Mechanism Research and Equipment Development of Laser Cleaning Rust

Liu JiNan¹, Sun YanHe¹, Fang Yuan¹, Tie Jun¹, Fan ChunYu¹, Zheng Hua², Zhang ChengBing³

¹China National Network Liaoning Electric Power Co., Ltd., Overhaul Branch, Liaoning Shenyang 110000
²North China Electric Power University, Beijing, 102206
³Beijing Zhongke Chuangshi Technology Development Co., Ltd., Beijing, 100084

Abstract: With the continuous development of laser technology, more and more attention has been paid to the research of laser cleaning mechanism and the development of finished equipment. This paper introduces the application of laser cleaning technology in rust removal of iron and steel, summarizes the physical mechanism of laser cleaning, and puts forward the condition of synchronous cleaning and passivation of floating rust layer and the method of double beam wet cleaning and passivation. In addition, a cleaning method and device for wet cleaning and de-rusting with two beams is proposed in this paper.

1. Introduction
Laser is a strong coherent light source, which has four outstanding advantages of monochromaticity, coherence, directionality and high brightness. Now it is widely used in scientific research, military, medicine and industry and commerce. In many laser applications, laser cleaning as a new environmental protection surface cleaning technology has attracted more and more attention. Laser cleaning is a kind of laser surface treatment. Through the way of no mechanical contact, the laser directly acts on the pollutants, making the pollutants vaporize, ablate and decompose, making the environment gas plasma, and impacting the pollutants. Finally, a new surface cleaning technology with high mechanization, which can effectively avoid substrate damage, controllable change of substrate surface morphology and high work efficiency is realized.

2. Physical basis of laser cleaning

2.1 Laser particle removal
There are three main adhesions between particles and solid surface, which are van der Waals force, capillary force and electrostatic force. For particles smaller than a few microns, van der Waals force is the main adhesion force, which is the interaction between the dipole moment of one side of the two objects in contact and the induced dipole moment of the other side, which is shown as gravity. The third kind of adhesion force is electrostatic force, because there is a contact potential difference between the particles and the substrate when they contact, driven by the electromotive force, the charge transfers between the particles and the substrate, forming a double charge layer with different
charge on both sides of the contact surface, forming a structure similar to the electrode plate. Figure 1 below shows three adhesion actions between particles of three forces and the substrate.

![Diagram showing three adhesion actions](image)

Figure 1. Three adhesion actions between particles of three forces and the substrate

The above three adhesion forces are all proportional to the particle diameter. In the dynamic analysis of particles, gravity will be ignored. It also shows that the smaller the particle size, the stronger the adhesion, the more difficult to be removed. When the particle diameter is reduced to a certain extent, it even exceeds the ability of some surface cleaning methods.

Normal incidence: under the pulse laser irradiation, there are two main mechanisms for the separation of particles from the solid surface, one is the thermal expansion of particles, the other is the thermal expansion of the substrate. In order to distinguish the contribution of two functions in cleaning, two special cases are selected for research, one is absorbing particles, transparent substrate, only the thermal expansion of particles, the other is transparent particles, absorbing substrate, only the thermal expansion of substrate.

Back incident: laser cleaning can take the way of incident from the back of the substrate, which can be divided into two situations: one is that the substrate is transparent to the incident beam, the other is that the substrate is not transparent to the incident beam, but the thickness is small. In the case of transparent substrate, the difference between normal incidence and back incidence is only limited to the absorption form of the light beam by the particle itself, which can be divided into two cases: when the particle size is large, the cleaning efficiency of back incidence will be higher. However, when the particle size is small, the above situation will gradually reverse, and the back incidence has no obvious cleaning effect, but the positive incidence has a better cleaning effect. Figure 2 shows a comparison of forward laser cleaning and back laser cleaning.

