Research on Fast "Blind Interpolation" Technology of High Density and Miniaturization Prefabricated Optical Cable

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Abstract: In this paper, a prefabricated optical cable SPM (Standard Prefabricated MPO/MTP) based on high density, miniaturization and ultra-precision positioning technology is studied. The prefabricated optical cable uses T-slot KEY key-oriented technology, primary key+auxiliary key positioning technology, arc center focusing technology, floating rendezvous and docking technology between P-guide pin and guide hole. It ensures ultra-precise positioning of Yin and Yang plug docking, and achieves fast "blind insertion" of all-optical links. The experiment proves that the high-density prefabricated optical cable meets the requirements of low loss and easy maintenance of the secondary physical circuit, and unifies the prefabricated optical cable interface standard of the intelligent substation, improves the reliability of the system communication connection, and truly realizes the modularization of the secondary physical connection of the intelligent substation, and standardized "plug and play" requirements.

1. Introduction

In accordance with the principle of "standardized design, factory processing and modular construction", the physical circuit of the secondary system requires "plug and play" prefabricated optical cable connection. At present, prefabricated optical cables have been widely used in smart substations. However, the prefabricated optical cable connectors commonly used in projects have a series of problems, such as the difficulty of cleaning the ceramic pin end face, the inaccuracy of a pin/sleeve or the insufficient pressure of the pin, the easy dislocation of the optical fiber, the easy breakage of the pin, the excessive optical loss, the large volume of the prefabricated plug, the inconvenience of field construction and installation. At the same time, the fiber end face of the conventional multi-core prefabricated fiber optic cable connector is susceptible to contamination, damage and difficult to repair, and the technical problems of the MIL-38999 standard series multi-core prefabricated cable theoretically do not support single mode fiber transmission. Conventional multi-core prefabricated optical cables are difficult to ensure that smart substation adopts single-mode and multi-mode transmission and interchangeability and versatility requirements, and affects later reconstruction and daily operation and maintenance. In view of the importance of long-term safe and stable operation of substations. In summary, this paper studies a prefabricated optical cable SPM (Standard Prefabricated MPO/MTP) based on high density, miniaturization and ultra-precision positioning technology to achieve low loss of secondary physical circuit, easy maintenance, unified interface and fast "blind insertion" of all optical links, and to meet the requirements of modular and standardized "plug and play" of secondary physical connection in intelligent substations.

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2. Blind Interpolation Technology of Prefabricated Optical Cable Based on Ultra-Precision Multi-Position Floating Connection

Due to the limitations of light and space in the cabinet, and the invisibility of the connector housing material, the high-density prefabricated cable needs to be designed as a connector with blind insertion and mis-insertion, which can be restricted in vision and touch. The occasion can still achieve accurate docking without being affected. Blind plug-in connection technology can adjust itself to the correct connection position according to the self-deployed guidance system, so it can ensure reliable and consistent accurate docking when it is difficult to understand its exact position through observation and touch, thus minimizing the error or danger caused by misconnection.

High density prefabricated optical cable SPM Plug and Play (Plug and Play) is based on the fast connection and locking of the cathode and the cathode plugs with adapter interfaces respectively, while realizing the precise positioning of the cathode plug PIN pin hole and the cathode plug PIN pin, and finally making the end face of the cathode and cathode plugs in elastic contact to form an optical transmission link. Therefore, the accuracy of the connection between the female and male plugs and the adapter and the positioning accuracy of the PIN pin hole and the guide pin are the key technologies for ensuring the contact state of the pin end faces of the female and male plugs and ultimately affecting the transmission quality of the prefabricated optical cable.

Since the high-density fiber optic connector has controlled the fiber core diameter mismatch and the end core angle tilt when manufacturing the male and female plug ferrules, it is necessary to calculate the influence of the core misalignment on the connection loss:

The decibel number of insertion loss is:

$$L\alpha(sm)=-10lg(1-Cd)$$

According to the "Q/GDW 11155-2014 National Network Enterprise Standard: Smart Substation Prefabricated Optical Cable Technical Specification" prefabricated optical cable multi-core connector insertion loss ≤ 0.8 dB (maximum value), ≤ 0.6 dB (typical).

According to "YD/T 1272.5-2009 Fiber Optic Active Connector Part 5: MPO Type", the maximum insertion loss of any two plugs connected through the adapter is ≤ 1 dB. Take $L_{\alpha(sm)}$=0.6 dB(typical value) and calculate C_d=0.129.Link loss C_d when single-mode core is dislocated:

$$C_d = K_d\left(\frac{d}{a}\right)^2$$

In the formula: K_d = 0.7, a = 4.5 um is substituted to calculate d = 1.93 um.

