4.9 Conventional Facilities and Site Considerations

4.9.1 Introduction

Different conventional facilities must be set up for the future Linear Collider. The detailed considerations in the following assume that the Linear Collider facility is built at DESY in Hamburg. Not all of them are valid at other locations without modifications. In any case coupling a new large accelerator complex to an existing laboratory site is advantageous from the point of view of investment cost, construction time and available know-how in accelerator technology, particle physics and synchrotron radiation research. Further boundary conditions we take into account here are the integration of the Free Electron Laser facility and the possibility to make use of existing accelerators and infrastructure at the DESY site.

These considerations lead us to a layout where the tunnel starts on the DESY site and runs northerly, along a straight section of HERA. By far the largest single construction is that of the tunnel for the accelerators, the beam line and for the various auxiliary components. This tunnel has a total length of approximately 33 km. The S-Band Linear Collider is housed in a double tunnel. The linear accelerator and beam lines are installed in a tunnel with an inner diameter of 2.5 m, while the service tunnel for the klystrons, modulators and auxiliary components has an inner diameter of 4 m. The accelerator tunnel is closed during beam operation but entry to the service tunnel is permitted so that repair and maintenance of components is possible during beam operation. An underground experimental hall for the Particle Physics detector is located in the center, surrounded by a tunnel for the damping rings. The central area layed out to also accomodate the X-ray Free Electron Laser laboratory. Administrative, social and technical buildings are placed on this common site, too. Additional underground halls and tunnels for the return arcs of the beam transfer lines are located at the two ends of the linac tunnel.

4.9.2 Overall Site Layout

The Linear Collider tunnel will be built underground at a depth of about 15 m. The main part of the tunnel is in sand and in ground water. With well-proven tunnel boring technology, buildings at the surface above the tunnel remain completely unaffected. As shown in the top view (see Fig. 4.10.1) the complete tunnel is straight (except for a short initial section, see below) and in a profile view (see Fig. 4.10.2) it is mainly horizontal (i.e. following the earth's curvature). HERA is rotated counterclockwise by an angle of 22.7^o out of the northerly orientation (approximately North-Northwest orientation). This orientation was chosen as the main direction of the Linear Collider. The beginning of the tunnel starts laterally shifted with respect to the HERA hall West and after 250 m bends with a radius of 500 m into the main direction. The main electron linac starts at the beginning of the straight tunnel. The initial section of the tunnel houses the pre-linac together with the beam preparation for the FEL operation. The injector linacs for the collider are located in the final focus section close to the

