THE LASER IGNITION DEVICE AND ITS APPLICATION TO OIL SPILLS

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ABSTRACT: *A laser ignition device, intended initially for the controlled burning of forest logging slash, has been developed and successfully tested, for this and other applications. The device employs a kilowatt class carbon dioxide laser, the output of which is beam expanded and then focused to give a small, intense spot of heat at distances from approximately 50 to 1,500 m. Acquisition and precise focus control are achieved by the use of a laser rangefinder and acquisition telescope. The device is fully steerable, can be ground based, airborne, or mounted on seacraft.*

For historical reasons, it is useful to introduce the laser ignition device (LID) concept from the viewpoint of forestry applications. Since initial conception, many additional applications for all or parts of the device have been determined. These include back burning, spot lightings, firebreak generation, selected undergrowth removal, tree stand spacing, pruning and trimming (e.g., near power lines), the safe ignition of oil spills and slicks, land management, and de-icing applications (for example, of television towers, aircraft and airport runways, and snow drifts). The device has an application wherever concentrated, localized, safe heat at a distance is required. "Spot" concentration diameters of a few centimeters are obtained, even at the greatest focal distance of 1,500 meters.

One major forestry application of the LID is in the regeneration burning of logging slash. Regeneration is the process by which the forest species harvested from a logging area (coupe) are replaced. To regenerate most forest types or to establish new plantations requires the use of hot fires set in fuels left on the ground after logging. The fires remove most of the fuel and prepare a suitable seed bed on which the new forest can be established. The controlled firing techniques aim to mimic nature's wild fire, which originally produced much of the existing forests. Figure 1 shows a typical area ready for regeneration burning after logging, and Figure 2 shows an established regeneration burn.

Existing lighting techniques include hand-held drip torches, aerial and electrical incendiary devices, and gun-operated incendiaries. All these techniques have access or safety problems or both. In recent years they have led to a significant number of disasters and near-disasters. Furthermore, many are costly, both in capital and in manpower.

The concept of the laser ignition device

A laser device, employing suitable optical systems, easily mobilized, and capable of igniting forest fuels at distances from 50 to 1,500 m from roadside vantage points, would satisfy the criteria of a safe and effective ignition facility. Other applications of the device (e.g. oil spill ignition), which have been mentioned in the introduction, follow almost automatically.

Other advantages of the LID—in addition to safety for many users and uses and effectiveness in application—include its ability to reach fuel sites in difficult terrain, its flexibility to be either ground based or airborne in helicopters or fixed-wing aircraft, instant availability, and rapid mobility. Furthermore, the device is self-contained, relatively compact, and simple to operate, provides shorter burn times because

