Development of Direct Core Monitoring Fusion Splicer S175

*By Akio Tanabe[*], Kazunori Yamamoto[*], Jun'ichi Kazama[*], Michihiko Kato[*],
Shinji Harada[*], Seiryo Mishima[*], Hidekazu Kojima[*2], Tsuremi Hino[*3],
Nobuharu Suzuki[*] and Hideyo Kawazoe[*2]*

ABSTRACT In order for a fusion splicer to be more compact, lightweight and its operating time to be much shorter, a new type of fusion splicer S175 has been developed. Not only has its basic performance been improved, but also various new functions have been added to the equipment. Another type of fusion splicer the S175K, which has a special setting mechanism for splicing special optical fibers, has been added to our products line-up.

1. INTRODUCTION

Because of the higher density of its transmission capacity, the WDM (Wavelength Division Multiplexing) has become a major transmission system, resulting in the rapid growth of the optical fiber components market. To cope with this market change, the demand for the fusion splicer as in-factory equipment is rapidly increasing, even though the demand for installation use, which grew significantly some 10 years ago, is now maturing.

This paper describes the characteristics of direct core monitoring fusion splicers, S175 and S175K.

2. STRUCTURE OF THE FUSION SPLICER

This equipment is a fusion splicer for single-core fibers, which has a core aligning function. The heat source of the equipment is arc discharging, as with conventional ones. S175 and S175K are not available for the multi-fiber type ribbons; therefore, we offer another type of fusion splicer, the S148, for multi-fiber ribbons.

As mentioned above, single-core optical fibers are used for transmission cables and optical fiber devices. The characteristics of the cable are listed below:

(1) Characteristics as transmission cables
  * Fewer types (mainly for single-mode (SM), multi-mode (MM), dispersion-shifted (DS) fibers)
  * Mainly for the splicing of similar cables
  * Of average quality in many cases (large core eccentricity)

(2) Cable wiring characteristics within optical devices
  * Many types (erbium-doped fibers (EDF), etc., special types)
  * Splicing of different types of fibers

S175 was developed to support the application for the former (transmission cable), and S175K for the latter (cable wiring within optical devices). These two types differ in their arc discharge design and splice loss estimation, which will be described later.

3. OUTLINE OF EQUIPMENT

3.1 Specifications

Table 1 shows the main specifications of S175. Basically, almost all the specifications for both S175 and S175K are the same. However, they differ in splice loss, estimation accuracy and splice time according to the type of fibers.

3.2 Appearance

Photo 1 shows the appearance of the equipment. Both S175 and S175K appear the same. In order to make them lightweight and robust, the body of the equipment is made of die-casting aluminum. A translucent polycarbonate cover on the top (not shown in the photo) is an accessory part. This cover is so designed to allow the equipment to splice optical cables with the cover attached. Therefore, the arc discharge at an installation site exposed to

Photo 1 Appearance of S175 splicer

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[*] Field Equipment Sec., Design & Development Dept., FITEL Products Div.

[*2] Design & Development Dept., FITEL Products Div.

[*3] Engineering Dept., FITEL Products Div.

Table 1 Specifications of S175

Items	Specifications	Notes
Size	111 x 285 x 181 mm	Approx. 20% less than the conventional
Weight	6.3 kg	Approx. 20% less than the conventional
Power source	AC 85~264 V DC 10~16 V	
Power consumption	20 W (stand-by) 70 W (max)	
Splice loss	Less than 0.03 dB on average	SM fiber (Furukawa-made)
Accuracy of splice loss estimation	±0.05 dB (<0.4dB) ±15% (>0.4dB)	
Splicing time	20 sec	Approx. 3 times faster than the conventional
Heat time for reinforcement	90 sec (cooling process included)	Approx. 1.1 times faster than the conventional
Operation monitor	5-inch color LCD XY 2-image-simultaneous display Automatic switching of magnifying ratio (x 132 ↔ x 264)	

extremely strong wind, such as on the side of a subway line, is barely affected by the wind. The body itself is designed to prevent the wind from blowing into it, and usually there is no need for setting the cover.

Operation buttons have been made larger, and are located near the LCD monitor making it easier to operate.

There are hooks in the front of the body for placing a plate to put tools in, providing space for tools even in small and uneven places.

3.3 Functions

3.3.1 Automatic Identifying Function for Optical Fiber Types

The optimum conditions for power and time of arc discharge depend on optical fiber type. Conventionally, program changes have been determined by the operator's judgement. This equipment identifies optical fibers through image processing, and automatically changes programs (SM, MM, DS). Manual selection is also available.

