Development of Optical Fiber-Power Composite Cables

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ABSTRACT Two types of optical fiber-power composite cables have been developed as under floor wiring cable, which is indispensable for realizing FTTD (Fiber To The Desk). VVR (round) and VVF (flat) types of ordinary 600-V polyvinyl insulated and sheathed cable have been adopted in the development. With VVR, an optical fiber unit is sheathed together with power lines; and with VVF, the cable structure is such that a hollow pipe is sheathed with power lines, into which an optical fiber unit is to be air-blown after cable installation, thereby comprising an optical fiber-power composite cable. The developed cables are expected to improve cable congestion under the floor, facilitating the construction of transmission lines for FTTD.

1. INTRODUCTION

The number of Internet users in Japan is estimated to have reached 27 million at the end of 1999 (a 59.7% increase over the previous year), rising to 77 million at the end of 2005. In terms of diffusion rate, Internet users account for 19.1% of every household, 31.8% of enterprises with 5 employees or over and 88.6% of enterprises with 300 employees or over [1)].

It is anticipated that data communications continue rapid expansion, thereby promoting a transition of wiring configuration for office LANs from the conventional ones based on twisted pairs to a new one that uses optical fibers. Thus, optical access cables have to be upgraded in terms of performance and cost in order to enable economical and rapid expansion of optical access networks.

In this paper, the design and development of new optical fiber-power composite cables is reported. The cables are to be used, approaching nearer to the users side than access cables, for wiring within office buildings and especially under the floor, and for connection between office cabinet and outlet so as to realize FTTD.

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2. NECESSITY FOR OPTICAL FIBER-POWER COMPOSITE CABLES

Telecommunications trunk cables led into an office building are connected to on-premises trunk cables, which run longitudinally to be connected to floor cables at the end-floor cabinet, while a required number of optical fibers are branched at each intermediate floor. On the other hand, longitudinal power cables are branched at each floor in a similar manner. Thus, in the conventional wiring, optical fiber cables and power cables are installed individually, resulting in the increase of wiring work hour and cable congestion under the floor.

In order to solve such a problem of congested wiring, it is necessary to develop an optical fiber-power composite cable including accessories so that the wiring work is improved in terms of working hour and cable congestion. Figure 1 shows the typical cable configuration in office buildings illustrating both the conventional wiring method and the new method based on composite cables.

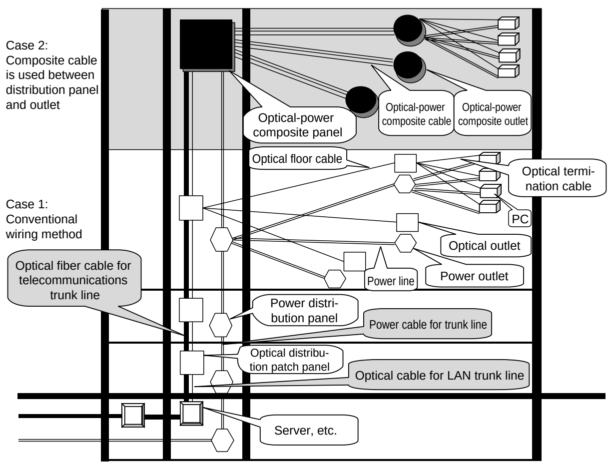

Figure 1 Typical cable configuration in office buildings.

3. REQUIREMENTS FOR OPTICAL FIBER-POWER COMPOSITE CABLES

VVR (round) and VVF (flat) types of 600-V polyvinyl insulated and sheathed cable are widely used for under floor wiring since they are low in cost due to large-volume production. We have designed and developed the optical fiber-power composite cable based on these cables. Requirements for the cable design are as follows:

1) Since the cable is cut and worked for termination at the site, the optical fiber has to be easily accessed for termination work.
2) The power line of the cable complies with JIS C3342 "600-V polyvinyl insulated and sheathed cable", so that the cable structure certified according to the Electrical Appliance and Material Control Law should not be changed.

The cables were designed to meet these requirements.

4. DEVELOPMENT OF OPTICAL FIBER-POWER COMPOSITE VVR CABLE

4.1 VVR Cable

The structure of VVR cable is stipulated in detail in JIS C3342 "600-V polyvinyl insulated and sheathed cable", where "V" stands for "vinyl" and "R" for "round". Table 1 shows excerpts from JIS C3342.

As can be seen, single- to 4-insulated wire cables with each wire consisting of vinyl-insulated single conductor or stranded conductor are stipulated. Multiple wires are to be S stranded with the specified conditions.

