COOLING AND THERMO STABILIZATION SYSTEM OF 100 MeV/100 kW ELECTRON LINEAR ACCELERATOR OF NEUTRON SOURCE DRIVER

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Abstract

Cooling system and temperature control technology elements of the linear electron accelerator of 100 MeV/100 kW is a complex technological system composed of three subsystems: the cooling klystron gallery equipment (30 C ± 1), cooling of the accelerator tunnel equipment (30 C ± 1) and the cooling and temperature control accelerating sections and waveguide (40 ° C ± 0,2). The block diagram of cooling and temperature control of the linear electron accelerator of 100 MeV/100 kW, describes the basic principles to formulate requirements to the cooling systems. It describes the status of the installation, commissioning and testing of the cooling and temperature control of the accelerator - driver subcritical "neutron source" KIPT.

INTRODUCTION

In NSC KIPT, Kharkov, Ukraine a neutron source based on a subcritical assembly driven by a 100 MeV/ 00kW electron linear accelerator was constructed and is under commissioning [1]. This neutron source is an USA (ANL)-Ukraine (KIPT) Joint project, and its accelerator is designed and constructed by Institute of High Energy Physics (IHEP), China. The design and construction of such an accelerator with high average beam current and low beam power losses is a technical challenging task.

The proposed NSC KIPT accelerator parameters are shown in Table 1. The layout of the accelerator is shown in Fig. 1. As one can see in Fig. 1, the accelerator is complicated system of powerful RF equipment, waveguides, accelerating sections, electromagnetic sections and power supply sources. To provide safe, stable and accurate accelerator operation all elements and devices mentioned above should be cooled and thermostabilized with corresponding cooling systems.

To separate the functions and operation modes of the cooling the whole cooling system of the NSC KIPT 100 MeV/100 kW accelerator was separated on three subsystems that are: the cooling klystron gallery equipment (30 C ± 1), cooling of the accelerator tunnel equipment (30 C ± 1) and the cooling and temperature control accelerating sections and waveguide (40 ° C ± 0,2). All cooling subsystems were designed and manufactured in IHEP, Beijing, China and now are under tests in NSC KIPT.

Table 1: NSC KIPT Neutron Source Accelerator Parameters

Parameter	Value	Unit
RF frequency	2856	MHz
Beam energy	100	MeV
Beam current (max.)	0.6	A
Energy spread (peak-to-peak)	4	%
Emittance (1σ)	$5x10^{-7}$	m*rad
Beam pulse duration	2.7	µs
RF pulse width	3	µs
RF repetition rate (max.)	625	Hz

Taking into account the total power of the RF accelerator equipment (more them 1 MW of total electric power), (40 ° C ± 0,2) cooling and thermo stabilization system of 100 MeV/ 100kW electron linear accelerator is one of the most crucial cooling subsystems stabilization of the accelerating equipment at the optimum sizes and parameters of accelerating sections and other RF equipment. The system was designed, manufactured and assembled to provide required permanent temperature modes and monitoring of the parameters of the accelerator in the thermo stabilization system. There are 12 temperature sensors (Pt100 thermocouple), a water level sensor in the tank, water flow sensors through heat stabilization objects and reserve sensors. To increase the accuracy of maintaining the set temperatures, the temperature control is carried out according to the proportional-integral-differential law. This makes it possible to maintain the temperature of the accelerating sections with an accuracy of ± 0.5 ° C, while in the stationary mode with slow changes with an accuracy of ± 0.2 ° C. Cooling and Thermo Stabilization System of 100MeV/100kW Electron Linear Accelerator works completely in automatic mode and does not require operator intervention, and in case of failure, it provides a blocking signal for other accelerator systems.

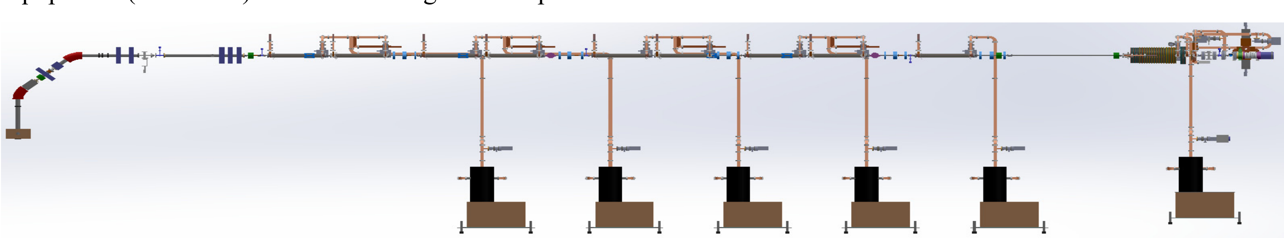

Figure 1: Layout of the NSC KIPT NS Accelerator

ACCELERATING STRUCTURE AND THERMAL CALCULATIONS

Due to the high averaged RF power losses in the accelerator section, water jacket cooling is needed to sufficiently cool down the structure. With the High Frequency, Steady State Thermal and Structural solver modules in the multi-physics software package ANSYS, numerical RF-thermal-structural-RF coupled finite element analysis (FEA) on the accelerating structure has been done in IHEP, Beijing, China. With beam-off case, the RF electric field amplitude distribution along the accelerating structure is shown in Fig. 2.

