THE PRESENT STATE OF ACTIVITIES ON DEVELOPMENT OF THE SUPERCONDUCTING RF-STRUCTURES FOR ELECTRON ACCELERATORS

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The works on development of 10-cm wavelength superconducting RF-structures (SRF) for electron accelerators have been conducted at Efremov Institute since 1969. The main stages of our researches were directly connected with the development of home - made high purity niobium (Nb) production technology. At early stages our industry produced only Nb ingots and rolled sheets of commercial purity with the impurities content not more than 1% . Therefore superconducting 2.8 GHz E_{01}-cavities made by method of half-cells forming from this Nb sheet with the subsequent welding offered a residual Q-factor not more than $1\ 10^7$. Need for a Nb of higher purity made us to adress to GIREDMET in 1971 where the works on galvanic deposition of Nb coatings free of refractory metals were at the very beginning. In addition to higher Nb purity this method for SRF-structures production permitted to avoid an electron beam welding. However, the Q-factor of already produced superconducting E_{01}-cavities and RF-structure prototype (Fig.1) did not exceed $Q_0<5\ 10^7$ what could be attributed to high degree of impurities concentration. To overcome this discouraging factor an induction installation SVIP-1 was constructed for annealing of Nb-products at temperatures up to 1850 ^oC in vacuum not higher than $1\ 10^{-7}$ torr. But neither vacuum annealing no multiple chemical polishing resulted in a cardinal increase of a Q-factor. It was this metal that later became the initial raw

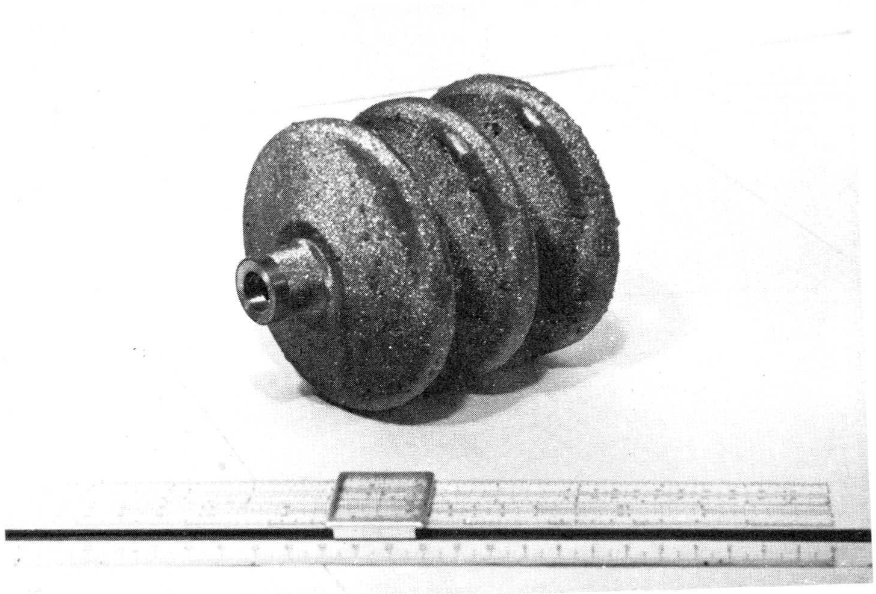

Fig.1 Prototype of a capture section produced by galvanoplastic method.

material for melting of Nb ingots of ultrahigh purity.

Parallel to above method the alternative method of SRF-structures production by turning the details from the NB-ingots (RRR = = 5-10) was studied. In 1976 an electron beam was accelerated up to 300 keV in the superconducting capture section ($\beta_{\varphi} = 0.7$, 3 cells) at $Q = 2\ 10^{8}$ and E= 3-4 MV/m. [1] Our investigations and KfK-CERN activities on development of the superconducting RF-separator have shown the importance of proper RF-power coupler location to achieve high accelerating fields. To eliminate higher RF-field components in the coupler we suggested and tested its construction placed on the drift tube in the region of weak RF-fields (Fig.2).