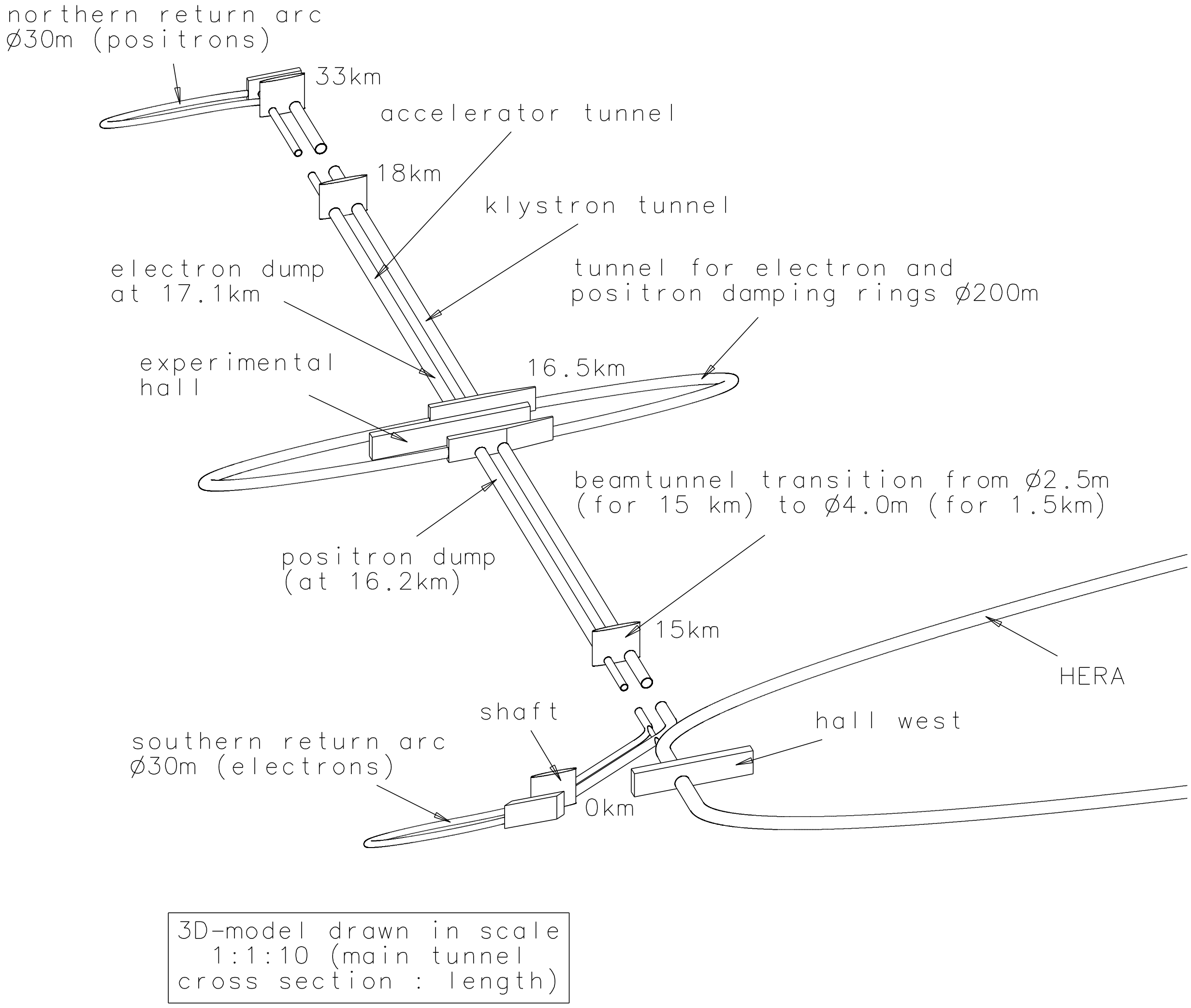

Figure 4.9.1: *Overall view of the S-Band Linear Collider at DESY.*

central area.

The interaction point HERA West is about 20 m above sea level. The axis of the main part of the linac tunnel lies about 10 m below sea level. The straight section HERA West has a slope of about 8 mrad out of the horizontal. Therefore there is a smooth transition from the initial slope into the horizontal direction with a bending radius of about 1000 km. Figure 4.10.2 shows an expanded profile of the linear collider area North-Northwest of DESY together with the collider tunnel. The depth of the tunnel below ground level of about 15 m is more than sufficient to guarantee shielding against radiation. The spacing between the linac tunnel and the service tunnel is 5 m (wall-to-wall). The tunnels are connected by 300 mm diameter pipes every 25 m. At 2 km intervals cross passages with a diameter of 2.5 m are foreseen. The tunnel is below

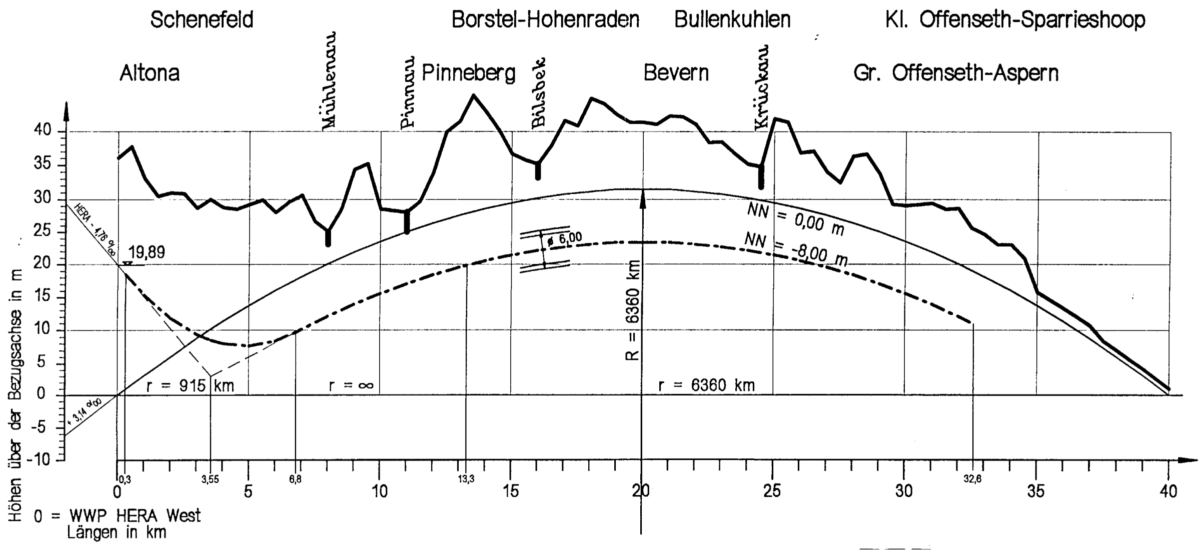

Figure 4.9.2: *Expanded profile of the Linear Collider area North-Northwest of DESY.*

the ground water level over nearly the entire length.

