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Effect of Distance between Two Optical Single Mode Fibers on Minimum Splice Losses by Using Arc Fusion Splicer

Dr. Salah Aldeen Adnan Taha
Laser and Optoelectronics Engineering Department, University of Technology/ Baghdad
Email: Salahadnan9999@yahoo.com

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Abstract

Old Researches were worked to find the splice losses between two single mode fibers (SMF-28/SMF-28) by using different arc fusion splicer without taking the effect of distance between them. We have conducted numerous experiments on this fiber where the fiber is cut and weld many times in order to find the fusion splice loss when the arc fusion power is fixed at (20 step) for different fusion times (1s , 3s , 6s , 9s), the fusion time and fusion power were used with changing of the distance to (10um,20um,30um). another splice losses were achieved by using another arc fusion power (30 step,40 step,50 step) by using the same arc fusion time and the distance between fibers as shown in fig's below , the minimum splice losses have been extracted from the different figures as below , these minimum splice losses compared with different arc fusion power and distance by using three-dimensional program ,Obviously when the distance between two fibers is increased(25-30)um, the minimum splice loss is decreased and vice versa when the distance is (10)um.

Keywords: Arc fusion time, Arc fusion Power, Arc fusion splicer, Optical fiber, splice loss.

تأثير المسافة بين ليفين بصريين أحاديي النمط على خسائر الربط الدنيا بأستخدام ماكينة لحام القوس

الخلاصة

أجريت دراسات عديدة لايجاد الخسائر بين ليفين احاديي النمط (SMF-28/SMF-28) باستعمال مكائن لحام قوس مختلفة بدون اخذ بنظر الاعتبار تاثير المسافة بينهم0 لقد اجريت التجارب العديدة على هذا الليف الضوئي حيث تم لحام وقطع الليف عدة مرات لاستخراج خسائر اللحام عندما تكون قدرة اللحام ثابتة (20 step) ووقت اللحام متغير (9s, 6s, 3s, 1s), قدرة اللحام ووقت اللحام تم استخدامهما عندما تتغير المسافة بين الليفين (10um, 20um , 30um) على التوالي , وتم استخراج خسائر اللحام الاخرى بأستخدام قيم اخرى من قدرة اللحام الثابتة حيث تم استخدام (30 step , 40 step , 50 step) وبأستخدام نفس اوقات اللحام والمسافات بين الليفين و كما مبين في الاشكال ادناه , وبعد ذالك تم استخراج اقل خسارة لحام من كل شكل وتمت مقارنة هذه الخسائر مع قدرة اللحام المختلفة والمسافات المختلفة بين الليفين بأستخدام شكل ثلاثي الابعاد وتبين بانه كلما زادت المسافة بين الليفين وبحدود معقولة um (25-30) تقل خسارة اللحام وكلما اقتربت المسافة (10)um بين الليفين زادت خسائر اللحام.

INTRODUCTION

Optical fiber fusion splicing is the process by which a permanent, low-loss, high-strength, welded joint is formed between two optical fibers. The ultimate goal of optical fiber fusion splicing is to create a joint with no optical loss yet with mechanical strength and long-term reliability that matches the fiber itself [1]. Perhaps the most popular splice is the fusion splicing technique, illustrated in Fig.(1). The fusion splicer uses micro-manipulators to bring the prepared ends of the fiber into close alignment. The ends are then heated, typically with an electric arc, until they grow molten and fuse together. As the joint cools, the surface tension at slightly misaligned fibers will pull the fibers into alignment. In these splicers the arc voltage is kept low, until the fiber ends are rounded, thereby avoiding bubble formation, and then increased to complete the fusing process. Losses caused by splices made with this technique are typically a few tenths of a dB[2].Since this technique uses the outside surface of the fiber as a reference surface, it is susceptible to losses due to variations in core elliptically, core concentricity, and core size. The fiber ends require preparation before splicing. Losses as low as several hundredths of a dB have been reported with these techniques. Note, however, that splicing fibers of unequal diameters by this technique will result in unacceptable misalignments [3].There are many previous investigations were done in this field, the photonic crystal fiber (PCF) and conventional fiber (SMF) have been fusion splicing by controlling the arc-power and arc-time of electrical-arc fusion splicer(FSM-60S),this work was achieved by two steps, first is by splicing (SMF-SMF),second step by splicing (SMF-PCF)[4].A repeatable, robust, low-loss angle splice between large-core [PCF-SMF] is achieved. Saturated absorption Spectroscopy is performed inside Acetylene-filled kagome with one end angle spliced to SMF [5]. The aim of this work is to find the effect of the change of distance between two single mode fibers (SMF-28/SMF-28) on the minimum splice losses by using arc fusion splicer type (25eM).

