Arc Power Calibration for Fusion Splicing Optical Fibers with Variety Diameters

Wenxin Zheng and Bryan Malinsky

Abstract

A novel arc calibration method has been developed for fusion splicing optical fibers with a large variety of glass diameters. This method heats the fiber with multiple short arcs and measures the amount of meltback at the corner of the fiber-ends. The fiber corner melting speed is found to be proportional to the fiber temperature. By varying the arc power of the multiple arcs, we can determine the desired arc power and appropriate melting speed for the tested fiber. This method has tested to be consistent and accurate using a newly released splicer with a controllable plasma zone. The splicer can automatically select the correct arc power for various fiber glass diameters. It enables the optimized splice parameters to be easily transferred to multiple splicers in production lines, resulting in consistent, high quality splice results.

Keywords: Fusion splicing, Arc calibration, Large diameter fiber, Fiber laser, Specialty fibers, Controllable plasma zone

1.0 Introduction

Unlike the telecom industry, where the majority of fiber glass diameters are typically around 125 micron, other fields (such as biomedical labs and fiber laser production lines) often use optical fiber types with a large variety of diameters [1 – 3]. For fiber lasers, large mode area fibers (LMA) with glass diameters of 125, 220, 300, and 400 micron are commonly used. For higher power output and transmission in fiber laser systems and biomedical systems, optical fibers with glass diameters of 550, 660, and 1000 micron are frequently deployed. We use glass diameter instead of cladding diameter in the text, since the fiber claddings, or part of fiber claddings, are not made of glass in many large diameter fiber (LDF) designs, such as double clad fibers (DCF), a few mode fibers, multi-mode fibers (MMF), and others. Moreover, even the glass diameter measurement would not be suitable for many double clad fibers, since their glass cross section could be hexagonal or octagonal to break up and eliminate the helical-modes. The glass diameter for shaped DCF is based on the average diameter.

The large variety of optical fiber is not only found in glass diameters. The fiber glass structures greatly differ among telecom fiber types. The core diameter can vary from 10, 15, 20, 25, 30, to 35 micron for LMA fibers. The number of cores can also change from single, dual, to multiple cores, such as 7 core fibers. The material of the core can also vary. It could be produced with pure silica, germanium doped silica, or simply holes for photonic crystal fibers (PCF). Even larger differences can be found in the cladding structure for polarization maintaining fibers (PMF). Additionally, the stress applying region can be found in different shapes, such as Panda, Bowtie, elliptical jacket, and other newly developed structures.

Dealing with such a large variety of fiber designs, fusion splicing those optical fibers becomes a vital topic and challenge. The requirement for splicing quality is substantially different from research labs to production lines. In research labs, people normally work with single unit splicing equipment and concentrate in optimizing splicing parameters to achieve best possible splices for large numbers of different fiber combinations. However, production lines normally use a larger number of splicing units and need to repeat similar combinations with a reliable consistency. There are two measurements of consistency: cross-machine consistency and overtime consistency. Cross-machine consistency requires consistency in applying lab-optimized splicing parameters to multiple splicers in a production-line environment. Overtime consistency requires consistency in splicing results over an extended period of repeated splicing in different splicing conditions, using the same splicing parameters. It is relatively easier to develop splicing equipment with large flexibility for making a few high-performing splices in the lab.

It is much more difficult to achieve cross-machine and over-time consistency for a splicer design for use in production lines. It is even a greater challenge to design for both the flexibility of labs and the consistency for production lines.

Different fiber glass diameters and structures require different heating area and heating power. A controllable plasma zone is provided by the new family of fusion splicers known as ARCMaster [4]. With its variable electrode gap distance, its oscillating plasma technique, its universal fiber clamping system, and its programmable special functions for individual motor and arc control, the ARCMaster machines provide flexibility in splicing and shaping a variety of optical fibers. In order to design for the flexibility required by labs and the consistency required by production lines, a fundamental technique known as arc power calibration was developed and implemented. The arc calibration method plays a critical role in assuring the quality of splices, in automatically selecting correct arc power, and in enabling the optimized splice parameters to be transferable to multiple splicers in production lines for achieving consistent splice results.