The service tunnel will be built by a tunnel boring machine similar to that used to construct the HERA tunnel. Identical concrete segments have been chosen for the lining of the auxiliary tunnel. The minimum inner diameter is 4 m, with the actual diameter increased to 4.2 m due to tolerances in the tunnel boring. A slightly different tunnel boring technology can be chosen for the accelerator tunnel, the return arcs and for the the damping ring tunnel. These tunnels will also be formed by a tunnel boring machine, but of a more simplified design. In this case complete concrete pipes are chosen for the lining of the accelerator tunnel. The tunnel boring machine and the complete piping will be moved by huge hydraulic cylinders. This tunnel boring technology is named “micro tunneling”. An underground experimental hall is in the center of the Linear Collider complex, with additional underground halls at the two opposite ends. These three halls are built in open-cut excavations. The experimental hall and the end station are located on new areas. The start station together with the main return arc are located on the existing DESY area; no additional area is needed for the linac itself, though for the tunnel boring it could be an advantage to use intermediate temporary shafts. Two damping rings are used for the damping of the electron and positron beams before acceleration in the main linac. The damping rings are located in a common tunnel around the experimental hall. The diameter of the tunnel is 2.5 m and the arcs have a radius of 100 m. The total length reserved for the beam delivery system with the interaction point in the center is 3 km. In addition to the high energy beam lines the accelerator tunnel houses the positron source, the positron and electron pre-linacs and the beam extraction lines to the dumps. The inner diameter of the accelerator tunnel is extended in this region to 4 m, to accommodate all components.

4.9.3 DESY Site

The Linear Collider tunnel starts on the existing DESY area next to the HERA hall West. At the beginning there is an underground hall. The tunnel boring machines for the main tunnels and for the return arc start in this hall. The starting point for the main tunnel boring machines is laterally shifted from the HERA hall West. After a distance of about 250 m the machines bend with a radius of 500 m into the main direction. From that point the tunnel is straight in a top view up to the end station. The same point is the beginning of the main linac. The initial section houses the beam preparation for the FEL operation. The connection between the collider and the HERA tunnel can be made by a small tunnel.

4.9.4 Experimental Area

The experimental hall with the interaction point is located in the center of the Linear Collider, at a distance of 16.5 km from the interaction point HERA West. The underground hall has an area of 30 m $\times$ 82 m and a height of 20 m below the portal crane. Space for a second hall with the same dimensions and laterally shifted is available for a second detector. The X-ray Free Electron Laser Laboratory is located together on a common area with the administrative-, social- and technical buildings. The electron dump is located at a distance of 800 m from the interaction point; the positron dump at a distance of 300 m. Both dumps are downwards orientated with a minimum angle of 20 mrad. Small underground halls with access from the ground level are foreseen for the dumps. The total length of the final focus area is 3 km, the length of the new DESY site about 800 m. The positron dump is located outside below an external area.

4.9.5 End Station

The end station is a small underground hall. This hall is necessary as a starting point for the tunnel boring, for access to the tunnel during installation and operation and for one connection of the dog bone arc. An additional shaft is necessary for the other connection for the return arc.

4.9.6 Tunnel Layout

The main components installed in the collider tunnels are the S-band accelerating sections mounted on girders, the beam lines for the low emittance and low energy electron and positron beams and the beam lines for the FEL Laboratory and the ELFE@DESY (Nuclear Physics) operation. In addition there are numerous auxiliary components including klystrons and modulators. During beam operation access is necessary to these components. For example the klystrons and modulators have to be repaired quasi continuously due to the large number and their relatively short lifetime. Thus for the S-Band Linear Collider a double tunnel solution was chosen. A small tunnel with an inner diameter of 2.5 m houses the S-band linear accelerator and the beam lines. A larger tunnel with an inner diameter of 4 m houses the auxiliary components. The tunnels are connected every 25 m by pipes of 300 mm inner diameter. In Figure 4.10.3 a tunnel cross section is shown, chosen at a position of the most complex situation. The cross section is vertically divided into two parts. One part is for the linear accelerator and the beam lines. The center of mass of an S-band section is just below the hook of the transport system. This allows an easier installation of most of the components. The transport system is a so-called monorail, utilizing an I-beam fixed at the top of the tunnel. The vehicle is used to transport equipment and persons. The other part is the main walk path, which is free at all times for emergency exit and for the lines-of-sight for optical survey. The auxiliary tunnel is divided horizontally and vertically into two parts. The lower part is reserved for cable connections and cooling pipes. The upper part is reserved for the horizontally oriented klystrons , modulators, electronics, power supplies and distribution, the transport system, similar to that in the other tunnel and for the emergency walk path. The two tunnels are connected by pipes housing the wave guides, which connect the klystrons and accelerating structures.

