TEMPERATURE REGULATION OF THE ACCELERATING SECTION IN CANDLE LINAC

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Abstract

The temperature of the CANDLE S-Band Linac high-power Radio Frequency (RF) components will be regulated by Stand-Alone Closed Loop (SACL) water system. The RF components are made of oxygen-free high conductivity copper and respond quickly to temperature changes. Temperature stabilization better than ± 0.1 C is required to achieve a good RF phase and energy stability. The temperature regulation and control philosophy along with the simulation results are discussed.

INTRODUCTION

Center for the Advancement of Natural Discoveries using Light Emission (CANDLE) is a project of third generation 3 GeV synchrotron light source. According to the design report, it foresees to use 6 meters DESY type S-band accelerating structure for linear 100 MeV accelerator used as a pre-injection system [1]. The resonant frequency of the linac main accelerator structure cavities is close to 3 GHz. Under normal operation approximately 65 % of the Radio Frequency (RF) power is dissipated in the copper structure walls. For accelerator structure, electromagnetic field resonant frequency is basically a function of the geometry of the cavities. As RF power is dissipated in the cavity wall, the copper wall will heat, and then expand, and its resonant frequency will decrease. This resonant frequency shift will be controlled by cooling system using an opposing shift design. Such method allows to maintain the accelerating structure resonant frequency and thereby to provide efficient acceleration of the electron beam with minimal klystron energy. Experience of other centers shows that for expected operating conditions, i.e. nominal steady RF load similar to DESY type S-band accelerator structure, surface temperature range from 30°C to 40°C and temperature stability must be better than 0.1°C. It requires accurate temperature stabilization of deionized water, which will serve as refrigerating medium stand-alone closed loop cooling system. The temperature regulation and control philosophy of Linac SACL cooling system along with the simulation results are discussed in this work

SACL WATER COOLING SYSTEM DESCRIPTION

Cooling water will be supplied to the accelerator section cooling tubs passages by SACL and temperature control systems, similar to those used in other linacs [2,3]. A flow diagram of such a closed-loop water cooling system is shown in Fig. 1. In this loop, water is pumped at a constant flow rate to the accelerator structure, where it takes up heat. On the return leg, a 3-way valve directs a portion of the flow through a liquid-to-liquid heat exchanger to dump heat to a chilled water source, while the remainder of the water is diverted through a by-pass line.

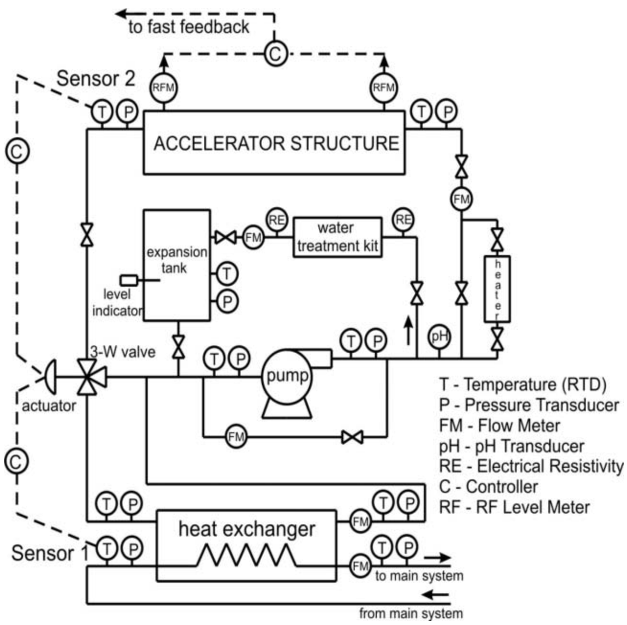

Figure 1: SACL water cooling system.

These two flows then mix before entering the pump for circulation back to the accelerator structure. In such a closed-loop circuit, water temperature regulation will be achieved by manipulating the hot-side liquid-to-liquid heat exchanger water flow rate while holding the cold-side water inlet flow rate constant, as far as possible. By changing the hot-side water flow rate, the overall convection coefficient of the heat exchanger is varied. Since the heat removal rate must remain constant for a steady-state condition, the liquid-to-liquid heat exchanger hot-side water temperature must change inversely to the overall convection coefficient to achieve a new and balanced operating condition. Consequently, increasing the water flow through the heat exchanger results in an increase in the overall convection coefficient, and an associated decrease in the mean outlet water temperature; and conversely, decreasing the water flow through the heat exchanger results in a decrease in the overall convection coefficient, and an associated increase in the mean outlet water temperature.

