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**CTF3-Note-077**

# ON THE REPLACEMENT OF THE ACHROMATS IN A STANDARD BEAM OBERSERVATION SYSTEM AT CTF3 BY FUSED SILICA LENSES

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**Abstract**

Optical transition radiation (OTR) is used routinely for beam profile measurements at the CLIC Test Facility (CTF3). The high radiation level during machine operation demands special attention to the layout of the image acquisition system. In particular, the CCD cameras have to be installed at floor level and thus require intermediate optics to ensure proper imaging of the OTR screen on the CCD chip. For that purpose two achromatic lenses are used, minimizing aberrations in the final image and ensuring a high light level at the position of the camera. However, radiation-induced darkening of the lenses perturbs the operation of the systems and requires regular replacement of the lenses. A possible solution to this problem could be the use of fused silica lenses that are inherently radiation hard.

Here, the present beam observation system (BTV/MTV) is described in detail and compared to an alternative setup where the second achromat is exchanged against a fused silica lens. Measurements in our optical lab compare both solutions.

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## Present Situation

Important points in the determination of the quality of a profile measurement system based on optical transition radiation are its spatial resolution and its dynamic range. While radiation hard cameras can be used even at short distances from the beam, thus minimizing the negative effects introduced by the optical system, their sensitivity is typically limited.

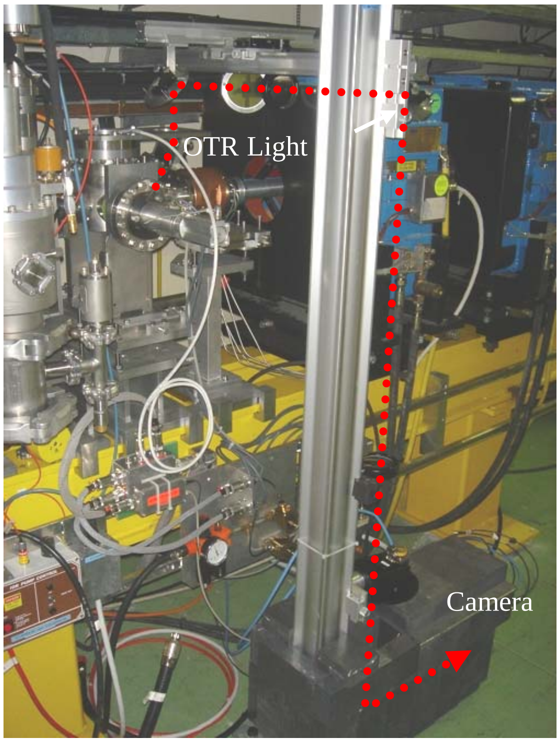


Figure 1: Photograph of the present optical line for the detection of OTR light by a lead shielded CCD camera in the CTF3 linac.

In our case, optical lines consisting of two achromatic lenses are installed at all transverse beam profile monitors to guide the emitted OTR to a standard CCD camera placed at floor level inside a shielding box. With the first achromat installed at a distance of only ~50 cm, this layout guarantees capturing most of the emitted light while maintaining a good spatial resolution. Today, all installations at CTF3 aiming at transverse profile measurements using OTR follow the design shown in Figure 1.

In total, at least four mirrors are installed to guide the OTR light towards the camera. The distances between the different elements slightly vary from one system to another due to spatial constraints. Typical values are given in the following Table 1.

Table 1: Distances between the mirrors in the present MTV systems at CTF3

| Element Description | Distance [mm] |
|---|---|
| Source | |
| Mirror 1 | 440 |
| Lens 1 (#322 278) | 50 |
| Mirror 2 | 410 |
| Mirror 3 | 520 |
| Lens 2 (#322 241) | 810 |
| Mirror 4 | 515 |
| Camera | 330 |

This system was analyzed with the ZEMAX code [i] - a comprehensive software tool for optical design that integrates all the features required to conceptualize, design, optimize, analyze, tolerance, and document virtually any optical system. It contains a huge library of lenses from a variety of manufacturers and allows the in-detail analysis of a specific optical system.

Since the photon yield, i.e. the number of photons created per incident electron is more or less constant with beam energy in our range of operation the main characteristic parameter that changes is the opening angle $\theta_{max}$ of the emitted OTR. It scales as $\theta_{\max} \propto 1/\gamma$ [ii]. Three different energies of the electron beam were considered and the corresponding angle of the emitted light are summarized in
Table **2**.

Table 2: Cone angle of the emitted OTR as a function of the electron beam energy

| Energy [MeV] | Cone Angle [º] |
|---|---|
| 25 | 2.29 |
| 80 | 0.73 |
| 160 | 0.36 |

An overview of the system is shown in Figure 2. Two different achromats with focal lengths of *f=310 mm* (Linos #322 278) and *f=1000 mm* (Linos #322 241) are used for imaging.
The camera objective lens is simulated by a (idealized) paraxial lens since the exact characteristics of the real objective lens are unknown. The final light on the CCD chip is limited by the free aperture of the filter wheel and the diameter of the objective lens. Vignetted rays are suppressed in Figure 2.