If $L_{\alpha(sm)}$=0.8 dB (maximum value), substitute Cd=0.1682Link loss Cd when single mode core is misaligned:

$$C_d = K_d\left(\frac{d}{a}\right)^2$$

Where: Kd=0.7, a=4.5μm is substituted into d=2.21μm. Therefore, for single-mode prefabricated fiber optic connectors, the core misalignment must not exceed 2.21 μm.

Link loss formula for multimode core dislocation:

$$L_{dm} = -10lg\left(1-\frac{2d}{\pi a}\right)$$

Where: take L_{dm}=0.6 dB (typical value), a=31.25μm is substituted into the calculated d=6.33181μm.

If in the formula: take L_{dm}=0.8 dB (maximum value), a=31.25μm is substituted into the calculated d=8.2541μm

Therefore, the multimode prefabricated fiber optic connector has a core misalignment of less than 8.254 μm.

The current MT ferrule dimensional tolerance can meet the above design requirements.

Therefore, it is important to design the center of the "T-slot guide core" inside the adapter to be consistent with the center of the female and male plug shields and the center of the ferrule. To ensure that the high density optical fiber connector's cathode and cathode plugs are accurately docked, not only can the accuracy and performance meet the requirements of use, but also can achieve the product at the most economical cost of mechanical processing.

The technology of "T-slot KEY key orientation", "primary key + auxiliary key orientation", "arc center focusing", "P-guide needle and guide hole floating rendezvous and docking" will be adopted to ensure ultra-precise positioning when connecting the positive and negative plugs. In this paper, the center of the "T-slot guide core" inside the adapter is designed to be consistent with the center of the female and male plug shields and the center of the ferrule to ensure accurate mating of the female and male plugs of the high-density fiber optic connector. Meet the accuracy and performance requirements of the application, and achieve the most economical machining costs.

2.1 T-slot Guidance Design

The bottom of the "T-slot guide core" inside the adapter and the bottom of the "guide T-slot" of the female and male plug shields are always aligned, and the main key way or primary key is at the same reference centerline. This ensures that the KEY keys of the rectangular socket body of the positive and negative plugs of the high-density optical fiber connector can be accurately and correctly inserted into the T-slot guide core of the adapter to complete the second "blind" connection between the PIN guide pin and the guide pin hole when the "primary key + auxiliary key" is aligned and inserted into the adapter's "main key slot + auxiliary key slot" from beginning to end.

The maximum offset of the bottom edge of the adapter "T-slot guide core" and the "T-slot" of the female and male plugs, and the maximum geometric tolerance of the primary key and the centerline of the primary keyway are discussed below(◎), as shown in Figure 1.

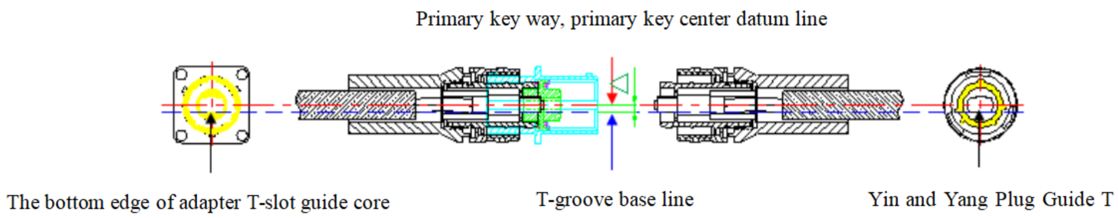

Fig.1. T-slot, key and keyway datum

According to the above calculation, the fiber connector meets the standard requirements of the connection loss: single mode maximum core misalignment $\triangle \leq 2.21\mu m$, multimode maximum core misalignment $\triangle \leq 8.254\mu m$, are smaller than the guide pin radius $A / 2 = 349.25\mu m$, That is to ensure that the PIN pin can be introduced into the pin hole and can achieve a "blind plug" connection.

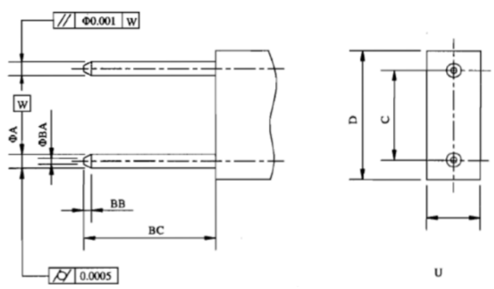

Fig.2. MT ferrule PIN guide pin

2.2 Positioning Design of Primary Key and Auxiliary Key

According to the "Primary Key/Key way Positioning" standard specified in GJB 599A-1993 General Specification for Rapidly Separating High Density Small Circular Electrical Connectors, the high-density prefabricated optical cable connector housing is made of No. 13 housing, N=95°. If the adjacent connector needs the function of anti-misinsertion connection, the other four key codes A, B, C and D can be used to realize it.