In early eighties production of high purity Nb ingots (99.99%, RRR = 200-1200) in GIREDMET was brought to the commercial level. By that time Efremov Institute succeeded in development and construction of special equipment for niobium treatment. In particular, the device JOK-EB6 for electron-beam welding of Nb products at U=25-30 kV with the beam current up to 200 mA in vacuum $1\ 10^{-7}$

torr was purchased, mounted and put into operation. The operating volume was o 600x800 mm. The getter pump with an arc titanium evaporator of about 2000 l/s capacity provided the background pessure in the UHV-furnace more than 1 10^{-9} torr.

Fig.2 Capture section made from casted Nb.

At Simferopol State University the works on chemical and electrochemical polishing of Nb structures working surfaces were performed. The effects of the different turning regimes on the surface roughness and depth of the damaged layer, its changes under different annealing conditions, polishing and electron beam welding, etc. were studied at Efremov Institute jointly with GIREDMET [2]. As a result Q = 2 10^{9} was achieved in the cavity N^{o} 12 (Fig.3) made of one of the first Nb ingots of NbR-0 grade (RRR = 950). NIIEFA and GIREDMET concentrated their efforts on development of Nb rolled sheets keeping the high quality of metal ingots. Q = $3^{9}10$ at E = 10-16 MV/m (limited due to electron emission) was achieved in the first superconducting E_{01}-cavity which half-cells were made from Nb sheet (RRR = 400) by lathe spinning.

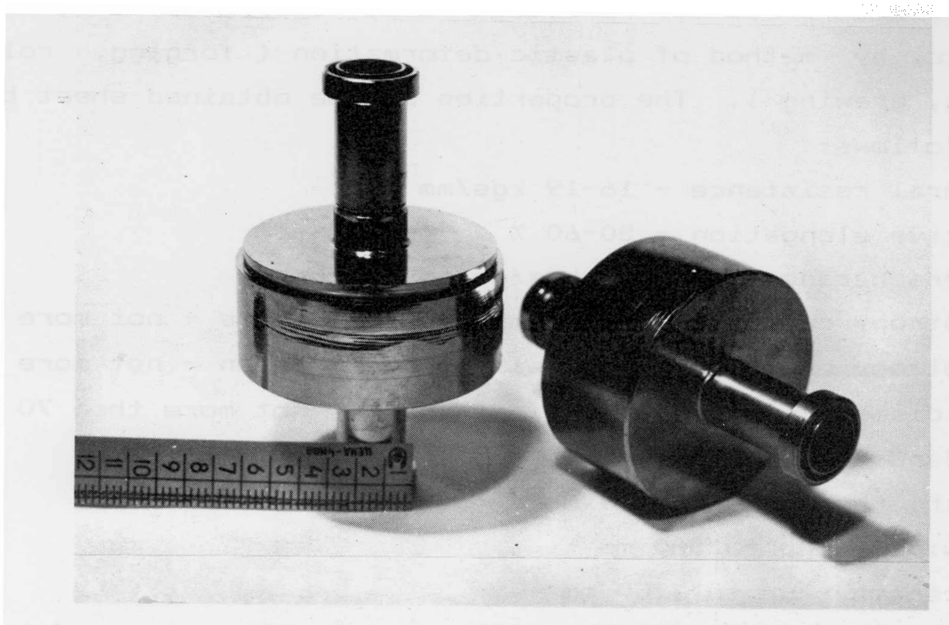

Fig.3 E_{01}-cavities:N^{o} 14 (left) made from monocrystalline and N^{o} 12 (right) from polycrystalline Nb.

Thus our joint many-years efforts have been a success: the production technology of high purity Nb ignots and sheets with the total impurities content from 0.01 to 0.001 % ppm has been developed and brought to the commercial level at GIREDMET experimental plants. The produced ingots are 100-150 mm in diameter, 200-600 mm in length with RRR = 200-1500. The content of the main impurities in Nb ingots is given in Table 1.

Table 1

Casted Nb grade	RRR	Content of impurities, ppm					
		O	C	N	W	Mo	Ta
NbR-00	1200	5	0.5-4	1-4	1-2	1-2	1-5
NbR-0	800-1200	5-10	0.5-5	1-5	1-5	1-5	5-20
NbR-1	500-800	10	2-5	2-5	5-50	1-5	10-30
NbR-2	200-500	10-20	2-5	2-5	<100	<100	10-50

Note: content of other impurity elements in Nb ingots is less than 0.05 ppm.

