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TxDOT Project 0-7084

Develop Improved Methods for Eliminating Striping on Roadway Surfaces: Final Report

Dr. Maurizio Manzo, University of North Texas
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16. Abstract This project investigated current stripes removal techniques, and a laser system was assembled and tested in the field. Current removal techniques, such as flailing and water blasting, can cause damage to the road surface and leave ghost stripes that may distract drivers. A literature review and survey responses from various DOT districts have shown that both flailing and water blasting leave scars, resulting in ghost markings. A laser system was assembled and tested on in-house-made samples for three different types of stripes (i.e., thermo by truck, hot tape, and paint) on concrete, and for white paint on asphalt. Photos were used to evaluate the cleanliness using a MATLAB script calculating Root Mean Squared Errors (RMSEs). Although the stripes were successfully removed, leaving the surface undamaged, the removal speeds were way below other methods (i.e., 1.7 ft/min (0.0193182 miles/hr) for thermo (by truck) stripes, 0.065 ft/min (0.0007386 miles/hr) for paint stripes, and 0.31 ft/min (0.0035227 miles/hr) for hot tape stripes), due to the relatively low output power of the laser (200W). The laser system was also tested in the field, using a pickup truck, showing that the system worked well in a real environment. A higher output power laser (i.e., 1000W) could significantly increase the removal speed of stripes on the road. A similar laser with an average output power of 1000W can be projected to have a removal speed of ~53 ft/min (0.60 miles/hr) for thermo (by truck) stripes, 44.6 ft/min (0.51 miles/hr) for hot tape stripes, and 158 ft/min (1.79 miles/hr) for paint stripes. This report presents the findings from this study, including test procedures and field test implementation of the use of laser technology for stripe ablation.		
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Zhenhua Huang

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ABSTRACT

This project aimed at investigating the current stripes removal techniques, and a laser system was assembled and tested in the field. Current removal techniques, such as flailing and water blasting, can cause damage to the road surface and leave ghost stripes that may distract the drivers. Literature review and survey responses from various DOT districts have shown that both flailing and water blasting leave scars, resulting in ghost markings. A laser system was assembled and tested on in-house made samples for three different types of stripes (i.e., thermo by truck, hot tape, and paint) on concrete, and for white paint on asphalt. Photos were used to evaluate the cleanliness using a MATLAB script calculating Root Mean Squared Errors (RMSEs). Although the stripes were successfully removed, leaving the surface undamaged, the removal speeds were way below other methods (i.e., 1.7 ft/min (0.0193182 miles/hr) for thermo (by truck) stripes, 0.065 ft/min (0.0007386 miles/hr) for paint stripes, and 0.31 ft/min (0.0035227 miles/hr) for hot tape stripes), due to the relatively low output power of the laser (200W). The laser system was also tested in the field, using a pickup truck, showing that the system worked well in a real environment. A higher output power laser (i.e., 1000W) could significantly increase the removal speed of stripes on the road. Using a similar laser with an average output power of 1000W, it can be projected to have a removal speed of ~53 ft/min (0.60 miles/hr) for thermo (by truck) stripes, 44.6 ft/min (0.51 miles/hr) for hot tape stripes, and 158 ft/min (1.79 miles/hr) for paint stripes. This report presents the findings from this study, including test procedures and field tests implementation of the use of laser technology for stripes ablation.

EXECUTIVE SUMMARY

Road stripe removal can be cumbersome at times. Current removal techniques, such as flailing and hydro-blasting, can cause damage to the road surface and leave ghost stripes that may distract drivers.

This project aimed to investigate current stripe removal techniques, and a laser system was assembled and tested in the field. A literature review about techniques and a survey were used to understand the current state-of-the-art and industry standards regarding the removal of road stripes. The survey was prepared and disseminated to various DOT districts from different states, such as Texas, New Hampshire, Missouri, Wyoming, North Carolina, Louisiana, Virginia, New York State, Minnesota, Alabama, Arkansas, Kentucky, Florida, Illinois, Indiana, Vermont, Wisconsin, Iowa, Virginia, and North Dakota.

The survey questions were focused on pavement marking removal methods, frequency of use, removal effectiveness, problems of scarring and ghost marking, effectiveness for marking materials and pavement surfaces, effectivity for marking thickness, removal speed, cost, environmental and health impact, and skill level required.

From both the literature review and survey responses, it was found that flailing and water blasting methods are commonly used for road stripe removal, with flailing slightly more frequently used than water blasting. In general, thermoplastic stripes exhibited the most severe scarring, followed by paint, epoxy, and then tape. The flailing method was found to be effective for removing thick marking (over 100 mil), was cheaper, and required a lower level of equipment and expertise compared to the water blasting method. On the other hand, the water blasting method was found to be more effective in removing stripes, exhibited lower scarring and ghosting, and was perceived as more environmentally and health-friendly when compared to the grinding method. However, water blasting was found to be less effective for removing thick marking, more expensive, and required a higher level of equipment and expertise.

A laser system was put together, consisting of a pulsed fiber laser with a wavelength of 1064 nm and 200 W average output power, a chiller, a laser scanner, air knives, a generator, and a compressor. The system was controlled by using an Ethernet connection via a laptop, and two software were used, one for controlling the laser only and another one for controlling the laser scanner and the laser.

First, the system was tested in the lab on concrete samples made in-house of three different white stripes (thermo by truck, hot tape, and paint). Paint from asphalt core samples was also tested. During the lab tests, the influence of laser irradiation parameters on the removal effectiveness was investigated. The removal effectiveness included the removal time and quality, in which the removal quality was evaluated by using a Matlab script that compared errors of grayscale tones on the images taken from samples between the original pavement area before striping and the stripe-removed area. The parameters included the average laser power (watts), pulse frequency (kHz), pulse width (ns), scanning speed (mm/s), fill pitch (mm), number of passes, and number of changing scan directions. Photos were taken from stripe samples and calculated the root mean squared errors (RMSEs).

