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N. S. Amaglobeli*, G. L. Glonti, L. N. Glonti,
V. M. Grebenjuk, N. S. Grigalashvili, A. G. Petrov

DUBNA–TBILISI MULTIWIRE **CSC** PROTOTYPE FOR THE **TOTEM** EXPERIMENT

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*High Energy Physics Institute of TSU, Tbilisi

Амаглобели Н. С. и др. E13-2004-49

Прототип МППК с катодным съемом информации для эксперимента ТОТЕМ

Разработана и создана пропорциональная камера с катодным съемом информации с малым содержанием вещества вдоль пучка вторичных частиц для эксперимента ТОТЕМ по исследованию дифракционного рассеяния на коллайдере LHC. Камера секторообразной формы имеет один чувствительный объем с анодными проволоками, расположенными перпендикулярно к радиусу, и катодами со стрипами, направленными дугообразно и под углом 30° к проволокам. Шесть таких камер вписываются в полный круг. Камера удовлетворяет всем основным требованиям эксперимента. В работе кратко описано достаточно простое и дешевое оригинальное оборудование и технологические методы, которые могут быть применены для массового производства камер, в том числе высокоточное склеивающее устройство СКЛУСТ, которое позволяет получать в лабораторных условиях плоскопараллельность ± 20 мкм, простой метод стабилизации натяжения проволок с ± 2–3 %-й точностью, тонкий обогреватель клея и др. Даются предложения для улучшения характеристик детектора. Данную разработку камеры, оборудования и технологии ее изготовления можно с успехом использовать и в других экспериментах, где могут потребоваться координатные детекторы с 2π-геометрией.

Работа выполнена в Лаборатории физики частиц ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2004

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Dubna–Tbilisi Multiwire CSC Prototype for the TOTEM Experiment

R&D and production of the multiwire proportional cathode strip chamber (CSC) prototype for the T1 telescope for the experiment on the measurement of the total cross section, elastic scattering and diffraction dissociation at the LHC (the TOTEM experiment) are described. The prototype has a 60° sector form, the plane of the anode wires is located at right angles to the radius, the cathode strips are arched and tilted 30° with respect to anode wires. It satisfies the main experimental requirements. Original specific methods and apparatus for manufacturing the chambers are briefly described. Among them is a gluing device SKLUST, which is intended for fabricating large area cathode planes of high accuracy (± 20 μm) in the laboratory conditions, as well as a simple method to achieve the correct (± 2–3%) wire tension during winding, a thin (0.3 mm) glue heater and others. Also some proposals are made for improvement of the chamber performances. The chamber R&D, methods and apparatus may be used in experiments where coordinate detectors with 2π geometry and a small quantity of matter are required.

The investigation has been performed at the Laboratory of Particle Physics, JINR.

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INTRODUCTION

The TOTEM experiment [1] is aimed at investigating the total cross section, elastic scattering and diffraction dissociation process in the proton–proton collision at the LHC energy. The experiment will be integrated with the CMS setup. Because for these measurements it is necessary to detect particles emitted in the very forward region, the experimental setup should consist of three parts for registration of the secondary particles at three pseudo-rapidity η areas. They are arranged on both sides of the collision point: the roman pots for the elastic and quasi-elastic (in diffraction dissociation) scattering registration and two forward inelastic detectors-telescopes T1 $(3.7 \leqslant \eta \leqslant 4.7)$ and T2 $(5 \leqslant \eta \leqslant 6.5)$ for measurement of the inelastic rates including events of diffractive type with full azimuthal acceptance (see Fig. 1, *a*). These two telescopes are placed symmetrically about the crossing point, each side including five 2π surfaces. Schematically their arrangement is shown in Fig. 1, *b*. Figure 2, *a* shows six 60° sectors for arrangement in each sensitive coordinate surface, which are intented for six chambers.