These ingots are used for manufacturing of different semi-finished products: sheets, rods, tubes, plates, disks, wire, etc. by method of plastic deformation (forging, rolling, pressing, drawing). The properties of the obtained sheet blanks are as follows:

- temporal resistance - 16-19 kgs/mm
- relative elongation - 50-60 %
- Vickers hardness - 35-45 kgs/mm
- anisotropy coefficient of temporal resistance - not more 3%
- anisotropy coefficient of relative elongation - not more 20%
- mean diameter of recrystallized grain - not more then 70 μm
- standard sheet dimensions:

    thickness - 1.5 - 4 mm

    width - up to 500 mm

    length - up to 1200 mm

Chemical composition and RRR of Nb sheets correspond to the parameters of the initial ingots. Besides, Nb sheets providing RRR in cavities at the level of 1000-1500 after vacuum annealing with a deoxidizing agent can be produced. The rods 10-90 mm in diameter, tubes 6-30 mm and 60-120 mm in diameter and disks up to 20 kg in weight with the characteristics similar to the above could also be produced if necessary.

The higher quality of rolled sheets made necessary optimization of RF structure half-cells fabrication method. Our experiments have shown that under spinning metal is appreciably thinner, the deformation is highly non-uniform, the working surface is of ripple character and there exists a high probability of impurities in Nb. Deep-drawing of half-cells by means of rigid moving die also offers some significant disadvantages, such as formation of cracks and scratches on the surface and foreign inclusions in a metal. Proceeding from above-said the method of half-cells forming from Nb sheets by means of an elastic die in a steel matrix is under study now. This method was used to form more than 20 half-cells (Fig.4) from the different batches of sheets with the Vickers hardness from 40 to 130 kg/mm produced in GIREDMET using the various schemes of rolling. Part of sheets was electrochemically polished at

Simferopol State University, the surface roughness up to 10-12 was achieved. Any clearly pronounced degradation of surface quality or any forein inclusions after forming have not been observed. We should note that the applied force under forming was practically constant and did not depend on the original sheet hardness.

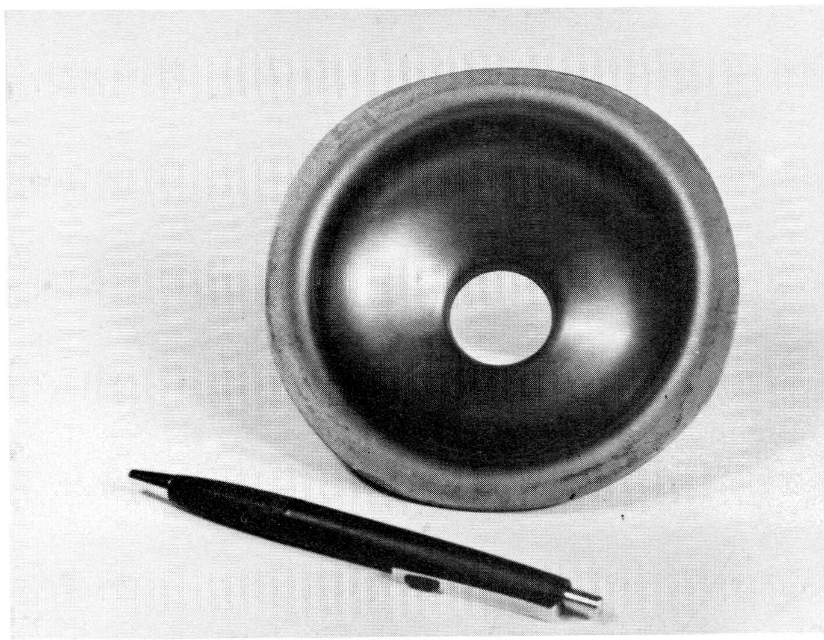

Fig.4 Half-cell of the RF-structure after deep-drawing.

