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Construction of Utility Tunnel power supply and distribution system

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Abstract. As an underground structure that can accommodate multiple municipal pipelines, the utility tunnel can not only coordinate the planning, construction, and management of various municipal pipelines, but also achieve intensive development of urban underground space. In theory, any municipal pipeline can be included in the utility tunnel, thereby eradicating phenomena such as "road zippers" and "aerial spider webs" in the urban construction process. As a massive underground structure, the utility tunnel has its own electricity demand. Only by constructing a safe and stable power supply and distribution system inside the pipe gallery can it effectively ensure personal safety and the reliability of pipeline operation.

Keywords: Utility Tunnel; power supply and distribution; precise design.

1. Overview

Currently, most discussions on the comprehensive utility tunnel power supply and distribution system in China refer to the building power supply and distribution system, first determining the load level, and then considering the power supply connection and specific distribution. This approach is effective in the field of architecture. However, in the field of utility tunnels, which represent the highest level of construction in the municipal field, if the utility tunnel is still considered as a standardized overall structure-leaving aside the pipeline entering the utility tunnel and discussing power distribution-it is not comprehensive enough. This article will sort out representative pipeline combinations in the industry, and use them as a starting point to analyze the architecture of the utility tunnel power supply and distribution system.

2. Electric power supply systems

2.1 Representative cross-section

There are many types of municipal pipelines, with different transmission media, piping material, and installation methods. Therefore, before determining a representative utility tunnel section, it is necessary to have a deep understanding of the characteristics of each pipeline.

The water supply pipeline is a pressure pipeline, which is less affected by the slope of the pipe. The conveying medium of thermal pipelines includes steam and hot water. Due to the large heat dissipation, insulation layer or treatment should generally be added before entering the utility tunnel. The drainage pipeline includes rainwater and sewage, which cannot be discharged together. Normal discharge requires a certain slope. Sewage pipelines are prone to producing toxic, flammable, and explosive gases such as hydrogen sulfide and methane. Corresponding monitoring equipment should be installed when entering the utility tunnel. Natural gas pipelines are generally pressure pipelines. Unlike buried pipelines, natural gas pipelines laid in pipe galleries are prone to external interference and damage, leading to leaks and safety accidents. Therefore, when natural gas pipelines are installed in utility tunnel, separate compartments must be set up. Due to high costs, gas companies generally have a lower willingness to enter gas pipelines into utility tunnel. Power and communication lines are generally cables. When laid in a comprehensive pipe gallery, the power and communication lines do not need sleeves, and the lines can be appropriately bent and arranged flexibly.

In addition, according to “GB-50838- Technical code for urban utility tunnel engineering”: natural gas pipelines and steam heating pipelines should be separately equipped with tunnel; the heating pipeline cannot coexist with the power cable in the same tunnel; cables above 110kV cannot be arranged on the same side as communication cables.

Based on regulatory requirements and cost-effectiveness analysis of pipeline corridors, the conclusions can be drawn: pipelines with high cost-effectiveness include power, wate supplyr and communication, while pipelines with low cost-effectiveness include thermal and gas pipelines. Drainage pipelines have high slope requirements and should be analyzed in detail. The installation clearance inside the utility tunnel includes the net height (not less than 2.4m), the distance between the top of the pipeline and the utility tunnel (not less than 0.8m), and the distance between the maintenance channel (not less than 1.0m). When there are no less than 3 types of pipelines installed, a standard section of the pipe gallery with moderate cost and less construction difficulty can be obtained, as shown in Figure 1.

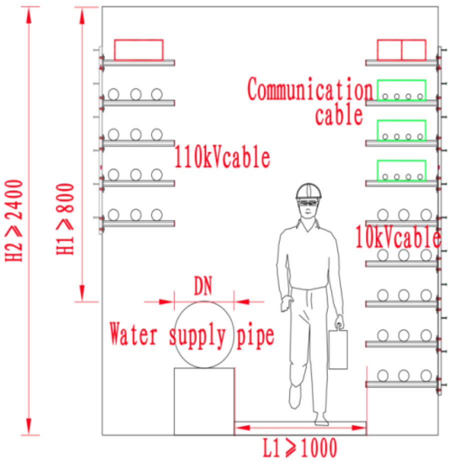

Figure 1: Standard section of utility tunnel/mm

This article mainly takes this section as an example for the power supply and distribution system architecture of the comprehensive pipe gallery, and the design standards for other combinations should be higher than this example.

