

Study of the Rogowski coil response in a plasma focus device

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Abstract. In plasma physics is very important understand the behaviour and amplitude of high intensity currents. The high intensity current pulses are measured by resistive and inductive sensors. Coil configurations are employed in the same form as inductive sensors. Rogowski coil is a representative example; that coil consists of a toroidal-shaped winding. In this work we built a Rogowski coil. The coil operation was realized in a plasma focus device. The results show a good performance. We also used the coil to measure the current and voltage changes with respect to time, during the normal operation of the plasma focus device. The maximum value of the current (348kA) was obtained. As a complementary work, we analysed the results by changing the central electrode of the device (needle electrode, gap electrode and plane electrode). It founds that the pinch time is independent of the configuration of the central electrode.

1. –Introduction

In power system applications as well as in other scientific fields, it is necessary to determine the characteristics of high intensity currents. High current pulses have been studied in lightning, electric arcs, and in plasma physics experiments. The current amplitude can vary from several few hundred amperes to kilo – amperes, in a few nanoseconds [1, 2].

These current pulses in plasma physics experiments are measured by resistive and inductive sensors. Unlike resistive sensors, inductive transducers are a non-intrusive measurement and provide good insulation between the circuit under test and measuring equipment. Different types of configurations of magnet coils can be used as inductive sensors.

A representative example of such sensors is a Rogowski coil. Walter Rogowski (1881 - 1947), best known for his research in electrical engineering, electro-technology, telecommunications and electronics primarily physical. In 1912 proposed the use of Rogowski coil, with toroidal shaped for polling the current changes with respect to time.

There are several forms to generate plasma in the laboratory, discharges in gases, and plasmas by magnetic confinement, inertial confinement plasmas, among others. However, the magnetic confinement systems can be classified into two groups:

- Equilibrium conditions, where the plasma pressure is balanced by external magnetic fields. Usually these systems are also characterized by using closed or quasi-closed geometry of the device: Tokamak, Stellarator, magnetic mirrors, etc. [3, 4].



• Non-equilibrium condition, where the plasma is accelerated by its own magnetic forces generated by the same link and self-confined, the geometry is opened in these devices: Z- Pinch, θ -Pinch Plasma Focus, etc. [5, 6].

The magnetic confinement consists in generating electrical pulses in a gaseous medium, producing plasma, without allowing inhomogeneity between the center and the walls of the device.

Rogowski coils are employed to measure the electrical currents of the system [7]. The principal objective of this work, it is build a Rogowski coil to measurement the current variations (dI/dt) in a pulsed discharge device. It is why in this section will explain the Rogowski coil and the pulsed discharge device briefly. The Rogowski coil (RC) consists in a helical winding around a toroidal-shaped, a representative form of this coil is shows in Figure 1 [8 – 15]. His principal operation is based in the measurement of the current induced by the magnetic field produced by the device. In that case, the total induced voltage is given by:

$$V_{coil} = -\mu_0 AN \frac{dI}{dt} \quad (1)$$

The equation (1) represents the relationship between the current variation (dI/dt) and the total potential difference induced (V_{coil}) in the coil, where A is the coil cross section, N is the turns number and μ_0 is the magnetic permeability.

In general, it can be said that the magnetic field variation produced by the current flowing through the coil conductor induces a voltage proportional to the change of the current with respect to time. Being proportional with the mutual inductance (M), then:

$$V_{coil} = -M \frac{dI}{dt} \quad (2)$$

Where:

$$M = \mu_0 AN \quad (3)$$

Interest in devices capable of generating high voltage and current in a very short time, of the order of nanoseconds, they have been grown considerably recently. Then, for that purpose several machines have been designed and constructed. In particular, pulsed discharges are formed to generate high voltage and current, specifically in this work we use a plasma focus device [16, 17]. In that device the variations of high voltage and current are critical, hence the use of a Rogowski coil for measuring the current variation can be done [18].

