NOISE-RESISTANT AND MECHANICALLY STRONG ROGOWSKI COILS USED TO MEASURE PARAMETERS OF HIGH-CURRENT PULSES WITH NANOSECOND FRONT

A.I.Gerasimov

All-Russia Scientific Research Institute of Experimental Physics

Pr. Mira, 37, Nizhni Novgorod region, Sarov, 607188, RUSSIA

E-mail: gerasimov@expd.vniief.ru

There are presented the characteristics of two versions of Rogowski coils with single- or multi-layer coil wound with a screened wire and with the toroidal core made of metal.

PACS: 29.27.-a

As a rule, in high-power electrophysical facilities it is required to measure parameters of pulsed currents (pulse shape, current amplitude, length of a pulse, front and trailing edge) from several kA up to several MA and with duration from units of ns to ms. As primary sensors the induction sensors (IS) are used most frequently. IS are installed in the annular slots of reverse hollow tube current guides so that they do not overhang the limits of the inner surface of current guides and do not decrease here the electric strength between coaxial conductors. This also protects sensors from electrical breakdown on them from high-voltage inner conductor, and, thus, protects the desired signal from interference.

However, when measuring currents I of hundreds of kA the drop of voltage L_n dI/dt on the slot inductance L_n approaches the value of ~100 kV and higher [1] what can initiate a breakdown on IS, form the way for flowing of a part of reverse high current through IS and distort the signal. Thus, at high currents I slots are made with minimal L_n, and sensors - with the smallest cross-section that diminishes their mechanical strength. It should be noted that in the course of operation together with common mechanical loads sensors are affected by pressure from the magnetic field $p=H^2/8\pi$ equaling, for example, ~1 MPa at I = 1 MA.

As a rule, the IS rigidity is formed by its core, polysterene or plexiglass, most frequently used as cores, are fragile materials that leads to a number of problems (at small cross-section of cores), especially those of large diameter (>500 mm). A framework made of thin sheet polyethylene is not firm enough, and, what is important, it "leaks" under mechanical loading.

Below presented are the data on two variants of interference-resistant and mechanically strong modernized Rogowski coils (RC) developed for measurement of currents of 10...2000 kA amplitude and 10...100 ns duration. They possess the small cross-section and, thus, are placed in narrow and shallow ring slots, operate in a self-integrating mode as the most interference resistant and most precisely transmitting the form of the measured current pulse, possess autonomous shields allowing to calibrate independently RC in the amplitude sensitivity and transient characteristic. Besides, the shield decreases capacitive couplings of RC with other conductors.

To measure the currents, it is expedient to wind the Rogowski coils with a pitch between turns [2]. However, at the outer diameter of RC >300 mm and small cross-section of dielectric toroidal core it possesses a small rigidity and strength. In the course of RC operation this can lead to a change of the pitch, and therefore to local changes of coil characteristic resistance ρ with regard to the shield which is its reverse current guide. Inhomogeneous ρ can excite parasitic high-frequency oscillations in the shield cavity; adding to the main signal, they will distort it [3]. That is why there was developed an original RC where the change of winding pitch did not affect the value ρ [4].

On toroidal frame 1 made of dielectric (Fig.1,a) a coil is wound by coaxial cable 2; each turn of the outer conductor 3 (braiding) is implemented with break 4 over the surface of solid cable dielectric 6. Outer conductor 3 serves as a shield for inner conductor 5.

All adjacent shields are subsequently electrically connected with each other without closing any break 4. Such a connector is annular conductor 7, soldered, for example, only to the beginnings (Fig.1,b) or only to the ends of all braiding turns (more than two conductors 7 can be used).The beginning of the first turn of conductor 5 is connected directly along the face of dielectric 6 by conductor 8 with beginning of its shield 3. The end of conductor 5 of the last turn is connected with load resistor 9 placed in electrode 10 which is coaxial to it and connected to the end of the shield of the last turn. A signal from resistor 9 is transmitted by cable 11 to recorder. Fig.1,c shows a variant of resistor connection. Here conductor 5 is put through the central hole in the in the isolating resistor case [5].

Thus, in RC toroidal coil conductor 5 and coaxial to it outer braiding 3, forming a shield of a number (according to the number of coil turns) of sections connected in parallel, are fixed through solid insulation over the whole coil length (except breaks 4), adjacent turns of conductor 5 are almost completely shielded from each other. Therefore, when producing or operating RC, local changes of winding pitch and deformation of core 1 do not affect the value of coil characteristic resistance ρ that remains constant over its whole length. This together with absence of the common hollow shield do not

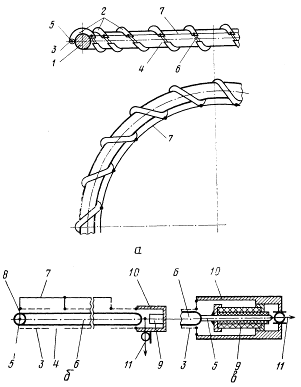

Fig.1. Device of RC with a coaxial cable coil (a), sweep of coil turns and their shields (b) and a variant of load resistor connection (c). Dashed lines - shields (braiding) of turns

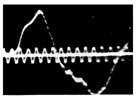

Fig.2. Signals from RC at measurement of current with 510 kA amplitude of the first half-wave. Marks – 100 MHz

provide conditions for excitation of parasitic electric oscillations and raises the accuracy of measurements of amplitude and time parameters of pulse current. Casual presence of liquid media with different values of dielectric and magnetic constants in RC, submersion of RC (partial or complete) in such media also does not change its electric characteristics.

