JET-P(93)62

Recent Developments in LIDAR Thomson Scattering at JET

P Nielsen, C Gowers, B Schunke, Yu Nizienko[1].

JET Joint Undertaking, Abingdon, Oxon, OX14 3EA, UK.
[1] The Troitsk Institute for Innovation and Fusion Research, Moscow, Russia.

Preprint of a paper to be submitted for publication in the Proceedings of
6th International Symposium on Laser Plasma Diagnostics,
Bar Harbor, Maine, USA, 25–28 October 1993

ABSTRACT

The principle of LIDAR Thomson Scattering has proven a valuable tool at JET. In connection with the new pumped divertor at JET we are installing a new LIDAR scattering system to diagnose the divertor plasma. The new system requires better spatial resolution than the present system and will therefore make use of a streak camera for detection. A streak camera can be used over a shorter measurement range. Recent experiments in the plasma edge were conducted to verify this technique. One of the weaknesses of the present system has been the relatively low repetition rate. Two new ruby lasers with higher repetition rate will be employed in the JET LIDAR scattering systems in the future. Particular emphasis will be put on describing the laser using Stimulated Brillouin Scattering for pulse compression. The implications for ITER of our experience with the JET LIDAR scattering systems are discussed.

INTRODUCTION

The LIDAR Thomson Scattering System has proven to be a very reliable tool, routinely providing simultaneous electron temperature and density profiles measurements at JET [1]. The technique especially lends itself to large devices with difficult access because of the back-scattering geometry. This means that only one access path is needed and alignment between laser and collection optics is simplified. The spatial resolution δl of a LIDAR system is given by,

$$\delta \ell = c / 2 * (\tau_{\text{laser}}^2 + \tau_{\text{det}}^2)^{1/2} \tag{1}$$

where c is the speed of light and τ_{laser} and τ_{det} are the width of the laser pulse and the combined response time of the detection system respectively. Using a ruby laser pulse of 300 ps pulse width and MCP photomultipliers coupled to fast transient recorder with a combined detection response time of 750 ps we have a spatial resolution of 12 cm. Software enhancement reduces the spatial resolution to 9 cm. The laser used in the main LIDAR scattering system typically generates a 20 s burst consisting of 3 Joule laser pulses every two seconds. The system has operated for several years with better than 97% reliability/availability.

Changes in the JET plasma typically occur on a time scale of a fraction of a second. It would therefore be desirable to have a system operating at something like

10 Hz. Even though the general profile features are well described by the present resolution there are certain cases when a better spatial resolution is required. We have demonstrated 5 cm spatial resolution at the outer edge of the plasma using a streak camera as detector [2]. To diagnose the new divertor plasma at JET we are installing a new LIDAR scattering system using the same streak camera.

New lasers are now installed for both LIDAR systems. The characteristics of both laser systems are described.

DIVERTOR LIDAR SYSTEM

DESCRIPTION

A layout of the new divertor LIDAR system is shown in fig. 1. A line of sight passing through the X-point was chosen. The line is closely following the ridge of the inner divertor plasma. By scanning the line of the scattering volume with respect to the plasma we should be able to make measurements throughout the divertor plasma. The length of the scattering volume is restricted to approximately 75 cm (5 ns on the streak camera) , which in principle allows simultaneous measurements from the X-point to the target point. By choosing a different time window we can alternatively select the region ahead of the X-point. This will potentially allow measurements of the SOL plasma. In the SOL plasma parameters change slowly along field lines. Because of the shallow angle between the laser beam line and the flux lines the effective cross field spatial resolution is significantly improved.

The access to the divertor region is unfortunately such that we have had to place optical components inside the torus vacuum both to guide the laser and to collect the scattered signal.These components not only have to survive the hostile plasma environment but also have to be able to withstand 400 ^{0}C during vessel baking. A number of dielectric coating were tested during one day of operation in JET. These tests and subsequent vacuum baking test did not identify a satisfactory coating choice. Instead we have chosen to use a special uncoated fused quartz prism to guide the laser beam and rear surface silver mirrors for the collection optics. The silver is protected by an overcoat of Al_2O_3.