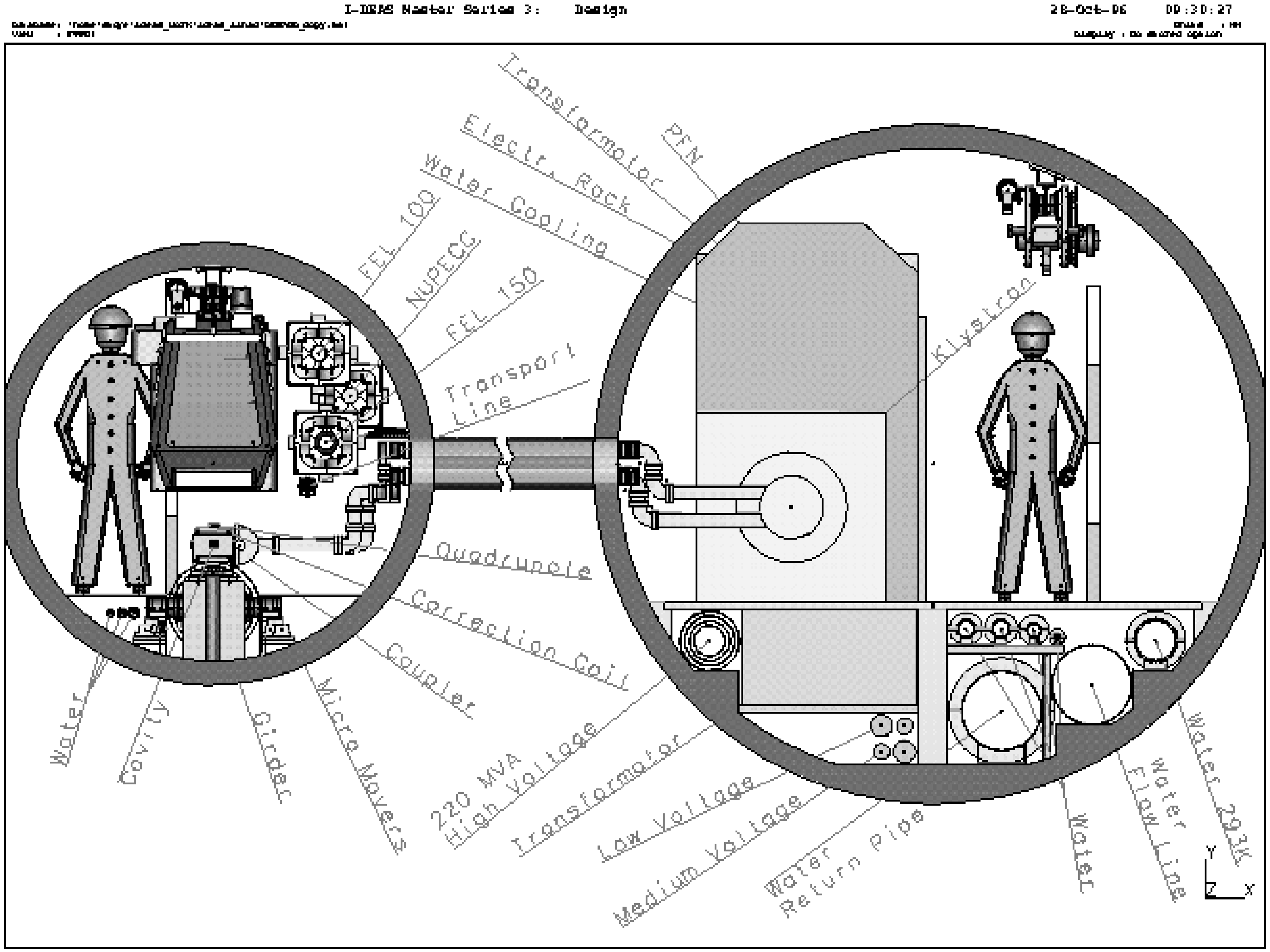

Figure 4.9.3: *Cross section of the S-Band Linear Collider tunnel.*

4.9.7 Power Distribution

The power distribution system is layed out for a total power of 225 MVA. This takes into account the reactive power, all subsystems and a safety margin for the linac power consumption (note that the nominal operating power is 140 MW). Three high voltage lines (110 kV) are foreseen at the two end stations and at the central area. After transformation to 36 kV, the power is distributed through the service tunnel (containing the klystrons and modulators) by 4 lines using 240 mm^2 Cu-cables. Each of these medium-high voltage networks supplies about 7.5 km of linac with 63 transformers, placed in the tunnel, which provide the low-voltage (690 V) network for the modulators and for the magnet power supplies. With this two-stage distribution system, power losses in the tunnel are reduced to 60 W/m in the medium-high voltage network and 30 W/m in the low-voltage network. The cable cross section can be successively reduced along the chain of 63 transformers. Heat losses in the transformers are removed from the tunnel by oil cooling and water heat exchangers. Installation of the transformers takes place in spaces available between modulators.

The cables are bundled in groups of three to minimize stray fields. In the linac tunnel, at a distance of about 6 m from the power line, the stray field amounts to less than 2 μT. In case machine operation demands lower stray fields, a solution with a co-axial power line is also conceivable.

In total some 1140 quadrupoles and 1720 correction magnets are installed in the linac (one vertical steerer for every quadrupole, one horizontal steerer for every 2nd quadrupole). All magnets have to be powered individually for optimum beam optics and beam-based alignment flexibility. In order to minimize cable costs and power losses, the power suppies are installed in the service tunnel. These devices are built in switched mode technology, which reduces the required volume and provides a high power conversion efficiency. For each linac, the total AC-power required for the magnets amounts to about 3 MW. Some additional power is needed for the beam transfer lines and for the beam delivery system.