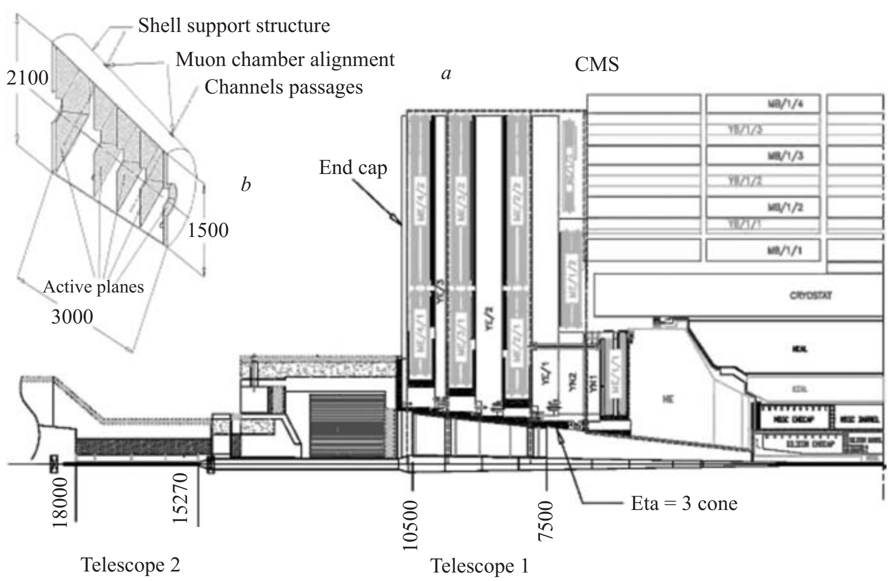

Fig. 1. *a*) The CMS/TOTEM layout and the position of the inelastic detectors-telescopes T1 and T2. (The Roman pots are placed in front along the beam at a distance of about 200 m from the interaction point and are therefore not shown in this figure.) *b*) The T1 chambers arrangement in the CMS end-cap cone

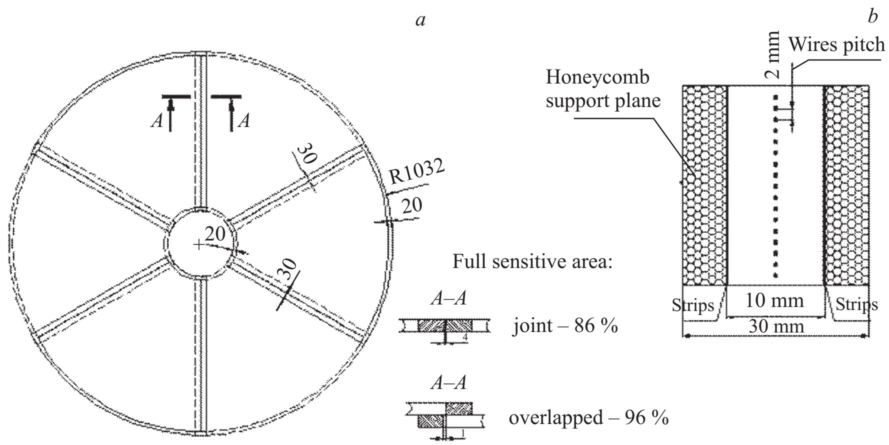

Fig. 2. *a*) The view of one plane with six sectors for T1 chambers. *b*) The chamber schematic view [2]

The proportional chamber with cathode strips in the capacity of the coordinate detector was chosen for T1 telescope [2]. A cathode strip chamber (CSC) is a multiwire proportional chamber with cathode strip readout [3]. As is known, the ratio of charges induced on several adjacent cathode strips by the passage of an ionizing particle through the wire chamber can give precise coordinate. This is possible by measuring the center of gravity of the pulses induced in cathode strips [4]. The accuracy required for the experiment ~ 0.5 mm is relatively easily realized for cathode readout. The CSCs can operate in conditions of high magnetic fields and high background rates.

Here we describe the CSC prototype for T1 telescope only. The prototype satisfies the main experimental requirements. Original specific methods and apparatus for chambers manufacturing are briefly stated, and some proposals for improvement of the chamber performance are expounded.

The chamber R&D, methods and apparatus may be used in experiments where coordinate detectors with 2π geometry and a small quantity of matter are required.

