# INVESTIGATION INTO THE AIR CONDITIONING OF LONG UNDULATOR SECTIONS IN TUNNELS

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*Abstract*

The new generation of X-FEL synchrotron radiation sources requires long undulator sections. The temperatures have to be controlled over long distances to ensure an uniform temperature distribution. At the TESLA project the undulators are located in tunnels. The tunnels should be built with a cross section as small as possible to reduce the tunnel costs. The limited space prevents the installation of space consuming air ducts between the undulator sections and the air conditioning equipment. The requirements for the temperature stability of the other tunnel sections are much lower which motivates a separation of the normal tunnel section from the undulator section. A dividing wall is the regular solution but it has some big disadvantages. A wall will complicate the monorail operation or impede the smoke removal in case of fire. A new air conditioning system will be installed and tested in the FEL tunnel of the TESLA Test Facility phase 2 (TTF2). The calculations of the temperature distribution will be presented.

## 1 INTRODUCTION

The undulators in the TTF tunnel require a constant temperature over a length of 75 m. The temperature must be 22 °C with a tolerance of ±1 °C to ensure a uniform magnet field of the permanent magnets. The tolerance may not exceed 1 °C over the whole length otherwise the SASE effect of the undulators does not work. The temperature of the tunnel air is influenced by inner heat sources including cables, pipes, electronic equipment and tunnel illumination. Other sources are the exchange of outside and hall air as well as the heat penetration through the sand and concrete. The variations of the outside temperature arise from diurnal variations, weather fronts and the seasons of the year.

Interesting questions concern the design of the air conditioning and heating systems. Therefore the company Krantz TKT made an investigation with the simulation program TAS [2].

## 2 LAYOUT OF THE FEL TUNNEL

The FEL tunnel is located between the building 28a and the FEL experimental hall 28c (see Fig. 1). The tunnel has a length of 125 m and a diameter of 5.20 m and matches the design of the TESLA Technical Design Report TDR [1]. The tunnel is covered by sand in the form of a blunt pyramid. The thickness of the sand is over 3 m.

The driveway to the tunnel looks like a hockey stick. The gate of the tunnel entrance is 4 x 5 m introduces leakage to the outside air. For reference, we define the air leak as leakage which stem from an equivalent opening in a door or wall. Adjacent to this gate is the inlet for the tunnel ventilation. The tunnel ventilation has an air heater. The tunnel has no connection to the building 28c and on the other end the tunnel is open to the building 28a. The tunnel continues inside the building 28a and 28. Inside the TTF hall the tunnel is built up by concrete blocks with the dimension of 6 x 4 m. Between the tunnel and the hall area are holes for access. This leads to an exchange of the outside, tunnel and hall air.

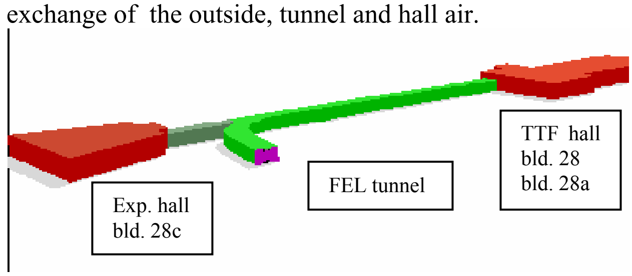


Fig. 1: Scheme of the FEL tunnel and TTF hall

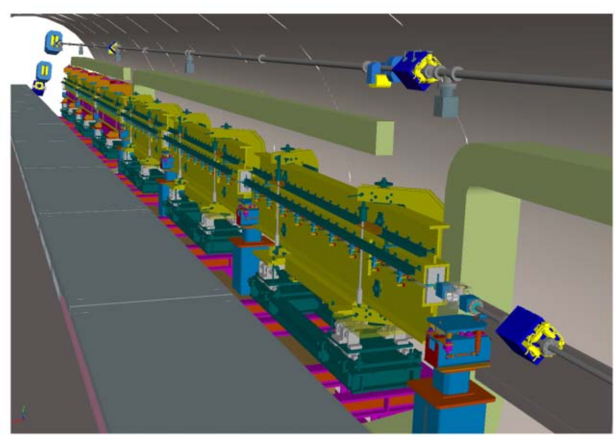

Fig. 2: Computer view into the FEL tunnel

The undulator section is shown in Fig. 2. The air inlet canals, depicted in light green, are located above the undulators. The air outlet canals are shown below. The air flows radially into the tunnel. The air conditioning is split up into small units. They are set up in the midway of the tunnel. The units are incorporated in containers. The top of the containers are drawn in grey. The containers can be removed by the monorail. A dividing wall between segment 3,4 and 1,2 (Fig. 3) would isolate the undulator section from the adjacent machine, but it will disturb the monorail operation and would restrict the smoke exhaust.