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LINAC TEMPERATURE CONTROL SYSTEM

An important feature of the accelerator structure control system is a high level synchronization of amplitude-phase characteristics of the accelerated beam. It requires strict stabilization of the RF frequency, amplitude and temperature. The temperature stabilization of the accelerator structure will be achieved by SACL temperature control scheme that will maintain the water temperature in the flow loop supplied to the RF structure so that resonance can be maintained in the cavities. The water temperature in the flow loop will be manipulated by adjusting the proportion of hot water returning from the accelerator structure. The mechanism for this manipulation is a "3-Way" control valve, whose control effort will be calculated via a multi-mode Proportional Integral Derivative (PID) control algorithm. The multimode PID algorithm will be consisted of: manual, temperature feedforward, temperature feedback, and RF error feedback modes. The manual mode will allow an operator to position the control valve by entering values manually into a graphical program screen. Manual mode should serve as the system startup and setting up, as well as override, if it is necessary for normal operation. The RF error feedback mode is intended for normal operation, to control resonance under RF power fluctuations. The temperature feedback mode will be used during the loss of RF power to maintain the cavities temperatures close to their resonant temperatures. The temperature feedforward mode must stabilize water temperature caused by stable and random temperature fluctuations on cold-side water inlet of exchanger. This mode will run in all stages of linac operation.

The RF error is a measure of how far is the cavity frequency from resonance. The RF error signal will be calculated using the average value of RF power difference between the input and output. Whenever this difference is measure at operation optimal value, i.e. when the cavity is in resonance, the RF error signal will correspond to the defined value of voltage. Hence, this value will be the set point for the PID feedback loop when the system is under RF error feedback mode. In case of RF power failure or trip, hence, decrease of heat load to the water cooling system, the control mode must be switched from RF error feedback mode to temperature feedback mode. This transition is necessary since in the case of RF power loss, the control valve would remain at its current position, and the temperature of the RF cavity would begin to decrease due to the loss of the RF heat load. The motivation for switching to temperature feedback mode is to keep the temperature of the accelerator structure as close to the temperature for which its resonant dimensions are achieved [4]. The information for the feedback mode will be picked up from the water temperature sensor at the end of accelerating structure water loop. Admittedly, this parameter will be the most representative of accelerator structure temperature, and will be the smallest time delay between it's and the section temperature changes. Added temperature error in Linac SACL by generalized water cooling system, measured on inlet of liquid-to-liquid exchanger probably will have oscillation behavior, period of which will be defined experimentally. Separate PID controller of temperature feedforward system will provide the control and correction of such temperature deviation as well as the random temperature fluctuation on exchanger input.

SIMULATION AND RESULTS

The accelerating section cooling passages consist of copper tubes that are brazed to the outer cylindrical accelerator periodical surface, 3D model of one sixth part segment of which is displayed in Fig.2.

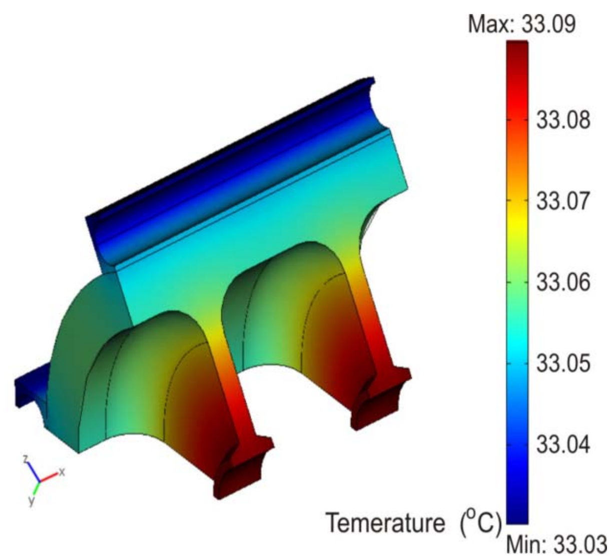

Figure 2: Accelerator structure 3D thermal model.

The thermal finite element and computational fluid dynamics numerical models, which have been performed in FEMLAB/MATLAB medium, are employed to optimize SACL parameters design. More details on these parameters can be found in Table 1. It presents the heat load and water cooling flow rates, as well as temperature conditions for the water and acceleration section.

A special attention in this work is devoted to the temperature oscillatory stability simulation for different PID algorithm modes and to various type temperature errors. Two main PID algorithm modes (RF error feedback and water temperature error feedback) have been simulated in MATLAB/SIMULINK medium. As it was mentioned above, the temperature feedforward mode existed in both cases. The temperature errors specifications, which have been used at the simulation, are shown in Table 2.