1. THE RESULTS OF THE TOTEM CSC PROTOTYPE R&D AND PRODUCTION

Each separate surface of the TOTEM T1 telescope includes six chambers with the $60°$-sector shape (see Fig. 2, *a*). They have one sensitive volume with three coordinate planes (one anode with wires and two stripped cathodes). This volume is formed by two Honey-Comb panels with glued cathode surfaces, the anode frame (the anode PCB glued to its backing) and spacing frame (see Fig. 2, *b*).

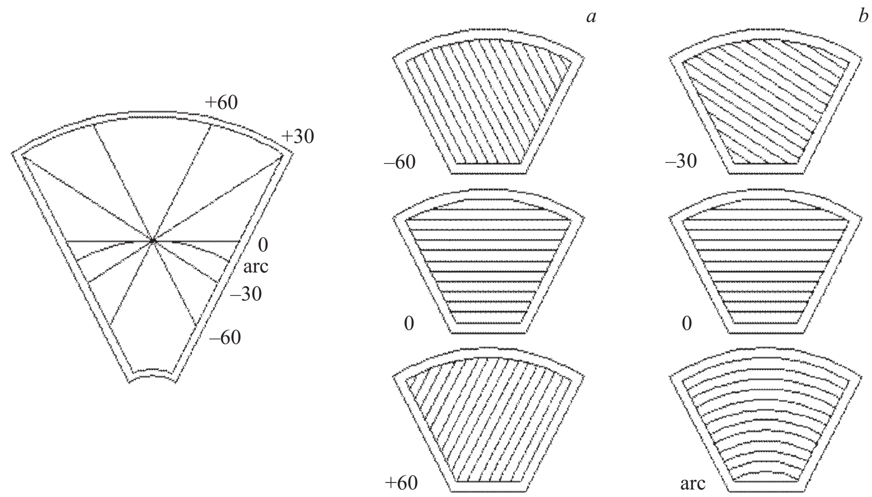

Fig. 3. *a*) Configuration of the wires and strips from [1]. *b*) The directions or shapes for wires and strips chosen in this work

Thus it is obvious that two cathode panels with anode and spacing frames are the basic mechanical parts of the chambers.

In [2] the trapezoidal chamber shape and three directions intercrossing at 60° for wires and strips were proposed as shown in Fig. 3, *a*. The hits occupancy distribution for 0° wires and for ±60° strips is shown in Fig. 4 [5]. For 0° the hits on the wires are allocated uniformly enough, but for ±60° the difference is very essential. The large strips are overloaded and the short ones are not practically loaded. We considered other directions and shapes of strips — arched and tilted 30° with respect to the wires, which are shown in Fig. 3, *b*. From various possibilities these (arc and 30°) were chosen as more perspective, taking into account the geometrical and experimental reasons, such as «direct» measurement of θ and relatively uniform distribution of the hits rates on the strips. In our case, hits occupancy will be the same for wires and arched strips, see Fig. 4 (0°), and for 30° strips the occupancy will be essentially closer to the wires one than for 60° strips.

Besides, during the design we were governed by the following reasoning:

1. To increase the chamber useful surface by the use of the full segment area.

2. To decrease chamber substance (especially the thickness of bars).

3. To satisfy other requirements of the experiment [2].

4. To make the prototype as simpler as possible for future mass production.

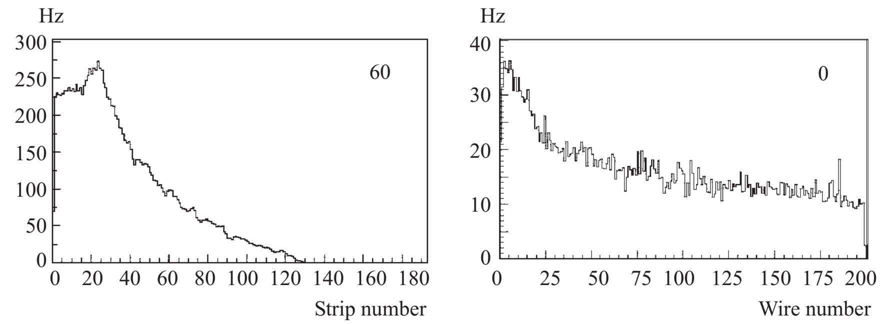

Fig. 4. T1 occupancy for wires at 0° and for strips at 60° relative to wires [5]

