STATE OF THE ART LASER DRESSING SYSTEM FOR SUPER ABRASIVE GRINDING WHEELS

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Abstract: *Conventional dressing methods available commercially are single point and roller dressers. Dressing is essentially a sharpening operation designated to generate a specific topography on the working surface of the grinding wheel. These techniques have seldom been satisfactory for superabrasive wheels. There are problems of high dresser wear, insufficient grain protrusion, improper generation of profiles, stresses being induced into wheels, time consuming, shortcomings of loading induced deformation & shape distortion and very low dressing efficiencies. Numerous works have been published on the feasibility of laser dressing of grinding wheels till now. Based on the reports and research works, the present effort has been to actualize the same conditions of laser dressing in actual high speed grinding conditions. The work presents a favourable and opportune environment for the technology of laser dressing to shape into reality.*

Keywords: *Superabrasive, Grinding Wheel Dressing and Pulsed Fiber Laser*

1. INTRODUCTION

Dressing removes the loading and breaks away the glazed surface so that sharp abrasive particles are again presented to the work. Dressing of metal bonded superabrasive wheels is one of the most challenging tasks in grinding technology. This is done with various types of dressers. Superabrasive wheels with CBN or Diamond, which are complimentary to each other on adaptability, come very close to being the ideal grinding wheel from the technical and economical points of view [1, 2]. The advantages of long wheel life, high grinding efficiency, high surface finish and dimensional stability have made them indispensable for applications in precision & super-precision grinding, high speed efficiency grinding, hard-to-machine materials grinding, and very high surface finish grinding [1]. Superabrasives are manufactured mainly on a three-bond system, resin bond (phenolic/ polyamide), metal (sintered/electroplated), and vitreous (glass/ceramic). For maximum utilization and maintaining high efficiency these need to be dressed and conditioned. The Machining with grinding Wheels [3], defines dressing and conditioning of grinding wheels. In brief, truing is conditioning the macro-geometry and maintaining concentricity of a wheel with specific mounting system, or maintaining trueness of form. Dressing is reconditioning of micro-geometry to expose the grit cutting faces from the bond material along with removing any residue left by material being ground; in the process, splintering the abrasive grains to make them sharp and free cutting. Researchers from the 80s to find a viable, efficient and a universal method of dressing superabrasive wheels took up these issues. Various non-conventional and non-contact methods have been applied to find an efficient dressing method. Investigations were carried into laser dressing method first of all in dressing an Alumina wheel [4] and superabrasive wheels [5]. Along with laser dressing non-contact methods, many other unconventional techniques were also studied, such as Stick-aided Loose Abrasive Dressing (SLAD) [6], Water-jet dressing [7], and Ultrasonic dressing [8] methods.

Extensive work has been done on electrical based dressing techniques too, like Electrochemical in-process Controlled Dressing (ECD) [9], Electrolytic In-process Dressing (ELID) [10], EDM truing etc. The main objective of the present work is to arrive at the feasibility of the laser dressing in actual grinding machine conditions. Effort has been taken in arriving and analyzing all the previous works on laser dressing for a relevant literature on this research field. Based on the reports and research works, concerted effort was undertaken to prepare a comprehensive literature base and the similar parameters of laser dressing were tried in actual high speed grinding conditions.

A work on the modeling of the energy absorption in laser dressing taking into account the position of laser beam irradiation with respect to wheel was undertaken [11]. From theoretical modeling it was concluded that the focal area on cylindrical wheel surfaces increased with increase in incident angle, which implied the decrease in energy density of laser irradiation also. The wheel diameter was also attributed to lower the absorbed energy though on a lesser intensity as compared to incident angle of laser irradiation. From experimental results of truing by a pulsed YAG laser on vitrified small CBN wheel, it was shown that absorbed energy decreases with increasing incident angle. A critical incident angle θ_c was estimated to exist, such that between θ_c and 90^o the laser processing became insignificant. For truing, two modes were used, one with incident angle mode and the other focus offset mode. The maximum incident angle employed was 70^o at which volume of material removal was 0.04mm. The limiting intensities were given to lie between $7.5x10^4$ W/cm^2 to $1.25x10^5$ W/cm^2 for the truing of vitreous bonded CBN wheel. The laser truing operation simulated a single point diamond dresser to yield a wheel profile resembling a micro-thread. It was reported that the truing resulted in smoother wheel surface with smaller protrusion of cutting edges and this resulted in lower grinding efficiency of the wheel. Fig. 1 shows the laser dressing system.