2.2 Important node settings

The important nodes of the utility tunnel include personnel entrances and exits, escape exits, hoisting ports, ventilation openings, pipeline branching ports, etc. The setting of these nodes has a significant impact on the power distribution of the utility tunnel.

For example, ventilation openings are generally located at the end of each fire compartment, and the power supply in the pipe gallery is generally divided by the fire compartment. Therefore, the design position of ventilation openings generally determines the division of power supply areas; fire protection and emergency lighting should generally be considered near personnel entrances and exits and escape routes; for the convenience of inspection and maintenance, the main distribution box should generally be located at the entrance and exit. The purpose, installation spacing, and recommended installation quantity of each node can refer to Table 1.

Table 1: Nodes of the utility tunnel

	Entrance/Exit	Escape	Hoisting	Ventilation	junction
purpose	enter and mainta	Escape from danger	Reserve feeding port	ventilate	Junction for pipes
spacing	/	200m	400m	200m	/
Amount	2	2	1	2	/

2.3 Power supply and main electrical scheme

All electrical loads within the utility tunnel are closely related to people's livelihoods. Interruption of power supply may affect the normal operation of a large number of important electricity consuming units (such as water, power, and network interruption), so it is recommended that the load level should not be lower than level two. The system should be powered by two circuits, using a segmented single bus. If conditions permit, it can be designed with two power sources. These two power sources are connected from different substations and adopt a "one in use and one backup" method. Both transformers can meet the electricity demand of all loads. The main wiring can refer to Figure 2.

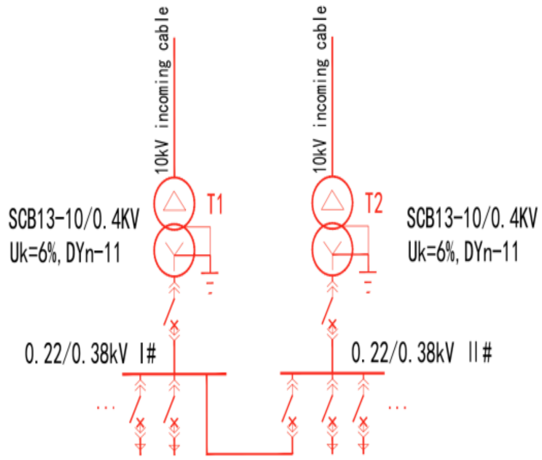

Figure 2: main electrical scheme

The voltage of the power supply system is 10/0.4kV, and the low-voltage voltage adopts a 220V/380V system. According to this method of power supply, the power supply radius cannot exceed 1 kilometer, which is suitable for small-scale utility tunnel projects.

2.4 Transformer

Due to the limited power supply radius, the power load of the utility tunnel itself is actually not large, and transformers can be selected according to the principle of "it is better to prepare than not use, and not to use but not to prepare". When calculating the load, the demand coefficient method is generally used, such as Equation 1. The demand coefficient can be selected according to the upper limit, and the coefficients K1 and K2 can also be ignored during simple calculations or engineering estimates.

$$Sc=\sqrt{[K_1\sum(K_dP_e)]^2+[K_2\sum(K_dP_e\tan\varphi)]^2} \quad (1)$$

Sc is the apparent power, and Kd is the demand coefficient.

After calculating the apparent power, theoretically, the transformer capacity can be determined based on this and the load rate (which can be selected between 50%, 60%, 70%, 80%, 85%).Based on years of engineering experience, the author strongly recommends that engineers choose the capacity according to the requirements of transformer economic operation and comprehensive energy efficiency. The rated capacity of transformers can refer to Equation 2.

$$SrT=S_{JP}/\sqrt{2\frac{P_0+K_QQ_0}{P_k+K_QQ_k}} \quad (2)$$

S_{rT} is the rated capacity of the transformer, S_{JP} is the critical load for the economic operation of transformer; P and Q are transformer loss.

The higher the load rate of the transformer, the corresponding increase in losses and operating costs will also increase. When installing a new transformer, it is not enough to simply choose the transformer to meet the usage needs and ignore the later operation and maintenance costs. The correct approach is to find the optimal point between the two, taking into account both initial investment and operation and maintenance costs.

