TRINAT
Laser-Fibre Coupling with ThorLabs PAF-X-15-B FibrePort
Summary

John Donohue
Supervised by John Behr
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1 Objective

A magneto-optical trap (MOT) is a device used to cool and trap atoms in a small volume using circularly polarized lasers and anti-Helmholtz coils. In a MOT, six laser beams (two in opposite directions in each of three orthogonal directions) effectively create a force that pushes the atoms towards their intersection (through the relativistic Doppler effect). The light must all come from the same source, since it is required to have the same wavelength. To separate it and manipulate it, as well as remove structure in the beam, the use of mirrors, beamsplitters and optical fibres is necessary. One of the challenges is coupling light from a laser into the optical fibre, as discussed in the following summary. In the end, using ThorLabs PAF-X-15-B fibre coupler, approximately 50% of the light incident on the port was coupled into the fibre. However, it is believed a better port may have been easier.

2 Setup

Laser light from a diode laser is emitted at a wavelength of $\lambda = 767nm$. After a brief series of mirrors (with some light split off), the laser light was put through a half waveplate ($\frac{\lambda}{2}$), rotated to allow maximum transmission through the tapered amplifier (see Appendix B). The polarized light was coupled into the fibre with the PAF-X-15-B piece, and the fibre was inserted into the BoosTA Laser Amplifier, which increased the power of the beam (instructions can be found in Appendix A).

From the amplifier, the beam entered an optical isolator (ThorLabs, IO-5-NIR-LP) to prevent potentially damaging reflections back into the amplifier. The optical isolator works by linearly polarizing the light and propagating it through a Faraday rotator, which rotates the polarization by some angle proportional to the magnetic field applied (in this case, forty-five degrees from the first polarizer). The light then exits a polarizer at forty-five degrees to the first. Any light reflected back into the device will be at that forty-five degree angle and will be rotated by the Faraday rotator to an angle perpendicular to the first polarizer, therefore unable to reach the amplifier.

After the optical isolator, the light is incident on a pair of mirrors and travels through a telescope (not part of the original design, explained further on). From there, the light hits the second PAF-X-15-B FibrePort, enters the second fibre and is able to be transported as needed.

2.1 Fibre

The fibre itself is meant to be polarization maintaining, useful since linear polarization is necessary at this stage. The entrance to the fibre has a mean field diameter (opening) of $a = 4\mu m$. The numerical aperture (sine of the angle of the acceptance cone) is therefore calculated as

$$NA = \frac{2\lambda}{\pi a} \approx 0.122 \tag{1}$$

Rays entering from within this cone should be accepted into the fibre.

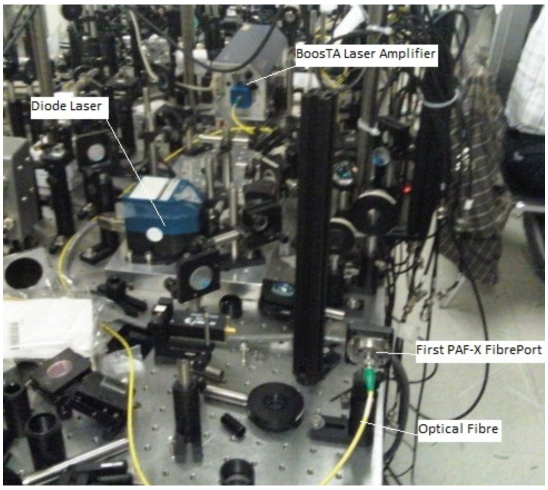

Figure 1: First half of setup, light travels from the diode laser to be coupled to the fibre, which is inputted into the BoosTA