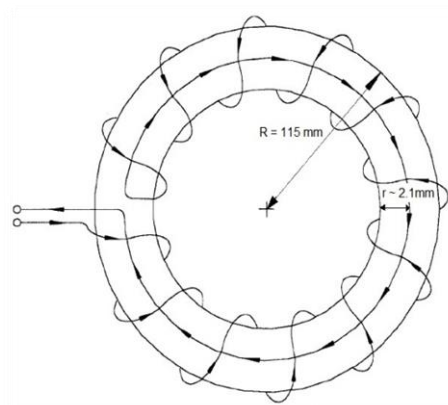


Figure 1. Dimensions of the Rogowski coil.

II. - Experimental Setup

This work was performed using a small plasma focus device (PFD) [16]; its capacity is 5kJ of energy at 38 kV. The device has an oxygen-free copper anode, with 40 mm long, and 50 mm diameter. The coaxial cathode is formed by ten copper rods arranged in a squirrel cage configuration at a radius of 50 mm. The insulator is an annular *Pyrex*® tube located at the base of the anode, Figure 2. Throughout the present work the plasma focus was operated in its neutron optimised regime, corresponding to a 2.75 torr of deuterium gas pressure.

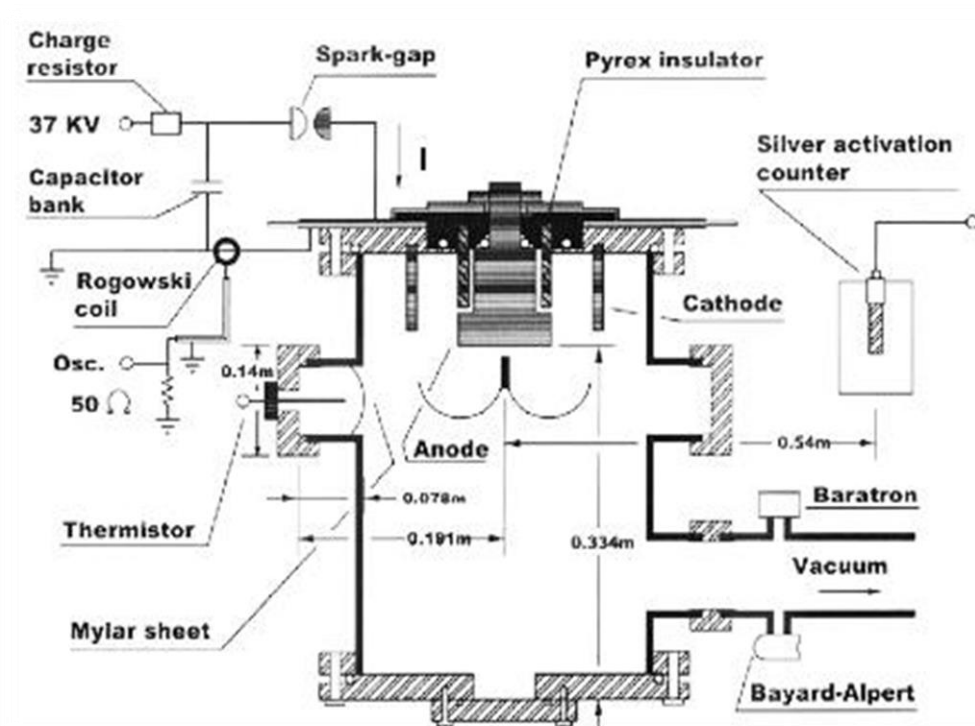


Figure 2. Pulsed Discharge device experimental setup [16].

The Rogowski coil [9 - 12] consists of a winding of 95 turns, toroidal-shaped of 21 cm in diameter and 4.2 mm internal diameter. Then, the mutual inductance provided by the Rogowski coil is:

$$M = \frac{\mu_0}{2\pi r} N^2 A = 317.6 \text{ nH} \quad (4)$$

It is noteworthy that the coil was connected to an oscilloscope for recording the signal. Figure 1 shows the dimensions of the coil built.

