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Laser Ignition Device and Its Application to Forestry, Fire and Land Management[1]

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Abstract: A laser ignition device for controlled burning of forest logging slash has been developed and successfully tested. The device, which uses a kilowatt class carbon dioxide laser, operates at distances of 50 to 1500 meters. Acquisition and focus control are achieved by the use of a laser rangefinder and acquisition telescope. Additional uses for the device include back burning, selected undergrowth removal, safe ignition of oil spills, and deicing. A truck mounted version will be operational by fall 1987 and an airborne version by summer 1988.

A laser ignition device (LID), intended initially for the controlled burning of forest logging slash, has been developed and successfully tested, for this and a number of 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 1500 meters. 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. Initially, the device will be truck mounted and will be operational by fall 1987. An airborne version should be available by summer 1988. Many additional uses to that originally envisaged have been determined. These include back burning, spot lightings, fire break 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 deicing applications, for example, of television towers, aircraft and airport runways, snow drifts. In summary, the device has an application wherever concentrated, localized, safe, at a distance, heat is required. "Spot" concentration diameters of a few centimeters are obtained, even at the greatest focal distance of 1500 meters.

One major forestry application of the laser ignition device (LID) is 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 wildfire 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.

Many lighting techniques already exist. These include hand held drip-torches, aerial and electrical incendiary devices, and gun-operated incendiaries. All of these techniques have access or safety problems or both. In recent years there have been a significant number of

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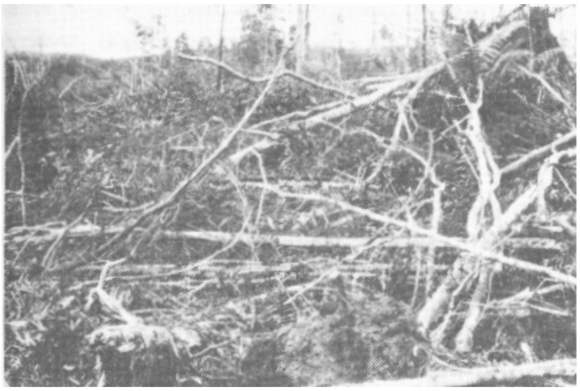

Figure 1--Typical area ready for regeneration burning after logging.

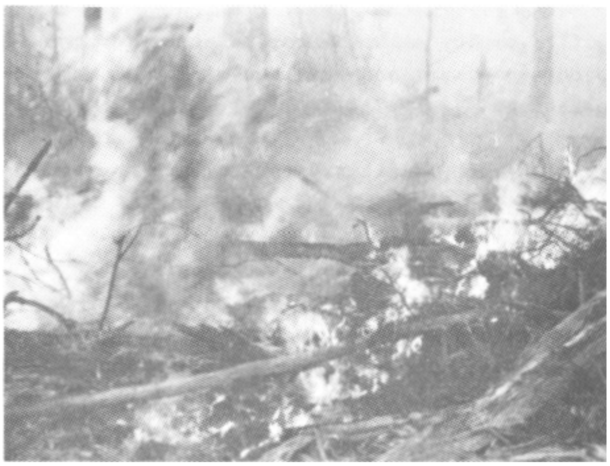

Figure 2--An established regeneration burn.

disasters and near disasters. Furthermore, many of these techniques are costly, from both the capital and the manpower aspects.

CONCEPT OF THE LASER IGNITION DEVICE

A laser device, employing suitable optical systems, which is "easily mobilized" and capable of igniting forest fuels at distances varying from 50 to 1500 meters from roadside vantage points, would satisfy the criteria of a safe and effective ignition facility. Other applications which have been mentioned in the introduction, follow almost automatically, e.g., oil spill ignition.

Other advantages, in addition to safety for all users and uses, and effectiveness in that success in application is guaranteed, include accessibility of fuel sites in difficult terrain, the ability of the device to be either ground based or airborne in helicopters or fixed winged aircraft, instant availability and rapid mobility. Furthermore, the device is self-contained and relatively compact, simple to operate, provides shorter burn times because of its high power density and ability to scan forest fire 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 using power takeoffs for ground based operation) and operators' salaries. Capital costs are not insignificant, but based upon current, and foreseen, uses can be amortised within 5 to 7 years from a cost-effective point of view.

In selecting a suitable laser for this application, cognizance must be taken of

(i) availability and size of suitable "high power," CW or lasers, or both,
(ii) propagation properties of laser beams through the atmosphere,
(iii) means of controlling the plane of focus of the laser beam with "precision" to avoid unwanted and/or uncontrolled ignition.

With regard to (i), and taking into account (iii), the ideal laser system is a kilowatt class carbon dioxide laser operating at a wavelength of 10.6 micrometers in a continuous wave mode. These lasers usually operate close to TEM_{oo} mode with a gaussian output beam profile steeply peaked at the center. Typical output beam dimensions might be 10 millimeters 2 diameter to $1/e^2$ points, and 12-13 millimeters total width. Beam divergence is usually of the order of 1-2 milliradians, and it is worth noting that with such an unfocused laser beam, the beam diameter at 1 kilometer from the laser is in excess of 1 meter. Power densities greater than approximately 40 watts per square centimeter are required for rapid ignition of most cellulose materials so that such an unfocused laser beam is useless for this purpose. With the focusing system used here, power densities up to 10^4 watts per square centimeter are obtained. For optical reasons, it is advantageous to operate the laser in other than single mode, enabling an increase in energy output and a minimizing of losses caused by optical obstructions such as mirrors and so on. This operation is achievable with the laser system described here.

