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Upgraded Alignment Control For The DIII–D Thomson Scattering Laser System

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Abstract-The Thomson scattering system measures electron density and temperature with the aid of eight pulsed ND-YAG lasers on the DIII–D Tokamak. DIII–D is the United States National Fusion Facility for magnetic confinement fusion experiments. The Thomson system probes the tokamak in three separate regions. The measurements from the different regions produce density and temperature profiles during plasma discharges. The laser light must be aimed through the DIII–D vessel with 1 mm of spatial accuracy to produce correct density profiles. Recent upgrades to the alignment system reduce the effort required to perform the initial alignment before plasma operations, and improve the monitoring and control of the alignment. The upgraded hardware allows for monitoring and control of the alignment from the Thomson control room during operations and from multiple key locations along the 35 m long optical path. In future upgrades the adjustment of the mirrors will be automated by utilizing feedback from a computerized beam analysis system that relays beam position information to the control computer. The newly established methods for setting up the YAG beams using the CCD cameras instead of burn paper offer a faster and more reliable method to prepare the system for plasma-operations. The YAG lasers are aimed with repeatable accuracy and any drifts can be detected and corrected during the small warm up period before each shot.

I. INTRODUCTION

The Thomson scattering system [1] is one of the main diagnostics on DIII–D. It measures the electron temperature and density profiles of the plasma with photon scattering of an intense pulsed laser by the free electrons in the plasma [2]. The Thomson system has expanded from one to three paths [3] through the tokamak to extend the measurements to previously unprobed regions of the plasma. Fig. 1 shows the Thomson system configuration.

II. THOMSON SYSTEM BRIEF DESCRIPTION

The Thomson room is outside the DIII–D neutron-shield. It houses the eight pulsed ND-YAG laser modules [4], their power supplies and cooling units, the laser firing control system, the data acquisition computer, and the operation and monitoring control consoles. The room is equipped with air-conditioning units that provide a thermally stabilized environment to the optical components. The eight laser modules are mounted on a heavy and stable table thereafter called the laser bench (LB). The laser beams traverse a network of tubes and mirrors and finally enter into the vessel through a narrow baffle tube attached to the vessel. Six meter focal length biconvex lenses converge the beams in the