III. –Results

Typical Rogowski coil signals during normal operation are shown in Figure 3.

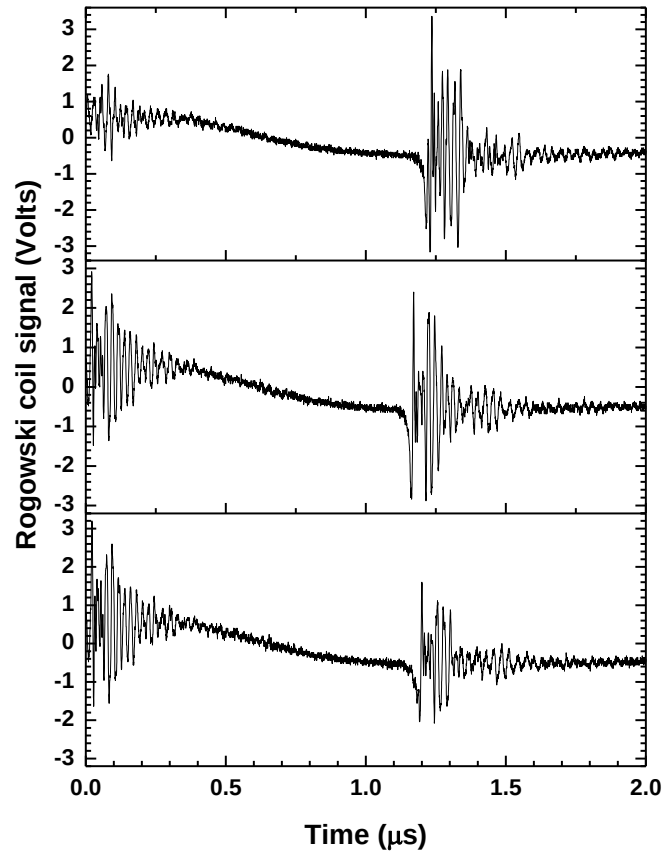


Figure 3. Rogowski coil signals during normal operation.

In a period time of 1.16 μs for pulse, it produced 35.2 ns of pinch time. Taking these values, the current was obtained by:

$$I(t) = I_0 \sin(\omega t) \approx (348 \pm 35) \text{ kA} \quad (5)$$

Different configurations of the central electrode were performed (Figure 4): with gap, planar electrodes and needle-shaped electrodes. The change in the pinch time with these configurations will be measure in each case.

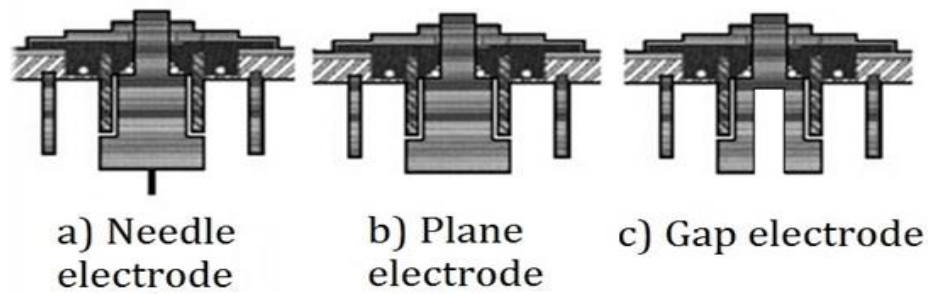


Figure 4.Central electrodes arranged on the PFD.

The Rogowski coil response produced in each configuration is displays in Figure 5. It can be that the pinch time is approximately the same for the three configurations. That implies that the pinch time does not depend on configuration of the central electrode.

