

A MODULAR COOLING SYSTEM FOR THE MEA HIGH DUTY FACTOR ELECTRON LINAC

J.G. Noomen, N. Geuzebroek, C. Schiebaan

National Institute for Nuclear and High Energy Physics, section Nuclear Physics (NIKHEF-K)  
(formerly: Institute for Nuclear Physics Research (IKO)) Amsterdam, The Netherlands

Introduction

For the cooling of the MEA electron accelerator a modular setup has been selected. Each klystron station (twelve in total) has been provided with an own pumping system and dry cooler. With a klystron station is meant the accelerator sections (including loads) fed by one klystron, the rectangular-wave guide network and the klystron itself. A modular system has been selected because:

- before completion of the whole machine some stations could already be used;
- a failure in one cooling system only effects one station and not the whole machine;
- the smaller components and the low water content facilitate maintenance;
- we had good experience with modular cooling units at our former small machine EVA.

However, temperature control in a modular unit demands more effort, because the low water content makes this unit more sensitive for disturbances.

Circuit description

In fig. 1 a simplified layout of a modular unit is shown. The blocks indicated by A, W and K represent respectively: both accelerator sections set in parallel, the rectangular-wave guide network and the klystron collector. Within the dashed-dotted line the water to air heat exchanger (dry cooler) is shown.

This cooler has been located outside the building, as close as possible to the rest of the unit. The cooler is provided with continuously adjustable fans (F) and continuously adjustable air valves (AV). Servo-motor feedback assures linearity between fan drive and fan speed. TT<sub>1</sub> to TT<sub>7</sub> are temperature sensors and transmitters; TC<sub>1</sub> to TC<sub>4</sub> are PI temperature controllers; TA<sub>1</sub> to TA<sub>3</sub> are temperature alarms (switch action); B1 and B2 are bolometers measuring the input resp. output power of one of the accelerator sections. The pump has been provided with a double speed motor. Part of the flow is led through the cooler. The water leaving the cooler is called the cold line (T<sub>c</sub>). The water passing the cooler is called the hot line (T<sub>h</sub>).

Circuit design

Temperature specifications are

- a fixed point on one of both accelerator sections  $45 \pm 0,1^{\circ}\text{C}$ ;
- the inlet water of the wave-guide network  $45 \pm 0,5^{\circ}\text{C}$ ;
- the outlet water of the cooler  $40 \pm 1^{\circ}\text{C}$ .

The latter has no direct relation with the beam performance but the stability of  $1^{\circ}\text{C}$  is necessary to fulfill the requirement of  $0,1^{\circ}\text{C}$  stability for the accelerator. Temperature control for the accelerator and wave guide network is obtained by three way pneumatic linear control valves (CV1 and CV2), provided with valve positioners and PI transducers.

