COMMISSIONING OF THE INJECTOR COMPLEX OF COSY-JÜLICH

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ABSTRACT

The Isochronous Cyclotron JULIC was upgraded over the last years to serve as injection machine for the new Cooler Synchrotron COSY-Jülich[1]: A new RF system replaces the former self oscillating unit to achieve more power, better stability of frequency/phase and amplitude and easier operation. Mineral insulated trim coils with modified winding patterns replace the old set of coils, which suffered severely from radiation damage. Several especially adapted ion sources provide the H_2^+- and H^--beams for the injection into COSY. The injector was extensively equipped with new instrumentation and computer control for compatibility with the COSY control system. An entirely new transfer beamline between the injector and COSY-ring is finished and ready for use. The cyclotron is back in operation since February 1992.

This paper gives a brief description of some modified subsystems, focuses on the commissioning procedure and reports first results.

1. INTRODUCTION

JULIC was originally conceived for the acceleration of light ions (p, d, $^3H^{2+}$,α) in the energy range of 22.5 to 45 MeV/A. After about 15 years of more or less continuous operation the machine was upgraded for the acceleration of light and medium heavy ions. So since 1987 a spectrum of additional ions was available. In September 1989 after more than 100000 h of operation the cyclotron was finally switched off as accelerator for experiments mainly in nuclear physics but also in life sciences, material investigation and others. - In order to serve as injector for COSY-Jülich the cyclotron complex (ion sources, accelerator, beam lines, technical infrastructure) needed extensive technical upgrading[2]. Emphasis was given to the development of H_2^+-beams, which are needed for the injection into COSY with first priority, but also to H^--beams as precursor for polarized particles. The optimization of beam parameters defines stability factors for magnetic field, RF amplitude and phase, which could only be achieved by new installations. To improve reliability, the trim coil system and parts of the technical infrastructure had to be rebuilt. The extensive upgrading of diagnostics equipment[8], general instrumentation and computer control was necessary, to simplify operation and to provide the basis for compatibility with the COSY computer control system. An entirely new transfer beamline was built between cyclotron and the COSY ring.

2. ION SOURCES

Four ion sources will be available for the different particles to be accelerated in COSY[3]. The types of sources are mainly determined by the fact, that the injection into the cooler synchrotron is performed by stripping. First COSY beams will be delivered by a H_2^+ source, which can be easily replaced by a H^-/D^- source. The main reason for this negative ion source is to study the injection, acceleration and extraction of negative ions in the cyclotron, which is of major importance for the future use of polarized particles. A H^-/D^- polarized source provides the only possibility to inject such ions into the ring by stripping.

The transmission through the source beam-line and the cyclotron can be remarkably increased by reducing the beam emittance much below the expected acceptance of the cyclotron. Experimental results imply, that a source with low emittance (< 35 $\pi\cdot$mm$\cdot$mrad at 8.2 keV) and medium high currents (> 100 μA) to avoid space charge effects would probably be the best choice. For injection into COSY H_2^+ beams of 80 MeV and currents above 10 μA are requested at the exit of the cyclotron.

A well adapted H_2^+ source was developped with the additional condition to maintain the advantage of an ECR source without any wearout components (see Fig. 1). Since the emittance of ECR sources increase with the axial magnetic field in the extraction region, it is reasonable to use low microwave frequencies like 2.45 GHz and lower the field in the extraction as much as possible. The best results have been achieved with a source consisting of a permanent magnetic multipole with zero axial magnetic field at the extraction and only one mirror coil at the opposite side as shown in Fig.1. By tuning the source parameters (solenoid field, microwave power, gas pressure and puller voltage) H_2^+ beams of about 100 μA with emittances in the range of 25 to 40 $\pi\cdot$mm$\cdot$mrad could be obtained.