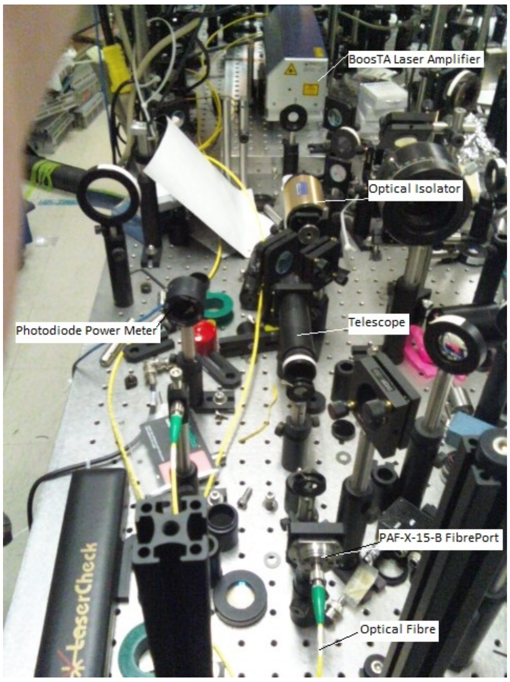

Figure 2: Second half of setup, light travels from BoosTA amplifier to the optical isolator IO-5-NIR-LP, through some mirrors and a telescope and is recoupled into a fibre by the PAF-X fibreport, which has laser light collimated out of it to measure on a photodiode.

3 PAF-X-15-B

Figure 3: ThorLabs PAF-X-15-B piece

The PAF-X-15-B is a FibrePort coupler produced by ThorLabs chosen mostly for its relatively low price (around $500) compared to a precision 5-axis stage. It consists of a port for the fibre to attach to and a lens to focus light onto it. The lens is controlled principally by five screws, adjusting the X and Y positions (horizontal and vertical), as well as Z/q/j (tilt/tip/yaw), which combined control the distance to the fibre tip. As laser light enters the lens, the focal point relative to the fibre can be changed by changing the Z/q/j positions in equal amounts. Note that no part of the port changes the position of the actual fibre, and the XY adjustments only move the lens with respect to the fixed fibre, serving only to centre the beam on the curvature of the lens.

3.1 Procedure

To test the amount of light accepted into the fibre, the following procedure was followed repeatedly.

1. Take fibre directly from polarizer section to PAF-X and shine onto wall.
2. Using X-Y controls, and then the tilt Z/q/j controls, center the beam through the two apertures after the optical isolator (the apertures should have previously been aligned with the beam from the amplifier)
3. To collimate the beam (ie make parallel), adjust the socket head cap screws of the Z/q/j controls in small, equal amounts, using a card to check if beam size is close to uniform over a space. If diverging, move lens further from fibre (counter-clockwise). If converging, move lens closer to the fibre (clockwise). Note that if the focus is too close PAF-X, a converging beam appears divergent if only checking past the focus.
4. Switch first fibre back to BoosTA Laser Amplifier and power on amplifier (Appendix A).

5. Turn second PAF-X such that the light from the amplifier is incident on the lens.
6. Attach second fibre to second PAF-X FibrePort, and the other end to a collimator aimed at a photodiode to measure output power.
7. If, after laser on and unblocked, no power is registered on the power meter, adjust mirrors until a signal is found.
8. Once a reading is found, VERY VERY LIGHTLY adjust the mirrors in both X and Y until a maximum is found.
9. Use the XY controls on the PAF-X to fine tune the maximum. Note these are extremely sensitive, and the force of simply inserting the Allen driver into the screw is enough to drastically change the power output.

   Note that the IR viewer can also be used to see very small power outputs, or to see light attenuated through the fibre, an indication that the laser is close to lined up (as some enters the fibre but is quickly reflected out due to being outside the numerical aperture).

3.2 Issues with Second FibrePort

Issues were quickly encountered with the PAF-X. The cap screws used for the Z/q/j controls, when not operated exactly in tandem, quickly became unstable. The screws work by threading through the tilt plate (which holds the lens). Once the screw is outside of the thread, control is quickly lost, and finding the thread again required disassembling the fibreport. The plunge screws can also be adjusted to provide a different counterforce. While altering these does not affect the position directly, it does change the maximum and minimum of the Z/q/j threading.

Once the piece was reassembled, new issues were encountered. The XY controls became coupled, such that the lens no longer moved in linear paths and movements were no longer completely reversable. It was discovered that care must be taken in reassembly so that the flat portions of the lens circumference (noticeable by a duller shine) are against the XY-screw tips and the leaf spring to prevent the screws from slipping.

The use of the XY controls on the fibreport was also called into question. These controls work by moving the lens, not the fibre itself. While their effect is noticeable when referencing the power meter, their effect is not particularly noticeable when centering through the apertures compared to the Z/q/j controls.