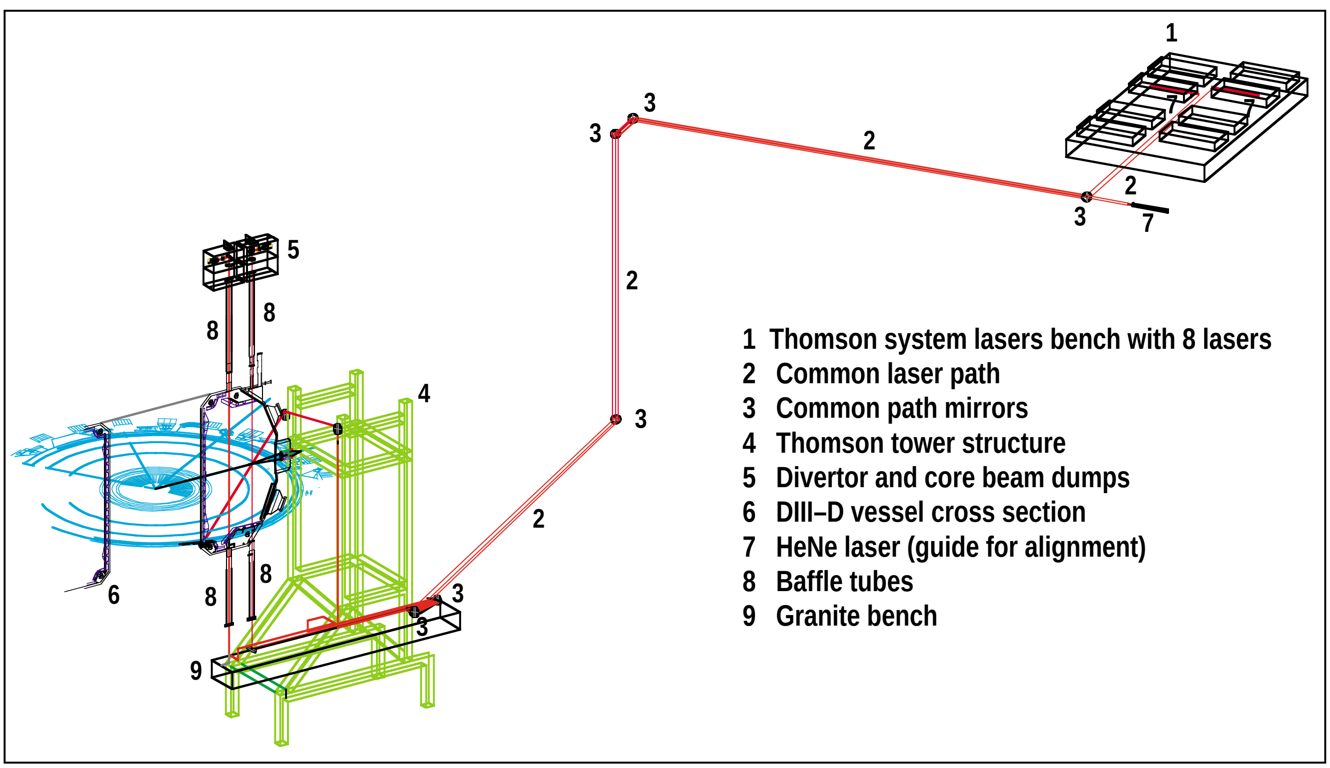

Fig. 1. Overall Thomson system architecture.

desired probe regions where the scattered photons will be viewed (Fig. 2). The Thomson tower holds the scattered photon collection-optical assemblies. The scattered photons come through the equatorial port R-0 and a port at a higher elevation called R+1. The scattered light is focused on to an array of fiber-optic cables that carry the light to the polychrometer [5]. The end cross section of each fiber is 1.5 mm x 3 mm. The DIII–D vessel and the Thomson tower rest on a large block of concrete that is supported by long concrete pillars driven down to the bedrock below the site. The Thomson tower acts as a stable platform for the laser optics and the collection lens since it isolates them from vibrations during plasma disruptions. The Thomson tower supper-structure is designed with electrical breaks to minimize eddy currents that could deflect it and throw the collection lens out of alignment. The divertor collection-optical setup is mounted on the Thomson tower and overlooks the plasma through a port located at a lower port called R-1. The central and core system share the same viewing port (R-0) but with separate fiber optic cables and holders added to the photon collection assembly. Each YAG laser has a motorized mirror mount located on the LB and serves to pack the beam in a specific pattern and to align the YAG beams relative to the guiding HeNe beam. The packing pattern helps the YAG lasers to get through the entrance baffle and through the exit baffle tube. The YAG lasers beams are arranged in a two by four matrix with one cm separation, which is as close as possible to pass through without overlapping or hitting the edges of the baffles inside the baffle tube. The overall beam path is 30 m long. The expansion from one system to three systems required the eight YAG lasers be split into three groups, with laser 7 assigned to the divertor system, lasers 2, 3, 4 to the central system, and the remaining four to the core system. To split the beams into three separate paths, two pick-off mirrors are placed on the stable platform [granite bench (GB)] below the DIII–D machine. The packing mirrors on the LB direct the appropriate beams to the pick-off mirrors [4]. An additional set of mirrors and a lens guide the beams into the baffle tubes. Larger diameter mirrors are required to handle the wider beam pattern on the common optical path to the GB.

