Modification of Regenerative Amplifier Resonating Cavity for New TAP Beam Line OPCPA Pump

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Abstract

The new shaped long pulse laser, which is pumping the OPCPA stage of the new Vulcan beam line features regenerative amplifier, that is currently laid out as a standing wave resonating cavity. It will be moved on the same optical table as the rest of the laser, due to space limitations. This paper discusses improvements that will be made to the cavity to increase its stability and to reduce it's size. Ultimately, the cavity will be laid out as a ring cavity, and it will be built on a 450x900mm breadboard.

1 Introduction

The concept of regenerative amplification works by passing a pulse of light through a resonating cavity until it accumulates most of the energy in the gain medium of the cavity[1]. In the case of the cavity discussed here, the gain medium is a YLF rod, which is pumped with 930nm light in a laser head assembly. The laser head unit is also referred to as an RBA module, from it's model name. In order for any gain through this module to be useful, the beam needs to stay within the cavity and have consistent orientation and beam size through the YLF rod. This means that the cavity needs to be stable[2].

The current limitations of the regenerative amplifier for the pump of the new TAP beam line are due to it's stability and physical size. To address the stability issue, the cavity was modeled using the reZonator[3] software package, to minimize the stability parameter P. ReZonator obtains the $ABCD$ ray transfer matrix of the round trip through the cavity and defines it's stability as:

$$P = \frac{A+D}{2} \quad (1)$$

Where for a stable cavity, $-1 < P < 1$. Ideally, P and C (from ABCD round trip matrix) will be as close to 0 as possible. As it is now, the regenerative amplifier is laid out as a standing wave cavity, meaning that the injected light pulse propagates between two end mirrors, passing through the laser head twice on each round trip. The cavity lases at 1053nm, with horizontal polarization. Due to the cut of the YLF rod, when the RBA module is operated at normal currents, there is an astigmatic thermal lens. However, this was not taken into account when the cavity was previously built[4]. Two models were constructed to fix this, one with a standing wave layout and one with a ring layout. Both models corrected for this astigmatism using a 2000mm focal length cylindrical lens.

CAD drawings of the cavity were made after each of the two models, which had the cavity on a 450x900 mm breadboard, as opposed to the currently used 1000x2000mm optical table. This was done to accommodate the relocation of the cavity in the front end of the Vulcan laser system. The LibreCAD[5] and AutoCAD[6] software packages were used for this.

2 Standing Wave Cavity Model

This model features two curved end mirrors, with radii of curvature of 2500 mm and -2000 mm respectively. The 83 mm YLF rod is included in the model, together with it's astigmatic thermal lens. The lens is modeled to have -3500 to -4000 mm focal length on the horizontal axis and 4000 to 5000 mm on the vertical axis. The values were taken off of the data sheet for the RBA module[7] for operating currents between 16 and 17 A. These are typical operating currents for the module used in this specific cavity. As it is, the model has a stability of 0.004 on the vertical axis, but it is unstable on the horizontal. To account for this, a cylindrical lens of 2000 mm focal length was added to the model. Figure 1 outlines the arrangement of these components.

The angle θ of the cylindrical lens can be adjusted to change the stability P_h and beam size on the horizontal axis. This stability was found to depend on angle following the relationship:

$$P_h = c_1[c_2 - \cosh(c_3\theta)] \quad (2)$$

Where the values of the parameters c_i for two typical currents are displayed in Table 1, as well as the angle of the lens for 0 stability parameter. This relationship is only valid between 0^o and 75^o.
The stability on the vertical axis P_v ranges from 0.0 to 0.1 with currents from 16 to 17 A, so it should not be

Current [A]	c_1	c_2	c_3	Angle for $P_h = 0$
16	0.261	2.01	1.94	39.7^o
17	0.255	2.31	1.99	43.5^o

Table 1: Stability equation parameters for two currents on RBA module in the standing wave cavity.

