Research on influencing factors of cable traction force in horizontal directional drilling

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Abstract. Horizontal directional drilling and pipe pulling technology is playing an increasingly important role in power engineering applications because of its low social and environmental impact and high construction speed. However, due to the more complex urban underground pipeline environment and the uncertainty in the process of cable pulling and laying, in order to ensure the safe laying of cables and later operation, so the cable traction force verification in the process of pulling is particularly important. Relying on specific engineering examples and relevant regulations and specifications, the cable traction force formula in the process of pulling the tube is studied, modified and given its arc-making section equivalent model, the selection principle of the discriminative cable traction method, and the influencing factors affecting the safety coefficient of cable traction force are studied.

1. Introduction

With the development of society, the construction of various municipal pipelines, subways and pipeline corridors leads to increasingly restricted transmission corridors for underground power cables, and the construction side gradually recognizes and circulates the horizontal directional drilling technology due to the difficulty of outsourcing the road interception openings and the requirements for construction progress [1-4]. However, at the same time, due to the complexity of urban underground pipelines and the uncertainty of the pulling construction trajectory [5], it is necessary to calibrate the cable traction force during the pulling process in order to ensure the safe laying of cables and their later operation.

This paper relies on the electric power supporting project for the expansion of the first central hospital in Tianjin, calculates the cable traction force under the trajectory of the project, amends the cable traction force calculation formula for the arc-making section of the pipe, gives the selection principle for the cable traction method and discusses the factors affecting the safety coefficient of the cable traction force.

2. Overview of project examples

The electric power supporting project for the expansion of the new site of Tianjin First Central Hospital is located at the intersection of Baoshan West Road and Jianyang Expressway in Xiqing District, Tianjin, and is a key project of the city. Because Baoshan West Road and Jianyang Expressway are both major traffic arteries, and the underground pipes are complex, if the conventional
method of river closure is adopted, on the one hand, the construction period is difficult and long, on the other hand, traffic control will also bring greater negative impact [6]. After expert discussion, it is determined to adopt the horizontal directional drilling and pulling pipe scheme for electric power construction. The pipe drawing adopts two bundles of 8-hole MPP pipes, which are coated with steel pipes. The pipe drawing trajectory curve is a conventional five section type. See Table 1 for specific parameters.

| Scale | Steel pipe diameter /mm | Radius of curvature /m | Maximum depth /m | Path length /m |
|-------|-------------------------|------------------------|------------------|----------------|
| 8+2   | 864                    | 1000                   | 12               | 401            |

### Table 1. Pipe drawing parameters.

3. Study on calculation model of cable traction force

*Technical specification and standard for horizontal directional drilling pipeline crossing engineering* [7] only gives the track design of pipe drawing and the mechanical calculation model of pipe body, and does not involve the relevant discussion of cable traction during later cable laying. It is discussed as follows with reference to the *Technical Regulations for Urban Power CableLine Design* [8].

| Bend type                          | Schematic diagram | Traction calculation model                                                                 | Corresponding drawing pipe Track segment |
|------------------------------------|-------------------|---------------------------------------------------------------------------------------------|------------------------------------------|
| Horizontal linear traction         | ![Horizontal Linear Diagram](image) | $T = \mu WL$                                                                                | Horizontal crossing section              |
| Inclined linear traction           | ![Inclined Linear Diagram](image) | $T_1 = WL(\mu \cos \theta_1 \sin \theta_1)$  
$T_2 = WL(\mu \cos \theta_1 \sin \theta_1)$ | First(Second) deflecting section            |
| Inclined surface traction (concave surface) | ![Inclined Surface Diagram](image) | $T_2 = T_1 e^{\alpha_2} \left( \frac{WR \sin \alpha}{1 + \mu^2} [(1 - \mu^2) \sin \theta + 2\mu (\cos \theta - e^{\alpha_2})] \right)$  
$T_2 = T_1 e^{\alpha_2} \left( \frac{WR \sin \alpha}{1 + \mu^2} [(1 - \mu^2) \cos \theta - e^{\alpha_2}] + 2\mu \sin \theta \right)$ | First arcing section                        |
|                                    |                   |                                                                                             | Second arcing section                    |

In Table 2, the traction calculation model of common tracks during cable laying is given. Combined with the five-segment track curve of pipe drawing, the integrated model for calculating cable traction in five-segment pipe drawing is given, and its schematic diagram is shown in Figure 1.

As the cable is laid, a conveyor can be placed in the observation wells on both sides of the pulling tube to provide power for the cable, it can be considered that the traction force of the cable is mainly used to resist the resistance generated in the pulling tube trajectory area, and then the friction force generated by the 20m length of cable taken at the entry point is used as the initial traction force $T_1$ of
the cable. According to the traction force calculation model and schematic diagram of each section in the below figure, the cable traction force at the end of each section can be calculated in turn.