Vibrations, temperature fluctuations along the beam path, and pointing instabilities of the lasers can cause the lasers to drift out of alignment. The Thomson lasers are outside the DIII–D pit and the light has to traverse through a network of tubes and mirrors mounted on various parts of the building before reaching the Thomson tower and the granite bench. During the course of the day the different parts of the building slowly drift in relation to each other due to temperature changes. In addition, the inherent pointing instability of the YAG lasers compound the alignment problem. If not corrected, any misalignment significantly affects the accuracy of the density measurement. As a result, systematic laser-to-laser variations can be observed on the measurement among YAG beams in the same pack.

To correct the beam drift, a network of motorized-mirrors was introduced on key points on the granite bench for each path. By monitoring the image of the alignment reference HeNe beam at the two relative reference points, the beam can be realigned by steering just two mirror mounts for each laser path. To correct for the YAG beam drift the operator periodically follows an alignment procedure and the YAG packing mirrors are adjusted for proper beam positioning.

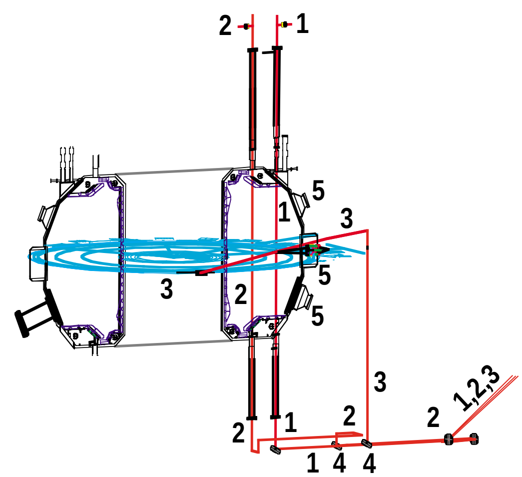

Fig. 2. Laser paths traversing three different plasma regions inside the DIII–D vessel.

III. THE BEAM-POSITION REFERENCE MONITOR NETWORK

Two absolute reference points are defined by the centers of the input and output baffles of each system. The original Thomson system had two quadrature detector photodiodes and analog electronics to determine the beam position. The scheme was plagued with problems such as voltage drift due to thermal effects and did not offer a direct indication on the state of the alignment. The quadrature detectors were replaced with CCD cameras. To monitor the alignment of the guiding HeNe beam, two relative references are established with CCD cameras on the stable platform. These relative reference points are mapped to the absolute references with a network of leaky mirrors, lenses, filters, and crosshair reticles. Fig. 3 is a simplified illustration of the beam monitoring and position control system. The HeNe beam passes through the back of the leaky mirrors, illuminates a cross-hair reticle and the image is focused onto the camera's CCD chip via the lens. NG and KG filters attenuate the light to the range of the camera. The set of NG and KG filters balance the huge difference in light intensity between the HeNe and YAG beams. A third camera monitors the beams at each exit point on the DIII–D vessel in a similar fashion. The central Thomson beam path is a special case and terminates inside the DIII–D vessel. The signals from the three exit cameras are used as a check during the initial setup.

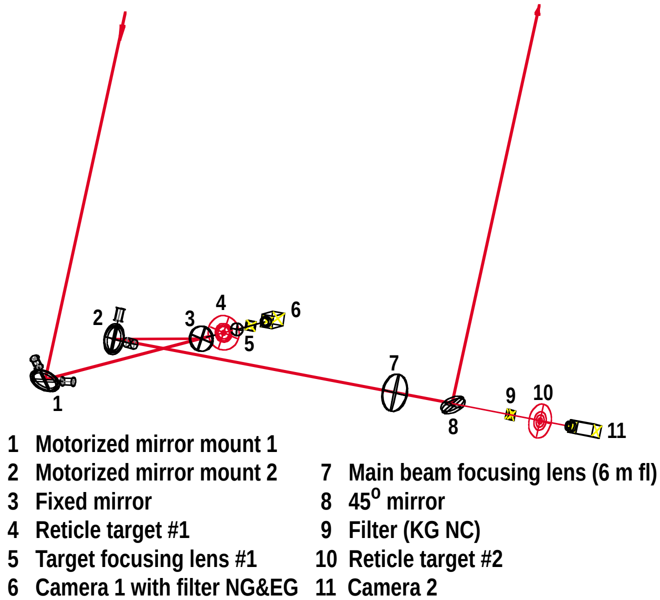

Fig. 3. Simplified illustration of the beam monitoring and position control system.