The mechanical characteristic of Nb-sheet make it possible to combine in one die all the necessary operations from stretching to flanging what reduces the cost of needed tooling manufacturing. The surface obtained in the stage of rolling can be easily transformed into the working one with minimum necessary operations and transitions. The proper treatment results in no micro-cracking and other defects even in more stressed parts of the working surface, inciuding one-dimensional, leading to higher surface resistance. Intergrained blocks and patchiness are hardly observable on the surface, and if any, they are easily smoothed at consequent chemical or electrochemical polishing. After locks fabrication the half-cells were assembled in pairs and their proper frequencies were measured. The maximum frequency shift for the whole lot of the cells was about 5 MHz. If the cells are made from one batch of metal, it is lower by a factor of 2-3. It shoul be emphasized that even working with one batch of rolled products, the forming operations sequence and regimes were widely varied, i.e. the above frequency shift would be less after the forming process optimization.

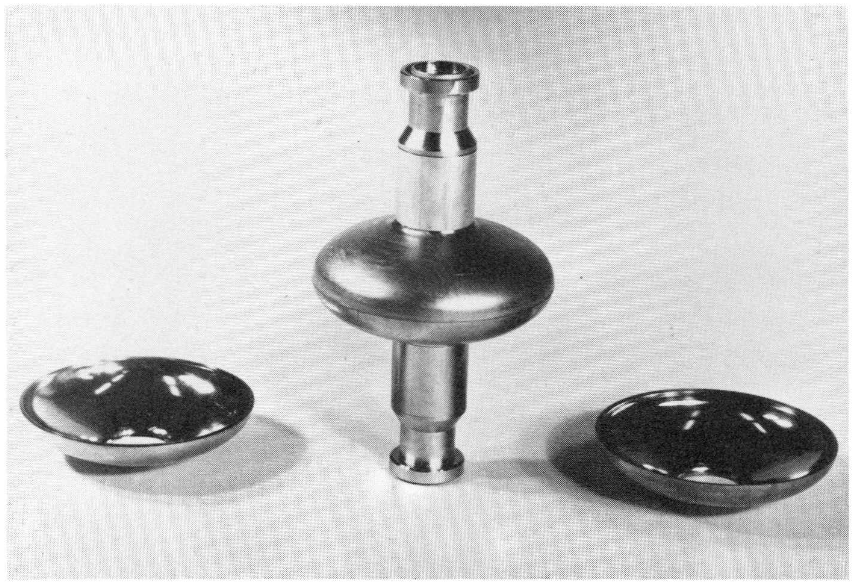

Fig.5 E_{01}-cavity and two half-cells after locks fabrication.

Two E_{01}-cavities (Fig.5) and accelerating SRF-structure (β_{φ}=1, 2.8 GHz, π-mode, 6 cells) are assembled from the fabricated half-cells and prepared for an electron beam welding. The results of RF-structure shape and geometrical dimensions optimization were shown in [3]. In addition to measured proper frequencies the cells differ in the working surface quality as they are made of various metal batches and polishing was applied in different stages of fabrication. An accelerating RF-structure (Fig.6) is planned to be tuned to the operating frequency by local pressing of the walls in the maximum diameter region and by electrochemical polishing of individual cells. Appropriate fixtures and devices are fabricated and tested both on the copper cavities and at tuning the second superconducting capture section to the uniform distribution of an accelerating field. Fig.7 shows the device for electrochemical polishing of the working surface of individual cells or an accelerating structure, as a whole. Depending on the metal removal and

Fig.6 Superconducting RF-structure made of Nb sheet prior to welding.