Coaxial property of conductors 3 and 5 significantly lowers interference from constituent of magnetic flux of measured current which is parallel to the central axis of the coils. Each section of the braiding 3 can have its own outer insulation (it is not presented in fig.1) as well as the whole coil can be fully covered by film or other insulation. The absence of the common bulky RC shield decreases the dimensions of the coils and the drop of voltage on the inductance of annular slot in the reverse current guide, what decreases a probability of breakdown to the coil in this place. The coils can be made as a multilayer one, for there is no capacitive coupling between adjacent layers. This allows enlargement of electric length (delay time) of the coils and its inductance (time constant), as well as sectionalizing of the coil in order to determine the current position.

There were produced and employed RC of the type described with a diameter of pass-through hole from 100 to 1700 mm meant for currents registering up to 1600 kA, with front and duration over the base equaling, correspondingly, ≥3 and 20…80 ns. Shielded conductors with polytetrafluorethylene insulation turned out to be convenient for coils, for example, a conductor МГТФЭ - 0.12 ТУ16 - 505.185 - 71 with 1.5 mm outer diameter over the braiding and inner conductor diameter ~0.5 mm. The width of break in each braiding turn was ~1 mm what was sufficient for electric strength between the end and beginning of turns of adjacent shields. For the typical turn length ~50 mm the interturn capacitance of inner conductors is reduced by ~50 times as compared to capacitance of common RC.

Outside the coil was wound by several layers of polyethylene film. Resistors ОМЛТ, С2-10-2 or УНУ-Ш, were employed, moreover, according to fig.1,b the wire leads were removed and holes were drilled over the cap faces [5].Several RC were implemented with two- and three-layer as well as four-section coils; breaks in the layers braids were located one in front of each other.

Coils of the diameter >300 mm were certified by rise time τ using coils as distributed energy storages, preliminary charged up to 1 kV and switched on the coils load by a miniature spark gap with solid insulation [6]; as a rule, τ was equal to the value <1 ns. RC sensitivity was determined experimentally and usually was $10^{-2}...10^{-3}$ V/A.

Fig.2 shows a form of a signal from one of RC with a frame outer diameter equaling 1180 mm.

Further analysis has shown that when measuring currents of duration <100 ns one can decrease the core cross-section and, thus, the total RC cross-section accompanied by a simultaneous rise of mechanical strength through implementation of the core of metal [7].

The influence of short-circuit loop in the cross-section of such a core is insufficient at measurement of current of tens nanoseconds duration and shorter. The magnetic field formed by measured current is centered near the core surface due to the effect of extrusion of magnetic flux from the area of closed turn circuit.

Fig.3 presents RC device [8]. On toroidal core 1 made of alloy D16 the coil 2 is wound with МГТФ - 0.12 conductor. Resistor 3 of УНУ - Ш type with resistive layers on face surfaces and with metallized outer 4 and inner 5 cylindrical surfaces is tightly put into the core hole. The end 6 of the coil conductor is soldered to lead 5 and its second lead 7 is connected to the core near the hole. In order to fix turns there are slots 8 in the core.

The signal from resistor 3 is transmitted along the cable (it is not shown in fig.3), whose central conductor enters lead 5 as a socket, and the braiding is connected to the core of resistor. On the cross-section A-A is also given a variant of RC with resistor of С2-10-2 type insulated with bush 9; wire lead 10 is connected to core 2. In fig.3,a the largest side of rectangular cross-section of core 1 is parallel to the common axis of device with measured current. At 0.5 mm thickness of insulation between the conductor and the core a decrease of amplitude of signal on the RC output is ~10% and can be compensated by increase of load resistor rating. The use of the core as a reverse Rogowski coils current guide turns out to be convenient. Together with Rogowski coils this current guide forms a line with distributed parameters, i.e. the core serves as an external shield. That is why the external shield may be not applied in the event that the total RC cross-section as well as dimensions of annular slot in the conductor are to be reduced what means to reduce thickness of wall of this conductor and its outer diameter. Moreover, the shield is not necessary, provided that the electric breakdown to the coil from the central conductor with measured current is absent, there would be no breakdown to the coil from the walls of the slot as well as charged beam particles would not come to the coil. In common cases a shield for RC is preferable. The shield allows one to calibrate RC outside the working device and then install RC into the slot without change of RC characteristics. One may adjoin the shield to the conductor with a slot at one point, and more expedient - to the place of load resistor connection to the core.

