THERMOSTABILIZATION SYSTEM OF VEPP-5 FORINJECTOR

K.V.Gubin, V.D.Hambikov, A.G.Igolkin, P.V.Martyshkin
BINP, Novosibirsk, Russia

HEATING EFFECTS AND ENERGY SPREAD IN A BEAM

The temperature condition changes in an accelerating structure influence on its RF characteristics. This fact leads to the change in the beam average energy as well as to the supplementary energy spread in the structure.

Let's consider ultrarelativistic charged particles in the field of the running RF wave with a phase velocity $\beta_{ph} = 1 + \Delta\beta_{ph}$. For the simplicity we shall assume that there is no group effects in the beam and no interaction between the beam and the accelerating structure.

If we assume that $\Delta\beta_{ph} L/\lambda << 1$ where L - the length of the structure, λ - the length of the RF wave, then the energy gained by the particle in the accelerating structure will be

$$\Delta E = -\frac{A\omega\Delta\beta_{ph}}{c}\left(\sin\left(\phi_0 - \frac{\omega L\Delta\beta_{ph}}{c}\right) - \sin\phi_0\right) \quad (1)$$

where A -- energy gradient of the structure, ω - perashion frequency and ϕ_0 - initial RF phase of particle.

For a beam of the phase length 2ϕ the part of heating effects in the beam energy spread can be estimated as

$$\delta = \frac{E_{0\min} - E_{\min}}{E_{0\max}} = \frac{\omega}{2c}\Delta\beta_{ph} L \sin\phi \quad (2)$$

where $E_{0\min}$ and $E_{0\max}$ - minimum ($\phi_0 = \phi$) and maximum ($\phi_0 = 0$) energy gain when $\Delta\beta = 0$, $E_{\min}$ - minimum energy gain when $\Delta\beta \neq 0$.

Relation between the change of resonant frequency and the phase velocity of RF wave can be written as [2]:

$$\frac{\Delta\beta_{ph}}{\beta_{ph}} = \frac{\beta_{ph}}{\beta_{gr}}\frac{\Delta\omega}{\omega} = \frac{\beta_{ph}}{\beta_{gr}}\alpha\Delta T_{av} \quad (3)$$

here α - the temperature expansion ratio of copper, ΔT_{av} - the value of average temperature changing.

Equation (2) together with (3) determines the maximum acceptable change of an average temperature of the accelerating structure with a certain energy spread limit caused by heating:

$$\Delta T_{av} = \frac{\lambda}{L}\frac{\beta_{gr}}{\pi\alpha\beta_{ph}\sin\phi}\delta \quad (4)$$

For the linear temperature distribution along the maximum acceptable temperature gradient Δ of the structure T will be

$$\Delta T = 6\frac{\lambda}{L}\frac{\beta_{gr}}{\pi\alpha\beta_{ph}\sin\phi}\delta \quad (5)$$

For the accelerating structure of VEPP-5 preinjector prototype the parameter β_{gr}/β_{ph} is equal to 0.02. Taking the value of acceptable energy spread of 0.5% for a beam of RF-phase length about 20°, we obtain that the system of thermostabilization should ensure the average temperature of the accelerating structure with the precision of ±0.1°C and the temperature gradient along the structure not more than 1.2°C.

TEMPERATURE CONDITIONS OF ACCELERATING STRUCTURE

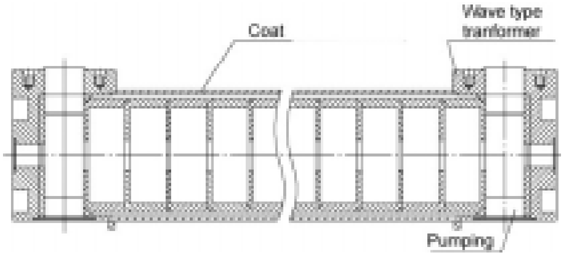

Fig. 1 Acceleration section.

Accelerator section (Fig.1) is a cylindrical disk-loaded waveguide placed inside the stainless steel coat for better rigidness. The inner surface of the coat and outer surface of structure form the channel with a ring-shaped section of water cooling system. The main parameters of section are listed in Table 1. Present construction of the section determines the method of thermostabilization: to stabilize the temperature and the cooling water flow.

Table 1. Main parameters of acceleration section.

Length	280 m
Inner diameter of structure	84 mm
Outer diameter of structure	100 mm
Inner diameter of coat	108 mm
Outer diameter of coat	112 mm
Resonance frequency	2856 MHz
Repetition rate	50 Hz
RF pulse duration	0.5 μsec
Heating per one pulse	up to 80 J

When the structure is filled with RF field, the part of energy transforms into heat in the skin-layer on the inner surface. The heating of the skin-layer can be estimated using the nonstationary equation of thermal conductivity $\Delta T \approx (P\delta)/(\alpha S)$, where P - pulse power of heating, δ - depth of skin-layer, α - thermal conductivity of copper, S - square of inner surface of accelerating structure.