The optical components are remotely controlled. The mirror adjusters are linked through special double bellow wobble-stick drives and long universal joint driveshafts to stepper motors on the main horizontal port. The laser and detectors are in the roof-laboratory outside the biological shield.

CHOICE OF DETECTOR

One difficulty for a LIDAR system is the high étendue normally required by the detection system, which in turn determines the size of the detector area. The exact étendue required depends on the length of the scattering volume and the available strength of the scattered signal. In the main LIDAR system this precludes the use of a streak camera. However, in the divertor plasma the region of interest is much smaller and the density is sufficiently high that we can restrict the light gathering power.

With the given access we are limited to an F/20 collection system. By focusing the laser to a pencil beam of 7 mm diameter in the scattering region it is possible to obtain an unvignetted region of 50 cm length when collecting light from a 2 cm diameter detector image area. In order to image the scattering volume onto a 1.5 mm diameter spot on the streak camera this immediately translates into F/1.5 optics at this point.With a sweep rate of 90 ps/mm and a sweep length of 50 mm and a laser pulse width of 300 ps we get a spatial resolution of 5 cm and a scattering length of ~70 cm.

Recent measurement using 1/6th of the main LIDAR collection system has proven the viability of the technique. Fig 2 shows an example of these measurements with a pellet entering the edge region of the plasma. The 5 cm resolution is clearly achieved. With the lower light gathering power we also proved the necessity for having a reasonable plasma density. At lower density levels we would still have 5 cm resolution of the raw signals. However, the resolved scale lengths of temperature gradients are longer when error bars of the fits are considered.

SPECTROMETER

The modest collecting power allows a relatively free choice for the spectrometer. With the large variation in temperatures in the divertor region ranging from 10 eV to 1 keV we have opted for a simple grating spectrometer.Using a 1200 lines/mm grating we disperse a 100 nm band (600-700 nm) onto the slit of the streak camera. The resultant spectral resolution is ~10 nm allowing measurement down to 10 eV if we can use the spectrum near the laser line. Using a highly doped ruby filter we have in the past successfully rejected light in a 4 nm band around the laser line. This technique is incompatible with the grating spectrometer. A holographic notch filter with a 10 nm notch width has been tested. An optical density of greater than 10^4 was measured when illuminating the filter with a ruby laser under the appropriate conditions. The transmission outside the rejection band was > 80%.

Scaling from the streak camera measurements of the plasma edge we know that the signal level is adequate. The laser energy and the collection efficiency are similar for the two experiments. The density in the divertor region is generally expected to be somewhat higher.

THE LASER

In order to get the best spatial resolution we would obviously like to have as short a pulse as possible with several joules of energy. In practice, however, we have to transport the laser pulse to the scattering volume. Given the present system we find a practical limit close to 1 Joule in a 300 ps pulse. The laser used in this diagnostic was built from an existing long pulse q-switched laser. Using Stimulated Brillouin Scattering phase conjugation and pulse compression techniques this laser was converted to give 300 ps pulses at 1 Joule [3]. A layout of the complete laser is shown in fig. 3.

The laser consists of an oscillator and two amplifiers. The oscillator is passively q-switched, producing single longitudinal, single transverse mode pulses of 25 ns duration. This pulse is amplified by two amplifiers with the polarization planes oriented orthogonally to each other. The polarization of the beam is rotated through 90^{o} by a quartz rotator. This minimises the cylindrical lensing which otherwise occurs in a ruby amplifier. The amplified beam is sent into a compression cell. The compression cell returns a 1.2 ns beam which is again amplified by the two amplifiers to an energy of ~ 3 Joule. Faraday isolators are used to deflect the return beam into the second compression stage and to isolate the oscillator. The second compression is completely passive, yielding final pulses of 1 J with pulse durations between 200 - 300 ps. The compression cells works through SBS as fast moving phase conjugate mirrors.

The laser currently operates at 1.5 Hz repetition rate using the original power supplies. We plan to upgrade the supplies to twice the charging rate. We do not expect to have to make significant changes to operate at 3 Hz.