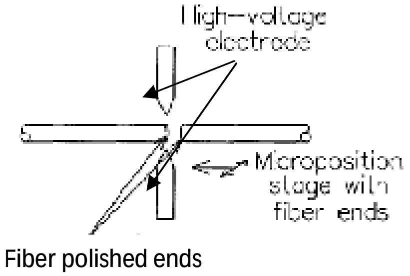
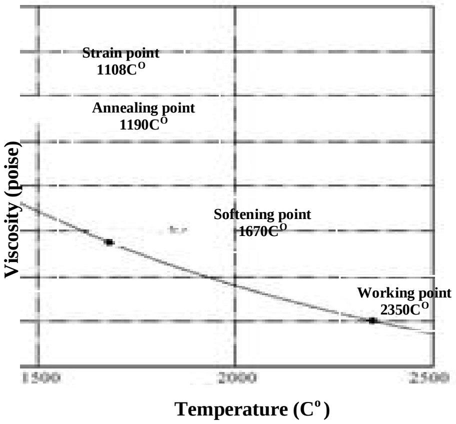


Figure (1) : Fusion splicing technique.

Surface Tension and Viscosity

Surface tension, γ, is a force that results from the subtle differences in molecular structure between the material at a surface interface and material inside the bulk, Surface tension is present in glass even at room temperature, but it cannot deform silica glass at such low temperatures because the glass viscosity is too high. Surface tension is responsible for joint formation during fusion splicing and is one of the most important and strongest mechanical forces experienced by the fiber tips. Surface tension is also the main cause for deformation of the fiber core that leads to splice loss. Viscosity inhibits fiber deformation since deformation requires relative motion and shear. The higher the viscosity, the stronger the resistance to deformation. Viscosity has units (mass/length.time) and is commonly expressed in the unit Poise (1 Poise = 1 g/cm· s =10 kg/m·s). Figure (2) depicts the viscosity of high purity vitreous silica as a function of temperature. At the softening point the viscosity is 10^7 Poise. Fusion splicing usually takes place when the viscosity is on the order of 10^5 Poise[1].

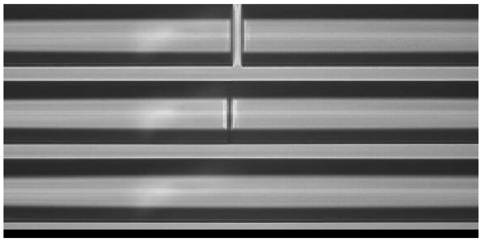


Figure(2): Variation of extremely pure Vitreous silica viscosity as a Function of temperature [1].

The working point of the glass which occurs when the viscosity is 10^4 Poise.

Glass evaporating from the hot zone is partly deposited on fibers in the vicinity – degrading surface quality and strength, and on parts of splicing machine contaminating them. Evaporation is compensated for by fiber overlap, a reduced volume of glass is accommodated in shorter length of fiber without change in diameter. As no air, gel, glue etc. separates fibers after fusion, strength close to one of pristine fiber, no reflection and low insertion loss are possible. The heat for fusion is provided by either:

- External electric discharge (arc fusion splicing),
- resistance heater located close to fibers (filament splicing),
- Hydrogen/oxygen burner (flame splicing), or
- CO2 laser radiation absorbed by the fibers (laser splicing). The first method is preferred due to compact equipment, fast operation and flexible control. Filament splicing is used for specialty fibers and when high splice strength is required. Other techniques are rarely used. Descriptions below cover arc fusion splicing only.Fig.(3) shows various stages during a fusion splice of ordinary single-mode fiber. Core and cladding regions of the fiber are visible and labeled. (a) Fiber tips aligned prior to splicing. (b) Fiber tips following hot push during joint Formation (c) Completed splice with a loss less than 0.01 dB[6].



