# Development of Series S176 Direct Core Monitoring Fusion Splicers

*by Kazunori Yamamoto *, Akio Tanabe *, Sunao Yokomizo *, Jun'ichi Kazama *, Shin'ji Harada *, Hideki Watanabe * and Turemi Hino **

**ABSTRACT** The splicers used in the installation of optical fibers for telecommunications systems, have, with the increasing use of WDM technology, been commonly used as manufacturing equipment in factories producing fiber-optic components. And as component factories shift to China and other Asian countries, prices have collapsed in the face of competition with new models introduced by other firms. Against this background, we have improved our price competitiveness and at the same time targeted the development of products that cover the full range of applications, from outdoor construction jobs to indoor fiber-optic component manufacture. The result has been the series S176 of direct core-monitoring fusion splicers. In terms of structure, we have made an appropriate distinction in the use of plastic and metal parts, and have succeeded in controlling costs while achieving high reliability. In terms of performance, series S176 has higher fusion splicing speeds, while being able to accommodate special types of fiber. Particular attention has also been given to the ease of operation of the equipment.

## 1. INTRODUCTION

With the wider penetration of the Internet, the use of dense wavelength-division multiplexing (DWDM) technology has grown at a dramatic rate. There has been a concomitant growth in the demand for fiber-optic components and the market for fusion splicers is also growing, no longer limited to network construction applications, but expanding to include factories for the manufacture of fiber-optic components.

The series S175 types now in use were developed with a primary focus on construction applications, but large numbers have also been sold for factory use based on their boasting the world's fastest fusion splicing speed, achieving the best record of sales up until the present. The shift of the production facilities of fiber-optic manufacturers to Southeast Asia, however, has also meant an increasingly cut-throat price competition. The new series S176 of direct core-monitoring fusion splicers has been developed to cover a wide range of applications both in construction and factories, while keeping costs low. The series comprises three of differing configuration: Type CF (cubic, front monitor), type CR (cubic, rear monitor) and type LP (low profile), allowing customers to select the unit optimally suited to their needs. Though differing in appearance, all three have in common their major structural com-

**Photo 1 S176 type CF (cubic, front monitor) splicer.**

**Photo 2 S176 type CR (cubic, rear monitor) splicer.**

**Photo 3 S176 type LP (low profile) splicer.**

* Design and Development Gr., Opto-Mechatronics Dept., Optical Connecting Products Div.

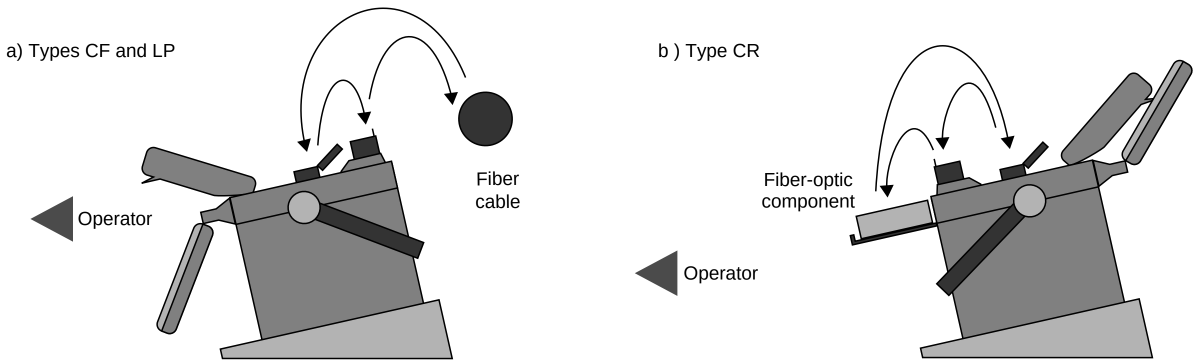


**Figure 1 Operating methods for series S176 splicers.**

ponents and parts, and plastic has been introduced widely for those parts for which it can be employed, reducing costs.