Table 1: Specifications of LDS

Sl No.	Parameter	Description
1	Laser medium/type	Pulsed Ytterbium Fiber laser
2	Energy per pulse	Approx. 1mJ @PRR=20 kHz
3	Wavelength	1064 nm
4	Pulse width	100 ns – 100 µs
5	Pulse rep. Rate	80 kHz (max)
6	Beam Quality	$M^2 < 1.8$

2. EXPERIMENTATION

This work mainly aimed at comparing the extent of damage caused to abrasive and bond material to determine the feasibility of laser dressing with selective bond material removal. It was further reported that due to its localized heating effect, laser dressing generates multiple cutting edges on individual grains without much wheel material wastage, facilitates exposure of new cutting edges in subsequent grinding operations by the removal of re-solidified layer, which in turn is supplemented by the presence of thermally induced multiple cracks. This work was subsequently carried forward by a series of works covering aspects of performance and profile study of laser dressed wheel and prediction of groove geometry by modeling average wheel properties for various parameters. From the performance point of view, it was shown that the grinding forces reduced drastically for laser dressed SiC wheels when compared to diamond dressing; although for Alumina wheels, laser dressing resulted in higher grinding forces. But the surface finish improved both for SiC and Al_2O_3 wheels in general, with increasing feed rates and decreasing intensities. A detailed work on grinding performance of laser-dressed Al_2O_3 wheel with dressing feed as a critical parameter was undertaken in.