Even when good control was established, a maximum of approximately only 5% of the light was transmitted through the fibre. Since all that could be manipulated on the end of the fibre coupling was being manipulated, it was assumed that the spot diameter of the beam was simply too wide to allow for efficient transmission. To change the spot diameter, a telescope was constructed to focus the beam at the fibre tip. The results of this process are described in the next section.

The problems were not only with the fibre, but with the beam itself. As mentioned, it was too wide to allow efficient transfer, but it also exhibited some structure, with two maxima when shifted in the x-direction (appearing to the eye as two intersecting circles). One peak is clearly inferior to the other, so selecting which to use is not an issue, although structure like this is one of the main reasons why the fibre is necessary to collimate the beam instead of simply using mirrors to take directly from the amplifier.

3.3 Telescope Solution

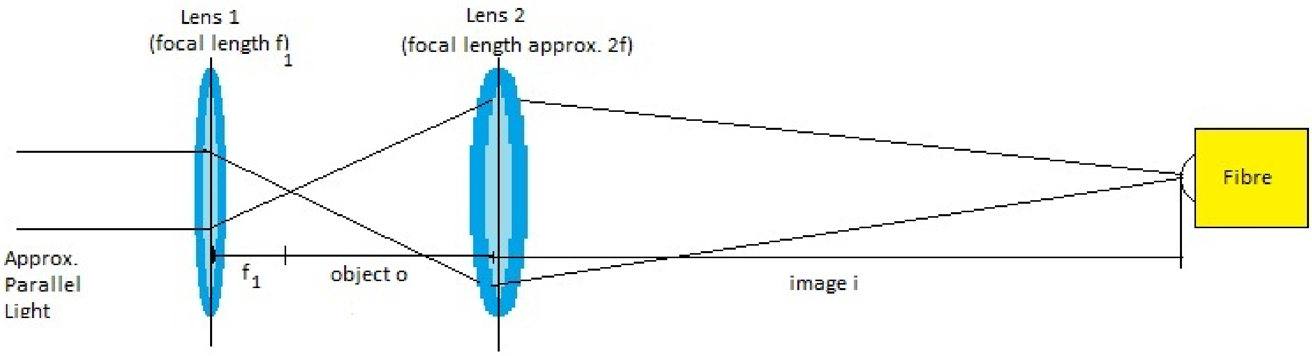

Figure 4: Ray-tracing diagram of the telescope setup used, highly exaggerated. Note that does not include the lens in front of the fibre on the PAF-X.

To focus the beam on the fibre, a telescope was constructed as in Figure 4. Nearly-parallel light (although with some divergence) is incident upon the first lens of the device, which has a focal length $f_1 = 30.4mm$, comes to a focus in the telescope around f_1 from the lens, and begins expanding again. It is then incident upon a second lens with a focal length $f_2 = 80.mm \approx 2f_1$. By moving the second lens, a position can be found where the light through the PAF-X lens is focused into the fibre and chances of collimation are best.

Using the notation in Figure 4 of the object o t being the point at which the first lens focuses relative to the second lens and the image i being where the the light is focused by the lens, the Lensmaker's Equation demands that

$$\frac{1}{f_2} - \frac{1}{o} = \frac{o - f_2}{of_2} = \frac{1}{i} \rightarrow i = \frac{of_2}{o - f_2} \tag{2}$$

be satisfied. Note that, in general, where the object is focused to by the first lens relative to the first lens does not matter, which is necessary as assumptions about the collimation of the incident light and the length of the tube relative to lens positions cannot be made at the proper degree of accuracy. The initial position of the object relative to the lens was constructed to be close to f_2, so the object distance can be modeled as

$$o = f_2 + x_0 + \Delta x \tag{3}$$

where x_0 is the distance from f_2 before the telescope is turned and Δx is the change due to turning the telescope. With the thread of the telescope used, the number of turns can be equated to a change in x as

$$\Delta x = (0.635mm) \times (\#_{turns}) \tag{4}$$

Therefore, i can be rewritten as

$$i = \frac{f_2^2 + f_2(x_0 + \Delta x)}{x + x_0} = \frac{f_2^2}{x_0 + \Delta x} + f_2 \tag{5}$$