The internal structure of the comprehensive pipe gallery is compact, and installing transformers inside it will greatly increase the total investment. Therefore, it is usually considered to install box type substations in the ground municipal facilities. Oil bed type transformers have a large volume and high fire protection requirements, and are not recommended for use. Most municipal engineering projects use dry type SCB13 series box transformers.

According to the different characteristics of electricity load, the electricity load in the utility tunnel can be divided into fire load and non-fire load, and the specific classification and detailed information of the two can be found in Table 2.

Table 2: Load classification

Fire load	Fire Alarm UPS	Emergency lighting	Control system UPS	Hydraulic manhole cover
Non-Fire load	Maintenance power	normal lighting	Air supply fan	Drainage pump

When conditions are limited and it is not possible to achieve redundant backup of dual transformers, important loads such as fire protection can be prioritized according to the classification in the table above to prevent fire, reduce the harm caused by fire, ensure personal and property safety, and provide electrical reliability for the system. At this time, the wiring is shown in Figure 3.

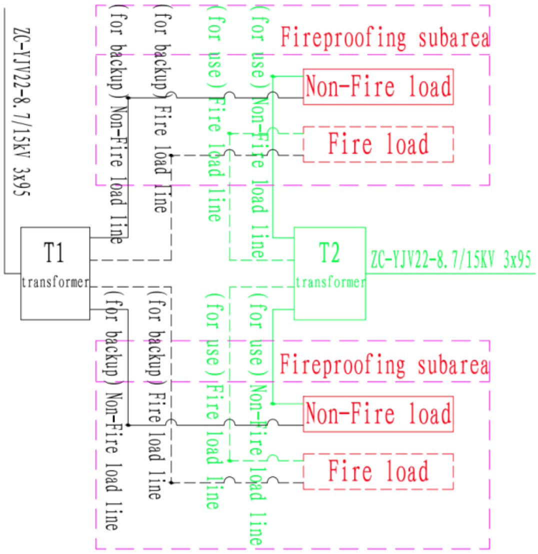

Figure 3: wiring diagram

2.5 Selection and installation of electrical equipment

The electrical equipment inside the utility tunnel mainly includes distribution cabinets, switchgear, lighting fixtures, power cables, and operation cabinets for various types of fans and valves. All types of distribution cabinets and switchgear should be fixed cabinets with a protection level of no less than IP54, and can be centrally installed inside the pipe gallery for easy maintenance and operation; The distribution box can be installed on the wall; Conventional lighting fixtures can be installed on the ceiling, evacuation indicator lights can be installed on the inner wall of the utility tunnel, with a installation height of no more than 1 meter, and exit sign lights can be installed above the exit; The high-voltage cables inside the utility tunnel can be installed on brackets; The cables for self-use in the utility tunnel can be installed in the bridge or trough box. Low voltage distribution cables should use NH-YJV-0.6/1KV power cables, control lines should choose flame-retardant cables, and fire protection cables are all non-combustible cables; The fans and drainage pumps are generally installed at the ventilation openings and collection pits, and the installation method should meet the professional requirements of the equipment. In addition, all electrical equipment in the pipe gallery cannot be located in areas prone to water accumulation; All conductive metal casings of electrical equipment should be effectively grounded; All cabinets should consider anti-corrosion measures; All distribution switches and conductors should meet thermal stability verification; All lighting fixtures should choose high-efficiency, energy-saving, and green lighting sources that meet the color rendering index requirements. The protection level of the lighting fixtures should not be lower than IP65, and the protection level against electric shock should be Class I.

2.6 Lightning protection and grounding

The above ground structures and the underground of the utility tunnel may not be equipped with direct lightning protection devices in principle. However, protective devices against lightning induced overvoltage should be installed, and an equipotential bonding system should be installed inside the pipe gallery. During the construction of the pipe gallery, pre embedding of connection plates and LEB terminal boxes should be done, and the welding points between the pre embedded parts and the main steel bars in the pipe gallery should not be less than two points.