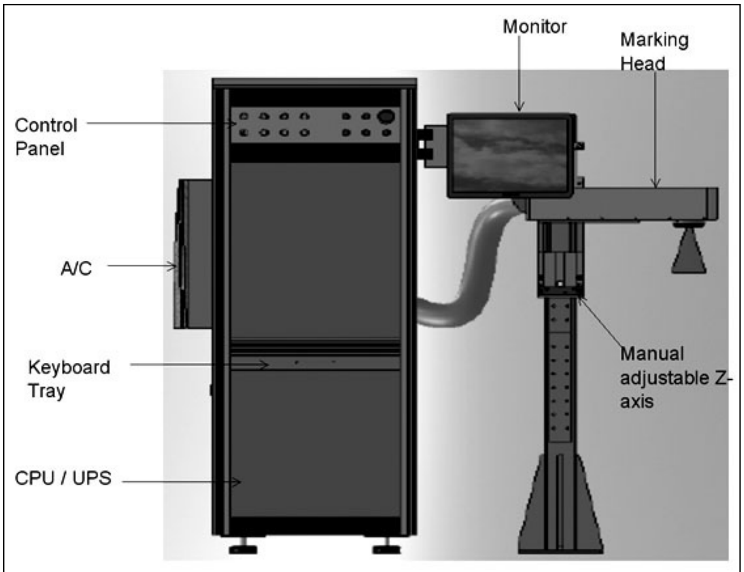

Fig 1. Laser Dressing System

In the present work, a suitable laser

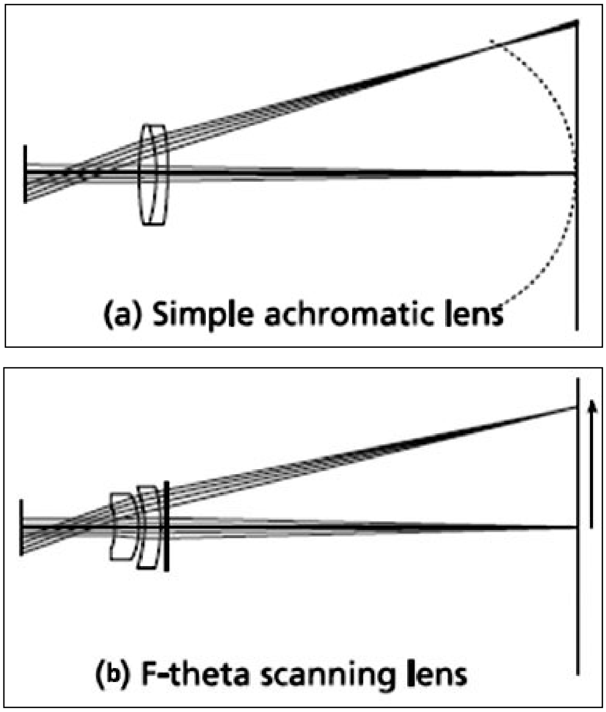

Fig 2. Focal Field of Chromatic Lens and f-theta Scanning Lens

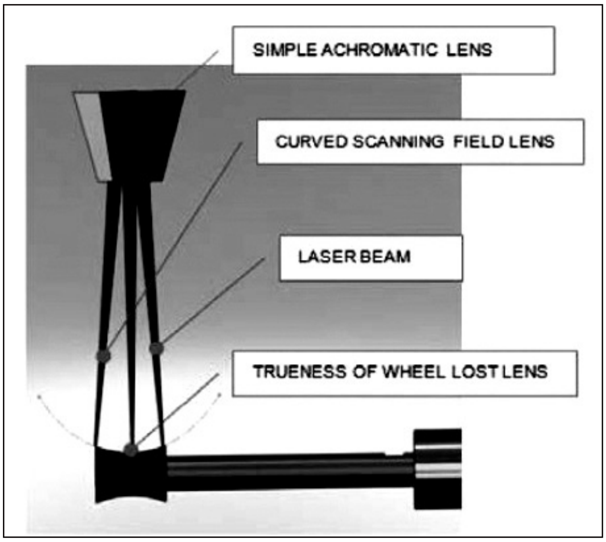

Fig 3. Effect on Cylindricity of Grinding Wheel Being Dressed by Chromatic Lens Scanning

system was selected and integrated to a cylindrical grinding machine. An attachment was devised to actuate the movements of the laser system, taking into account the effects of parallelism, angularity and precise control of height (focal length of laser beam) as shown in Fig. 4. The aspect of flat field scanning by laser beam was also considered in this work, which has not been reported till date. Flat field scanning is very much crucial, as the dressed grinding surface has to be maintained within sub-micron cylindricity to achieve the high precision surface finish and

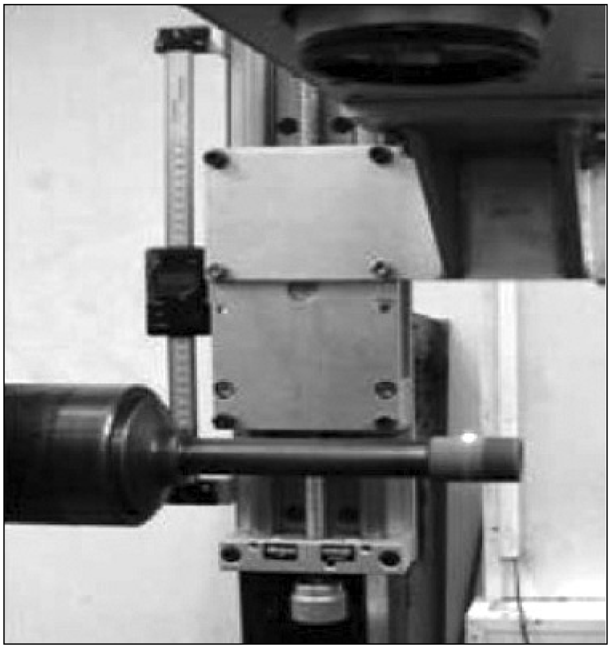

Fig 4. Dressing Setup

Table 2: Dressing Parameters

Sl No.	Parameter	Experiments			
		1	**2**	**3**	**4**
1	Power (W)	6	8	10	12
2	PRR (kHz)	10	20	30	40
3	Scan Speed (mm/s)	4	6	8	10
4	Number of Scan	10	12	14	16
	Beam Spot Diameter (µm)	100			
5	Wheel	Resin bonded Al_2O_3, 25 mm			
6	Wheel Speed	18,000 RPM			

trueness after grinding. Table 1 shows the specifications of the LDS. Also, it is very important to achieve sufficient energy density of laser beam without changing the spot size that happens in case of simple achromatic scanning lens as shown in Fig. 2 and Fig. 3. The formulae for calculation of repetition rate and scan speed were arrived. Fig. 5 shows the theoretical calculations, which were used in this work.