From the tests it was shown that thermo by truck stripes were the easiest to be removed using the laser, followed by paint, and hot tape stripes. The removal speeds for stripes with standard width were 1.7 ft/min (0.0193182 miles/hr) for thermo by truck stripes, 0.065 ft/min (0.0007386 miles/hr) for paint stripes, and 0.31 ft/min (0.0035227 miles/hr) for hot tape stripes. In all tests it was found that all 200W average power was needed to ablate the stripes, and that the output power was insufficient to achieve high removal rates.

The laser system was then put on a pick-up truck, with the aid of a pallet and dampening material to absorb vibration during the transportation. The laser scanner was mounted on the back of the truck, and dampening material was also used. Field tests were performed on white thermo stripes on concrete. Tests showed that the system was successful at removing stripes from concrete but exhibited slow removal speeds.

To meet the stripe removal speed requirements for practical applications, one possible solution is to increase the output power of the laser (e.g., over 1000W) and/or its frequency (over 200KHz) coupled together with a 3-phase generator and a larger scanner, and able to achieve removal speeds of ~53 ft/min (0.60 miles/hr) for thermoplastic stripes, 44.6 ft/min (0.51 miles/hr) for the hot tape stripe, and 158 ft/min (1.79 miles/hr) for the paint stripe.

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CHAPTER 1.

1.1 Introduction

Eliminating existing roadway striping or pavement markings is a real challenge, as the stripes must be completely removed without causing damage to the road surface. Sometimes, these stripes are even more difficult to remove than the underlying asphalt. Moreover, the materials used in asphalts are very porous, allowing the striping paints to penetrate through surface pores into the deeper underground. Therefore, it is necessary to utilize powerful equipment and efficient technologies for eliminating striping on roadways.

The most commonly used techniques for striping removal are flailing and hydro-blasting. However, these techniques can cause damage to the road, creating problems for drivers, as images of the old markings are created (ghost stripes). These scars can confuse drivers, especially at night and/or in wet weather conditions.

Some methods work well with a specific type of stripe material and/or on a specific type of surface. Research project 0_7084 reviewed various current methods used to remove stripes from paved roads and introduced a novel method based on laser ablation. A prototype was assembled and tested in the field.

Chapter 2 of this report discusses the pros and cons of existing striping methods. In addition, the responses from a national survey sent to experts in the field from various DOT districts are also presented.

Chapter 3 describes the laser equipment used and the test results conducted in a lab environment for different types of stripes and pavements (i.e., concrete and asphalt).

In Chapter 4, the laser prototype assembly is described, and preliminary field tests are presented.

Finally, Chapter 5 discusses the implementation of future technology.

CHAPTER 2.

2.1 Existent striping methods

Blasting: Several blasting removal techniques are currently available, such as high-pressure water blasting, sand blasting, hydro-blasting, dry ice blasting, shot blasting, crushed glass blasting, and soda blasting. Usually, a large truck is used with a mounted mobile high-pressure (40,000 psi) water blasting system, containing the location of the supply water tank and return waste storage tank [1-4].

Flailing: Flailing can be used on any marking type with the drawback of scarring of the road surface. All flailing equipment removes the roadway markings by using abrasive rotating disks or spindles for removing marking, similar to an orbital sander.

Other methods are burning, chemical, and masking.

A search in the current literature showed that the blasting method removes all types of markings without leaving a deep scar; however, this method still resulted in shadow lines from the removal process. Flailing left scars after the removal of the stripes. Also, both methods created dust and debris [1-4].

2.2 Synthesis study

Survey responses were collected to obtain answers to specific questions regarding pavement marking removal methods, including their frequency of use, effectiveness, problems related to scarring and ghost marking, their suitability for marking materials and pavement surfaces, and their impact on removal speed, cost, environment, and health. The survey was distributed to various DOTs including TxDOT, New Hampshire, Missouri, Wyoming, North Carolina, Louisiana, Virginia, New York State, Minnesota, Alabama, Arkansas, Kentucky, Florida, Illinois, Indiana, Vermont, Wisconsin, Iowa, and North Dakota, as well as some contractors.

The analyzed survey data indicated that flailing is the most common method, followed by water blasting. Both methods are primarily used on thermoplastic and paint stripes materials, but also work on all types of markings.

Table 1 summarizes pros and cons of flailing and water blasting methods.

Table 1: Pros and Cons of flailing and water (hydro) blasting.

Grinding		Water (hydro) blasting	
Pros	Cons	Pros	Cons
Effective for removing thick marking (over 100 mil)	Surface damage	Removal effectiveness	Less effective for removing thick marking
Cost	Ghosting	Low scarring	Cost
Requires low level equipment and expertise		Low ghosting	Requires higher level of equipment and expertise
		Perceived as environmental & health friendly	

Flailing and water blasting have similar effectiveness for high-speed removal (>20-ft/min). Comparing flailing for the four marking types, thermo by truck causes the most severe scarring, followed by paint, epoxy, and then tape. Thermo by truck and epoxy produced severe ghost marking, followed by paint, and then tape.

