A brief analysis of the power cable planning and design of the utility tunnel

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Abstract: The urban utility tunnel plays an important role in improving the utilization efficiency of urban underground space. With the vigorous promotion of the construction of urban utility tunnel, the scale of power cable into urban utility tunnel is also increasing rapidly. There are some problems in the planning and design process of utility tunnel, such as the lack of technical specifications or the inconsistency of existing standards and norms. Thus, some detailed design requirements of the overall design, section design and ancillary system design of the power pipeline are proposed in this paper, especially the details of the power cables entering into the utility tunnel are discussed in detail, providing a reference for other engineering. It would be helpful for the electric power cables entering into the utility tunnel in the future.

1. Introduction
With the continuous progress of urbanization, the pressure of improving urban environment and shortage of various public resources is increasing [1]-[2]. The utility tunnel, which is a new type of underground space development and utilization, has solved the problem of urban development [3]-[5] and can produce high social economy benefits [6] and environmental benefits [7]. The Ministry of Housing and Construction promulgated the Technical Specification for Urban Utility Tunnel (GB 50838-2015) in 2015 [8]. However, due to the vast territory of China and a large number of pipelines such as water supply pipeline, power pipeline, communication pipeline, thermal pipeline, gas pipeline, rainwater pipeline and sewage pipeline accommodated in the utility tunnel, there are some problems in the planning and design process of utility tunnel, such as the lack of technical specifications or the inconsistency of existing standards and norms.

Under this background, based on the national, local and industrial standards and successful construction experiences about completed utility tunnel [9]-[10], some advices on the problems about the power pipeline entering into utility tunnel are proposed this paper. It provides a reference for the planning and design of power pipelines in the utility tunnel.
2. Overall Design

2.1 Planning coordination
Based on the demand of power system, the planning of utility tunnel should be combined with the long-term planning of urban power system and the layout planning of power system facilities [11]-[12]. The utility tunnel planning should be combined with municipal construction, highlighting the planning principles first, paying equal attention to construction and management, adapting measures to local conditions, and being economical and practical. At the same time, the planning should coordinate and negotiate with the power system on the basis of the preliminary line location planning of the utility tunnel. The direction of power lines and the layout of power supply facilities should be optimized to achieve the integration of the utility tunnel planning and the power pipeline planning and maximize the efficiency of the utility tunnel [13].

The section size of the utility tunnel electric cabin (the cabin with power pipelines in the utility tunnel, the same below) should first meet the safety, reliability and economic requirements of power grid construction, operation and maintenance in the near future. Considering that the design and use life of the utility tunnel is 100 years, it is difficult to rebuild and expand later. Therefore, the section design of the utility tunnel should be forward-looking and reserve appropriate space to coordinate with long-term planning.

2.2 Pipeline compatibility
According to the compatibility analysis of various pipelines, the common cabin layout principle of pipelines in the utility tunnel need to be reasonably determined. Considering the combustibility of gas pipelines and the thermal radiation of thermal pipelines, power pipelines should not be laid in the same cabin with gas and thermal pipelines. The corrosive and flammable gases produced by rainwater and sewage would affect the service life and safe operation of power cables and equipment. Therefore, it is not suitable for power cables to be arranged in the same cabin with rainwater and sewage pipelines. The normal operation of power cables needs waterproof. When water supply pipelines and power cables share cabins, water supply pipelines should be arranged under the power cables to avoid accidents such as short circuit, discharge and explosion of cables caused by leakage of pipeline.

Communication pipelines are divided into coaxial communication cables and optical cables. Coaxial communication cables are seldom used nowadays. There is serious electromagnetic interference between coaxial communication cables and power cables. Coaxial communication cables and power cables could not be laid together in the utility tunnel because their safety net distance is very large. As a common material, the interference between optical cable and power cable is very small, so optical cable and power cable could be laid in common cabin without special technical measures. That is to say, the communication cable can be laid in the same cabin with the power cable. However, it should not be laid on the same side with the 110 kV and above voltage level of power cable, so as to avoid the interference of the high-voltage power cable to the signal of communication cable.