There is one main key slot in each interface hole of the two ends of the adapter and it is in the same reference position. Several auxiliary key slots (slot width h+A/4) are designed on the left and right sides of the main key slot (slot width h+A/4), and the angles of γ1, γx and β1,βy are formed with the main key slot. The angle of the auxiliary key slots in the interface hole of the two ends of the adapter is in the same direction, as shown in Figure 3.

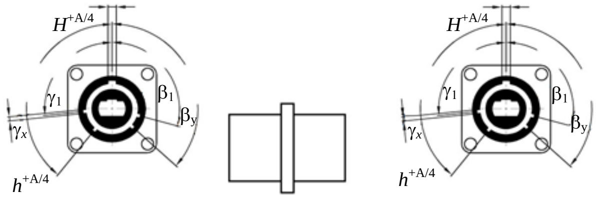

Fig.3. Adapter blind insertion structure

The primary key (key width H−A/4) h on the outer circumference of the female and male plug protection housings and the auxiliary keys (key width h−A/4) designed on the left and right sides of the primary key remain the same as the angle formed by the primary key. The number of inner keyways is the same, the angles are the same, and both are γ1, γx and β1, βy but opposite directions, and x and y can be zero or natural numbers, as shown in Figure. 4.

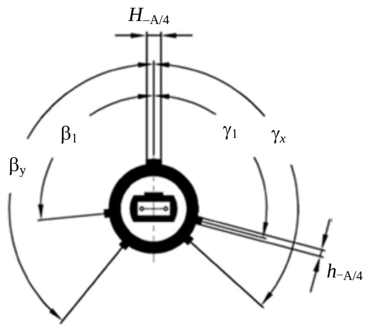

Fig.4. The blind and inserted structure of the protective cover of the female and male plugs

When the cathode and cathode plug protective shell is matched with the adapter, only when the main key is aligned with the main key slot and the corresponding auxiliary key is aligned with the auxiliary key slot, can the blind insertion be realized and the anti-misinsertion connection be ensured.

2.3 Aggregation Design of Circular Center

High-density fiber-optic plug connector The outer contour of the rectangular ferrule is a full-circle partial arc with a standard outer diameter ΦE of the arc, a standard reference diameter ΦA of the PIN guide pin, and a top width S of the KEY key, as shown in Fig. 5. The diameter of the arc in the "T-slot" of the protective casing of the female and male plugs is Φe, and the groove width s at the bottom of the T-slot is assumed to be $\Phi E<\Phi e\leq\Phi E+\Phi A/2$, $S+\Phi A/2<s\leq S+\Phi A$, at this time When the male and female plug rectangular ferrules are respectively engaged in their protective casings. Because the width and direction of the "T-slot" in the protective case limit the KEY key position of the rectangular plug body, the rectangular plug body of the positive and negative plug always focuses in the central direction of the inner arc of the protective case, and the KEY key of the rectangular plug body of the negative and positive plug always sits in the same direction, as shown in Figure 6. E, e, S and s are the arc reference diameter and KEY key width dimensions corresponding to the rectangular socket body and adapter of standard high density optical fiber connector respectively.

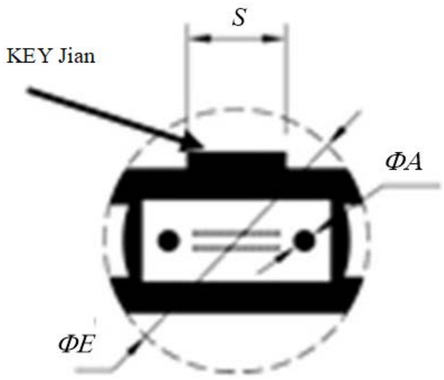

Fig.5. Rectangular pin body

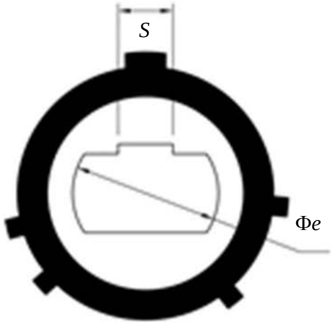

Fig.6. Yin and Yang plug protective housing

According to the standard "YD/T 1272.5-2009 Optical Fiber Active Connector Part 5: MPO Type", we can check the top width of KEY key S=3.0+0.1, E=8.44+0.1, A=0.698+0.1. Calculate the diameter of the arc in the "T-slot" inside the protective casing of the female and male plugs: $\Phi 8.44 < \Phi e \leq \Phi 8.789$; the groove width at the bottom of the T-slot: $3.349 < s \leq 3.698$. The design is shown in Figure 7.

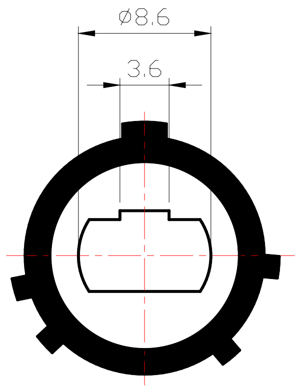

Fig.7. Yin and Yang plug protective shell design size

2.4 Floating Rendezvous and Docking Design of Guide Pin and Guide Hole

Due to the actual tolerances of machined parts, the assembly components or components also have dimensional tolerances and geometric tolerances. In order to eliminate these tolerances and ensure the natural rendezvous and docking of MPO head and mother head and the close fit of optical fiber end face, the design concept of floating rendezvous and docking is introduced.