Figure(3). Images of a fusion splice between two pieces of standard single-mode fiber (SMF) during different stages of the splice process[6].

Arc Fusion splicing of Single-Mode Fiber

The mode-field diameter (MFD) of a single-mode fiber is physically useful because it relates to the performance of the fiber in an optical system. Specifically, the MFD determines the sensitivity of the joint losses at a connector or splice to misalignment. The MFD will also determine the sensitivity of the fiber to excess losses due to microbends and macrobends. In addition, the cutoff wavelength and the dispersion properties of the fiber can be inferred from a spectral measurement of the MFD. For splice between single mode fibers, insertion loss (α) resulting from core offset, MFD difference and angular misalignment is given by the following formula[1,7].

$$\alpha = -10\log\left[\frac{4\omega_{g1}^2\omega_{g2}^2}{\left(\omega_{g1}^2+\omega_{g2}^2\right)^2}\exp\left(-\frac{4\delta^2+(2\pi/\lambda)^2 n^2\omega_{g1}^2\omega_{g2}^2\sin^2\theta}{2\left(\omega_{g1}^2+\omega_{g2}^2\right)}\right)\right] \quad \text{……. (1)}$$

where ω_{g1} and ω_{g2} are Gaussian radii of spliced fibers or (MFD) of SMF's, δ is lateral offset between fiber cores, θ is the angular misalignment, n is refractive index of fiber material and λ the operating wavelength. According to fusion splicer setup, core offset and angular misalignment were neglected, MFD misalignment is neglected due to similar MFD of two SMF. The splice losses in our experiments are due to arc fusion time and arc fusion power [8].

Arc fusion splicing of two single, polymer-coated, multimode or single-mode silica fibers of 125 μm cladding diameter usually includes eleven steps [9].

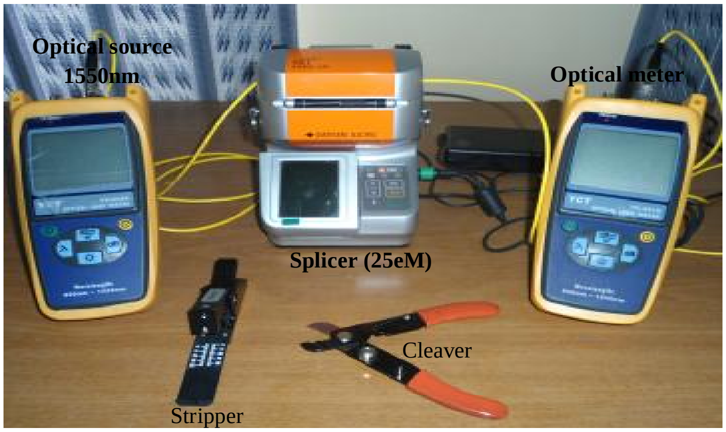


Figure (4):The schematic of the experimental setup for measuring the splicing loss between two SMFs.