Let another horizontal axis be introduced to the system, such that the distance from the seconds lens to the fibre tip is given by z. As the laser beam travels as a Gaussian beam (generally, see Brooker's "Classical Modern Optics" text for more information), the beam waist expands as

$$w(z) = w_0\sqrt{1 + \left(\frac{z - i}{z_0}\right)^2} \tag{6}$$

where w_0 is the beam waist at the focus and z_0 is the Rayleigh range,

$$z_0 = \frac{\pi n w_0^2}{\lambda} \tag{7}$$

where $\lambda = 767nm$ is the wavelength of the laser light and $n \approx 1$ is the refraction index of the medium (in this case air). When $z = i$, $w(z) = w_0$, or a focus on the fibre tip. The power transmitted should be inversely proportional to the beam waist at z (i.e. $P \propto \frac{1}{w(z)}$), so using an arbitrary scaling constant k, the power transmitted can be modeled by changes in the telescope as

$$P = \frac{k}{\sqrt{w_0^2 + \left(\frac{\lambda}{\pi}\right)^2 \left(z - \frac{f_2^2}{x+\Delta x} - f_2\right)^2}} \tag{8}$$

Using Physica, equation (8) was used to fit data taken by rotating the telescope lens and optimizing power at each quarter-turn. The variables k, w_0 and z were fit as $k = 13.660$, $w_0 = 1.03 \times 10^{-2}mm$ and $z = 740.3mm$. The results are plotted in Figure 5. These values imply a Rayleigh range of $z_0 \approx 0.43mm$. Note that the equations are incomplete, as none of them account for the lens in front of the fibre (the PAF-X lens).

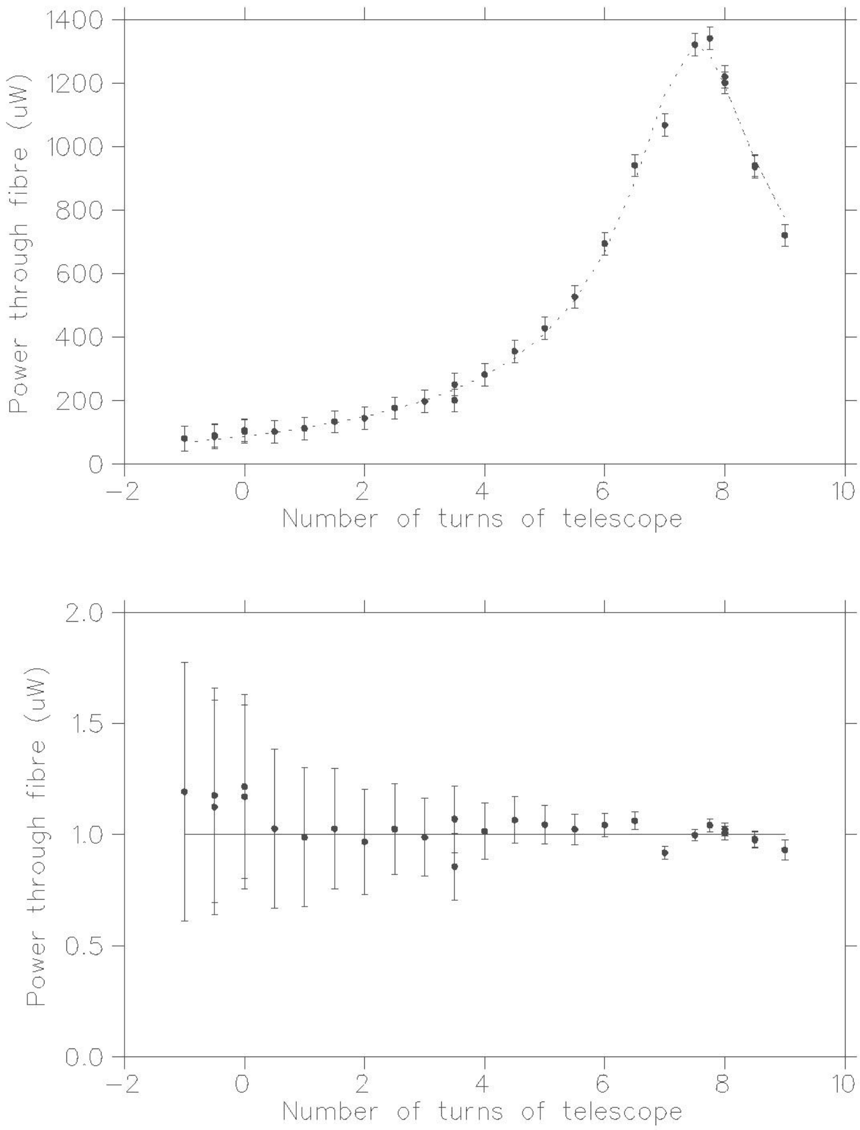

Figure 5: Plot of the optimized power through the fibre with number of turns of the telescope, bottom plot $\frac{data}{fit}$

