26C7 LIFETIME STUDIES OF AN e-BEAM SUSTAINED CO_2 LASER FOR SPACEBORNE DOPPLER WIND LIDAR

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INTRODUCTION

The European Space Agency programme for Development of a CO_2 Laser for Spaceborne Doppler Wind Lidar Applications (Reference 1) addresses both performance and lifetime aspects. Lifetime issues are of particular importance due to the 10^9 pulse life requirement for a spaceborne laser operating continuously at 10Hz for a period of three years. Such a lifetime is very demanding, being one to two orders of magnitude greater than has been achieved for a laser of this type. Earlier phases of the programme led to the selection of e-beam sustained laser technology; particularly critical lifetime issues were identified as the electron transmitting metal foil separating the electron gun and the laser, and the gas life. Investigations to both foil and gas lifetime issues are described in the following sections.

FOIL THERMAL PROFILE

The foil in an e-beam sustained laser fulfils two roles which are largely conflicting. It serves as the vacuum seal between the laser, at about one atmosphere pressure, and the gun, at approximately 50μbar, which requires high mechanical strength. It must also provide good transmission for electrons, which requires a thin foil of low atomic number. A compromise is arrived at whereby the combination of the thin foil and its support structure provides a transmission of around 10% but is thick enough to withstand both the one bar pressure differential and the superimposed 0.7 bar pressure pulse produced by the discharge.

The mechanical strength of the foil is dependent on temperature. As the foil will heat up due to absorption of some electrons, this must be taken into account, particularly at a high pulse repetition frequency.

A method for characterising the temperature of the foil and support structure has been developed, using a pyroelectric vidicon with video recording. The vidicon camera was positioned directly above the electron gun, with ZnSe lenses to focus on to the foil. This technique provides temporal resolution of order 100μs, spatial resolution of order 1mm and thermal resolution about 0.5°C.

After a careful calibration procedure, a series of foil materials were tested at conditions expected to be representative of the prototype laser operating at 10Hz. Conventional materials tested were 15μm titanium, 25μm aluminium, 94.5% Ti/3% V/2.5% Al alloy of 6μm and 12.5μm thicknesses. Testing was also performed on clad metals comprising the two thicknesses of alloy coated with a 10μm aluminium layer using an unbalanced magnetron sputterer.

Generally, the titanium and titanium alloys reached a maximum temperature 100°C above ambient, whereas the aluminium and aluminium clad foils rose to about 40°C above ambient. These values were used as inputs to the experiments and analysis in the following section.

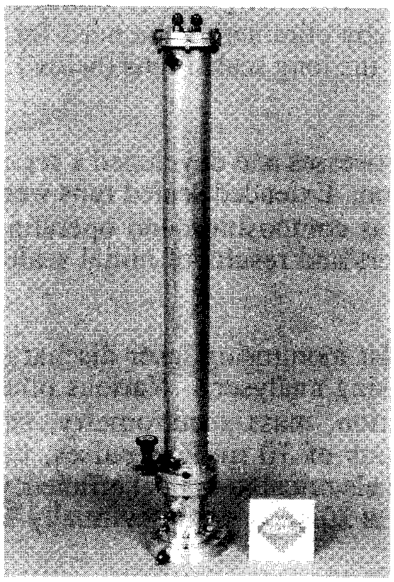
HIGH TEMPERATURE FOIL FATIGUE

The principal potential failure mode for a foil is expected to be fatigue due to the successive pressure pulses produced by the laser discharge.

Fatigue tests at room temperature have been previously carried out under contract to Lockheed Missiles and Space Company, in support of the NASA LAWS programme (Reference 2). For this work, a simulator was designed and built to mimic the pressure pulse generated by the laser, but operate at much greater pulse repetition frequencies. The simulator was mounted on a powerful vibration testing machine, which vibrated in a vertical direction at frequencies of up to 4kHz. As the equipment moves upwards, so does the column of liquid contained in the upper section, supported by the horizontal foil The force required to move the liquid is provided by the foil, which is thus subjected to an equal and opposite reaction. This reaction constitutes the pressure pulse. Changing the height of the liquid column or the density of the liquid changes the amplitude of the pressure pulse applied to the foil.