The calculation were done with analytical estimations and with ANSYS code. T the ANSYS simulation results met with the analytical one. Since ANSYS cannot simulate the beam loading effect, the electric field amplitude and the corresponding RF heating loss distributions were scaled from the beam-off case. The scaling relation can be obtained from the analytical calculation.

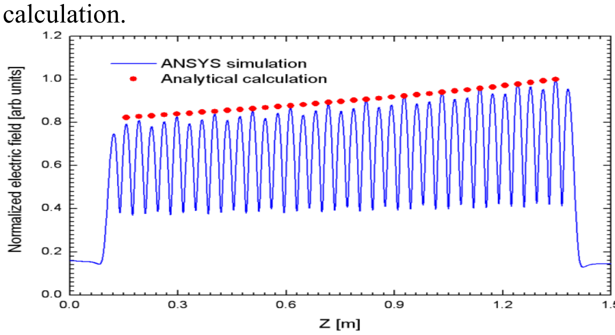

Figure 2: The electric field amplitude distribution along the accelerating structure.

For accelerator accelerating structure, due to the high average RF input power (the maximum value is 20 MW×3 μs×625 Hz = 37.5 kW), cooling water jacket just outside each accelerating structure with water flow rate of 10 t/hour should be used. The water jacket is an annular water pipe with internal and external diameters of 10[2]mm and 116 mm respectively. As an example, when the water cooling temperature is controlled to be 40°C, the temperature distributions along the structure for both the beam-off and beam-on cases are shown in Fig. 3. It can be seen that the maximum temperature rise located at the output coupler part when the beam is off, which is due to the highest electric field. On the contrary, when the beam is on, due to the beam loading effect, the input coupler part will have the highest electric field and maximum temperature rise. For both beam-off and beam-on cases, the highest temperature rise are located at the iris tip parts. The maximum temperature variations are ~10°C and ~7°C for both cases.

Figure 3: Temperature distributions along the structure for beam-off (upper) and on (lower) cases.

The longitudinal and transversal deformations of the accelerating structure for 40°C cooling water are shown in Fig. 4 and Fig. 5. The longitudinal deformation can cause electric field phase shift, while transversal one is the major source of frequency shift. Here the phase shifts caused by longitudinal deformations are ~0.72° and ~0.60° for the beam-off and beam-on cases, respectively. With a scaling law of $\Delta f/\Delta(2b) = -36$ kHz/μm, the frequency shifts caused by the transversal deformation can be roughly calculated to be 0.68 MHz and 0.58 MHz for both cases.

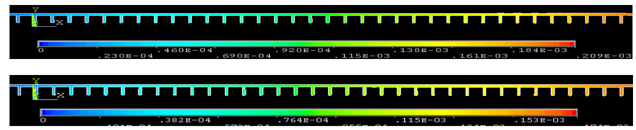

Figure 4: Longitudinal deformations along the structure without (upper) and with (lower) beam.

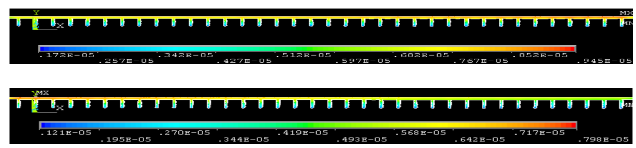

Figure 5: Transversal deformations along the structure without (upper) and with (lower) beam.

The VSWRs of the accelerating structure versus frequency for both beam-off and beam-on are shown in Figure 6. It can be seen that the RF heating will cause the VSWR curves shift downward to lower frequencies by ~0.6 MHz and ~0.5 MHz for both cases respectively, which are a little bit smaller than the scaling law estimations. This small difference is due to the fact that the scaling law calculation is estimated by the largest transversal deformation, while in reality that not every cell has that large deformation. The bandwidth of the structure is ~5.4 MHz defined by VSWR ≤ 1.2, which is fairly larger than the RF heating resulted frequency shift and assures the stable operation of the accelerating

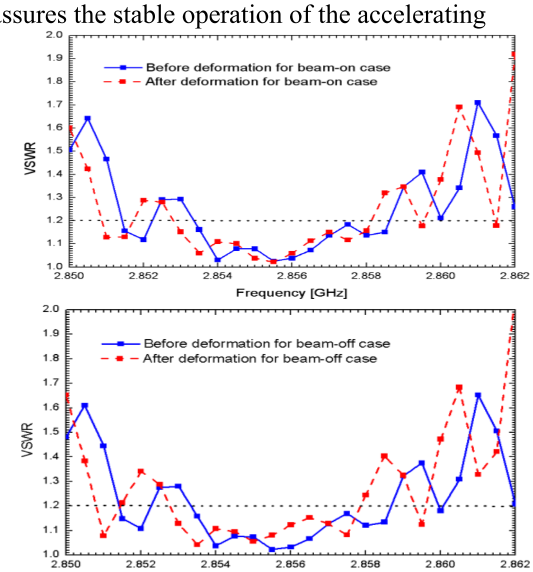

Figure 6: VSWRs of the structure versus frequency for both beam-off and beam-on cases.