**Figure 1.** Schematic diagram of traction force calculation of five section pipe drawing cable.

Since the specification [8] mainly aims at the conventional cable laying methods (pipe arrangement, cable trench, shaft, etc.), the bending radius involved is also for the bending radius of the cable (e.g. when YJLW03-64/110kV-1×800 cable is laid, R = 20D = 2.2m) [9], and in the pipe drawing track, the radius of curvature of the arc making section involved is for the pipe. When the steel pipe is made of steel, the radius of curvature of the pipe drawing is more than 1000m. It is necessary to verify the rationality of directly adopting the specification formula.

Taking the specific project as an example, it is calculated that:

\[
\beta = \arctan\left(\frac{H - L_1 \tan \alpha}{L_2}\right) = 4.16^\circ
\]

The angle is small, close to horizontal, and can be calculated as follows:

\[
L_{\text{arc}} = R \theta = 145.39 \text{m}
\]

\[
L_{\text{sla}} = \sqrt{BB'^2 + B'C^2} = \sqrt{L_2^2 + (H - L_1 \tan \alpha)^2}
\]

\[
= 145.27 \text{m}
\]

\[
\Delta\% = \frac{L_{\text{arc}} - L_{\text{sla}}}{L_{\text{arc}}} = \frac{145.39 - 145.27}{145.39} = 0.08\%
\]

Where: \(\alpha\) is the earth penetration angle; \(\beta\) is the inclination of arcing section; \(R\) is the radius of curvature; \(\theta\) is the radian of arcing section; \(\Delta\%\) is the error.

Since the angle of the oblique straight line of the arc making section is small, and the length of the oblique straight line is almost the same as that of the arc making section, the arc making section can be equivalent to an oblique straight line with an inclination angle of \(\beta\). Then, T3 (T5) is calculated from T2 (T4).

The revised formula is as follows:
\[ T_3 = T_2 + WL_{sla} \left( \mu \cos \beta - \sin \beta \right) \]
\[ = T_2 + W \sqrt{L_2^2 + (H - L \tan \alpha)^2} \left( \mu \cos \beta - \sin \beta \right) \]
\[ T_3 = T_4 + WL_{sla} \left( \mu \cos \beta_3 + \sin \beta_3 \right) \]
\[ = T_4 + W \sqrt{L_4^2 + (H - L \tan \alpha_2)^2} \left( \mu \cos \beta_3 + \sin \beta_3 \right) \] (5)
(6)

\[ T_1 \quad T_2 \quad T_3 \quad T_4 \quad T_5 \quad T_6 \]
\[ -2 \quad 0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \]
\[ \text{cable traction force/kN} \]
\[ \text{Inflection point} \]

**Figure 2.** Traction force curve of each section under two calculation methods (outer steel pipe).

Figure 2 shows the comparison diagram of traction force curves of each section under the three calculation methods of arc length equivalent method of arc making section and code recommendation method before correction (R=2.2 and R=1000).

\[ T_1 \quad T_2 \quad T_3 \quad T_4 \quad T_5 \quad T_6 \]
\[ -2 \quad 0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \]
\[ \text{cable traction force/kN} \]
\[ \text{Inflection point} \]

**Figure 3.** Traction force curve of each section under two calculation methods (without steel pipe).

It can be seen from Figure 3 that when the uncorrected model (R=1000) is adopted, T3 decreases compared with T2 and is negative, which is obviously unreasonable and discarded;
When the uncorrected model ($R = 2.2$) is adopted, the change value of the two arcing sections ($T_2 \rightarrow T_3, T_4 \rightarrow T_5$) is very small, and the traction force borne by the cable is almost not increased, which is inconsistent with the facts and is discarded.

The use of arc section equivalent model, the two arc section of the first and last end of the traction force changes, combined with the actual construction of the tube, the arc section length is larger, the cable friction should be significantly higher, the arc section of the first and last two ends of the traction force change law and arc length equivalent method of calculation under the results are more consistent, so the use of arc section equivalent model is more reasonable.

When pulling the tube without the jacket steel pipe, the radius of curvature is smaller than the radius of curvature when the jacket steel pipe, it is verified that the trend of cable traction force changes under the three formulas is the same as when pulling the steel pipe, so the arc-making section equivalent model can be used to calculate the arc-making section cable traction force.