4.9.8 Water Cooling System

The number of access points to the linear collider tunnel is minimized for cost reasons. We expect to have only three entrance points to the main tunnel where main supplies like water, air and electricity can be brought into the tunnel. This requires a carefully designed cooling system which is capable of transporting the power lost in the tunnel back to the surface. In order to reduce the amount of water, the beam pipe diameter and the velocity of water flow at the same time, maximum efficiency is required which leads to comparatively high operating temperatures of the components in the tunnel. We expect a water temperature of more than 70 C° in the return line. Such a high water temperature leads to an increase in efficiency of the heat exchangers and cooling towers as well, but also requires carefully heat shielded components in the tunnel to minimize the heat loss and keep the tunnel at reasonable temperatures. The layout for the cooling circuit of the S-Band linear accelerator is divided up into four separate

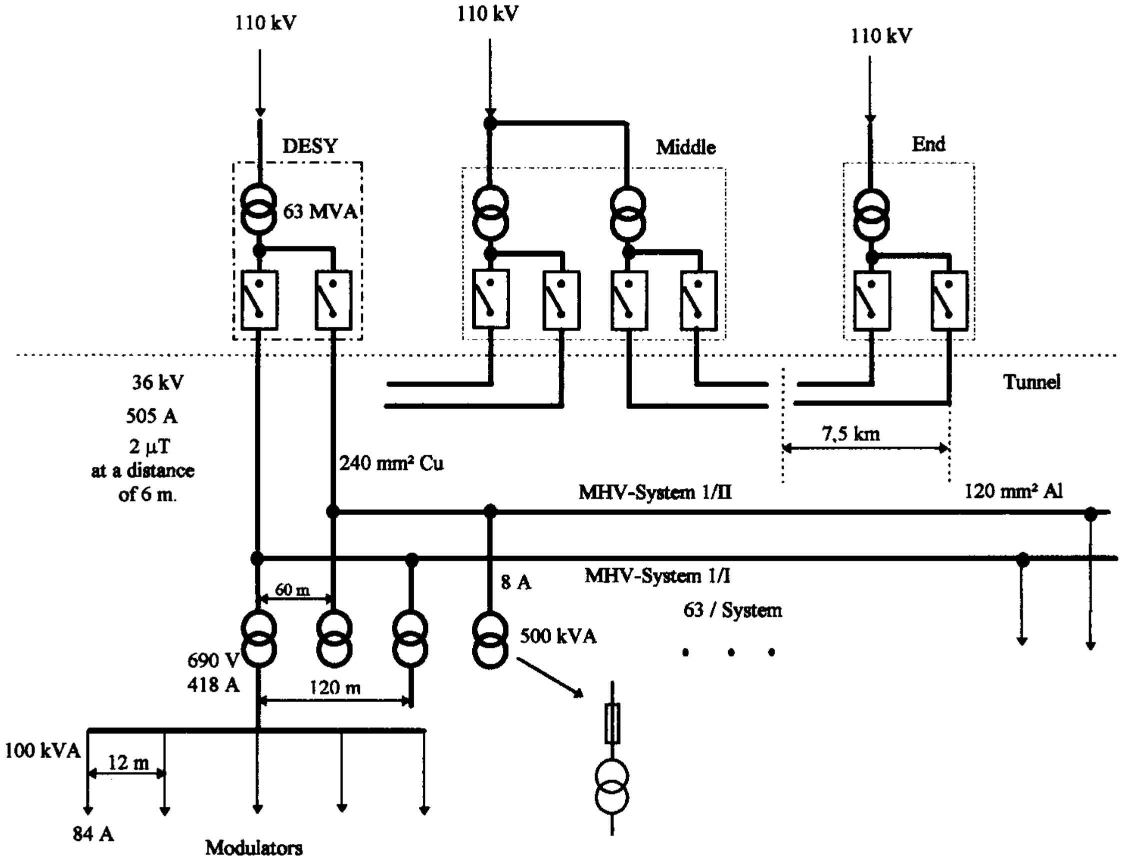

Figure 4.9.4: *Sketch of the power distribution system.*

cooling systems. Every cooling station has cooling towers, heat exchangers, pumps and control systems. In addition to the water system there will be a sub-cooling station for the air in the tunnel. This is important, because the air temperature in the tunnel increases with time due to residual power loss in the tunnel. The air cooling system heats up the cooling water from 15 C° to almost 30 C° and finally feeds the water into the main supply line. The diameter of the cold water tube is a function of the heat losses in the tunnel which we assume to be 300 W/m at maximum. This requires that this part of the supply water is cooled down by a refrigerator system which itself is connected to the cooling tower water.

