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Fusion Splicing of Double-Clad Large Mode Area Fibres for Fabrication of High Power Fibre Lasers

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ABSTRACT

Fusion splicing is a fibre connection technology that is a key element in the fabrication of high power fibre lasers. Obtaining low optical transmission loss fusion splices remains a challenge in the development of high power fibre lasers. To address this problem, splicing experiments were conducted to find the best parameters to produce low splice losses (<0.1 dB). Due to the large number of splice parameters, the experimental methodology made use of fractional factorial design which enables the reduction of the required number of experiments by performing them at a certain specific combination of parameters. A system was setup to conduct splice loss measurements. The splice loss results were analysed by using a statistical tool called the analysis of variance (ANOVA) which revealed that gap distance and arc power 2 splice parameters have a stronger influence on the splice loss. Optimal splice parameter set points were found that produced the lowest average splice loss.

FUSION SPLICES IN FIBRE LASERS

Fibre lasers have become the dominant laser architecture due to their compact design, excellent beam quality and high output power. An all-fibre laser system (figure 1) can be achieved by splicing components together. This research aims to find the best splicing parameters that can provide quality fusion splices for the purpose of ultimately building a simple, compact, robust and reliable thulium-doped all-fibre laser.

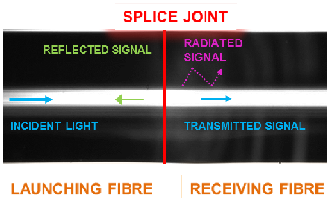

Fig 2: Illustration of fusion splice (splice joint) and splice loss (radiated signal).

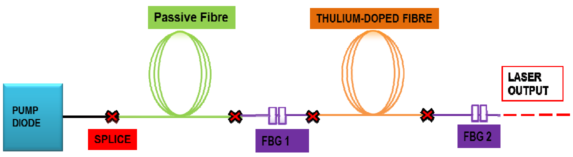

Fig 1: Thulium-doped all-fibre laser; Fibre Bragg grating (FBG 1: 99.9% reflection at 1939.8 nm; FBG 2: 10% reflection at 1938.8 nm);Double clad passive and thulium-doped fibre (25-400 μm); 150 W Dilas pump diode.

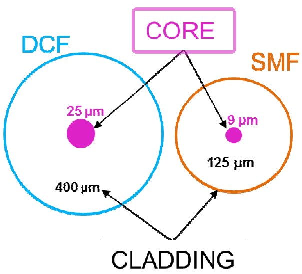

Fig 3: Illustration of the dimensions of double clad fibre (DCF)and single mode fibre (SMF).

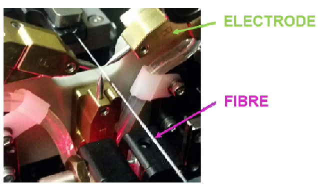

Fig 4: Two aligned DCF in LDS, with three electrodes.

The performance and integrity of an all-fibre laser (figure 1) is critically dependent on the quality of splices between different components constituting a fibre laser. Arc fusion splicing is the technique used to interconnect fibres and fibre components [1]. This interconnection forms a joint called fusion splice (figure 2). Poor fusion splices cause splice losses (radiated signal-figure 2) that lead to power loss that can cause catastrophic damage to components due to localized heat, decrease in optical to optical efficiency and as well as degradation in the beam quality of fibre laser [2]. Due to the large core and cladding of the double clad fibre (DCF) (figure 3), a splicing experiment has to made with a large diameter glass processing splicer (LDS) that can conform to the dimension of DCF. Three electrodes (figure 4) are used to generate a plasma in which glass fusion takes place.

PARAMETER SPACE

The LDS has seven variable parameters. The search for favourable splice parameter set points firstly makes use of a parameter space which is defined by seven parameters that are varied over three levels. Parameter space (table 1) makes the search more comprehensible by choosing discrete values for each parameter that are anticipated to be in the vicinity of optimal parameters. For this experiment values chosen were closer to the values of a setting (level 2 of table 1) that was assumed to be the acceptable setting due to good visual inspection of splices that was produced by the setting found on LDS.

