PROTOTYPE OF THE HIGH VOLTAGE SECTION FOR THE 2 MEV ELECTRON COOLER AT COSY-JUELICH

J. Dietrich[#], FZJ, Juelich, Germany

M.I. Bryzgunov, A.D. Goncharov, V.V. Parkhomchuk, V.B. Reva, D.N. Skorobogatov, BINP, Novosibirsk, Russia

Abstract

The design, construction and installation of a 2 MeV electron cooling system for COSY-Juelich is proposed to further boost the luminosity even with strong heating effects of high-density internal targets. In addition the 2 MeV electron cooler for COSY is intended to test some new features of the high energy electron cooler for HESR at FAIR/GSI. The design of the 2 MeV electron cooler will be accomplished in cooperation with the Budker Institute of Nuclear Physics in Novosibirsk, Russia. The design and first experiments of a new developed prototype of the high voltage section, consisting of a gas turbine, magnetic coils and high voltage generator with electronics is reported.

INTRODUCTION

The COSY synchrotron accelerator and storage ring provides unpolarized and polarized proton or deuteron beams for internal or external hadron physics experiments in the momentum range from 300 MeV/c to 3.7 GeV/c [1]. Electron cooling is applied at low energies, at present mainly at injection energy, to prepare low-emittance beams to be used after acceleration and extraction for internal and external experiments. Stochastic cooling, covering the momentum range from 1.5 GeV/c up to the maximum momentum, is used to compensate energy loss and emittance growth at internal experiments. Requests for future COSY experiments as WASA – a detection system from CELSIUS accelerator of The Svedberg Laboratory (TSL) at Uppsala with a pellet target [2] - are higher luminosities ($> 10^{32}$ cm^{-2} s^{-1}). There are two possible ways i) increasing the band width of the stochastic cooling system and/or ii) electron cooling up to maximum momentum. For operations with thick internal targets, fast (magnetized) electron cooling is the only technically feasible solution. For electron cooling up to maximum momentum of COSY an electron cooler up to 2 MeV electron energy has to be developed together with the Budker Institute in Novosibirsk [3,4].

PROPOSED 2 MEV ELECTRON COOLER

Basic Parameters and Requirements

The basic parameters and requirements are listed in Table 1. The most important restrictions are given by the

---

[#]j.dietrich@fz-juelich.de

available space at the COSY ring itself. The height is limited by the building up to 7 m, the length of the cooler in beam direction by the existing electron cooler and the ring itself to 3 m. The acceleration of polarized beams at COSY must to be taken into account. Space for compensating magnets must be foreseen to achieve conservation of polarisation.

Table 1: Basic Parameters and Requirements.

COSY 2 MeV Electron Cooler	Parameter
Energy Range	0.025 ... 2 MeV
High Voltage Stability	$< 10^{-4}$
Electron Current	0.1 ... 3 A
Electron Beam Diameter	10 ... 30 mm
Cooling Length	3 m
Toroid Radius	1.5 m
Variable Magnetic Field (cooling section solenoid)	0.5 ... 2 kG
Vacuum at Cooler	10^{-8} ... 10^{-9} mbar
Available Overall Length	7 m
Maximum Height	7 m
COSY Beam Axis above Ground	1.8 m

Preliminary Technical Design

The proposed electron cooler consists of a high voltage vessel with electrostatic acceleration and deceleration columns, two bending toroids and cooling drift section. The preliminary scheme of the cooler is shown in Fig. 1 [3]. The basic features of the design are i) the longitudinal magnet field from the electron gun to the collector, in which the electron beam is embedded, ii) the collector and electron gun placed at the common high voltage terminal and iii) the power for magnet field coils at accelerating and decelerating column is generated by turbines operated on SF$_6$ gas under pressure. The cathode of the electron gun is immersed in the magnetic field. The electron beam is accelerated to an energy up to 2 MeV. After that the electron beam is bent in the toroid and is guided to the cooling section. After the main solenoid the beam is returned to the electrostatic column. Here it is decelerated and is absorbed in the collector located in the head of the electrostatic column. Each toroid consists of two parts. The first one bends the magnetized electron beam in the vertical plane on 90^0. The second one bends the electron beam on 180^0 in a plane, which is inclined on 45^0 to the vertical plane. Such a complicated 3-D geometry provides compactness of the system. The dipole kick for protons in the bending toroids near the cooling

section will be compensate by dipole magnets which will be installed near the large toroid coils as close as possible. The Electrons receive dipole kicks due to the inhomogeneity of the magnetic field. These kicks must be compensate by electrostatic kickers which will be inserted in front of the cooling section. Electrostatic bending for better recuperation efficiency will be used [6,7].
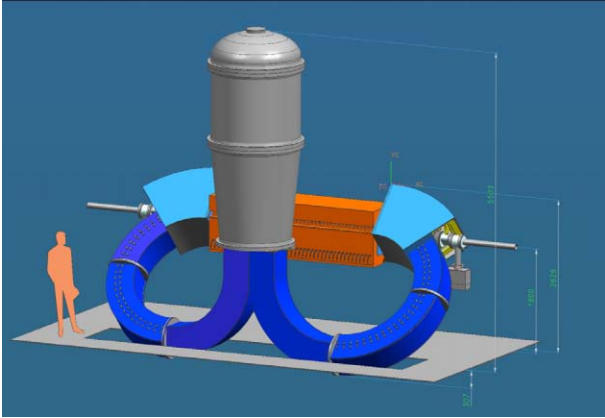

Figure 1: Layout of the proposed 2 MeV electron cooler for COSY.