2.3 Pipeline Number
The number of 10 kV and above voltage level of power cables laid in a single cabin should not exceed 42 and 110 (66) kV and above voltage level of power cables should not exceed 24 [14]. The main consideration is that it would cause problems such as large calorific value and large impact range of accidents when the number of power cables in a single cabin is large.

In addition, safety isolation measures should be taken between 110 (66) kV and above voltage level of power cables and 35 kV and below voltage level of power cables. The main reason is that the failure rate of 35 kV and below voltage level of power cables is relatively high [15]. After adopting safety isolation measures such as fire-proof partition, the influence of failure on 110 (66) kV and above voltage level of power cables laid on the same path can be avoided.
3. Section design

3.1 Flat and longitudinal section
Longitudinal gradient of the power cabin of the utility tunnel should not be less than 0.2%, so that the pool of water in the tunnel can flow into the catchment pit easily. Considering the convenience of cable laying, operation and maintenance, the longitudinal gradient of power cabin should not exceed 30%. When the power cabin of the utility tunnel is connected with other power channels, the longitudinal gradient of which should be connected smoothly and not abruptly. When the longitudinal gradient of the power cabin exceeds 10%, anti-skid measures such as treading should be set at the aisle board.

3.2 Cabin size
The net height of the power cabin of the utility tunnel should be not less than 2.4 meters and not more than 3.5 meters. When the net height is more than 3.5m, the installation, replacement and inspection of the space cables on the upper part of the power cabin are inconvenient, which leads to the ineffective utilization of the space. When the brackets are installed in one side of the power cabin of the utility tunnel, the width of overhaul access should not be less than 0.9 m. When the brackets are installed in two sides of the power cabin of the utility tunnel, the width of overhaul access should not be less than 1 m. Besides, when the utility tunnel is equipped with electric overhaul vehicle, the width of overhaul passage should not be less than 2.2 m.

3.3 Spatial arrangement
The power cables in the power cabin are sorted in the order of from high to low and from bottom to top according to the voltage level. The relative position of each circuit cable in the power cabin should remain unchanged, so as to minimize the crossing of cables; the dual-circuit power supply in the same direction should be laid on both sides of the power bunker. Weak power cables, control cables and communication optical cables in the power cabin should be laid on the top floor, and fire protection measures should be set up.

When the number of bracket layers is limited by the channel space, the adjacent power cables of 35 kV or below 35 kV can be laid in the same bracket layer. When the voltage level of adjacent power cables is 110 kV or above 110 kV, each circuit of which should be equipped with bracket separately. In the tunnel, single core cables of 110kV and 220kV should be laid out in "Pin" type while the cables of 500kV should be laid out in three phases and on different brackets. For horizontal serpentine cable, the length of serpentine ranges from 8m to 12m and the offset value of serpentine amplitude should not be less than 1.5D. D is the nominal outer diameter of finished cable. For vertical serpentine cable, the length of serpentine ranges from 4m to 6m and the offset value of serpentine amplitude should not be less than 1.5D.

3.4 Power cable turning radius
The demand for bending radius of power cable should be met in any laying mode and all the changing parts of the route conditions. The allowable bending radius of the cable shall meet the demand of cable insulation and its structural characteristics. The minimum allowable bending radius of power cable is as follows:

| Project | Cables of 35kV and below | Cables of 110(66) kV and above |
|---------|--------------------------|-------------------------------|
|         | Single-core cable        | Three-core cable              |
|         | Unarmored                | Unarmored                     |
|         | Sheathed                 | Sheathed                      |
| Laying  | 20D                      | 15D                           | 15D                           | 12D                           | 20D                           |
| Working | 15D                      | 12D                           | 12D                           | 10D                           | 15D                           |
Based on the conventional outer diameter of power cable and the experience of project, the turning radius of 10 kV cable should be 2.0 m, and that of 110 (220) kV cable should be 2.5 M. The access (exit) of power cables in the power cabin are carried out in three-dimensional space. The cabin space needs to be extended both in plane and height. Combined with its minimum turning radius and engineering experience, when considering the access and connection of power cables, the height and width for the cabin of 10 kV power cables should be increased by 1.5 m and 1.35 m respectively, and that of 110 (220) kV power cables should be increased by 1.5 m and 2.0 m respectively.

