CARBON-CARBON WINDOWS, INTENDED FOR EXTRACTION OF ELECTRON-AND PROTON BEAMS FROM ACCELERATORS INTO ATMOSPHERE

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On the basis of a carbon-carbon composite, coated with an anticorrosive coating, the authors have developed vacuum-tight windows, made of a material, resistant to the irradiation. These windows are intended for the extraction of high-power electron- and proton beams into the atmosphere. One uses them for disinfection of large volumes of the drinking water and its purification from toxic chemical compounds. The windows are also applied in the branch of the electron-nuclear power engineering, where the proton beam have an energy of 1 GeV and an average power of 30 MW must be injected into the reactor.

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As regards the realization of the radioactively technological processes, one deals with the problem of the beam extraction from the accelerator either into the atmosphere or into the reactor zone [1-5]. As a rule, the beams are extracted through thin metallic foils. The principal requirements to the window materials are the following:

1. Low losses of the beam energy.
2. High solidity and temperature stability.
3. High thermal conductivity.
4. High resistivety to the X-ray-and neutron irradiation.
5. High service durability.
6. Low-cost manufacture of the window of a prescribed geometry.

For the window production, one uses Be, Al, Ti and their alloys (mainly those of Ti [6]). Under the conditions of the air-cooling of one of the surfaces, the windows made of Ti are transparent to the electron beams of the current 0.64 A and the energy 1 MeV, i.e., the beams of the power 640 kW. However, this window has the form of a flat bar of the length 80 cm and the surface 64 cm^2. The structural behavior of the material, the admissible operating temperature and the maximum efficiency of the heat transfer from the window to its refrigerating medium prescribe the window sizes and configuration. In series of radiotechnologies, there exists a demand for the windows of large sizes. In particular, they are necessary in the branch of the water purification from microbiological and chemical contaminations with the help of the electron beam, where a high productivity is required (dozens of thousands of cubic meters of water per diem) [1-4]. This is conditioned by the fact that, because of the radiation safety, one must use the electron beams of the energy up to 6 MeV during the water processing. At the same time, the total track length of the electrons of such energies in the water does not exceed 3.5 cm [7,8] Therefore, processing of large volumes of water is possible only by enlarging the water surfaces under processing, i.e., by enlarging the extraction window sizes. Besides, the beam average power must be higher than 1 MW. The authors consider that it is expedient to use the windows of pyrocarbon or carbon-carbon composition materials (CCCM). A series of unique attractive properties are inherent in CCCM-such as high strength-to-weight ratios, which withstand the temperatures higher than 1000^0 C. In addition, the thermal conductivity increases with the heightening of the temperature. CCCM are highly resistant to the temperature cycling and inertial to the influence of a large number of chemical media. These materials are also highly resistant to X-rays and to the neutron radiation (their characteristics remains in the neutron fluence of $2 \cdot 10^{22}$ n/cm^2 [9-11]. Because of a small atomic weight of CCCM, the beam of charged particles, passing through it loses small amounts of energy. Therefore, the thickness of the extraction window made of CCCM can be of about several millimeters, whereas its surface can be rather large.

The usage of CCCM for the extraction windows is especially advantageous in the branch of the radiation- and high-temperature techniques, where one of the window sides is being washed with a liquid refrigerant. If the window surface is cooled with the running water, heavy-current beams of the average power from units up to dozens of MW can be extracted through it. This very fact makes the window application prospective for D&C of the electronuclear reactor (the power amplifier). This construction implies that the proton beam is to be injected into the active zone through the window, which is being washed with the liquid lead under the temperature 400…900^0C (the energy of the beam is 1GV, its current is 30 mA and the average power is 30MW) [5].

At the same time, in addition to such tempting characteristics, a series of drawbacks is inherent in CCCM. They are a low corrosion-resistance to oxidizers and a high porosity, which results in gas-permeability. As the authors have demonstrated, these defects can be eliminated with the help of protective tightening covers. In this case, CCCM would meet all requirements stipulated by the construction of the extraction windows. Gas impermeability of the material is achieved by siliconizing CCCM and their coating with high-temperature coatings. The elaborated methods of CCCM coating just slightly affect the energy losses of electrons, conditioned by their passage through the material.

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The experimental data available give grounds for the supposition that the extraction windows of large diameters (≥ 300 mm) should be made of CCCM.

In Fig.1, one can see changes in the beam distribution functions after the passage through the CCCM plate of the thickness 2 mm, sodden with silicon.