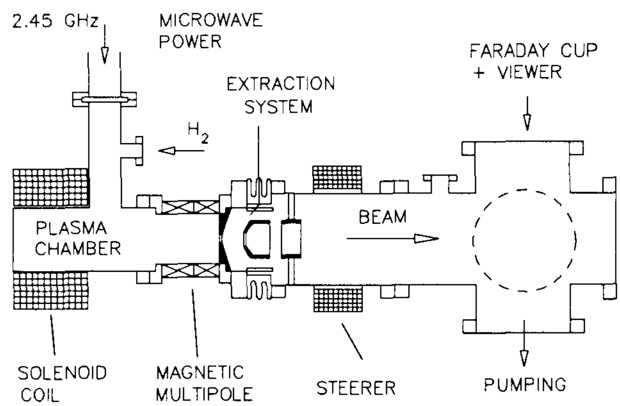

Fig. 1. H_2^+-ion source

The H^-/D^- source bought from IBA company was originally designed for extraction voltages of 25 to 30 kV. When only 4.5 kV is applied, which is needed in our case, the large divergence of the low energy beam resulted in an incomplete matching between the source and the existing beam line. The situation could be remarkably improved by introducing two additional electrostatic electrodes behind the puller.
The big superconducting 14 GHz ECR source, which had been developped for heavy ion acceleration with the cyclotron, was frequently used since shutdown of JULIC in 1989 for atomic physics experiments. In connection with COSY it is supposed to deliver heavy ion beams for medical applications in a somewhat later stage of operation. - The polarized ion source is realized in form of a collaboration of the universities of Bonn, Köln and Erlangen. It is going to be assembled at its final location by the end of the year.

3. TRIM COILS

At JULIC the tuning of the isochronous field is performed by three pairs of trim coil arrangements (plates) mounted on the hill sectors of the pole tips inside the vacuum chamber. The new design was necessary because of severe radiation damage of the old units, where extensive use had been made of epoxy resin for insulation as well as for the mechanical fixing of the structure. The new coils were optimized in respect to radiation damage and from vacuum point of view. Mineral insulated cable material was used, made by Pyrotenax Ltd., Canada. The square shaped coaxial copper cable with an outer dimension of 6.35 mm and a MgO-powder insulation of 0.5 mm allows an effective (indirect) cooling of the conductor. In total 9 coils of four windings each are combined with 5 water pipes for cooling. The coil/cooling channel configuration was inserted into a solid copper plate with precisely milled grooves and then soft-soldered at a time in a vacuum environment.
Trim coils have to correct the variation of relativistic mass increase, saturation effects in the iron of the hill sectors and local field errors. Concentric sector coils are well suited to cover the first two items, but local field errors can only be corrected by adequate field differences of subsequent coils. Accurate field measurements[4] had to make the basis for the precalculation of trim coil current sets before the beam could be accelerated, but also for the interactive optimization during operation. Since JULIC has a 3-fold symmetry it is sufficient to do field mapping for a sector of 120°. Figure 2 shows one trim coil mounted on the hill sector together with the strongly simplified field mapping equipment. The hall probe of a high precision

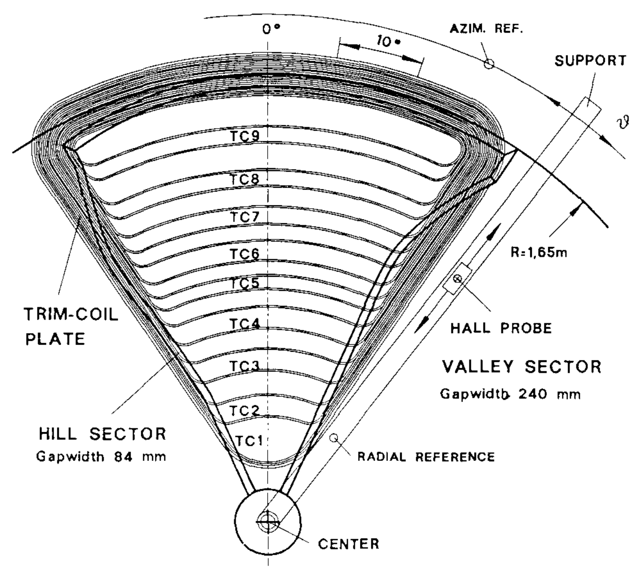

Fig. 2. Trim coil with field mapping unit

field measuring unit could be positionned by DC motors azimuthally over ± 60° from the center line of the hill sector and radially up to $R_{max} \approx 1.6$m. The integral field on an orbit has to be measured with an accuracy of $1 \cdot 10^{-3}$. Due to field gradients of up to 0.25 T/cm in the hill-valley region, the precision for positioning the probe must be 0.1 mm or 0.005°. A PC based system was used to perform field mapping, i.e. to control the motion of the probe and to do the corresponding data acquisition. The main field was measured for H_2^+ ions of 80 MeV, which corresponds to a level of 0.65 T in the valley region. Then with the main field switched on the trim coil fields were subsequently measured with maximum positive as well as negative excitation, to improve accuracy.