![Comparison of forward laser cleaning and back laser cleaning](image)

Figure 2. Comparison of forward laser cleaning and back laser cleaning

2.2 Laser film removal

From the perspective of cleaning, the film can be divided into two types. The first one is called heterogeneous layer, that is, the film material and the substrate material are completely different. The
second corresponding is called the homogenous layer, that is, the substrate material contains the elements of the substrate, or the derivatives of the substrate. The main cleaning mechanism is different when laser is used for removal. The heterogeneous layer can be cleaned under the non-gasification mechanism, while the homogeneous layer can only be cleaned through the gasification mechanism generally, and the cleaning effect is obvious when the laser energy density reaches the ablation threshold of the film.

The gasification mechanism is a general mechanism for laser candle burning removal. It only needs the laser energy density to reach the gasification threshold of the surface material, which is applicable to all light absorbing materials. The specific removal methods include direct gasification and recoil pressure, as shown in Figure 3 below. The blue arrow in the right figure represents the direct gasification of laser, and the gray arrow represents the recoil pressure.

![Figure 3. Laser gasification removal](image)

3. Removal and purification of embroidery layer

3.1 Double beam laser wet cleaning and simultaneous purification

The efficiency of wet laser cleaning is much higher than that of dry laser cleaning. The liquid membrane solution commonly used in wet cleaning is water. If the rust removal water is not properly treated, it will cause secondary corrosion of steel and reduce the effectiveness of this cleaning method. In the experimental device, there are two lasers at the same time, one is used for rust removal and cleaning, and the other is used to remove the liquid residue in front of wet cleaning.

![Figure 4. Double beam laser wet cleaning device](image)
3.2 Decoy and passivation of medium pulse width laser scanning cleaning
Based on the carbon steel, the floating rust layer on the surface of the carbon steel was cleaned. The laser pulse width is fixed at the same time. It is the characteristic pulse width of the long modulation mode in the medium pulse width laser. It has the advantages of easy high-energy fiber weighing, high power and low loss, and long-distance transmission. The laser system can easily remove the floating rust on the surface of carbon steel, and its cleaning mechanism is the thermal elastic expansion of the substrate. At the same time, by controlling the surface temperature rise of the metal substrate and selecting the appropriate laser energy density, the goal of cleaning and passivation is achieved simultaneously.

4. Conclusions
The objects of laser cleaning can be divided into two kinds: particles and film. There are three kinds of functions for the removal of particles, one is thermal elastic expansion, the other is laser ablation, the third is explosive boiling of liquid film in the gap, among which the thermal elastic expansion mechanism is the main one. There are a variety of specific embodiments, which can be divided into normal incidence, angle incidence and back incidence. In this paper, two beam wet cleaning method and cleaning device, one is pulse laser and the other is quasi continuous laser. With the help of liquid film, the cleaning efficiency of laser de-rusting can be improved. By adjusting the number of pulses to control the surface temperature rise of substrate, the active oxidation and passivation of steel can be realized. The line scanning method of quasi continuous laser is used to remove the floating rust and realize the cleaning and passivation simultaneously.

Acknowledgement:
State Grid Company Science and Technology Project "Research and Application of High Voltage isolating switch online eliminating equipment based on Laser cleaning Technology", Project No.: SGLNJX00YJJS1900393.

References
[1] Zhou Bingxia et al. Laser principle[M]. China: National Defense Industry Press, 2009:1-14.
[2] Qiang Baohua, Shilong. Large scale data index construction and cluster performance analysis based on Hadoop MapReduce [J]. 2012,32 (4):310−311.
[3] Zhang Yongkang, Yao Hongbing, etc. Real time monitoring system of laser embroidery removal based on plasma intensity signal [J]. China laser.
[4] L Chen Ruifang, et al. Study on friction and wear properties of laser shock strengthened Fe Ni alloy [J]. China laser, 2010, 7:114-115.
[5] Zhang Yongkang, et al. Laser shock treatment to improve fatigue property of alloy [J]. China laser, 2012, 10.
[6] Zhang Chuanjun. Comparative study on several advanced methods of decoy in modern industry [J]. Mechanical research and application, 2004:162-165.