Automatic beam alignment system for Astra, first stage

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Introduction

The new front end of Astra [1,2], in particular the part between the 1kHz preamplifier and the first amplifier, comprises very long optical path lengths, it is distributed over two optical tables and parts of the beam path are at heights of up to 0.5 m above the table. These factors are detrimental to the stability of the beam alignment and make it prone to be affected by temperature drifts. Therefore this section of the laser chain was chosen for the deployment of the first part of an automatic beam alignment system.

A prototype of this automated feedback system was developed off-line prior to the installation.

Setup

The principle of the system is illustrated in Fig. 1. The beam positions are monitored by digital CCD cameras which use standard CCTV lenses to image a certain plane in the beam through the back of an HR mirror. The software controlling the system calculates the centroid positions of the acquired images. If a deviation from the predetermined setpoint values is detected, the beam is steered back by means of motorised actuators fitted to mirror mounts located upstream from the cameras.

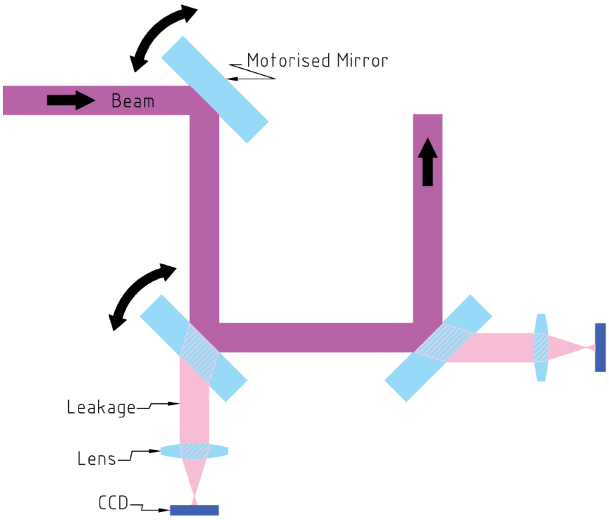

Figure 1. Principle of automatic beam alignment system.

Fig. 1 shows a system which consists of only two sensor/actuator units, but this principle can be extended in order to control the beam positions at many rather than only two reference points. To have the units operating in pairs ensures that the downstream beam path after such a pair is then fully defined, both in terms of position and direction. For applications where the beam pointing direction is more important than the beam position, a far field rather than a near field image can be used, i.e. the beam is focused onto the sensor, or, in other words, the plane that is imaged onto the sensor is at infinity. The hardware components used for sensors and actuators are shown in Fig.2, which is a photograph of a part of the installed system. The sensors are digital CCD cameras (Marlin F033B, Allied Vision Technologies) with an IEEE1394a/FireWire interface. The actuators are piezo driven fine pitch screws (Picomotor, New Focus).

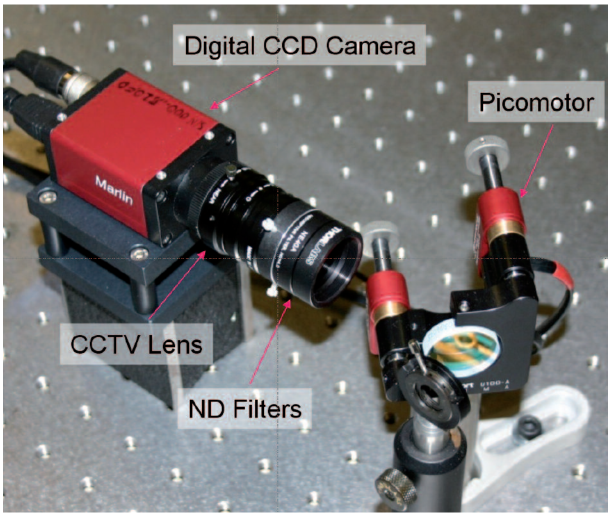

Figure 2. Hardware components of the automatic alignment system.

Digital cameras were chosen because they are easier to interface (A/D conversion happens inside the camera; power, data readout, and camera control use a single cable); they provide additional information about the beam profile; it is easier to assess if the beam "is actually there"; and because the active area can be adapted to the beam size by choosing a region of interest (ROI) in the control software. Picomotors were preferred to other actuators like stepper motors or piezo stacks because of their compactness; their relatively low cost; and the fact that they hold their position when powered off and that they show no creep.

Fig. 3 shows the locations of the five cameras and motorised mirror mounts which have been installed so far. The locations were chosen such that the beam is kept on a defined path after coming onto the table, when passing through the stretcher and when entering the first amplifier.