40 C THERMOSTABILIZATION SYSTEM LAYOUT AND EQUIPMENT

The accelerator equipment that should be cooled and thermo stabilized with 40 C cooling subsystem involved the following items: 10 accelerating sections with the total heating power of about ~ 230 kW; the injection accelerator part of 6 kW heating power with prebuncher and buncher; 6 wave guiding lines for each klystron amplifier with total heating power of about ~ 30 kW. The total cooling capacity of the 40 C thermostabilization cooling loop is ~270 kW. As it was shown above, the requirements to the high stabilization of the accelerating section parameters require the high temperature stability of the equipment that in the case of NSC KIPT 40 C cooling system is ± 0.2 C.

Figure 7 shows the thermostabilization system layout.

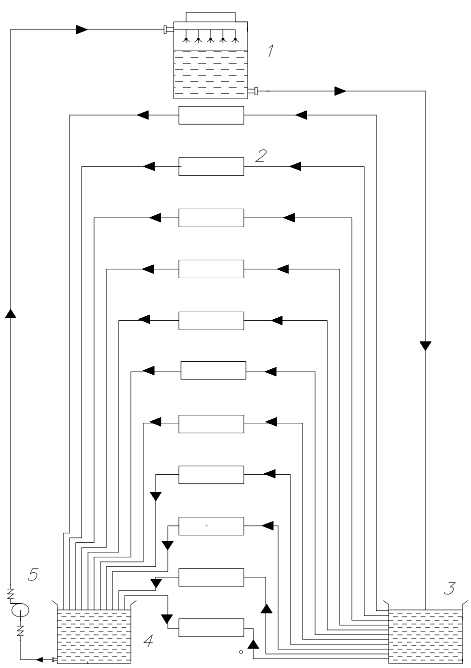

Figure 7: Layout of the 40 C thermostabilization system.

The system consists of 11 separate local cooling loops for each accelerating section and start part of the accelerator. Water for each secondary cooling loop (2) goes from the cold water storage tank (3) and is collected in the tank of the worm water (4). From the tank (4) water is pumped to a cooling tower (1) with circulating pump (5).

Layout of each local cooling cabinet is shown in Fig. 8. The first cooling loop of the local cooling cabinet includes heat-exchanger (3), automatic water heater (5), set of water parameter sensors, cooled devise (6), water storage tank (1), circulating pump (2). The secondary cooling loop includes the pump (4) and heat-exchanger (3).

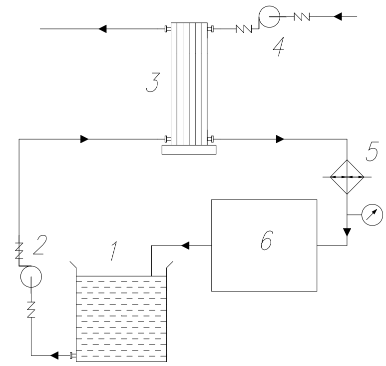

Figure 8: Layout of the 40 C local cooling cabinet.

The cabinets of the primary local cooling loops with circulating pump, set of water parameter sensors, water heater and water tank are installed in the accelerator tunnel next to each accelerating section.

The cabinets of the secondary local cooling loops with circulating pump, water storage tank, set of valves and heat-exchangers of K210-44M-P12 type are installed in the room next to the accelerator tunnel that eliminate the possibility of the equipment irradiation.

The water velocity in the primary and secondary cooling loops are 100 and 60 m^3/h respectively.

The water pressure in the primary cooling loop is 0.23 kPa.

The secondary cooling loop has open scheme and is equipped with two 2.2 kW fans cooling tower of CDW 85ASY type.

SYSTEM TEST OPERATION

During 2013-2016 the cooling system was assembled and tested. Since July 2016 the system is under test operation and is being used for the injector and accelerator commissioning. Despite some failures with water level sensors, touchscreen control panels and controllers the system proved all design parameters and specifications. The first experiments with electron beam showed that the system capable to keep required temperature within range of ± 0.2 C.

It provides confidence that 40 C cooling thermo stabilization system of NSC KIPT 100 MeV/ 100 kW linear accelerator insures the save and accurate operation of NSC KIPT SCA Neutron Source with design modes.

CONCLUSION

The NSC KIPT 100 MeV/100 kW linear accelerator cooling system was designed and developed in IHEP, Beijing, China. Now the system is assembled in NSC KIPT, passed all technical tests and is under test mode operation for the accelerator beam commissioning.

REFERENCE

[1] A. Zelinsky *et al.*, “Test and Commissioning Results of NSC KIPT 100 MeV/ 100 kW Electron Linear Accelerator, Subcritical Neutron Source Driver”, Presented at IPAC’17, May 2017, Copenhagen, Denmark, Paper TUPIK033.

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