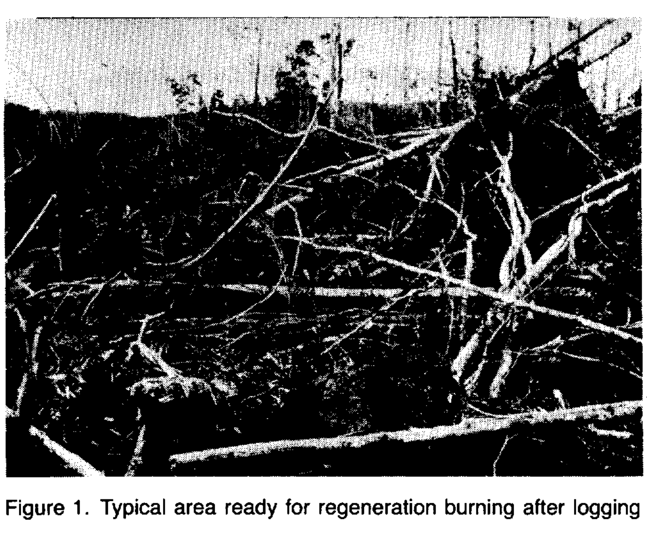

Figure 1. Typical area ready for regeneration burning after logging

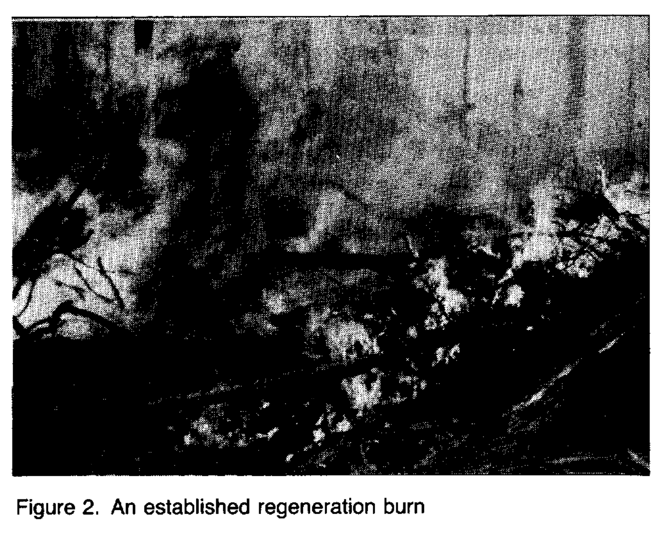

Figure 2. An established regeneration burn

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of its high-power density and ability to scan fuel areas, and is cost-effective in that it may be operated by one or at most two persons. Operating costs are thus limited to transport fuel costs, power generation costs (e.g., engine fuel for truck power takeoffs in ground-based operation) and operators' salaries. Capital costs are not insignificant, but based on current and foreseen uses can be amortized within two or three years.

In selecting a suitable laser for a particular application, several factors should be considered:

1. Availability and size of suitable high-power CW lasers
2. Propagation properties of laser beams through the atmosphere
3. Means of controlling the plane of focus of the laser beam with precision to avoid unwanted or uncontrolled ignition

With regard to (1), and taking into account (3), the ideal laser system is a kilowatt-class carbon dioxide (CO_2) laser operating at a wavelength of 10.6 μm in a continuous-wave mode. These lasers usually operate close to TEM_{00} mode, with a gaussian output beam profile steeply peaked at the center. Typical output beam dimensions might be 10 mm diameter to $1/e^2$ points, and 12 to 13 mm total width. Beam divergence is usually on the order of 1 to 2 mrad. With such an unfocused laser beam, the beam diameter at 1 km from the laser is greater than 1 m. Power densities greater than 30 W/cm^2 are required for rapid ignition of most cellulose materials, so that such an unfocused laser beam is useless for this purpose. For optical reasons, it is advantageous to operate the laser in other than single mode, enabling an increase in energy output and minimizing losses caused by optical obstructions such as mirrors. This is achievable with the laser being employed here.

Alternatives to CO_2 lasers include Nd-YAG lasers operating at 1.06 μm in a multimode configuration. The main disadvantage with these is the shorter wavelength, which reduces the energy absorbed by fuels for a given power density. As output power increases, beam divergence, and hence other optical properties, such as minimum spot size and energy spillover, also increase, making these lasers less attractive.

Point (2) is of some significance with regard to thermal blooming and the propagation of laser radiation through a turbulent atmosphere. Quite clearly, the longer the wavelength the less these effects on any laser beam. A turbulent atmosphere is normally caused by thermal gradients near ground level, by the effects of winds, and so on. While this effect is significant at optical and near-infrared wavelengths, it becomes negligible at a wavelength of 10.6 μm over the ranges of interest here.[4] Provided the energy densities along the path of propagation are small enough, thermal blooming will not present any problem either. For a kilowatt-class CO_2 laser operating as proposed, thermal blooming may be completely neglected.