The Experimental Procedure

In our experiment, SMF-28 was used , which is considered the standard optical fiber for telephony,cable television, cladding diameter($125 \pm 1.0\mu m$)[8,10], To accurately measure the splice loss, we set the experiment as follows: firstly, the transmission power in SMF-28 was measured by power source and meter with wavelength of 1550nm and recorded as a reference measurement (P_1). Secondly, the SMF-28 was cleaved at the middle part , Thirdly , the two sides of the optical fiber were stripped by (JIC – 375 Tri – Hole) stripper and the protective polymer coating around optical fiber was removed. Fourthly, the optical fiber was cleaved perpendicular to the longitudinal axis of the fiber by Cleaver. Step Five was done by cleaning the two fibers (SMF-28) by Alcohol and Tissue. Figure 4 shows the experimental setup used for measuring the splicing loss between two SMFs. For fusion two ends of fibers the fusion splicer type SUMITOMO (25eM) was setup at typical parameters: Prefusion time , prefusion power, gap, and overlap. Prefusion power sets the power from the beginning of arc discharge until the start of fiber stuffing. Prefusion time is the time during which the prefusion power is discharged. The gap between the fibers before fusion affects the area available at the tip of the fibers during the prefuse stage. Overlap parameter sets the overlap of the fibers during fiber stuffing. Both ends of optical fiber (SMF-28) were placed in the splicer type (25eM) as in Fig.(4) and fusion spliced ,the transmission power with losses in SMF was measured again (P_2) by using Laser (source– meter) of 1550nm wavelength , splice loss was calculated by using the equation[3, 11].

$$\propto = -10\log\frac{P_2}{P_1} \qquad \ldots.(2)$$

Where ($\propto$) the fusion splice loss in (dB) of one point, (P_2) is output power after fusion splice, (P_1= 425.3µW) is power source (Reference measurement) before fusion splicing. the smf-smf distance was changed (10,20,and 30) according to the arc fusion power of splicer**(25em)**. um and the splice losses were reading for every distance when the arc fusion time changed (1s,3s,6s and 9s).For constant arc power(20,30,40, and 50)step, so both ends of two optical fibers were cleaved and spliced once for every distance (10,20, and 30) um at every arc fusion time (1s,3s,6s and 9s) and constant arc power (20,30,40, and 50)step, The results and calculations are illustrated in tables (1,2,3, and 4), the total numbers of arc fusion splice becomes 48 points as in fig's (5,6,7 and 8).

RESULTS AND DISCUSSION

The fusion splice losses

The results and the splice losses of optical fiber (SMF-28/SMF-28) were illustrated in tables (1, 2, 3, and 4), figures (5, 6, 7, and 8) have been drawn from the tables above respectively. According to the arc fusion splicer **(25em)**, in order to form a fusion splice, the fiber must be softened, meaning that its viscosity must be reduced to a certain value (typically about 10^5 Poise) by heating it above 2000^o c.

Table (1): Arc power = 20 step

Arc Time (s)	Fiber-Fiber distance 10µm		Fiber-Fiber distance 20µm		Fiber-Fiber distance 30µm	
	P_2 µw	α dB	P_2 µw	α dB	P_2 µw	α dB
1	116	5.64	67.1	8.01	5.25	19
3	411.1	0.14	378.3	0.51	408.1	0.18
6	379	0.5	385.8	0.42	301	1.5
9	380.5	0.4	401.6	0.24	427.6	0.00

Table (2): Arc power = 30 step

Arc Time (s)	Fiber-Fiber distance 10µm		Fiber-Fiber distance 20µm		Fiber-Fiber distance 30µm	
	P_2 µw	α dB	P_2 µw	α dB	P_2 µw	α dB
1	218.7	2.9	286.1	2	42.6	2
3	399.9	0.28	363	0.6	269.1	0.7
6	297.8	1.56	382.8	0.47	329.6	1.12
9	388.1	1.56	385.8	0.42	379	0.5

Table (3): Arc power = 40 step

Arc Time (s)	Fiber-Fiber distance 10µm		Fiber-Fiber distance 20µm		Fiber-Fiber distance 30µm	
	P_2 µw	α dB	P_2 µw	α dB	P_2 µw	α dB
1	401.5	0.25	422.8	0.08	321.1	1.22
3	380.4	0.48	320.1	1.23	208.3	3.1
6	233.6	2.6	370.4	0.6	326.8	1.14
9	373	0.5	367.3	0.63	288.5	1.68

Table (4): Arc power = 50 step

Arc Time (s)	Fiber-Fiber distance 10µm		Fiber-Fiber distance 20µm		Fiber-Fiber distance 30µm	
	P_2 µw	α dB	P_2 µw	α dB	P_2 µw	α dB
1	353.5	0.8	231.1	2.64	No connection	Arc too strong
3	345.4	0.9	273.3	1.9	203	3.28
6	216	2.94	330.5	1.09	126.1	5.27
9	193.1	3.42	353.6	0.81	199	3.28