3.3.2 Mismatch Loss Alarm Function

Multi-mode fibers with 50 µm and 62.5 µm core diameters are mainly used. It is very difficult to distinguish them at the installation site. Mis-splicing of dissimilar type leads to a substantial splicing loss. The equipment measures the difference between two fibers through image processing, and warns not to connect them. This function is also useful with single-mode fibers.

3.3.3 Automatic Additional Arc Function

This method is effective for the attenuation function which is optional (a function which intentionally shifts the core center to obtain desired optical loss), and effective for dissimilar optical fiber jointing by S175K. The additional arc is automatically continued until splicing conditions are optimized through image processing.

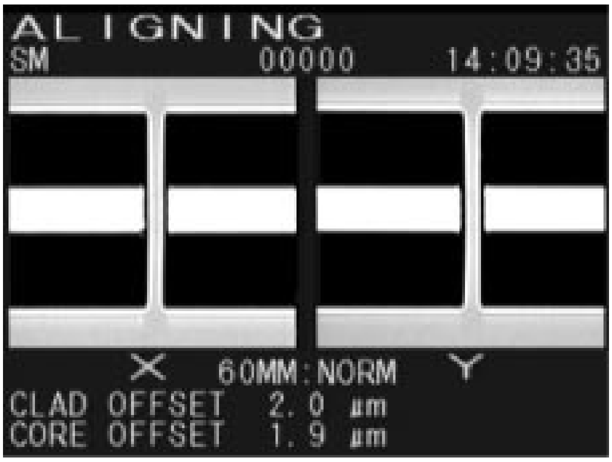
3.3.4 Multi-display

As shown in Photo 2, the following pieces of information are displayed on a 5-inch color LCD.

* Fiber image (simultaneous display of two images from two directions)
* Process name (multi-languages applicable)
* Operational auxiliary message (multi-languages applicable, scroll display applicable)
* Fusion splicing program name
* Heating program name
* Heat oven operation monitor
* Discharge cycles counter (electrode service hours warning function)
* Timer (built-in calendar free from the year 2000 problem)

3.3.5 Splice Data Memory

It has a memory capacity of up to 400 splicings consisting of splicing dates and splice loss, etc. Creating a histogram on the display or data transmission through a PC is avail-


ALIGNING
SM 00000 14:09:35

60MM:NORM
CLAD OFFSET 2.0 µm
CORE OFFSET 1.9 µm

Photo 2 LCD display in operation

able. Discharge inspection data for arc power adjustment are stored up to 100 cycles.

3.3.6 Remote Control

The following functions are available as options:

- * Remote control of the equipment
- * Management of fusion programs and others.
- * Management of image data

3.3.7 High Speed Heat Oven

Reduction in operating hours for the reinforcement process has been attempted by combining a heater element that has an optimized temperature profile for protection sleeves of 40 mm and 60 mm in length and a high-power cooling fan. Using the protection sleeve of 60 mm length, the reinforcement is completed in 70 seconds for the heating process, and in 20 seconds for the cooling process, totaling 90 seconds. This oven has an automatic clamp mechanism, which allows the setting of an optical fiber into the heat oven using both hands, in addition to a pre-tensioner which automatically removes slack from the optical cable in the protection sleeve.

3.3.8 Fiber Illuminating Lamp

Using two lamps consisting of high intensity LEDs, the optical-fiber-positioning V-groove is illuminated in order to easily set a fiber into it even in a dark place.

3.4 Structure of the Equipment

3.4.1 Optics Design

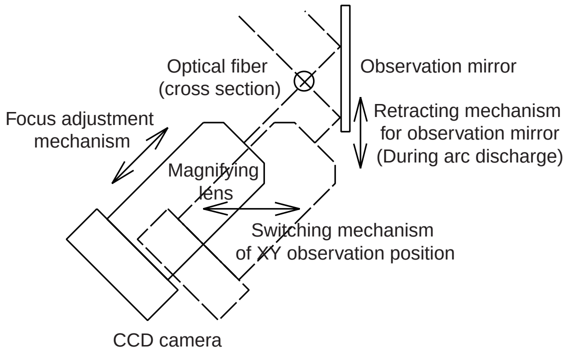
Figure 1 shows a schematic diagram of the optics design. In order to accurately measure the three dimensional position of an optical fiber, it is necessary to observe it from the two directions that are perpendicular to each other. The equipment has two completely independent optics systems in each direction. Higher observation accuracy due to the new improvements greatly contributes to the reduction in splicing hours.