4. RF SYSTEM

A new system for rf power generation and control replaces the former self oscillating unit[1,5]. This modification was done in close cooperation with the industry in such a way, that a contract with HERFURTH GmbH, Hamburg, covered the new RF power generator and most of the low level subsystems like signal generation, frequency tuning, regulation and control, while the cyclotron group was responsible for all installations in the vacuum chamber like frequency tuning elements, coupling loops inclusive feedthrus, pick ups for phase, amplitude etc.

Figure 4 is a simplified schematic of the system. Operation of the rf is controlled by a special dedicated micro-computer, which controles more than 20 tuning elements and monitors the proper operation of signal detection and conditioning, regulation loops etc. The frequency is generated in a synthesizer, which was selected for a very good short term stability. Power amplification is achieved in a two stage setup. Two solid state wideband amplifiers of 1 kW each in parallel serve as preamplifier for a power stage equipped with the SIEMENS tetrode RS 2058 CJ. The nominal output power is 100 kW in the frequency range of 20 to 30 MHz.

The rf power is transfered to the cyclotron via a 6 1/8" coax-line over a distance of about 21 m. After passing a tuned impedance transforming network, the power is coupled inductively into one accelerating sector. Multiple loop control was necessary for amplitude and phase regulation, to achieve the specified long and short term stability. The resonance frequency of the accelerating system is preset within the operating range by motor driven panels in the dees. Simultaneously also the adjustable coax line on top of the machine is pretuned. The coax line is terminated with two watercooled variable vacuum capacitors in parallel, which are the active elements of the resonance frequency fine tuning loop arranged around the resonator. Amplitude regulation is performed by two superposed control loops (Fig. 3). A fast inner loop stabilizes the amplification factor between power splitter 2 and directional coupler 1, hence suppressing amplitude modulation contents introduced by the non ideal power amplifier. The amplitude setting is achieved by use of an overall regulation loop, which also defines long term stability. It is appearent, that for a long term stability of $<1\cdot 10^{-4}$ the characteristics of demodulator 4 is of prime importance. - The regulation scheme is completed by an overall phase regulation loop.

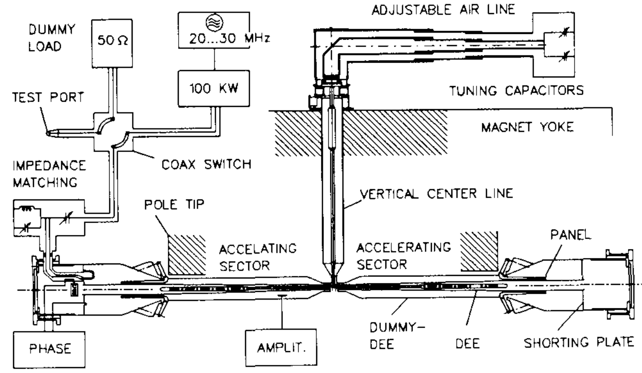

Fig. 4. Simplified schematic of the rf system

Figure 3 shows the situation in normal mode operation. Because of the influence of the multipactor effect, the switching on procedure requires a modified