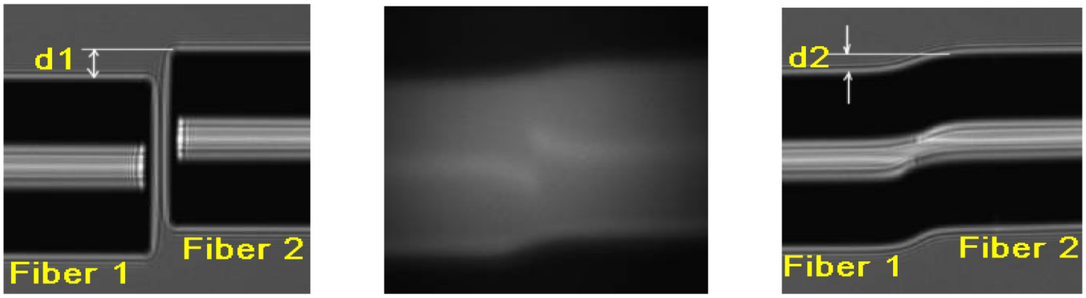
In the last decade, arc calibration methods have been studied by many different splice manufacturers [5-8] to overcome the inconsistency of splicing results. The inconsistency comes from three major reasons. Firstly, the tolerance of electronic components and mechanical parts may cause cross-machine inconsistencies. Secondly, aging electrodes and silica deposits may cause both cross-machine and over-time inconsistencies. Lastly, variations in the environment (pressure, temperature, humidity, etc.) cause overtime inconsistency. In order to improve and solve the inconsistency, there were two existing categories of arc power calibration methods: the traditional meltback method, and the offset splicing method.

1.1 Traditional melt-back method

In the traditional meltback method, the two fiber-ends are stripped, cleaved and aligned to a distance and heated by arc discharge (shown in Fig. 1 for 125 micron fibers, see also [6]). The fiber-ends are heated and the meltback distance is measured along the fiber axes. The arc power is reduced if the meltback distance is too large, or is increased if the meltback is too small. The normal heating time is about 8 to 20 seconds with splicing arc power. The recommended meltback value is from 100 microns to 250 microns depending on the fiber diameter. This process has to be repeated until a proper arc power is reached. This method takes substantial effort for fiber preparation especially for LDF. Moreover, the melting of large fiber portions results in heavy silica deposits on electrodes for LDF over 250 micron diameters. The electrode condition is considerably changed by the meltback method which consequently makes the arc calibration inaccurate.

(a) Before arc discharge | (b) Arc discharge | (c) After arc discharge

Fig. 1: Traditional meltback method for arc power calibration. The meltback value is measured at fiber axis by subtracting D1 from D2. Fiber meltback causes heavy silica particles to deposit on the electrode tips for LDF fiber types, and leads to inaccurate arc calibrations.



(a) Before offset spicing (b) during offset splicing (c) After offset spicing

Fig. 2: Offset splicing method for arc power calibration. The offset variation is measured at fiber axis by d1-d2. The Fiber 1 and Fiber 2 are of the same fiber type. This method works well for telecom fibers with 125 micron diameter only.

1.2 Offset splicing method

In offset splicing method, the fibers are spliced with an axis offset (see Fig. 2 for 125 micron fibers [6]). The offset variation caused by surface tension is measured. The arc power needs to be reduced if the offset variation is too large or increased if the offset variation is too small. Similar to the traditional meltback method, this method typically requires multiple fiber preparations and splices to reach an acceptable arc power. This method works well for telecom fibers, since most of the fiber glass diameters are consistently 125 micron. However, the offset splicing method would not work for a large portion of various diameter fiber types, as the suitable arc power would need to be established for each fiber before splicing. Therefore, this method only applies to fibers with a consistent diameter, such as 125 micron glass diameter telecom fibers.

1.3 A novel technology of variable power melt-back method

Both traditional meltback method and offset splicing method described in the above sections have a few variations. For example, the meltback distance can be calculated using the hot fiber images during pre-fusion by examining the length of the light-emitting part of the heated fiber [8]. The meltback method can also be combined with the offset splicing method [7] for telecom fiber types.