IV. THE BEAM POSITIONING CONTROL NETWORK

In the first few years of operation of the new systems (divertor and central Thomson), the new optical mounts installed downstream of the pick-off mirrors did not have motorized capability. In 1999 we added two motorized mirror mounts for each of the new systems. Six new stepper motor controllers were built to accommodate the upgrade. These controllers were connected to a PC via a serial port and a special program was developed to send commands to them. These controllers allow for correction of the HeNe alignment laser, by moving these motorized mirror mounts. The Divertor and Central optical paths also required two additional HeNe guidance lasers, one for each system. In order to make the alignment easy these new HeNe lasers were installed inside the designated YAG laser units. Laser 7 is the only assigned laser for the divertor system and a HeNe laser was installed in laser 3 to mark the central system beam path. The installation of the HeNe beam inside lasers 3 and 7 mandated the necessity to have a motorized and adjustable mirror mount for making the YAG beam relative to the HeNe beam collinear. The final YAG turning mirror mount of laser 3 and 7 was modified to accept two miniature piezoelectric motors to allow for fine two-axis far field position control 35 m away. A special piezo electric controller from New Focus (model 8732) was used to achieve control of the final turning mirror mounts. The controller was connected to a PC via the serial port and a special program was developed to allow for control of each mirror mount. A PC is used to periodically check and adjust the relationship between the HeNe and YAG lasers during operations. An STD bus-based stepper motor currently manages the eight packing mirror mounts. Plans are under way to replace the STD bus-based controller with the same type of controller currently used for the HeNe laser alignment by 2002.

V. INTEGRATION OF THE ALIGNMENT MONITORING AND BEAM POSITIONING CONTROL SYSTEMS

The complexity of the Thomson system and the 1 mm accuracy requirement demands that fine adjustments be made on mirrors at multiple locations through out the system. Multiple reference target video images must be available on the local display monitor while these adjustments are being made. This means that a video distribution and routing network is needed for the CCD cameras. In addition it is desirable to direct any of the motorized mirror mounts from a set of convenient locations via remote control. The solution was to utilize a distributed network of embedded micro-controllers that follow the same communication protocol. Since the four new stepper-motor controllable mirror mounts are distributed at various locations along the laser path, a stepper motor controller module was implemented to allow it to be remotely controlled via an IEEE-485 inter-connection scheme. To achieve this we used the stepper motor controller module (MN100) from Micro-kinetics Corporation. This setup can be expanded easily by connecting additional IEEE-485 devices at any location along the laser path. Five custom devices were built to have remote control capability like the MN100: a video switcher, a HeNe beam laser shutter controller, and three identical remote controllers. With the aid of these remote controllers a person can move mirrors, select video signals, and shut on or off the desired HeNe beams. The remote controls were installed at key locations i.e. the granite bench, the Central path entry port at 105 degrees, and at the beam exits for Core and Divertor. The network of IEEE-485 control-devices can also be commanded from a special program that resides on a PC in the Thomson room.