The inner "T-slot guide core" of the adapter is the key component to realize the "floating rendezvous and docking". Its function is to guide the female and male plugs to complete the "docking of the PIN guide pin and the guide hole". The main and auxiliary keys are arranged at the front end of the plug protection shell and have a concave U-shaped cylindrical guide hole on the inner side of the front end surface, and the outer diameter of the U-shaped cylindrical guide hole is ΦG+A/4 and depth Ba, as shown in FIG. When the male and female plugs are axially advanced along the main key way in the adapter, the front end first contacts the "T-slot guide core", and the inside of the guide core is a T-shaped groove with a circular arc. The size is the same as the "T-slot" arc diameter Φe in the plug protective housing and the groove width s at the bottom of the T-slot. The two sides of the guiding core are respectively convex U-shaped cylinders with outer diameter ΦG−A/4 and width Xa. The T-groove guide core has a total width B. In the middle of the guide core is a cylinder matching the main and auxiliary keyways of the adapter, and the outer side of the cylinder is a spherical body. The guide core is mounted inside the adapter with micro-movement in X, Y and Z directions and swing in Z direction, as shown in Fig. 9. When the concave U-shaped cylindrical guide hole contacts and gradually leads into the convex U-shaped cylinder, because the guide core has a floating design of axial micro-movement and three-dimensional micro-swing, the KEY key rectangular insert body will be precisely guided into the guide core T-shaped groove. Whether it is the positive plug with PIN guide pin or the negative plug with guide pin hole when connecting the adapter, the first floating intersection of the PIN guide pin will eventually lead into the guide pin hole and realize the precise contact connection of the end face of the rectangular plug. The rectangular ferrule fiber end face is at a height Bb from the bottom of the concave U-shaped cylindrical guide hole, and Bb>Ba. This structure design is convenient for cleaning and maintaining the fiber end face of the high-density fiber movable connector, and assuming B=2Bb–Bo, 0< Bo<(I−J)/2, the rectangular ferrule body is subjected to the axial elastic force, so that the female and male rectangular ferrules float and rejoin for the second time, and ensure that the fiber end faces are in close contact with each other. Bo is the continuous compression amount of the yin-yang rectangular ferrule body subjected to the elastic action, and the I-J value is the ultimate compression amount of the rectangular ferrule body.

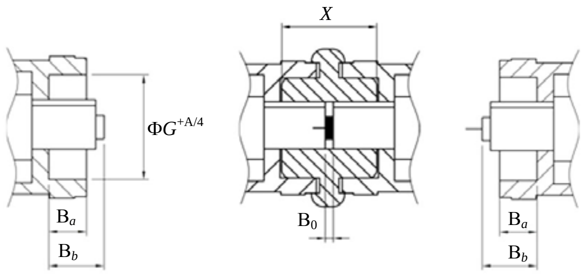

Fig.8. Yin and Yang plugs and their floating rendezvous and docking

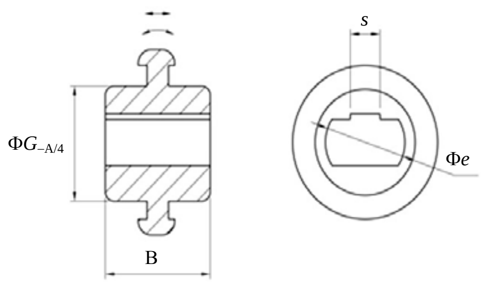

Fig.9. Adapter T-slot guide core

The adapter that can realize the "floating rendezvous and docking" and the "T-slot guide core" are designed as follows:

X-direction displacement: width of groove in adapter housing - width of T-groove guide core outside = 4.9-4.4 = 0.5mm;

Y, Z direction displacement: inner diameter of the groove in the adapter housing - outer diameter of the T-shaped groove guide core = φ19.8-φ19.2 = φ0.6mm;

Z-direction oscillation: tan-1 (X-direction displacement / inner diameter of the groove in the adapter housing) = tan-1 (0.5/19.2) = 1.49°.

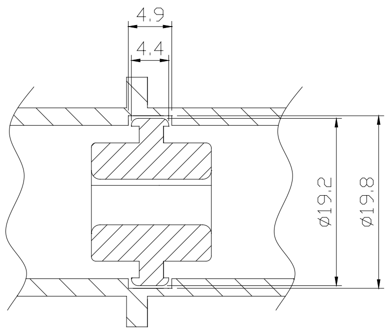

Fig.10. Design dimensions of the "T-slot guide core" inside the adapter

Round corners are designed at the opening of both ends of the "T-groove guide core" to facilitate the insertion of MPO plugs and female plugs into the "T-groove guide core" and ultimately realize the "blind insertion" technology of ultra-precision connection.