CHAPTER 3

3.1 Laser selection and software

The laser selected for this project is IPG Laser GmbH (Model: YLP-OLRC). The system is a maintenance-free pulsed fiber laser with a wavelength of 1064 nm and water cooled, with 200 W

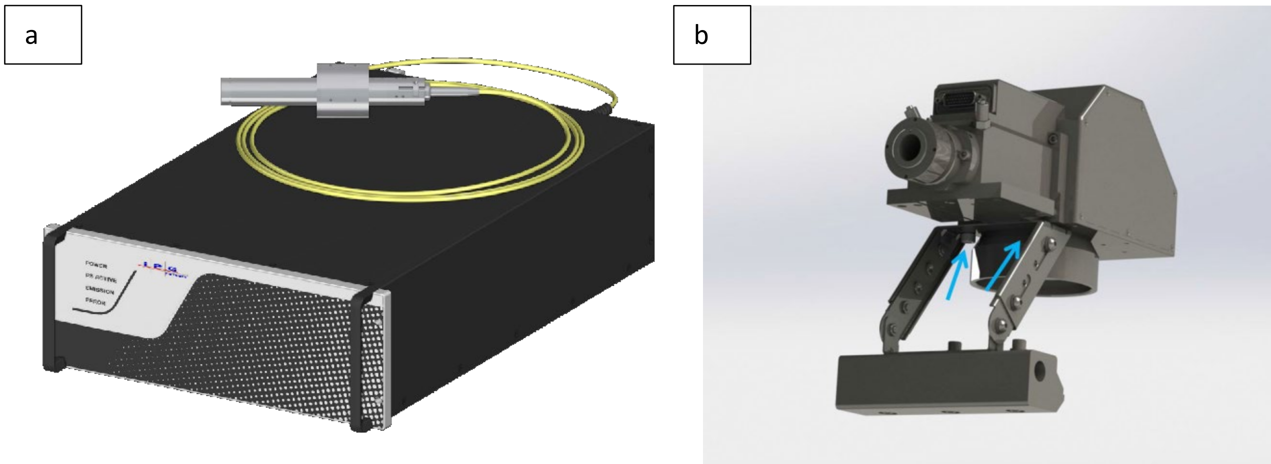

Figure 1: a) Solid state fiber laser; b) laser scanner.

average output power. The laser scan head made with a galvo-mirror was used to scan the laser beam at a selected speed. The optics selected provided a focal length of 254 mm with a scanned area of about 100x100 mm. Air knives are added to the scanner to avoid damages to the optics during the ablation process.

The laser software allows for the tuning of several laser parameters, such as power, pulse frequency, and pulse width. Figure 1a displays the graphical user interface (GUI) of the laser

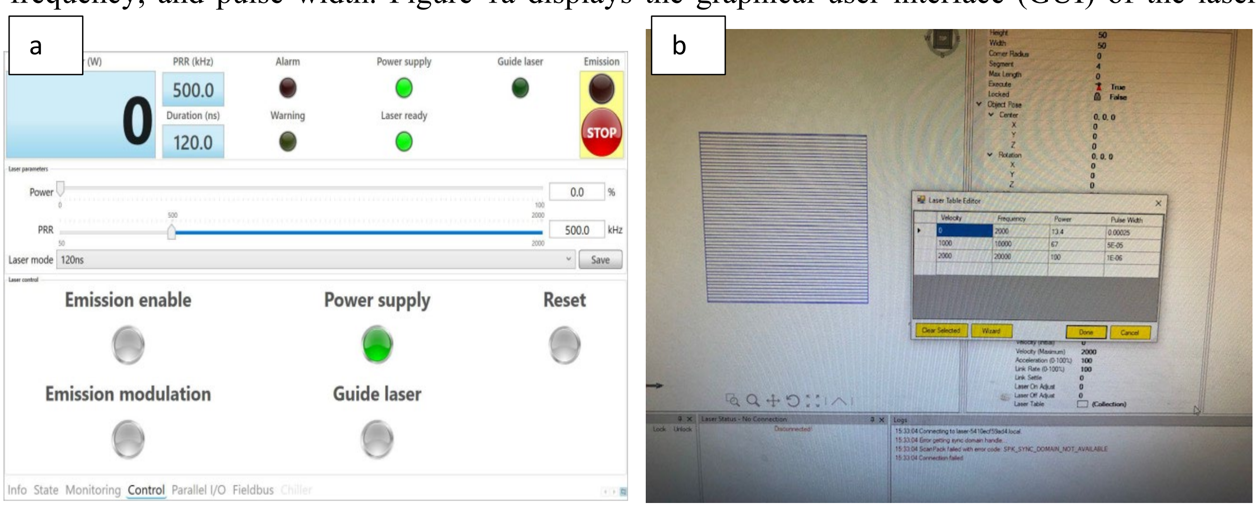

Figure 2: a) Laser's software; b) laser scanner's software.

software, while Figure 2b shows the GUI of the laser scanner software. The software enables control of both laser parameters and laser scanners, including the ability to adjust the scanning area, scanning velocity, and fill pitch, among others. The fill pitch is an essential parameter that directly impacts the ablation process by affecting the energy deposited per unit area.

3.2 Laboratory tests and analysis

Three types of white concrete pavement stripes, i.e., thermo by truck, hot tape, and paint were removed using the proposed laser equipment. Moreover, white paint on asphalt surface was also removed.

To quantitatively analyze images, Grayscale images containing a range of gray tones can be used to compare sets of images (a reference and a test image) pixel by pixel from white to black, for a better representation of images. A MATLAB program was developed for calculating the average grayscale difference between the laser-removed pavement surfaces and the original pavement (as a control). Three comparison errors, Root Mean Squared Error (RMSE), Mean squared error (MSE), and Mean absolute error (MAE) were calculated from various ablated regions using different laser parameters.