Alternatives to CO_2 lasers include Nd-YAG lasers operating at 1.06 micrometers 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, energy spillover, and so on increase also, making these lasers less attractive.

Point (ii) is of some significance vis-a-vis thermal blooming and the propagation of laser radiation through a turbulent atmosphere. Quite clearly, the longer the wavelength the less do these effects have on any laser beam. A turbulent atmosphere is normally caused by thermal gradients near ground level and by the effects of winds and so on. While this effect is significant at optical and near infra-red wavelengths, it becomes negligible at a wavelength of 10.6 micrometers over the ranges of interest here (see, for example, papers by Tatarsky 1960). 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.

Perhaps the most critical area conceptually is point (iii). For propagation distances up to about 1500 meters, and laser powers in the kilowatt class, the limiting factor which determines the minimum obtainable spot size is Fraunhofer diffraction. For a diffraction limited spot, its 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

$$P\,D = P_{out}\,\frac{4r^2}{\pi(1.22\lambda^2 d^2} =$$

$$(0.855)\,\frac{r^2}{\lambda^2 d^2}\,P_{out},$$

where P_{out} is 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 kilowatt laser, will produce power densities of 40 and 25,000 watts per square centimeter at focal distances of 1500 meters respectively.

To achieve this focal range, clearly some focusing optics, operating at 10.6 micrometers must be included, prior to the final projection aperture, to vary the output convergence angle. Two alternatives exist:

(1) employ a two mirror telescope as the projection system and vary the mirror separation;

(2) employ auxiliary optics and leave the mirrors fixed.

For a number of reasons, including mechanical difficulties in moving mirrors, and optical problems associated therewith, option (2) has been selected. This consists of two optical sub-systems which move relative to each other. By the careful control of the designs and movements of the optical sub-systems, 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 represented essentially by three modules, the laser, the focusing optics, and the projection telescope.

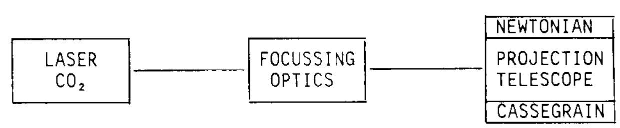

Figure 3--Block diagram of LID concept.

PRACTICAL CONSIDERATIONS

The previous section describes, in general terms, the principles of operation of the laser ignition device. Pertinent to its successful and safe operation is knowing precisely the distance to the target to be ignited. In forestry applications, focal distances are required to an accuracy of ± 2 meters at a distance of 1000 meters, 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 oil spills, and for selected melting of snow drifts or ice.

For these reasons a laser rangefinder is employed to determine the distance to the target. The output of this is used to control the focus of the laser beam onto the target, and this 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 target by means of 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 degrees in altitude and ± 180 degrees in azimuth are provided. In a typical operational mode, the device pans at a rate of approximately 0.5 m sec^{-1} at target. Faster or slower, including zero, speeds are also available, by use of a joystick control.

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

TESTING OF LID

As early as 1980, a prototype LID was constructed and tested using a 200 watt carbon dioxide laser. Figure 4 illustrates schematically the arrangement used then with the 200 watt laser mounted beneath, but fixed to, the telescope. The test successfully demonstrated the principles of operation and confirmed theoretical predictions of spot sizes at given distances. However, due to instabilities in the particular laser employed, sustained ignition of logging slash fuels was not consistently satisfactory.

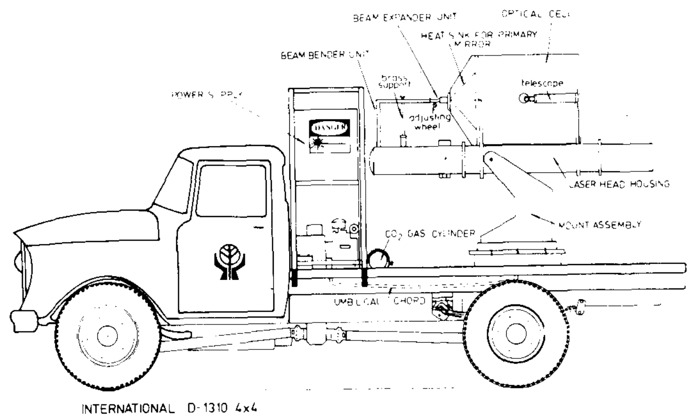

Figure 4--Schematic of first Laser Ignition Device on truck.

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

The laser ignition device is now being manufactured on a commercial basis, arising from the very successful tests referred to above, and from the tremendous interest expressed in its potential in North America, Europe and Australia. As mentioned in introduction, a commercial version of the device, containing further improvements upon the above-mentioned prototypes, will be available for demonstration in the 1987 North American fall.

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