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Temperature Control of the ESS Phase Reference Line

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Introduction and Background

Fig. 1: Phase reference line of copper (left), heating cables and temperature sensors attached (middle), and insulation applied (right).

- Phase reference signals for all accelerating components along the 600 [m] linear accelerator.
- Radio-frequency (RF) wave in a rigid coaxial line made of copper. Temperature changes induce phase instability because of length variations of the line (17 [ppm/deg C]).
- Phase change $\Delta \phi$ between $x_i$ and $x_f$ at time $t$ proportional according to

$$\Delta \phi \sim \int_0^t T(x,t) - T_{cal}(x) \, dx,$$

with $T$ and $T_{cal}$ the current temperature and the temperature at calibration, respectively.

- Requirement: $\max_{x,t} |T(x,t) - T_{cal}(x)| \leq 0.1$ [deg C] for 600 [m] phase reference line.

Requirements for temperature stabilization of the line within the requirements.

Models of the heat dynamics

Feedback control

Phase reference signals

Control Design

EPICS (controller implementation and monitoring)

x 30

Prototype Setup at Lund University

Fig. 2: Block diagram of the process dynamics (left) and schematics of phase reference line cross section with insulation (right).

- Feedback control used for temperature stabilization of the line within the requirements.
- Models of the heat dynamics developed and simulated using both analytic and numerical solutions of the partial differential equation for heat diffusion $\nabla^2 \cdot k \nabla T + Q = \rho \cdot c \cdot \frac{dT}{dt}$.
- Inputs and disturbances: Ambient air $T_{air}$, heat by controller $u$, and RF heat losses $mgp$.

Simulation Results

Fig. 3: Stationary temperature in cross section with heat losses in conductors (left) and time & radial temperature dependence (right).

- Analytic (black) and Numerical (red) Step Response from $T_{air}$
- Temperature on Copper
- Temperature on End Flanges
- Temperature on Direction Couplers
- Temperature on Direction Couplers
- Experimental Results

Further experimental results available in the report:

Fig. 4: A 4.5 [m] prototype with two directional couplers was setup and used for controller development and experimental evaluation.

- A prototype control system for temperature stabilization of the ESS phase reference line.
- Observed control error variations with respect to the calibrated temperature (also for out-of-loop temperature sensors) clearly within $\max_{x,t} |T(x,t) - T_{cal}(x)| \leq 0.1$ [deg C].

Conclusions