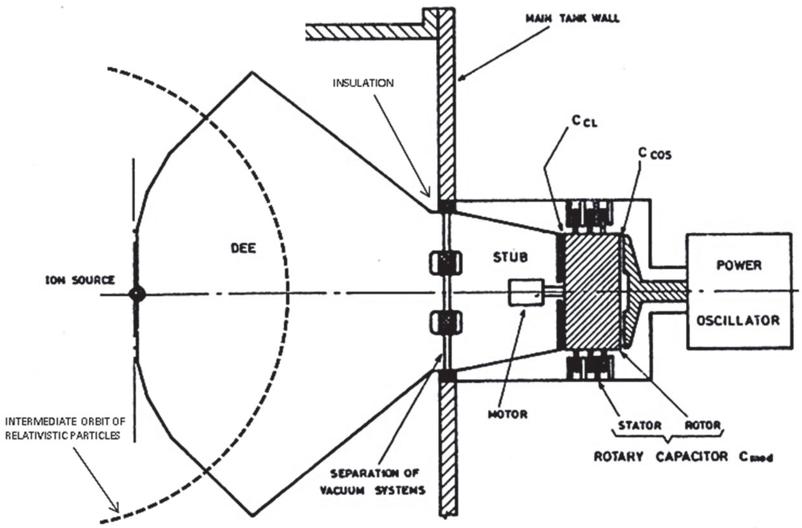

Fig. 2.5. Schematic plan view of the RF system [12].

The entire assembly was housed in an Al-alloy casing evacuated by a turbo-molecular pump that was later replaced by a cryo-pump. To reduce the risk of voltage breakdown due to oil vapour, a rotary-face seal retained the oil and a turbo-molecular pump mounted on the shaft removed any leaking oil. Despite these precautions, electrical breakdown caused by condensation of oil vapour remained a serious concern. A delicate element was the ceramic insulating bushing and the vacuum seal of the main bearing. Since the Rotco was also subject to a flux of activating high energy neutrons, two identical assemblies were constructed to provide a spare for reducing downtime after a breakdown.

The RF circuit design was initiated at CERN with modelling and simulation, and continued by industry where detailed design of the hardware was made to a functional specification and construction was started. But the project suffered significant delay and in 1973 it was agreed to transfer the partially built equipment to CERN, which undertook further development and finalised the construction. The CERN team had to carry out numerous repairs and improvements of the electrical and mechanical elements in order to get it working. The Rotco and its spare were put into operation in 1974. However, the design was intrinsically fragile and both assemblies were plagued by electrical and mechanical problems for several years, and the team had to make a continuous effort to gradually improve reliability. This has entailed the redesign of many components [14].

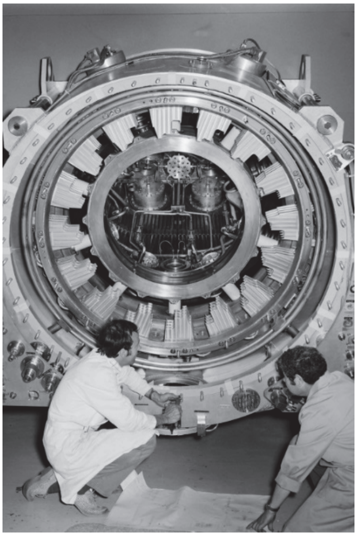

Fig. 2.6. View of the stator of the modulating capacitor seen from the generator side. The rotor is removed.

This project is an example of a technological development where the design and construction was entrusted to an industrial partner who in retrospect was over-ambitious and had taken on work that extended beyond its competence level. This was a hard lesson for CERN, signalling the need to better prepare in-house the design of complex technical apparatus, including the construction and thorough testing of models and prototypes.

2.3 Discovery of the $\pi \rightarrow e\nu$ Decay: Rare and Precious

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In 1948 at Berkeley, π-mesons were produced for the first time with an accelerator [15] and observed in its prominent decay $\pi \rightarrow \mu\nu$. Several searches for the $\pi \rightarrow e\nu$ decay remained however unsuccessful. These searches were motivated by the idea that all Dirac particles, such as electrons and muons, would have the same weak interaction constant ("electron-muon universality"). Assuming the Fermi description of weak decay and the symmetric coupling of electrons and muons to π-mesons [15] the ratios R= $(\pi \rightarrow e\nu)$ / $(\pi \rightarrow \mu\nu)$ for the so-called Axial-Vector and Pseudo-Scalar interaction were calculated to be 1.28×10^{-4} and 5.49 respectively. For scalar, vector and tensor interaction the decay $\pi \rightarrow e\nu$ was expected to be forbidden.