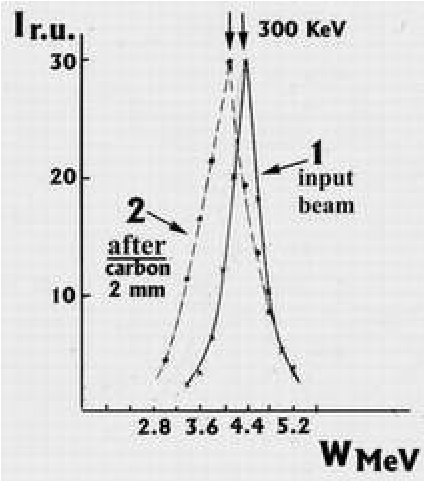

Fig.1. (1) the input beam; (2) the beam after the passage through the CCCM plate

These graphs indicate that the electron beam of the energy 4 MeV loses 300 keV of it due to the passage through the plate. These losses are much lower than those typical of the traditional materials, used for the extraction windows (Be, Al, Ti). The table below depicts the principal characteristics of the materials, used for the extraction windows. These data are taken from [9-11].

	Characteristics of the materials.					
	Be	Al	Ti	CCCM		W
ΔE MeV/cm	3.5 (e)	4.5 (e)	6.4 (e)	1.5 (e), 5.5 (p)*		32 (p)*
λ,W/(cm, 0C)	1.8	2	0.15	0.2	0.1	1.15
C ,J/(g 0C)	2.1	0.98	0.54	1.27	0.5	0.152
ρ, g/cm^3	1.85	2.7	4.5	1.2	1.5	19.29
T, ^{0}C	450	100	450	1100	20	1000

Electrons of the energy 1…5 MeV are marked with *(e)*; (p)* denotes protons of the energy 1 GeV.

Because of a high coefficient of the CCCM compressive strength, the extraction window made of this material must have the form of a bowl or cone. For such shapes, the compression load prevails.

The techniques elaborated in the NSC KPTI permit making the CCCM hemispheres of the radius 1m and thickness 0.2…1 cm (the bowl area is 6.24 m^2).

According to the calculations, the extraction windows of such sizes have a rather high margin of safety, which provides for highly efficient water purification with electron beams.

Fig.2 depicts a draft of the construction of a chamber for the water processing with the high-power heavy-current electron beam. The window for the electron extraction from the accelerator, made of CCCM, has the shape of a bowl. In the water, the total track length of an electron of the energy 5…10 MeV ranges within 3-6cm [7,8]. It is possible to irradiate the water volume (2.4-4.71)·10^2 m^3 with the beam of the mentioned energy if the beam is extracted through the hemispherical window of the radius 1m and the beam electrons are uniformly distributed all over the window surface. In this case, the beam power can be about 16 MW, the average electron current being up to 3.2 A the power emitted at the extraction window being about 700 kW.

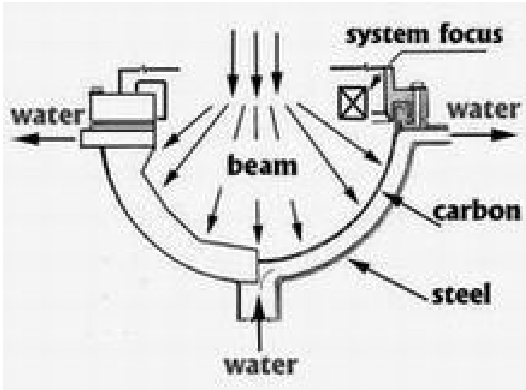

Fig .2

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The analysis given to the data concerning the application of CCCM indicates that the windows of CCCM with silicon coatings are also applicable in the construction of the power-amplifying reactor [5].

As it is supposed, the proton beam would be extracted from the reactor through the tungsten hemispherical window of the radius 10 cm and thickness 1.5…3 mm into the reactor area, where nuclear reactions are to be initiated in fissionable materials. The temperature near the window wall must be maintained at the level ~500^{0}C. According to the calculations, for this construction the margin of safety is ~2.7 under the temperature up to 1200^{0}C. The calculated maximum temperature in the CCCM window of the given construction is close to the values that provide the maximum strength factor of the material.

CONCLUSIONS

1. For the first time it is demonstrated that carbon-carbonic composition materials (CCCM) can be used for the making of large windows for the charged particle extraction from the accelerator. These windows are intended for the beams of high average power (dozens of kW-dozens of MW) and currents of some amperes.