In this article, a new arc calibration method for a large range of fiber sizes is described. This method heats the fiber with multiple short arcs with variable arc power. The meltback is then measured at the corner of the fiber-ends instead of at the fiber axis. The fiber corner melting speed is proportional to the fiber temperature. By varying the arc power of the multiple arcs, a proper melting speed and the desired arc power can be reached for the fiber under testing. This method is tested successfully for fiber diameters from 80 μm to 660 μm in ARCMaster Splicers with controllable plasma zone.

2.0 Meltback with Variable Power

2.1 Process of the variable-power meltback method

When a cleaved fiber-end is heated by a very short arc discharge, in the range of 0.3 seconds to 1 second, the fiber-end will not change if the arc power is too weak. If the same fiber-end is heated repeatedly using the same arc time but gradually increasing the arc power, we can observe that at a certain power level, the corner of the fiber-end will start to round back as shown in Fig. 3.

A few key techniques are employed in the process of the variable arc power meltback. Firstly, the arc heating time is very short, and it will vary depending on the measured fiber glass diameter. For 125 micron diameter fibers, the arc time can be only 0.3 second instead of a few seconds in the traditional meltback. Secondly, the arc power starts at a low power level and it increases in a small enough step to prevent the fiber-end from deforming too quickly. Thirdly, the corner meltback can be measured in many different ways. For example, the starting point of corner deformation can be measured, as shown in Fig. 3. The change of radius of the fiber corner or the variation of the corner area can also be measured as indicators of the meltback amount. In this article, the first definition, shown in Fig. 3 step 4, is used as the meltback value.

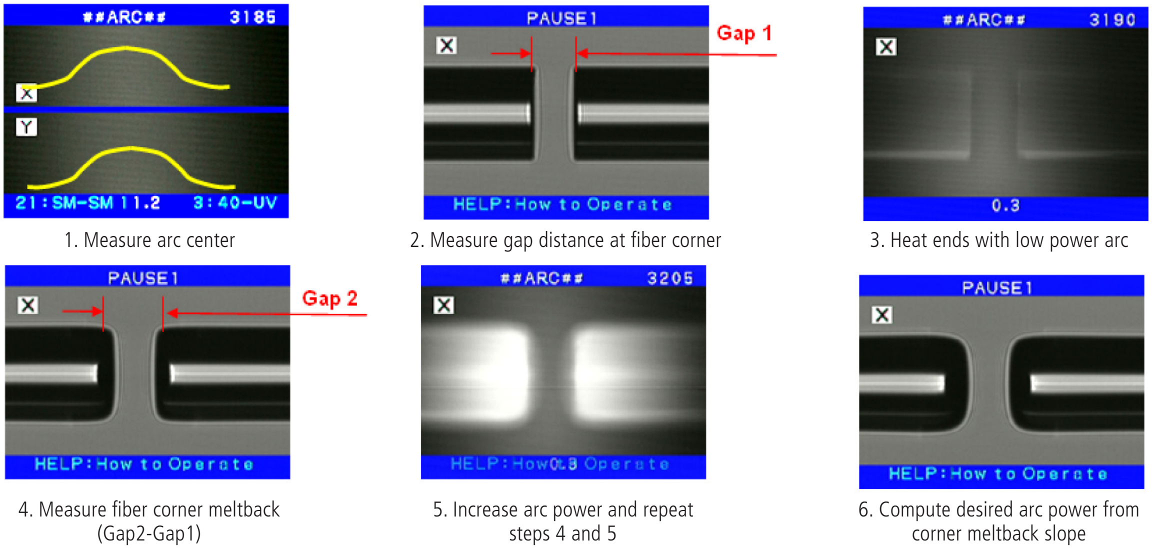


Fig. 3: Process illustration for viable arc power meltback method used in arc power calibration. The axis meltback is very limited and not measurable in many cases. The electrode condition is not impacted by this arc calibration.