4 Conclusion

While difficulties were encountered with the PAF-X-15-B, eventually decent coupling was achieved, with approximately 60% of the incident power being transmitted through the fibre after using a telescope. However, were the setup to be restarted, I would recommend using an easier piece that wouldn't require an external telescope or that can adjust position in the Z direction independently of tilt and yaw. That being said, the light was coupled and many of the imperfections of the beam from the laser amplifier were corrected and proved useable in the offline MOT.

A Instructions for Operation of BoosTA Laser Amplifier from Computer

In order to expedite further use of the BoosTA Laser Amplifier, step-by-step instructions are included below:

1. Turn on computer, open terminal and open fil “boosta.trm”
2. Turn on laser power
3. Enter command “remote on”
4. Turn key off and then on again
5. To check connection, enter “temp?” to check temperature
6. Command “laon” to turn laser on (may have to wait for temperature stability)
7. Command “lcurr k” to set to k mA (900 mA was used)
8. Command “meascurr” to measure current, “lcurr?” for most recent setting
9. To turn off, use commands “laoff” followed by “remote off”
10. Computer has tendency to freeze when in communication with laser, if so can turn off manually with key and power source

B Polarization Entering First Port

The half waveplate (before the first fibre and amplifier) determines the polarization throughout the fibre, as it is supposed to be polarization maintaining. The linearly polarizaed light from the diode laser was put through a half waveplate on its way to the first fibre, changing the angle of polarization, and the power through the waveplate was measured with the rotation of the polarizer.

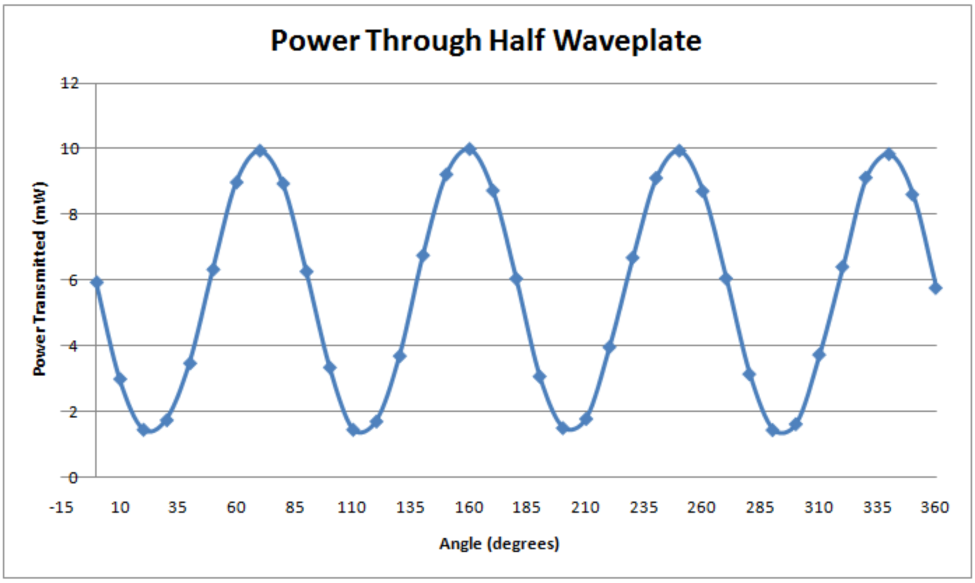

Figure 6: Power transmitted VS polarization angle

This is the expected behaviour from the half waveplate. This is necessary as the taper amplifier requires linear polarization at a fixed angle, and the polarization-maintaining fibre keeps the light linearly polarized.

C References

ThorLabs Part Information:
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Garland and Sezerman, Shedding Light on Hybrid Optics,
http://www.osa-opn.org/Archives/BackIssue.aspx?j=OPN&v=10&i=2 Brooker, G., "Modern Classical Optics", p. 165