MAST YAG Thomson scattering upgrade alignment system[a)]

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The recent upgrade to the MAST YAG Thomson scattering while enhancing the diagnostic capabilities increased the complexity of the system. There are eight YAG lasers now operational, doubling the number from the previous setup. This means alignment between each laser individually and reference points is essential to guarantee data quality and diagnostic reliability. To address this issue an alignment system was recently installed. It mimics the beams alignment in MAST by sampling 1% of the laser beam that is sent into a telescope which demagnifies by a factor of 8. The demagnified beam is viewed with a CCD camera. By scanning the camera the profile and position of the beams in the scattering zone and in a range of several meters inside MAST can be determined. Therefore alignment is checked along the beam path without having to sample it inside the vessel. The experimental apparatus and test procedures are described. [doi:10.1063/1.3475377]

I. INTRODUCTION

The YAG Thomson scattering diagnostic has been a central scientific tool in the scientific operation of MAST.[1] The latest upgrade allows a more flexible operation while providing increased data quality.[2] Several features were improved with a new 130 spatial points core system now operational, up from the 19 previously existing ones. The number of Nd:YAG lasers was doubled from four to eight. Given that each laser runs at 30 Hz the total diagnostic repetition rate is now 240 Hz. The capability for burst mode operation, where the lasers are fired as close in time as needed, is enhanced with the increase in the number of lasers.

As the new system has grown in complexity laser alignment has became a critical control parameter. If the YAG lasers are not aligned between themselves, the collection optics and the fibers, density profiles from laser to laser will differ. Therefore in order to compare data from different lasers proper alignment must be maintained in time.

The basic tools used to check and monitor laser alignment are HeNe alignment lasers. Each YAG laser has a corresponding HeNe which follows the same flight path. As the HeNe wavelength is inside the visible part of the electromagnetic spectrum visual checks in the MAST area can be performed to confirm proper laser alignment. This kind of alignment check is not possible during MAST operations and relies on good alignment between each YAG laser and the corresponding HeNe.

To enhance data quality, maintain calibration, facilitate alignment testing, and optimize the diagnostic, an alignment system was designed and installed. This system is located on the lasers flight path just before the MAST vessel. There a fraction of the YAG lasers (<1%) is sampled and characterized. This is done by sending the laser beams through a telescope that demagnifies by a factor of 8. Subsequently an image is acquired by a CCD camera. By scanning the camera the profile and position of the beams in the scattering zone and in a range of several meters inside MAST can be determined. Using this method alignment is checked along the beam path without having to sample it inside the vessel. A feature of the system is that control and data acquisition can be performed remotely during operations when due to safety reasons area entrance is not possible.

II. SYSTEM DESIGN

The alignment system, shown in the schematic in Figs. 1 and 2, is positioned on the flight path of the laser beams just before the Brewster window which the beams go through to enter the MAST vessel.

In order to be able to image both the alignment HeNe laser and diagnostic YAG, a selective filtering system was included in the conceptual design and implemented. Therefore after the beamsplitter the first two elements that block excess light are a neutral density filter and a YAG mirror. The YAG mirror blocks mainly the YAG beams, with most of the YAG light reflected, without reducing significantly the HeNe beams energy. The YAG light which is reflected by this mirror is directed to a calorimeter. For control proposes the power of this fraction of each laser beam is measured. The total energy per beam is inferred using this data.

The following set of components form a so called Keplerian or refracting telescope which is at the core of the concept of this laser alignment tool. Such a telescope consists of two positive lenses, i.e., both focal distances ($f_1=150$ mm and $f_2=19$ mm) are numerically positive,

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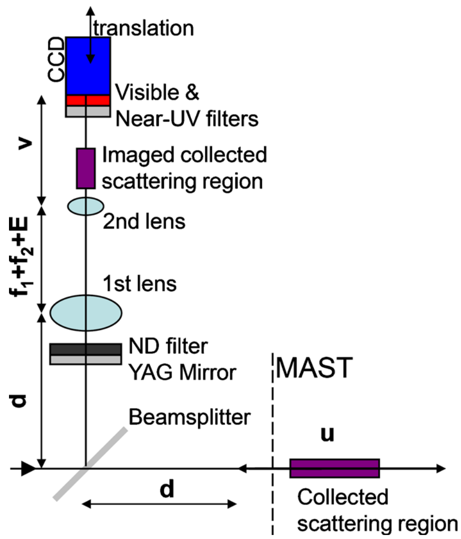

FIG. 1. (Color online) Diagram of the alignment system showing all the optical components, focal, and other optical distances. The scattering region with a length of ~1.5 m corresponds to an interval of ~25 mm after the telescope.