2.2 Arc power calibration

As shown in Fig. 4, the corner meltback defined in Fig. 3 step 4 is measured for different arc power levels and plasma zone settings. Each curve in Fig. 4 represents one meltback test, which consists of 20 to 30 re-arcs of 0.3 sec. arc length, but with variable arc power. The arc power level varies from 0 bit (~ 10.5 mA) to 100 bit (~ 14.5 mA) with 25 bit increments. Between each power increment, 5 re-arcs were performed with constant power to determine the meltback speed. 5 tests were performed for each plasma zone setting which varies from 1 mm electrode gap to 3 mm electrode gap, with 1 mm increments to verify the consistency. In all tests shown in Fig. 4, SMF28 was used to compare meltback speed and study the stability of the method.

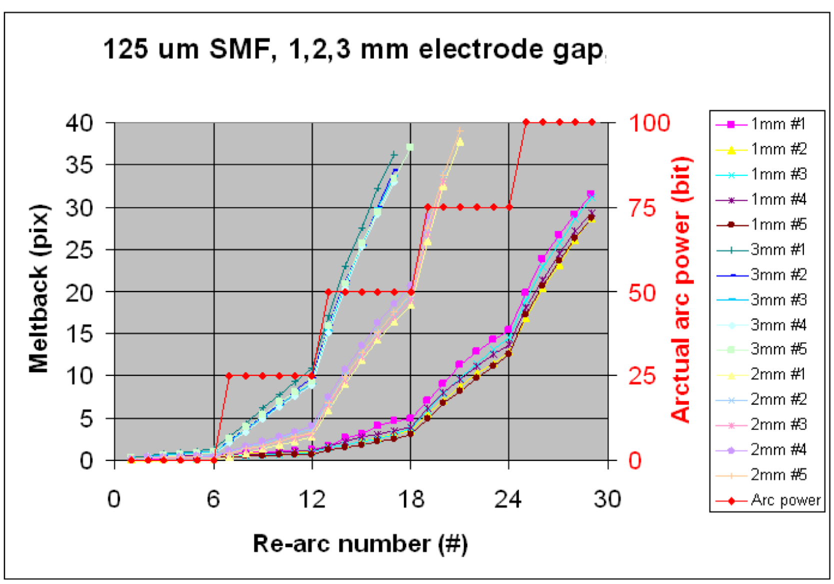
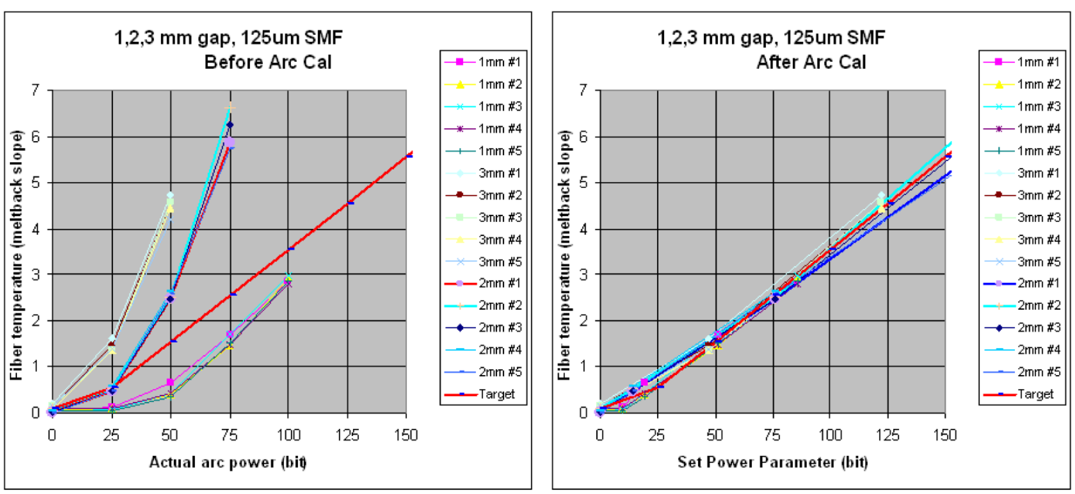


Fig. 4: Meltback test with different arc power levels and different plasma zones. The arc power varies from 0 bit (~ 10.5 mA) to 100 bit (~ 14.5 mA) with 25 bit increments. The plasma zone varies from a 1 mm electrode gap to a 3 mm electrode gap with 1 mm increments. Each curve represents one meltback test which consists of 20 to 30 re-arcs of 0.3 sec. arc length. Five tests were performed for each plasma zone setting to verify the consistency. The red curve is showing the arc power. Each dot on the curve represents one re-arc.

