High voltage pulse of short duration to feed solenoids for intense ion beam transport

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Abstract

A high voltage pulser up to 50 kV, with a main pulse of 2 μs time duration, was realized using a fast high voltage capacitor of 150 nF (50 kV) connected to the ground by a homemade spark-gap. The circuit, contained in a metallic box, had short electric connections in order to reduce any stray inductances. The diagnostics was performed by two systems: an auto-integrating Rogowski coil and an integrator connected to a current transformer, both suitable for pulses longer than 1μs. In order to get the above characteristic the Rogowski coil circuit must have a ratio L/R higher than 1μs, while the integrator, formed by a resistance and a capacitance, must get the product RC higher than 1μ. In the first system, the load resistance can be easily reduced, instead it is very difficult to reduce the coil resistance. The Rogowski coil we build exhibited a ratio L/R=2 μs, while the integrator circuit connected to the transformer exhibited a value RC=5 μs . We made a solenoid with an inductance of 2.8 μH (11 rings, length 14 cm) which was fed by the current generated by the pulser up to 4 kA, 1 μs at 24 kV of charging voltage. Under the above conditions, we estimate a magnetic field of 0.4 T applying the Ampere law. Actually, the magnetic field was measured in dc mode by means of a Hirst GM07 gauss-meter having a conversion coefficient of 0.08 mT/A which determined a magnetic field at the center of 320 mT. Potentially, at the maximum voltage of 50 kV we can get a magnetic field up to of 0.7 T.

Introduction

To focus hadron beams of cylindrical symmetry, a magnetic field provided by a solenoid is used[1]. At moment the magnetic field structure is not well known since depends on the development of the Flame facility in Frascati. Flame is a high power Laser with an intensity up to 10^{21} W/cm^2[2]. An experiment is in progress named LILIA. The aim of LILIA is to study, design and verify a scheme which foresees the production, the characterization and the transport of a proton beam toward a stage of post acceleration. To improve the transport or to enhance the beam emittance, a magnetic field of suitable gradient is necessary. We challenge to get a short solenoid to be fitted inside the interaction chamber of Flame with a maximum field of 0.7 T.

Theory

In this phase we wanted to make a solenoid utilizing the material available in the LEAS laboratory. We used as conducting wire a common 10 mm diameter copper tube. It formed a solenoid composed of 11 rings of 3 cm radius and 14 cm length. By the Ampere law

$$B = \mu_o \frac{iN}{l} k$$

where k is the factor of correction, we can estimate the magnetic field. To get fields of the order of Tesla, high currents in the range of tens kA are necessary.
The value of the inductance of the above solenoid is computed by the ratio Φ_{B}/i obtaining $L = 2.8\,\mu H$.
Fig. 1 reports a working scheme of the solenoid.

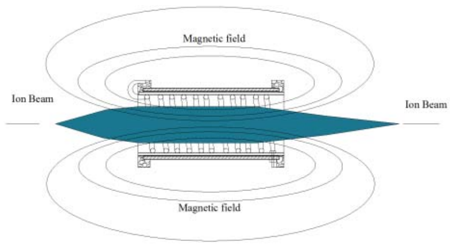

Fig. 1: Schematic distribution of the magnetic field

Materials and methods I

To get the above value a high voltage must be applied to solenoid. So we made a pulser composed by a capacitor (150 nF, 50 kV) closed on the solenoid by a home-made spark gap, Fig. 2

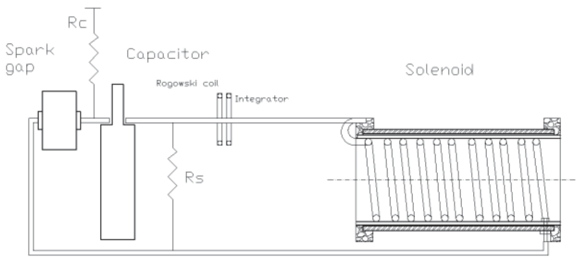

Fig. 2: Scheme

A high voltage power supply charges the capacitor by the charging resistor *Rc* and *Rs*, discharging resistor. The supply current was measured by two diagnostic systems. Under 24 kV charging voltage, both systems provided a pulse current of about 4 kA as maximum value, with a damped sinusoidal waveform of frequency 230 kHz. The main pulse duration was 1 µs, while the total duration was of 20 µs. Fig. 3. shows the output signals recorded by two different diagnostic systems: upper trace by an integrator connected to a current transformer; bottom trace by a Rogowski coil.

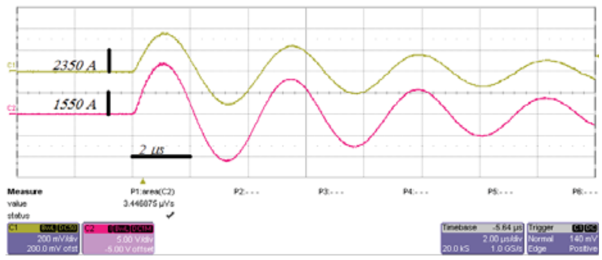

Fig. 3: Output current waveform: Upper by an integrator; bottom by a Rogowski coil.