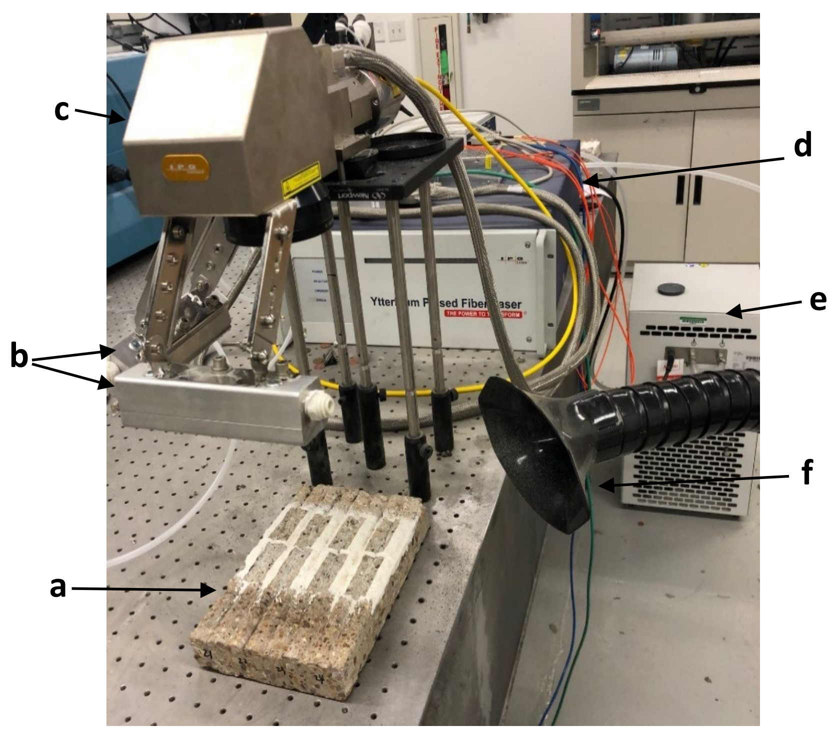

Figure 3: Laser scan system including: a. sample, b. pressured air knife, c. laser scan head, d. laser, e. water cooler, f. fume extractor.

To improve the removal efficiency, the scanning time was minimized using grayscale errors between the stripe removed zone and the control one as parameters.

The experimental setup is shown in Fig 3. The fume absorber was used to collect fume from the ablation process and the air knife was used to protect the optics of the scanner from the debris.

Figure 4 shows a concrete specimen with different laser ablated regions of a white thermo (by truck) stripe. Different laser parameters were tested. The highest average laser power of 200 W with a pulse width of 60 ns and pulse frequency of 20 - 30 kHz was utilized during the removal of the thermo (by truck) stripes. The galvo-mirror, which scans the laser beam used for removing the stripes, was set to 2000 mm/sec. The laser beam was positioned perpendicular to the sample's surface.

The thickness of the tested white thermo (by truck) stripe was about 100 mil (2.54 mm). An area of 0.8 × 2 in (20 × 50 mm) was removed from the specimen by the laser. It was found that the

Figure 4: Photograph of a white thermo (by truck) stripe on concrete specimen with different ablated regions.

shortest scanning time of 2.33 – 4 s (with the average errors smaller than 0.13) can be achieved with the following laser parameters showed in table 2:

Table 2: Parameters used for the removal of a white thermo (by truck) stripe from concrete.

Pulse frequency	30Hz
Pulse width	30ns
Number of passes	2- 10
Scanning Speed	8000 – 9000 mm/s
Number of scanning direction	2 - 10

Using the optimal time, for a 4-inch stripe (100 mile in thickness), the speed removal is 1.7 ft/min (0.0193182 miles/hr.).

Fig. 4 shows different ablated regions of the thermo (by truck) stripe specimen.

Similarly, areas of size 0.8 × 2 in (20 × 50 mm) were removed from a hot tape stripe as shown in Fig. 5. It was found that the shortest scanning time of 62 – 90 s (with the average errors smaller than 0.15) can be achieved with the following laser parameters showed in table 3:

Figure 5: Photograph of a white hot tape stripe on concrete specimen with different ablated regions.

Table 3: Parameters used for the removal of a hot tape stripe from concrete.

Pulse frequency	30Hz
Pulse width	30ns
Number of passes	2- 3
Scanning Speed	1000 – 3000 mm/s
Number of scanning direction	6 - 10

Using the optimal time, for a 4-inch stripe (140 mile in thickness), the speed removal is 0.065 ft/min (0.0007386 miles/hr). This can be improved with the current system based on the cleanness values desired and evaluated at a driving distance.

Also, for the paint stripe, areas of size 0.8 × 2 in (20 × 50 mm) were removed using laser ablation and it was found that the shortest scanning time of 13-36 s (with the average errors smaller than 0.13) can be achieved with the following laser parameters:

Figure 6: Photograph of a white paint stripe on concrete specimen with different ablated regions.

Table 4: Parameters used for the removal of a white paint stripe from concrete.

Pulse frequency	30Hz
Pulse width	30ns
Number of passes	2- 3
Scanning Speed	1000 – 3000 mm/s
Number of scanning direction	6 - 10

The speed of removing the 4-in tape stripe was 0.31 ft/min (0.0035227 miles/hr). Tests were also made on asphalt cores received from the TxDOT Fort Worth Material Science Lab. The cores were covered by white paint stripe with a thickness of less than 40 mil (<1 mm).

Fig. 6 shows the removal process of paint stripe of 2.5” × 2.5” square from asphalt by multiple scans.