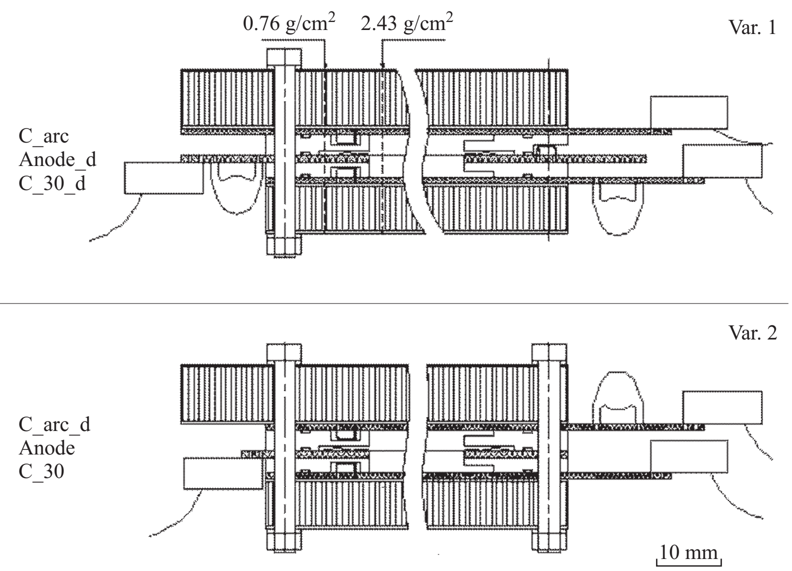

Fig. 5. The CSC prototype cross section

Two versions of the chamber were designed and manufactured following these conditions: one with high-voltage anode and the other with high-voltage cathode. They are shown in Fig. 6. The chamber with HV anode was completed with the wire winding and actuated. The chamber's main performances are presented in Table 1.

Two extreme holes were chosen for coordinate basic mark and chambers alignments on the large arc of the chamber. All anode and cathode readouts were designed for 3M-type connectors.

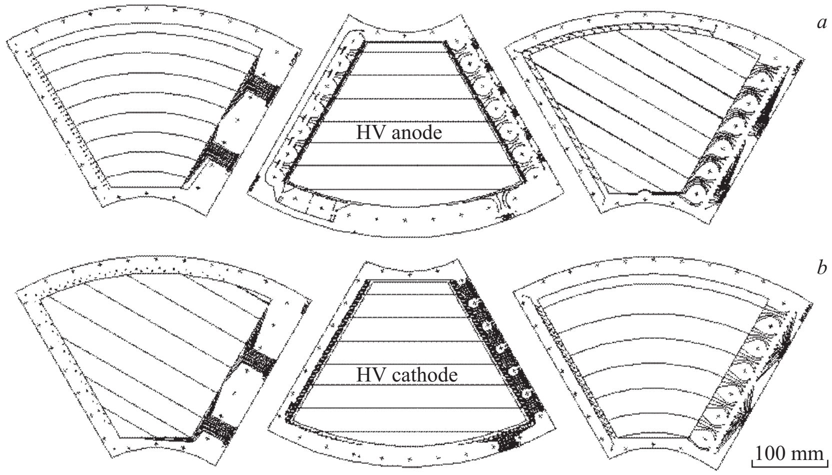

Fig. 6. The prototype's views: *a*) the version with HV anodes; *b*) the version with HV cathodes