For the grounding system of cast-in-place utility tunnel, the main steel bars can be used as the grounding electrode. The grounding devices for transformer neutral point grounding, electrical equipment protection grounding, and metal exposed conductive parts can be shared, and the grounding resistance should not exceed 1 Ω. If it does not meet the requirements, an artificial grounding electrode should be added. In addition, all metal pipes entering and exiting the pipe gallery are connected to the grounding device, forming an equipotential space throughout the entire utility tunnel. The grounding plan layout inside the utility tunnel can refer to Figure 4.

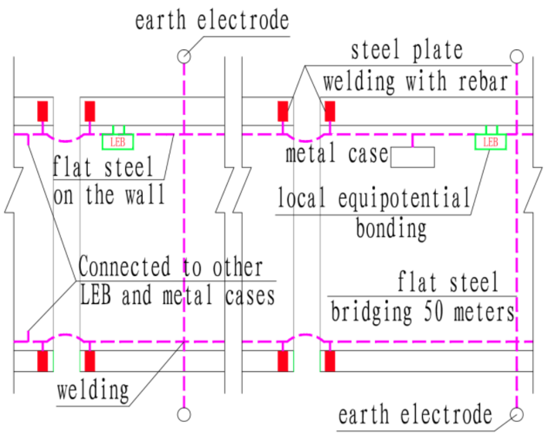

Figure 4: Grounding layout plan

2.7 Lighting System

The lighting inside the utility tunnel includes two parts: routine lighting during maintenance and visits, and emergency lighting. The average illuminance of conventional lighting above the maintenance channel shall not be less than 15lx, and the local illuminance at entrances and equipment operation points shall be enhanced to a level of 1001x. Energy saving LED light sources can be selected for the lighting fixtures; Emergency lighting is usually set up to guide personnel evacuation in the event of a fire. Emergency lighting fixtures should use waterproof and moisture-proof LED fixtures, and the setting of evacuation indicator lights should meet the requirements of the Technical Standards for

Fire Emergency Lighting and Evacuation Indicator Systems. Safety exit signs should be installed at safety exits, escape exits, and fire doors. The protection level of all lighting fixtures in the pipe gallery shall not be lower than IP65, and the protection level against electric shock shall be Class I.

The conventional lighting inside the pipe gallery usually has the following characteristics: uniform arrangement of lamps, high reflection ratio, and basically unobstructed lighting. When designing lighting systems, we can chose the utilization coefficient method. The luminous flux of lighting fixtures can be converted based on the illuminance and design spacing, using the conversion method shown in Equation 3.

$$P\eta=\frac{\boldsymbol{E_{av}A}}{\boldsymbol{NUK}} \quad (3)$$

In this equation: P is the power of a single lamp (W); Eav is the average illuminance (lx); A is the calculated area (m^2); N is the number of lamps when calculating the length; U is the utilization coefficient; K is the maintenance coefficient of the lighting fixture; A/N is equal to the product of the distance between the lamp and the effective width of the pipe gallery. The product of the lamp power and luminous efficiency obtained from equation 3 can be used as a whole as an indicator for selecting lamps. When the light efficiency is high, low power lamps can be selected, and when the light efficiency is low, high power lamps can be selected. This overall consideration of lighting effects gives engineers a certain selection space, while also reflecting the concept of efficient and energy-saving engineering construction.

2.8 Fire protection and automatic control system

The automatic fire alarm system for the utility tunnel adopts a regional centralized alarm method, consisting of a control center fire alarm host computer, a fire alarm linkage control cabinet, a fire alarm control cabinet, temperature-sensing cables and fire extinguishing controllers, fire detectors, smoke detectors, audible and visual alarm devices, etc. Due to the relatively enclosed space of the utility tunnel, there are many differences in fire automatic warning and fire linkage control compared to conventional buildings and structures. When a fire occurs, the alarm signal from any two fire detectors or any one fire detector and the manual alarm button in the same fire protection zone is used as the linkage trigger signal. Once the signal is triggered, the following linkage control is performed:

① Close the ventilators and fire dampers in the fire zone and adjacent zones, and cut off the non-fire protection circuits in the power distribution cabinet;

② Activate all audible and visual alarms in the tunnel;

③ Activate all emergency lighting and evacuation indicators in the tunnel, and turn off the safety exit lights in the fire zone;

④ Close all normally open fire doors in the fire zone;

⑤Automatically activate the fire extinguishing system, feedback the action signal and fault alarm signal to the control center, and use the fire linkage controller or fire extinguishing controller to activate the automatic fire extinguishing equipment, such as ultra-fine dry powder extinguishing and high-pressure water mist extinguishing.

