A HIGH POWER FIBRE LASER FOR ELECTRON BEAM EMITTANCE MEASUREMENTS*

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Abstract

We present the latest results on the development of a high power fibre laser system for a laser-wire measuring electron beam emittance in an ILC-specification environment. The laser consists of a commercial Ytterbium (Yb) doped fibre laser system producing 1μJ pulses at 6.49MHz, which can be locked to an external frequency reference. This output has been amplified in a single 70cm rod type photonic crystal fibre (PCF), producing ~ 100μJ pulses in a burst mode at 2Hz (limited by diagnostics).

INTRODUCTION

A laser-wire is a non-invasive method of measuring particle beam emittance. A high power laser is focussed to an extremely small spot size and scanned across a particle beam. The number of scattered photons (proportional to the overlap of the laser and particle beam) are measured further down the accelerator to give the particle distribution, which can be measured using this technique down to the micron level [1-3].

The specifications of a laser suitable for use in an ILC-like environment are shown in Tab. 1.

Table 1: Required laser parameters

Parameter	Value
Repetition rate	6.49MHz
Pulse energy	50 - 100μJ
Pulse duration	~ 1ps
Beam quality	$M^2 < 1.1$
Wavelength	~ 500nm

EXPERIMENT

To reach the energy required for a laser-wire experiment it is necessary to amplify the output of our commercial laser system. This is done in a rod type photonic crystal fibre, which gives high amplification without nonlinearities. The amplification of the seed pulses in the PCF is shown schematically in Fig. 1. The seed pulses from the commercial laser (Amplitude Systèmes, Bordeaux, 1μJ, 6.49MHz, 1037nm, 200ps) [4] are modulated using an intrasystem EOM to produce bursts as short as 9 pulses long. The pulses are transmitted through an optical isolator which protects the seed laser from back reflections or lasing in the PCF, a λ/2 plate to correctly orient the laser polarisation with the axis of the polarisation maintaining fibre and then a series of lenses to couple the seed into the core of the fibre.

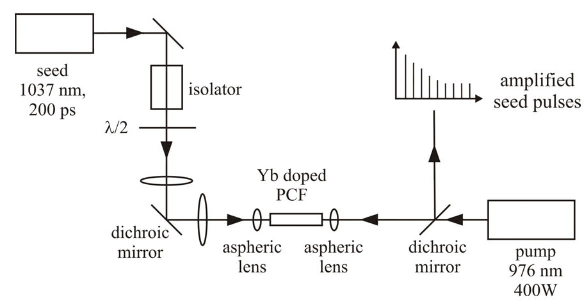

Figure 1: Experimental arrangement.

The rod type PCF has a core diameter of 70μm, an inner cladding diameter of 200μm and an outer diameter of 1.7mm [5]. The seed is coupled into the core, which is doped with Yb, and the pump laser (400W, 976nm, Newport) is coupled into the inner cladding at the other end of the fibre. This counter-propagating geometry allows independent optimisation of the pump and seed coupling and efficient use of the pump energy. The seed and pump are separated by dichroic mirrors at either end of the fibre, which is made entirely of silica with no polymer coating, and is supported in a metal V groove. Due to the high efficiency of fibre lasers, the large surface area to volume ratio and the excellent thermal properties of the silica, the fibre requires no active or passive cooling and we have observed no damage to the fibre despite the high peak and average power output.

The core of the PCF is surrounded by a microscopic array of air holes which create a waveguide structure. This means that the core can have a large diameter while still remaining single spatial mode, which is important for preserving the beam quality of the seed after amplification. The large core area allows for high levels of amplification and the avoidance of nonlinearities. However, it also means the core has a very small numerical aperture (NA ~ 0.02), which requires careful alignment of the seed.

To achieve the high single pass amplification required the fibre amplifier is operated in a burst mode [6]. Here the pump beam is turned on <1ms before the seed burst enters the amplifier, illustrated schematically in Fig. 2. Turning on the pump beam before the seed means

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significant upper state population (gain) is created in the amplifier which can be extracted by the seed pulses. The pump beam remains on during the seed amplification but there is not enough energy to replace the upper state population extracted by each seed pulse in the time between them (~155ns) and each pulse sees a smaller gain until the system reaches a steady state. This leads to an amplified burst train that exponentially decays in pulse energy to a steady state value.