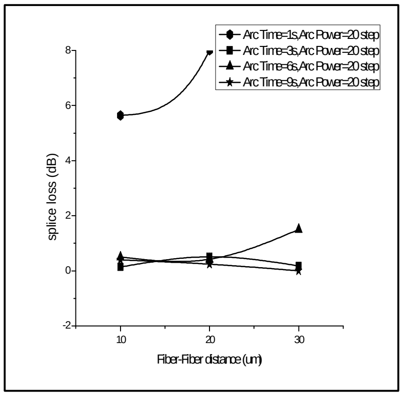


Figure.(5): Splices losses against (SMF-SMF)

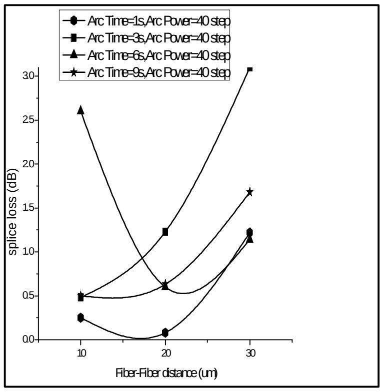


Figure.(7): Splices losses against (SMF-SMF)

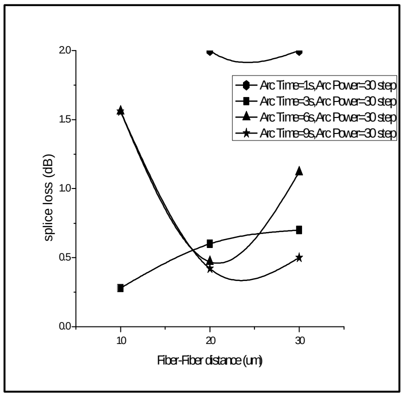


Figure.(6): Splices losses against (SMF-SMF) distance

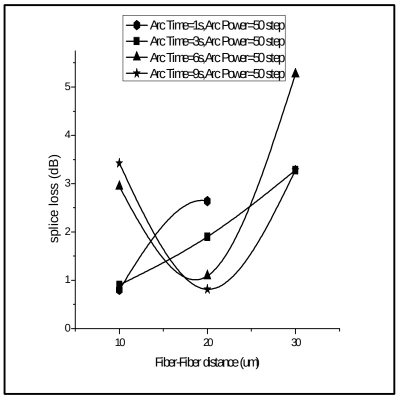


Figure.(8): Splices losses against (SMF-SMF) distance

The transmission power (P_1 and P_2) in (SMF-28/SMF-28) were measured by using Laser (Source - Detector) of 1550nm wavelength, the loss was calculated by using the equation (2) , Firstly fig.5 was selected to discuss the results where the arc power is fixed at (20 step) and the distance had been varied between two fibers from 10um to 30um for different fusion times (1s,3s,6s and 9s), At (1s) the splice losses increased with increase of distance (5.64 dB, 8.01dB, 19dB) for (10um,20um,30um) respectively due to low temperature (~ 1300^{o}C) and high viscosity of two fibers (more than 10^5 Poise) before softening point of SMF which will cause power mismatching between two fibers according to Fig.2[1], minimum splicing losses (0.14dB) was achieved at fusion time (3s) for distance(10um) when the viscosity is on the order of 10^5 Poise which will cause power matching between two fibers. When the distance increased to (20um) the losses increased to 0.51dB due to mismatching between two fibers. At (6s) the same results as above, the optimized minimum splice losses (0.00 dB) was achieved at fusion time (9s) for distance(30um) it means that the temperature of two tips of SMF were above (2000^{o} C) and viscosity was reduced to a certain value (typically about 10^5 Poise) and optimizes the power match between two fibers and hence minimize the splicing losses to (0.00 dB).Figure (6) represents the splice losses when the arc power is fixed at (30 step) and the distance had been varied between two fibers from 10um to 30um for different fusion times (1s,3s,6s, and 9s),the minimum splicing losses (0.28dB) was achieved at fusion time (3s) for distance (10um) and the maximum splicing losses (2.9dB) was achieved at fusion time (1s) for distance(10um) due to the relationship between temperature and viscosity respectively. Secondly figure (7) represents the splice losses when the arc power is fixed at (40 step) and the distance had been varied between two fibers from 10um to 30um for different fusion times (1s,3s,6s, and 9s) the minimum splicing losses (0.08dB) was achieved at fusion time (1s) for distance (20um) and the maximum splicing losses (3.1dB) was achieved at fusion time (3s) for distance (30um) due to the relationship between temperature and viscosity respectively. Figure (8) represents the splice losses when the arc power is fixed at (50 step) and the distance had been varied between two fibers from 10um to 30um for different fusion times (1s,3s,6s, and 9s), the minimum splicing losses (0.8dB) was achieved at fusion time (1s) for distance(10um) and the maximum splicing losses (5.27dB) was achieved at fusion time (6s) for distance (30um) due to the relationship between temperature and viscosity or due to arc power and distance, so the principal reason of increase and decrease of the losses are temperature , viscosity , distance, and matching between two fibers.