For propagation distances up to about 1,500 m, and laser powers in the kilowatt class, the limiting factor that determines the minimum obtainable spot size is Fraunhofer diffraction. A diffraction-limited spot's diameter is given by

$$\frac{1.22\,\lambda}{(r/d)}$$

Where: λ = wavelength
r = radius of beam at output of projecting optics
d = distance to focus

The corresponding power density at focus is given by

$$PD = P_{out}\frac{4r^2}{\pi(1.22\lambda)^2 d^2} = (0.855)\frac{r^2}{\lambda^2 d^2}P_{out},$$

Where: P_{out} = the laser output power

Note that this analysis applies only for a uniformly illuminated projection aperture, and requires modification to take into account, for example, a gaussian laser beam, optical obstructions, and so on.

Simple calculations show that a meter-class projection aperture is required to achieve acceptable spot size at the focal distances of interest. This projection aperture, illuminated by, say, a 1 kW laser, will produce power densities of 30 W/cm^2 and 25,000 W/cm^2 at focal distances of 1,500 and 50 m respectively.

To achieve this focal range, clearly some focusing optics, operating at 10.6 μm, must be included prior to the final projection aperture, to vary the output convergence angle. There are two alternatives: (1) employ a two-mirror telescope as the projection system and vary the mirror separation, and (2) employ auxiliary optics and leave the mirrors fixed.

For a number of reasons, including mechanical difficulties in moving mirrors and associated optical problems, the second option has been selected, with two optical subsystems that move relative to each other. By carefully controlling the designs and movements of the optical subsystems, diffraction-limited spot sizes are obtained over the desired focal range.

A block diagram of the overall concept is shown in Figure 3, where the system has been divided essentially into three modules: the laser, the focusing optics, and the projection telescope.

Practical considerations

The previous section describes in general terms the principles of operation of the laser ignition device. Its successful and safe operation requires knowing precisely the distance to the target. In forestry applications, focal distances are required to an accuracy of ±2 m at a distance of 1,000 m, to avoid ignition of material beyond predetermined boundaries. Similar tolerances will apply for the safe, exclusive ignition of other materials, such as oil slicks, and for selective melting of snow drifts or ice.

For these reasons a laser rangefinder is employed to determine the distance to the target. The output of the rangefinder is used to control the focus of the laser beam on the target, which is updated approximately every 3 seconds. Operation of the laser rangefinder and focusing mechanisms are fully automatic, with built-in calibrations and checks. Any thermal effects on the LID are automatically calibrated out upon command from an operator. Focal calibration at a very short distance (~10 m) is also available.

As mentioned above, the laser beam is projected onto the target by a single-mirror or two-mirror telescope. The telescope is mounted on an altitude-azimuth support, both axes being driven by variable speed motors. Motions of ±45° in altitude and ±180° in azimuth are provided. In a typical operational mode, the device pans at a rate of approximately 0.5 m/s at target. Faster or slower speeds are available, controlled by use of a joystick.

Acquisition of ignition sites is by means of an auxiliary optical telescope and/or television monitor located adjacent to the laser rangefinder. Once a site has been selected, ignition is activated by a push-button control on the joystick hand paddle. Virtually instantaneous ignition is obtained, and in forestry applications firestorm conditions are obtained at the above-mentioned panning rates.

Application of laser ignition device to oil spills

As mentioned above, the laser ignition device is fully steerable and can be airborne in either fixed-wing aircraft or helicopters. With its focusing and accurate parting capabilities, it is ideal for the controlled ignition of oil spills, particularly in cold and frozen regions such as the Arctic.

