Surface Cleaning with Laser Technology

*Georg Heidelmann**
adapt laser systems LLC,
Kansas City, Missouri USA

This paper will describe the latest developments of Nd:YAG laser equipment for surface cleaning and preparation, including paint and oxide removal and microroughening. Industrial off-the-shelf laser ablation systems will be presented in mid to high power ranges for multiple applications. Laser applications (*i.e.,* cleaning, joining preparation, paint and oxide removal) in various industries, such as automotive, food and aerospace will be presented and their capabilities and limitations discussed. Mobile, handheld and fully automated laser surface treatment technology will be presented, offering a clear picture of the capabilities of laser surface preparation. The focus of the presentation will be on Nd:YAG laser systems, but other laser systems, such as CO_2- and fiber lasers will also be discussed. Laser surface cleaning technology is being used by various automotive manufacturers and suppliers as well as other industrial and governmental users. Approximately 300 laser systems have been installed in industrial surface preparation applications.

Keywords: *Laser cleaning, Nd:YAG laser, surface cleaning.*

Introduction

Advanced industrial lasers have evolved well beyond simple cutting and welding applications. Laser technology now offers an industrial de-coating and surface cleaning solution that is cost effective as well as responsive to environmental concerns. From the automated cleaning of molds to precise de-coating to oxide removal, laser surface treatments are proving to be an attractive option to traditional labor or cost intensive cleaning methods.

In the past decade laser paint removal and cleaning systems have generated significant interest as a viable alternative to conventional cleaning and paint removal technologies. Research of flexible, reliable and powerful laser systems for cleaning and paint removal operations began in the late 1980s with the modification of welding or cutting lasers into laser systems for surface preparation. This approach did not meet the requirements for surface preparation, which are significantly different than those for cutting and welding. In the early 1990s, research took place around the globe for more efficient, reliable laser systems for surface preparation work. It took another few years to develop the technology from experimental laboratory systems to dependable systems capable of use in day-to-day industrial operations. Today, a wide variety of industries have adopted laser systems a range of surface preparation tasks. Applications including: mold cleaning, paint removal, de-oxidation, joining pretreatment, oil and grease removal, and many more.

Operating principle

The laser generates a directed and monochromatic beam of light. In order to create high power density, the laser beam is also typically tightly focused. In the focal point, the intense laser beam is absorbed by the contamination or paint layer and it sublimates the target material, *i.e.*, paint or contamination (Fig 1).

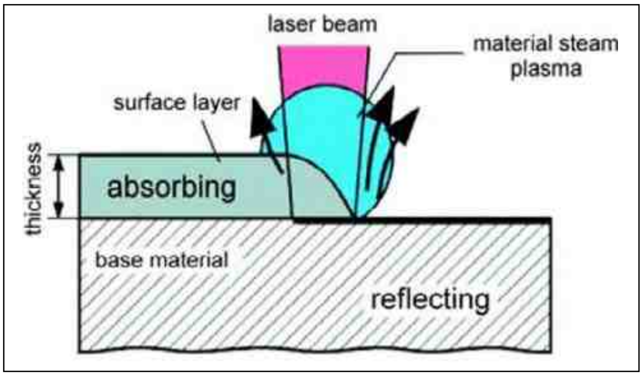

Figure 1—*Operating principle (Nd:YAG laser).*

* *Corresponding author:*
Georg Heidelmann
adapt laser systems, LLC
2615 Holmes St
Kansas City, MO 64108 USA
Phone: (816) 531 7402
E-mail: Heidelmann@adapt-laser.com

Figure 2—*Close up of laser pulse ablating target layer.*

This vaporization will, in combination with the resulting microthermal shockwave, remove the target material as long as the target material is able to absorb the laser energy. The better the target material absorbs the energy, the faster it can be removed.

Color, chemical composition and thickness of the target layer all have a direct impact on the effectiveness of the process. The removal process automatically stops once a metal, or otherwise relatively reflective, substrate is reached. Reflective surfaces do not generally absorb the laser energy. The heat transfer into the substrate material can be a critical factor. To minimize this effect, many laser equipment manufacturers use pulsed laser sources.