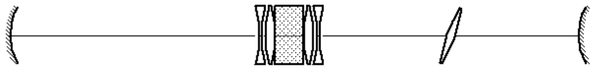

Figure 1: Arrangement of the standing wave cavity, with curved end mirrors, YLF rod with astigmatic thermal lens, and horizontal cylindrical lens. Taken out of reZonator software package.

problematic. There is a trade-off however, between beam stability and diameter through the crystal, which could cause the output beam to have less energy, or even damage the YLF crystal if the beam is to have the same energy. Fortunately, in this case, the difference in energy is of only 9% and it can be accounted for by turning up the gain on the rod amplifiers. The radii of the beam on the horizontal and vertical axes through the cavity are plotted in Figures 2 and 3. The beam is elliptical, and will need to be corrected by a pair of anamorphic prisms before going through the amplifiers, to avoid losses.

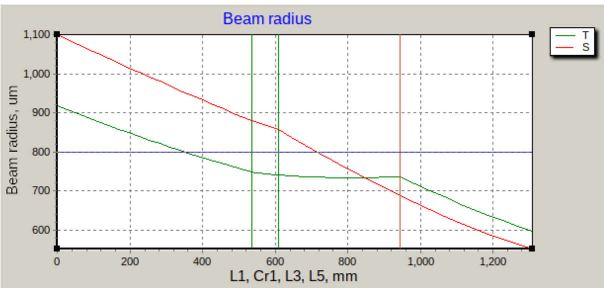

Figure 2: Beam radius through the standing wave cavity with thermal lens caused by a 16 A current through the RBA module, with cylindrical lens at 39.7^o. Red is vertical axis, green is horizontal axis.

Current [A]	P_h	P_v
17	-0.004	0.004
16	-0.061	0.113
0 (off)	-0.417	0.596
0 (off and no cylindrical lens)	0.596	0.596

Table 2: Stability values for different currents on the RBA module in the standing wave cavity, with the cylindrical lens at 43.5^o.

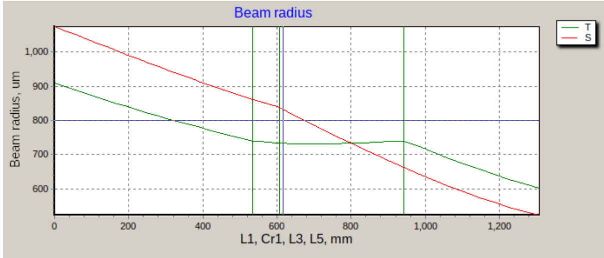

Figure 3: Beam radius through the standing wave cavity with thermal lens caused by a 17 A current through the RBA module,with cylindrical lens at 43.5^o. Red is vertical axis, green is horizontal axis.

3 Ring Cavity Model

This second model also features the thermal lenses on the YLF rod, and the same cylindrical 2000mm lens used to correct this. However, this model only features one component used for refocusing, which is a 1500mm focal length lens. The stability of the cavity is only worsened by twisting the cylindrical lens, unlike in the previous model, so an angle of only 5^o is used on both the cylindrical and spherical lenses, to avoid back reflections into the rod. Stability values for this model are outlined in Table 3.

Figure 4: Arrangement of ring cavity, with astigmatic thermal lens on the YLF rod, one spherical and one cylindrical lens.

The beam radius increases with the length or perimeter of the cavity, so a 2000mm cavity length was chosen as a compromise between space efficiency and beam radius through the YLF rod. If the RBA is turned on, up to to 17A and 16A (Figures 5 and 6), the beam is a lot less elliptical than in the standing wave model, so almost no correction is required to make it circular. If turned off, the beam is elliptical (Figure 7), which can be corrected by removing the cylindrical lens (Figure 8).

Current [A]	P_h	P_v
17	0.030	-0.024
16	-0.021	0.029
0 (off)	-0.322	0.245
0 (off and no cylindrical lens)	0.239	0.245

Table 3: Stability values for different currents on the RBA module in the ring cavity.

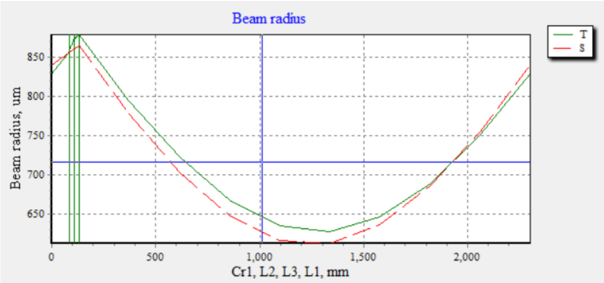

Figure 5: Beam radius through the ring cavity with thermal lens caused by a 17 A current through the RBA module. Red is vertical axis, green is horizontal axis.