Scanning the laser beam over wheel surface in vertical alignment along with a simultaneous rotation of the wheel in order to simulate actual grinding conditions performed the dressing. Even though the strategy depicted for theoretical estimation above is a straight groove, the laser actually generates a helical groove over the

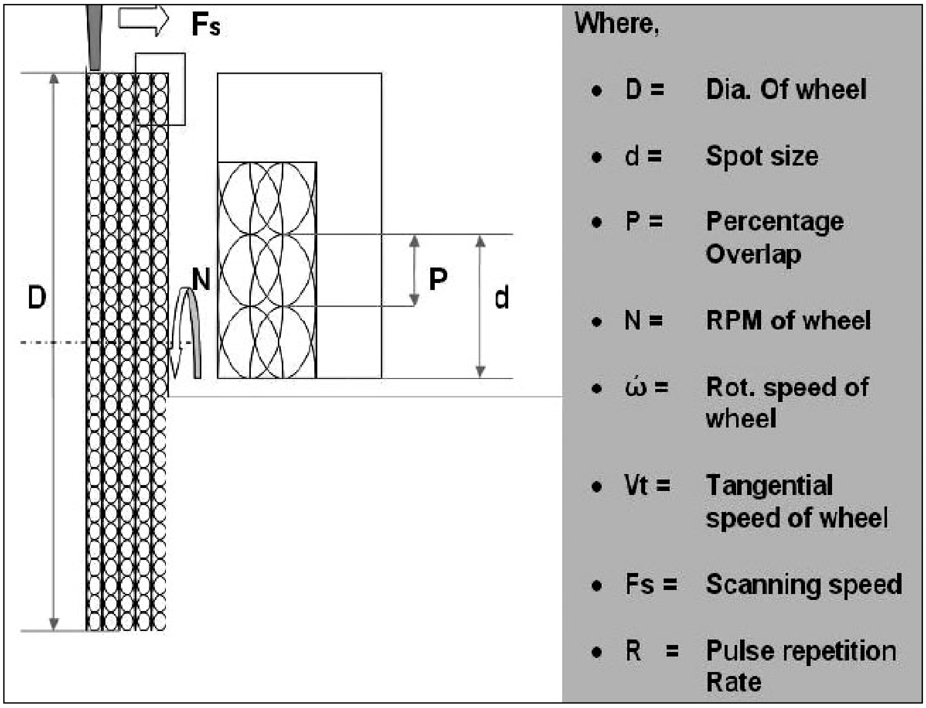

Fig 5. Dressing Strategy and Parameters

Average Power = Pulse energy x PRR Peak Power = Pulse energy/ Pulse Duration Laser Intensity = Peak power / Beam spot Area

3. DISCUSSIONS

The present work mainly tried to arrive to the feasibility of the laser dressing in actual grinding machine conditions. The dressing strategy achieved was a helical groove realized by the scanning motion against a fast rotating wheel. Experimentation was carried out based on the parameters, which are shown in Table 2. The dressed wheel was characterized by imaging under a confocal microscope revealing the true dressing capabilities of laser beam. The dressed wheel surface was studied for dress ability by using pulsed laser in actual grinding

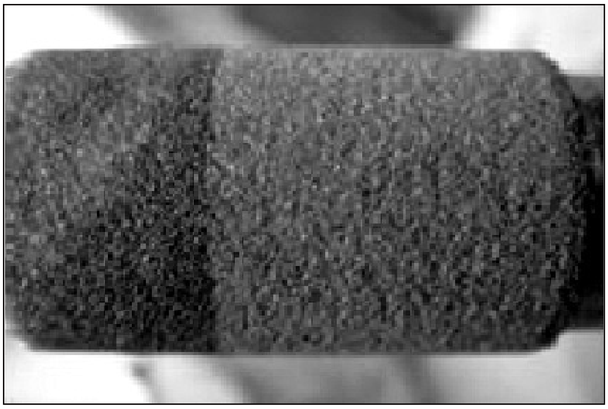

Fig 6. Laser Dressed Wheel with Loaded Portion

wheel surface, and the feed, scanning speed and intensity of laser finally decides the percentage overlap (P) of grooves for proper dressing. The laser power and pulse repetition rate too, play a vital role, which are related to the dressing parameters, which were used in this experimentation. Fig. 6 shows the differences between before and after laser dressing of grinding wheel.

