Temperature stabilisation of the accelerating structure

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Abstract

An important issue for the operation of a Linear Collider with heavy beam loading is the temperature stability of the accelerating structure. The phase and energy error is a function of the temperature distribution on the surface of the accelerating structure. Calculations prove, that keeping the temperature constant at a specific point on constant gradient accelerating structure minimises the energy error. This will be used for a feedback system. The temperature at this point is a function of the inlet water temperature, the average RF-power and the beam loading.

Temperature Distribution

An important issue for the operation of a Linear Collider with heavy beam loading is the temperature stability on the accelerating structure. The heat source is the difference of the total input power and the power extracted by beam loading. This difference can be calculated as the vector sum of the accelerating voltage and the beam loading. The shunt impedance, the altennation , the repetition rate and the pulse length are additional parameters. The phase error itself is a function of the temperature distribution calculated by this difference voltage. It is a function of the wavelength, the group velocity, the thermal expansion coefficient and the temperature difference between the steady-state situation and the instantaneous average temperature at every point on the surface [1].

The taper of the group velocity is linear and its value at the inlet side is ≅ 4% and at the outlet side ≅ 1.3 % of the velocity of light. The temperature rises almost linear, but the temperature distribution on the surface is not.
In order to calculate this temperature distribution the following assumptions were made :

- the heat flow over the circumference is at every point the same
- because of the symmetry only 1/8 of the geometry is calculated
- the temperature gradient over the thickness has been neglected
- the water inlet and outlet are on the same side as the beam input (counter flow)

The following picture shows the average temperature between the cooling tubes.

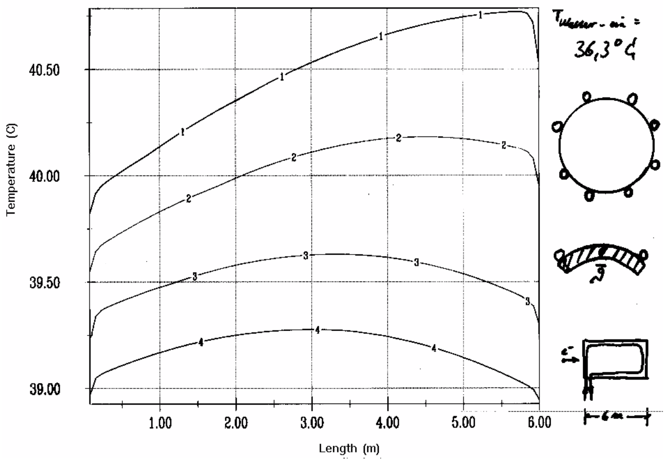

Fig. 1 : Distribution of the surface temperature
curve 1 : no beam
curve 2 : beam current 100 mA
curve 3 : beam current 200 mA
curve 4 : beam current 300 mA

The temperature at the surface rises along the length of the structure in absence of beam current. With increasing beam current the power which is dissipated along the structure decreases. Therefore the heat flow into the water is lower at the end of the structure than at the beginning. This effect is more pronounced with increasing beam current. Because the heat flow from the surface to the water is a function of the temperature difference between them, the surface temperature increases at first and then decreases along the length with increasing currents.

The strong gradients on both ends are produced by the heat flow into the tubes and in addition the return of the water at the end.

The temperature distribution in a 3D-plot is shown in the next picture. The beam current is 300 mA

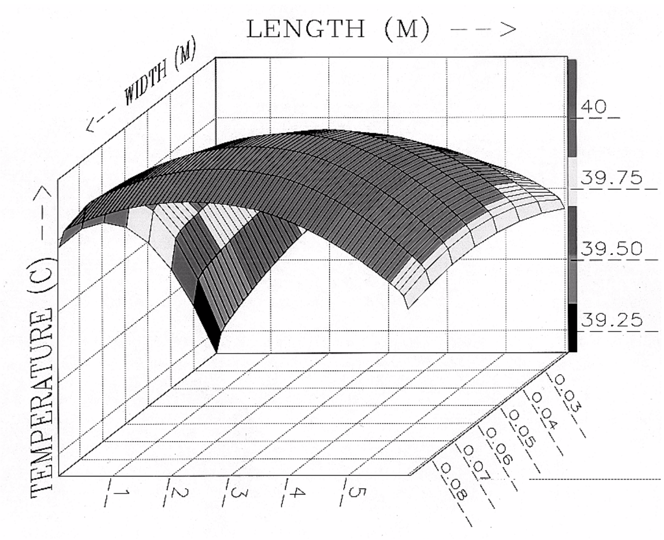

Fig. 2 : Distribution of the surface temperature
beam current 300 mA

The next picture shows the phase error caused by the temperature distribution from figure 1. The temperature for the steady-state system was arranged to be 40 ^{0}C with a constant temperature at the inlet.

