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DEVELOPMENT OF A SAMPLER TO CHARACTERIZE RADIOACTIVE MATERIALS

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ABSTRACT

It is very important to find a method of decontamination for nuclear contaminated objects without generating large amounts of radioactive waste. In order to develop an appropriate method it?s necessary to know how much the object is contaminated and what the contaminant is. The project focus was to develop a sampler that may give this information with high precision, generating few waste and easy to operate. The sampler used a pulsed Nd:YAG (Neodymium-doped Yttrium Aluminum Garnet) laser in its fundamental wavelength of 1064nm to ablate the materials surface, then the particulates generated by the ablation were sucked by a vacuum pump, collected by a filter and then analyzed in a gamma-spectrometer to determine which contaminants were present in the sample. A set of two mirrors attached to two DC motors was controlled by a computer interface using the software LabView to make the laser beam scan and ablate a determined area of the materials surface.

1. INTRODUCTION

There is a focus in the development of new methods of material decontamination nowadays, a large amount of facilities needs some sort of material decontamination to reduce costs and to send the radioactive waste to its proper destination. As important as the decontamination is the characterisation of the radioactive elements in the materials, some elements are poorly attached to the surface, some became gases relative low temperatures and these properties must be considered before the decommissioning.

Usually, the decontamination method is performed using chemical substances to remove the radioactive material of the near surface, a strong acid or an alkaline solution, but this method often creates a problem because it converts the solid waste to a liquid form. Liquid wastes are harder to manage and they need to be converted back to the solid form in order to proceed to the disposal.

Physical methods os decontamination can also be used, as a sandpaper or another abrasive material to ablate the surface, but this method releases radioactive dusts in the air, exposes the worker and ends up contaminating more than the sandpaper. An alternative that has been studied is the decontamination of materials using lasers, it is interesting because it generates fewer waste than any other method, though it also generates particulate and aerosol materials that has to be treated.

2. THE METHOD

There are more than one method to decontaminate a material using lasers, when the laser beam hits the surface of the material it is absorbed and the molecules agitates, thus rising its temperature, and by controlling the intensity of the beam it is possible to make the material evaporates or sublimates.

2.1. Continuous Laser Ablation

Usually, the term *laser ablation* refers to remove material using a pulsed laser, but it may be performed with a continuous wave (CW) laser if its intensity are high enough, generally achieved by focusing the laser beam. The depth which the laser beam will be absorbed, or in other words, the amount of material that will be removed in a single pulse, depends on the material optical properties and the laser wavelength (λ), for instance a wavelength of 193nm may be used to ablate materials like highly transparent quartz, which does not have a high absorption coefficient for higher wavelengths. [1]

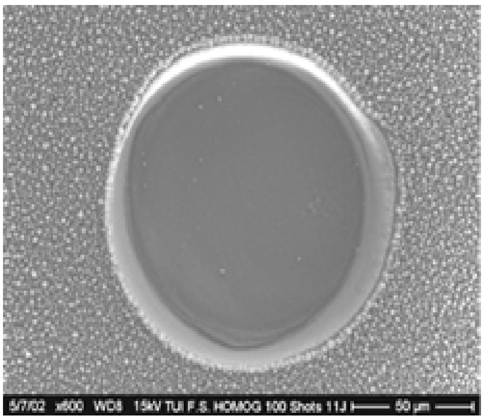

Figure 1: 100 μm crater in fused silica.

2.2. Pulsed Laser Ablation

The laser beam intensity decays as it passes through a medium, as the following:

$$I(x) = I(0)e^{-\alpha x} \quad (1)$$

Where α is the absorption coefficient of the medium. A contaminated material usually is contaminated only in the near surface layer, this way it is possible to think of a layer, or a coating, of contaminated material with thickness D that has to be removed. The ablation occurs in two different ways that depends if the inverse of the coefficient $\alpha^{-1} \ll D$ or $\alpha^{-1} \approx D$ and it is very important to notice that the absorption coefficient varies with the laser wavelength, this way it is possible to change the laser wavelength in order to produce a different result.