Assuming P=100 MW, $\delta = 10^{-6}$m, S=2m^2, we obtain that by the end of RF-pulse the heating of skin-layer will be about 0.13°C. Taking into account that without cooling the heating would be about 20°C we suggest that even for the single pulse duration, and for the time of several milliseconds between pulses as well, all the heat will be distributed uniformly along the radius of accelerating structure.

Present estimations illustrate that the distribution of temperature along the radius of accelerating structure and pulse nature of heating can be neglected. Thus, we can analyze one-dimensional model with quasistationary heating: long and thin rod of copper (accelerating structure) with nonuniform heating along it placed into cylindrical coat. In the ring channel formed by the outer surface of structure and the inner surface of coat, the cooling water is circulated. Thermal contact with air and heat currents from butt-ends supposed to be equal to zero.

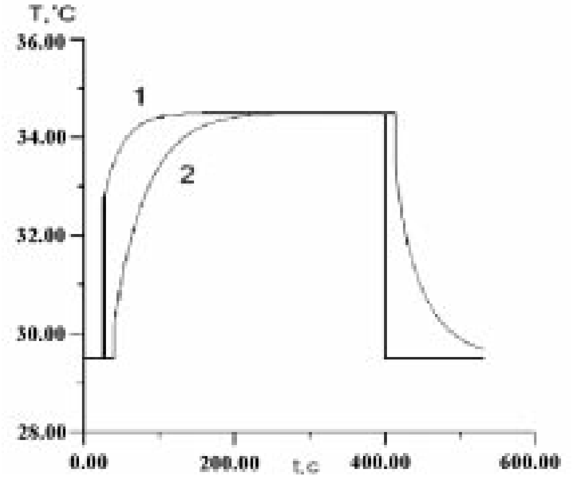

Fig. 2. Numerically simulated corellation between input (1) and output (2) cooling water versus time.

So, we should solve the system of three nonstationary equations of thermal conductivity with common boundary conditions of third kind. Analytical solving of such a system in general case is rather complicated. Due to this fact, numerical simulation based on the method of finite differences was realized. This model was experimentally tested on the prototype of accelerator section and thermostabilization system of VEPP-5 preinjector.

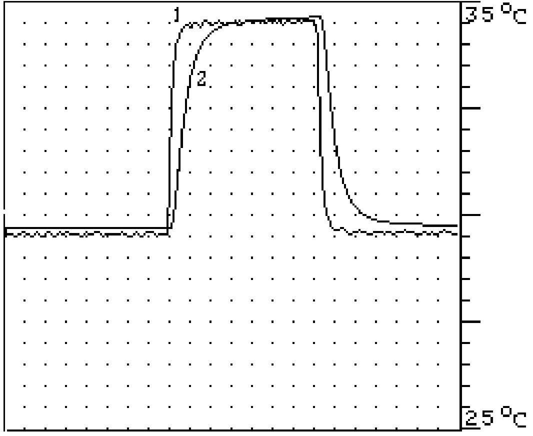

Fig. 3. Experimental corellation between temperature of input (1) and output (2) cooling water versus time. The scale of horisontal axis – 60 second per point. Water flow is 0.27 lps.

In the experiment the temperature of cooling water at the section entrance was changing and the cooling water flow was constant. The dependence of the input and output water temperature and its flow on the time was measured and expected value of this dependencies was numerically simulated with the same parameters. Several series of measurements were done.

In Fig.2, 3 expected and measured data are shown. The difference between it does not exceed 2%.

Thus we can calculate the temperature distribution in structure and water along the axis of section in any moment of time with any input parameters such as flow and temperature of the water and RF power in the section.

To determine the section sensitivity to the disturbance of input water temperature, the following model was tested: temperature disturbance was put over the steady-state of section without RF power. ($T_{as}(x,t) = T_c(x,t) = T_w(x,t) = 0$)

$$T_w(0,t) = \begin{cases} 0, & t < 0 \\ T_{dist}, & 0 < t < \tau \\ 0, & t > \tau \end{cases}$$

where T_{as} - temperature of accelerating structure, T_w - temperature of water, T_c - temperature of coat, T_{dist} - value of disturbance.

