LASER CLEANING APPLICATION ON LADY’S CHURCH ATRIUM
FROM BUCHAREST CITY CENTRE

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ABSTRACT
Located in Bucharest city center, The Lady’s Church was built in 1683 by Princess Maria Cantacuzino on the site of other wooden church. It was painted in fresco by the famous Greek painter Constantin Mina. Because of the unhealthy policy of urbanism and of the high pollution generated especially by a very intense traffic, this historic and artistic site was deteriorated. The poor conservation condition of the stone doesn't allow application of traditional cleaning methods. Being first large Romanian applicative project consisting in laser cleaning application on site, the laser regime was prepared and followed by a careful thermal control of the surface. It was used a Raffaello Nd:YAG laser developed by Quanta System. This system has some advantages: more laser wavelengths available, more pulse energy and more average power for an improved cleaning speed and compact and rugged design for improved reliability. Thermacam E4 was used for thermal monitoring. Surface’s relief preservation was controlled on site using microscope system Laser x-y. This laser cleaning method is the first one done in Romania in collaboration with the national authority for historical monuments attendance.

KEYWORDS: Q-Switched laser, cleaning, stone

1. INTRODUCTION
Conservation and protection of cultural heritage has turned more and more into a race against time; environments all over the world had become increasingly aggressive causing damage or at least deterioration where they are concerned.
A primarily objective of this research has been the assessment of the prospects opened by the adaptation of the laser technology in art conservation. Traditional methods rely on mechanical or chemical techniques. Because these processes are difficult to control, extensive expertise is necessary in order to achieve an optimal result.
Furthermore, optical techniques can be applied on-line to evaluate the cleaning process and carefully monitor its progress safeguarding against any damage.
Conventional techniques do a lot against most of the factors that endanger art objects, but new approaches of advanced technology have to be explored in order to preserve the heritage of human civilization.
The origin of laser cleaning can be traced back to the early 1970s when Italian Petroleum Institute funded John Asmus from University of California, San Diego, to visit Venice and to study laser holography in order to record the city’s decaying artifacts. During his work Asmus observed that when the focused ruby laser beam touches the statue substrate, the encrustations are removed. Since then this technology has developed rapidly and laser cleaning has become a practical and reliable technique offering the conservator a high level of precision and control. It presents numerous advantages, being a physical process which ceases shortly after the laser pulse has ended, it preserves surface relief, it is versatile, controllable, non-contact, selective and - a very important fact – environmentally preferable.
Based on the material of the artifact, we can talk about two directions of laser cleaning: organics and non-organics. Organic artworks as well as non-organic ones are affected physically, biologically and chemically during their life.
When a laser beam interacts with a solid target, a variety of events may take place including thermal and photochemical ablation of surface molecules, shock wave formation with mechanical disruption of the surface layers, vaporization of organic fragments as well as other less well known phenomena.
Depending on the nature of the material, each of those interactions can be selectively enhanced by proper choice of the laser
parameters including wavelength, peak power, pulse duration, pulse shape, repetition rate, irradiance geometry and laser spot size. The characteristics of the material to be ablated are also quite important. These include the absorption coefficient of the material, its reflectivity, thermal diffusion, enthalpy of evaporation and heat capacity. The photo physical, thermal, chemical and mechanical properties of the material influence the ablation. In addition, the plasma which is created can influence the effective coupling of laser radiation to the surface.

2. LASER CLEANING PROCESS

Laser cleaning should be regarded as a generic practice requiring specific adaptation to the precise combination of object (substrate) and encrustation (pollutant layer) requiring removal. At the same time, this inherent complexity results in a technique capable of adaptation to a wide variety of specific requirements.

The selective removal of impurity layers is governed by the control of the laser pulse fluence in respect to the ablation threshold fluence values of the substances to be removed or to be saved.

We will use a simplified one dimensional model in order to demonstrate the principle of selective vaporization [1-4], assuming that:
- the laser beam is uniform and has no transverse variation in intensity,
- the encrustation layer is uniform and planar,
- the beam diameter is much larger than the thermal diffusion distance or than encrustation’s thickness.