Table 1.Accelerator structure cooling parameters

Accelerator structure length	6 m
Pulse RF-power per section	31 MW
RF pulse length	3 µs
Pulse repetition rate	2 Hz
Average power (cooling capacity)	186 W
Cooling water flow	12 l/min
Temperature rise	0.25 ºC
Temperature range	30 ºC - 40 ºC
Temperature stabilization	0.05 ºC
Pressure drop	0.5 bar
Tube diameter	8 mm
Water velocity	1.3 m/s
Convection coefficient	0.55 W/cm²C

Table 2: Temperature errors specifications

Error	Sensor	Form(amplit.)	Mode
error 1	sensor 1	sin(±0.25ºC)	feedforward
error 2	sensor 1	step(±0.25ºC)	feedforward
error 3	sensor 2	step(±0.3ºC)	Tem.feedback
error 4	sensor 2	rand.(±0.05ºC)	RF feedback

Simulation result within 2000 seconds, with switching of temperature errors and PID algorithm modes, is shown in Fig. 3. As indicated in the bottom diagram, feedforward controller copes easy with stable and random (600 second after start) temperature errors on inlet of exchanger, keeping water temperature in required range. This result can be improved by means of variation PID controller signal delay value. As concerns the form and amplitude of random temperature error on exchanger inlet used in modeling, it regards as the worst case of temperature deviation in the secondary CANDLE water cooling system [5]. In reality, such sharp temperature rise is not foreseen. At the moment of the loss (900 second after start) and return (1500 second after start) of RF power in accelerating structure, when switching the temperature error feedback mode the required temperature stability recovers during about 100 seconds. However, cumulative experience on other linacs shows that such situation will originate extremely seldom, by virtue of reliable RF error feedback mode functioning.

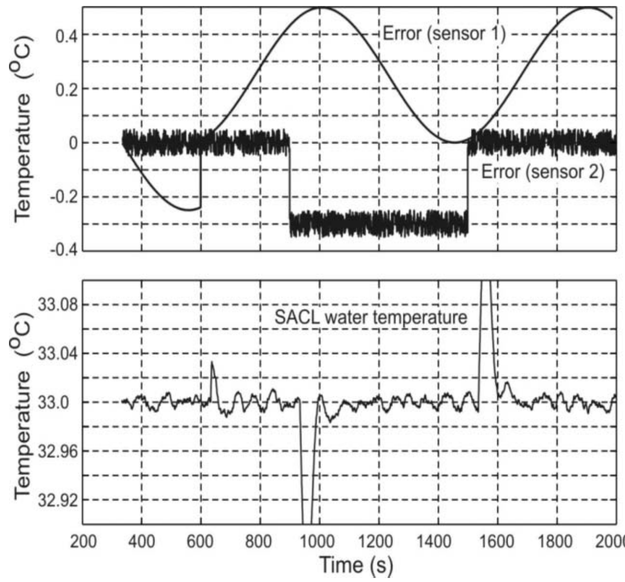

Figure 3: SACL water temperature stability simulation

CONCLUSION

The study is focused on the design and analysis of water cooling and temperature control system for CANDLE linac. Based on the experience of other centers, general algorithm of temperature control system for RF accelerating structure has been developed. Some parts of this work deals with parameters optimization and testing, performed by means of computer simulation technology. The analysis of simulation results verifies the propriety of the choice.

REFERENCES

[1] V. Tsakanov et. al, CANDLE Design Report, ASLS-CANDLE R-02-001, 2002.

[2] R. Dortwegt, S. Pasky and M. White, "Improved Temperature Regulation of APS Linac RF Components," Proc. of the 19th Internat. Linear Accel. Conf., pp. 1001-1003, Chicago, IL, 1999.

[3] J. Bernardin, C. Ammerman, S. Hopkins, "The Design and Performance of a Water Cooling System for a Prototype Coupled Cavity Linear Particle Accelerator for the Spallation Neutron Source", Proc. of 6th ASME-JSME Thermal Engineering Joint Conference, TED-AJ03-537, 2003.

[4] C.A. Treml, S.K. Brown and J.D. Bernardin, "Resonance Control Cooling System for a Proto-typ Coupled Cavity Linac," Proc. of 8th Internat. Conf. on Accel. and Large Exper. Physics Control Systems, pp. 419-421, WEAPO76, San Jose, CA, 2001.

[5] S. Tunian, et. al "CANDLE Cooling System Design", ASLS-CANDLE R-03-023, 2003.