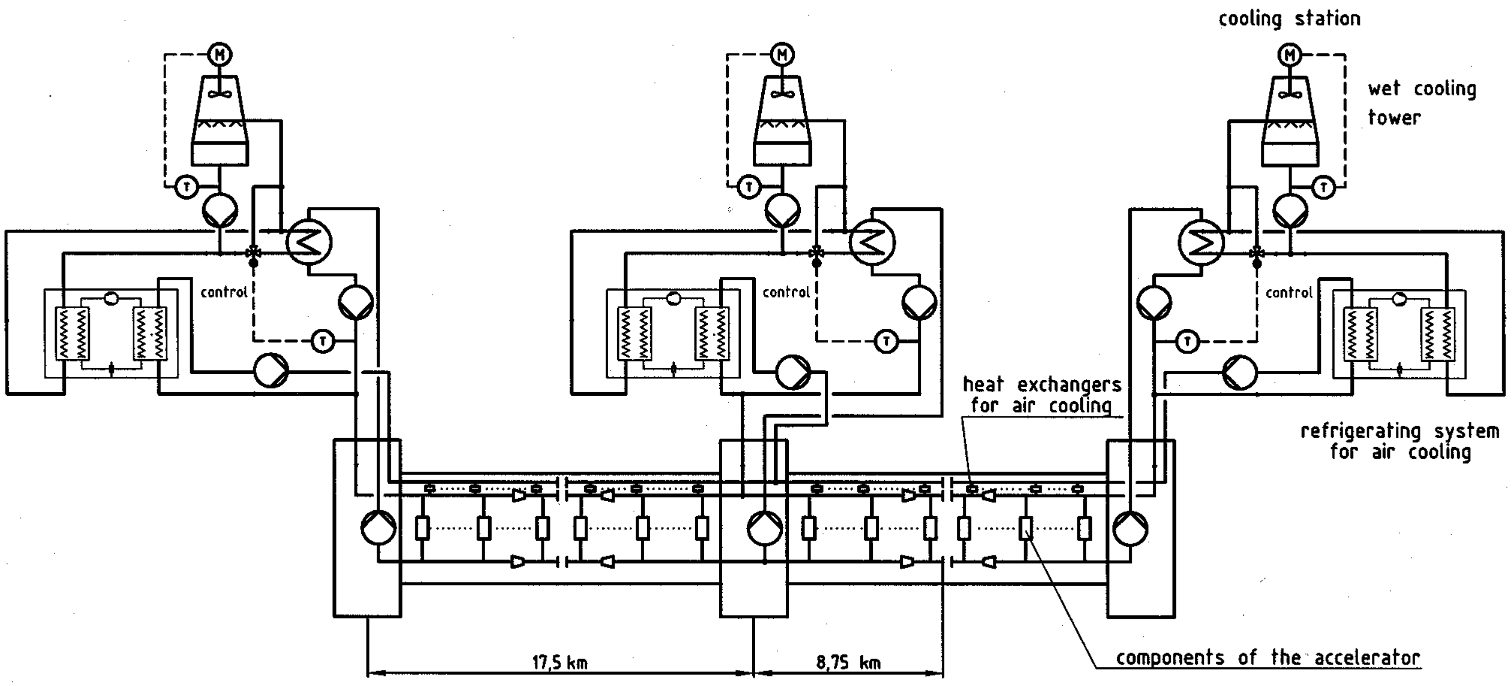

Figure 4.9.5: *Layout of the cooling plant for the linac. The middle station actually is twice as big as the end stations and consists of two stations.*

The cooling tower is a so called wet cooling tower which operates by evaporation of part of the water. An important number for such a cooling tower is the maximum humidity in the air which can be tolerated. A number derived from this is the wet bulb temperature. For this linac a value of 19.5 C° to 20.0 C° is preferable. Almost 25 towers for every station are required similar in size to those installed at DESY for the HERA ring. The fan velocity of the cooling towers will be controlled to maintain a constant temperature at the heat exchangers. The heat exchangers themselves will be controlled by a bypass system to provide a nearly constant temperature into the tunnel. The main tubes in the tunnel are distribution tubes. Because all elements are connected in parallel there will be a subdividing systems to avoid too many connections to the main tube which at the feed end have a diameter of almost 1 meter. The material of the main tubes is stainless steel and copper and copper for the distributing tubes. The length of the distribution system will be 14 to 28 meters, which is the distance between two or four sections. The next figure shows the elements of the distribution system in the tunnel.

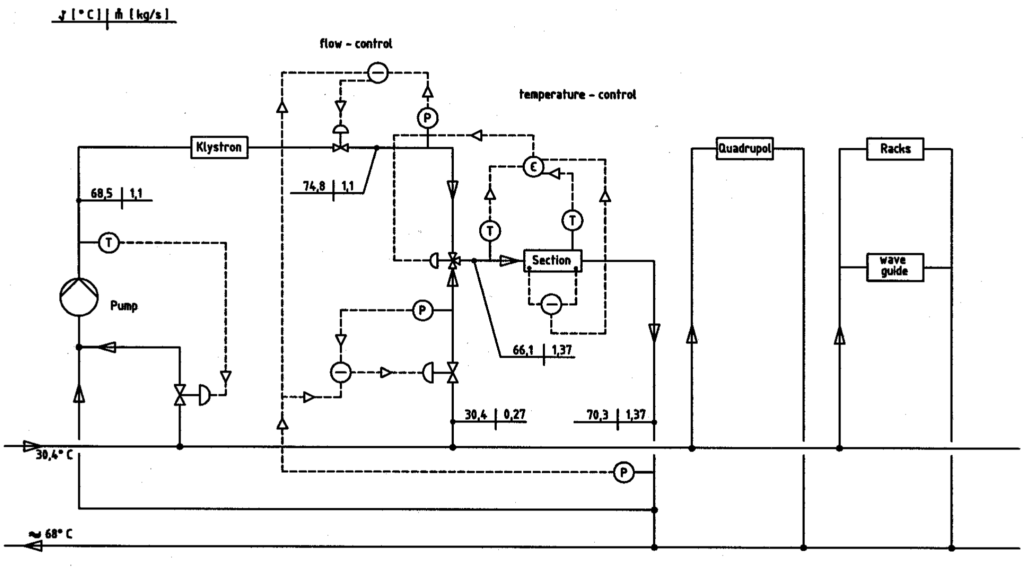

Figure 4.9.6: *The distribution system in the tunnel with the temperature control of the structures and the feedback/feed-forward controls.*