Types CF and CR have been designed primarily for applications inside factories for the manufacture of fiber-optic components, allowing the splicing of fibers with short surplus lengths, and free modification of the positional relationships among fiber-optic components. The units are also tilted forward, reducing the strain on the cervical and spinal vertebrae of operators, and the units can accommodate batteries, allowing them to be used in overhead stringing of lines during construction.

Type LP has fewer moving parts and is of a more robust design, enclosed in an aluminum body for construction applications. It has a lesser overall height, and is also suitable for certain factory applications.

All types provide a fusion splicing time of 11 sec (in high-speed mode), the fastest in the world, and make possible low-loss splicing of fibers of a wide variety of specifications.

## 2. GENERAL DESCRIPTION

### 2.1 Equipment Arrangement

For the external appearance of the units see Photos 1 through 3.

In types CF (cubic, front monitor) and LP (low profile), the operating monitor is located at the front and the wind protective cover for the splicing mechanism open and close to the front, and the reinforcement sleeve heater at the rear. This layout is appropriate because, in the laying of optical fiber cables the operator, for reasons of cable arrangement, the fusion splicer is generally operated at the front while the closure for the cable joint is positioned to the rear of the splicer. (see Figure 1a).

In type CR (cubic, rear monitor), the operating monitor is positioned in the rear and the direction of opening and closing of the wind protective cover and the reinforcement sleeve heater are on the front. In factories manufacturing fiber-optic components it is usual to position the fiber-optic components or modules toward the operator to perform the splicing and storing operations, and this layout is appropriate (see Figure 1b).

In both of these types, there are cases in which, depending on the cable laying conditions or module configuration, the reverse layout may be more convenient. In such cases types CF and CR can be made interchangeable by changing the direction of mounting of a sloping pedestal under the unit (hereinafter referred to as the bottom base) and using a software switch to reverse top to bottom the display on the operating monitor screen. Units will operate even with the bottom base removed, but by inclining the unit in the direction of the operator the optical fiber may be easily put in place without crouching deeply into the rear of the splicing portion.

Type LP, like that of the previous series S175, is of robust construction, with the operating monitor accommodated in an all-aluminum body. The layout of the internal components has also been changed to make the working surface lower, reducing the height difference between the pre-processing steps and the working surface and improving the ease of operation. Batteries cannot be accommodated internally but an optional high-capacity battery optimally suited to factory applications can be installed on the rear panel of the unit.

### 2.2 Specifications

Table 1 shows the main specifications.

### 2.3 Functions

2.3.1 Fusion of Short Lengths

The key to reducing the size of fiber-optic components and modules is to reduce the dimensions of the reinforcement sleeve used for the fusion splicing section. To achieve this the dimensions of the fiber chuck have been reduced to the maximum extent possible allowing splicing of fibers with a lead length of 5 mm (left and right total 10 mm) for fibers with an outer diameter of 0.25 mm. This made possible the use extremely small sleeves having an overall length of 20 mm.

2.3.2 Auto-start

In applications in the inspection process in fiber-optic component factories, where products are spliced to a measuring instrument, there are cases in which the number of splices made reaches 300 to 500 per day, and there is a major need to reduce the fusion splicing time