The laser parameter selected were the same as the paint stripe removal test of the concrete specimen. The first scan only removed a small portion of the white stripe as shown in Fig. 7a. The second scan removed most of the stripe as shown in Fig. 7b. The third scan removed the whole

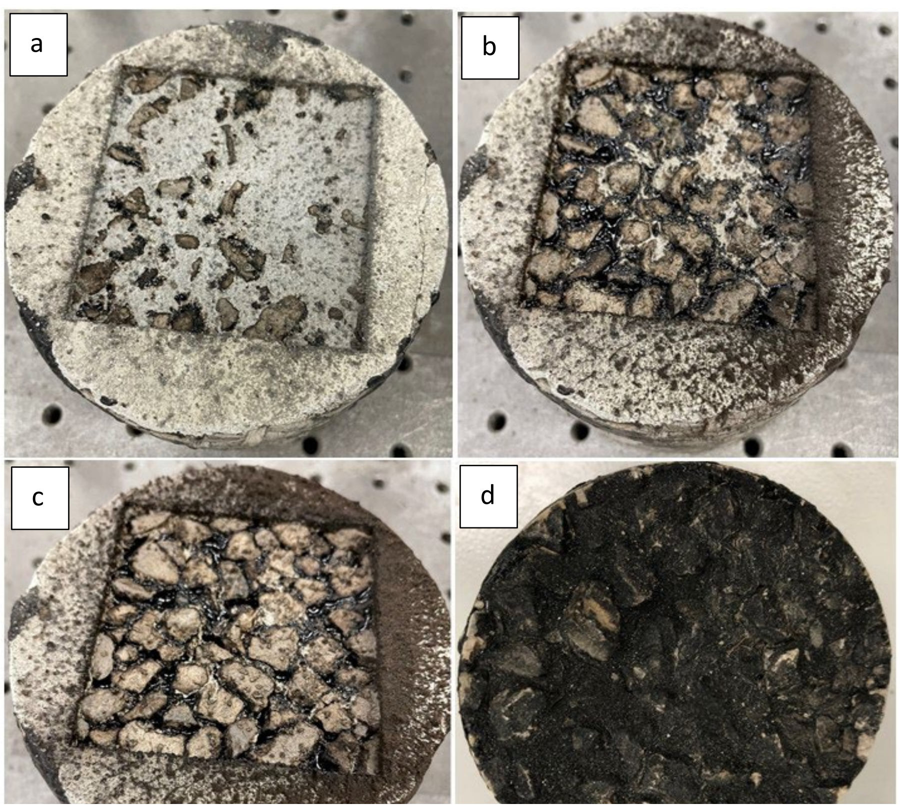

Figure 7: Removal of paint stripe from asphalt by multiple scans: a) first scan; b) second scan; c) third scan; d) control.

white stripe but melted the superficial layer of the asphalt, showing coarse aggregates (see Fig. 7c). Fig. 7d shows the control sample before the laser removal process.

CHAPTER 4

4.1 Laser equipment assembly

The laser box was mounted on a pallet, together with various controllers as shown in Figure 8a. The Chiller unit was also mounted on the pallet and was used to maintain the laser operational internal temperature (Figure 8b).

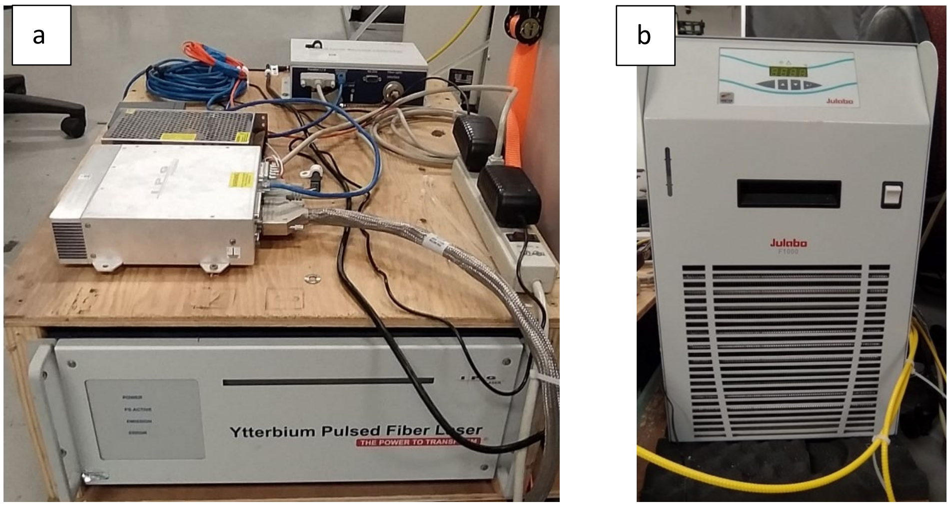

Figure 8: a) Ytterbium pulsed fiber laser and controllers assembled in a pallet; b) chiller.

The laser scanner was mounted on the back of the pick-up truck using a custom-made adapter for the hitch. The laser scanner was used to move the laser beam at high speed within an area of about 160x160 mm.

Figure 9: Scanner connected to the hitch of the pick-up truck.

The scanner was connected to the hitch of the truck and was placed at 254mm from the surfacer road (focal length of the lens).

The pallet containing both laser and chiller, an electrical generator, and a compressor were placed onto the truck bed (see Fig. 10). The compressor provided air to shield the optics of the laser scanner from ejected glass beads.

