SUPERCONDUCTING VERTICAL ACCELERATOR FOR APPLIED PURPOSES

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The electron superconducting 5 MeV continuous 10 mcA beam accelerator structure, composition and parameters are considered. Superconducting 14 cells section based on TESLA-shape structure with 646 mm length and vertical disposition in cryostat are used in accelerator. /1/

1. TOPOLOGICAL ACCELERATOR SCHEME.

The accelerator consists of traditional elements (injection, beam forming and transportation, vacuum, RF feeding, control systems). Besides there are elements caused by the presence of superconductivity: Nb/Cu accelerating cavity, vertical helium cryostat, RF chopper. Fig. 1 shows the accelerator topological scheme, the calculated parameters in table 1.

Table 1. Calculated accelerator parameters.

N	Parameter	Value
1	Electron maximum output energy MeV	5
2	20 grade bunch energy spread %	0.5
3	Injection energy keV	40
4	Accelerated particle current mcA	10
5	Working frequency f GHz	3
6	Accelerating structure length mm	646
7	Cavity cells number	14
8	Synchronous particle phase in the accelerating cavity grade	10
9	Accelerating rate MeV/m	7.3
10	Accelerating cavity maximum electrical field along the axis kV/cm	135.6
11	Accelerating cavity maximum electrical field on the superconducting inner surface kV/cm	300
12	RF power total losses in cavity cells W	
	quality factor $Q=1.0\times10^{10}$	1.4
	quality factor $Q=1.0\times10^{8}$	106

On Fig. 1. you can see the accelerator vertical part which is caused by the choice of vertical type of cryostat (10) which is stipulated by the purpose of accelerator.

The injector (1) generates continuous electron beam with 40 keV nominal energy and up to 2 mA beam current. Elements (2 ...8) create the preliminary beam forming system. The beam transportation from injector and its focusing in front of the chopper is realized by the special electron- optical system EOS-1 (2).

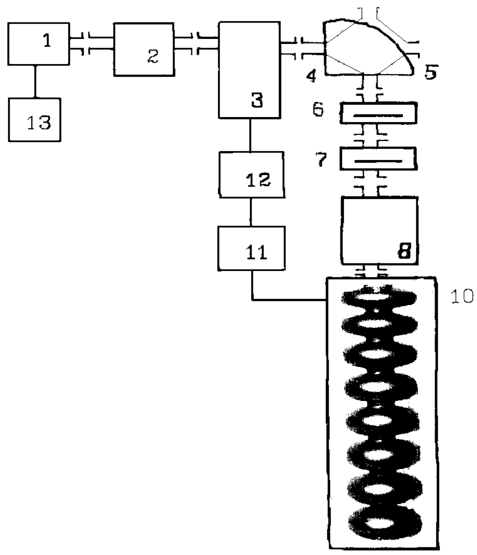

Fig. 1. The accelerator topological scheme.

After the chopper cavity the part of beam passed through the slot is 90 grades bends by the bending magnet (5) and drops onto the collimating slot (6). EOS2 system matches the beam emmittance to the accelerator beam channel transverse acceptance.

At the accelerator end there is a cryostat in vertical position (10) with the superconducting cavity (SCC) inside it (9). The accelerating and chopper cavities are electrically coupled through their feeding and phasing systems (11 - 12).

2. PRELIMINARY BEAM FORMING SYSTEM

Prismatic chopper cavity is excited on the H101 - wave. The lengths of walls are the same and equal to 76 mm. If W(inj)=40 keV, b=20 mm, beam divergence angle is 0.2 rad, loss power is 0.85kW and the electrical field in the cavity center is 20 kV/cm. The cavity quality factor with the chosen dimensions is 1.04×10^{4}. At the cavity output the beam fan-like diverges as a result of RF magnetic component influence.

The preliminary beam forming system parametrs ensuring the matching particle bunches to accelerator channel by transverse motion were determined by means of 40 keV electron transverse motion dynamic calculation at the beam forming section from injector to superconducting cavity. By this calculation the normalized emittance was taken to be equal to 2×π×mm.mrad. At the injector output (1 in Fig.1) the crossover has in its section the beam diameter equal to 1 mm and the beam divergency equal to 10 rad.