2.2.1. Normal ablation ($\alpha^{-1} \ll D$)

If the material does not have coating or its coating has an absorption coefficient very close to the material ($\alpha_c \approx \alpha_m$) the laser beam will be absorbed totally, or almost totally, before it passes through the thickness D of contaminated material, this will increase its temperature and cause it to sublimate, or if its intensity is too high the material will become plasma for a few seconds and then will be dispersed.

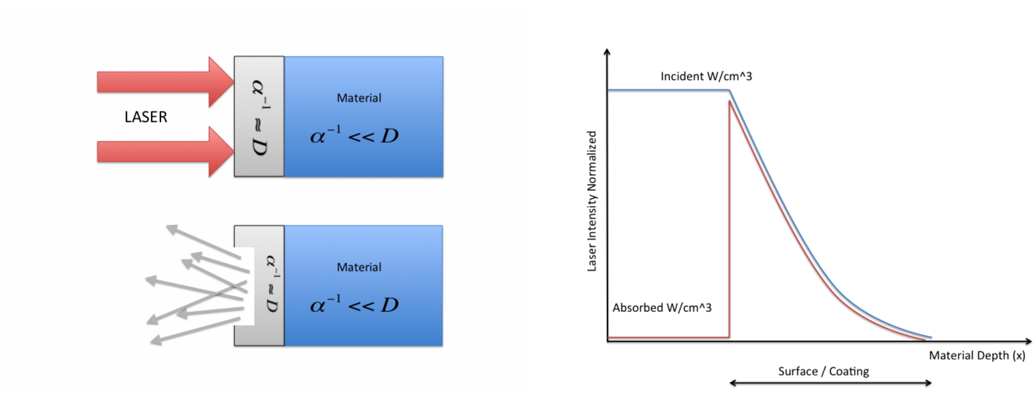

Figure 2: Normal ablation process with a pulsed laser in a material with no coating.

2.2.2. Detachment and ejection ($\alpha^{-1} \approx D$)

If the material has a coating that the absorption coefficient $\alpha^{-1} \approx D$, which means that the coating won't absorb much of the laser, it will pass through without losing much intensity and after the coating it will be absorbed by the material, for it has $\alpha \ll D$, the material will become plasma and then eject the coating above leaving a smooth surface with no contamination. [2]

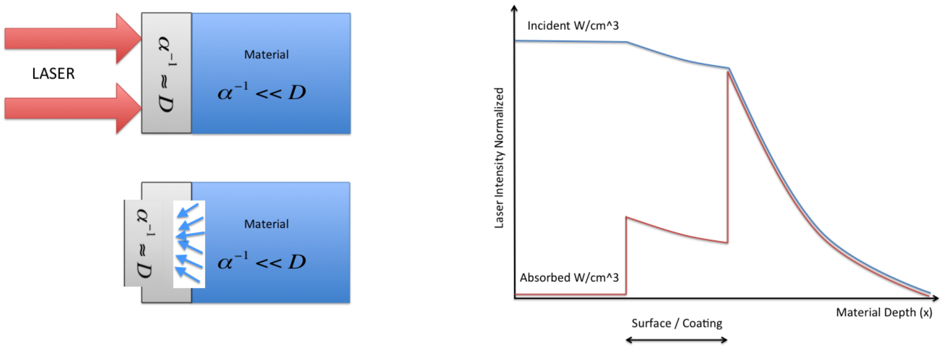

Figure 3: Detachment and ejection process with a pulsed laser in a coated material.

3. THE SAMPLER

To characterize which are the contaminants is necessary to produce a scanner so the laser beam can ablate a known area, there are numerous ways to produce a scanner, but some ways are very complicated and sometimes expensive. The beam needs to change its original route and it is usually done by mirrors, as the beam needs to scan an area the mirrors have to be articulated, in order to automate the process the mirrors may be attached to an electric motor.

Attaching a mirror into a rotary motor, off its centre, will scan a circle, placing another mirror off-centre in front of the first one will produce a scanner based on a mathematical figure called *Hypotrochoid*.