Conventional two-directional observation method required the setting of an objective mirror near the optical fibers. Because of faint scratches or contamination, the mirror is a frequent maintenance item and had to be replaced periodically. The new optics system of the equipment has made the mirror unnecessary and has improved the MTBF (Mean Time Between Failure) of the splicing system.

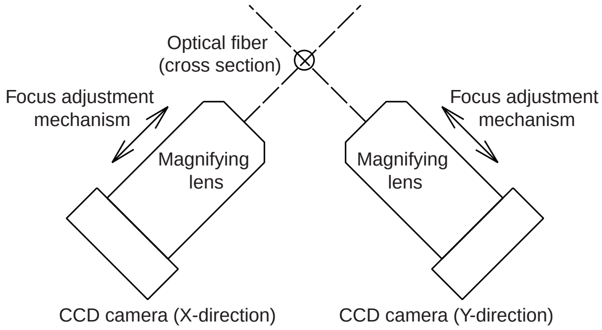
3.4.2 Image Processing Mechanism

A method for inputting camera image signals into the image processing circuit was designed to simultaneously process two observation images, and has contributed to the reduction in processing time.

Figure 2 shows a schematic diagram of the mechanism for capturing image data. Two interlacing cameras are synchronized, and the output image signals are alternately switched field by field in order to digitize them by an A/D converter. Thus this processing has made it possible to simultaneously capture two images within a time needed for capturing one image.



Conventional mechanism



Adopted new mechanism

Figure 1 Comparison of optics design

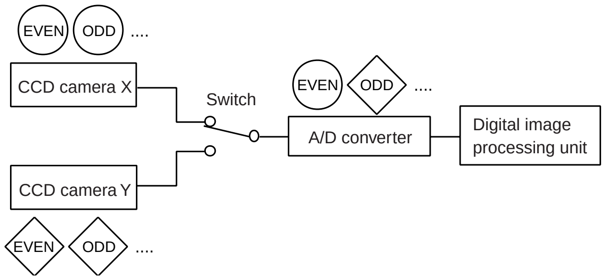


Figure 2 Capturing image data

The captured image data are displayed on the LCD monitor after converting the scanning direction by the scanning converter. The conversion of the display magnifying ratio and the fine adjustment of the display position are carried out during the image data conversion.

3.4.3 Aligning Mechanism

Figure 3 shows a new aligning mechanism. Conventionally, in order to make it smaller, the aligning mechanism is divided into two groups, in which one fiber moves along the X-direction only and then the other along the Y-direction.

The equipment adopts a new mechanism in which one fiber is aligned in the XY-directions, the other fiber is fed only in the Z-direction.

The V-groove block is floating on XY linear bearings and supported by two swing arms with bearings. When one swing arm rotates, the other bearing of the swing arm works as a guide. Cylindrical ceramic components are mounted at an right angle to the contact points of the

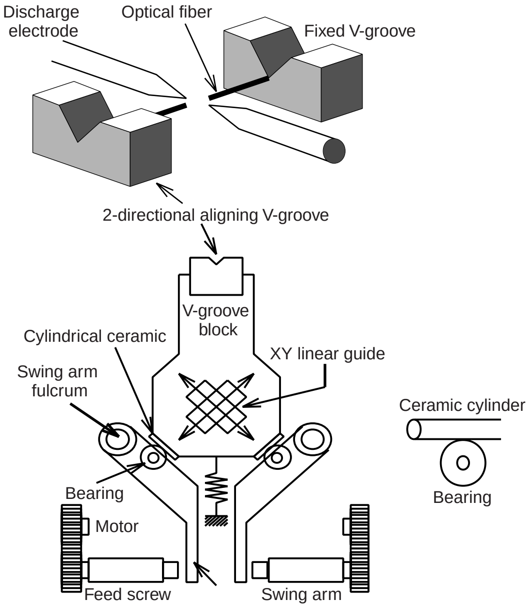


Figure 3 Aligning mechanism

bearings and the V-groove block in order to eliminate fluctuations in the position at which the reaction force of the spring is activated.

3.4.4 Arc Discharge Design

The arc discharge divides into two types by heating areas, a narrow arc and a wide arc. Figure 4 shows a schematic diagram.