MODIFICATIONS TO THE MAIN LIDAR SCATTERING SYSTEM

The main LIDAR scattering system remains virtually unchanged. We intend to make some small changes to the spectrometer to improve the performance at the low temperature end, i.e. at the plasma edge. The present lowest temperature the system can measure is 200 eV. Changing the channel dividing point between the two channels nearest the laser line we expect to be able to measure down to 100 eV.

THE 4 HZ LASER

The main change to the existing LIDAR scattering system is the new 4 Hz ruby laser. The laser is build on the same principles as the old laser, i.e. a single pulse out of a mode-locked pulse train from the oscillator, followed by a number of amplifiers. To reach 4 Hz operation the specification of the maximum output energy was reduced to > 1 Joule per pulse. The final amplifier consists of two alternating 16 mm diameter rods operating at 2 Hz. The laser beam is passed through vacuum pinholes between amplifiers to reduce the non-spherical distortion of the thermal lensing. The cylindrical lensing is kept to a minimum by applying different levels of pumping in the c-axis plane and in the perpendicular plane of the rods.

The old laser is operated intermittently with the new laser. The two lasers are combined into the same beam path by a polarizer. The polarization of one laser is rotated through 90^o by an electromagnetic TGG-crystal Faraday rotator after the combination to make the resultant polarization the same.

CONCLUSIONS AND PROSPECTS FOR LIDAR ON ITER

Even though LIDAR Thomson scattering is only used at JET we regard the technique as having achieved maturity. We have successfully made a number of improvements and are installing new systems taking advantage of various developments in technology. We have shown the ability to regularly and reliably measure profiles over long paths with a spatial resolution of order 10 cm and using a streak camera over limited lengths with 5 cm resolution.

With the much larger plasma dimension on ITER we regard the longer spatial resolution as adequate allowing the use of large area MCP photomultipliers. Depending on the choice of laser wavelength MCP detectors with better response towards the infrared could be useful, e.g. Ga-As. Even though shorter laser pulses are more difficult to generate than the pulses required for conventional Thomson scattering we have nevertheless available ruby lasers build on different principles which already operate at several Hz. Other lasers could be used using fundamental frequency and/or frequency doubling. Techniques are available for frequency shifting. With the laser development currently taking place in other fields we expect an adequate choice of lasers for the purpose of developing a LIDAR scattering system for ITER. The main problem in designing such a diagnostic is the question of access and choice of materials and coating for the components facing the highest neutron flux. Additional research is required in this area.