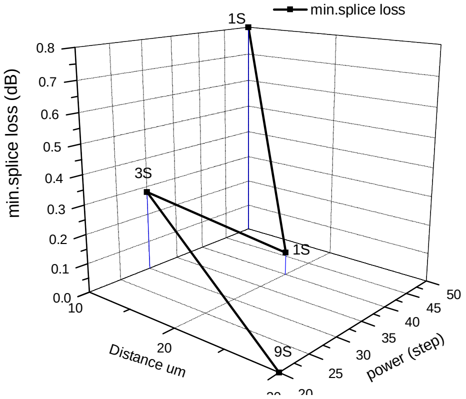
The minimum splice losses

From the tables (1,2,3, and 4), Figures (5, 6,7,and 8) above, the minimum loss points were selected as illustrated in the table below.

Table (5): Minimum splice losses

Arc power (step)	Minimum splice (dB)	Distance (µm)	Arc Time (s)	Fig.
20	0.0	30	9	5
30	0.28	10	3	6
40	0.08	20	1	7
50	0.8	10	1	8

From fig.(5) and table (1) at distance (30 µm) the minimum splice loss (0.00 dB) was achieved at fusion time (9s) and fusion power (20 step) , From fig.(6) and table (2) at distance (10um) the minimum splice loss (0.28dB) was achieved at fusion time (3s) and fusion power (30 step) , From Fig.(7) and table (3) at distance (20um) the minimum splice loss (0.08 dB) was achieved at fusion time (1s) and fusion power (40 step), From Fig.(8) and table (4) at distance(10um) the minimum splice loss (0.8dB) was achieved at fusion time (1s) and fusion power (50 step) . The minimum splice loss (0.00 dB) was achieved when the viscosity is on the order of 10^5 Poise and the temperature of two tips of SMF was (~2200°C) which will cause power matching between two fibers. Fig.(9) collects the minimum splice loss (0.0, 0.28, 0.08, and 0.8) dB.



Figure(9): The minimum splice losses vs. distance (um) and arc fusion power (step).

CONCLUSIONS

Many conditions were investigated to splice (SMF-28) – (SMF-28) leads us to conclude the following :

a) At distance (30 µm) the minimum splice loss (0.0 dB) was achieved at fusion time (9s) and fusion power (20 step) because of the viscosity is on the order of (10^5 Poise) and the temperature of two tips of SMF was (~2200^{o}C) which will cause power matching between two fibers.

b) At distance (20 µm) the minimum splice loss was increased to (0.08 dB) at fusion time (1s) and fusion power (40 step) because of increase the viscosity to (10^7 Poise) and decrease the temperature of two tips of SMF to (~1670^{o}C) .

c) At distance (10 µm) the minimum splice loss was increased to (0.28 dB) at fusion time (3s) and fusion power (30 step) because of increase the viscosity to (~ 10^{10} Poise) and decrease the temperature of two tips of SMF to (~1300^{o}C) .

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