PULSED MAGNETIC SYSTEM OF THE RELATIVISTIC ELECTRON BEAM ACCELERATOR «TEMP-B»

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The paper presents the magnet system for electron beam focusing and transport developed, manufactured and applied in this work including: an inductive sensor for magnetic field strength measurement, having characteristics similar to those of the Hall sensor, with which a map of the magnetic field in the accelerator diode has been obtained; a synchronizer designed to control the accelerator magnetic field triggering in the wide time interval; a stand for Rogovski loop calibration, used for noncontact measurement of the current in magnetic field solenoid coils.

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INTRODUCTION

Magnetic systems, being an integral part of charged particle accelerators, are designed to perform such functions as: particle injection in and ejection from the accelerator channel beam focusing and transport. Using a detailed magnetic field map, measured with an increased accuracy, it is possible to improve appreciably the main accelerator performance – efficiency of particle beam transport throughout the accelerator channel [1].

The objective of this work was to develop, manufacture and apply the magnetic systems operating under radiation conditions, in order to obtain a high-power magnetic field in the accelerator. To deliver a required energy to the target in the form of a shaped high-power relativistic electron beam (REB) one needs a magnetic field strength of tens kOe.

MAGNETIC SYSTEM

Beam parameters are directly related to the energy loss on diode construction units. In diode constructions with a long cathode holder going beyond the shaping and transporting line, the vacuum surface of an accelerating column insulator is bombarded by electrons. As a result, the number of discharges on the insulator surface increases and the diode commutation time decreases.

To transport a high-current electron beam it is necessary to apply a focusing magnetic field having a sufficiently high strength. Then, the Larmor radius of the electron beam, moving in such a field, will be much less than its diameter (beam cross-section). Reasoning from the above, we have decided to use the magnetic focusing method on the accelerator "Temp-B". The magnetic system comprises two solenoids one of which increases the magnetic insulation of the accelerating column, and other one shapes and transports the relativistic electron beam (REB).

Magnetic fields of these solenoids, being in phase, are triggered by synchronizers at a given time.

The magnetic field is produced by the pulse discharge current of an energy storage capacitor through the solenoid coil. The magnetic field strength is calculated by the following equation:

$$H = H_j\left[\frac{h_1}{b-a}\ln\frac{b+\sqrt{b^2+h_1^2}}{a+\sqrt{a^2+h_1^2}}+\frac{h_2}{b-a}\ln\frac{b+\sqrt{b^2+h_2^2}}{a+\sqrt{a^2+h_2^2}}\right],$$

where h – solenoid length, h_1, h_2 – distance from the solenoid ends to the measurement point, a and b – internal and external radii of the solenoid,

$$H_j = \frac{0,4\pi\cdot NI}{h},$$

where N – number of turns, I – electrical current in the solenoid.

A cylindrical solenoid designed for REB focusing and transport is powered by the bank of 40 K41I-7 capacitors with a capacity of 100 uF each. The solenoid is placed in the accelerating column. The solenoid case end is located on the distance of 700 mm from the high-voltage electrode end at which the cathode holder stem is fastened. The solenoid enclosed in the stainless steel case has the length of 510 mm and consists of 150 coils. The solenoid inductivity is 0.9 mH. When the capacitor bank charged to 2 kV is discharging, the maximum 3 kA electrical current, flowing through the solenoid, creates the magnetic field strength equal to 10.27 kOe. The coil heating in one triggering action reaches 6.8°C.

A conic solenoid (30 mH inductance, 0.5 ohms resistance), designed for diode magnetic insulation formation, is powered by the bank of 40 IM2-5-140U4 capacitors with a capacity of 140 mkF each. The transformer oil-immersed solenoid is located above the accelerator column. It has a length of 830 mm and consists of 208 coils. When the capacitor bank charged to 2.5 kV is discharged, the electrical current flowing through the solenoid creates the magnetic field strength equal to 4.1 kOe.

Solenoids have been turned on so that maximum strength values were synchronized. This was done by selecting a consistent delay in turning on the second solenoid located on the synchronizer rack.