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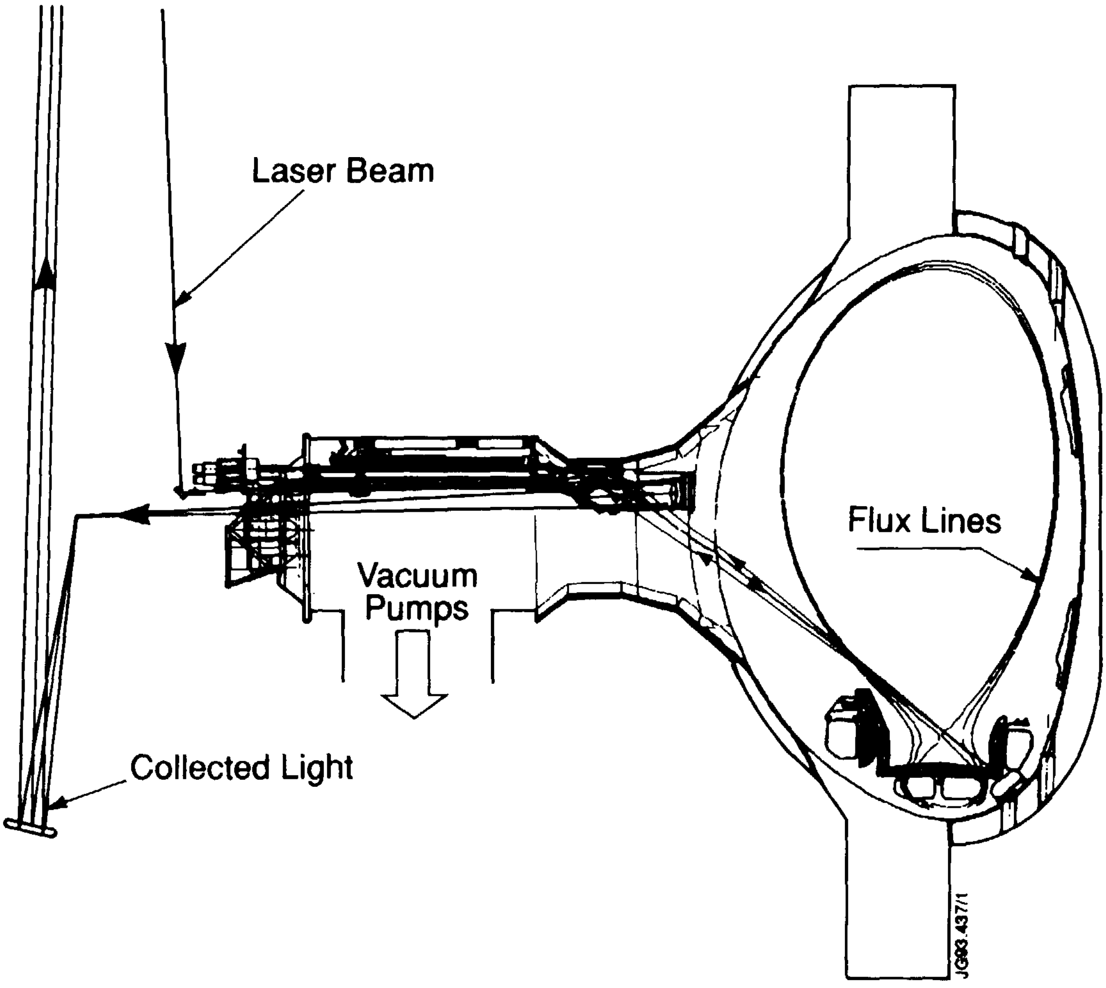

Figure 1: Layout of new Divertor LIDAR System. The laser beam line is indicated relative to the flux lines calculated for a 6 MA plasma.

