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Developing Laser Based Operations and Facilities for Corrosion, Sealant, and Coating Removal

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ABSTRACT

An advanced state-of-the-art laser-based coating removal/surface preparation facility requires the integration of the laser technology and components, robotic motion control systems, vision systems, waste collection, and facility automation/control functions. Combining these industrially proven and commercially available technologies will permit the use of the emerging laser based capabilities for the removal of corrosion, sealant, and coatings in the support of a wide range of production operations. The facility employing these technologies can also be used, virtually without change, for pre-bond or pre-coating surface preparation of aluminum, titanium, composite or other structural materials.

The primary issue that the facility design has to encompass is quite straight forward – What are the real production tasks to be performed in the facility and what are the detailed requirements for completion? These will include such factors as throughput needs, waste collection and disposal, storage and staging space, maintenance and repair of the equipment, personnel skills and so forth.

These detailed production requirements drive the overall design of the facility. They must accommodate the size of the parts to be stripped, provide throughput to support the expected operation schedule as well as the available space for the facility, etc. As is always the case, there is no single facility concept or design that comprehensively meets the production requirements across a large and dynamic production operation, such as the depot maintenance of a wide and often expanding range of aircraft types.

This presentation/paper will cover the art-of-the-possible now in laser based maintenance operations. It will cover the key steps in developing and implementing a functional, advanced laser based production facility. Four examples of facility concepts for specific production situations will be presented.

Keywords: corrosion, lasers, laser stripping, decoating, coating removal, production stripping, decoating facility maintenance, corrosion removal, surface preparation, laser ablation, hazardous waste reduction, worker injury reduction

INTRODUCTION

An advanced state-of-the-art laser-based coating removal/surface preparation operation or facility requires the integration of the laser technology and components with robotic motion control systems, vision systems, waste collection, and automation/control functions. Combining these industrially proven and commercially available technologies and components will permit the use of laser based capabilities for the removal of corrosion, sealant, and coatings in the support of a wide range of production operations. The facility employing these technologies can also be used, virtually without change, for pre-bond or pre-coating surface preparation of aluminum, titanium, composite or other structural materials.

The design and implementation of a successful operation or facility must be based on the real production tasks to be performed. The detailed requirements for the facility must consider such factors as:

- Parts size and weight variations,
- Intricacies and complexity of the parts,
- Part substrate materials,
- Production throughput needs,
- Removal/surface preparation requirements,
- Waste collection and disposal,
- Component storage and staging space,
- Maintenance and repair of the facility equipment,
- Operator personnel skills, and
- Other facility specific factors.

These detailed production requirements ideally drive the overall design of the operation and facility. If available space can be provided for the facility, its features must accommodate the size of the parts to be stripped, and must house the appropriate technology to insure the operational time and throughput needs to support the expected operational schedule are satisfied. As is always the case, there is no single operational or facility concept that comprehensively meets the production requirements across a large and dynamic production operation, such as the depot maintenance of a wide range of aircraft types and components to be worked.

This paper covers the art-of-the-possible in laser-based surface preparation operations. It will briefly review the key steps to develop and implement a functional, advanced laser-based operation. Multiple operational concept examples for specific production situations will be presented.

LASER STRIPPING ADVANTAGES

The requirement to strip coating layers or corrosion from parts using conventional or legacy methods presents problems that include on-the-job injuries, pollution issues, hazardous materials usage, hazardous waste generation and disposal, and damage to the parts themselves. The use of a laser in a surface preparation or cleaning operation not only solves these problems, but also reduces the operational costs associated with the process.

The advantages of laser stripping as compared to other methods include:

- Reduced worker injuries
- Reduced floor space required to house the equipment
- Reduced hazardous waste generation
- Reduced volume of coatings residues
- Reduced hazardous material use
- Reduced labor hours to complete stripping
- Reduced or no damage to substrate materials – yielding increased component life
- Reduced stripping operation life cycle costs

The most common worker injuries resulting from conventional stripping processes, including sanding, chemical stripping, and media blast operations are shoulder and elbow problems, and carpal tunnel syndrome.

Plastic media blast (PMB) and chemical stripping (CS) operations also require significant storage areas for materials, both before and after the decoating operation. The PMB, CS, and hand sanding methods also require substantial personal protection equipment to shield the workers from the hazardous operational environment, thus requiring additional operational support equipment.

These three decoating methods in particular generate hazardous waste. Chemical stripping uses hazardous chemicals and the media used for the other two methods are rapidly contaminated with coatings residues and must eventually be disposed of as hazardous materials.

Using the Laser Automated Decoating System (LADS) operating at the Ogden Air Logistics Center, we can demonstrate many of the advantages of a laser removal process. For example, an F-16 radome can only be decoated with the CS process twice. When a third decoat is required, the radome has to be condemned because of damage to the composite structure caused by the chemical stripping. Media blast operations also frequently damage the structure after repeated strip operations.