4. Research on cable traction mode
After the cable conduit laying of power engineering is completed, cable traction laying is required. At present, cable traction methods are mainly divided into two categories: Traction head traction and steel mesh sleeve Traction [10-11]. Electric power engineering common excavation laying method (row of pipes, cable trench, etc.) in the work well interval is small, cable laying can provide power for the cable through the conveyor, so the cable traction in the common excavation laying method does not play a controlling role in the choice of cable traction method is also relatively arbitrary. For the cable project involving horizontal directional drilling, the length is often 300-500m, and the working well cannot be set in the middle of the track to provide power for the cable. At this time, the cable traction can reach nearly 30KN, so it is necessary to verify the traction.

Table 3. Maximum traction force of different cable laying methods (N / mm$^2$).

| Traction mode | Traction head | Wire mesh sleeve |
|--------------|--------------|-----------------|
| Stressed part | Copper core  | Lead core       |
| Allowable traction strength | 70           | 40              |
| Copper core  | Lead core    | Lead sleeve     |
| 70           | 40           | 10              |
| Aluminum sleeve | 20         | Plastic sleeve |
| 20           | 7            |

The permitted traction strength under different traction methods $T_{\text{max}}$ is given in Table 3, and this paper combines the specific project to calibrate the cable traction force under each traction method, and introduces the safety factor $K = \frac{T_{\text{max}}}{T_{\text{s}}}$ for analysis.

This paper takes five kinds of 35 ~ 220kV common cables as the research object in Table 4, and successively calculates the factors affecting the safety factor of cable traction under the premise of a certain trajectory.

Table 4. Common cable parameters.

| Model       | Diameter d/mm | Conductor section s/mm$^2$ | Single weight W/kg/m | Cable section s/mm$^2$ | s/W |
|-------------|---------------|----------------------------|-----------------------|------------------------|-----|
| YJV22-26/35kV-3×300 | 89.2          | 3×300                      | 12.58                 | 6249                   | 71.54 |
| YJLW03-64/110kV-1×800 | 104           | 1×800                      | 14                    | 8495                   | 57.14 |
| YJLW03-127/220kV-1×1200 | 131          | 1×1200                     | 21.26                 | 13478                  | 56.44 |
| YJLW03-127/220kV-1×2000 | 143          | 1×2000                     | 30.08                 | 16061                  | 66.49 |
| YJLW03-127/220kV-1×2500 | 150          | 1×2500                     | 36.24                 | 17671                  | 68.98 |
As shown in Figure 4: Under the verification of the trajectory of the project example, the safety coefficient of cable traction force under both traction methods is above 2.5, which can theoretically meet the actual needs of the project, and the safety coefficient is not much different, and the advantages and disadvantages of the two traction methods cannot be distinguished from the theoretical calculation results alone.

Wire mesh sleeve traction method has the advantages of large force area, easy to disassemble, etc., and is widely used in low-voltage power engineering, but the wire mesh sleeve requires on-site construction and installation, installation error is large, prone to broken strands, fall off and other accidents, and the use of wire mesh sleeve traction completed, due to the traction part of the cable sheath of about 1.5m length in the traction process received a large tension, in order to ensure the late cable safe operation, the length of the cable needs to be cut off, causing losses to the project itself. The traction head is mostly pre-installed at both ends of the cable by the manufacturer, the process is relatively mature, the construction error is small, and it is not easy to fall off and other accidents. Therefore, the traction head is preferred in the process of cable traction.

Since most 35kV cables are coaxial three core cables, it is difficult to use the traction head to traction the three copper cores at the same time in the existing process, so the steel mesh sleeve traction mode is adopted; The 110kV and above cables are single core cables with large copper core section, and the traction head shall be preferred.

As can be seen from the figure, the safety factor of 2500 cross-section cable is the highest under the traction head method, followed by 2000 cross-section and 800 cross-section cable, and the safety factor of 1200 cross-section cable is the lowest, and the variation pattern is consistent with the ratio of cable conductor cross-section to unit weight. When the single weight of the cable is certain, the larger the cross section of the cable conductor, the higher the safety factor.

5. Conclusions
This paper combines relevant regulations and specifications as well as actual engineering cases to study the cable traction force involved in the application of horizontal directional drilling in power engineering, and the following conclusions are obtained.

(1) The calculation formula of cable traction force is modified, and the equivalent model of arc making section for calculating cable traction force is obtained, so that the theoretical calculation value of cable traction force is consistent with the actual law;
(2) 35kV coaxial three core cable shall adopt the traction mode of steel mesh sleeve, and 110kV and above voltage grade cables shall adopt the traction mode of traction head;

(3) On the premise of determining the pipe drawing track, the safety factor of cable traction force is related to the cable conductor section and the cable single weight. When the cable single weight is certain, the larger the conductor section is, the higher the safety factor is.

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