When two fibers with a core displacement shifted from the axis of the clad are spliced by aligning their cores, an offset occurs with respect to both clad axes. However, the surface tension produced by the melted joint portion will decrease the offset of the clad axes, resulting in the occurrence of an offset in the core axes. One method for decreasing the core offset is the IAS (Intentional Axis Shift) control method in which the axis adjustment is done by estimating the direction and length of the shift to be caused by the surface tension beforehand and intentionally shifting the core axes. The effect of the surface tension can be easily controlled by narrowing the heating area thereby reducing the deformation range of the joint.

For transmission cable splicing use, therefore, narrow arc discharging is more suitable than wide arc discharging. S175 aligns the axis of the optical fiber with the center of the arc discharging spot so as to get a narrow arc discharge area, and the strength of the arc discharge is relatively weak.

On the other hand, splicing dissimilar types of optical fibers (different mode-field diameter) produces a difference in the mode-field diameter at the splicing point and eventually generates an optical loss (mismatch loss). The mismatch loss can be reduced through a smoothing process by the arc discharge heat. In order to smoothen the difference more evenly, it is necessary to heat a wide area, and thus a wide arc is more suitable. S175K offsets the center of the arc discharge from the axis of the optical fiber and the arc discharge strength is set high.

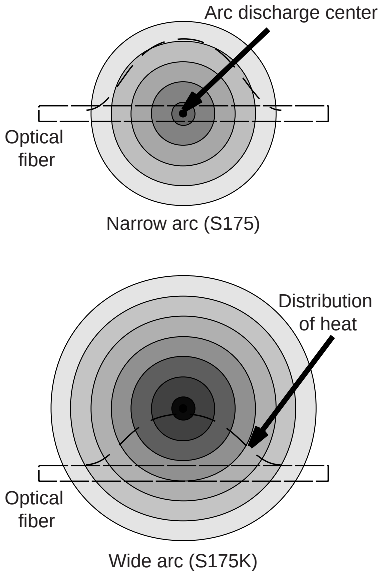


Figure 4 Distribution of heat during arc discharging

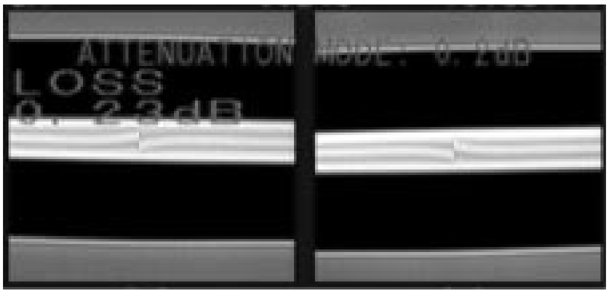


Photo 3 Identified micro bending deformation of spliced portion

3.4.5 Splice Loss Estimation Program

The estimation of splice loss is made by identifying the shapes of the optical fiber cores through image processing. Evaluation items used are the conventional offset, the core tilt and new items of the micro-bending in the splicing point to make a more accurate estimation. Photo 3 shows the deformation due to micro-bending. For the development of the program, we obtained cooperation from the Scientific Technology/Analysis Dept. FITEC Corp.

S175K adopts an algorithm in which the change in mismatch loss produced while splicing dissimilar fibers is estimated by using the deformation of the core image (core-contrast) as a reference. Figure 5 shows the relationship between these factors. Lateral coordinates are a parameter called the core-contrast changing ratio, denoting the change of the core image clarity before and after splicing represented in the ratio. The clarity of the core image becomes lower every time the arc discharge occurs. The splice loss continues to decrease at first, and then begins to increase. A contrast-changing ratio that minimizes the splice loss depends on the optical fiber type and the wavelength used, but is barley affected by the arc discharge strength for a selected combination of fibers to be spliced. After estimating the splice loss from the experimental curve it is possible to get a minimum splice loss by combining the curve with the automatic additional discharge function.

4. CHARACTERISTICS

4.1 Splice Loss and Estimation Accuracy in S175

Figure 6 shows a histogram of splice loss for a single-mode fiber (Furukawa-made). We also carried out the tests for splice loss of multi-mode fibers and DS fibers and confirmed a low level of splice losses.

Figure 7 shows a histogram of splice loss for a single-mode fiber of 1 µm core eccentricity.