The threshold fluence $F_o$ of a particular material with density $\rho$ is determined by the reflectance $R$ and the heat of sublimation per unit weight $\Delta H_s$ (which is the sum of the heat of melting and evaporation per unit weight), further, the absorption coefficient and the heat affected zone [5]

$$F_{o,1} = \frac{2F_o}{k} \left( \frac{\alpha t}{\pi} \right)^{1/2}$$

The distance $z$ that a thermal wave will travel into the material is determined by the thermal diffusion coefficient of the irradiated material, $\alpha$, and the duration of the laser pulse, $\tau$. It commonly reaches values between 1 and 10 µm in the case of the absorption of nanosecond laser pulses.

The thermal diffusion coefficient is:

$$\alpha = \frac{k}{(\rho C_V)}$$

with $k$ - the thermal conductivity and $C_V$ - the specific heat.

Selective vaporization of the encrustation is related to the absorption coefficients of the pollutant layer and of the substrate, since:

$$F_o = (1-R)I_o = \beta I_o$$

where $\beta$ – absorption coefficient and $I_o$ – incident flux.

If all variables are held constant, different values of $\beta$ of the substrate and the pollutant layer can result in significant difference in the surface temperature reached by the two layers.

$$T_{(o)} = C\beta I_o$$

where $C$ is a constant.

One important factor that is a must for a successful cleaning is that the encrustation should be removed by vaporization while the melting temperature of the underlying substrate should not be reached.

In order to locate the accurate parameters for the laser cleaning, there were made some tests, according to the major investigations and experiments regarding laser cleaning of stone substrates.

3. EXPERIMENTS

The laser employed for stone cleaning was a Q-switched Nd:YAG laser working at all four harmonics (1J energy at 1064nm and 600mJ at 532nm). These two wavelengths were used for preliminary tests at our institute laboratory and on site.

A series of test were performed on different sorts of stone that can be found on Romanian territory. Among them we had some sorts of limestone quite similar with the limestone used at Lady’s Church columns.
These laboratory tests monitored the stone behavior at laser irradiation at different wavelengths and energies.

The stones were artificially covered with a black candle smoke. During laser cleaning several IR images were recorded to monitor the temperature variation at the stone surface and also to establish a connection between emissivity of the material and cleaning degree. All stone samples were analyzed using optical microscopy with a microscope that had a CCD camera mounted on the optical path in order to get digital magnified images of the samples.

Encouraging results gave us the opportunity to apply the laser cleaning at a different level directly on cultural heritage. Our preliminary tests on Lady’s Church columns were performed in the same manner as we proceeded with laboratory samples. Under direct control of art restorers we started with low energies, 70% from maximum output for both IR and green wavelength. The laser energy was increased with 5% at a time and we stopped when art restorers considered that cleaning results are balanced between the quantity of dirt removed and preservation of original stone surface. The green wavelength offered a mild cleaning but no matter how high was the energy there was still a quantity of dirt even if the stone started to be affected. Therefore we’ve decided to work with the IR wavelength at energies from 80% to 95% of full power depending on the specific problems that we will meet. Several tests were performed after we applied a small quantity of water using a brush or using a poultice. There were no differences between the modes that water was applied on the surface. During the preliminary tests we’ve noticed that there was no difference between the wet samples and the dried ones. Later on, during the cleaning campaign we used to apply water using a brush on the areas with a thicker layer of dirt.

Laser Cleaning is a selective process that assures the success of restoration and conservation techniques. The specialists from National Art University from Bucharest collected some stone samples from our tested areas. After a series of serious investigations, they have concluded that the stone layer is not affected by laser beam, the only differences from sample to sample being related to quantity of dirt that is still on the surface of the stone. Their studies were performed at Laboratory for Conservation from National Art University, Department for Artwork Conservation.
A number of tests were performed, in order to prove that laser cleaning is harmless for artwork material as much as is effective for dirt layer removal. During laser irradiation we recorded a series of IR vide files in order to monitor the temperature variation on stone surface. We’ve noticed that the temperature rises by 4-5 degrees Celsius and in 10 seconds the stone has already the initial temperature.

4. CONCLUSIONS

Several methods were compared to laser cleaning, such as combined chemical and mechanical removal. The results proved that laser cleaning has a higher speed, precision and selectivity having no mach compared to other methods. This intervention had a very high impact of among the specialists in architecture restoration, stone conservation/restoration, because the technique was presented in many occasions but only this year this technique was available in situ showing its advantages compared to other methods, proving its reliability and endurance.

REFERENCES


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