**Table 1 Specifications of series S176 splicers.**

| Type designation | S176CF, S176CR | S176LP |
|---|---|---|
| Dimensions (excluding protrusions (WxDxH) mm)<br>Reduction from previous model | 169x203x179.5<br>34% | 192x277x154<br>13% |
| Weight (kg)<br>Reduction from previous model | 4.2<br>33% | 4.8<br>24% |
| Supply voltage | 85-264 V (50-60 Hz)<br>Using S950<br>(parts in common) | 85-264 V (50-60 Hz)<br>Using S950 |
| Power consumption<br>Normal/maximum (W) | 22.66 / 56.23 | 28.5 / 65.63 |
| Battery-powered<br>5-min intervals (splice + sleeve) | 30 times (w/ S940) | 60 times (w/ S942) |
| Types of fiber spliced | SM, DS, MM, NZDS, CS980, CS980-SM, FelX1060-SM, EDF-SM, etc. | |
| Splicing loss (dB) | SM: 0.02 DS: 0.04<br>MM: 0.01 NZDS: 0.04 | |
| Splice loss estimating accuracy | ±0.05 dB (≤0.4 dB)<br>±15% (>0.4 dB) | |
| Length cut | Fibers >ϕ 0.25 mm: 5-16 mm<br>Fibers ϕ0.4-0.9 mm: 16 mm<br>(optionally supports 10 mm) | |
| Connection time | High-speed mode 11 sec<br>High-precision mode 13 sec<br>Reduction from previous model: 6 sec | |
| Reinforcement sleeve heating time | 60-mm sleeve 90 sec<br>20-mm mini sleeve 40 sec | |
| Monitor | 5" color LCD two-screen simultaneous display, automatic switching of magnification (132x <=> 264x) | |

and the burden imposed on the operator. By adding the auto-start function to the automatic selection function of the conventional fusion program, the work required of the operator is reduced to merely placing the fiber on the fusion unit and closing the wind cover.

2.3.3 Arcing Test

In order to optimize the strength of the arc discharge that melts the optical fiber, it was necessary in the former series S175 to perform the arcing test for each type of fusion program. This poses no particular problem when there are only a few types of fiber but it imposes a significant operating burden when there are more specialized fibers, as are used in fiber-optic components. In series S176, the results of the arcing test are fed back into all of the fusion programs, so that if the arc test is performed once at the start of a day's shift, it becomes unnecessary to repeat it even if the fusion program is changed.

2.3.4 Estimated Splice Loss

In addition to the misalignment, bending, tilt and mismatch losses used conventionally in estimating splice loss, the series S176 units add cleave angle for improved estimating accuracy.

With respect to splice inspection, it is possible to select a high-speed mode which simplifies a portion, suitable when priority is to be given to fusion time.

2.3.5 Splicing Different Fibers

There are a wide variety of fusion programs provided to handle the non-zero dispersion fibers used in fiber-optic communications networks, small mode field diameter single mode fibers used in the manufacture of fiber-optic components, erbium-doped fibers, and so on. In splicing between different types of fiber, stable TEC (thermally expanded core) fusion, a technique for smoothing out differences in mode field diameter, can be achieved by means of the automatic additional arcing function used in type S175K.

Up to 64 fusion programs can be stored in the internal memory, and by means of an optional remote control program it is possible to externally store an unlimited number in a personal computer.

2.3.6 Attenuation Splicing

By means of eccentric fusion it is possible to carry out attenuation splicing in which the desired amount of optical attenuation is obtained, eccentric fusion in which the desired amount of eccentricity is obtained, and high-precision attenuation splicing by connecting up with an optical power meter and a personal computer.

2.3.7 Reinforcement Sleeve Heater

In addition to the reinforcement sleeves of series S175, measuring 40 mm and 60 mm in length, a heater element adapted to extra-small 20/25/30 mm sleeves has been developed. Cooling fans are also incorporated for improved cooling and reduced total reinforcement time.

2.3.8 Remote Control Function

Connection with a personal computer supports the editing and saving of fusion programs, the upgrading of firmware, and trouble-shooting. It also makes possible the high-precision attenuation splicing referred to above.

2.3.9 Addition of a Short-Cut Key

The many special functions of the fusion unit and modifications to the program constitute a complex tree structure, but frequently used functions can be stored and then recalled with a single key. Return to the fusion function can also be accomplished with a single key-push.

2.3.10 Fiber Holder System

Conventionally, with a core-aligning fusion unit, a tight holder is used which sets the fiber directly on the fusion unit by hand. Envisioning a factory situation with inexperienced operators, a new fiber holder system was employed as an option. Once the fiber has been set into the adapter and pre-processing steps carried out, it can easily be set to the fusion unit as is, eliminating the fear of damage to the fiber.

