Electromagnetic pulse suppression in laser plasma interaction experiments on the Vulcan Petawatt laser

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Introduction

Recent work[1)] has shown that a large electromagnetic pulse (EMP) can be generated within the Vulcan Petawatt[2)] target chamber and a combination of measurements and calculations have yielded field strengths of $H\sim5Am^{-1}$ and $E\sim5kVm^{-1}$. This can be problematic for experiments where sensitive electrical equipment is placed inside the target chamber, since the cables required can be several metres in length and are vulnerable to large voltage and current impulses.

During a recent experimental collaboration between Imperial College and AWE, investigations into petawatt laser-cluster interactions[3)] were carried out. The cluster source consists of a cryogenically-cooled solenoidal gas jet (Parker Hannifin Corporation Series 99)[4)], which is driven by an externally-triggered pulse generator (IOTA ONE). Recent petawatt experiments on *unclustered* gas targets have shown that the drive electronics for these jets can be damaged by the EMP and gas jets have been pneumatically operated in an attempt to overcome this problem. Cluster production, although well characterised using a solenoidal valve[4)], has not been investigated using such a source and it is therefore necessary to overcome the EMP by other means.

Experiment and Development

The extent and timescale of EMP were not well known at the time of our experiment, and so a modular system was used, incorporating several different suppression techniques.

The final design is shown in Figure 1. Gas filled surge arresters (SA), which break down above a certain threshold voltage (90V, 230V and 350V devices were used here) and rapidly (over a few ns) short circuit, were used in series with high voltage diodes in order to prevent the triggering of the SAs by the gas jet driver pulse, which would hinder the performance of the cluster source. Also incorporated into the device was a forward-reverse biased zener diode pair. The impedance of the array is dramatically lowered when the voltage applied exceeds twice the zener voltage and current is allowed to flow. A 10kΩ potentiometer was added in series to trim this threshold to an appropriate level, within the limit allowed by a fixed 220Ω resistor (not shown), which was also included in the chain. Other components added were 100pF capacitors, chosen to shunt the high frequency EMP spike to earth, and damped inductor electromagnetic interference (EMI) suppressors (RS part number 239-084), placed between the modules along all three connections.

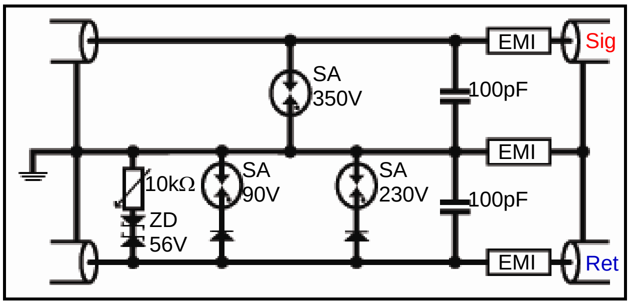

Figure 1. Circuit diagram of a suppressor module showing components: Zener diodes (ZD), Spark arresters (SA) and EMI suppressors. The signal (Sig) and return (Ret) lines are also shown.

The EMP suppression system consisted of two identical modules, one situated close to the gas jet, but outside the target chamber, and one close to the gas jet driver. These were linked together and to the driver box via two shielded coaxial cables and the final module fed through the target chamber wall to the gas jet via a single isolated BNC feed-through.

The testing phase was split into two stages. Prior to the petawatt experiment, a prototype was tested using time-resolved Rayleigh scattering to assess cluster formation[4)]. The optical probe laser used was a frequency doubled Nd:YLF mode-locked oscillator with average power ~ 25mW and λ=527nm. This was focussed at ~f/100 a few mm below the gas jet and light scattered at ~90º was collected at ~f/3 and imaged onto a PMT. The scattered signal, S_{RS}, scales as $S_{RS}\propto\sigma_R n_c$, where σ_R is the classical Rayleigh scattering cross-section and n_c is the cluster number density[5)]. Since σ_R is a function of cluster radius and refractive index, which are governed by the nozzle and gas parameters, it should ideally be unaffected by the presence of the EMP suppressor. Therefore the measurement of S_{RS} provides a comparison of n_c, and hence the performance of the cluster source, between suppressed and unsuppressed operation.

The final devices were also tested *in situ* by monitoring the voltages on the gas jet driver signal and return terminals using a 500MHz digital storage oscilloscope connected via two high impedance probes.