For modern physical devices the problems of magnetic field monitoring under real experiment conditions with high radiation loads in accelerators are of current importance. Especially, current information about the magnetic field state is necessary for the accelerator steady operation. Usually, the magnetic field measurements are carried out outside the accelerator.

The magnetic filed strength has been measured, at first, with a Hall sensor. However, at high intensities its characteristics get the nonlinear region, therefore, for subsequent measurements a measuring coil was used. The measuring coil consists of 2000 coils of 0.1 mm copper wire on the insulating frame of 20 mm in diameter with the time intergation of 1 s.

Fig. 1 presents the magnetic field distribution along the accelerating column axis where curve 1 is the strength of the conic magnetic field solenoid and curve 2 is the strength of the cylindrical magnetic field solenoid.

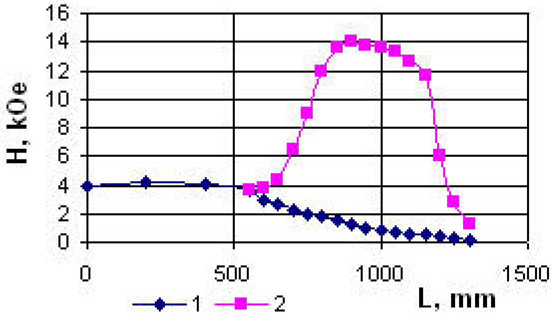

Fig. 1. Magnetic field distribution along the accelerating column axis

Fig. 2 shows the magnetic field strength distribution on the cylindrical field radius, where 1 – magnetic field strength distribution at a distance of 70 mm from the solenoid axis; 2 – 37 mm from the axis; 3 – along the axis.

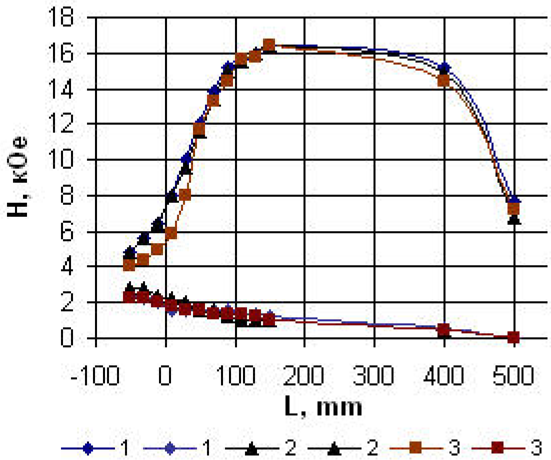

Fig. 2. Magnetic field strength distribution along the cylindrical field radius

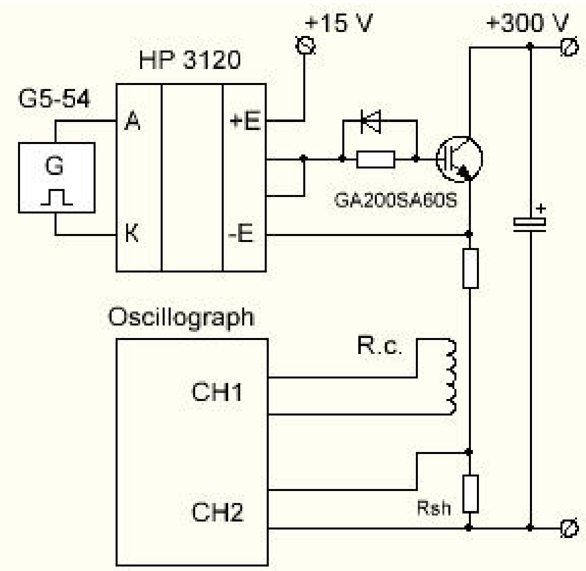

Fig. 3. Schematic representation of the stand for Rogowski loop calibration

The stand shown in Fig. 3 allows one to obtain rectangular current pulses of 80 A and a duration of several microseconds. The current commutation is performed with a key made on the IGBT GA200SA60S transistor which is driven by the NR3120 driver with optical isolation. The signal from the shunt (Rsh) and the Rogowski loop is fed to the oscillograph.