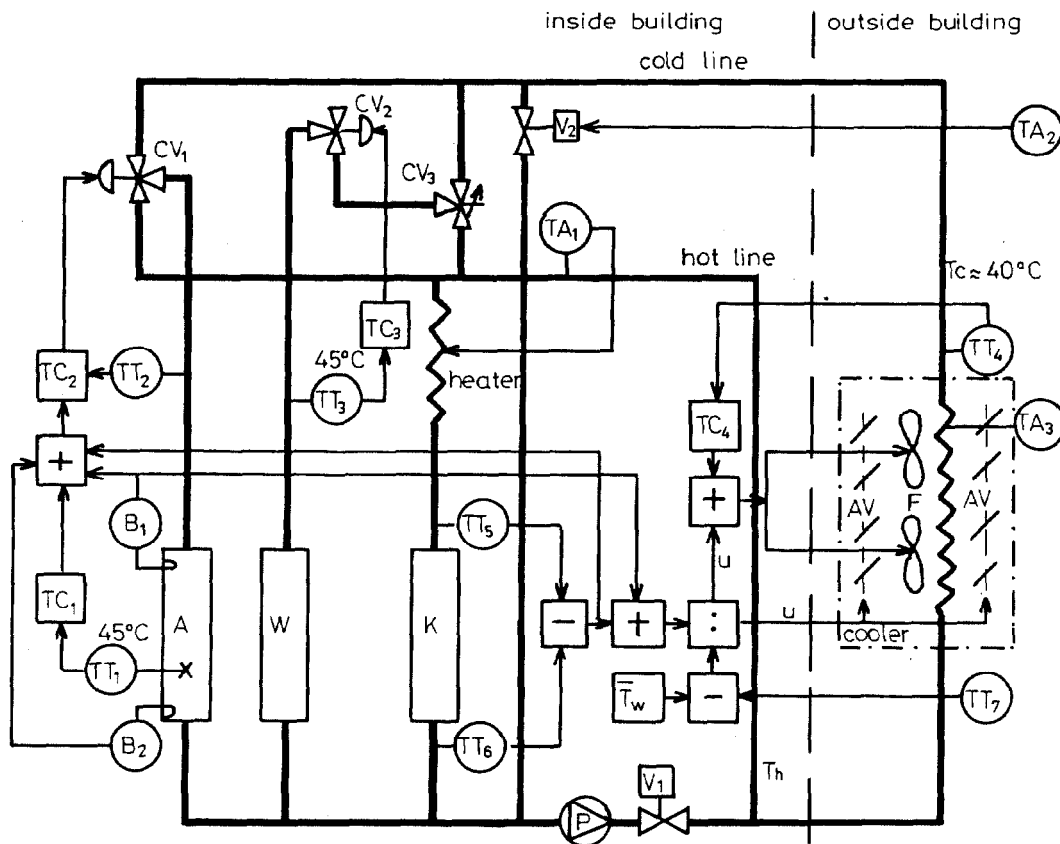


Fig. 1

The resolution is  $1,5 \cdot 10^{-3}$ , so the temperature stability is limited by the valve performance to  $\sim 0,01^\circ\text{C}$ .

Control of pump speed and interlocks (not shown in fig. 1) is done by a P.L.C. (Programmable Logic Controller) system. During transition of the pump speed, valve V1 is closed. The lower the ratio of heat production and heat capacity, the easier it is to achieve temperature stability. This ratio is relatively low for A and W and high for K. For this reason we have considered to split in one cooling system for A and W and one for K. However we decided not to split, because of the disadvantages

- two totally separated cooling systems instead of one have to be installed per klystron station;
- a considerable waist of power since additional heating power in the A and W system would be necessary to create the hot line temperature.

Th increases linearly with the power according

$$Th = 45 + 5,5 \alpha - 3 \beta \quad (1)$$

$\alpha$  and  $\beta$  are the ratio of nominal and maximum value of video, respectively R.F. power ( $\beta \leq \alpha$ ).

Th must always be above  $45^\circ\text{C}$ . This explains why the klystron is connected to the hot line. Connecting the klystron to the cold line would cause the hot line temperature drop below  $45^\circ\text{C}$ .

The temperature sensors TT<sub>1</sub> to TT<sub>7</sub> are thermistors (N.T.C.'s). The reasons we have chosen for this type of sensor were:

- good performance, high sensitivity, negligible hysteresis, good repeatability and reproducibility;
- good experience at application in our former small accelerator EVA.

High accuracy control instruments with N.T.C.'s as temperature sensor are not commercially available. At the time we started the design, also suitable function modules applied in the feed forward drives were not available. Therefore we had to develop this equipment by ourselves.

The bolometers B1 and B2 are of the barreter type. Barreters have been chosen instead of crystal detectors because of

- better reproducibility;
- much less difference in sensitivity;
- better linear response;
- easier temperature compensation

#### Operational mode

In operational mode, full cooling capacity is available, the pump is running on high speed and the temperatures are controlled on the specified values. There are two types of disturbances:

- variations of the cooler outlet water temperature ( $T_c$ );
- power change in the components A, W and K.

Variations of  $T_c$  are important in the steady state, when the accelerator is running at a fixed energy, duty cycle and beam current. The variations of the accelerator temperature induced by the cooler may not exceed  $0,1^\circ\text{C}$ . This is attained in two steps:

- a double control action for the cooler (air valves and fans) to minimize the cooler water outlet variations;
- a master-slave control for the accelerator to minimize the influence of the cooler water outlet temperature on the accelerator water inlet temperature.

In case of a power change, the transient time and the maximum deviation are important. To improve the response on power changes, fans (F) and accelerator control valve (CV1) are provided with feed forward drives.

#### Cooler control

The required cooler capacity is approximately given by the relation

$$K \approx \frac{P}{T_w - T_a} \approx \frac{P}{\Delta}$$

P is the power

T<sub>a</sub> the inlet air temperature

T<sub>w</sub> approximately the average cooler water temperature and can be assumed to be a constant.

The capacity of the cooler is approximately given by

$$K \approx \emptyset k \approx S k$$

$\emptyset$  is the air flow

k the air valve setting

S the fan speed.

The water flow through the klystron collector is constant. The difference between input and output temperature (TT<sub>5</sub> and TT<sub>6</sub>) is proportional with the klystron collector power. The time constant is relatively low (a few sec.), making this signal suitable for feed forward drive. Bolometer B1 produces a signal proportional with  $\beta$ . By proper addition of this signal to the difference between TT<sub>5</sub> and TT<sub>6</sub> we obtain a signal proportional with P, the total power to be cooled. TT<sub>7</sub> measures the cooler inlet air temperature. Therefore signal U corresponds with  $P/\Delta$ . The air valves are set proportionally with  $P/\Delta$ . The cooler outlet water temperature is controlled by TT<sub>4</sub> and PI controller TC4. The fan setting is also provided with feed forward drive corresponding with  $P/\Delta$ . For good control a minimum fan speed is required. In case of low values of  $P/\Delta$ , the fan speed is forced to this minimum by the air valve setting (k). However we may not force the fan speed to raise too much with only partly opened air valves, otherwise the fan will produce an unacceptable noise level.