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 a constant gradient accelerating structure minimizes the energy error (see section 4.2.4). For control purposes the following values will be measured: the temperature 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 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. This cannot be done by heating or cooling. Therefore a hot and a cold line is required and the required temperature is mixed by fast pneumatic mixing valves. For this circuit a simulation was made without the advantages of the feedback-system for the control. Fig. 4.10.7 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.

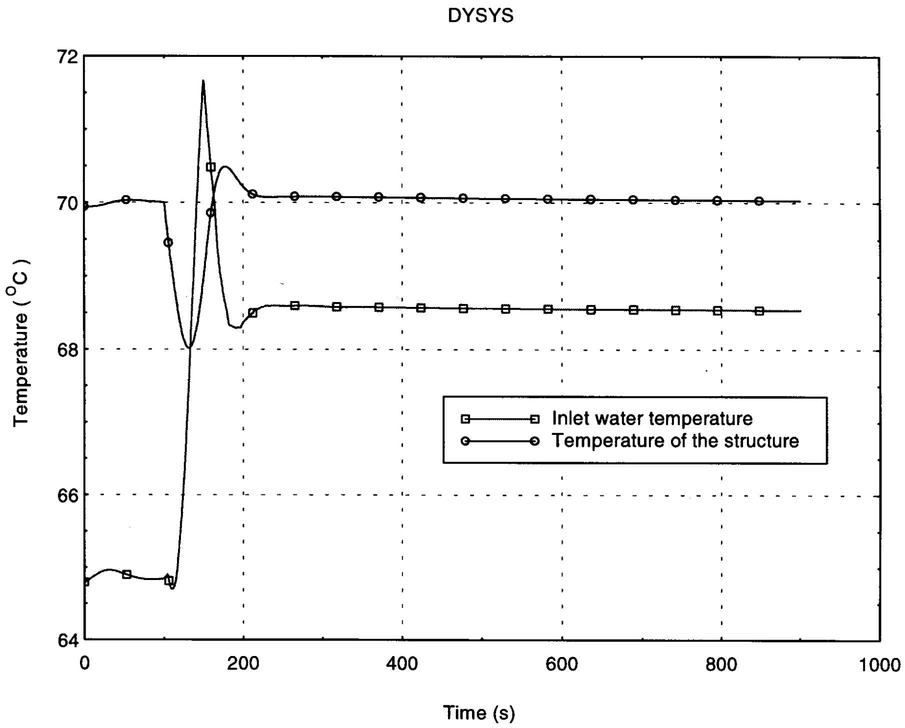

Figure 4.9.7: *Response of the cooling system to power change (3 times less) without any feed-forward and feedback.*

The water will be de-ionized with a conductivity of $1\mu S/cm$. Therefore the only possible materials are: stainless steel, copper and bronze (gun-metal) . The maximum pressure in some of the RF-elements is very low. Therefore booster pumps in the return water line will be necessary to keep the pressure in the return line as low as possible. The diameter of the tubes varies over the length so that the pressure gradient will have a nearly linear characteristic. The first diameter will be 700 mm. The pressure losses over the length will be 2.7 bar. The temperature of the return water will be 60 C° - 70 C°. Therefore the return water tube will be insulated with a thickness of 100 mm. The heat loss from the return water into the tunnel will be 50 W/m. To minimize the mechanical stress in the tubes by thermal expansion there will be compensators in the tubes. Every six meters will be a slide support point for the tube and between two compensators a fixed support point. For the slide elements PP-sheets are preferred. These elements are already used as slide sheets in the other DESY accelerators. The last or direct connections to all elements (e.g. magnets, klystrons etc.) will be done by EPDM-rubber tubes. The advantage is resistance to radiation, high flexibility for the connections, good and quick installation, direct connection between elements at a high electrical potential and ground shorted copper tubes.

4.9.9 Air Conditioning and Ventilation

The tunnels have a length of about 15 km without intermediate access. There are connections foreseen between the linac tunnel and the service tunnel every two km. During machine operation the latter tunnel is accessible for maintenance and repair work. The tunnel is an underground building and therefore forced ventilation is required. The regular velocity of air motion is 0.6 m/s, which will be enhanced to >0.8 m/s in case of an emergency for smoke removal. The pressure drop along the 15 km tunnel will be 1500 Pa. Special precautions are necessary in order to be able to open emergency doors at the tunnel end under this relatively high pressure. In case of a fire during machine operation, smoke detectors will shut down the machine and persons will leave the service tunnel through the nearest connection to the linac tunnel. The connections have fire-proof doors so that the linac tunnel serves as a safe and smoke-free escape exit. Both the fire load (transformer oil, cables, etc.) and the number of potential ignition sources (high voltage equipment, power supplies, etc.) are high so that such a safety concept is particularly important.