Materials and methods II

The Rogowski coil[3] utilized was composed of 140 rings realized by a conductive wire of 0.8 mm in diameter. The diameter of the rings was 2 cm , while the one of the coil was 3.5 cm. Its inductance was $11\mu H$ while its resistance 0.4 Ω. To get the proprieties of an integrator, the coil was closed on a load resistor of 0.5 Ω. In this conditions the integrating time $L/R = 12\,\mu s$. Therefore, by the theory, the longest pulse that the system can diagnose is less than $12\,\mu s,\ 1 \text{ or } 2\,\mu s$. Diminishing the *R* value, the integrator time increases only up to $4\,\mu s$ and the response tends to zero.
The second diagnostic system, the integrator connected to a current transformer, was composed of a coil with 60 rings connected to an integrator composed of a resistor of 331 Ω and an capacitor of 15 nF connected to ground. The small number of rings allows to diminish the stray capacitance between the coil and the case, avoiding the oscillations and allowing the application of the integrator of high input impedance.
The calibration of both systems was performed by means of a fast exponential pulse. It was obtained by a pulser containing a 110 nF capacitor connected by a fast switch to a 50 Ω coaxial structure as shown in Fig 4.

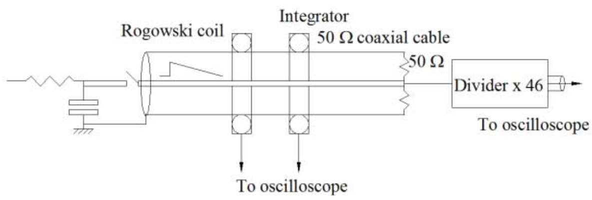

Fig. 4: Experimental setup for calibration.

The input current is calculated by the signal of the divider multiplying for 46/50, bottom trace Fig.5. The upper trace is the Rogowski coil response. The attenuator coefficient is A=310 A/V.

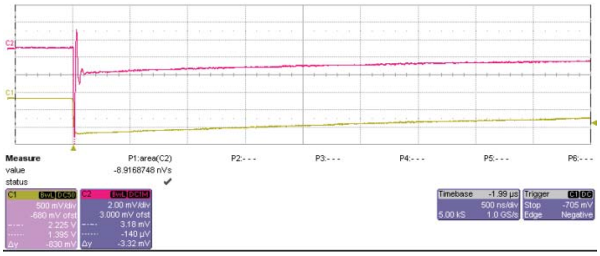

Fig. 5: Rogowski coil calibration. Attenuation A= 310 A/V.

Fig. 6 shows the waveform of the input current (upper trace) and the response of the integrator/transformer (bottom trace). The attenuator coefficient is A=260 A/V

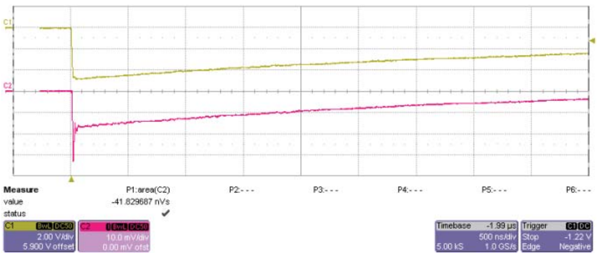

Fig. 6: Integrator/transformer calibration. Attenuation A= 260 A/V.

Results

The magnetic field provided by the solenoid can be evaluated by the theory utilizing the current intensity value. By Fig. 3 the maximum current is about 4 kA and the corresponding field is 0.4 T. Due to the experimental conditions this value is oversized. The high voltage does not allow to get a direct measurement of the field, so we fed the solenoid with a low voltage in order to get a modest current value, 10 A. In these conditions we measured the magnetic field inside the solenoid utilizing the gaussmeter GM07. Under the above current condition, the magnetic field was very modest and the correlation between field and current was 0.08 mT/A. By this value we determined the magnetic field at 4 kA current, which was 320 mT.

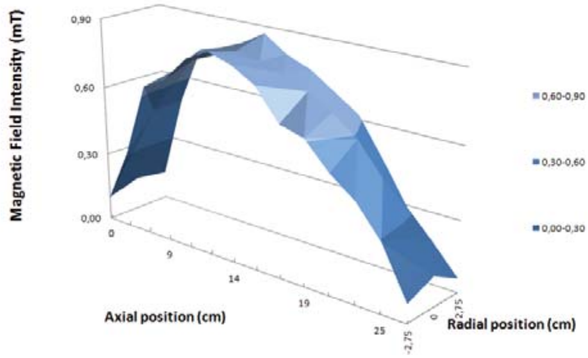

Fig. 7: Magnetic field inside the solenoid @ 4 kA.

Conclusions

We have realized magnetic field pulse with the main duration of 2 μs, 320 mT at 24 kV power supply. The pulse waveform was a damped sinusoid for a duration of 20 μs. At the maximum voltage of 50 kV we can get a magnetic field of 0.7 T of the same duration.

References

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