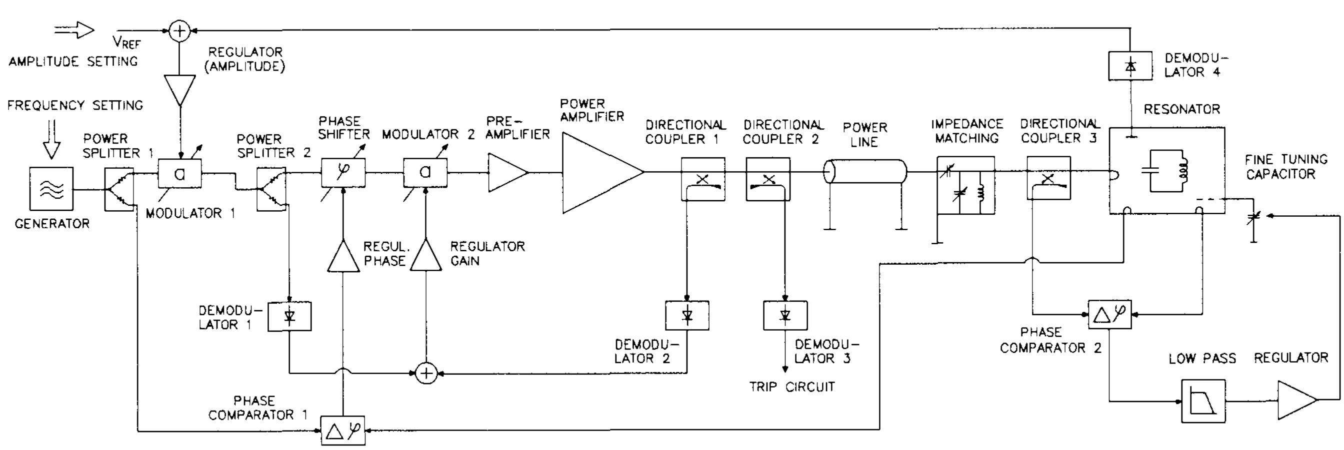

Fig. 3. Circuit diagram of the rf-system (normal mode operation)

system configuration. In this case trip- and safety-circuits as well as part of the regulating loops are switched to an inactive state by the control computer. Amplification factors for signal conditioning etc. are adapted, to respond on the very low levels during start up. After presetting all tuning elements in the system, rf power of maximum only 1 Watt is applied to the resonator, to be safely free from multipactoring. When the resonator has been precisely tuned in closed loop mode to the operating frequency, then for start up a rf burst is generated. For approximately 10 μs the maximum available rf power is applied to the system, in order to increase the voltage in the resonator with a slope of $> 1 kV/\mu s$, which is necessary to overcome the multipactor effect. After 500 μs the system is switched to normal mode operation.

As the improvement in stability of amplitude and frequency/phase had been a first order argument for the new rf system, these figures were checked carefully during the acceptance tests and the first time of operation with beam. Short term amplitude stability in normal operation, refered to the maximum accelerating voltage of $\hat{u}_{max} = 45$ kV in our cyclotron was well below the specified figure of $\hat{u}/\hat{u}_{max} < \pm 1 \cdot 10^{-4}$ for all settings of voltage and frequency in the tuning range. Phase stability refered to the output of the master oszillator proved to be $\Delta\varphi < \pm 0.3°$.

$\hat{u}_{max} = 45$ kV is needed in JULIC, which correspond to rf power of only 45 kW. But the above described switching on procedure is significantly simplified with the extra power of up to 100 kW.

5. TRANSFER BEAMLINE

The H_2^+ or H^-/D^- particles of about 40 MeV/A must be transfered from the cyclotron over a distance of about 100 m to the COSY ring, which is to be filled with protons by stripping injection[6]. The transfer beamline was constructed by a department of the SIEMENS company[7]. All the 57 magnets of the beamline connected to 19 computer controlled power supplies are now running with the proper B[l]-curves. The vacuum system is also fully accepted and provides a pressure of $p < 1 \cdot 10^{-7}$ mbar, dropping to $p < 1 \cdot 10^{-10}$ mbar near the COSY ring. The beamline was tested section by section with a H_2^+ beam of 76 MeV and intensities of about 4 μA. The first section, which matches the cyclotron beam with an emittance of 6 $\pi \cdot$mm$\cdot$mrad to the subsequent FODO structures and achromatic sections, produced the designed beam waist at its end. Most of the magnets can be set to the calculated field levels within a tolerance of 2%. Without the limitations by beam slits about 97% of the beam current can be transported to section I6. Even if the beam at the entrance of the beamline is misadjusted by ± 1 mrad in horizontal or vertical plane, losses do not exceed 10%. The local distribution of the full intensity beam is measured at 7 positions along the beamline by grids of 30 wires (wire diameter 0.1 mm, distance 1.5 mm). As the H_2^+ particles, hitting the wires, are stripped to protons, the shadow of the wires can be observed in the H_2^+ beam for detailed diagnostics. The protons appear as bright lines on the scintillator screen with half the rigidity of the H_2^+ ions. - The acceptance tests for the last two beamline sections have to be done in September, when the COSY ring is ready to accept the first ions by stripping injection.

6. CONCLUSION

Because of severe interaction between the various tasks at the COSY injector complex, the modification took a relative long time. The cyclotron was back in operation with internal H_2^+ beam in November 1991 and with extracted beam in February 1992. New instrumentation and especially the new computer control, which was available in a preliminary version only, caused a series of difficulties. As the beam was urgently needed for the commissioning and acceptance tests of the transfer beamline, debugging is not yet completely finished. - Up now H_2^+ beams of up to 8.5 μA could be extracted from the cyclotron.

7. REFERENCES

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