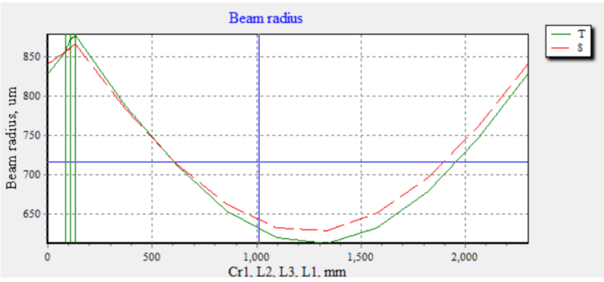

Figure 6: Beam radius through the ring cavity with thermal lens caused by a 16 A current through the RBA module. Red is vertical axis, green is horizontal axis.

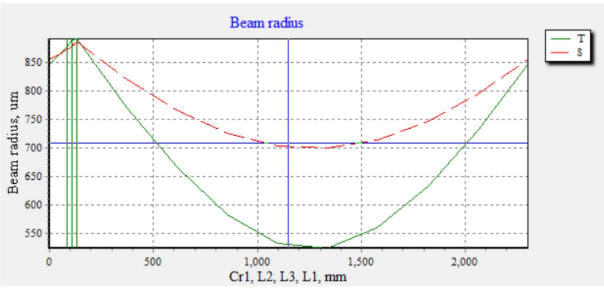

Figure 7: Beam radius through the ring cavity with the RBA turned off. Red is vertical axis, green is horizontal axis.

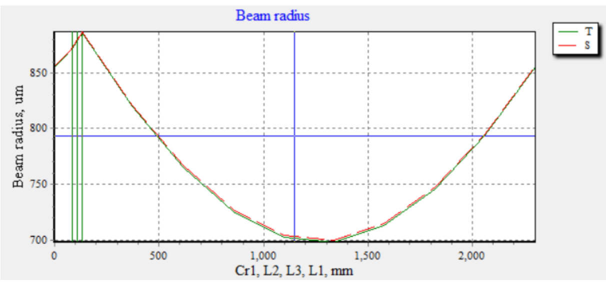

Figure 8: Beam radius through the ring cavity with the RBA turned off and with the cylindrical lens taken out. Red is vertical axis, green is horizontal axis.

4 Cavity Layout Drawings

The cavity was drawn so that it fits on a 450x900mm breadboard, which will fit on the optical table with the rest of the system, once it is moved in the front end. The two drawings can be found in Figures 9 and 10 in the appendix.

The approach used for the standing wave cavity model was to bend the path of the beam through the cavity, using two mirrors at 45^o. The beam is lined up through the Faraday isolator with fiber collimator and M1. To line up the injection into the cavity, M2 and M3 can be used. There is also enough space on the breadboard for diagnostics, but the layout has to be modified.

The ring cavity is laid out in such way that it has a perimeter of 2m and has enough mirrors to line the beam up onto the polarizers and laser head. The collimator and the first mirror after it line the beam up onto the Faraday isolator, and the next two mirrors line the beam up onto the polarizer at the top. The beam is ejected through the polarizer at the bottom. The cylindrical and spherical lenses are placed as close to the laser head as possible. Space has been allocated for diagnostics to the left of the laser head.

5 Discussion

The standing wave cavity can be made more compact, it has less components, and it double passes the YLF rod, decreasing the amount of round trips that the beam has to take to achieve the same energy. However, this limits the distance between the concave end mirror and the RBA, since the pulse must not overlap itself in the YLF rod. This restricts the diameter of the beam through it. The ellipticity of the beam needs to be corrected also, to reduce losses. This cavity can accommodate pulses up to 3.0ns wide. The end mirrors of the cavity have to be custom made, as no optics supplier keeps them in stock.

The ring cavity has a more complex layout, which makes the beam easier to point through alignment sensitive components. The beam is approximately circular, so no adjustments need to be made to correct it. This cavity can also accommodate longer pulses, of up to 5.5ns wide. The 1500mm focal length lens is kept in stock by most optics suppliers, so it is easier to get than the end mirrors for the standing wave cavity. The stability of the cavity also changes less with the current through the laser head, as can be seen from Tables 2 and 3. However there may be more energy leaking out because of the amount of mirrors used.