3. Loss Analysis and Verification of High Density Prefabricated Optical Cable

The high density prefabricated optical cable is composed of prefabricated protective case (including plug protective case and adapter protective case), multi-core and multi-row optical fiber plug-and-pull connector, optical cable, etc. The prefabricated negative plug and prefabricated positive plug are respectively blindly inserted to connect the two ends of the adapter to realize multi-core and multi-row optical link "Plug and Play". The high-density fiber optic patch cord is a multi-core multi-row plug connector (MPO or MTP for short) featuring a rectangular ferrule with a nominal diameter of 6.4 mm and 2.5 mm, utilizing the left and right sides of the end face A φ0.7 mm diameter guide pin hole is positioned and docked with the guide pin, and an axial pressure is applied to the ferrule body by a spring attached to the tail of the ferrule body until the female plug and the tape guide with the pin guide hole are connected. The outer frame sleeve of the male plug of the needle is respectively connected with the adapter to form a docking. See Figures 11 and 12.

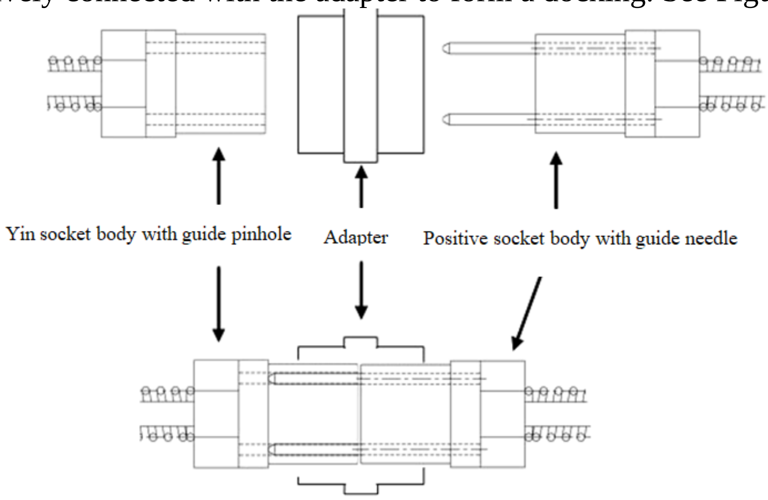

Fig.11. High-density fiber optic patch cord structure

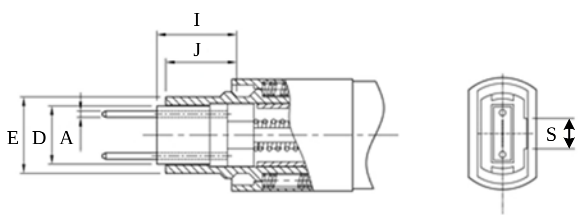

Fig.12. High density fiber optic connector male plug

The high-density optical fiber movable connector has a single row of 1~12 cores or 1~16 cores, double rows of 1~24 cores or 1~32 cores, and multiple rows of up to 72~96 core fibers are connected at the same time, as shown in Figure. 13, The ferrule body end face of the male plug is contacted to realize.

The main factors affecting the link loss of high-density fiber optic connector are the core diameter mismatch, lateral misalignment and angle tilt between the output fiber end face and the input fiber end face. The following is a detailed analysis of the impact of these factors on link loss. When analyzing and calculating the impact of one factor, it is assumed that there are no other factors.

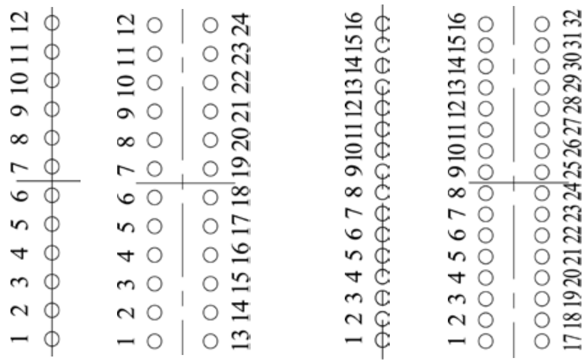

Fig.13. 12,16-core single-row and double-row optical reference axis position

3.1 Effect of end Core Diameter Mismatch on Connection Loss

When the diameter of single mode optical fibers is mismatched, the connection loss Ca is calculated by the following formula:

$$C_a = \left[\frac{\omega_1^2 - \omega_2^2}{\omega_1^2 + \omega_2^2}\right]^2 \tag{1}$$

In the formula, 1 and 1 are the width coefficients of the Gaussian beam of the input fiber and the output fiber, respectively, and it can be seen from the formula (1) that in the case of the single mode fiber, loss is generated as long as the diameter is mismatched.