The software controlling the system is written in LabView 7.1 and runs on a standard PC under Windows XP. The control software acquires the camera images, calculates the centroid beam positions inside a certain ROI, compares these positions to pre-determined setpoint values and finally applies the necessary corrections to the Picomotors. The set of corrections for all motors are calculated as the product of a vector containing all measured deviations and a control matrix. This matrix-based approach enables all corrections to be carried out at the same time rather than having to carry them out sequentially, mirror-by-mirror. The control matrix is the inverse of the response matrix, which contains the deviations induced on all cameras by moving each motor by a unit amount. With the 5 sensor/actuator units currently installed, 10 parameters (5 horizontal and 5 vertical positions) are actively controlled, which means that the control matrix contains 10x10 elements. A screenshot of the software's user interface is shown in Fig. 4. Shown on the front panel are the image data from all cameras (provisions were made for the addition of a 6th camera), a time series graph of the measured position deviations, and the magnitude of the Picomotor motions applied during the last iteration.

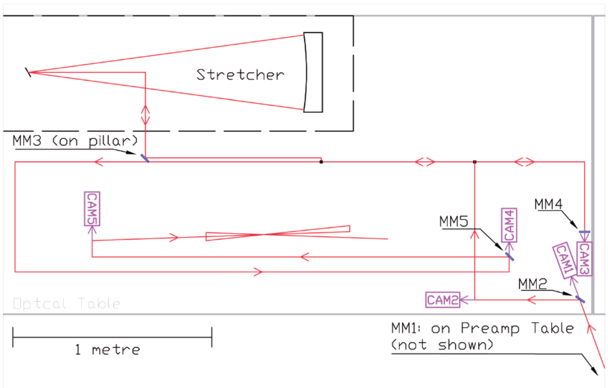

Figure 3. Layout of optical table showing locations of motorised mirrors (MM) and cameras (CAM).

Results

There are two main purposes to the alignment system. The first is to bring the beams back to their set positions after switch-on of the laser system and hence to speed up the set-up procedure. Fig. 5 shows graphs of the beam positions and Picomotor motions after switch-on on a particular day. It can be seen that some spots are initially displaced by a considerable amount, corresponding to several beam diameters. After 5 minutes, all displacements are corrected. This rather slow response is mainly due to the slow update rate with which the images are acquired. Optimising the control software and using a different FireWire interface card should bring about a considerable improvement in the future. It is furthermore possible to reduce the amount of averaging and damping that is applied in the software if large deviations are detected. After the initial approach, no more significant deviations are usually detected during the day.

The second purpose is to compensate mechanical drifts and keep the beam positions stabilised during laser operations. As said before, the alignment system achieves this very well and it is interesting to analyse what corrections need to be applied for this purpose. Fig. 6 shows the corrections applied to one particular mirror over the course of a day. It is obvious that a strong correlation with the room temperature exists and that one direction is much more strongly affected by temperature drifts. The magnitude of the corrections is quite significant: starting from a well aligned beam, a movement of 150 steps by the motor under consideration already leads to noticeable clipping of the beam and a drop in pulse energy by 30 % after the next amplifier stage.