As the EOS1 and EOS2 electron optical systems the two identical single electrostatic lenses were chosen. In the EOS1 lens the beam is focused and enters into chopper cavity with the diameter nearly 1 mm. The EOS1 tubes diameter is 7 mm. The electrical potential of central lens electrode is 23.2 kV.

At the end of 60-mm drift space between chopper and the bending magnet front edge the beam along X-axis dimension reaches 13 mm. By the bending magnet calculations the version of 90 grade magnet with the pole dimensions 200 mm and the gap between them 25 mm was chosen. By calculation the magnetic field was supposed to be homogeneous and equal to 0.005 Tesla.

3. RF FEED SYSTEM.

This system ensures the creation and keeping the necessary level of coherent RF oscillation is superconducting cavity (SCC) and does the same in the “warm” chopper cavity. The main RF feed system parameters are presented in the table 2.

Table 2. Parameters of electron accelerator RF feed system.

N	Parameter	Value
1	Superconducting cavity (SCC) feed power W with nominal accelerating field level and total beam current: Quality factor Q=1.0×10^{10} Quality factor Q=1.0×10^{8}	 51.7 56
2	SCC beam current load W	0 ..50
3	Chopper power feed kW	1
4	Feed frequency GHz	3
5	Tolerable SCC and chopper RF field phase shift instability grade	5-10
6	Tolerable field amplitude unstability % chopper	5

The use of superconducting cavity makes untolerable the electrical break-downs arising in SCC. Hence the necessity of a fast operating field amplitude control system folows which might not permit the field amplitude increase higher than the defined level more then 5 % when sudden and important accelerator work changes happen to occur.

The additional requirements to RF feed system following from the necessity of this system commissioning and electron beam parameters regulation during accelerator operation lead to desire to have deep (to 100 %) and separate chopper and SCC amplitude regulation as well as the total (360 grades) changes of this fields phase differences.

The SCC linac RF feed system must ensure the wanted definite electromagnetic conditions in two accelerator systems, i.e. chopper and SCC so it is realized in two systems itself.

3.1 Functional scheme and the operation principle of the RF feed system of SCC

The SCC linac RF feed system is created on the base of autogenerator sceme where the accelerating cavity is the oscillation system main element defining frequency.

Functional scheme of this system is shown on Fig.2. Autooscillations arise in the contour consisting of RF element: SCC (1), directed couplers (2) and (4), RF amplifiers (3) and (7), phase shifter (5), attenuator (6) and ferrite circulator (8).

Thanks to the high level of quality factor SCC renders the strong stabilizing influence on the autooscillation frequency. The frequency stability tolerances here are ensured in a natural way if destabilizing effects on outer concerning SCC elements of autogenerator contour evoke the increase of phase shift to 0.4 radian.

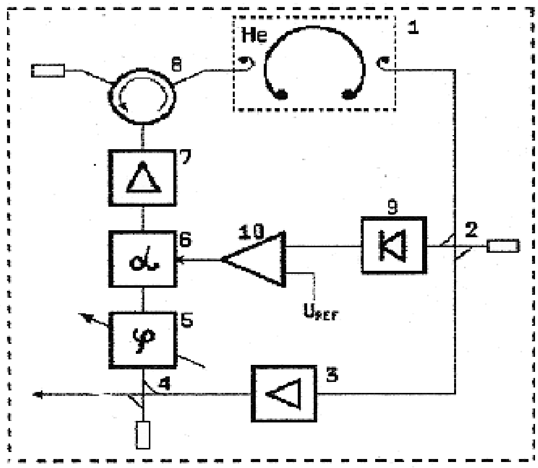

Fig. 2. The SCC RF feed subsystem functional scheme.