We can clearly observe from Fig. 4 that when arc power is constant, each meltback curves grow linearly, which corresponds to constant meltback speed. Every time the arc power is increased, the steeper slopes of the meltback curves indicate a faster meltback speed. The meltback speed can thus be calculated in each region of constant arc power, as indicated by the red step curve. The calculated meltback speed is plotted in Fig. 5 (a). We also note that the meltback speed is related to the temperature of the fiber-ends. Since the meltback value is measured in pixels with digital images, we can use pixels as a unit of measurement, and thus measure the meltback speed (related to fiber temperature) shown by the Y axis in Fig. 5 is in pixels per re-arc. Moreover, all the meltback speed curves in Fig. 5 (a) can be approximated by parabolic curves, since the actual heat energy applied to the fiber-end is proportional to the square of the arc current, which is denoted by the X axis in Fig. 5. Fig. 5 also shows that a larger electrode gap indicates a higher meltback speed, and a higher temperature at the fiber-ends. This means that in order to get the same fiber-end temperature at different plasma zone settings, we need to apply different actual arc power.

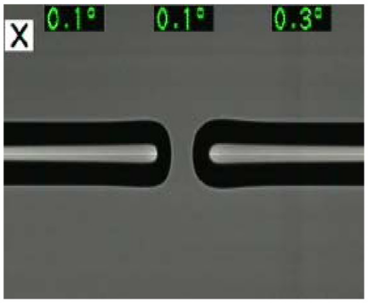
From Fig. 5, we can set a desired target curve (red) mathematically. This target curve can either be a curved line or a straight line. We can use this target curve to regulate nominal arc power (not actual) with meltback speed. The same target curve can be used for all different plasma zone settings. A set of correction factors can then be introduced to generate the same meltback speed with the same settings of the nominal arc power. Fig. 5 (b) shows the same meltback speed data as Fig. 5 (a) but instead it shows nominal arc power for the X-axis. Nominal arc power is used by operators to set their desired power. The goal of arc calibration is to project the actual arc power to the nominal arc power. In other words, we can use arc calibration to find the set of correction factors. This set of correction factors is then employed to create a new domain of nominal arc power. Within the new domain, the same arc power setting will generate the same fiber-end temperature (thus, the same meltback speed) regardless of the fiber glass diameter, electrode condition, plasma zone setting, or environment condition. The calculation of the correction factor is straightforward. The difference between the target curve and measured meltback speed curve can be used as the set of correction factors.



(a) Meltback speed vs. actual arc power (b) Meltback speed vs. nominal arc power

Fig. 5: Meltback speed computed from the tests shown in Fig. 4 is projected from the actual arc power domain to the nominal arc power domain by the arc calibration process. After arc calibration, the same power setting will achieve the same fiber temperature (meltback speed) regardless of the plasma zone settings. The Y axis indicates the scale of pixels per pre-arc.