Since the equipment could be vibrated at 4kHz, a 10^9 pulse lifetest could be completed in just a few days. Although the pressure change is not so fast as is believed to occur in the laser discharge, the risetime is, nevertheless, only about 100μsec.

During the ESA sponsored programme, the simulator design was modified to incorporate hot liquid, in order to heat the foil to temperatures up to 325°C. This is well above the anticipated maximum operating temperature of about 120°C based on the foil thermal profiles experiments. A photograph of the simulator is shown in Figure 1.



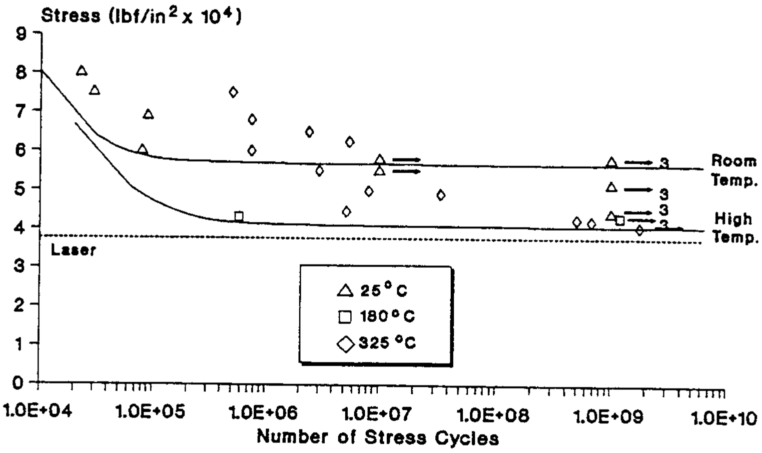


Figure 2: Room Temperature fatigue curve (top) and High Temperature fatigue curve (bottom) for 12.5μm 94.5% Ti/3% Al/2.5% V alloy

Figure 1: High Temperature Foil Test Unit

Aluminium had already been shown to be unsuitable as its yield strength is such that when used in a laser, its elastic limit is exceeded. 15μm titanium, 12μm and 6μm titanium alloys were fatigue tested at temperatures up to 325°C for 10^9 cycles. Fatigue curves for the most promising candidate material, 12.5μm titanium alloy, are shown with experimental data at 180°C and 325°C in Figure 2: Data points at room temperature (Reference 3) are also plotted.

The anticipated laser operating stress is also shown in Figure 2 and can be seen to be below the high temperature (325°C) fatigue curve, and therefore considerably below the 120°C fatigue curve which lies between the room and high temperature curves.

The results of the foil thermal profile and high temperature foil fatigue tests led to the selection of the 12μm Ti alloy foil for the prototype laser, as a lifetime well in excess of 10^9 pulses at its maximum operating temperature can be confidently expected.

PARAMETRIC STUDY OF GASEOUS CATALYSIS

In a CO_2 laser, dissociation occurs during the electrical discharge leading to production of CO and O_2. The presence of O_2 at levels of approximately 0.5% and above leads, in a self-sustained device, to excessive electron attachment and arcing instead of the required glow discharge. In an e-beam sustained laser, the discharges are inherently very stable and tolerant to attaching species such as oxygen. However, as the level of oxygen increases, the discharge impedance increases, lowering the discharge current and resulting in reduced energy output (Reference 4).

A CO oxidation catalyst can be used to control the levels of CO and O_2 built up in the laser (Reference 5). An alternative method, in an e-beam sustained laser, is to take advantage of an effect by which primary electrons from the electron gun directly cause re-combination of CO and O_2 (Reference 6). Potential advantages of eliminating the solid catalyst are the resulting absence of particulate shedding, reduced isotopic scrambling, lack of additional flow impedance, reduced weight and reduced cost.