The multimode fiber connection loss is calculated by the loss calculation formula under the condition of steady distribution of optical power:

$$L_{\mathrm{am}} = -10\lg(\frac{a_2}{a_1})^2 \tag{2}$$

In the formula, a1 and a2 are the input fiber core diameter and the output fiber core diameter, respectively, and the loss is small when the input fiber core diameter is smaller than the output fiber core diameter, and vice versa.

When a1 a2 < 1.5 um, the increase of connection loss is more gentle for both single-mode and multi-mode fibers.

When a1□ a2>1.5 μm, the multimode fiber connection loss is still slowly increasing, but the single mode fiber connection loss will increase sharply.

It can be seen that the input fiber and the output fiber select the same specification fiber and the core diameter tolerance is controlled within 1.5 μm, which has the least impact on the connection loss of the high-density fiber-optic plug connector.

3.2 Effect of end core Dislocation on Connection Loss

When connecting high density optical fiber plug-in connectors, it is assumed that the core diameters of the output optical fiber end face are the same as those of the input optical fiber end face, and there are transverse or longitudinal dislocations as shown in Figure. 14 or Figure. 15.

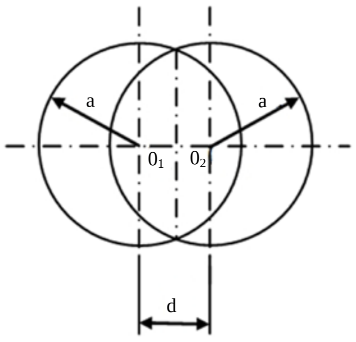

Fig.14. Core lateral (X-direction) misalignment

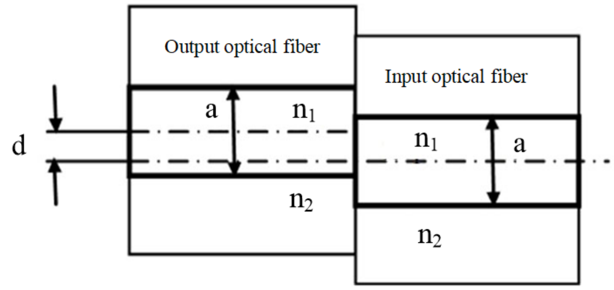

Fig.15. Core longitudinal (Y-direction) misalignment

The link loss Cd when the single mode core is misaligned can be calculated by the following formula [16]:

$$C_{\mathrm{d}} = K_{\mathrm{d}}\left(\frac{d}{a}\right)^2 \tag{3}$$

Kd is the core dislocation loss coefficient of single mode fiber. For known single mode fiber, Kd is a fixed value, D is the offset when transverse or longitudinal dislocation, and a is the core diameter of the fiber.

The link loss when the multimode core is misaligned is obtained by the loss formula under the condition of steady distribution of optical power[16]:

$$L_{\mathrm{dm}} = -10\lg\left(1-\frac{2\mathrm{d}}{\pi a}\right) \tag{4}$$

When the offset D changes, the BPM software based on beam propagation method is used to simulate and calculate the optical field at the optical fiber junction. The relationship between the transmission efficiency and the offset D of the single-mode optical fiber junction can be obtained, as shown in Figure 16.

When d < 0.75 um, the increase of connection loss is relatively flat for both single-mode and multi-mode fibers.

At d > 0.75 μm, the single-mode fiber connection loss will increase sharply, while the multimode fiber connection loss will slowly increase.

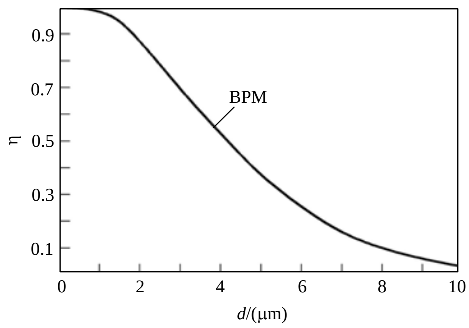

Fig.16. Transmission efficiency and core offset d

3.3 Effect of end Core Angle Tilt on Connection Loss

The high-density fiber-optic plug connector is assumed to have a core tilt angle of on the end face of the female plug and the end face of the male plug.

The loss when the angle of the single-mode fiber is tilted can be derived by the following formula [16]:

$$C_{\mathrm{a}} = K_{\mathrm{a}} \left(\frac{a}{\sqrt{2\Delta}}\right)^2 \tag{5}$$

In formula Kα, the angular tilt loss coefficient of the end surface is a constant value of Kα and for known single-mode fibers.