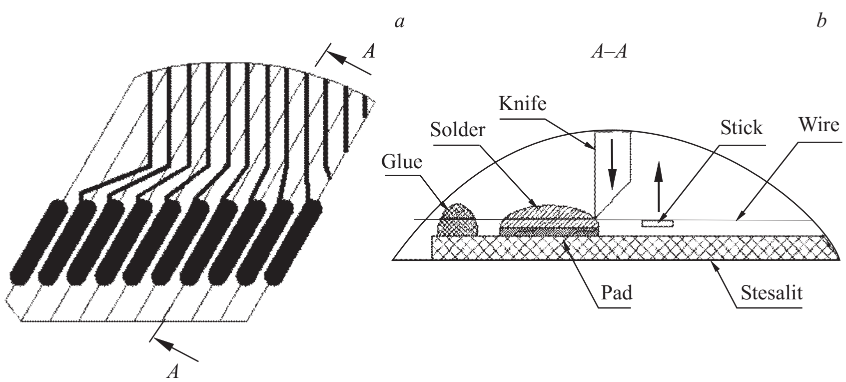

Fig. 7. *a*) Protected Readout pieces. *b*) Wire cutting mode

The pulse output pieces from wire pads were taken out in such a way as to protect them from casual wire cutting (see Fig. 7, *a*). As may be seen, the wires nowhere cross pieces near the wire cutting area. Such pieces, together with the use of the cutting method, shown in Fig. 7, *b*, completely exclude their damage.

Table 1. Some geometrical, mechanical and electrical performances of the prototype

No.	Performance	Tolerances	
		Designed	Actual
1.	Inner/outer radius Sector degree	137/408 mm 60°	
2.	112 anode wires	with 2 mm wire spacing	
3.	2×32 cathode strips	with arc and 60° relative to radius	
4.	Wire fixation and spacer bars thickness	(5±0.025) mm	(3 ± 0.020) mm
5.	Cathode plane unflatness	±0.030 mm	±0.020mm
6.	Wire-to-wire pitch	(2 ± 0.025) mm	
7.	Wire diameter	(0.025 ± 0.001) mm	
8.	Wire tension	(60 ± 3) g	$(60 \pm 2)\%$
9.	Panel thickness	(10 ± 0.1) mm	(20 ± 0.1) mm
10.	Absolute strip position including strip unstraightness	±0.05 mm	
11.	Groove width range	(0.3 ± 0.050) mm	
12.	Matter along the secondary particle beam: — near the bars — on the sensitive area		 2.5 g/cm^2 1.1 g/cm^2
13.	Leak current assembled chamber without wires		0 nA / 5.8 kV
14.	Leak current at air after wire winding		$\sim$ 20 nA / 3.1 kV
15.	Efficiency (by Sr^{90} and Ar80% + $CO_2$20% + isoprop. spirit $\sim$ 0.01%)		98% plateau at 2.7 kV length $\sim$ 150 V

Also, coordinate planes with chamber in joint or overlapped arrangement were considered, and useful areas of 86% and 96%, accordingly, were obtained (see Fig. 2, *a*).

For chamber testing there were used the Read-Out electronics (LIAF, Gatchina) with the following properties:

Sensibility	2 μA
Outlet pulse duration	$\sim$ 15 nsec
Channel variation by t°	0.1 μA/10°
by supply	0.1 μA/1%
Cross talk	40 dB,

and the chamber Read-Out system CROS with 16 word × 32 bit memory station, RML control unit RML CU and Serving module CROCAMAD.

In conclusion it must be noted that this prototype is almost identical to the T1 middle chamber near the small radius region. For the full-size prototype design it may be easily continued in the direction of the large-radius arc of the chamber. To do this, the anode and cathode read-out patterns should be repeated up to the large arc. Only near the large arc the anode parts design will be again necessary.