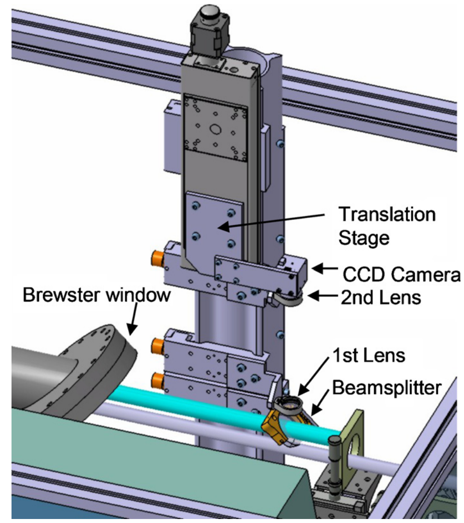

FIG. 2. (Color online) Schematic of the alignment system on the laser flight path just before the MAST vessel Brewster window. The beamsplitter intersects the YAG beam and samples vertically part of it (<1%).

which are set up sharing a common focus. Therefore the lenses are separated by an interval equal to the sum of both focal distances.

Two lenses combined in such a way form an afocal system, i.e., a parallel beam of light incident on such a system emerges from it as a parallel beam. The laser beams incident on the system are focused at the common focus by the first lens and emerge as a parallel beam from the second. Given that the first lens has a longer focal length than the second lens, the system works as a beam reducer. The demagnification is a necessary condition for the system to operate so that the set of beams (width ~ 27 mm; height ~ 7 mm) can fit onto the CCD chip (width—6.5 mm; height—4.9 mm) used to image it. The beam transverse demagnification ratio (M) if the system is afocal is constant and is given by f_2/f_1 hence being independent of the position. (The transverse demagnification for the implemented system is 0.127.)

The longitudinal demagnification of the system is also independent of the position and is the square of the transverse demagnification. This means that after the telescope there is a demagnification both longitudinally and transversely of what will occur inside the MAST vessel. Therefore the position after the telescope that corresponds to a well defined point in the MAST vessel can be shown to be given by Eq. (1),

$$v = f_2 + \frac{f_2^2(f_1 - u)}{f_1^2}. \tag{1}$$

If the lenses are not set apart exactly by a distance equal to sum of the focal lengths that difference (E), which is shown in Fig. 1, must be taken into account. If that is the case the equations that characterize the telescope and thus the alignment system are

$$M = \frac{E(f_2 - v) + f_2^2}{f_1 \cdot f_2}, \tag{2}$$

$$v = f_2 + \frac{f_2^2}{\frac{f_1^2}{(f_1 - u)} + E}, \tag{3}$$

where v is the position after the second lens and u is the position inside the MAST vessel, measured from the equivalent distance from the beamsplitter to the first lens (d=60 mm) onward as shown in Fig. 1.

Chromatic aberration impacts the ability to set up the lenses with the exact separation and thus affects the performance of such systems. For the lenses that were chosen the sum of the focal lengths differs by ~830 μm between the HeNe and the YAG wavelengths. This value should be used as the correction factor E in Eqs. (2) and (3).

The image acquisition is performed by a camera mounted on a translation stage both remotely operated. By scanning the camera using the translation stage the profile and position of the beams in the scattering zone and in a range of several meters inside MAST are determined. To protect the camera from the beams energy and to guarantee data quality, a set of filters is directly mounted on it. One filter lets the visible and near-UV to be transmitted while blocking most of the light at the YAG wavelength (1064 nm). The other filter transmits the HeNe wavelength while block-

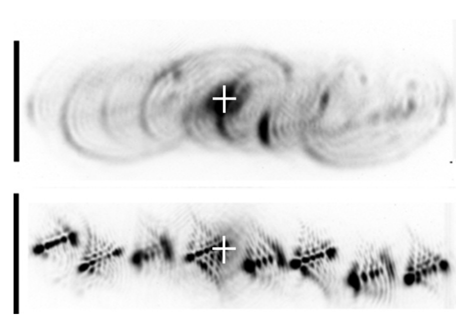

FIG. 3. The eight YAG laser positions are compared to the reference laser diode. The top image corresponds to the outboard limit of the scattering region and the bottom one to the inboard. The center of the reference diode laser is indicated by the cross. For both images the real dimension is approximately 7 mm in height and 27 mm in width.

ing shorter wavelength visible light to reduce noise. This setup balances the initial power of the beams, higher for the YAGs (>10 W) and lower for the HeNe (<10 mW), allowing for both lasers to be acquired at the same time by the camera.