The laser intensity, known as the laser power per beam spot, is a critical parameter for the heat transfer into the substrate material. Very short laser pulses with a pulse duration of only a few nanoseconds (nsec) in combination with a very small focus diameter 200 μm (0.08 in.) or longer pulses in the millisecond (msec) range with a larger focus diameter 5 mm (0.2 in.) result in a minimal heat transfer into the substrate material. Under normal operating conditions and with the right process parameters, damage to the substrate material can be eliminated (Fig. 2). The heat transfer factor of continuous wave laser systems is much higher and might result in substrate temperatures that will damage the substrate. Test results with a handheld pulsed Nd:YAG laser with an average laser power of 500 W (peak power of over 400 kW) on an aircraft aluminum sheet resulted in maximum substrate temperatures of 80°C (170°F).

Laser types for surface preparation

Currently three kinds of laser types are typically used for surface preparation works. The main differences among the three kinds of laser sources for surface preparation are the methods of laser generation, the resulting beam delivery configurations and the ablation effectiveness.

Diode pumped Nd:YAG laser

The solid state laser uses a synthetic crystal as the active medium to generate a laser beam. The operative wavelength of 1,064 nanometer (nm) lies within the transmission bandwidth of common optical glass and enables the use of fiber optic cables for beam delivery (Fig. 3). Fiber optics dramatically increase the flexibility of laser beam delivery. Nd:YAG lasers can be used for work on hard-to-reach areas. The maximum fiber optic length is 50 m (150 ft).

Diode pumped Nd:YAG lasers are nearly maintenance free and very simple to operate. Newer Nd:YAG lasers are extremely mobile and versatile. Q-switched systems for surface cleaning reach average laser power levels of up to 1,000 W. Q-switched Nd:YAG laser systems generate laser power levels well beyond the average power of the laser source. A Q-switched 150 W solid-state laser will generate a peak pulse power of over 160 kW. This high peak power and the good beam parameter result in an intensity high enough for removing many target materials with acceptable production rates.

TEA-CO_2 Laser

The TEA-CO_2 laser uses a specific gas mixture as the laser medium and must be continuously refilled. The wavelength of a CO_2 laser is 10.6 μm and lies outside the transmission bandwidth of glass. Fiber optic delivery of short pulsed CO_2 radiation is not possible. Complex beam delivery systems using turning mirrors and line-of-sight beam ducts are required to deliver the beam. Mobility and accessibility of CO_2 laser systems are restricted by the optical delivery system. CO_2 laser systems in the field of surface preparation reach power levels of up to 2 kW average laser power.

Fiber laser

Fiber lasers are often used for cutting and welding applications. These lasers work in continuous wave (CW) mode and reach very high power levels, up to 20 kW. The appeal of fiber lasers lies in a very good cost-to-power ratio and an excellent beam quality. Unfortunately CW lasers are usually not suited for laser cleaning tasks, since they easily damage the substrate.

A pulsed fiber laser offers better surface cleaning characteristics due to the lower thermal impact to the substrate. One still has to deal with the Gaussian beam profile of the fiber laser, which in many cases creates too much laser intensity in the center of the beam to clean substrates without damage. A fiber-fiber coupling creates a flat top beam, but reduces the cost advantage over other laser types. Q-switched fiber lasers are currently available in power ranges of up to 200 W.

Figure 3—*Fiber coupled Nd:YAG laser optic.*

Laser cleaning applications

A versatile technology such as laser cleaning offers many possible applications. In fact, laser cleaning technology is being used to restore historic relics dating back thousands of years as well as on the current NASA space shuttle. Most of the systems used in industrial applications are fiber-coupled Nd:YAG laser systems in a power range of 20 to 1,000 W, either handheld or fully integrated in an automated process.

In most applications, an organic contamination layer or coating is being removed from a substrate (Fig. 4). Many applications require a gentle removal, without damage to the underlying substrate. Since the cleaning process depends greatly on how well the target layer is absorbing the laser energy, the full potential of laser cleaning can often only be established after an initial test. Those tests can be carried out on small samples in the laser application lab or in the field on the actual target. In most cases the initial tests can be carried out with small lasers, since this test has only to prove if the process itself will work. Cleaning speed is usually a function of laser power and is scalable based on the initial test.