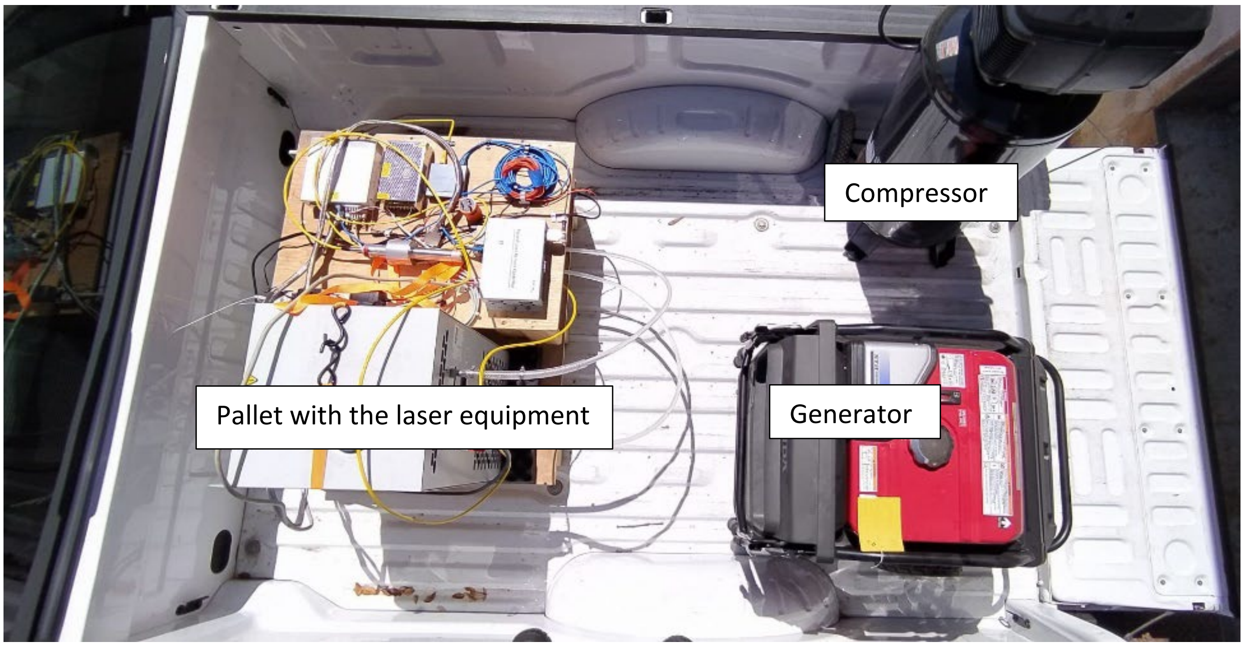

Figure 10: Instrumentation layout on vehicles' trailer, top view.

The communication between laser and user control takes place via ethernet cable to a pc.

4.2 Laser field tests

The laser equipment was tested during the ablation operations in a low-traffic area in Grand Prairie, near a Stripe-A-Zone facility (see Fig. 11). Protective laser glasses were used, and a portable barrier was placed nearby the laser scanner. As the ablation process was performed with the truck steady in position and only moved to ablate different portions of the stripe, there were no issues caused by possible vibrations. The ambient temperature outside was about 99°F, and the humidity was about 43% on a sunny day. Despite the temperature sensor mounted on the equipment frequently registering higher than 110°F under direct sunlight, the equipment worked well, proving the system's ruggedness in operating outside ideal laboratory environmental conditions.

During field tests, portions of white thermo (by truck) stripes were removed from the concrete surface. The length of each portion was 4.72 inches, and the removal time was 779 seconds (about 13 minutes). Three different tests were performed as showed in Fig. 12. In test 1, the distance between the scanner and the surface (clearance) was about 8.5 inches, and the ablation operation was stopped early once burning occurred. Test 2 was performed with a clearance of about 10 inches

Figure 11: Traffic control during the ablation operations.

from the surface and showed better results. Lastly, test 3 was performed at about 10.6 inches from the concrete, showing suboptimal performance.