3.5 Bracket material selection

Only when the working current of cable bracket and bridge bracket is more than 1500A and the cable are AC single core cable, the non-ferromagnetic material should be selected. In other condition, the steel should be selected. Common non-ferromagnetic materials are thermosetting polymer materials composed of alkali glass fibers, m-phenyl resins, Au304L stainless steel or 321 stainless steel, etc. In strong corrosive environment, corrosion-resistant rigid material can be used in ordinary bracket (arm bracket), flame-retardant FRP or aluminum alloy can be used to make ladder and tray made up of cable tray.

The power cable bracket is composed of pillars and brackets. Pillars and other components connected with the wall of the utility tunnel are in the form of pre-embedded channel. The installation place of the bracket on the column and hanger could be moved up and down, and the bracket spacing can be adjusted by 5 cm each time.

3.6 Stent horizontal length

The bracket for power cable should be designed according to the principle of "the same size bracket for the same voltage level cable". The length of the bracket should meet the requirements of laying cable and its fixing device. In addition, apart from satisfying the deformation caused by cable bending, horizontal serpentine and temperature rise, the bracket length should be increased by 50-100 mm. The 110 kV and 220 kV single-core cables, laying horizontally or vertically serpentine in the gallery, should be designed according to the thermal expansion of the cables. For horizontal serpentine cable laying, the net length of 110 kV cable bracket should not be less than 650 mm and that of 220 kV cable bracket should not be less than 750 mm.

Considering the uncertainties of cable voltage level caused by local practices and long-term expansion of power departments, it is suggested that the net length of 10 kV and 110 (220) kV power cables should not be less than 750 mm. Among them, 500 kV cables are laid in three-phase manners and different brackets, and the net length of the brackets should not be less than 440 mm.

3.7 Vertical spacing of bracket

The vertical distance between layers of brackets should meet the requirements of laying cables and the requirement of fixing and fitting joints as well as the requirements of the width of longitudinal snake-shaped laying and the requirement of deformation caused by temperature rise. The minimum net distance between cable bracket shall not be less than that the regulation in Table 2.

| Cable Types and Laying Characteristics | Minimum net distance between bracket |
|---------------------------------------|-------------------------------------|
| Control cable                         | 120                                 |
| Power cable                           |                                     |
| More than one cable per layer          | 2\(d+50\)                            |
| One power cable per layer              | \(d+50\)                             |
| Three Power Cables in pin character pattern | \(2d+50\)                        |
| Cable laying in groove box             | \(h+80\)                            |

Note: \(h\) and \(d\) denote the height of tank housing and maximum outer diameter of cable.
Low voltage cables such as communication and controlling laid in the top of bracket should be arranged in the fireproof tank box. Considering the size of the tank box and the requirements of installation and maintenance, it is suggested that the vertical net distance between the upper bracket and the roof of the cabin be 300 mm. The outer diameter $D$ of 10 kV cable is generally about 100 mm, while 2D+50 is not more than 250 mm. The spacing of 10 kV cable bracket should be 350 mm when the cable is laid in the bridge. When placing 110 (220) kV cables horizontally or in ‘pin’ shape, considering that the cable outer diameter $D$ is not more than 120 mm and 2D+50 is not more than 290 mm as well as the effect of cable connector, the spacing of 110 (220) kV cable bracket should be 500 mm. Laid in vertical serpentine shape, each phase of 500 kV cable should be laid on bracket respectively and the spacing of bracket layers should not be less than 500 mm.