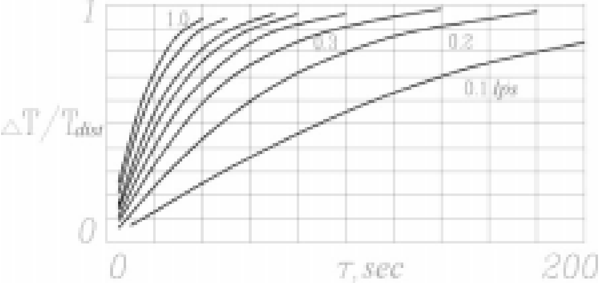

Fig. 4. Corellation between maximal deviation of average accelerating structure temperature, relating to amplitude of disturbance and the duration of temperature disturbance of cooling water at the section entrance.

The results of simulation are shown in Fig.4. As one can see, with the present geometry of section (Table 1) and the flow of water in certain bounds the following correlation is observed:

$$T_{dist}\,\tau\,Q \le 2\ [\mathrm{l}\ ^\circ\mathrm{C}] \qquad (6)$$

Correlation (6) determines the quality of thermostabilization of water at the entrance of the section.

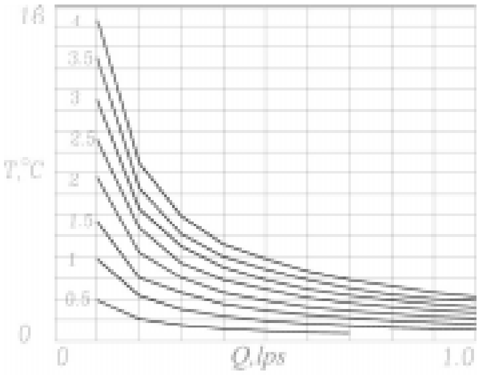

Fig. 5. Corellation between the average accelerating structure temperature and the cooling water flow at different power of RF-heating.

Next problem: how does the steady-state condition of section sense influence the change of water flow and RF power. Simulations were done for RF power range from 500 up to 4000 W and the flow range from 0.1 up to 1.0 lps. The main results are:

- over the whole range of RF-power the temperature gradient along the section is not significant and with a flow over 0.2 lps it does not exceed 0.6°C;
- knowing the heating power we can select the flow for each section in order to compensate the tolerance of RF parameters of different sections with the help of

calculated correlation between the average temperature of section and the flow of water (Fig.5), the mentioned correlation is

$$Q\,T / P \approx 0.5\ [\mathrm{l\ °C / kJ}] \qquad (7)$$

It allows to determine the section sensitivity to disturbances of heating and water flow.

TECHNICAL REALIZATION AND PRESENT STATUS

Technically the system of thermostabilization supposed to be performed by two-contour water scheme (Fig.6). All elements to be stabilized are connected in parallel to the inner closed water contour. The temperature stabilization is realized as a controlled heating of input water by the heating unit, individual for each element. Dumping of heat surplus is produced by the heat exchanger.

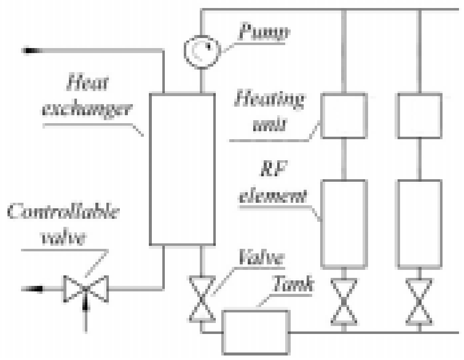

Fig. 6. Sheme of two-contour thermostabilisation system.

This construction allows to stabilize the cooling water flow through elements, to decrease the power consumption, to change the individual heating conditions for each element of accelerator, to compensate the tolerance in RF parameters during the adjusting process.

Main characteristics of the system are shown in Table 2. At the present time the assembly of water contours is in progress. The heating unit that consists of heater, controlled power supply, flow meter, thermistors and control device, has been completely designed, tested on preinjector prototype and now is in serial production.

Table 2. Main parameters of thermostabilization system.

Number of elemets/branches	20
Flow of water per branch	0.5..1.0 lps
Total flow	15..20 lps
Operating temperature of elements	40±3°C
Precision of temperature stabilization	0.1..0.2°C
Peak power consumption	300 kWt
Nominal power consumption	50..100 kWt
Capacity of water in the system	10 m^3

REFERENCES

1. A.V.Alexandrov and others. Test of prototype of preinjector for VEPP-5. Preprint INP 97-64, Novosibirsk, 1997.
2. O.A.Waldner and others. Disk-loaded waveguides references guide. Moscow, Atomizdat, 1977. (in Russian).
3. S.S.Kutateladze. Heat transfer and hydrodynamical resistance. Moscow, Energoatomizdat, 1990. (in Russian).