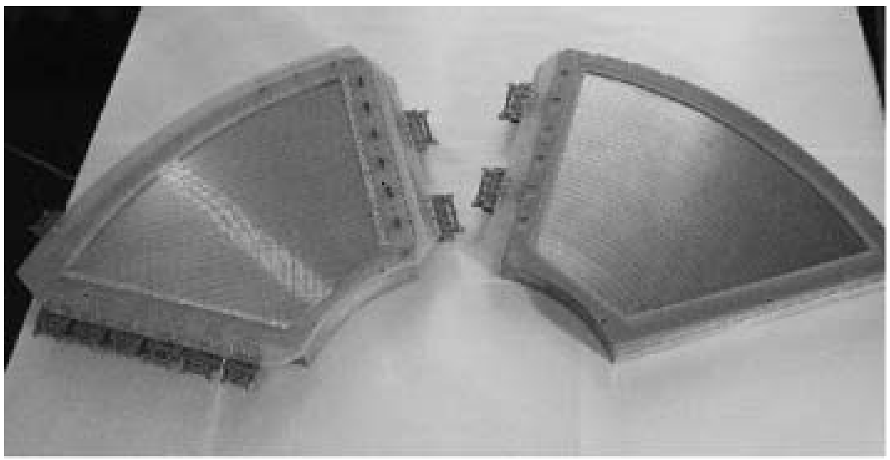

Fig. 8. Internal view of the manufactured T1 CSC prototype

2. SPECIFIC APPARATUS AND PRACTICE FOR CSC MANUFACTURING

1. The prototype cathode and anode patterns were made by PCB technology. But simultaneously for the full-scale chambers the large plotter for strips cutting was adapted by the CMS muon chambers manufacturing experience [6]. The plotter DGF which we used for this aim has the following performance data:

Working area	1189 × 884 mm
Basic step	0.010 mm
Dynamics accuracy of movement	0.030–0.050 mm
Static accuracy for achieving ultimate point	0.030 mm
Working condition	continuous.

It was added by the diamond cutting point and dust separator. The plotter was tested on the 1100-mm-long foiled glass-cloth sample for cathode strips cutting and to obtain good results (strips and groove have the accuracy ± 0.030 mm).

2. For anode bars and cathode surfaces gluing we used a precision gluing device SKLUST having the precision surfaces with vacuum clamping and spacers [7]. The device is designed for gluing high-precision plane or plane-parallel articles. Under **laboratory conditions** it is a simpler way to manufacture such articles, which makes it possible to obtain plane-parallel bars or large cathode surfaces to an accuracy of ± 0.020 mm (max. deviation) using **non-calibrated** foiled (or unfoiled) glass-cloth with a tolerance over the thickness of $\pm 0.15-0.20$ mm or worse. The working devices can produce articles from 300×400 to 2400×300 mm*. The SCLUST allows manufacturing high-accuracy articles without any technological operations except for gluing. That reduces the production cost. The device has good experience of use.

3. We always use the glue heating during chamber gluing. As is known, it reduces the hardening time and makes the gluing place stiffer. We used Araldit AW106/HW953U as glue. In inaccessible places we effectively apply the heater from the thin (~ 0.3 mm) copper glad glass-cloth in which selected current is passed. Such a heater is flexible enough and can be used practically everywhere. One of such heaters used for the chamber backing gluing is shown in Fig. 9.

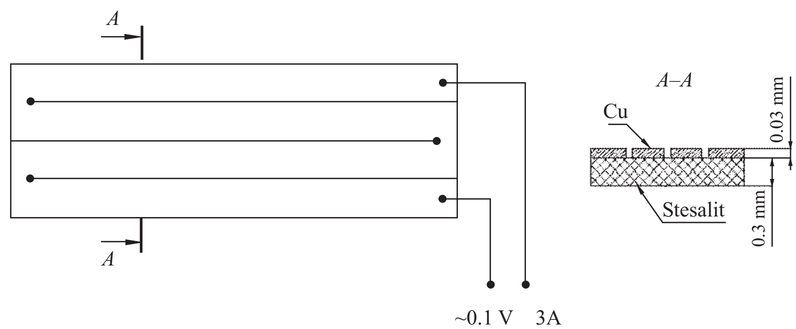

Fig. 9. Glue heater for chamber parts gluing

4. For the anode wire plane manufacturing, a rotating wire winding machine with simple damper setup, shown in Fig. 10, was used. Such a simple device without electronics permits one to obtain the $\pm 2-3\%$ wire tension. As is shown in the figure, between the wire tension motor and wire direction roller for laying wire on the winding frame, two rollers are added, from one of which a load of

*For the area 200×200 mm an accuracy of ± 0.005 mm (max. deviation) was reliably obtained.

weight equal to 2T (for this case 120 g) and chain with links weighing of order of wished accuracy (in our case about 1.0 g) are suspended*.