2.3.11 Multiple Power Supplies
Both type CF and type CR have a power supply slot that accepts any of three power sources--AC, built-in batteries or external DC.

Type LP can also accept three power supplies, although the batteries are attached to the rear panel.

**2.4 Structure**

2.4.1 Optics
The basic structure is the same as that of the previous series S175, which monitors images of the fiber from X and Y directions at right-angles to the fiber, using independent optical systems, each provided with an objective lens and CCD camera for each of the directions.

The dimensions of the optical system determine the depth dimension of the equipment. Series S175 used an objective lens of about 10-power and a 1/3-inch CCD, but series S176 uses a lens of about 7.5-power and a 1/4-inch CCD, maintaining the same resolution despite the saving in size. The light source is a red LED, but a diffuser is used to reduce directionality and increase uniformity.

2.4.2 Image Processor
The series S176 features dual frame memories. These allow images from the X and Y directions to be accepted simultaneously, providing full parallel processing for the two directions. Data can be read in without wait time from either odd- or even field timing, achieving a significant shortening of the frame data read-in cycle (from 120 msec in the series S175 to only 45 msec) and resulting in a high degree of real-time processing.

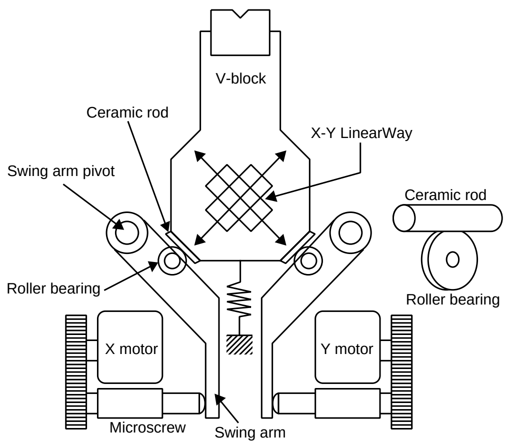


**Figure 2 Aligning mechanism of the series S175.**

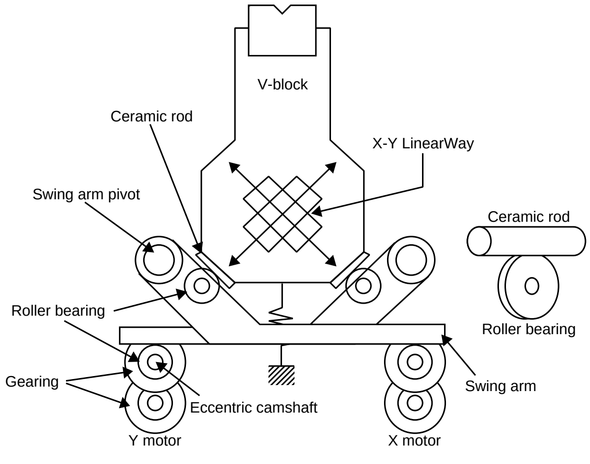


**Figure 3 Aligning mechanism of the series S176.**

2.4.3 Aligning Mechanism
In the earlier series S175, the rotary motion of a motor was converted into straight motion by means of a microscrew (see Figure 2). Series S176, however, uses an eccentric camshaft to reduce cost and shorten operating times (see Figure 3). The eccentric portion of the camshaft is engaged by a bearing, and between the aligning arm and eccentric camshaft there is a smooth relative motion. The relationship between the angle of rotation of the camshaft and the perpendicular displacement provides a sinusoidal motion, but the range used is 45-135 deg, which produces a substantially linear action. The use of the eccentric camshaft means that the distance traveled per rotation of the motor is about five times greater than in series S176, resulting in high-speed alignment action. This inherently meant an increase in hysteresis due to backlash, but modifications were made to the control system that solved this problem.

The same mechanism is used for focusing also.