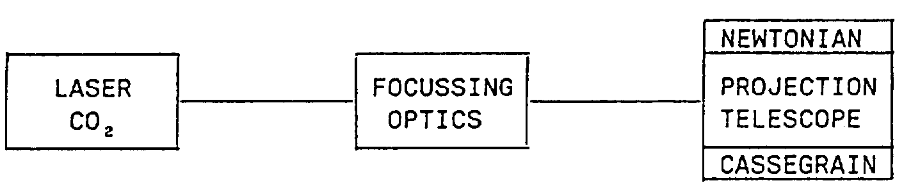

Figure 3. Block diagram of laser ignition device concept

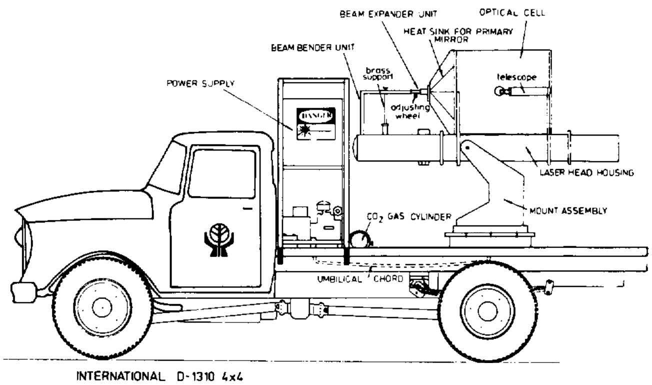

Figure 4. Schematic drawing of first laser ignition device mounted on truck

Conventional means of removing oil spills include skimming up the oil and direct burning. Skimming devices do not perform very satisfactorily in sea areas containing ice because of congestion. Furthermore, direct burning is often difficult in colder climates, which tend to render fires extinguishable. The device described here can be used to preheat the oil and then ignite it, on land, water, or ice.

An oil spill on ice may appear as a large mass or as a number of smaller puddles. As in logging slash ignition, it is essential to generate an oil vapor zone above the oil patch, to maintain ignition once achieved. With the laser ignition device, the beam is controlled to produce the required heat path at the oil site, providing more than adequate heating of the oil to the vapor phase. In this type of operation the laser operates in CW mode. Power densities are such that adequate heating for ignition of oil is possible over a wide range of distances and a wide range of physical conditions (for example, temperature, wind, and water content). Tests have been carried out to simulate these conditions.

If the laser ignition device has inadequate power density for oil ignition within a few seconds when operated in CW-mode, it can be rapidly switched to pulse mode. In this mode intense energy pulses of microsecond-class width are produced, causing instantaneous ignition of the oil vapor. Switchover times between CW and pulse modes of laser operation are less than one second, enabling the oil vapor phase to be maintained.

Successful ground-based ignition tests have been carried out under a variety of conditions; in each case virtually instantaneous ignition was achieved. This means of safe ignition of oil spills from a distance will also be extremely cost-effective relative to current conventional methods.

Testing

As early as 1980, a prototype LID was constructed and tested usin a 200 W CO_2 laser. Figure 4 illustrates schematically the arrangemen used, with the 200 W laser mounted beneath, but fixed to, the tele scope. The tests successfully demonstrated the principles of operatio and confirmed theoretical predictions of spot sizes at given distances However, owing to instabilities in the particular laser employed, sus tained ignition of logging slash fuels was not consistently satisfactory

Later, the initial LID system was modified to carry a Spectra Physics 810 laser with an output power in excess of 500 W. Test carried out with this laser in 1985 were extremely successful from al points of view. Firestorm conditions were obtained with forest fuels over a range of several hundreds of meters, including fuels of signifi cantly different moisture content. Other types of fuels (e.g., plastic and synthetics) have been ignited successfully in the field. Ignition o additional materials in both normal and adverse conditions caused for example, by high winds have been simulated in the laborator using power densities and spot sizes obtained with the actual LID i the field. For example, the trimming of trees, ice cutting, and oi residue and oil slick ignition have all been tested successfully.

The LID is now being manufactured on a commercial basis, arisin from the very successful tests referred to above, and from the tremen dous interest expressed in its potential in North America, Europe and Australia earlier this year. A commercial version of the device containing further improvements on the prototypes, will be availabl for demonstration in the 1987 North American summer.

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