$$\text{Rep Rate, } R = \frac{\pi DN}{60\,(d-2pd)}$$

$$\text{Scan Speed, } F_s = (d-2pd).\,N$$

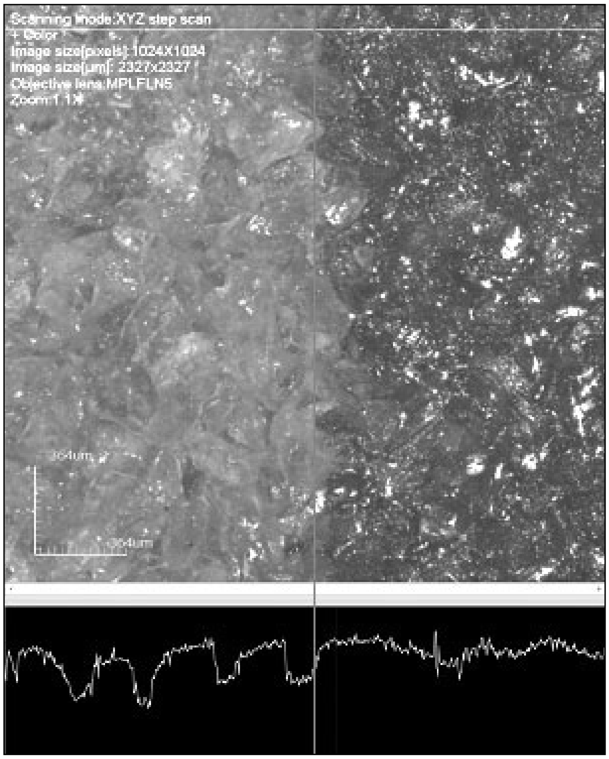

Fig 7. Surface Topography of a Loaded Wheel

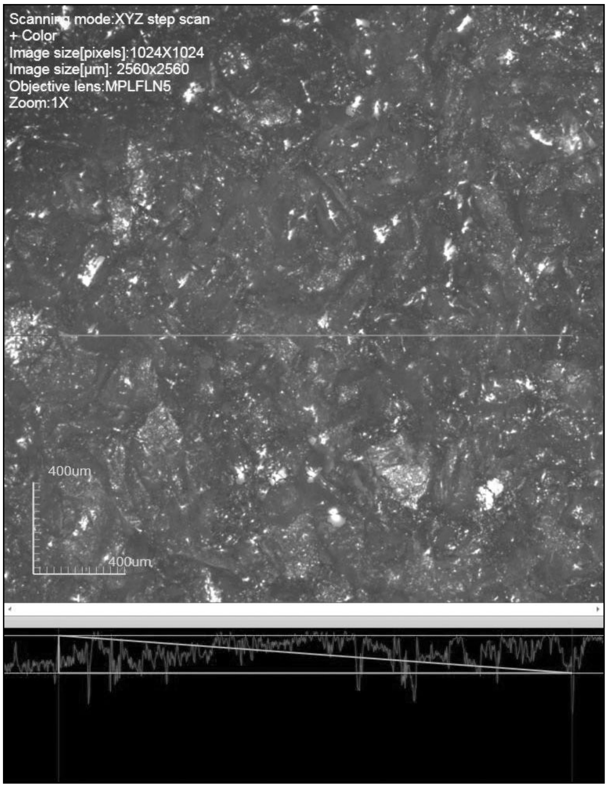

Fig 8. Surface Topography of the Interface of the Laser Dressed Wheel

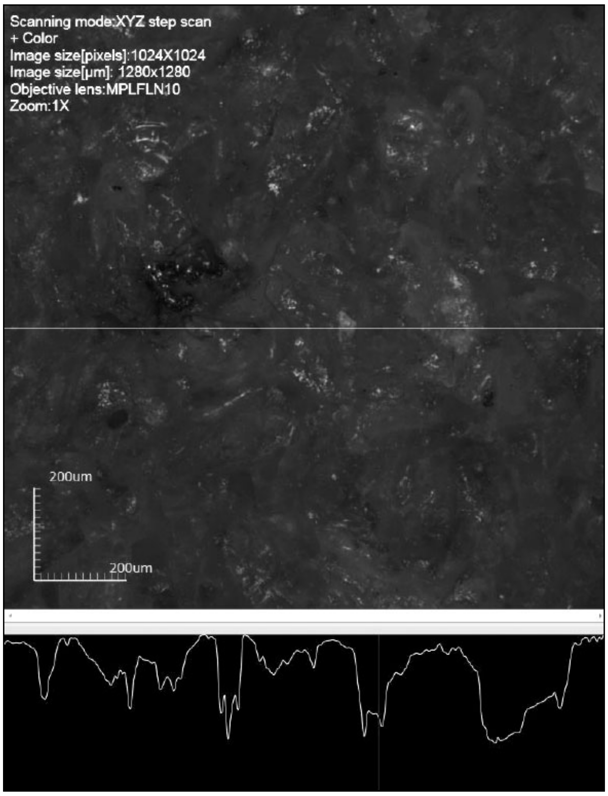

Fig 9. Surface Topography of a Laser Dressed Wheel Surface

conditions. The strategy that was achieved is a helical groove track with an overlap of 0.50. The images clearly depict the improvement in the wheel conditioning after laser dressing. The amount of chip pockets generated and the degree of the dressing achieved clearly serves as a confidence booster for further works on superabrasive wheels. It proves that laser dressing can be really achieved even in actual grinding conditions, thus also giving the possibility to investigate into in-process dressing.

Fig. 7 depicts a fully loaded wheel surface image. The sectional profile of the loaded wheel represents that there are no chip pockets as metal has loaded in the spaces between abrasive grains. Thus, the wheel profile appears as a continuous jagged line without any prominent valleys or troughs.

In Fig. 8, is depicted the laser dressed surface of the grinding wheel with image taken at the interface of loaded and dressed regions. From the sectional profile it is evident how the dressed region has been cleared off the loaded material revealing the peaks and troughs clearly. As such the cutting edges of the abrasive material is protruded sufficiently, necessary for grinding.

Fig. 9 is shown depicting the fully dressed surface of the grinding wheel. From the profile section it has become evident how laser dressing has generated prominent peaks and troughs through out the wheel. Satisfactory surface topography can be obtained under the appropriate conditions. The dressed wheel surface has relatively large particles with considerable porosity in between. The particles are irregular in shape with a few bonding bridges between them. A wide distribution of the size of the grinding grains was seen, but the shape of the grains appeared to be regular or equi-axed with well-defined vertices and edges on each grinding grain.

4. CONCLUSION