2.4.4 Use of Plastic Parts
Table 2 compares the number of components (including screws) in the former series S175 and the new series S176, and it can be seen that the count is reduced by more than 100. Parts made of plastic are increased to about 30. Selective use was made of thermoplastics and thermosetting plastics with glass filler, depending on the level of performance demanded of the component. A wide variety of quality tests, shown in Table 3, were carried out to confirm problem-free performance after 270,000 consecutive operations, and high-temperature, high-humidity splice loss characteristics. Plastics are even used for the case cover in both Type CF and Type CR, and electromagnetic discharge noise was successfully suppressed (EN55022, Class 2).

**2.5 Splicing Fibers in Different Types**
In the manufacture of fiber-optic components and modules, it is common to have to splice together two types of fiber having different mode field diameters, and normally this mismatch in diameters results in splice loss. The difference in mode field diameter is particularly great between erbium-doped or other high-delta fibers and ordinary single-mode fibers, and the splice loss due to mismatching is extremely large. TEC is the name for the technique whereby this mismatching loss is reduced by heat-

**Table 2 Structural component count.**

| | S176 | S175 |
|---|---|---|
| Total number of components | 770 | 881 |
| Number of molded plastic components | 31 | 2 |

Table 3 Results of reliability tests.

| Main parameters for evaluation | Result |
|---|---|
| Splice loss profile, low temperature (-10°C) | No change |
| Splice loss profile, high temperature (50°C) | No change |
| Splice loss profile, high humidity (40°C, 90%RH) | No change |
| Splice loss profile, low atmospheric pressure (640 hPa, equiv. to 3600-m elevation) | No change |
| Splice loss profile after low-temperature (-40°C) and high temperature (60°C) storage | No change |
| Splice loss profile after vibration test (1.5 G, 10-500 Hz at 0.1 octave/min sweep) | No change |
| Splice loss profile after dropping test from height of 1.2 m in original case, packaged | No change |
| Splice loss profile after 270,000 operations of various actuators | No change |

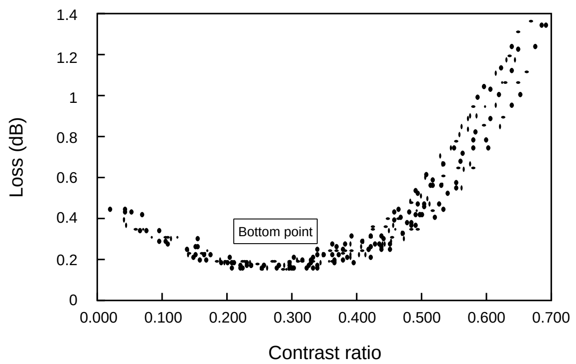


**Figure 4 Relationship between splice loss and contrast ratio for CS980 and single-mode fibers.**

ing the splice.

When the splice is heated the core and dopant undergo thermodiffusion but generally speaking, for fibers with a small mode field diameter to satisfy single-mode conditions, both the refractive index of the core and the concentration of dopant are high. Thus diffusion proceeds rapidly and the mode field diameter increases rapidly. In such cases there is a timing that assures that the two mode field diameters will match and the splice loss will be minimized. If heating is continued longer, the discrepancy in mode field diameter will be reversed and splice loss again increases.

Within the equipment the mode field diameter is not directly measured; rather the change is quantified indirectly using changes in light-dark contrast in the fiber image. The relationship between splice loss and contrast ratio when splicing Corning CS980 fibers to single-mode fibers is shown in Figure 4, the bottom point in which being thought to be the point at which the two mode field diameters are substantially the same. Series S176 has an automatic control system that applies added heating incrementally as it monitors the change in contrast until the optimum point is reached.