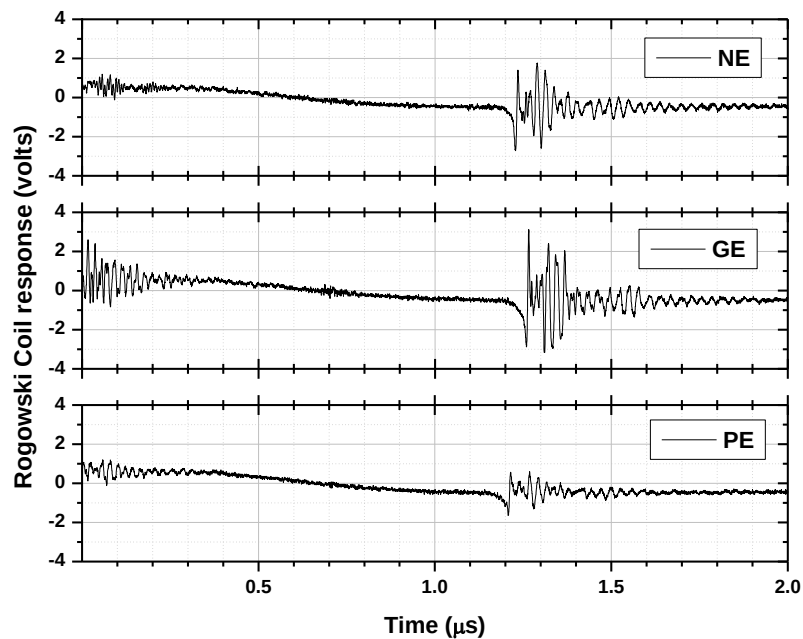


Figure 5. Rogowski Response. NE - Needle electrode, GE – Gap electrode and PE - Plane electrode.

Individual results for each configuration are shown in Figures 6, 7 and 8.

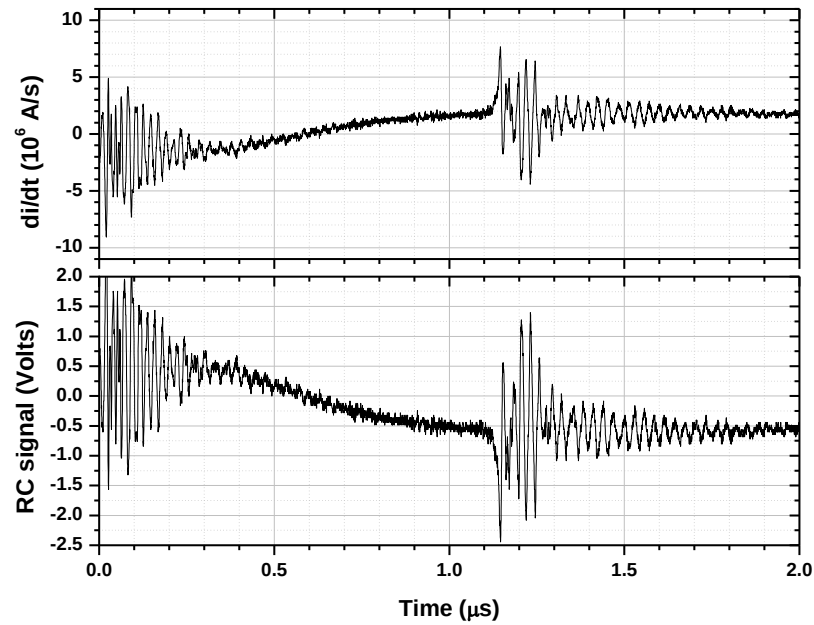


Figure 6. Rogowski coil signals using Needle electrode.