6 Conclusion

Ultimately, the ring cavity will be built, since it can produce a circular beam on the output, and the optics used to construct it are more readily available. It also requires a smaller angle of incidence on the square lens for the cavity to be stable. Beam radius and stability depend less on the current through the RBA module, which makes it more tolerant to adjustment.

References

[1] R. Paschotta, article on 'regenerative amplifiers' in the *Encyclopedia of Laser Physics and Technology*, 1. edition October 2008, Wiley-VCH, ISBN 978-3-527-40828-3

[2] R. Paschotta, article on 'stability zones of optical resonators' in the *Encyclopedia of Laser Physics and Technology*, 1. edition October 2008, Wiley-VCH, ISBN 978-3-527-40828-3

[3] http://www.rezonator.orion-project.org

[4] T. Critchlow, W. Shaikh, *Modelling and performance of a Regenerative Amplifier Laser Cavity and the rod amplifier chain for the 30J 10 PW CTL pump laser and development of Arbitrary Waveform Generator control software*, 2012

[5] https://librecad.org

[6] https://www.autodesk.co.uk/products/autocad/

[7] https://www.photonicsolutions.co.uk

Appendix

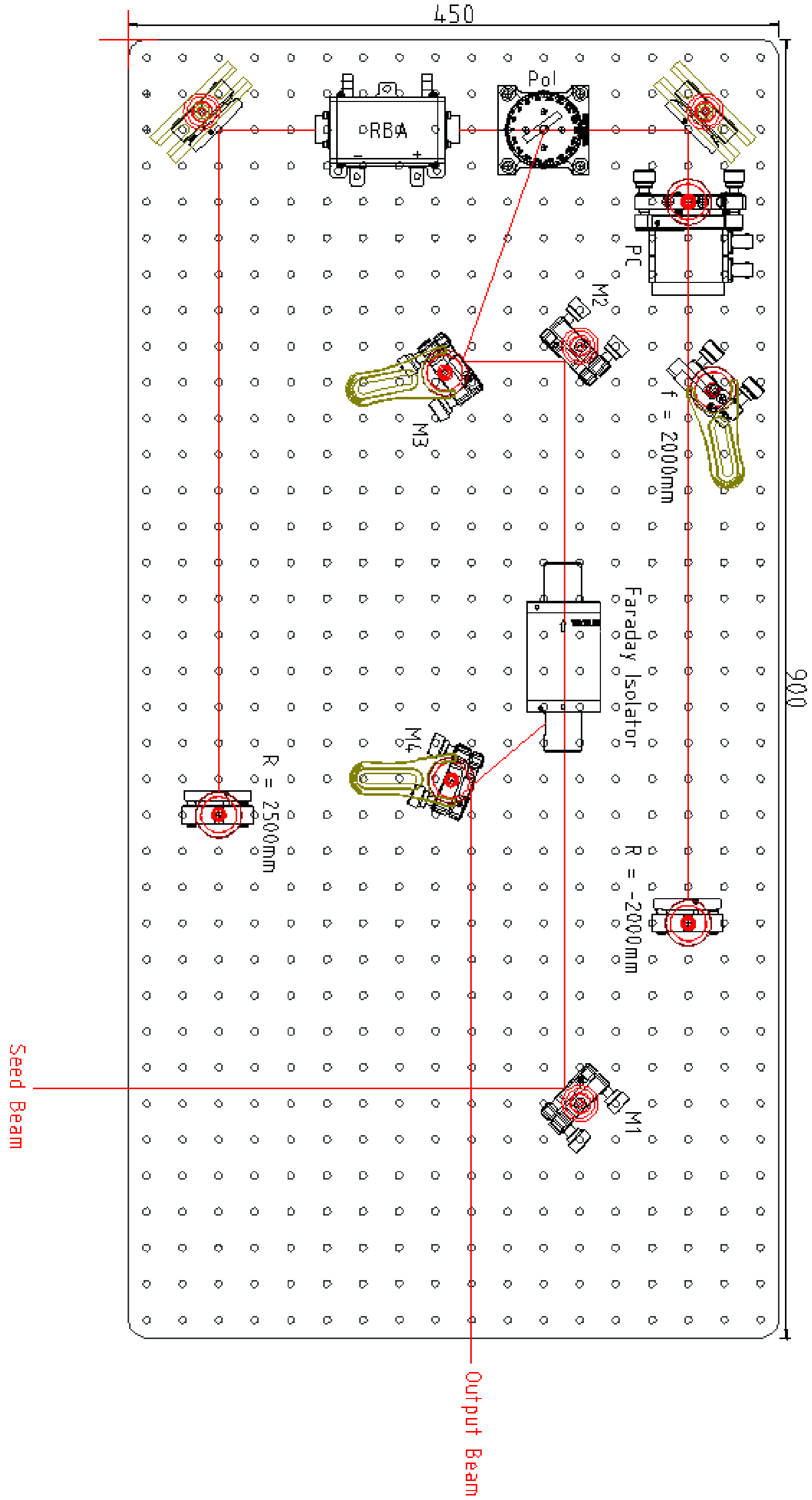

Figure 9: Arrangement of the standing wave cavity on a 450x900 mm breadboard.

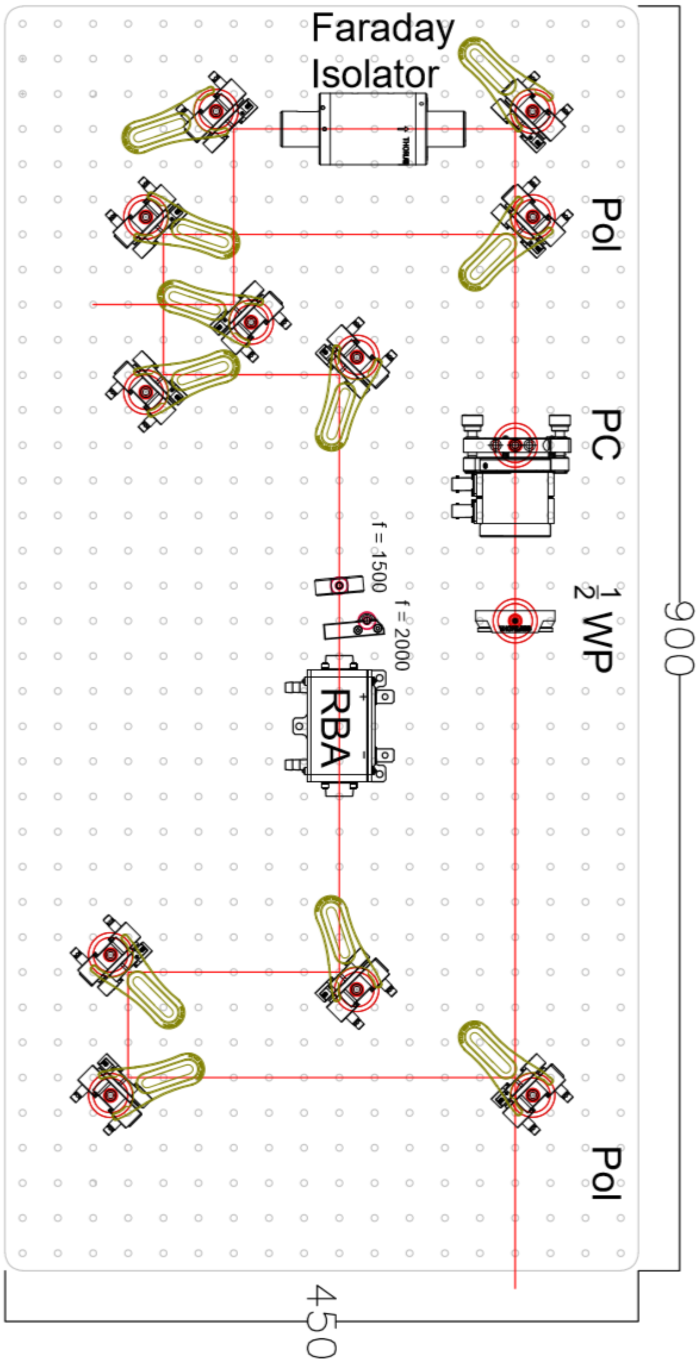

Figure 10: Arrangement of the ring cavity on a 450x900mm breadboard.