In some erbium-doped fibers the rate of diffusion of the mode field diameter is extremely rapid, and to allow for such cases the heating temperature can be lowered to

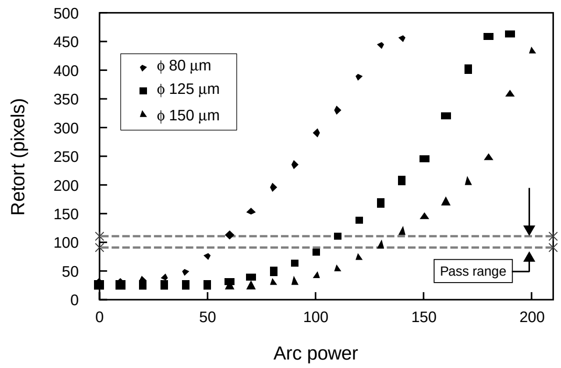


**Figure 5 Relationship between arc power and retort in fibers of different diameter.**

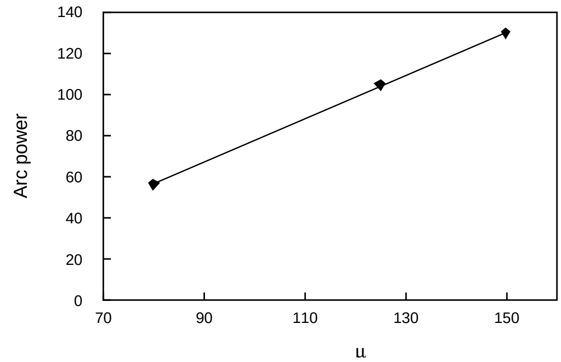


**Figure 6 Correlation between fiber diameter and arc power.**

reduce the rate of diffusion, thereby achieving a lower splice loss.

### 2.6 Splicing Fibers of Different Diameter

In splicing fibers of different type, the control system can eliminate the differences in core diameter (mode field diameter) but to make splices between fibers when clad diameters are different, elaborate care was taken to control the arcing, as well as to adjust the focus during fiber observation and measure misalignment of the axes.

Figure 5 shows the relationship between arc power and retort in fibers of 80-, 125- and 150-µm diameter, retort being the amount of retreat due to surface tension when the end of the fiber is heated, and value for evaluation during arcing tests. In other experiments the retort was consistently in the range of 90 to 110 pixels showing that splice loss was at the minimum. Figure 6 shows a plot of fiber diameter against the optimum arc power. From these results it may be seen that the series S176 provides automatic compensation for arc power in accordance with the fiber used. And it was not necessary to perform further arcing tests even when fiber diameter changed.

Focus is adjusted individually for the right and left fibers for measurement of fiber position.