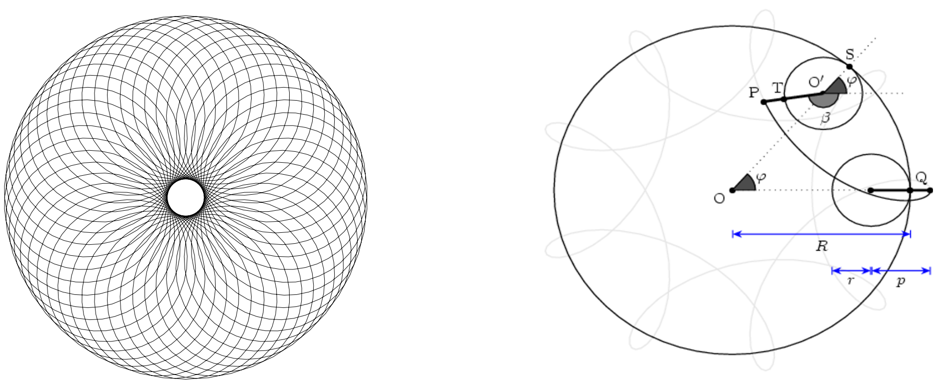

Figure 4: On the left, one form of hypotrochoid and on the right the parameters which the hypotrochoid depends on.

An hypotrochoid may be written using the following cartesian equations:

$$x(\theta) = (R - r)cos(\theta) + p * cos(\frac{R - r}{r}\theta) \tag{2}$$

$$y(\theta) = (R - r)sin(\theta) - p * sin(\frac{R - r}{r}\theta) \tag{3}$$

Or its equation in polar coordinates:

$$r(\theta)^2 = (R - r)^2 + 2p(R - r)cos(\frac{R}{r}\theta) + p^2 \tag{4}$$

It is easier to use the equation in polar coordinates as it is being used two rotary motors, this way θ may be understood as the angular velocity of one motor to the other and R and r as the angle formed by the plane of the mirrors and the normal vector of the motors axis. Knowing these equations a program was developed using the software LabVIEW (*Laboratory Virtual Instrument Engineering Workbench*) to draw the hypotrochoid and see how its form changes as the parameters of the equation also changes.

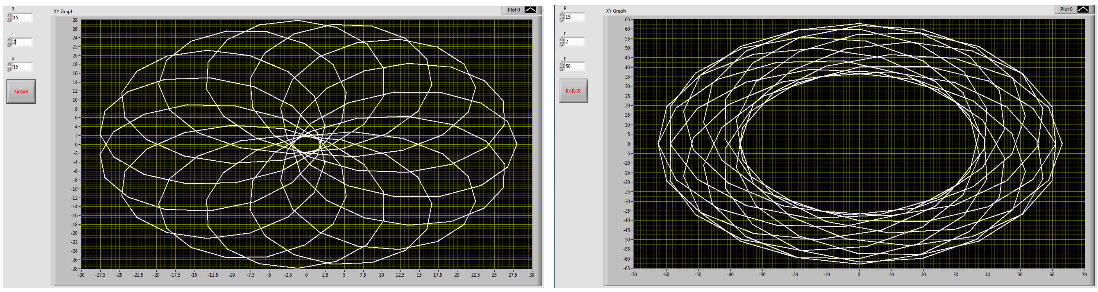

Figure 5: Hypotrochoids simulated with LabVIEW, the left one uses $R = 15$, $r = 2$ and $p = 15$, the right one uses $R = 15$, $r = 2$ and $p = 50$.

To control the velocity of the motors a PWM (*Pulse Width Modulator*) was built, a PWM is an electronic device that may use simple electronic components to control the duty cycle of an electric motor, a lamp or a light-emitting diode (*LED*).

The Figure 6 shows the simulation of a PWM made using a software called Yenka. [3] Yenkas technology module allows the user to simulate electronic circuits with a huge variety of components using a free home license, as long as it is not used for commercial purposes.

Knowing the figure formed, once the parameters are set, by the figure 5 and knowing the diameter of the laser beam it's possible to calculate the area that the laser will scan in the material surface, thus allowing to estimate the contamination by area.