4. Design of ancillary system

4.1 Design of grounding system

The grounding system in the utility tunnel should form an annular grounding grid. The grounding resistance, of which the contact potential difference and step potential difference should be checked, should not be greater than 1Ω. When the grounding resistance is less than 1 ohm or the requirement of the internal pipeline, the artificial grounding body added outside the utility tunnel are connected with the natural grounding body. The hot-dip galvanized flat steel with a cross-section area not less than 60 mm×6 mm should be used in the grounding grid of the power cabin so as to meet the requirement for the passing of the fault current. Welded overlap rather than bolt overlap should be used in the grounding grid. The electric cabin should be equipped with grounding device and grounding lead-out point, and the setting distance between grounding lead-out points should not be more than 500 m.

4.2 Communication system design

Fixed voice communication system should be set up in the power cabin of the utility tunnel, and wireless communication system can be set up according to management requirements.

Fixed voice communication system is divided into IP fixed telephone and optical fiber telephone. The number of devices hanging on the tunnel network is relatively small and other data packet affecting the quality of the call is also small in utility tunnel of small scale. IP fixed telephone, which can satisfy the quality of the call as well as save investment, can be used. On the other hand, optical fiber telephone shall be used as a fixed voice communication device in the utility tunnel of large scale in order to ensure the quality of the call.

Wireless voice communication system can be divided into traditional wireless intercom technology and IP-based WIFI intercom system. Traditional wireless intercom system, with the advantage of mature technology and high stability, can only transmit voice and simple message, and it is insufficient in the expandability of wireless coverage system. Based on IP, the WIFI intercom system, which can provide multimedia cooperative communication capability as well as transmit voice, text, pictures, video, Email and other contents, is easy to maintain. Under the trend of the development of intelligent utility tunnel, IP-based WIFI intercom system is suggested to use in power cabin.

4.3 Automatic fire extinguishing system at cable joint

In the fire accident of the utility tunnel, the main cause is the self-ignition of the power cable. The main causes of power cable on fire are: 1) interphase fault 2) short to ground 3) bad contact 4) line overload.

At present, cross-linked cables, which rules out the possibility of large-scale ignition caused by oil-filled cable leaking, are used in the utility tunnel. At the same time, flame-retardant cables are used for laying cables. Besides, the temperature of high-voltage cables are monitored by monitoring system, once there is abnormal temperature situation, it can be dealt with beforehand. Therefore, the probabilities of occurrence of causes 1), 2) and 4) are low. The artificially installed connection of power cable may be not tight, leading to poor local contact and increased resistance as well as
overheating, which result in the explosion and combustion of the joint. In recent years, most of the fire accidents occur at the cable joints, so automatic fire extinguishing system should be set up at the cable joints.

4.4 Drainage system
There are seven main reasons for hydrops in the power cabin: 1. leakage of the water supply pipe interface in the same cabin; 2. water intake at the opening of the comprehensive pipe gallery; 3. backwashing water in the utility tunnel; 4. leakage at the structural joints of the utility tunnel; 5. emptying and maintenance drainage of the water supply pipe in the same cabin; 6. explosion of water supply pipe and drainage; 7. drainage of fire water.

The remaining water is very small except 5, 6 and 7 cases. When the pipe bursts, the electric valve on the main pipe can be operated to isolate the accident area quickly, while the maintenance personnel can assist the drainage outside. The drainage design is not considered. So, the automatic drainage system in power cabin is mainly aimed at the situations 5 and 7.

5. Concluding remarks
Power cable is one of the most important types of pipelines among various types and quantities of pipelines in the utility tunnel. Served as a carrier of high voltage and strong current, there is own characteristics of corridor design in power cable. Based on the comparative analysis of the utility tunnel and related electric power codes as well as practical engineering experience, some special requirements different from other pipelines in the design process of the utility tunnel power cabin are put forward. Considering the complexity of the utility tunnel design and the requirements of the pipeline departments, the design of the power cabin should still be carried out in accordance with the local conditions.

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