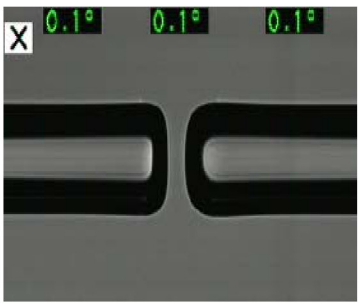
2.3 Arc calibration results



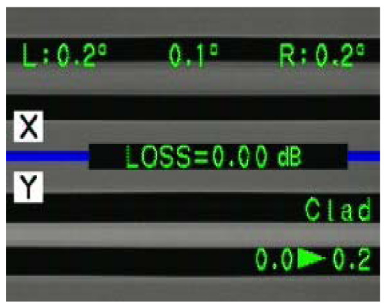
(a1) 125 µm fiber-ends after arc cal

(a2) Spliced with 1 mm electrode gap

(a3) Spliced with 3 mm electrode gap

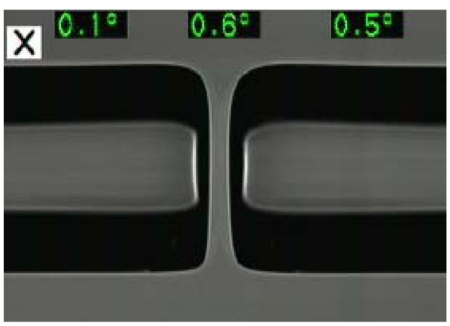


(b1) 220 µm fiber-ends after arc cal

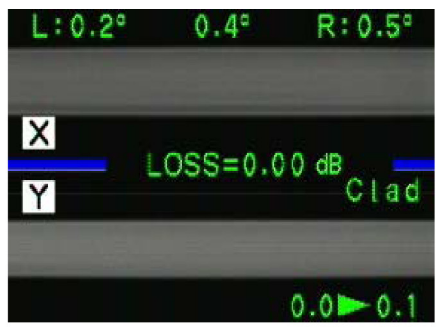


(b2) Spliced with 1 mm electrode gap

(b3) Spliced with 3 mm electrode gap



(c1) 400 µm fiber-ends after arc cal



(c2) Spliced with 3 mm electrode gap

Fig. 6: Fiber-ends after arc calibration and splicing for 125, 220, and 400 micron glass diameter fibers shown in groups (a), (b), and (c), respectively. The fibers are also spliced with different plasma zone settings. The same nominal power setting is used for all above fibers and plasma zones, to get similar splice results. In group (c) there is no picture for 1 mm electrode gap, since the small plasma zone is not strong enough to splice 400 micron fibers.

From the examples shown in Fig. 6, we can see the results of the new arc calibration method. Using the previously described arc calibration method, the 125, 220, and 400 micron fibers can be spliced with the same arc power setting in different plasma zones. In other words, with arc calibration operators can easily attain desired splice results for very different fiber types and plasma (electrode) conditions. For any new or unknown types of fibers, the engineers could easily tweak splicing parameters using the same power setting without the tedious search for the right power level.

The pictures of fiber-ends after arc calibration in Fig. 6 also show the limited axis meltback and limited fiber shape deformation. In comparison, the traditional meltback method in Fig. 1 (c) shows much higher amounts of deformation. This new meltback method thus has very limited impact on electrode tip conditions, especially for large diameter fibers, which are prone to degraded electrode conditions using more traditional methods.

As discussed in previous sections, both the traditional meltback and the offset splicing methods require multiple fiber-end preparations and re-cleaving, since the cleaved fiber-ends were no longer available due to the meltback or splice process. Though fiber-end-preparation might not be tedious for standardized telecom 125 micron fiber types, multiple fiber-end-preparations for shaped large diameter fibers could be both expensive and time-consuming. With the new method discussed in this article, no re-cleaving is necessary since the arc starts from very low power and gradually increases to a desired level in a continuous re-arcing process.

3.0 Summary

A novel arc calibration method is developed for fusion splicing optical fibers for a large variety of glass diameters with consistent and accurate results. This method heats the fiber with multiple short arcs and measures the meltback at the corner of the fiber-ends. The fiber corner melting speed is proportional to the fiber temperature. By varying the arc power using continuous re-arcs, an ideal melting speed can be reached. This ideal melting speed represents the desired arc power for the fiber being tested and to be spliced. This method is tested successfully for fiber diameters from 60 micron to 1000 micron in Splice Master Splicers shown in Fig. 7 with a controllable plasma zone. The method can automatically select the correct arc power for different fiber sizes. It allows operators to easily transfer optimized splice parameters to multiple splicers in production lines resulting in consistent and high quality splice results.

(a) FSM 100P splicer for fibers up to 500 µm   (b) FSM 100P+ splicer for fibers up to 1200 µm

Fig. 7: The variable power arc calibration method is implemented in the ARCMaster Splicer family for splicing and shaping a large variety of optical fiber types.

4.0 Acknowledgements

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