Results and Performance

The results of the initial testing phase are shown in Figure 2. The scatter signal is unaltered on the rising edge, but the tail is slightly stretched by the presence of the EMP suppressor, suggesting a modest reduction in jet closing speed. This is of minor importance, since the increase in the opening time, $t_{open,}$ is only marginal and this should not affect the laser-cluster interaction provided that the peak of the scatter signal is timed to coincide with the laser.

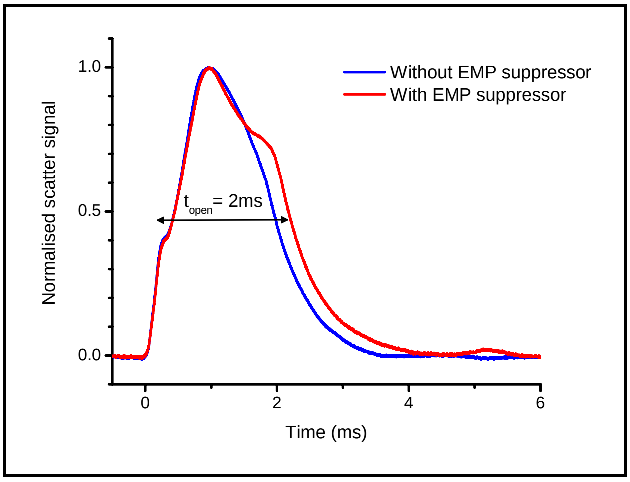

Figure 2. Time resolved PMT signal of light Rayleigh scattered by ~30nm Argon clusters (P~50bar, T~160K) produced by a jet with t_{open}=2ms.

The effect on the trailing edge of the drive pulse can also be seen in Figure 3. From Figure 3(a) there is a large (>1kV) spike in the return cable due to the back EMF induced as the solenoid closes. This triggers the gas-filled SAs, as can be seen from the electrical noise that occurs *after* t_{open} in Figure 3(b), and the voltage is immediately shorted to earth.

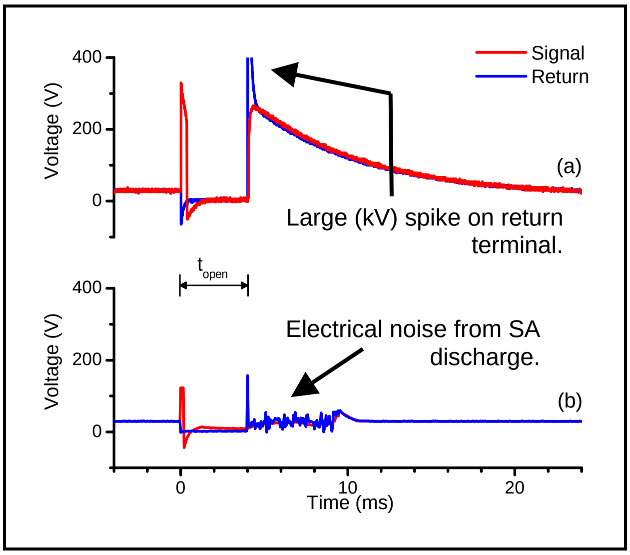

Figure 3. Signal and return voltages for a gas jet (P~60bar) without (a) and with the suppressor system (b). The former has t_{open} = 4ms and the latter is a trace with t_{open} = 2ms with the time axis doubled for comparison. The return line SAs in (b) are triggered by back EMF shown in (a), which is induced in the solenoid as the jet closes.

The initial 300V spike in Figure 3(a) in the signal line is not a consequence of back EMF, since it also occurs when the gas jet is replaced by a 1kΩ load resistor (not shown). This spike does not trigger the signal SA, since the voltage applied is just below its threshold. However, from Figure 3(b) this spike has been reduced by the EMP suppressor, and this is probably due to the 100pF/EMI low pass filter. Larger capacitors were tested in the development phase to further reduce this peak and seemed to hinder the gas jet's opening. It is possible that this large voltage is necessary for the initial acceleration of the solenoid against the high pressure gas and should therefore be tolerated by the EMP suppressor.

Conclusion

The success of the EMP suppressor can ultimately be demonstrated by the survival of the gas jet driver throughout multiple petawatt laser shots, including the first petawatt shot ever recorded on the Vulcan system5). Although it was not possible to fully characterise cluster production using the modified source, data3) from the petawatt experiments have shown interesting phenomena that strongly suggest that clusters were successfully produced by the modified source.

The continual development of laser-plasma physics into regimes of ever-increasing intensity brings with it new technical complexities and problems. Here we have demonstrated successful suppression of the electromagnetic pulse created during petawatt laser plasma interactions. This may be of particular importance when designing plasma physics instrumentation for similar ultra-intense laser systems.

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