PROTOTYPE OF THE HIGH-VOLTAGE SECTION

High Voltage System

The high voltage system consists of the vessel, the accelerating and decelerating column, high voltage sections and high voltage head with gun and collector. The high voltage sections for the 2 MeV electron cooler (Fig. 2) contains: high voltage power supply, coils for the magnet field along acceleration and deceleration columns, power source and control units for measurement and control of parameters for each section. Each section has two high voltage power units on 30 kV. Using of two power units allow to decrease the voltage for insulation inside the single section from 60 kV to 30 kV. The voltage between the sections amounts 60 kV. The whole 2 MV column consists of 34 sections. The electric field between the sections will be 30 kV/cm. To suppress sparking a SF_6 gas pressure of about two bars is sufficient. Special measures must be taken to prevent destructions from sparks. Accelerating rings are surrounded by collar rings. The simplest system of powering the high voltage sections and power supply for the magnetic field is a mechanical electric generator. The most popular system consists of a electric engine on ground potential and an insulation shaft (plastic) which transfers power to an electric generator on high voltage potential. In the present case too many generators (>35) along the acceleration column and to the high voltage terminal would be necessary. The twisting moment of the shaft for the first generator would be 35 times larger than for the last one. Vibrations of the whole system could be an other disadvantage. Therefore turbo engines with integrated electric generators (maximum electric power of 0.5 kW) at each section are proposed. A compressor at ground potential will pump SF_6 gas from the vessel, compress it to 4-5 bar and feed it to a thermo exchange chamber and gas filter. After this the pressurized gas is directed with plastic tubes along the high voltage column. At each section the pressurized gas is used to drive a turbo generator for production of the electric power (Fig. 2) and after this the gas is used for cooling and regulating the temperature constant.

Turbine

The power supply of the section is provided by the turbine device. The turbine generator consists of gas turbine with 24 permanent magnets and stator with 36 coils. The coils connected at three series lines so that generator produced three-phase AC signal with shift 120 degree. The nominal frequency depends from loading current and usually is near 2 kHz. This high frequency of AC power enable to obtain the transformers and smoothing capacity inside power supply more compact.
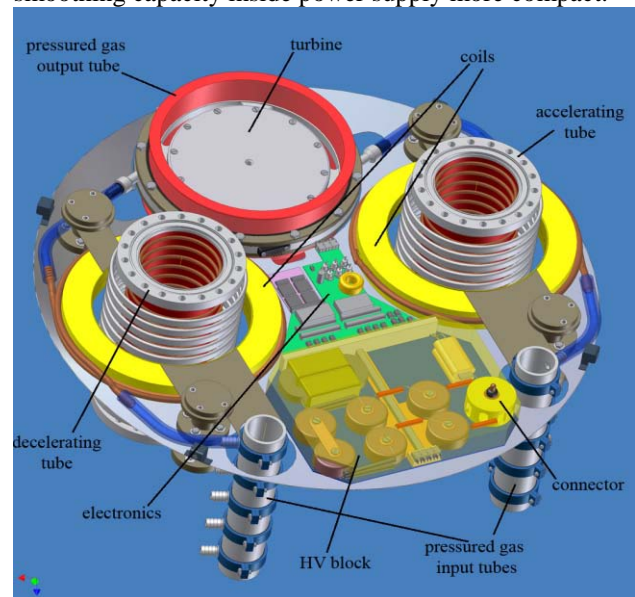

Figure 2: Layout of a complete high voltage section.

The maximal power produced by the generator was 670 W. The efficiency of electricity production at the turbine is 17%. The temperature of exhaust air was on 4-5 degree less than initial temperature and will used for cooling the electronic elements inside sections.

Electronics Board

The electronics board realizes all the control functions of the section. The control functions include the analog measurements, the feedback system, the processing of the alarm signals and communication with the central computer. The board contains also the drivers of the power electronic switches. The board is divided functionally on the digital, analog and power parts.