2 A technique of the CCCM coating is developed. When applied to the extraction windows, it provides for their gas impermeability and corrosion stability. At the same time, the electron energy losses remain low (1.5 MeV/cm).

3 At the first place, the extraction windows of CCCM are prospective for the development of accelerating systems, intended for sterilization of large volumes of water (thousands of m^3 per diem).

Preservation of strength properties of the siliconized CCCM under high temperatures (100…1400^{0}C), insensitivity to radiation flows and their other specificities permit using this material for the development of new high-temperature techniques, unrealizable by other methods. In particular, this material seems to be prospective for a system of the ion beam extraction into the reactor area of the electronuclear reactor (the energy amplifier-a promising installation of a new type). In comparison with tungsten, CCCM is preferable as the substance for the extraction windows, being cheaper and easier in processing. Consequently, when one deals with large constructions, they are much more economic than the systems where tungsten is used. Besides, a high degree of the neutron radiation resistance permits replacing of the system of the ion beam extraction simultaneously with the nuclear fuel reboot (once in 5 years).

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REFERECES

1. E.A.Abromyan, G.D.Kulushov. Intense electron beams *// Fizika. Tekhnika. Promeneniye*. M.: "Ehnergy", 1984 (in Russian).
2. M.A.Tumanyan, D.A.Kauhansky. *Radiation sterilization*. M.: "Meditsina", 1974,
3. V.N.Shubin, Yu.I.Sharanin, Brusentsova et al. *Radiation disinfection of polluted water*. M.: "Ehnergoizdat", 1985 (in Russian).
4. C.Rubbia, J.A.Rubio, F.Carminati, N.Fietier, J. Galvez, C.Geles, Y.Kadi, R.Klapisch, P.Mandrillon, J.P.Revol, Ch. Roche // *Conceptual Design of a Fast Neutron Operated High Power Energy Amplifier. European Organization for Nuclear Research. CERN / AT / 95-44(ET)*. 1995.
5. V.L.Auslender, I.L.Chertok/ Extraction of the electron beam through the foil // *Prybory I Tekhnika Ehksperimenta.* 1998, №6, p. 99-103 (in Russian).
6. Handbuch der Physic, b 34/ Springer-Verlag. Berlin, 1958.
7. Tables of physical quantities. Reference book/ Ed. by I.K.Kikoin. M.: "Atomizdat" (in Russian).
8. V.S.Chirkin. *Thermal physical properties of materials.* M.: "Fizmatgiz", 1959 (in Russian).
9. V.S.Ostrovsky. *Porosity and permeability of carbon materials*. M.: Mintsevetmet USSR, 1971, p.89 (in Russian).
10. V.A.Gurin, V.F.Zelensky. Gas-phase methods of producing the carbonic and carbon-carbon materials//*Problemy Atomnoj Nauki i Tekhniki (76).* 1999, № 4, p.13-31.

УГЛЕРОДНЫЕ ОКНА ВЫВОДА ЭЛЕКТРОННЫХ И ПРОТОННЫХ ПУЧКОВ ИЗ УСКОРИТЕЛЕЙ В АТМОСФЕРУ

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Разработаны вакуумплотные окна вывода из радиационно-стойкого конструкционного материала на основе углерод-углеродного композита с антикоррозийным покрытием для вывода в атмосферу мощных электронных и протонных пучков. Такие окна необходимы для вывода из ускорителя электронных пучков, при решении задачи обеззараживания и очистки воды в больших объемах. Эти же окна могут быть использованы для электроядерной энергетики, ввода протонного пучка в реактор мощностью 30 МВт. Прочностные характеристики полусферического окна из углеродного материала отвечают предъявляемым требованиям к окну реактора.

ВУГЛЕЦЕВІ ВІКНА ВИВОДУ ЕЛЕКТРОННИХ І ПРОТОННИХ ПУЧКІВ ІЗ ПРИСКОРЮВАЧІВ В АТМОСФЕРУ

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Створені вакуумщільні вікна виводу із радіаціно-стійкого конструкційного матеріалу на основі вуглецьвуглецевого композиту з антикорозійним покриттям для виводу в атмосферу потужних електронних і протонних пучків. Такі вікна потрібні для прискорювача електронних пучків, при вирішенні проблеми обеззараження і очистки води в великих об'ємах. Ці вікна можуть бути використані для елктроядерної енергетики, вводу протонного пучка в реактор. потужністю 30 МВт. Міцністні характеристики полусферичного вікна із вуглецевого матеріалу відповідають потребам, що пред'являються до вікна реактора