In Fig. 4 the upper ray is a shunt signal, the lower one is a Rogowski loop signal obtained from the cylindrical field solenoid coils. The Rogowski loop signal corresponds to the shunt signal with a coefficient of 0.34 kA/mV.

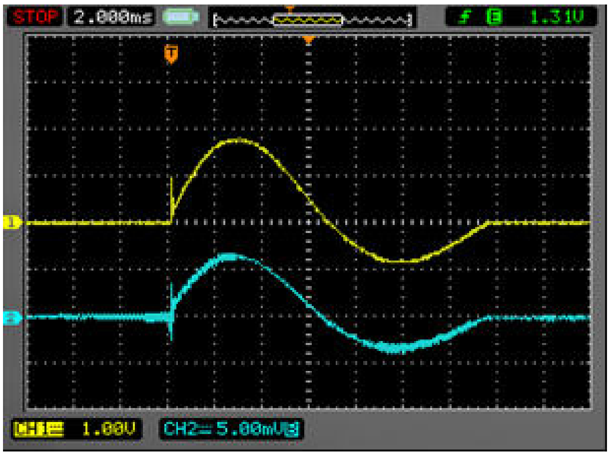

Fig. 4. Oscillograph of the cylindrical magnetic field solenoid current measured with the help of shunt (1) and Rogowski loop (2)

SYNCHRONIZER

The synchronizer assembled of units is a completed functional device. Synchronizer units are arranged in the case "CAMAC" by the appropriate unit commutation. The synchronizer consists of a trigger-pulse unit and a delay unit. A trigger-pulse unit is made on the base of I-NE chips and a multivibrator. It enables to carry out triggering, both in the manual mode, and by the external positive pulse with the amplitude to 50 V.

The delay units based on the K155AG1 monostable multivibrator have different duration of adjustable delays which are determined by the external elements R and C connected to the multivibrator. The output pulse shaper includes a multivibrator and three transistors. The amplitude of the positive pulse output is 500 V.

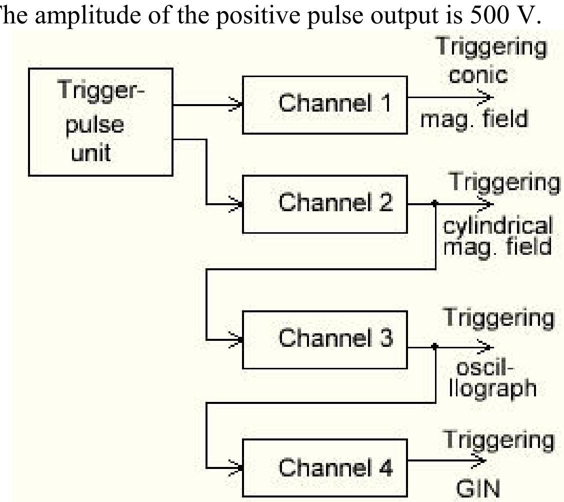

Fig. 5. Block diagram of the synchronizer

A block diagram of the synchronizer is shown in Fig. 5. Channel 1 provides actuation of the first magnetic field conic solenoid without delay. Channel 2 provides actuation of the second magnetic field cylindrical solenoid with a delay of 20 μs, which is adjusted in step of 0.2 μs·10. Channel 3 is triggered by channel 2 and provides the oscillograph triggering with a delay of 5 ms and adjustment of 0.1 μs·10. Channel 4 is triggered by channel 3 and provides triggering of a pulse voltage generator (PVG)) with a delay of 100 μs and adjustment of 10 μs·10.