4.2 Investigation on Composite Cable Structure

The cable structure investigated for optical fiber incorporation is a round 3-insulated wire type, and the conductor size was selected as 2 mm^2 --the smallest nominal cross-sectional area among the stranded conductors. Figure 2 and Table 2 show the cross section and the dimensions of the VVR cable studied, respectively.

In terms of optical fiber incorporation into this cable structure, it was considered that the optical fiber would be most advantageously combined without changing the basic cable structure and dimensions when the space at the shoulder of the three power lines was used for accommodation.

4.2.1 Investigation on Optical Fiber Unit Structure

In view of LAN configuration using this composite cable, the number of optical fiber to be incorporated in the cable was determined as eight --2 fibers for 4 bi-directional channels. The cross section of the optical fiber unit is shown in Figure 3, where 8 fibers are stranded around a central tension member, then covered with thermoplastic resin.

The outer diameter of the unit should be appropriately designed so as not to interfere with the binding layer of the cable, because excessive diameter may degrade its lateral pressure performance. Accordingly, UV coated fiber of 0.25 mmϕ was used for the unit, and GI fiber of 50/125 cross section was selected in view of application for LAN environments.

During cable manufacturing, the optical fiber unit is stranded simultaneously with the power lines in the same stranding pitch. The stranding pitch is stipulated by JIS as "30 times or less of the center diameter of the insulated wire layer", or about 117 mm or less in this case. Consideration has to be given whether the strain on fiber remain under the allowable limit when the optical unit containing the fibers are stranded in this pitch and subsequently wound on a reel. We have calculated the minimum bending radius to be imposed on the fiber, taking

Table 1 Excerpts from JIS C3342.

Discrimination of cable core	Single insulated wire	Black
	2-insulated wire	Black, White
	3- insulated wire	Black, White, Red
	4- insulated wire	Black, White, Red, Green
Stranding pitch of cable core	30 times or less of the center diameter of the insulated wire layer for nominal conductor cross section of 100 mm^2 or less	
Sheath	Black	

Table 2 Dimensions of VVR cable.

Structure	Dimension
Conductor	2 mm^2 in nominal, 7/0.6 strand
Insulation thickness	0.8 mm
Sheath thickness	1.5 mm
Outer diameter	11.0 mm

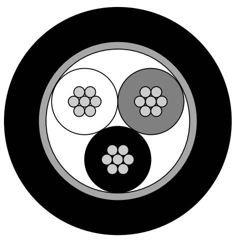

Figure 2 Cross-sectional view of VVR cable.

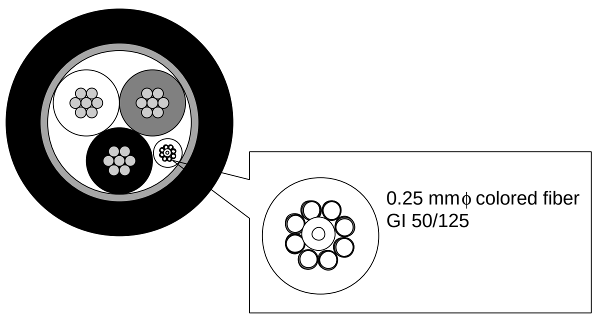

Figure 3 Cross section of optical fiber-power composite VVR cable.

such factors as the stranding pitch of the fiber in the optical unit and that of the unit in the cable together with the bending radius of the cable, and it was confirmed that the radius was more than the allowable limit for fiber.

4.2.2 Temperature Rise during Current Loading

Temperature rise during current loading has to be considered for such an optical fiber-power composite cable. Accordingly, we have experimentally evaluated the temperature rises during both short-circuited operation and current loading of nominal current, based on the allowable current of the cable.

The allowable current is 15 A, so that the short-circuited current at which the circuit breaker operates is calculated to be 234 A. Figure 4 shows the temperature rise in the cable and the loss increase of the fiber when the cable was subjected to the short-circuited current, and Figure 5 shows these characteristics when the cable continued to carry the allowable current. Table 3 summarizes the results of the measurements.

In the short-circuit experiment, although a circuit breaker operates in 0.2 second, the duration time was set to 1 second so as to keep on the safe side. It is seen that the temperature rise is below about 14°C, while it is about 10°C when the cable continued to carry the allowable current, and that no deterioration is seen for the cable characteristics. Thus, it may be concluded that the cable withstands the intended application as an optical fiber-power composite cable.