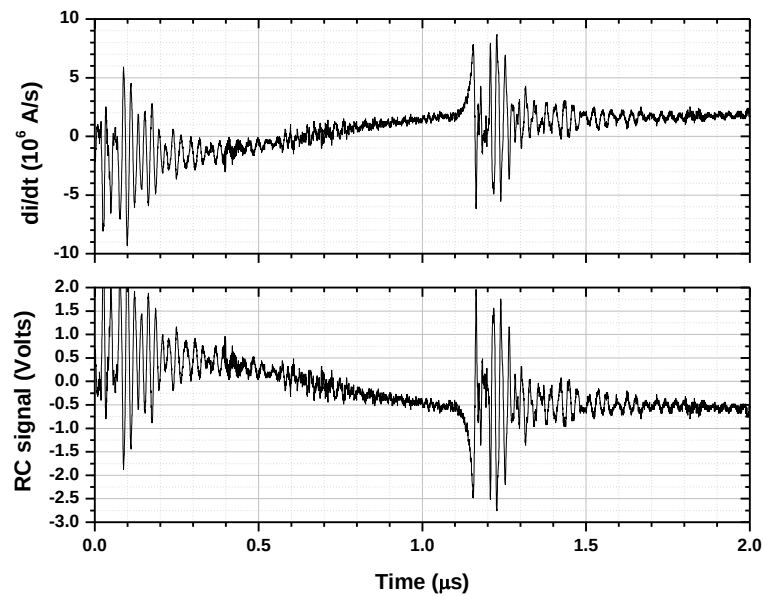


Figure 7. Rogowski coil signals using Gap electrode.

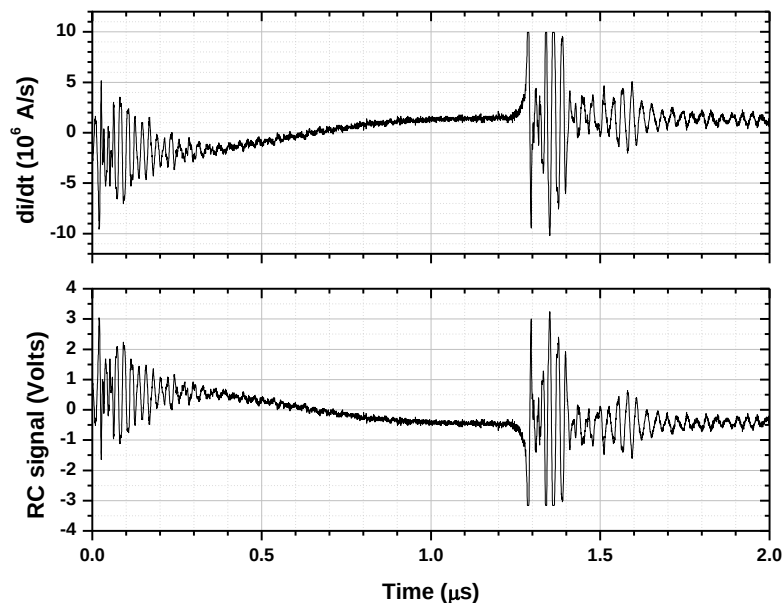


Figure 8. Rogowski coil signals using Plane electrode.

From Figures 6, 7, and 8, it observes that the maximum values of $de \, dI/dt$ are between 5×10^6 and 10×10^6 A/s, in a pinch time of approximately 37 ns. The pinch time is approximately the same for the three types of electrodes studied in this work (see Figures 5, 6, 7 and 8), which is consistent with existing theories [19, 20, 21]. That pinch time depends on the dimensions of electrodes and not from the configuration of the central electrode.

These changes in the configurations of the central electrode are present in the final stage (compression) and its subsequent evolution. For example, in PE configuration the hard x-rays are the radiation main production; in GE configuration, the ions and electrons become more important and in NE configuration, the production of neutrons and soft x-rays generation emerge as the principal source of emission. These results verified that the changes in the central electrode configuration do not modify or change the evolution of the current sheet, only modifies the compression stage. Likewise the current calculated for each case shown. It known that in plasma focus, the signal changes from shot to shot.

IV. -Conclusions

The conclusions of this work are:

- A Rogowski coil was built.
- The Rogowski coil operation in short circuit testing was proof.
- Maximum values of current variation (dI/dt) were found in the order of 10^6 A/s.
- Time pinch were approximately of 37 ns.
- The pinch time is independent of the configuration of the central electrode.
- The maximum value of the pinch current was (348 ± 35) kA.
- The Rogowski coil is a very good instrument to measure the current variation in pulsed devices.

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