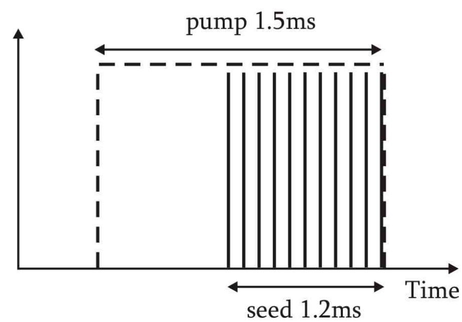

Figure 2: Burst temporal structure.

Experiments were carried out to find the optimum time delay between the pump and seed that maximised the amplified seed pulse energy i.e. before significant parasitic reduction in the gain by amplified spontaneous emission (ASE) in the fibre.

RESULTS

The amplified seed pulse train is shown in Fig. 3.

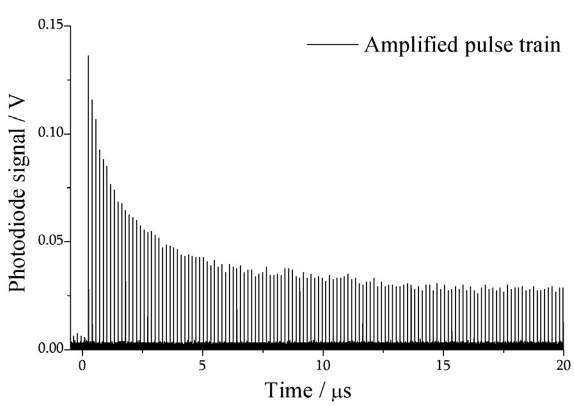

Figure 3: Amplified seed train.

The decay from the first pulse, which sees the highest gain in the fibre amplifier, to the steady state is clear. This data was taken using a pump burst 1.5ms long, with a 0.3ms delay between the pump and seed bursts which ended at the same time (i.e. the seed burst was 1.2ms long) and a burst pump energy of ~450mJ. The input seed pulse energy was 0.7μJ. The amplified seed energy over the whole train was 117 ± 0.11mJ, and the energy in the first pulse was 105μJ, slightly exceeding the design specification for the system. There was no ASE or spectral broadening observed in the output of the laser at this level of amplification, indicating negligible nonlinearities in the amplifier.

The amplified output had excellent beam quality, which is shown in Fig. 4. This is a CCD camera image of the amplified seed output, showing a nearly perfect Gaussian intensity profile.

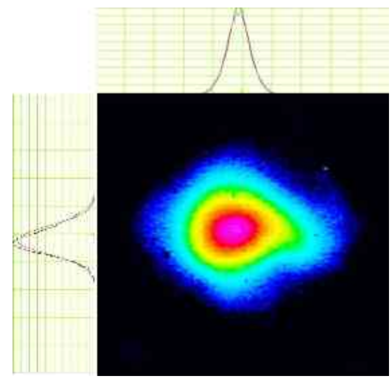

Figure 4: Amplified seed output with lineouts through the peak and Gaussian fits.

The system currently operates at 2Hz, which is limited only by the diagnostics. This is expected to be easily upgraded to several tens of Hz without any adverse effects.

FUTURE WORK

Currently the amplified seed pulses are ~200ps long. Future work will concentrate on recompressing the pulses to 1 – 10ps and frequency doubling them to 519nm. To verify the quality of the amplified output a full M^2 analysis must be carried out, to enable the calculation of the beam size at the laser-wire interaction point. Further studies to optimise the amplification will be carried out, with the aim of having 3 – 10 pulses in the seed train >100μJ, which will allow us to carry out laser-wire experiments on several electron bunches per train at the ATF2, significantly decreasing the time required to make a full measurement.

CONCLUSION

We have reported major progress towards a high power fibre laser system suitable for use in a laser-wire experiment using innovative photonic crystal fibres. The laser has exceeded the design specification of >100μJ per pulse using very high gain burst mode transient amplification.

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