Using pulsed ytterbium fiber laser sources, a great potential for high precision and a highly reliable method for dressing of the resin bonded grinding wheel is observed. A lot of other works are reportedly coming out giving details into the laser working, their parameter optimization and thermal modeling. Although all these works have contributed to a very good knowledge base for laser dressing and truing of grinding wheels, mainly for the Superabrasives, seldom have they delved into working out a pragmatic and practical solution in the development of a universal dressing method. The aspects of maintaining perfect cylindricity, and generating perfect generators on wheels after laser dressing where not thoroughly observed, which were bound to come into play as most of the works were undertaken not on the grinding machines, but on experimental setups. Researchers [5] have already pointed out the cylindricity errors that were seldom avoided as the wheel were detached from machines, dressed outside and again installed back onto the grinding machines. However, deriving judicious conclusions from the vast knowledge base for critical laser parameters and formulating strategies to avoid obstacles already faced, along with proper planned experimentations and with provisions for stringent production oriented design for incorporating the dressing operation on actual production machines, a universal dressing method using laser as a tool is feasible. The present work was concerted to generate a collection of all available works and compare them for the feasibility of laser dressing and applying the most preferred parameters for dressing in actual conditions. Accordingly the preliminary studies were carried out and found to be satisfactory. Form the confocal images it was observed that when the power is 10 W, the optimized grits were obtained. Depending upon the laser processing parameters used, the high thermal energy produced during laser processing caused melting and/or vaporization of the grinding wheel material on surface. Thus both melting (followed by re-solidification) and/or vaporization resulted in modification of surface topography. Also, it was observed that laser dressing reduced the porosity on the region near to the surface of the grinding wheel. Further consolidation on the work is envisaged for superabrasive wheels and proving them for the commercial viability of this technology. Moreover, with day-by-day reduction in the cost and sizes of laser units, the most intimidating obstacle of high cost is also expected to dissolve and the commercialization of laser dressing technology shows a good feasibility owing to its numerous benefits.

5. REFERENCES

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