Therefore the following calculations were made without dividing walls.

## 3 PARAMETERS FOR CALCULATION

The tunnel is subdivided in 7 tunnel segments and the TTF hall. The undulators are installed in segment 2 and 3.

The parameters are:

| Tunnel: | | Undulator: |
|---|---|---|
| diameter | 5,2 m | |
| circumference | 16,3 m | |
| cross area | 21,2 m² | |
| length | 125 m | 75 m |
| wall area | 2038 m² | 1225 m² |
| volume | 2650 m³ | 1592 m³ |

| Sand cover: | |
|---|---|
| thickness | s >3 m |
| thermal conductivity | $\lambda$ = 1.5 W/m·K |
| density | $\rho$ = 1700 kg/m³ |
| cp-value | cp = 880 J/kg·K |
| ground water | T = 10.9 °C |

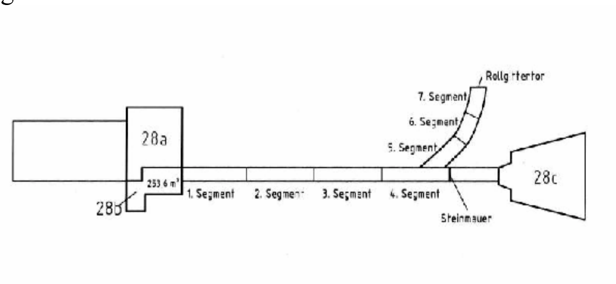


Fig. 3: Segmentation of the tunnel and TTF hall

Inside the segments the temperature and the humidity are constant but the air exchanges between the segments. The air flow determines the energy transport in the longitudinal direction. The energy flow in the transverse direction goes through the tunnel wall, the surrounding sand and the ground water.

## 4 CALCULATION

### *4.1 Tunnel with natural air exchange*

The first calculations were made for an empty tunnel without any forced ventilation or heat sources. The thermal flow into the tunnel comes only through the air leakage, the sand overlay and the ground water. The weather data were taken from a weather station near Hamburg. The simulation result for one year is shown in Fig. 4. The variations of the outside air temperature is damped by the sand overlay. The phase shift comes from low velocity of the caloric through the sand. Surprising is that the average of the sine wave of the tunnel air is higher than the outside air. The air exchange through the holes from the warm hall (18 °C in winter) is probably the reason for this observation.

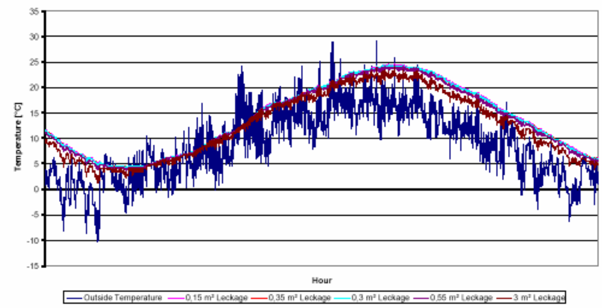


Fig. 4: Temperature gradient in segment 3 over one year
blue: outside air temperature
red brown: 3 m² leakage opening
light blue: 0.3 m² leakage opening

The tunnel air with natural air exchange varies from 5 °C in spring to 25 °C in autumn. The average temperature is 15 °C ± 10 °C. The dependence on the opening at the tunnel ends is small. This is not the same in the case of one day. The temperature gradient of one day is of concern with respect to short-term time stability. The day number is not really relevant for the short-term stability but the size of the opening. The calculated temperature variations are shown for the coldest (Fig. 5) and warmest day (Fig. 6) of the year. The short-term temperature gradients are the same but the absolute values are different. The day number is not really relevant for the short-term stability but the size of the opening.