## 3. CHARACTERISTICS

### 3.1 Splice Loss Profile

Figures 7 and 8 are histograms of splice loss between

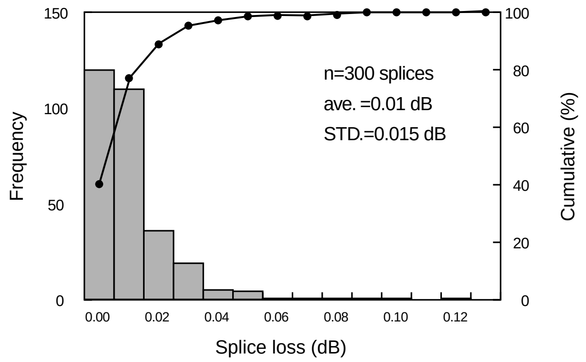


**Figure 7 Histogram of splice loss for single-mode fibers.**

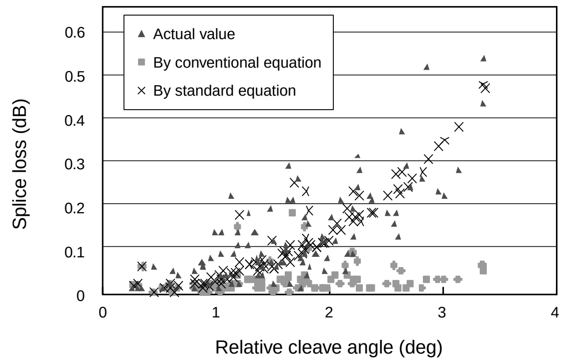


**Figure 9 Comparison of accuracy of equations used to estimate splice loss.**

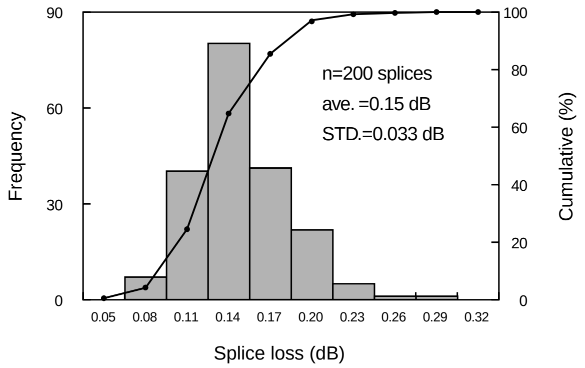


**Figure 8 Histogram of splice loss for Corning CS980 and Furukawa single-mode fibers.**

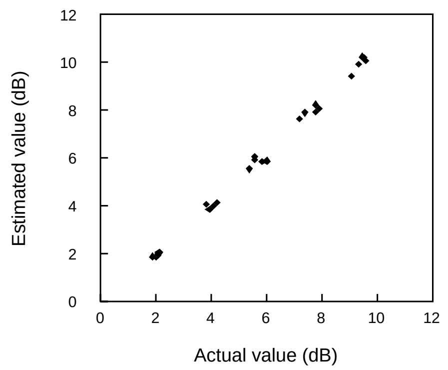


**Figure 10 Accuracy of splice loss estimation for single-mode fiber.**

ordinary single-mode fibers, and between Corning CS980 and Furukawa single-mode fibers.

CS980 and single-mode fibers have mode field diameters with respect to 1550 nm of 6.76 and 10.74 µm respectively, and the theoretical mismatch loss is 0.90 dB. The TEC fusion effect results in measured values averaging 0.15 dB, showing that the two mode field diameters have been adequately matched.

### 3.2 Estimating Accuracy

As can be seen from the above, it has become the practice, in calculating estimated splice loss, to take into account not only misalignment, bending, tilt, and mismatch losses, but also the additional item of cleave angle. In conventional methodology, when the cleave angle was large due to faulty maintenance of the fiber cutter, the estimated loss was sometimes shown as very small in comparison with the value of splice loss actually measured.

The relationship between the relative cleave angles of the left and right fibers was found experimentally, and Figure 9 shows the actually measured results, those obtained by the conventional estimation equation, and the newly estimated values using added compensation. With ordinary fiber cutters the difference in relative cleave angles is about 1 degree or less, at which estimated loss values pose no problem. At angles greater than 1 degree, however, it will be appreciated that the conventional technique of estimation is extremely inaccurate. Though it must be said that there remains room for improvement, the addition of cleave angle, ca greatly improve the accuracy over conventional estimates.

In the region where relative cleave angle is less than 1 deg, estimating accuracy for single-mode fibers is good, as shown in Figure 10.

## 4. CONCLUSION

With a view to a finely-tuned response to varied customer requirements, a series of fusion splicers comprising three types has been developed, with cost kept low. In addition to accommodating different requirements by the presence or absence of a case or the reinforcement sleeve heater, or modifications to the fiber holder system, a wide variety of options are also available, including a foot switch for greater efficiency and easier operation, a tight holder for loose tube-type fiber splicing, a close-in illumination lamp, and a work table for placement of fiber-optic modules and case.

Enhancements to basic functions include built-in batteries (Types CF and CR) for splicing short lengths, and a splicing time 35% less than the previous series (11 sec in high-speed mode).

This series constitutes a line-up of high-end fusion splicers that is already commercially available, catering to a wide range of markets, from the laying of fiber-optic communications networks to the manufacture of fiber-optic components.