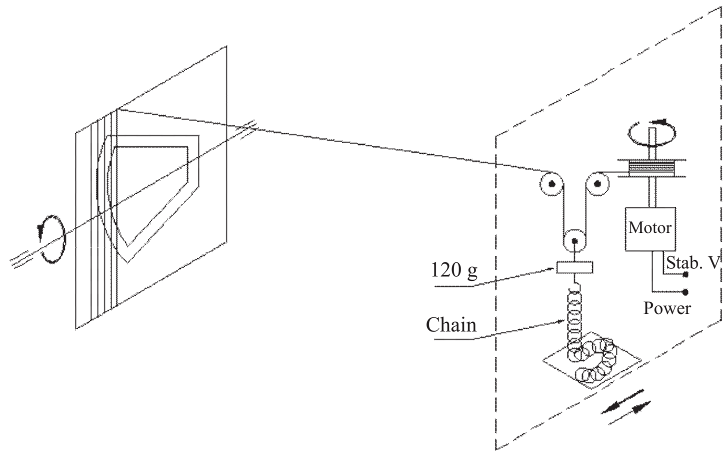

Fig. 10. Scheme of the rotating wire winding machine and the damper setup with chain

The damper works in such a way: where the tension has increased tendency the weight with chain is lifted and the load increases and where the tension is decreased the load decreases. By this means the quick tension change compensation occurs. Furthermore, such feedback very substantially decreases the wire cutoffs possibility during wire winding, which is especially important for very thin wires.

5. At the prototype manufacturing after mechanical parts completion without wire winding the chamber was tested by high-voltage leakage at 5.8 kV. It allows all possible defects to be beforehand revealed and clearly separated from the possible wire current leakage after wire winding.

Besides, some devices and modes suitable for the mass production of the chambers were developed:

- Device for the bars and Honey-Combs on arc and direct cutting by the diamond cutter;
- Device for the gluing by heating the Honey-Comb cathode panel's sides with earthling strips;

*This device, first described here, was also successfully used earlier for [8, 9].

- Semi-automatic glue cladding machine for the wire gluing for its fixing on the bars before soldering (see Fig. 11, *a*);
- Chamber parts washing gadget with $\sim 4\pi$ rotation possibility (see Fig. 11, *b*);
- HV unit for chamber electrical testing before and after wire winding;
- The chambers sealing by non-draining narrow sealant ∅0.3 mm (see Fig.12);
- Stand for testing the chamber by electronics.

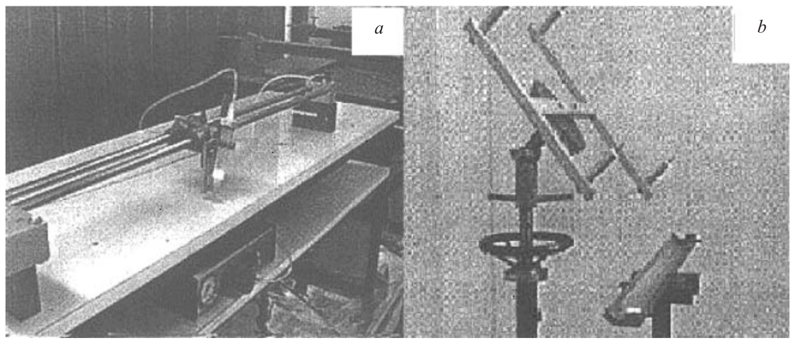

Fig. 11. *a*) The semi-automatic glue cladding machine. *b*) The 4π rotating chamber washing gadget

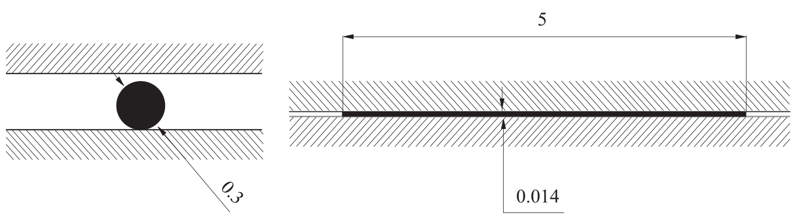

Fig. 12. The chambers sealing by non-draining narrow sealant ∅0.3 mm

3. PROPOSAL FOR IMPROVING THE CHAMBER PERFORMANCES

1. It is possible to reduce the substance along the beam by decreasing the anode and spacer frames thickness (2×5 mm $\rightarrow 2 \times 3$ mm). This will require increase of the manufacturing accuracy, which is quite possible using the SKLUST device.