A laser diode mounted near the MAST vessel, aligned with respect to collection optics and fibers, is used as a stable reference. In Fig. 3 the YAG lasers in the outboard and in the inboard are compared with the diode reference laser.

III. DATA AND RESULTS

The alignment system was implemented, tested, commissioned, and operated successfully in support of MAST scientific campaigns. The alignment obtained is consistent with both alignment visual checks and data gathered from an optical fiber alignment system.

A second alignment testing tool is based on a split fibers technique. In this system each fiber is dual, which means it is composed by two bundles of fibers. The bottom fiber has in its field of view the upper half of the scattering region on that point. The upper fiber views the other half. The fiber bundles from these upper and lower regions have different lengths. The subsequent delay in one of the signals is used to differentiate bottom and top of the fiber at arrival in the spectrometer. The two optical fiber lengths are 30 and 45 m, respectively, giving an optical delay of ~90 ns. Each fiber bundle consists of 130 individual fiber strands, is circular at the spectrometer end, and rectangular at the collection lens end. The rectangular fiber bundle is 13 fibers wide by 10 fibers high. In the two split bundles the top five and bottom five rows travel different paths allowing the relative up down ratio of the laser beam intensity to be determined.

In Fig. 4 data obtained by the split fibers are presented. After acquiring the data from the upper and lower part of the fiber bundle, the ratio between the two signals is calculated. If the intensity of signal is similar on the upper and lower parts of the fiber bundle, that means the beam is centered and so half of it is acquired by the bottom part of the fiber and the other half by the top part of it, hence the system is aligned.

One of this dual fiber bundle is positioned to acquire data from the outboard of the plasma and another is positioned in the inboard. Therefore the alignment is checked on the two edges of the scattering region allowing to infer the laser alignment through it. During the MAST 2010 scientific campaign, with the Thomson scattering upgrade fully commissioned, operational data from both systems were checked exhaustively and the systems retained coherence throughout this period of time.

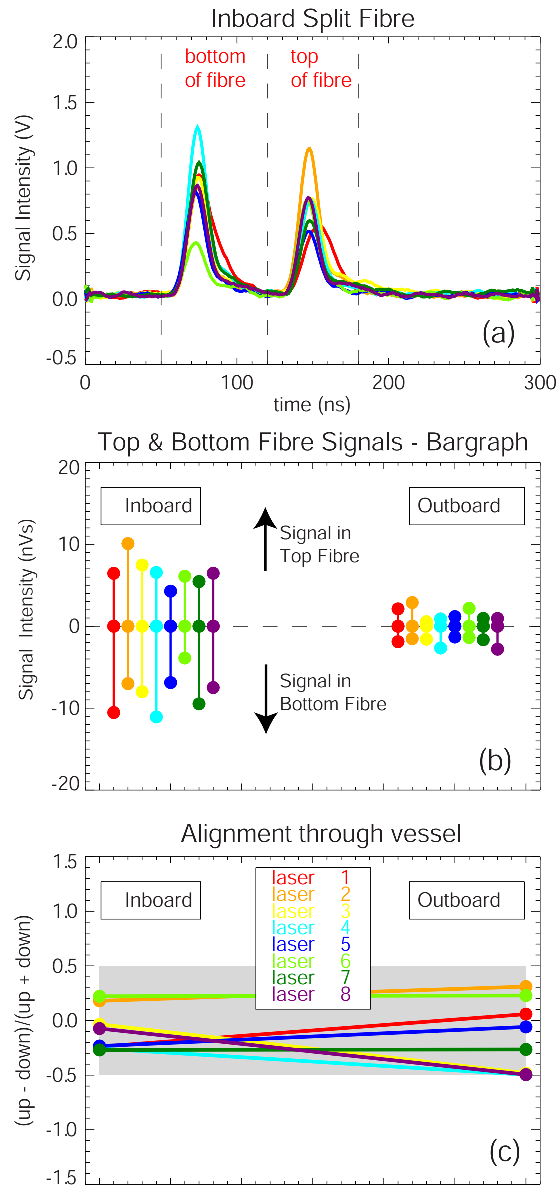

FIG. 4. (Color online) Alignment split fiber data and analysis. (a) Scattered signal for all lasers on both the upper and the lower parts of the split fiber. (b) Signal intensity displayed as a bar graph. (c) Alignment through the scattering region inferred by the position measured by the split fiber both on the inboard and on the outboard.

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