The multimode fiber connection loss is based on the loss formula under the steady distribution of optical power [16]:

$$L_{\mathrm{a(mm)}} = -10\lg\left(1 - 0.36\frac{a^2}{\Delta}\right) \tag{6}$$

When the core inclination angle α increases, the connection loss of single-mode or multi-mode fibers will gradually increase with α2/, and the influence of inclination angle on the connection loss of single-mode fibers is much greater than that of multi-mode fibers.When the end face tilt angle is controlled within α < 0.4°, a low loss of less than 0.1 dB can be obtained regardless of the single mode fiber or multimode fiber connection.

3.4 Effect of Inclined Connection on Echo Loss

When single mode optical fibers are inclined to connect, as shown in Figure. 17, there are axial clearance D and radial offset d.

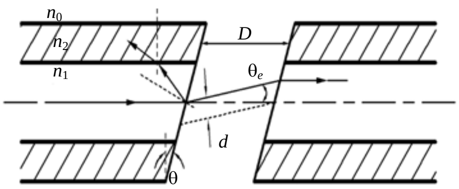

Fig.17. Single mode fiber beveled connection

The Fresnel reflected light at the connection interface returns at 2 angles, and the power reflection coefficient of the slope connection [18]:

$$R = R_{\mathrm{o}} \exp\left[-\left(\frac{\pi n_2 \omega_2 \theta}{\lambda}\right)^2\right] \tag{7}$$

R_0 is the Fresnel reflection coefficient when the plane is connected. Figure 8 (ω = 5 μm, n2 = 1.46) is a theoretical curve of different end face inclination and return loss.

The Rayleigh scattering of the fiber itself is about 65 dB, and the bevel connection with the face angle of inclination 8 is sufficient to meet the requirements of the system application.

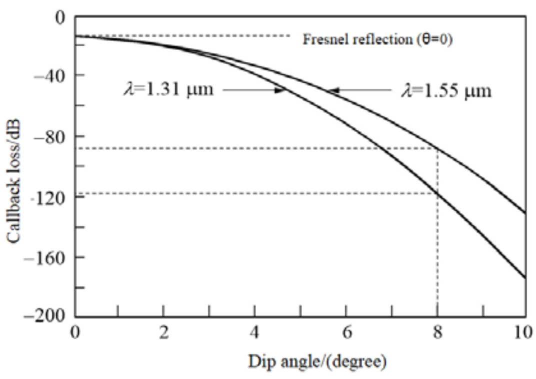

Fig.18. Theoretical curve of end face inclination and return loss

3.5 Link Loss Verification of High Density Prefabricated Optical Cable

When measuring the connection loss of multimode optical fibers and single mode optical fibers, using LED light source, the peak wavelength of multimode optical fibers is 850 nm/1300 nm.

The single-mode fiber has a peak point wavelength of 1310 nm / 1550 nm. The high-density prefabricated cable connection loss test link is shown in Figure 19.

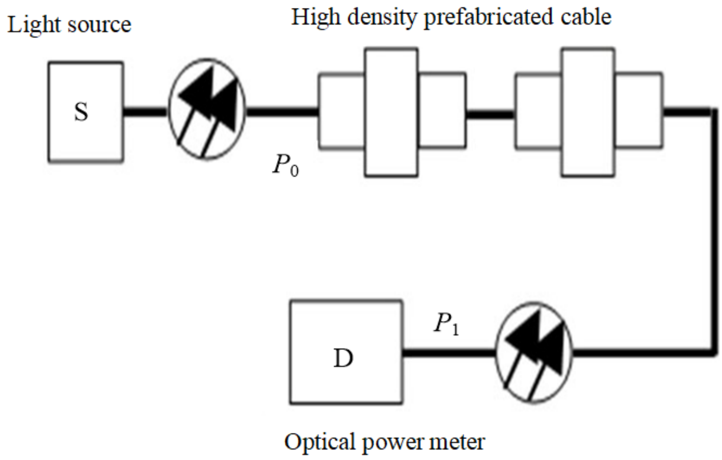

Fig.19. High-density prefabricated cable connection loss test schematic

The connection loss value a is calculated according to the following formula:

$$a = -10\lg(\frac{P_1}{P_0}) \tag{8}$$

The return loss of single mode optical fibers is measured by the return part of the input power along the input path. The measurement benchmark is the directional coupler method. The measurement link is shown in Figure 20. Echo loss RL is calculated according to the following formula [14]:

$$RL = -10\ \log\frac{p_1' - P_1}{P_0} + 10\ \log T_{2,4} \tag{9}$$

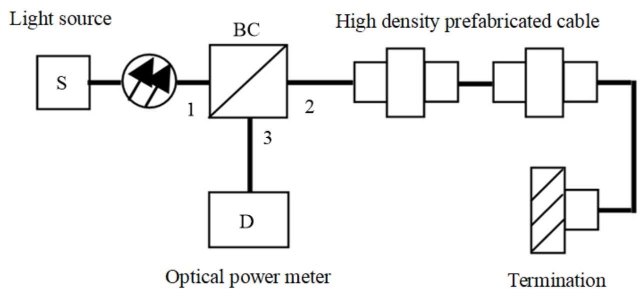

Fig.20. Schematic diagram of single mode fiber return loss measurement

We prefabricated 54 high-density prefabricated optical cables, using double-row 24-core 62.5/125 μm multimode fiber, PC end face, and a total of 1296 optical links as multi-mode test samples; At the same time, 54 high-density prefabricated optical cables were fabricated, using double-row 24-core 9/125 micron single-mode optical fibers with an inclined angle of 8 degrees APC end face. A total of 1296 optical links were used as single-mode test samples. The link loss values of multi-mode high density prefabricated optical cables and single-mode high density prefabricated optical cables are validated by "substitution method" by "insertion loss measuring instrument", respectively, as shown in Figure. 21.

Fifty-four prefabricated high-density optical cables with two rows of 24 cores, 9/125 micron single-mode and 8 degrees oblique APC end face are fabricated. A total of 1296 optical links are used as echo loss test samples at the same time. The "replacement method" is used to verify the return loss value of the high-density prefabricated cable link by the "return loss meter" test, as shown in Figure 22.

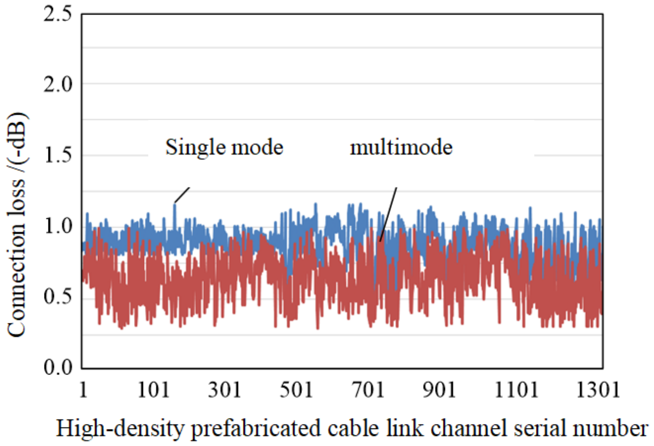

Fig.21. Multimode, single mode high density prefabricated cable link loss value

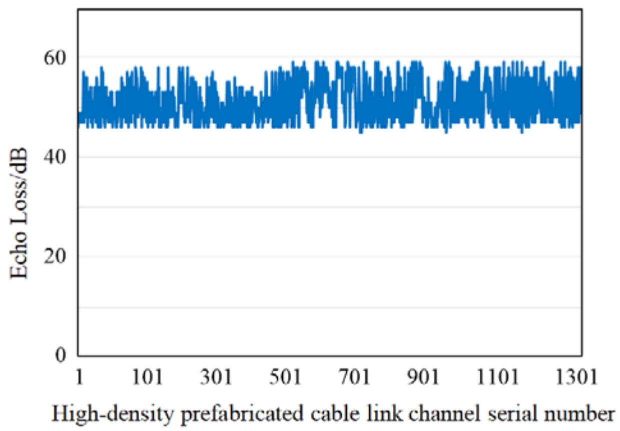

Fig.22. Single mode high density prefabricated cable link return loss value

The experimental results show that the high-density prefabricated optical cable technology is applicable to both multimode fiber and single mode fiber. For the data analysis of 1296 multimode optical links and 1296 single mode optical links of all tested high density prefabricated cables, the maximum link loss value is <-1.15 dB, and the link loss is typically ≤-0.8 dB. Below GJB1919-94: 3.10.1 The maximum loss per link of conventional multi-core prefabricated fiber optic cable with 62.5 um core diameter is defined as 1.8 dB, and the minimum value of single-mode fiber echo loss of high density prefabricated fiber optic cable is more than 48 dB by verification.

4. Conclusion

The high-density prefabricated optical cable based on multi-core and multi-row optical fiber plug-and-pull connector is designed by blind insertion technology which combines the outer circle "primary key + auxiliary key" of the cathode and positive plug protection case and the inner hole "T-slot guide core" of the adapter. The T-slot KEY key guide, the "primary key + auxiliary key positioning", "arc center focus", "P guide pin and guide hole floating rendezvous and docking" and other technologies ensure ultra-precise positioning of the male and female plugs. Experiments show that the high density prefabricated optical cable technology is not only suitable for multi-mode optical fibers, but also suitable for single-mode and dual-mode (multi-mode + single-mode) optical fiber connection. It can achieve the unification of 2-24 cores and even more cores of high density prefabricated optical cable interface.

In summary, the research results of this paper "prefabricated optical cable based on high density, miniaturization and ultra-precision positioning technology" can achieve the secondary physical circuit with low loss, easy maintenance, unified interface and all-optical link fast "blind insertion". Realize the modular and standardized "plug and play" requirements for the secondary physical connection of intelligent substation.

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