2. The substance becomes smaller by about 20% if instead of five chamber rings three are used (Fig. 12). The first and last chambers may be made with two anode layers. Besides, in this case two anodes therefore load the middle cathode panel. It also favors reduction of materials, chamber planes, required quantity of chamber kinds, amount of chambers support, emergency chambers quantity, and therefore of cost.

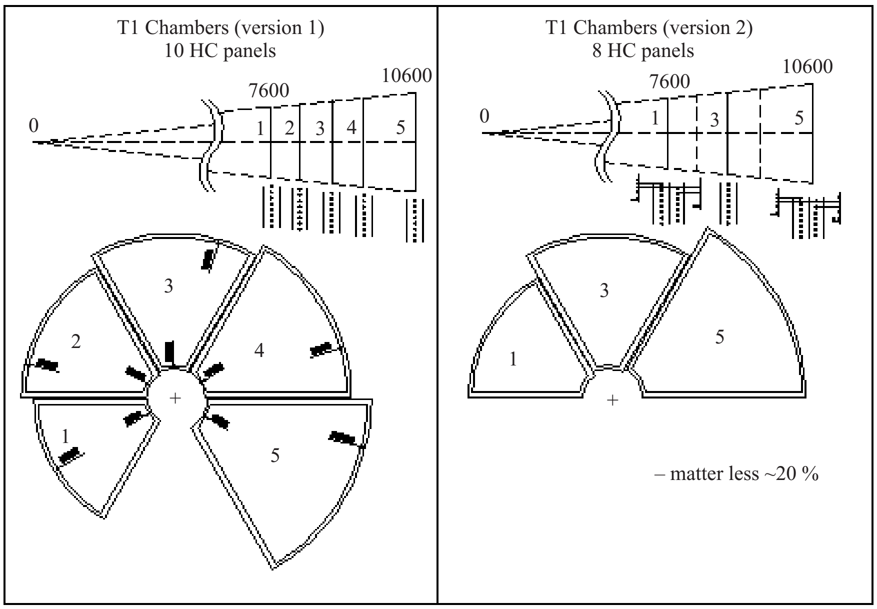

Fig. 13. Possible change in the T1 telescope scheme from five coordinate planes to three ones, with the quantity of coordinate planes being the same

3. When the anode wire tension is decreased with decreasing wire length to the chamber's narrow part, the full tension lowers. This makes the chamber more durable.

During the work the basic engineering was also considered and prepared for the chamber production (The EDR Project) by the following scheme:

Diagram of the production engineering;

Sequence of operations;

Work bays and equipment;

Quality assurance.

Finally, Fig. 14 presents preliminary results of the large CSC design with the radius 180/1020 mm. The directions of the wires and strips of two cathodes are shown in the figure.

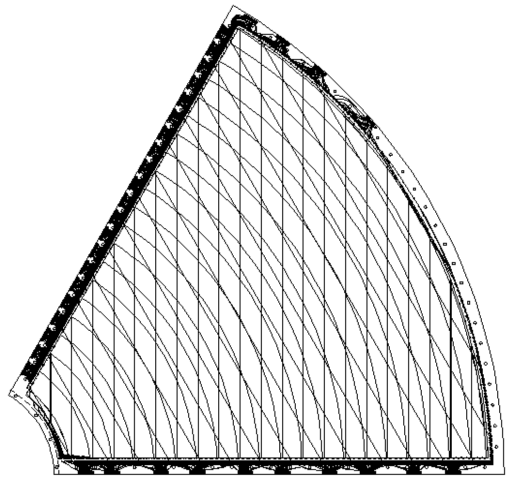

Fig. 14. The preliminary design of the large full-scale CSC. The anode and cathodes are projected on one plane

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Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@pds.jinr.ru
www.jinr.ru/publish/