A gentle laser cleaning is nowhere more demanded than in the aviation industry. Laser systems have been certified and are being used by civilian aircraft manufactures to remove coatings precisely, such as the area around grounding contacts. Sensitive equipment can easily be protected from the laser beam, making the laser a very versatile tool for cleaning critical parts in difficult environments (Fig. 5). One of the largest customers for laser paint removal in the United States is the US Air Force, which uses lasers in all key maintenance depots as a method for aircraft paint removal.

Another application for lasers with great potential is the cleaning of production molds (Fig. 6). Lasers are being used to clean very large steel molds in the aviation industry for composite structures, molds in the automotive industry, and even molds used for the preparation of food. Laser surface preparation is a very clean process and it generates no additional waste and does not spread waste around, like CO_2 blasting. Further, laser cleaning does not degrade the precise geometry of expensive tooling in the same manner as abrasive cleaning methods. This enables the technology to be automated or integrated in existing production lines with considerable ease. For example, laser cleaning systems are being used to clean molds in large baking ovens. Cleaning is carried out while the oven is producing a product, resulting in zero downtime. Laser cleaning of chromium plated or coated molds can cause a problem, since the plating might be removed by the laser. Again, an initial test will immediately prove the cleaning concept (Fig. 6).

Figure 5—*Manual laser cleaning with a 300 W laser.*

Figure 4—*Paint removal in B-52 center tank.*

Figure 6—*Laser-cleaned tire mold.*

The automobile industry is a key user of lasers for surface treatment operations. Lasers are used by OEMs to remove oxides and oil residues from body parts in fully automated manufacturing lines prior to welding and soldering applications. Tier 1 suppliers use lasers to clean surfaces prior to gluing or other joining operations. The removal of oxides, which absorb Nd:YAG laser energy extremely well, allows for high production rates and is a main application. Low operating and initial investment costs, in combination with very high reliability and consistent quality are the key decision drivers for laser cleaning in automotive related applications.

Summary

In a relatively short period of time, many fields of application have emerged for laser surface cleaning. Over 300 installed laser cleaning systems are currently in use. Research, demand and economics have enabled a growing future and have created huge potential for this technology in the U.S., where new applications are continually materializing.

Finishers Think Tank

Continued from page 19.

tives. Titration to a determined endpoint provides a quantitative addition of the alkali additive. By the operating ratio, the detergency additive is calculated, and added to maintain the desired operating ratio of both in the bath.

Other supporting analyses of the cleaner can be incorporated to monitor age, soil loadings, and if effective service life has been achieved. Usually a ready-to-dump cleaner can be tested for specific levels of contaminants. These values can be used as a guide to monitor service life of a newly made-up cleaner. Examples include metal contaminants (*e.g.*, chromium, copper, iron and zinc), extent of soil emulsification, solution density, and effect of water break test on previously cleaned coupons.

Soak cleaner waste treatment

Spent solutions are effectively treated by adjusting pH, releasing emulsified oily soils, precipitating metals and filtration. Clear solution is discharged per local POTW or municipal waste water authority regulations. Depending on plant processes, treated water may be recycled for use in previously tested for or non critical applications.

Complete waste treatment of a spent aqueous cleaner may be one quarter or less when compared to proper shipment and incineration of spent chlorinated solvents.

Next month we will review ultrasonic and mechanical cleaning. ***P&SF***

Answers to I.Q. Quiz #456

From page 20.

1. Aluminum and zinc

2. A cold shut is a condition where metal has not completely melted into itself, in a situation where two flows within the die cavity meet

3. (a) Molten metal must be smoothly delivered throughout the cavity and (b) air within the cavity is expelled completely the cavity as the molten metal enters

4. Gating design - the geometry of that introduces the molten metal into each part cavity.
   Die temperature - maintaining molten flow until the cavity is completely filled.
   Die wear - lack of maintenance.
   Mold release compounds - casting sticking to the die on removal

5. Plating over pores results in blistering and/or peeling. Surface pores can trap chemicals in the cleaning and acid pickling operations, and can be held in place through the rinsing operations. Ultimately, trapped chemicals can leak out through cracks in the plating, leading to staining at least and blistering at worst.