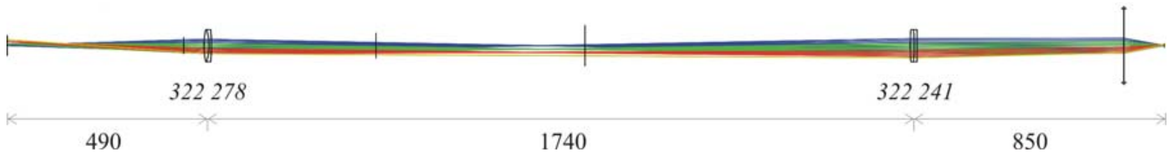


Figure 2: Overview of the optical line as it is presently used at CTF3. Vignetted rays are not shown.

From the given geometrical dimensions, the overall magnification can directly be calculated to be $m=0.18$. The main purpose of the second lens is to reduce the number of vignetted rays considerably. Its effect on the overall magnification is not very large.

## Radiation Damage

One problem of the present lens geometry is the fact that the second lens is located at more or less the same height as the beam pipe, i.e. shower particles resulting from beam losses directly hit and thus strongly damage this lens. *A priori*, this is not a problem as long as the light intensity still remains high enough and no additional aberrations are introduced.

The achromats installed at CTS.MTV1040 were installed in the machine during two year of operation at 1-5 Hz while the lenses at CL.MTV1030 were installed close to a place where the losses are high during three weeks of operation at 33 Hz when experiments with both the linac and the PETS [iii] were done. Photographs of the lenses are shown in Figure 3 and Figure 4. In order to find out about the degrading of the lenses, the light transmission at two different systems was determined by means of a small laser and a photo diode. The results are summarized in Table **3**.

Figure 3: Achromatic lenses installed at CTS.MTV1040 after two years of operation. The second lens (which is located at the same height as the beam pipe) is shown on the right.

Figure 4: Achromatic lenses installed at CL.MTV1030 after three weeks of operation. The second lens (which is located at the same height as the beam pipe) is shown on the right.

Table 3: Measured relative light output for the lenses shown in Figs 3 and 4.

| | **Relative light output [%]** | **Relative losses [%]** |
|---|---|---|
| No lens | 100 | -- |
| New lens | 94 | 100 |
| CLS.MTV0440 lens 1 : 2 years | 67 | 72 |
| CLS.MTV0440 field lens : 2 years | 58 | 62 |
| CL.MTV1030 lens 1 : 3 weeks | 81 | 86 |
| CL.MTV1030 field lens : 3 weeks | 64 | 68 |

Thus at MTV0440 a light intensity reduction of 55.8% during 2 years of operation at 1-5Hz was found, while the light intensity decreased dramatically at MTV1030 by 41.6% during only three weeks of operation at 33 Hz. While the drop in light transmission alone would not necessarily justify a replacement of the elements, the fact that the darkening is not homogeneously distributed over the entire surface, does.

In certain areas, the achromats thus have to be replaced yearly along with the CCD camera that also gets heavily damaged by the radiation. This not only signifies additional costs, but also regular exposure of the personnel to radiation during the intervention and shall be avoided in the future.

## Comparison Between the Two Systems

A detailed comparison of the two different systems can only be done based on actual measurements since neither the characteristics of the fused silica lens are not known in detail, nor the exact properties of the camera objective lens.

To get a first qualitative comparison between the two setups, a test screen with an imprinted regular pattern was used. The screen was illuminated by the ambient light in the room and only a quick alignment of the optics was done, why the image quality as shown in the following Figure 5 is not optimized. The only purpose of this quick test was to get a rough idea whether or not the two systems are somewhat close to another in terms of final image quality.

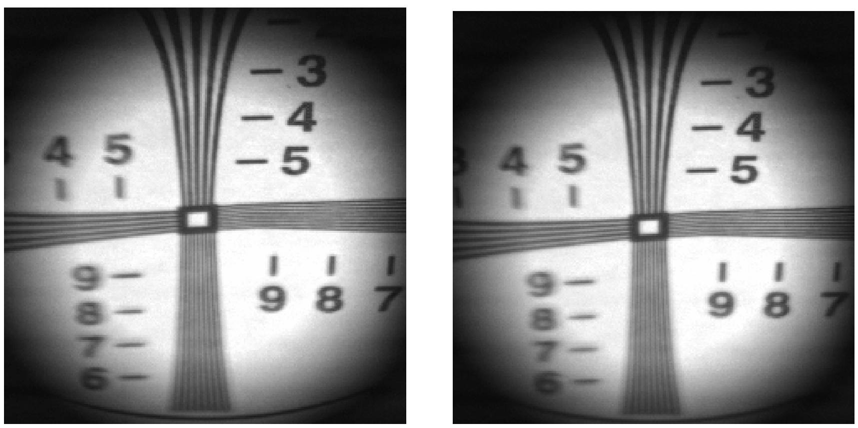


Figure 5: Sample Image observed with a standard setup consisting of two achromatic lenses (left) and with the second lens replaced by a fused silica lens (right).