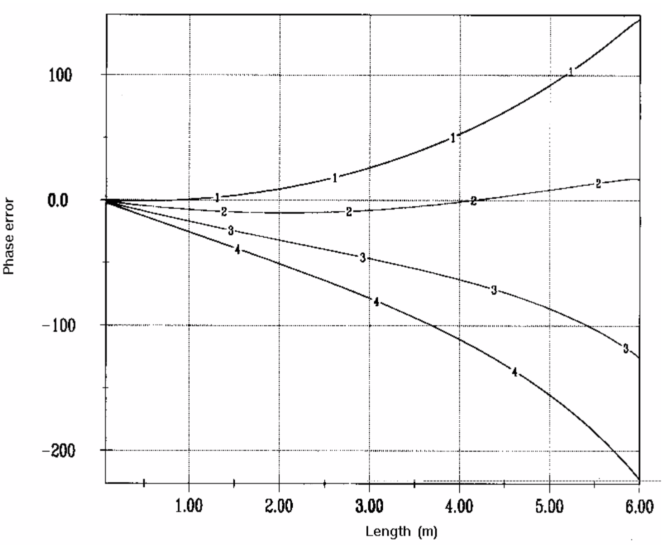

Fig. 3 : Integrated Phase error along the section
curve 1 : no beam
curve 2 : beam current 100 mA
curve 3 : beam current 200 mA
curve 4 : beam current 300 mA

The integrated phase error turns into a beam energy error along the structure length. This energy error on the other hand can be minimised by changing the inlet water temperature unless the integrated phase error is zero, which is always possible because positive and negative phase deviations appear along zero. Calculation shows that at a specific point the temperature remains constant with varying beam or RF power, and varying inlet water temperature for compensation.[2]

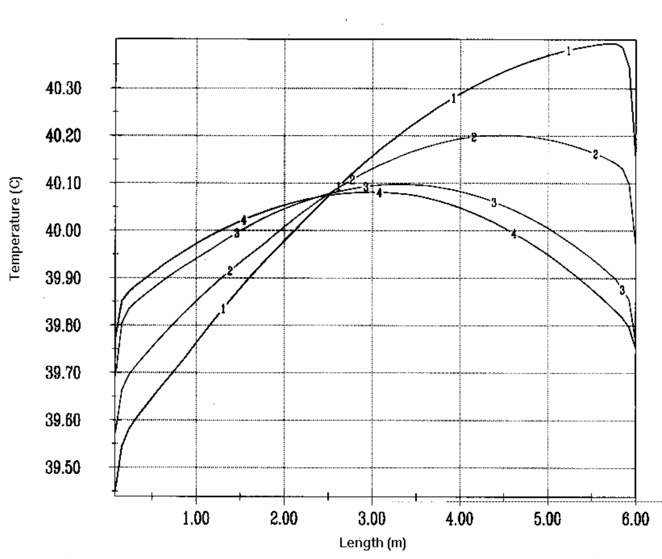

Fig. 4 : Surface temperature with optimised inlet water
temperature in order to cancel the sum of the
single cell phase error towards the end
of the structure
curve 1 : no beam
curve 2 : beam current 100 mA
curve 3 : beam current 200 mA
curve 4 : beam current 300 mA

Cooling circuit

There are two layouts for the cooling circuit of the linac :
The **first** one is for the test-facility. The main demand for this cooling circuit was the high temperature stability over a large range of power deviations.[3]
The **second** is for the overall layout. The main demand here was to have a simple cooling system with only a few elements but flexible power handling capabilities

For the control of both systems the same elements will be used :
the temperature is measured by a sensor at the specific point, the temperature of the inlet water and the RF-power difference between the input and output. The last one will be used for a fast feedback system: with beam loading a definite input temperature is required and therefore it is possible to change the inlet water temperature before the surface temperature changes. The time available to do this depends on the water flow and the heat capacity of the structure and is about two seconds. Therefore in both systems a hot and a cold line is required and the reqired temperature is mixed by fast pneumatic mixing valves.

At the test-facility the solenoid of the klystron is used as the main heat source for the hot line and for the power reduction (cool line) a heat exanger. The rectangular waveguides have a similar control system. The scheme is presented in the next picture

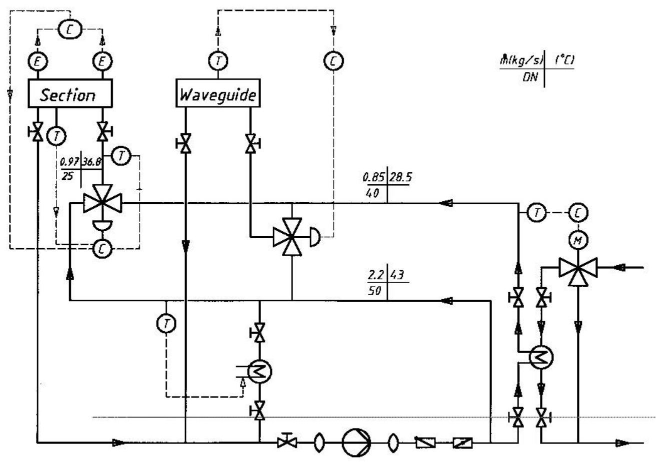

Fig. 5 : Outline of the cooling system for the test-facility

For this circuit a simulation [4] was made (without the feedback-system !): the power in the section and in the waveguide was reduced by a factor of five (this means e.g. changing the repetition frequency from 50 Hz to 10 Hz). The next picture shows the result:

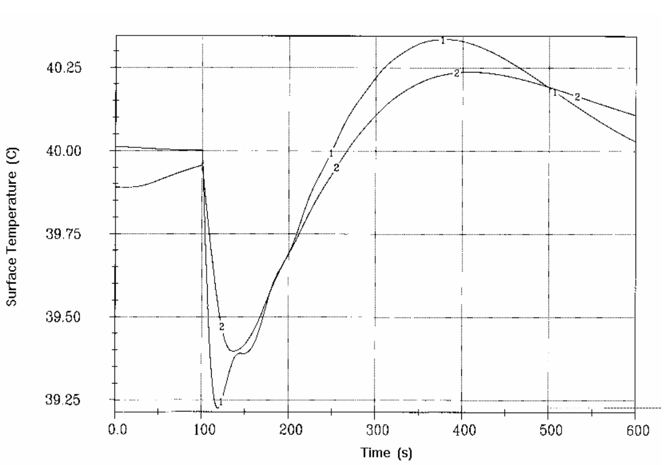

Fig. 6 : Temperature of the surface by changing the repetition frequency from 50 Hz to 10 Hz
curve 1 : accelerating structure temperature
curve 2 : waveguide temperature

For the Linac Collider the klystron collector is used as a main heater source. It isn't possible to connect the heater with the supply water tube because the waterflow wouldn't be enough for cooling the section. Therefore it is connected with the return water tube and so a booster-pump is needed. The next picture shows such a possibility using only a few elements but on the other hand not applicable for a large range of power changes.

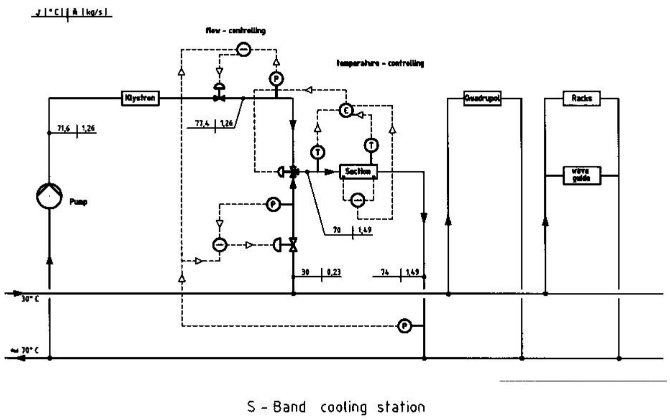

Fig. 7 : Outline of the cooling system, overall layout

For this circuit a simulation was also made without the advantages of the feedback-sytem for the control. The next picture shows the inlet water temperature into the structure and the structure temperature when the power into the structure and klystron is reduced to a third of the previous value

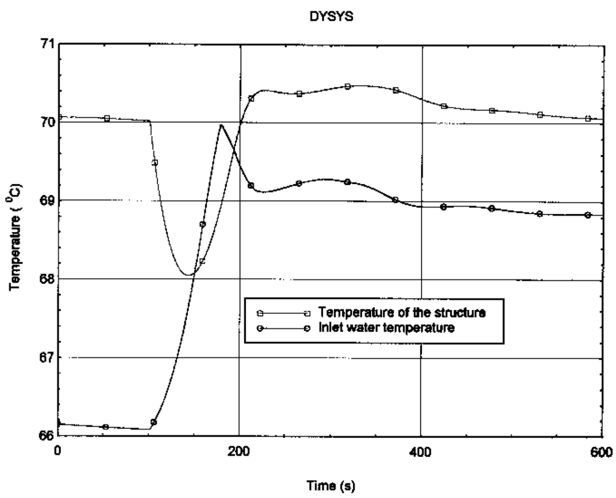

Fig. 8 : Temperatures by changing the power into the structure and klystron

References

[1] P. Lapostolle, A.Septier, 'Linear Accelerators Accelerating Structures Technology ', North Holland Publishing Company, Amsterdam 1980
[2] J. Hamsom, 'High duty factor electron linac'
[3] J.G. Noomen, N.Geuzebrouk, C. Schiebaan, ' A modular cooling system for the MEA high duty factor electron linac, IEEE Transactions on Nuclear Science, Vol NS - 28, No 3
[4] Frank-R. Ullrich, 'Leistungsrampen des PETRA-Ringes' , MKK-Aktennotiz 24/91 , DESY Internal Report