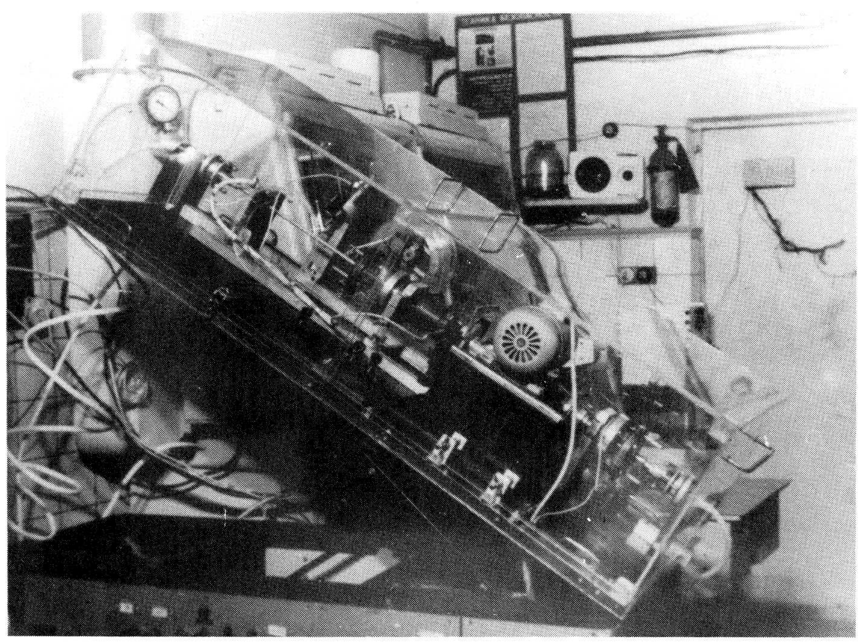

Fig.7 Instalation for electro-chemical polishing of RF-structures and E_{01}-cavities from niobium.

treatment conditions, different acid solutions on the base of $HF-SO_3-R-H_2O$ (where R is an organic component) are used. Polishing and lustring treatment is made, depending, first of all, on the voltage in the range of 3-9 V. An electrolyte temperature was maintained in the limits of 24-27 ^oC in all the regimes.

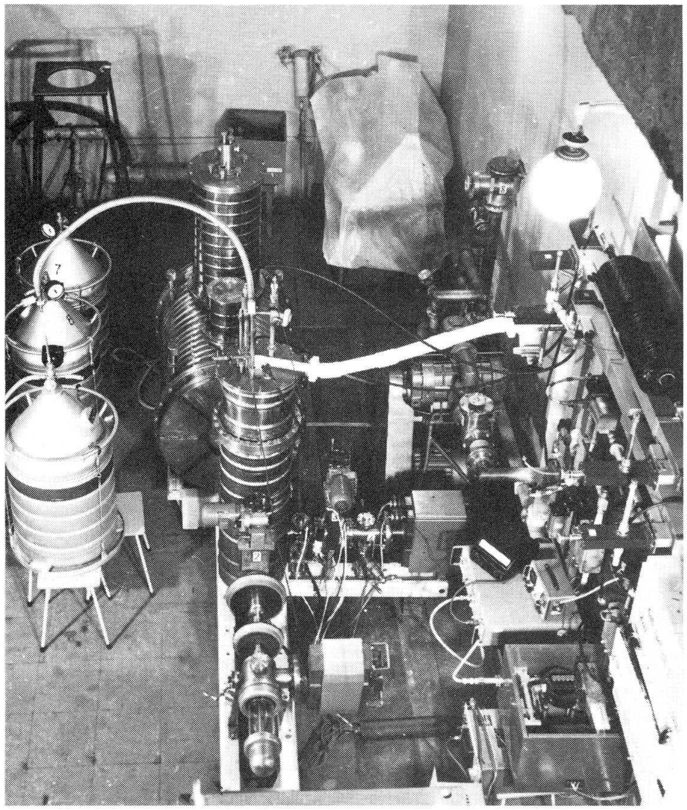

Fig.8 Experimental pilot superconducting linear accelerator.

The treatment process is controlled with a personal computer by means of periodic measurements of electrolyte conductivity and temperature, residual and anode currents, cell voltage. It is revealed that the regimes of electrochemical polishing of the Nb sheets from different batches (i.e. fabricated according to the different rolling schemes) greatly differ. Chemical polishing of E_{01}-cavities and capture sections is performed either in $HF-HNO_3$ solution at initial temperature -30^oC or in $HF-H_2SO_4-HNO_3$-$R-H_2O$ solution at T = 40-50 ^oC.

The RF-structure being developed is planned to be subjected to the complex tests under accelerated electron beam on the test facility being a pilot superconducting linear accelerator (Fig.8). Continious electron beam with current up to 500 μA at

80 keV is injected by gun into a copper grouping cavity and accelerated up to about 400 keV in a superconducting capture section. In the background of Fig.8 one can see a cryostat of the main accelerating RF-structure. In the neighbouring hall home-made commercial cryogenical helium installation KGU-150/4,5 is being assembled. It will be used as a source of cold gas for a low-temperature device at T = 1.85 K located in one of the cryostat throats. Helium bath of the cryostat contains two 6-cell RF-structures.The second superconducting RF-structures is planned to be made from Nb sheet of one and the same bath with RRR > 1000.

References:

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