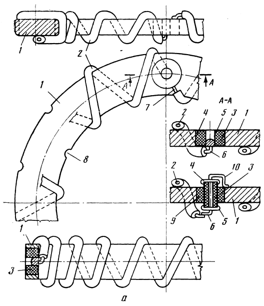

Fig.3. RC circuit with metal core. a - variant of washer resistor location in the hole of rectangular core when its largest side is parallel to the common axis of the device with measured current

The rise time τ of transfer characteristic of RC with diameters > 300 mm was determined experimentally, as it was described above. The value τ depends greatly on inductance of resistor and a method of connection of a signal transmitting cable to it; in RC data inductance is minimal. That is why, as a rule, τ ~ 1 ns. The constant of time of integration of RC is > 1 μs. Sensitivity of RC is 10^{-2}-10^{-3} V/A.

The majority of the used RC have external shields with azimuthal gap, electrically connected to the core near the load resistor. The shield additionally reduces the wave resistance ρ of the coil. However, the influence of ρ on the amplitude of voltage U of signal on resistor R<<ρ is small in the self-integrating mode [9]:

$$U \approx IR\rho[w(R+\rho)]^{-1},$$

where I - measured current, w - a number of coil turns. Several sensors were made with coils cable winding, as well as with sectionalized coils to control the position of electron beam current.

Fig.4 presents the oscillograms of signals from RC.

Employment of RC with metal coils facilitates their production, especially, at diameters >500 mm, increases mechanical strength of RC, reduces cross-section and outer dimensions, increases the precision of measurements and stability of RC electrical characteristics.

RC of both types were applied both in the self- integrating mode and in the differentiating mode, at production, experimental study and test of units of high-power linear induction electron accelerator LIA-30 (40 MeV, 100 kA, 25 ns) with water-insulated radial lines in inductors [10].

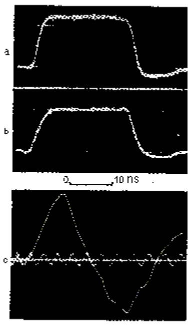

Fig.4. Calibration current pulse (a) and corresponding signal from RC (b) possessing a core with 1200 mm outer diameter and 3·16 mm² cross-section made of aluminium alloy as well as a signal from RC when measuring current with the first half-wave amplitude of 590 kA (c). Marks - 100 MHz

REFERENCES

1. S.A.Ekdahl // *RSI*. 1980, v.51, №12, p.1649-1651.
2. D.G.Pellinen, M.S.Di Capua, S.E.Sampayan et al. // *RSI*.1980, v.51, №11, p.1535-1540.
3. J.M.Anderson // *RSI*. 1971, v.42, №7, p.915-926.
4. A.I.Gerasimov, E.G.Dubinov // *Prib. Tekh. Eksp.* 1988, №3, p.93-95 (in Russian).
5. A.I.Gerasimov, E.G.Dubinov // Prib. Tekh. Eksp. 1983. №3. p.110-112(in Russian).
6. A.I.Gerasimov, E.G.Dubinov // *Prib. Tekh. Eksp.*1983, №2, p.139-141 (in Russian).
7. A.I.Gerasimov Inventor’s Certificate № 1213854 // *Byull. Izobret*., 1986, №46, p.284 (in Russian).
8. A.I.Gerasimov // *Prib. Tekh. Eksp*. 1991, №1, p.150-152 (in Russian).
9. V.Nassisi, A.Luches // *RSI*. 1979, v.50, №7, p.900-902.
10. A.I.Pavlovski, V.S Bossamykin, A.I.Gerasimov et al. // *Prib. Tekh. Eksp*.1986, №2, p.13-25.

ПОМЕХОУСТОЙЧИВЫЕ И МЕХАНИЧЕСКИ ПРОЧНЫЕ ПОЯСА РОГОВСКОГО ДЛЯ ИЗМЕРЕНИЯ ПАРАМЕТРОВ СИЛЬНОТОЧНЫХ ИМПУЛЬСОВ С НАНОСЕКУНДНЫМ ФРОНТОМ

А.И. Герасимов

Приведены характеристики двух вариантов поясов Роговского с одно- или многослойной катушкой, намотанной экранированным проводом, и с тороидальным сердечником из металла.

ПЕРЕШКОДОСТІЙКІ І МЕХАНІЧНО МІЦНІ ПОЯСИ РОГОВСЬКОГО ДЛЯ ВИМІРУ ПАРАМЕТРІВ ПОТУЖНОСТРУМОВИХ ІМПУЛЬСІВ З НАНОСЕКУНДНИМ ФРОНТОМ

А.І. Герасимов

Приведено характеристики двох варіантів поясів Роговського с одно- або багатошаровою котушкою, намотаною екранованим проводом, і з тороїдальним осердям з металу.