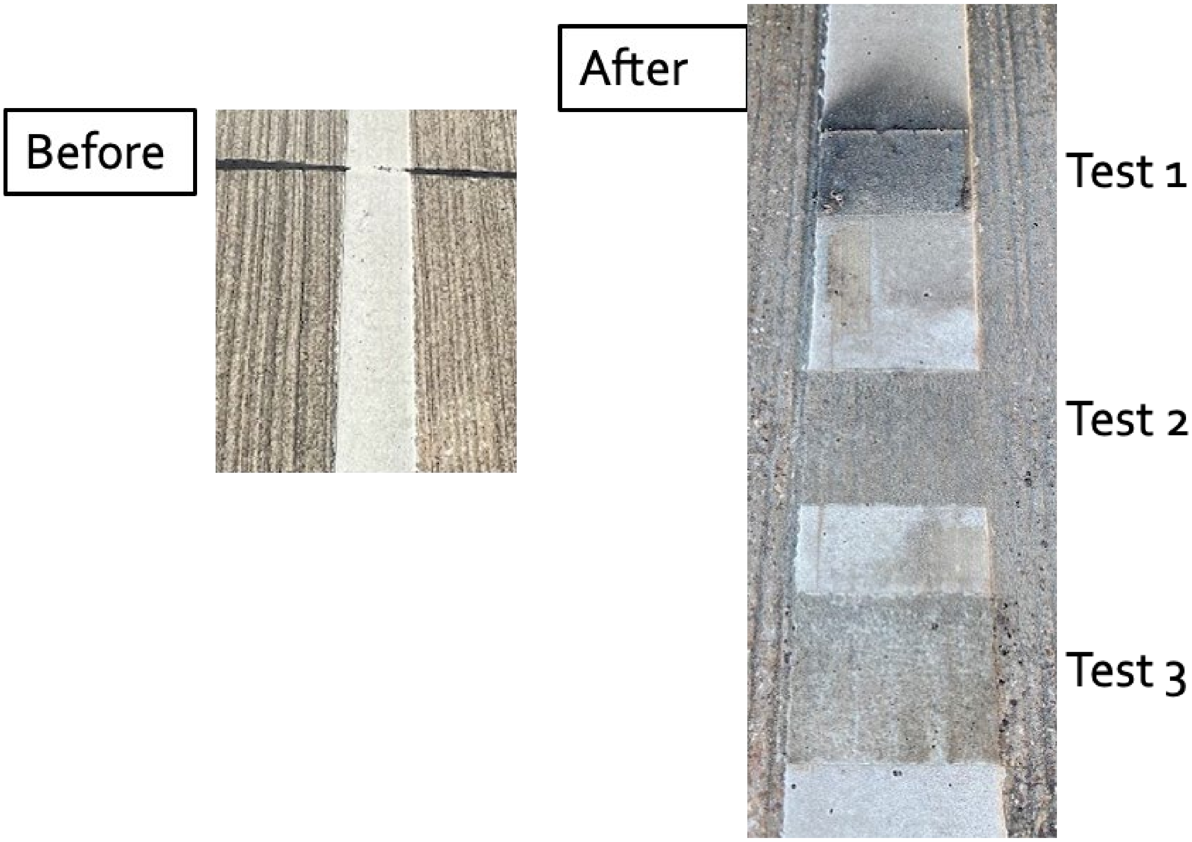

Figure 12: Field test on the ablation of thermo (by truck) white stripe from concrete: three tests were conducted, each one at a different clearance.

4.3 Value of research (VoR)

Table 5: Value of research (VoR).

Selected	Benefit Area	Qualitative	Economic	Both	TxDOT	State	Both	Definition in context to the Project Statement
x	Customer Satisfaction	X			X			Improved appearance of removed striping will improve conditions for the driving public
x	Improved Productivity and Work Efficiency		X		X			More effective and more cost effective removal methods will offer cost savings
x	Safety			X			X	Reduction or elimination of "ghost stripe" after removal will better inform drivers of the lane locations, thus allowing better lanekeeping and reducing accidents

Table 5 shows the value of the research, including customer satisfaction, improved productivity and work efficiency, and safety. From the preliminary test, the appearance of the removed stripe is improved when compared to current methods, as the substrate appeared undamaged after the stripe removal (field test were conducted only on concrete), which can also lead to reducing (or eliminating) ghost stripes.

However, the cost per mile of the proposed laser removal method was very high due to the slow removal speeds achieved by the system tested herein. To produce a cost-effective method, it is recommended to use a higher power laser system (see Chapter 5), or a combination of both mechanical (i.e., flailing) and laser methods. Moreover, it is recommended to have an environmental study during the ablation process to select proper personal protective equipment (ppe) (i.e. masks filtering dusts and other chemicals, goggles, etc.).

CHAPTER 5

5.1 Laser method technology: future implementation

The assembled equipment was proven to be effective in removing stripes from concrete and asphalt surfaces, reaching TRL 6. However, the removal speed of the laser equipment was not comparable with other methods in use. Therefore, additional options for future implementation of this method are: i) hybrid mechanical/laser removal striping method; and ii) the use of a higher power laser system. In the first option, the first layer of the stripe can be removed using a mechanical technique (flailing), then use the laser to only remove the left portion of the stripe; this can speed up the operation of removal. On the other hand, a higher power laser can be used, avoiding the complexity that a hybrid process could present.

In fact, the fluence (energy deposited per unit of area) generated by the 200W average power laser used in this study can be increased when using a more powerful laser such as a laser with an average output power of 1000W. Although the initial cost of the apparatus can be higher, the removal rate of the ablated material can increase. Based on some data in literature, it can be projected to have a removal speed of ~53 ft/min (0.60 miles/hr) for thermoplastic stripes, 44.6 ft/min (0.51 miles/hr.) for the hot tape stripe, while for the paint stripe the removal speed would be 158 ft/min (1.79 miles/hr.), and further research would be needed to experimentally evaluate the removal rate.

Moreover, the removal area can be increased as well due to the use of a larger laser scanner. The optical elements used with higher power laser scanners allow higher distance from the focal point, which is also useful to decrease possible damages from glass beads impact when expelled from the stripes during the ablation process.

5.2 Laser method technology: 1000W laser equipment

A laser system of 1000W requires a more powerful chiller to control the laser temperature during the operations. The schematic of the laser box is shown in Figure 13. Example of laser specs are the following:

- Average Power: 1000 Watts
- Wavelength: 1064 nm
- Pulse Durations: 25, 50, 70, 100 nanoseconds and CW option