The power consumption in the service tunnel amounts to max. 7.5 kW/m. Most of the heat is removed by the water cooling system. Air ventilation does not contribute significantly to cooling, which is dominated by the tunnel walls. We allow for no more than 100 W/m of losses to the tunnel air, which requires to shield the hot water return pipe. For acceptable working conditions, the temperature in the service tunnel should not exceed 25°C.

The layout of the ventilation system is sketched in Fig. 4.10.8. A recirculation of the tunnel air is not possible. At the beginning of the linac tunnel fresh air is blown into the tunnel. If necessary, the air will be heated and dryed to ensure a relative humidity below 50 % in the tunnel. At the endstation hall the air from the tunnel is extracted.

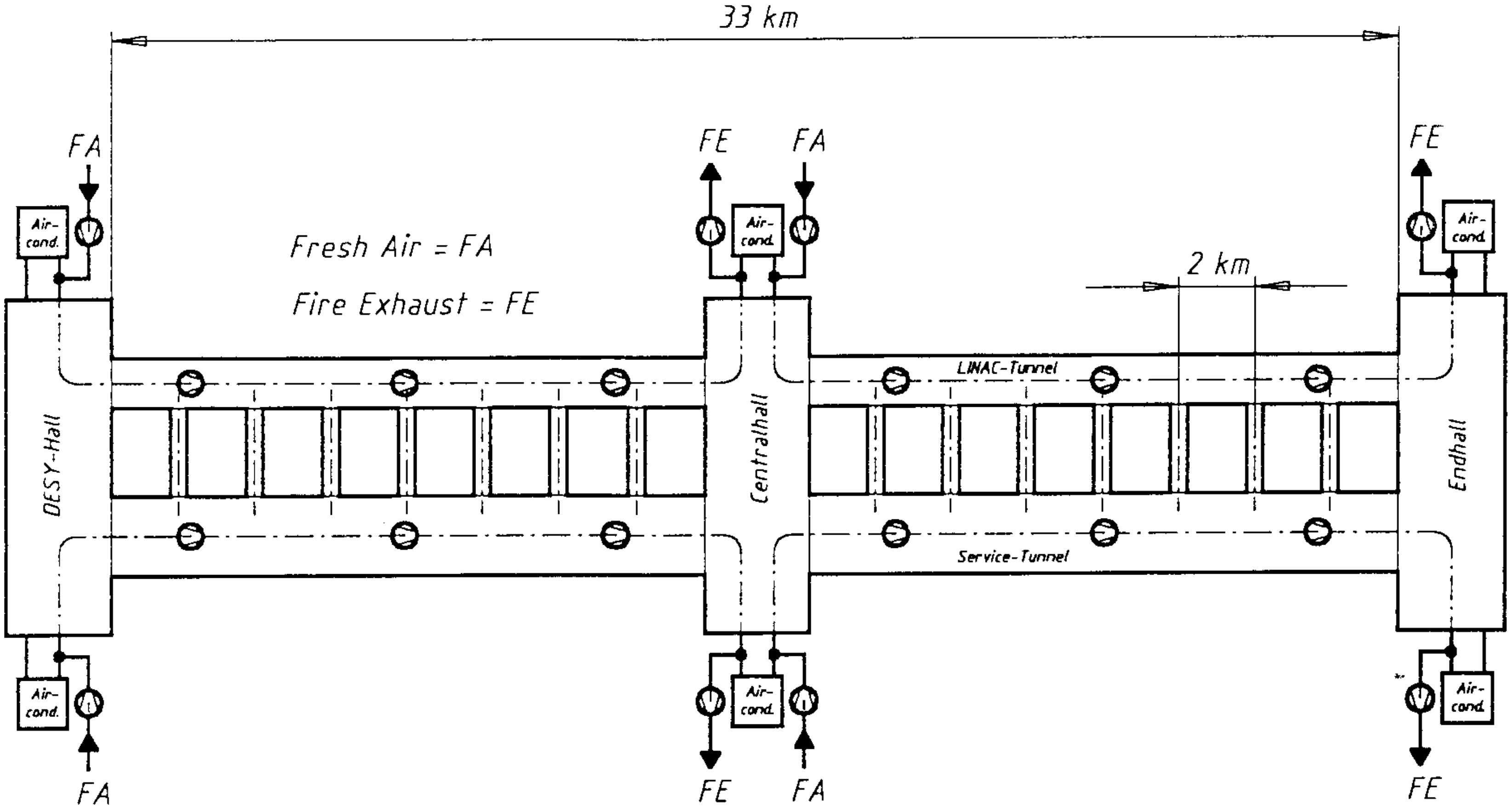

Figure 4.9.8: *Sketch of the ventilation system for the linac tunnel.*