Table 1: LDS splice parameter space defined by seven parameter and three levels. The restriction of the parameter space produced 18 experiments

Level	Gap Distance μm	Prefuse Time (s)	Arc time 1 (s)	Arc Time 2 (s)	Arc Power 1 (W)	Arc Power 2 (w)	Overlap
1	40	0.8	0.2	5.5	69	69	10
2	50	1	0.3	6	71	71	15
3	60	1.2	0.4	6.5	73	73	20

Secondly, the splicing experiment followed a fractional factorial experimental design in which all splice parameters are varied simultaneously during a collection of experiment, as a substitute of executing many series of experiments in which one splice parameter is changed at a time [1]. Taguchi orthogonal array is incorporated in the design, whereby each distinct splice parameter level appears an equivalent number of times in the array (figure 5).

Table 2: Example of fractional factorial experimental design with the integration of Taguchi orthogonal array for a parameter space that has three parameters varied over two levels.

EXP NO	PARAMETER 1	PARAMETER 2	PARAMETER 3
1	1	1	[illegible]
2	1	2	2
3	2	1	2
4	2	2	[illegible]

EXPERIMENTAL SETUP

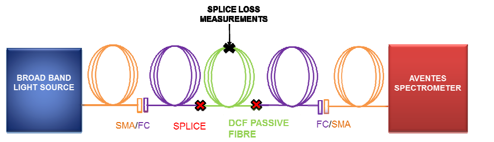

Fig 5: The construction of splicing experiment made use of power source that is connected to multi mode fibre (400 μm) that was used to launch broadband light to into fibres. Aventes spectrometer was used to take transmission spectra and splice loss measurements . A reference measurement was taken with the passive fibre (25-400 μm) spliced to both ends of multi mode fibres (400 μm). The passive fibre was severed in the middle then spliced together with different splice parameter setting according to values in table 1.

RESULTS

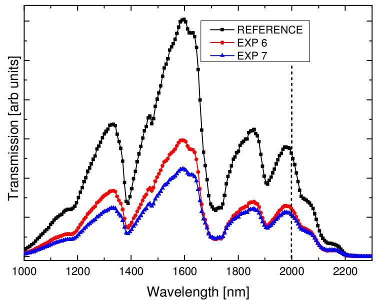

Figure 6: Transmission spectrum obtained from aventes spectrometer.

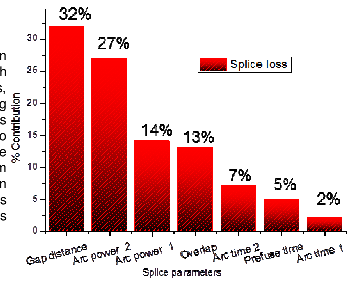

Fig 7: The relative contribution and importance of each parameter towards splice loss, calculations made by using the ANOVA. The ANOVA uses sum of the squares to quantitatively examine the deviation of a parameter from the overall experimental mean and this is referred as variation between parameters [3].

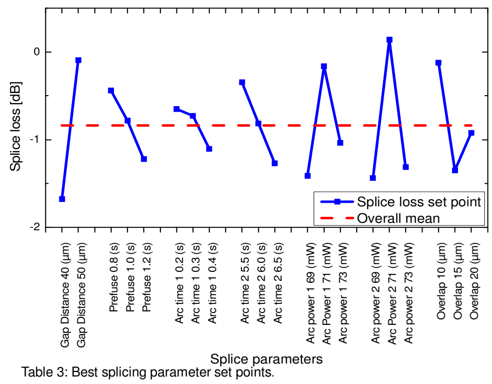

Fig 8: A plot of splice losses of all seven parameters. Arc power 2 and the gap distance have the highest splice loss ratio and they have a strong influence on the splice loss ratio. The best parameter level set points are the set points with the lowest splice loss ratio.

Table 3: Best splicing parameter set points.

Parameters	Gap Distance	Prefuse Time	Arc Time 1	Arc Time 2	Arc Power 1	Arc Power 2	Overlap
Splice loss (dB)	-0.09	-0.44	-0.65	-0.35	-0.16	0.14	-0.12
Optimal Parameter set points	50	0.8	0.2	5.5	71	71	10

CONCLUSIONS

- Gap distance and arc power 2 are more significant splice parameters as they have a higher contribution and a strong influence towards splice loss.
- Optimal parameter set points were found to enable quality low fusion splices for 25/400 μm passive fibre.

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