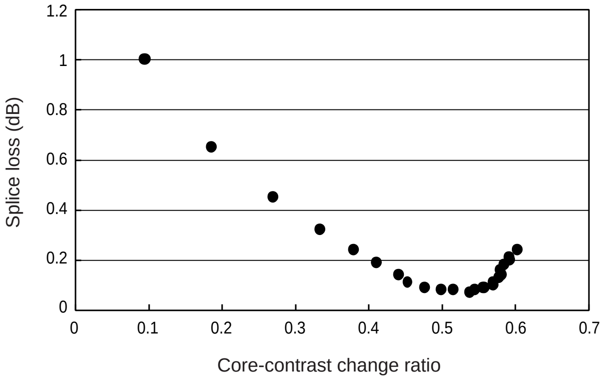


Figure 5 Splice loss vs. deformation of core image

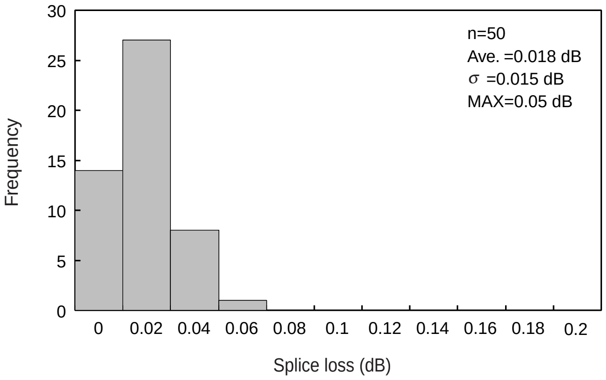


Figure 6 Histogram of splice loss for single-mode fiber with ordinary eccentricity

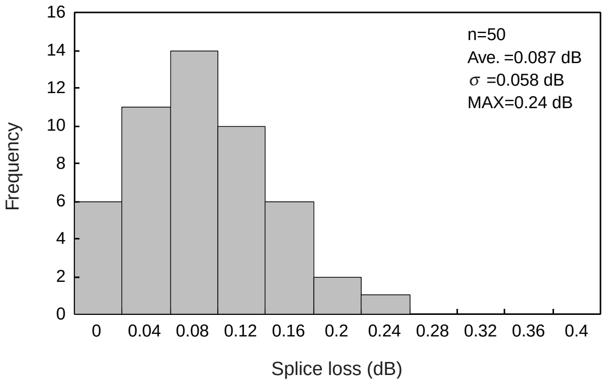


Figure 7 Histogram of splice loss for single-mode fiber with high core eccentricity

Figure 8 shows the relationship between splice loss and splice loss estimation of single-mode fiber under the presence of micro-bending.

4.2 Splice Loss and Estimation Accuracy in S175K

Figure 9 shows a histogram of splice loss in the case of splicing between EDF (Lucent-made HE 980) and SM (Corning-made SMF28). In the ordinary splicing method, a mismatch loss of about 0.7 dB is produced. By combining the wide arc discharge with an automatic additional discharge function, S175K reduced the splice loss to 0.1 dB. Various combinations of optical fibers from many manufacturers were tested for splice losses in the same way to

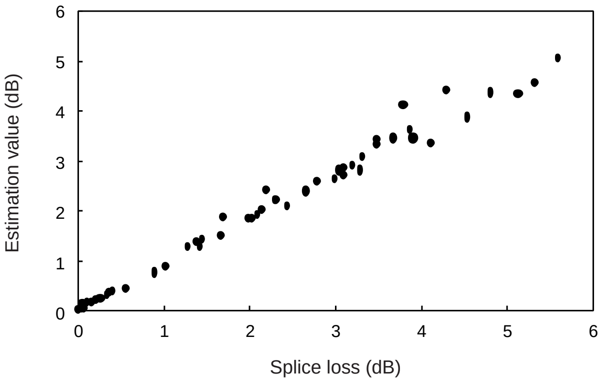


Figure 8 Accuracy of splice loss estimation under the presence of micro-bending

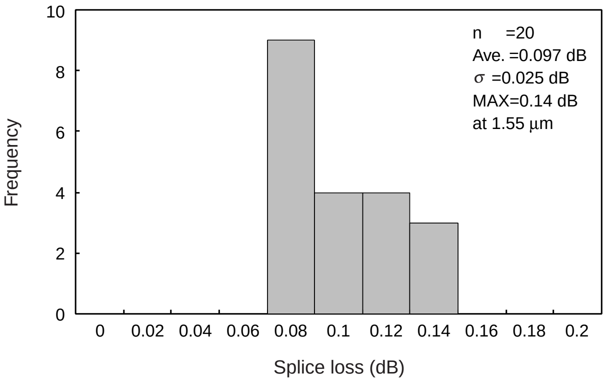


Figure 9 Histogram of splice loss between erbium doped fiber and single-mode fiber