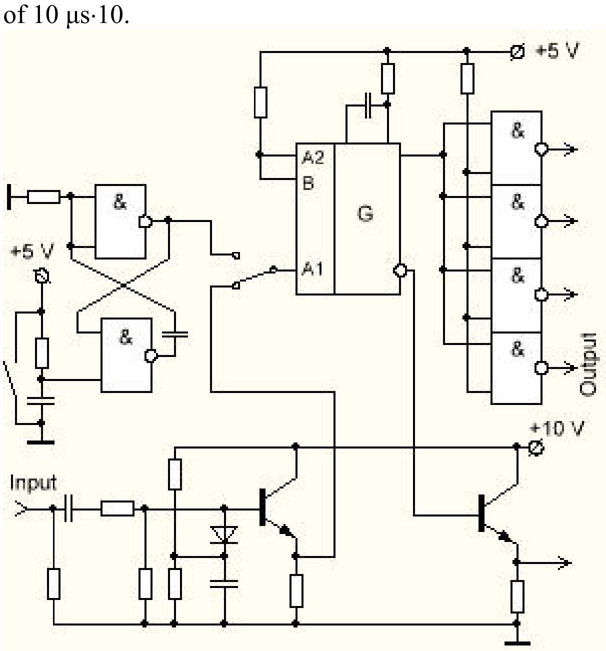

Fig. 6. Schematic representation of the trigger-pulse unit

The trigger-pulse unit and the delay unit schematic diagrams are presented in Figs. 6 and 7.

The experimental results show that the magnetic system having a cylindrical magnetic field of 11 kOe strength and a conic field of 4 kOe strength enables to obtain the beam current of 12 kA [3]. If only the cylindrical field has been actuated the beam current was equal to 10.5 kA.

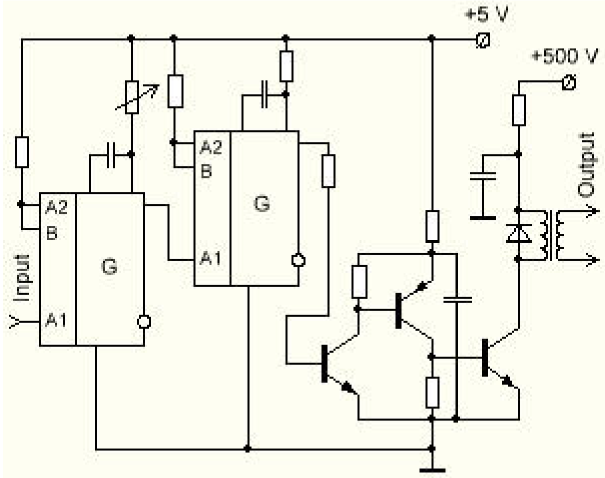

Fig. 7. Schematic representation of the delay unit

CONCLUSIONS

1. In the presented magnetic system the magnetic field strength distributions were obtained. This result allows one to evaluate the charged particle beam path and to choose an optimum place for the cathode and target location.

2. The scheme applied for magnetic diode insulation, using a conic magnetic field solenoid, permits to get a higher beam current.

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ИМПУЛЬСНАЯ МАГНИТНАЯ СИСТЕМА УСКОРИТЕЛЯ РЕЛЯТИВИСТСКИХ ЭЛЕКТРОННЫХ ПУЧКОВ «ТЕМП-Б»

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Рассчитана и изготовлена магнитная система для фокусировки и транспортировки электронных пучков. Изготовлен индуктивный датчик для измерения напряженности магнитного поля, аналогичный по своим характеристикам датчику Холла, при помощи которого была снята карта магнитного поля в диоде ускорителя. Разработан и изготовлен синхронизатор, позволяющий управлять запуском магнитных полей ускорителя в широком временном диапазоне. Разработан и изготовлен стенд для калибровки поясов Роговского, с помощью которого измеряется ток в катушках соленоидов магнитных полей на бесконтактной основе.

ІМПУЛЬСНА МАГНІТНА СИСТЕМА ПРИСКОРЮВАЧА РЕЛЯТИВІСТСЬКИХ ЕЛЕКТРОННИХ ПУЧКІВ «ТЕМП-Б»

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Розрахована і виготовлена магнітна система для фокусування і транспортування електронних пучків. Виготовлений індуктивний датчик для виміру напруженості магнітного поля, аналогічний за своїми характеристиками датчику Хола, за допомогою якого була знята карта магнітного поля в діоді прискорювача. Розроблений і виготовлений синхронізатор, що дозволяє управляти запуском магнітних полів прискорювача в широкому тимчасовому діапазоні. Розроблений і виготовлений стенд для калібрування поясів Роговського, за допомогою якого вимірюється струм в котушках соленоїдів магнітних полів на безконтактній основі.