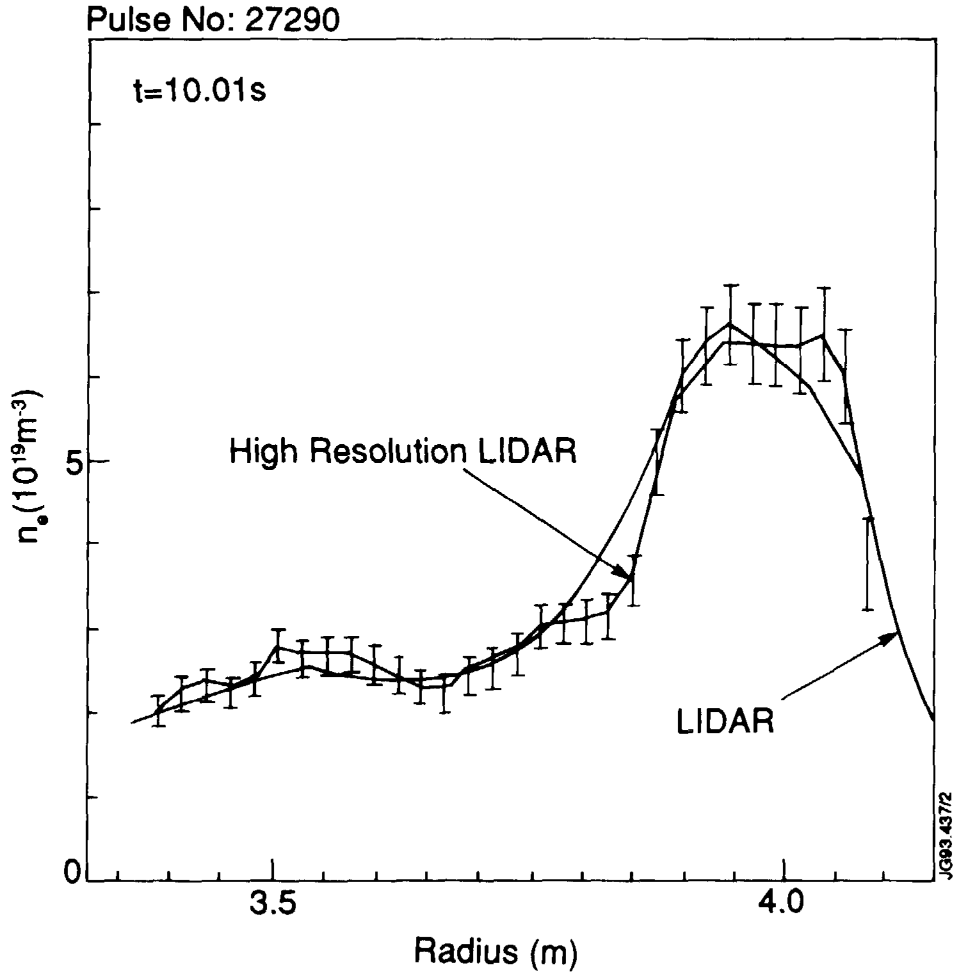

Figure 2: Density profile at the plasma edge in a pellet fuelled discharge. Comparison is made between the high resolution system to the profile from main LIDAR system

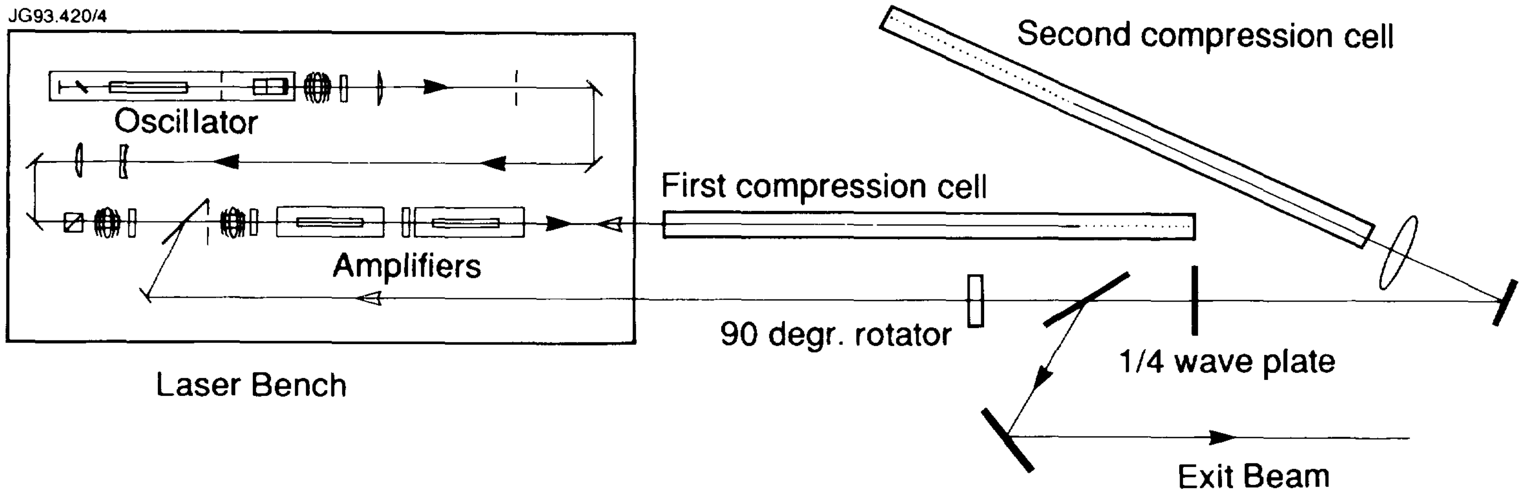

Figure 3: Layout of pulse compression laser showing the two SBS pulse compression cells.