When the utility tunnels constructed in the city reaches a certain scale, it should be equipped with a tunnel monitoring platform. Correspondingly, as long as an utility tunnel monitoring platform is set up, it should be equipped with an automatic control system. Most of the utility tunnel automatic control systems in China adopt the first, second, and seventh layers of the ISO open system interconnection network model, which are the network layer, data link layer, and field device layer, respectively. The entire system uses gigabit networks to connect the core switches and field devices, and uses single-mode optical fibers as the medium to form an Ethernet ring network, covering multiple subsystems such as power system monitoring, environmental monitoring, motor monitoring, intelligent lighting, and fire monitoring to Figure 5.

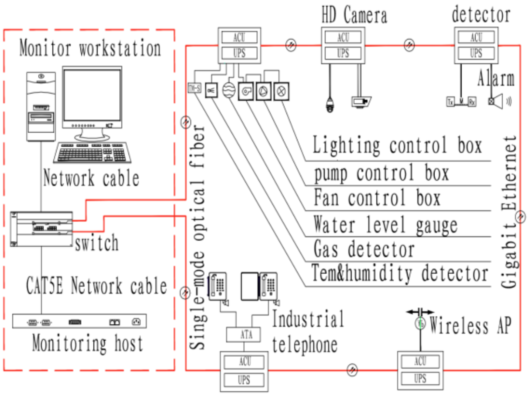

Figure 5: Monitoring platform system of utility tunnel

Taking a single fire prevention zone within a utility tunnel as an example, the data collected by on-site monitoring and control equipment mainly includes temperature and humidity, water level, real-time operating conditions of fans and pumps, real-time operating conditions of lighting, well cover monitoring, anti-intrusion alarm signals, and more. The system responds and controls on-site electrical equipment in milliseconds based on the collected data, effectively dealing with various emergencies within the utility tunnel, such as fires, excessive levels of harmful gases, water ingress into the tunnel, and intrusion alarms. The installation of on-site equipment for the automation control system can refer to Figure 6.

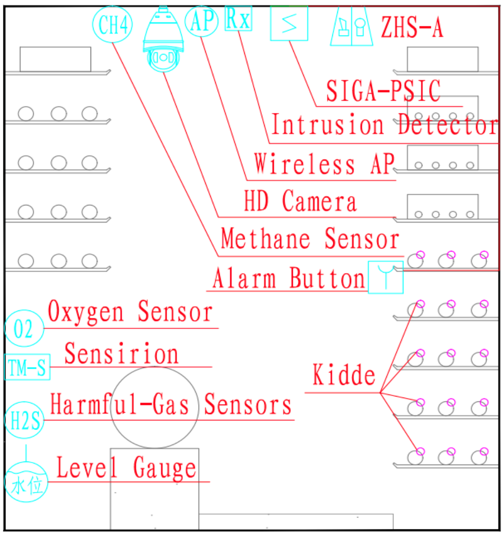

Figure 6: Field device of utility tunnel

The utility tunnel monitoring platform is a core platform for the intelligent operation of multiple tunnels or even all tunnels in a certain area of the city. It not only provides information interconnection and sharing for various subsystems within the utility tunnel, but also accurately, reliably, and quickly responds to various emergencies, achieving real-time monitoring and intelligent management. Therefore, comprehensive planning should be carried out at the initial stage of tunnel construction to lay a solid foundation for subsequent construction.

3. Conclusion

Against the backdrop of "new infrastructure better supporting high-quality economic development," the development of utility tunnels in China has gone through various stages, from exploration to pilot projects, and then to normalized construction. With the continuous improvement of the construction scale and quality of utility tunnels, the establishment of power supply and distribution systems within these tunnels has also been continuously developing and improving. Utility tunnels serve as both carriers for urban high-voltage power lines and contain numerous electrical equipment to ensure their normal operation. It can be said that the construction level of the power supply and distribution system within utility tunnels directly determines the quality of the tunnels' engineering. Every urban infrastructure worker should attach great importance to this, adhere to meticulous design during the construction of utility tunnel power supply and distribution systems, and make their own contributions to protecting the city's "arteries" and "lifelines".

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