The parametric study (described in Reference 6) studied both the dissociation of CO_2 and the recombination of CO with O_2 caused by a high energy (approximately 100 keV) electron beam in a typical CO_2 laser gas mixture. The variation of reaction rates with electron energy and current, inter-electrode spacing and gas composition was studied.

The study identified a set of conditions for which dissociation of CO_2 can be offset by recombination due to unthermalized secondary electrons, thereby eliminating the need for a solid catalyst. These conditions were used as a starting point for the long sealed runs (below).

EXTENDED SEALED RUNS

The parametric study (above) investigated short-term processes and developed a set of conditions for which CO_2 dissociation is offset by recombination. Extended sealed runs were also carried out in order to investigate long-term trends in gas composition and operating parameters. Full details of the diagnostics, operating parameters and results of initial sealed runs have been described fully elsewhere (Reference 7).

Three runs, each of 10 million pulses, were carried out whilst monitoring laser discharge parameters and the level of CO and O_2 in the gas mixture using analysers. Various other analytical techniques were also used, including IR absorption, mass spectrometry, gas chromatography, and Draeger tubes. After the first two runs of 10 million pulses, the operating parameters of the laser were optimised for maximum electrical to optical efficiency. Following this, a third run of 10 million pulses was carried out at 20Hz, operating virtually 24 hours per day (Figure 3).

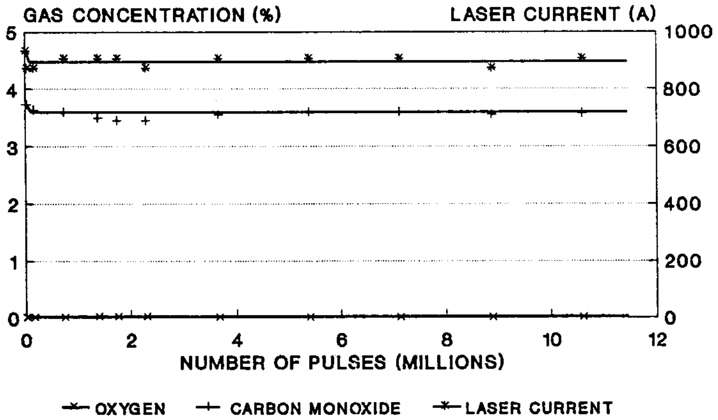


Figure 3: 10^7 pulse run under optimised laser conditions.

The result of the 10^7 run is very encouraging; no change in gas composition was seen, an observation confirmed by gas chromatograpic analysis. The electrical parameters of the laser were also constant after a short initial fall.

During the lifetests, damage to the ZnSe windows occurred and was investigated using a scanning electron microscope, IR absorption, and measurement of the laser damage thresholds of substrates and coatings.

CONCLUSIONS

The work carried out has addressed two critical areas of e-beam sustained CO_2 laser technology for spaceborne Doppler Wind Lidar; foil and gas lifetimes.

The foil thermal profile study determined that during operation the maximum foil temperature in a laser of this type, is 100°C above ambient. The high temperature foil fatigue tests showed that foil lifetimes well in excess of 10^9 pulses can be confidently expected at this temperature.

The parametric study identified a set of conditions for which dissociation in a CO_2 laser is offset by recombination due to the effect of the high energy electron beam. These conditions were used for a 10^7 pulse lifetest, undertaken at 20Hz, without solid catalyst, over which the gas composition and laser discharge parameters were found to remain constant.

As the requirement is for a 10^9 pulse lifetime, further tests to 10^8 and 10^9 pulses are needed to confirm the integrity of the gas composition over these lifetimes.

Damage to the ZnSe windows has emerged as an issue which requires further work to overcome damage effects, and to test the long-term effectiveness of any solution.

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