PID Regulator

The system of the voltage measurement contains two types of divisors ("slow" and "fast"). One part ("slow")

contains resistive divisor. It becomes non-effective at large frequencies. It means that it can't stabilize high-frequency modes of voltage error. Another part ("fast") contains capacitance divisor, which is non-effective at low frequencies, but it is effective in high frequencies. Using these two divisors in parallel scheme in the feedback system one can achieve better stability. Operating part sets the value of high voltage using Pulse Width Modulator. The feedback is realized with digital method. The voltage error is measured using measuring part and after that the operating part sets new (corrected) value of high voltage. PID controllers are used in this scheme. In PID controller three parameters of input signals (proportional, differential and integral) are summed up.

Stability of High Voltage

To estimate the contribution of the fast feedback two test (with feedback and without it) were made (Fig. 3 and 4). One can see that in the case when the capacitance feedback is present (Fig. 4) the frequency of remain ripples is several times higher then in the case when the capacitance feedback is absent (Fig. 3). It means that the "fast" feedback provides the damping of higher frequencies of the voltage error.
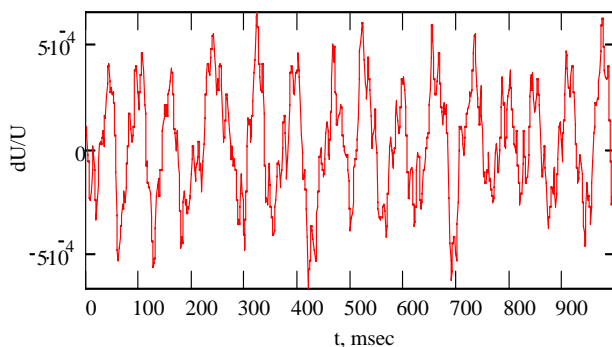

Figure 3: Voltage error without capacitance feedback. The mean square deviation amounts about to $\sqrt{<\left(\Delta U/U\right)^{2}>} \approx 2.7 \cdot 10^{-4}$.
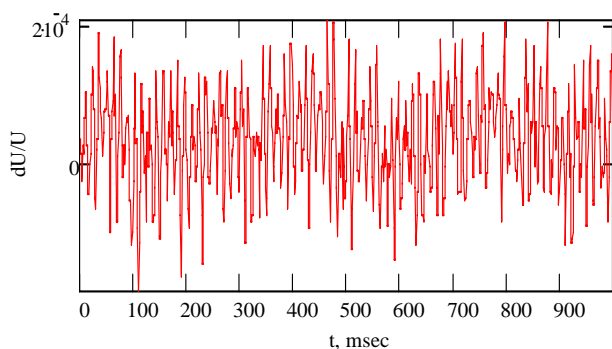

Figure 4: Voltage error with capacitance f eedback. The mean square deviation amounts about to $\sqrt{<\left(\Delta U/U\right)^{2}>} \approx 7.7 \cdot 10^{-5}$.

SUMMARY

The development of a 2 MeV electron cooling system for COSY is essential for the future COSY physics program, it delivers higher beam quality and higher luminosity. The 2 MeV COSY electron cooler would be an intermediate energy step to future high-energy magnetized cooler projects like the HESR high energy electron cooler in the FAIR project [9] and would be extremely useful for finding optimal technical solutions and prototyping many elements.

A prototype of the high- voltage section was tested at BINP successfully. At one single section a voltage of +25 kV to -25 kV without any SF_6 gas isolation was obtained. At 30 kV sparking between sections occurs in agreement with estimations for testing in air. The specified voltage stability of better 10^{-4} was reached. The magnetic field in one section coils reached the specified value of 500 G. In a next step three of such high voltage sections will be combined and long life time tests performed.

REFERENCES

1. R. Maier, Nucl. Instr. Meth A 390, (1997) 1.
2. J. Zabierowski et al., The CELCIUS/WASA Detector Facility, Physica Scripta T99, (2002) 159.
3. V. V. Parkhomchuk, Electron Cooling for COSY, Internal Report (2005).
4. V. B. Reva et al., Budker INP proposals for HESR and COSY electron cooler system, AIP Conf. Proc. 821 (2006) 308 . J. Dietrich et al., AIP Conf. Proc. 821 (2006) 299. J.Dietrich et al., EPAC'06, Edinburgh, June 2006, TUPLS080, p. 1684 (2006) ; http://www.JACoW.org.
5. V. V. Parkhomchuk, Nucl. Instr. Meth. A 441, (2000) 9.
6. V. V. Parkhomchuk, Recuperation of Electron Beam in the Coolers with Electrostatic Bending, Poster, AIP Conf. Proc. 821 (2006) 341.
7. V. V. Parkhomchuk, Development of a new generation of coolers with a hollow electron beam and electrostatic bending, AIP Conf. Proc. 821 (2006) 249.
8. Y. I. Golubenko et al., Accelerators of ELV-Type: Status, Development, Applications, Budker INP 97-7, Novosibirsk (1997).
9. D. Reistad, The HESR Electron Cooling Proposal, AIP Conf. Proc. 821 (2006) 289.