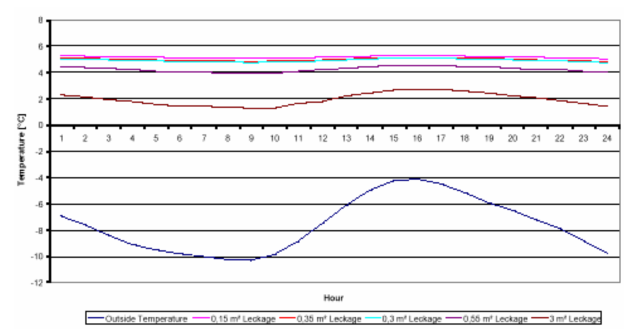


Fig. 5: Temperature gradient in segment 3 of the coldest day

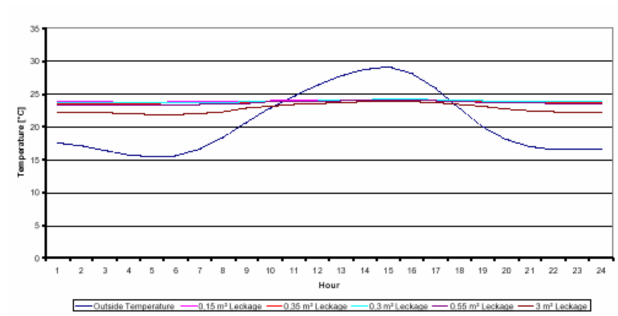


Fig. 6: Temperature gradients in segment 3 of the warmest day

### *4.2 Tunnel with heat sources*

During operation of the accelerator with beam there are heat losses to the tunnel air. The losses stem from the power cables, electronic racks, illumination etc. These inner losses in the tunnel are assumed with 200 W/m in segment 2 and 3, in which the undulators are installed. The result of the calculations show Fig. 7 taking into account the additional heat load.

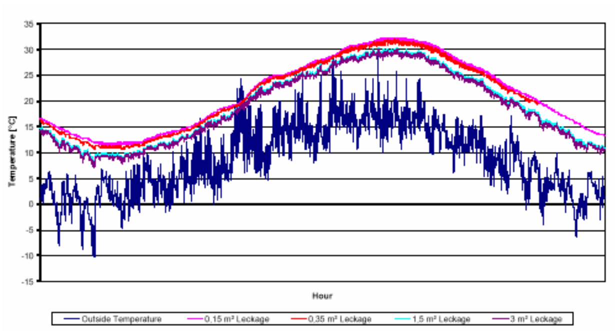


Fig. 7: Temperature gradient in segment 3 over one year, 200 W/m losses in segment 2 and 3

The results of this investigation are:

- The average of the tunnel air temperature is 5 °C higher.
- The maximum temperature exceeds 30 °C.
- Air conditioning for the undulator sections is necessary.

### *4.3 Design of the air conditioning system*

Air conditioning is required to guarantee the requested temperature of 22 °C ±1°C. The requirements for the air conditioning are during the:

a) installation phase: tunnel heating is required the whole year

b) FEL operation phase: heating in winter time and air cooling in summer time

c) shut down phase: heating in winter time and air cooling for a short time in summer

There were several calculations made to find the optimum for an uniform temperature distribution along the 75 m undulator section. The final result that an air conditioning of the inlet air is necessary. In this case one can remove the dividing walls.

Heating the tunnel and reaching steady-state conditions will take time because of long time constants. The installed capability of the heaters should be over-designed to speed the heating of the tunnel walls and the undulator sections. The safety margin should be 50 % of the calculated power.

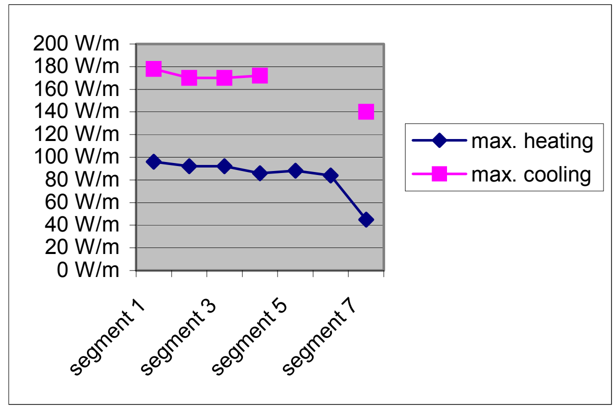


Fig. 8: Cooling and heating capability for 22 °C

## 5 CONCLUSION

The FEL undulators demand an uniform tunnel air temperature over 75 m. The sand overlay over the tunnel is at least 3 m but the seasonal variations penetrate through it. The air exchange between the outside air on one end and the TTF hall on the other side causes short time disturbance of the tunnel temperature. The calculations show that heating and cooling of the tunnel air is necessary. During the installation period only heating is required to bring up the tunnel temperature to 22 °C. This reduces the warm-up-time during the commissioning of the machine. For FEL operation a system of distributed air conditioning units with local radial ventilation in the undulator section is sufficient. Dividing walls are not necessary.

The influence of the air leakage rate of the tunnel air temperature at the tunnel ends is hard to estimate. The estimated error of the short time behaviour is about 50%. The weather seasons have no major impact when the tunnel is closed and the air exchange is minor.

In the future the TESLA X-FEL facility may be built in Ellerhoop near Hamburg. The undulators are installed in tunnels which are 20 m under the surface. The length of the undulator sections are up to 150 m. The temperature demands are 22 °C ±0.3 °C over the length of 150 m. The challenges are the length of the undulators and the small tunnel air temperature tolerances. This needs further investigations.

## 6 REFERENCES

[1] TESLA Technical Design Report, Part V, The X-Ray Free Electron Laser, DESY 2001 – 011, March 2001

[2] Numerische Gebäudesimulation für den Testtunnel TESLA-Undulator, Dr.-Ing. E. Fiedler, Bergisch Gladbach, May 2002