The dashed lines in fig. 2 show possible idealized curves for k and S as a function of  $P/\Delta$ . For these curves k is assumed to be proportional with k. The solid lines represent more realistic curves. The dashed-dotted line shows the fan setting obtained just by feed forward drive.  $P/\Delta$  in percentage is related to  $\frac{\hat{P}}{\Delta_0}$ .

P is the maximum power

$\Delta_0 = T_w - T_{a0}$

T<sub>a0</sub> is the maximum outside air temperature at which the maximum power still can be cooled.

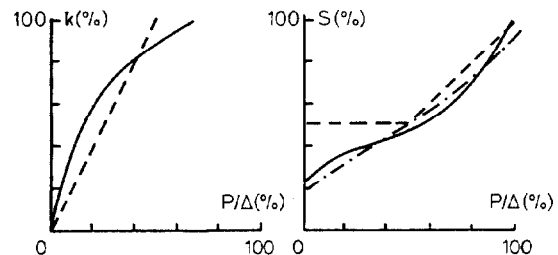


Fig. 2

### Accelerator temperature control

To suppress the fluctuations caused by  $T_c$ , the inlet water temperature is controlled by TT2 and PI slave controller TC2. The accelerator temperature itself is controlled by TT1 and PI master controller TC1. Without beam, the accelerator inlet water temperature  $T_{ai}$  is:

$$T_{ai} = 45 - 3,5 \beta \quad (2)$$

From (1) and (2) we can deduce an expression for the position of control valve CV1

$$\delta V1 = \frac{5,5\alpha + 0,5\beta}{5 + 5,5\alpha - 3\beta}$$

This can be approximated by

$$\delta V1 \approx 0.1 + 0.45\alpha + 0.27\beta,$$

demonstrating the effect of linear feed forward drive.

By a proper combination of B1 and B2 we can correct for the beam loading effect.

### The wave guide network temperature control

The wave guide inlet water temperature stability of  $0,5^\circ\text{C}$  is easily obtained by TT3 and PI controller TC3. If CV2 was directly connected to the hot line, the used valve stroke would reduce to 33% of its maximum, in case of  $\alpha = \beta$ . By introducing the manual three way valve CV3 the used valve stroke can be doubled. If we don't want to distort the linear behaviour of CV1 too much, the size of CV3 must be at least 1.5 times the size of CV1. However, since the flow through the wave guide network is less than 10% of the total flow, CV3 is still a relatively small valve.

### Performance

In the steady state the temperature stability is,  
accelerator  $< 0,02^\circ\text{C}$

wave-guide network  $< 0,1^\circ\text{C}$

cooler outlet water  $< 0,5^\circ\text{C}$

At full range video power changes:

Transient time  $< 200$  sec.

Accelerator temperature deviation  $< 0,3^\circ\text{C}$

### Stand by mode

Stand by mode is characterized by low power consumption, frost protection, no cooling capacity available, pump running on low speed and the system kept on temperature ( $45^\circ\text{C}$ ) within a few degrees. Only in this mode the heater can be powered on three fixed levels. Two of them can be preselected between zero and 24 KW in steps of appr. 1 KW, by simple inter-connecting wiring. The lowest level is automatically switched on for compensation of the normal ambient heat losses. These losses are minimized by providing the whole system including the cooler housing with insulating material. The second level is a value between the lowest level and the maximum 24 KW. This level is set by TA1 if the hot line temperature drops a few degrees below  $45^\circ\text{C}$ . If the hot line temperature decreases still a few degrees more (in spite of the heater power enhancement) the heater is set on maximum power, again by TA1 which is a double thermostat. The second and maximum level are switched on when the heat losses are more than normal, due to bad functioning valves (CV or AV). Since the heater is set on fixed values the surplus on power must be compensated to prevent the hot line temperature to raise too much beyond  $45^\circ\text{C}$ .

Therefore the cooler air valves (AV) are now disconnected from the feed forward drive and connected with the output of TC1. The fans are switched off. For mechanical reasons we don't want the accelerator continuously go up and down in temperature. Therefore, the heater is not reset by TA1, but must be manually reset. TA3 is a frost protection thermostat sensing directly in a tube of the cooler block.

If the outside air temperature drops below  $5^\circ\text{C}$ , valve V2 is opened by TA2, to make sure that water flows through the cooler. The losses in the cooler will now increase because the average water temperature in the cooler has been increased. This can cause a drop of  $T_h$ , resulting in more heater power. If the temperature in the cooler still drops below  $5^\circ\text{C}$ , the heater is set on maximum power level by TA3.

### Acknowledgement

The work described in this paper is part of the research program of the National Institute for Nuclear and High Energy Physics, section Nuclear Physics (NIKHEF-K), made possible by financial support from the Foundation for Fundamental Research on Matter (F.O.M.) and the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).