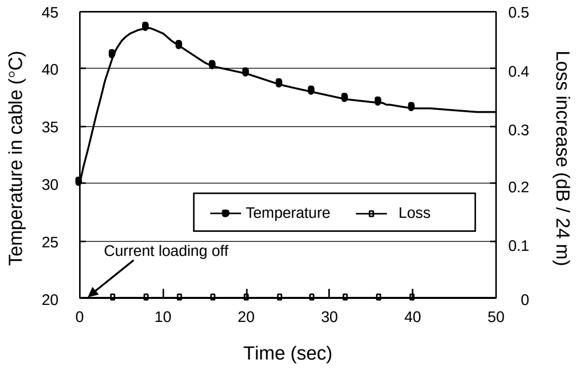

Figure 4 Temperature rise and loss increase of VVR composite cable subjected to a short-circuited current of 237 A x 1 sec.

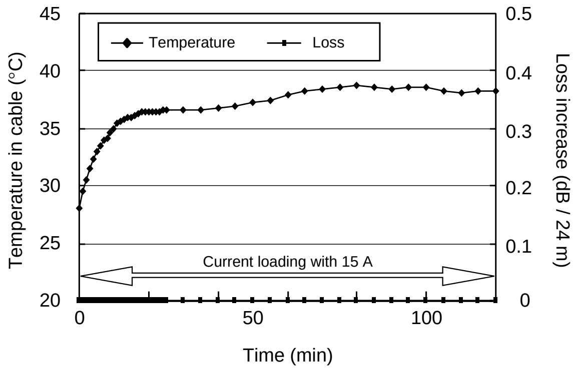

Figure 5 Temperature rise and loss increase of VVR composite cable subjected to an allowable current of 15 A.

4.3 Cable Characteristics

Table 4 summarizes the results of the evaluation of cable characteristics. As can be seen, the cable satisfies the characteristics required for general optical fiber cables.

5. DEVELOPMENT OF OPTICAL FIBER-POWER COMPOSITE VVF CABLE

5.1 VVF Cable

The structure of VVF cable is stipulated in detail in JIS C3342 "600-V polyvinyl insulated and sheathed cable", where "V" stands for "vinyl" and "F" for "flat". The VVF cable is most extensively used in office building wiring for power supply, permitting easy installation under the floor due to its flat cross section. Figure 6 shows the structure of the VVF cable.

5.2 Problems with VVF Cable Structure

In the case of the VVR cable, as described in Chapter 4, the optical unit that contains fiber is assembled by strand-

Table 3 Temperature rise and loss increase of cable during current loading experiments.

	Short-circuit test	Allowable current test
Temperature		
Initial value	30°C	28°C
After current loading	44°C	38°C
Loss increas	0 dB / 24 m	0 dB / 24 m

Table 4 Optical and mechanical characteristics of optical fiber-power composite VVR cable.

Test item	Results
Optical characteristics (λ=1.30 µm)	
Average transmission loss	0.80 dB/km
Temperature dependence at -10°C~+60°C	Loss change: 0.05 dB/km or less
Mechanical characteristics (λ =1.30 µm)	
Tension (400 N)	
Bending (R = 55 mm)	Loss change: 0.01 dB/km or less
Twist (±90°C/1 m)	Residual: None
Lateral pressure (1200 N/25 mm)	
Impact (7 kg, 60 mm)	
Fiber accessibility	Good

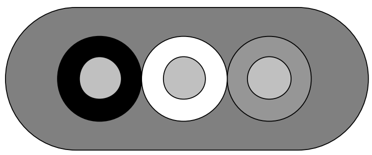

Figure 6 Cross-sectional view of VVF cable.

Table 5 Dimensions of VVF cable.

Structure	Dimension
Conductor	2 mmϕ in diameter
Insulation thickness	0.8 mm
Sheath thickness	1.5 mm
Outer dimension	6.6 mm × 14.0 mm, approx.

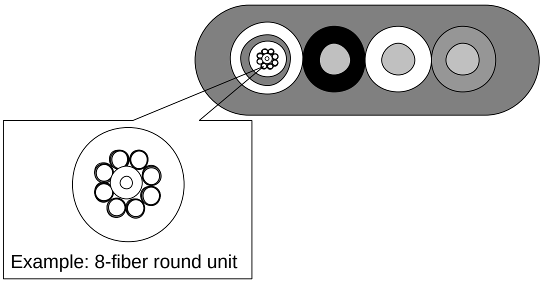

Figure 7 Cross section of pipe-composite VVF cable.

ing it in the same pitch as the power line, forming a composite cable structure. With the VVF cable, on the other hand, the following problems about optical unit assembly arise due to its simple structure of flat cross section:

1) Large strains will be generated on the optical unit when the cable is bent in the plane of cable width.
2) Large stresses will be imposed on the fibers because the optical unit is of tight structure.