As can be seen in Figure 5 no immediate differences between the two optics were observed. Thus more quantitative tests were done using a homogeneous Mille Luce M1000 [iv] light source and a test pattern consisting of various slits and circles of well defined sizes, Figure 6.

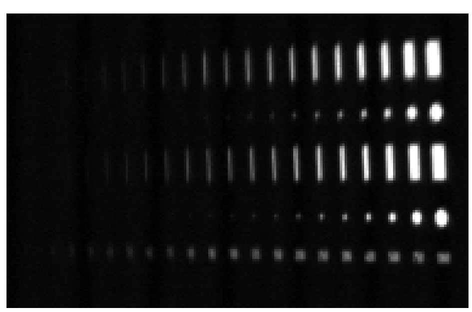

Figure 6: Test screen used for a quantitative analysis of the two setups.

The images were split into four different sections and the diameter of the circular apertures determined. This allowed a direct comparison between the system with two achromats and the one where the second achromat is replaced by a fused silica lens. It furthermore creates an images that resembles to a certain degree to the beam spots observed in the machine.

The following Figure 7 summarizes the analysis and shows that the variation of the determined diameters is very small and below the statistical error for these measurements (4%). Thus a replacement of the achromat at least in areas where a high radiation level can be expected should be foreseen in the future.

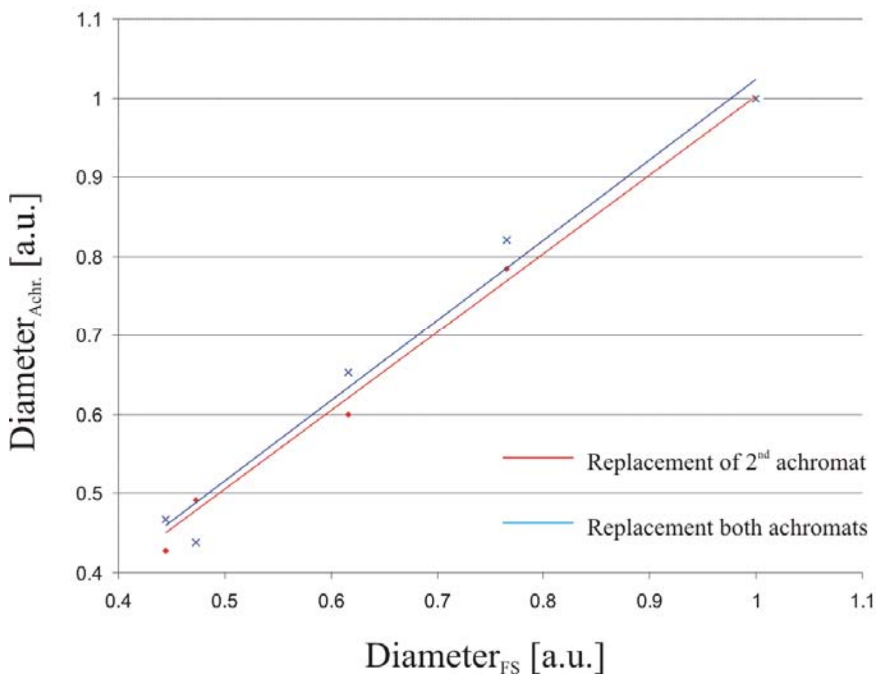


Figure 7: Measured diameters of the test sample for the two considered cases. Deviations are always below the 4% level and are found in positive and negative direction.

It was also tried to replace both achromats by fused silica lenses but the resulting deviations reached the 10% level and were thus too large for the envisaged measurements.

## Conclusion

High radiation levels in some sections of CTF3 required regular replacement of the used achromatic lenses and thus lead to additional costs and interventions in these critical machine areas. Fused silica lenses proved to be a possible solution to that problem. Despite the wavelength dependence of their index of refraction, aberrations in the final image are reasonably low in a way that the present performance of the system can be guaranteed after a substitution of the second achromatic lens.

## References


[i] http://www.zemax.com

[ii] L. Wartski,"Etude du rayonnement de transition optique produit par des électrons d'énergie 30 à 70 MeV. Application aux diagnostics de faisceaux de particules chargées.", Thesis at the Université de Paris-Sud (1976)

[iii] I. Syratchev," 30 GHz High Power Production for CLIC", Proc. Int. High Energy Density and High Power RF Workshop, Kalamata, Greece(2005)

[iv] http://www.stockeryale.com/i/foi/products/mille_luce.pdf