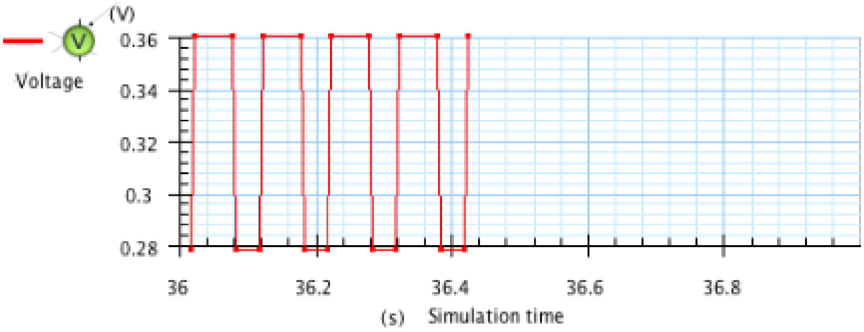

Figure 6: Simulation of a PWM controlling the duty cycle of an electric motor.

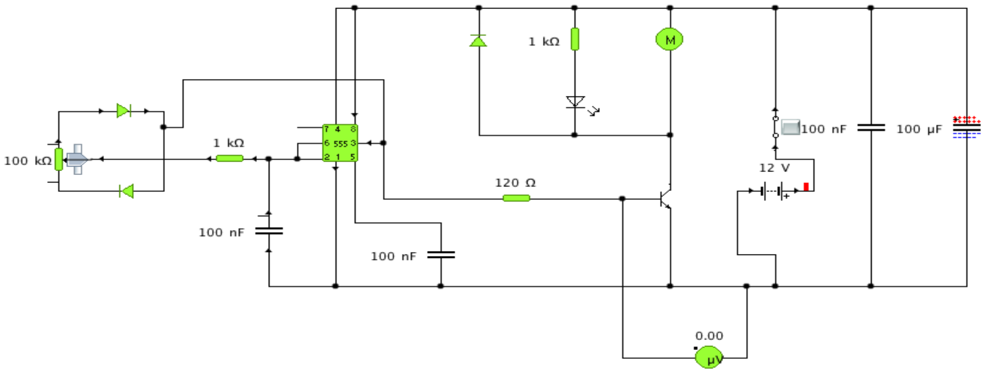

Figure 7: Electrical scheme of a 555-based PWM simulated with Yenka, the not specified diode may be replaced with any of the N4000 family.

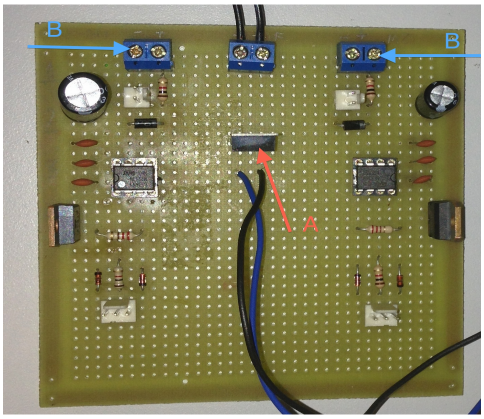

Figure 8: A *PWM* prototype made to control a set of dc motors from 5% up to 95% it's duty cycle. The B output, the blue arrows in the figure, is where the motor is plugged in. The red arrow, or the A input, is a voltage regulator LM7805.

4. CONCLUSIONS

After the construction of a prototype, made with two DC motors hold by an optical post, a PWM and a laser pointer, it was possible to see some points that need focus on, in order to improve the method.

The scanner used two mirrors attached, off-centre, to electric motors oscillating in every revolution. It is nothing to be worried about when you are working with low speed, but when the motors starts to spin faster it may vibrate in the resonant frequency of the optical post grip, this caused the motor to slips while rotating and breaking the mirror used. Further tests shall be made with a post specially designed to hold the motor or moving it and letting the mass centre stay exactly where the grip is.

Another point to be considered is that, as we want to estimate the contamination, the scanned area should be homogeneous, though the hypotrochoid has several points where the laser beam overlaps. As a LabVIEW program were developed to generate the mathematical figure based on the given parameters, the same program may be used to tell the laser not to beam in the point where it would overlap, but to do this it is necessary to let the program control the laser by the serial port and have more precision with the motor revolutions, as well as it has to be passed as a variable to the program. The precision and information about the motor may be acquired using a hardware, usually a *National Intruments* hardware, to control two step-motors.

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