These problems were investigated to find a solution.

5.2.1 Investigation on Cable Structure

The VVF cable investigated for optical fiber incorporation is a 3-insulated wire type, as is the case with VVR, and a solid conductor with a diameter of 2 mm was selected. Table 5 shows the dimensions of the VVF cable. The number of fiber is eight, the same as for VVR.

If the optical unit is sheathed jointly with the insulated conductors for power line coated with talc thus forming a flat cross section, strain on the fiber together with protrusion of cores present problems. Solid structure of optical unit seemed unsuitable to deal with this problem, so that loose structure was studied once. However, since fibers are encapsulated in the optical unit that is bulk sheathed with insulated conductors, it was feared that severe bending during cable installation might adversely influence the fibers.

It was decided, therefore, to make a pipe composite VVF structure by bulk sheathing a polyethylene pipe with the insulated conductors, into which an optical unit was to be air-blown after cable installation using compressed air, thereby comprising an optical fiber-composite power cable [2]. This cable structure eliminates those problems of fiber strain during cable installation as well as lateral pressure on the fiber. Figure 7 shows the cross section of a pipe-composite VVF cable.

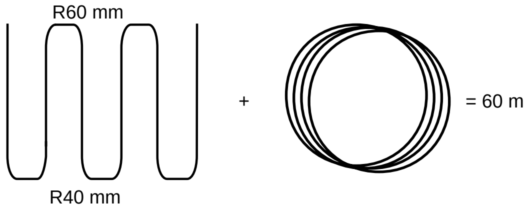

Figure 8 Test line configuration for blowing-in experiment.

Table 6 Optical characteristics of optical fiber-power composite VVF cable after blowing-in test.

Test item	Test results
Averaged transmission loss (λ =1.30 μm)	0.80 dB/km

The pipe, 2.5 mm in inner diameter and 4.0 mm in outer diameter, is made of polyethylene. The outer diameter of the pipe is nearly equal to that of the insulated conductor --3.6 mmϕ, thereby suppressing increase in cable thickness and enabling to achieve the same pattern of bending behavior. The optical unit is also shown in Figure 7.

5.2.2 Blowing-in Characteristics

A pipe-composite VVF cable was installed and tested for blowing-in characteristics of optical units using a test line shown in Figure 8. As shown, a 10 m piece of the pipe-composite VVF cable was installed with two 180° turns 60 mm in radius and three 180° turns 40 mm in radius, and a 50 m long pipe having a cross section of 2.5/4.0 mm in loose bundle was connected to the cable making the total pipe line 60 m in length. Subsequently, an 8-fiber round unit was air-blown into the test line.

Blowing-in experiments were carried out from the both ends alternatively, and it was confirmed that the entire length of fiber unit was successfully blown-in within 1 min 20 sec to 1 min 30 sec. Moreover, the unit was checked for optical characteristics after blowing-in, and no problems were found. Table 6 shows the transmission loss of the optical unit measured after blowing-in.

6. SUMMARY

Two types of 600-V polyvinyl insulated and sheathed cables that are in extensive use for power supply wiring have been incorporated with 8-fiber optical fiber unit, comprising optical fiber-power composite cables applicable to FTTD.

VVR: A cable structure has been developed in which an optical unit is placed at the shoulder of the three power lines, and all of them are stranded in the same pitch. This enables to offer an optical fiber-power composite cable without changing the outer diameter of the original VVR cable.

VVF: A cable structure incorporating a hollow pipe has been developed, into which a fiber unit can be blown-in when the need arises. Moreover, the number and the type of fiber can be selected by appropriate selection of the optical unit.

These composite cables are fully provided with the characteristics generally required for both power cables and optical cables. Furthermore, the cables enable reduction in the number of cables to be installed, thereby improving cable installation work as well as cable congestion.

7. IN CONCLUSION

The development of new optical fiber-power composite cables capable of coping with implementation of FTTD has been reported. It is anticipated that optical fiber installation approaches nearer to the users side during the course of FTTD and FTTH implementation. We plan to continue developing high-performance, low-cost cables required for FTTD and FTTH.

The optical fiber-power composite VVR cable reported here is an achievement of the joint study by Kinden Corporation and Furukawa Electric, and the product has been in practical use since July 2000, under the trade name of "GIGA-POWER" cable.

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