- Maximum Pulse Energy 100 mJ

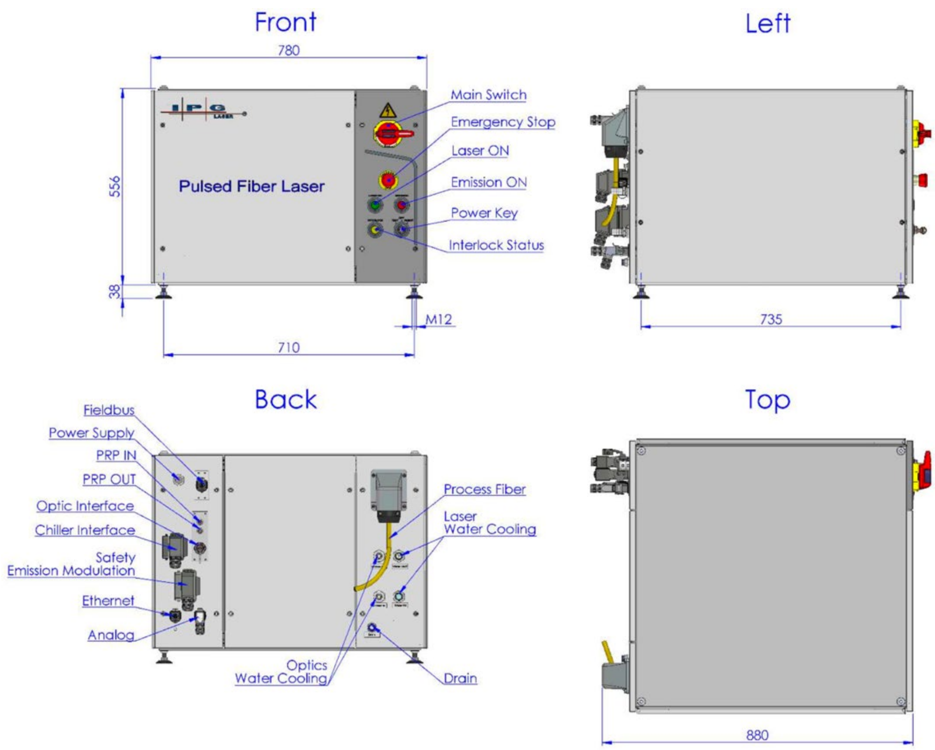

Figure 13: Schematic of a 1000W laser (lengths are in mm).

Figure 14 shows the laser scanner for a high-power laser. External interfaces are available for easy integration with automation. The scanner can be mounted on a robotic arm and can include a camera. The system can be programmed to recognize the type of stripe, pavement, and estimate

Figure 14: 2D Laser scanner for a high-power laser.

the stripes’ thickness to automatically adjust laser’s parameters for the optimal ablation of the stripe, putting the system to compete and possibly substitute other stripes removal methods (TRL 8).
The scanner can be selected with a lens of 410mm generating a scanning field size of 200x200 mm. The current system has a lens of 254mm with a much smaller scanning field area.
The system (laser and chiller) requires a 3-phase generator of few KWatts to be powered, such as the one showed in Figure 15.

Figure 15: 3-phase generator.

Table 6 shows the weight of each component for the proposed 1000W laser system. The system can be assembled and integrated on a pick-up truck or a trailer, and conveniently modified to absorb vibration during transportation and its use.

Table 6: Estimated Weights of laser equipment (1000W)

Components	**Weight (lbs)**
Laser box	450
2D Laser scanner for a high-power laser	30
Chiller	700
3-phase generator	600
	Total 1780

5.3 Laser method technology: projected equipment lifetime

The proposed high-power equipment (1000W) is projected to have a long lifetime. In fact, based on the manufacturer and industry standard information, a laser diode can last in average about 50,000 hrs [7]. Based on a 60 hr/week work, that equates to a duration of about 16 years. Similar lifetime expectancy is typical for the laser scanner. However, regular replacements of the protective lens (glass lens cost a few hundred dollars) should be performed to maintain optimum ablation conditions.

A diesel generator (3 phases) has a lifetime expectancy of about 30,000 hr, which means about 9.6 years duration based on a 60 hr/week work, while a water chiller should last about 20 years based on the same work hours per week [8,9].

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APPENDIX A

TxDOT Specifications

Item XXX

Eliminating Existing Pavement Markings and Markers Using Lasers

1. Description

Eliminate existing pavement markings and raised pavement markers (RPMs) using thermal ablation from a pulsed fiber laser source

2. Removal Quality

The removal quality is evaluated by comparing the errors of Grayscale tones on the images between the original pavement area before and after the stripe is removed using the Matlab program provided. To achieve high removal speeds and acceptable removal quality follow the recommended settings in “equipment”.

3. Equipment

Use fiber pulsed lasers with an average output power of >200W (wavelength 1064nm). Do not use in wet/ice conditions. The presence of dirt/debris could slow down the process. Mechanical treatment to prepare the surface can increase the removal speed (i.e. flailing)

Use the below settings for optimum results:

Type of stripe	Pulse frequency (kHz)	Pulse width (ns)	Number of passes	Scanning speed (mm/s)	Fill pitch (mm)	Number of changing scan direction	Estimated scan time (s)	Optimal removing speed of 4-in stripe (ft/min)
Thermoplastic	30	30	2 - 10	8000-9000	0.3-0.5	2-10	2.33 - 4	1.7
Hot tape	30	30	2-3	1000-3000	0.2	6-10	62 – 90	0.065
Paint	30	30-120	2-3	2000-8000	0.2 –0.45	4-12	13-36	0.31

4. Laser Treatment Method Procedures

The laser scanner should be placed at a distance from the paved surface equal to the focal lens installed. Lens with a shorter focal length assures a faster process but may damage the optics due to the closeness to the surface and possible contact with glass beads during the ablation process. It is recommended to use at least 25cm focal length optics (clearance). The laser scanner head should be maintained parallel to the surface for optimal results. Also, vibration should be minimized during operations.

To power the laser system, use a high-quality electric generator to avoid issues with the laser output; also adjust the cooling system temperature based on the external humidity. A sensor in the laser box is present to help adjusting the temperature according with the OEM manual.

Use compressed air at 150 psi via air knife/knives to protect the optics during operations and avoid glass beads damage to the scanner's lens.

5. Measurement

This Item will be measured by each word, symbol, or shape eliminated; by the foot of marking eliminated; or by any other unit shown on the plans.

This is a plans quantity measurement Item. The quantity to be paid is the quantity shown in the proposal unless modified by Article 9.2., "Plans Quantity Measurement." Additional measurements or calculations will be made if adjustments of quantities are required.

6. Payment

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Eliminating Existing Pavement Markings and Markers" of the type and width as applicable. This price is full compensation for the elimination method used and materials, equipment, tools, labor, and incidentals. Removal of RPMs will not be paid for directly but will be subsidiary to the pertinent bid items.