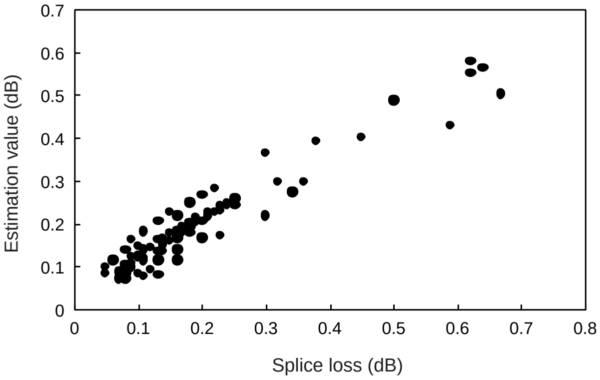


Figure 10 Accuracy of splice loss estimation between erbium doped fiber and single-mode fiber

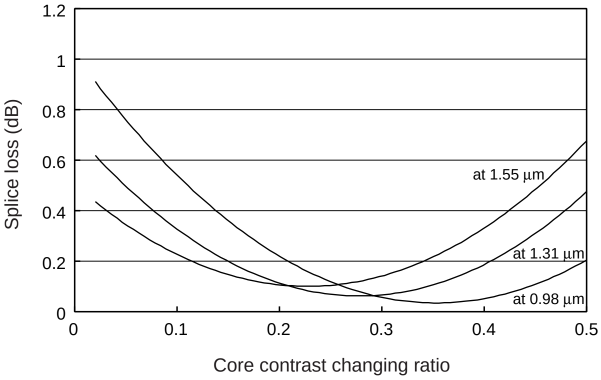


Figure 11 **Wavelength dependency of dissimilar fiber splicing**

see fluctuations in splice loss, but all of them were low. However, we found that lot-to-lot fluctuations in mode-field diameters of special fibers were relatively large. Therefore, fine setting adjustment is needed in these cases.

Figure 10 shows the relationship between splice loss and estimation value in the combinations mentioned above. In order to denote the accuracy in non-optimum splice conditions, the values of large splice losses generated by excessive or short arc discharge hours are illustrated in the figure. The estimation errors greatly depend on the quality of optical fiber end-faces and the fluctuations in the mode-field diameters.

The mismatch loss is a function of the mode-field diameter (spot-size) 1), and the mode-field diameter is a function of the wavelength; therefore, the mismatch loss is wavelength dependent. This is because the mode-field diameter change due to wavelength change depends on the refractive index profile of the optical fiber.

Figure 11 shows the relationship between core image change and splice loss in the case of splicing the EDF (FiberCore-made DF1500F-0980) and the FlexCor™-1060 (Corning-made). The core-contrast changing ratio for minimizing splice loss differs for every wavelength; therefore, a different splice setting must be done according to the wavelength used.

4.3 Reliability Test

Table 2 shows the results of major reliability tests under various conditions. Other items were evaluated in the conditions pursuant to Bellcore specifications 2) and no problems were found.

Table 2 **Results of reliability tests**

Main evaluation items	Results
Splicing characteristics at low temperature (-15°C)	No change
Splicing characteristics at high temperature (+50°C)	No change
Splicing characteristics at high humidity (38°C, 90% RH)	No change
Splicing characteristics at low pressure (640 Hpa, equivalent to 3660 m height)	No change
Splicing characteristics after storing at low temperature (-40°C) and high temperature (+60°C)	No change
Splicing characteristics in vibration tests (1.5 G, sweeping at 0.1 octave/min. in the range of 10 to 500 Hz)	No change
Splicing characteristics after being dropped from a height of 1.2 m, packaged in a storage case	No change

5. CONCLUSION

A direct core monitoring fusion splicer S175 was first developed. This equipment has the following basic features: small size, lightweight, shortening of splice and heat reinforcement time, higher accuracy of splice loss estimation, and easy-to-use functions such as: an automatic identifying function for optical fiber types, and simultaneous displays of two directional observation images on 5-inch LCDs. Another type, the S175K, has also been developed with emphasis on splicing of special fibers.

The reliability test of the equipment was carried out in conditions pursuant to Bellcore specifications and all items were found to have no problems.

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2) Bellcore Generic Requirement for Single Fiber Single-mode Optical Splices and Splicing Systems, GR-765-CORE, ISSUE 1, SEPTEMBER 1995.

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