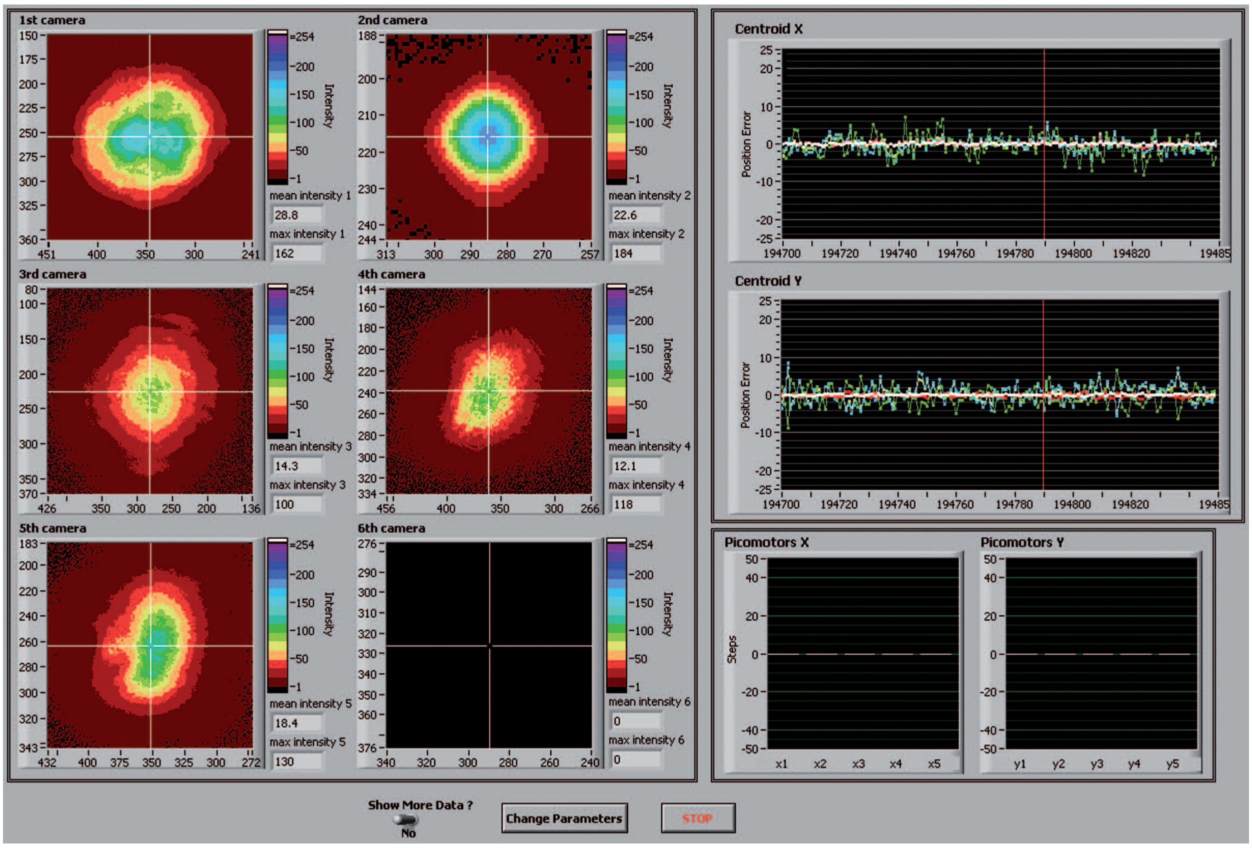

Figure 4. User interface of control software.

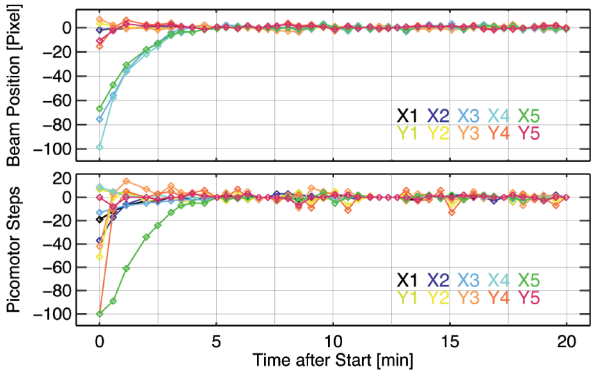

Figure 5. Deviations of beam positions (upper panel) and applied Picomotor motions (lower panel) after switch-on of the laser system.

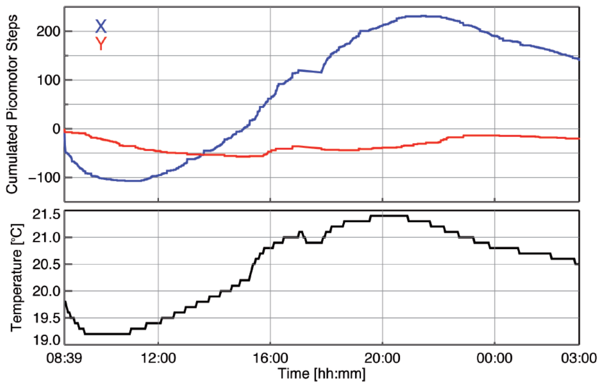

Figure 6. Upper panel: Distance travelled by the motors on one particular mirror during the course of a day; lower panel: room temperature in laboratory.

Conclusion and Outlook

The automatic control system has greatly improved the stability and consistency of the system performance and has also reduced the need for operator intervention. Added benefits are that the cameras provide information about the beam profile and could be used to monitor the energy. It is planned to extend this system throughout the whole Astra Gemini laser chain.

References

1. A. J. Langley, K. Ertel, E. J. Divall, J. M. Smith, C. J. Hooker and J. L. Collier, *CLF Annual Report*, RAL-TR-2005-025, 214, (2005)
2. A. J. Langley, K. Ertel, E. J. Divall, J. M. Smith, O. V. Chekhlov, C. J. Hooker and J. L. Collier; *New Front-End for the Astra Gemini Project*, CLF Annual Report, (2006)