The part of oscillation energy produced by the autogenerator RF feed system is taken by the directed coupler (4) and then is used for the chopper synchronization. The synchro-signal phase is defined by the field which has been stabilized under the all factors influence. The main advantage of the proposed scheme is that it shows when there is an error in the synchronization phase signal but there is no always component arised by the SCC own frequency instability.

This advantage cancels the necessity of hard stabilization of the cavity temperature, the thermostat vapor pressure and other stabilization measures to compare with the use of independent high stability independently existing generator.

There is an important drawback of this feed system version based on the autogenerator with accelerating SCC in the backward couple chain. This system has extreme sensibility of the stable oscillation amplitude to the accelerating beam current. As a result of the beam turn off the extra energy is stored in the cavity and the field amplitude increases many times. If the generator backward couple loop is closed, this phenomenon increases since the cavity field increase in this case is accompanied by the increase of the entering RF power.

To remove this drawback an extra amplitude regulation contour is inserted into autogenerator (Fig. 2). This contour is closed through the directed coupler (2), amplitude detector (9), error signal differential amplifier (10) and attenuator (6). If the SCC oscillation amplitude does not coincide with the defined amplitude then the error signal is arised with which the attenuator (6) compensates the found deflection independently of its arising reason.

Now we report on the main low level subsystem characteristics. The SCC nominal field level backward couple signal power is 2 ..3 mW. This level control is realized by the regulation loop in the range 20-100% of nominal value accordingly to a given voltage on the amplifier input (10).

The chopper synchronization signal level taken from the directed coupler (2) is no less than 3 mW. The tolerable phase shift unstability between the low level subsystem input and chopper synchronization output is no more than 1 grade.

3.2 The chopper cavity feed system

Fig.3 shows the chopper RF feed system functional scheme. It consists of two regulation contours for the cavity amplitude and field phase control.

The amplitude regulation contour is analogous to the SCC feed system. Its purpose is to stabilize the chopper cavity RF field voltage level and to ensure its regulation to keep chopping defined operation. This contour consists of the (1 ..7) elements chain (Fig. 3). The stabilization of backward couple RF signal (the directed coupler input, (2) in Fig. 3) is realized with the static error no more than 5% then the weakening change inserted by the chopper cavity is no more than 10 dB. The field level regulation is realized by means of the differential amplifier supporting input (4) continuous current voltage change.

The phase regulation contour is built like the continuous type RF generator (13) phase frequency auto-tune system. The backward couple RF signal coming from the chopper cavity is compared in phase detector (10) with the SCC RF system supporting signal. The voltage error through the low frequency filter (11) and continuous current amplifier (12) influences on the generator (13) correcting its oscillation frequency and phase. The phase shifter block (8,9) allows to establish the value of phase shift between the fields in chopper cavity and in SCC according to the particle dynamics requirements.

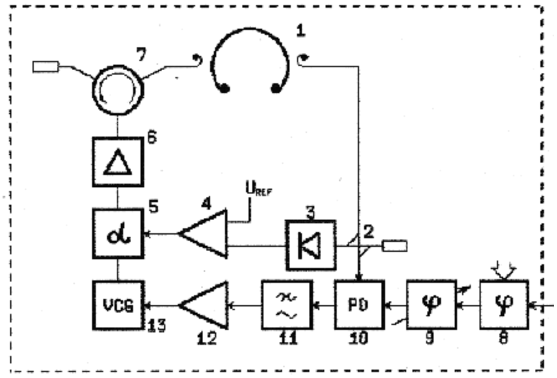

Fig.3 The chopper RF feed system.

The generator (13) ensures the signal level sufficient to obtain the maximal SCC feed power with the weakening inserted by the attenuator (5) up to 10 dB. The assumed final cascade amplification coefficient is 50 dB and the required generator output power level is 0.12 W.

4. RF ACCELERATING STRUCTURE

The concurrent calculation of the particle dynamics and RF structure accelerating geometry is given in /1/.

The accelerating structure based on Nb/Cu or High Tc is made by galvanoplastic technique of the cupper shells /2/ and the magnetron spattering of SC films .

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