The upgrade includes stepping motor controllers for the six motorized mirror mounts. The six two axis mirror mount micro-controller units were built with commercial modules from Mikro-kinetics Corporation. This company has a product line which is specialized in stepper motor drivers. These controllers are designed to communicate via the IEEE-485 protocol and was chosen to be the base of the automated alignment system. The MN100 controller utilizes a serial character command and reply scheme for communication when connected on the IEEE-485 bus and other similar devices. The IEEE-485 uses a differential voltage to send the information. The immunity to noise is ideal for the noisy environment and long cables in our system. The video switching device contains an embedded micro-controller that controls a special video switch chip. The unit, when commanded, selects the desired video signal from many cameras in our system. The chosen output signal is routed through a single video cable laid along the optical path of our system for viewing from multiple monitors. In the DIII–D pit, there is at least one monitor next to each remote controller. There is also a farm of nine monitors in the Thomson room so that all the signals from all video cameras can be observed simultaneously from the Thomson control helm.

VI. ALIGNMENT CONTROL AUTOMATION PLAN

The system is to be automated for operation with minimal supervision. The ultimate goal is to make the alignment sub-system be controlled by the Thomson main computer. The alignment main control process will have the task of continually adjusting the mirrors based on values obtained from a beam analyzer and specific cameras observing the guidance HeNe beams (HeNe feedback). Prior to a DIII–D shot cycle, the YAG lasers go through a warmup phase and start lasing 20 s before the plasma discharge. Due to thermal pointing instability of the YAG lasers, the beams drift slightly but become stable before the shot starts. The shot lasts between 3–8 s and at present the lasers are turned off at the end of the shot. The plan is to extend the lasing period beyond the shot's end to capture position information for each YAG laser beam. By capturing the images from the reference cameras the position information can then be used to correct the effects of any alignment drifts. Between shots the alignment operation will be repeated to maintain the alignment.

To achieve feedback control, the output of the video router is connected to a frame grabber to capture the HeNe and YAG images from the reference beam position monitoring cameras. If any deviation is detected from the desired position the motor controllers can be commanded to compensate accordingly.

One of the future enhancements of the system will be the integration of the alignment control computer's software with the Thomson master operation control program. The beam analyzer is an essential part of the system. Its software in particular needs flexibility and communication capability. We chose the package from Spiricon (LBA 400). It offers intercomputer communication via GPIB and can become a slave of the control computer. Other desirable features include capability for background subtraction from multiple cameras, and an intuitive user interface. The gain setting for all the system's cameras will be calibrated so the YAG beam intensity can be monitored as well as HeNe and YAG beam positions.

VII. A NEW YAG ALIGNMENT PROCEDURE

The recent upgrade improves the YAG laser beam alignment. Instead of a burn paper, CCD images are used to align the eight YAG beam positions. The camera allows the operator to perform YAG beam alignment during plasma operations as well as during the initial alignment setup. The alignment monitoring system allows the operator to check the alignment during the shot and make adjustments afterwards. Once the guiding HeNe beam has been aligned, each individual YAG beam can be aligned to the HeNe using the packing mirror. The operator follows a special alignment procedure on the control computer console allowing each YAG to be lasing by itself in turn while all others only flash. Each Laser's YAG image on the CCD camera is used to guide the laser to its proper position during the procedure. This method is faster and more reliable than the burn pattern method and has been tested throughout operations last year.

VIII. CONCLUSION

This new alignment system is operational. By incorporating the IEEE-485 communications scheme, a modular design, for various components that are spatially distributed, can be achieved. Through computer control in the Thomson room or by any of the three special remote controllers in the pit, the Thomson operator has the ability to look at the video signals from all the CCDs and move the motorized mirror mounts at any point along the laser path. This reduces significantly the time and effort needed to complete the daily initial alignment. The new hardware also provided us with a set of tools that can be used to troubleshoot the system from the operator's console. The quality of the Thomson data has been improved due to the new alignment controls. The newly adopted YAG alignment procedure has resulted in less systematic variation in the density measurement among lasers. The beams are positioned with much better accuracy and confidence than before. The YAG lasers are aimed with repeatable accuracy and any drifts can be detected and corrected during the small warm up period before each shot. An effort to automate the YAG and HeNe alignment using feedback from the alignment monitoring system is planned for 2002. The system will be designed in such a way as to require minimal operator supervision.

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