Such damage is not found when the laser process is used. In the 10 plus years of LADS operation, not a single F-16 radome was condemned as a result of the laser decoating process. The LADS facility has also decoated structures from rotor blades to wheels without damage to the substrate.

The LADS requires 7.5 labor hours to decoat an F-16 radome. Chemical stripping requires 23 labor hours to decoat an F-16 radome. LADS operation enables a two-thirds reduction in decoating labor hours.

The bottom line economical advantages of the LADS process are the reduction in decoating labor, reduction in the volume of disposable hazardous waste, and part life extension. These cost savings enabled the recovery of the initial facility investment of over $6 million during the first three years of operation. To-date the total cost savings impact of the LADS exceeds $20,000,000.

LASER STRIPPING FACILITY DESCRIPTION

Any operational laser stripping facility consists of the following major integrated subsystems:

- Laser Beam Generation
- Laser Beam Delivery
- Surface Monitoring

- Motion Control
- Waste Collection
- Subsystems Integration and Control

All the operational parameters mentioned above in the introduction will impact the complexity, size and the implementation method of these components. As with any stripping approach, there is no single, one-size-fits-all solution/design for a laser stripping facility. The following paragraphs briefly discuss the considerations and possibilities for identifying and selecting an appropriate configuration and subsystems.

Laser Beam Generation Subsystem

The laser beam generation subsystem is the engine that powers the entire surface stripping operation. The laser system choice is based on the total operational plan. Some of the operational requirements that impact the laser selection include strip rate, throughput, and the structural complexity required to support the applications.

Single laser strip rates vary from tenths of a square foot per minute using low power Nd:YAG lasers to over 80 square feet per hour using high powered CO_2 lasers. However, strip rate may not be the driving factor on throughput. Parts handling, parts preparation, or final cleanup may well be the 'longer poles in the tent.'

Structural complexity might require a small workhead to enable access to critical areas of the structure. Access driven requirements could lead to the decision that a laser type that can utilize fiber optic beam delivery is needed.

Beam Delivery Subsystem

The beam delivery subsystem is the transport system that gets the working medium to the work location. The key parameter in the choice of the beam delivery subsystem is the laser type employed for the stripping task. Other operational criteria, such as structural complexity, need for flexibility, distance between the laser generator and work area, and workhead size can also interact with the choice of the beam delivery method. Again, the total operational plan must be considered. Using hand held lasers for touch-up after the majority of the part's surface area is stripped might be the better option than redesigning to reduce the workhead size to allow access to a confined area of the part to be stripped. Reducing the workhead size could reduce the strip rate for the larger portions of the task. Therefore, the maximum throughput might be achieved with the larger workhead and the touch-up hand held laser combination, instead of a smaller workhead that would require no touch-up operation.

Surface Monitoring Subsystem

By recognizing surface characteristics, the surface monitoring subsystem allows automating the stripping operation and adds additional provisions for insuring no damage to the substrate. Surface monitoring systems are often referred to as vision systems. The vision system can be as simple as the eyes of the operator or as complicated as the automated, color-selective real time high speed vision system. Automated vision systems enable automated control of the stripping process, as compared to operator perception which requires manual intervention. Sophisticated automation features can control the stripping process to a specific layer of multi-layer coatings by issuing a "don't fire" command to the laser when a specific color is seen. This ability also can provide the "don't fire" signal when the substrate is recognized.

Motion Control Subsystem

The motion control subsystem coordinates the motion of one or more of the components of the facility such that the working medium strips the entire part. The motion control system can move the part, the laser workhead, or both. This system can rely upon the hand/eye coordination of the operator, or it can be totally automated through robotics. In all cases, the ideal motion control system will enable the entire scope of the required dimensional motion necessary to strip the part of concern. The structural complexity may necessitate anywhere from one to six degrees of motion. Again, the total operational plan must be considered. Using hand held lasers for touch-up after the part is stripped might be the more cost-effective option than adding all the degrees of robotic motion needed to totally strip a part.

If one chooses to move the part, then the work area around the laser workhead is required to be more than twice the size of the largest part to be stripped. If the laser workhead can be moved around the part, then the work area needs to be only slightly larger than the largest part to be stripped.

Waste Collection Subsystem

Currently most waste collection concepts used in a laser stripping facility are based on a vacuum waste collection. In these subsystems, the waste collection channel is generally integrated into the beam delivery workhead component. The waste collection system can vary from the simple “let it fall and swipe it up” approach to a complex solids and airborne particulate collection system. The impact of stripping hazardous materials such as chrome is obviously a concern in the design of the waste collection system.

Subsystems Integration Control

The unit which integrates all of the subsystems of the laser stripping facility is extremely important. Regardless of the amount of integration, this unit is where all the operator and system safety interlocks are contained. This unit also controls the functions of the various subsystems to insure the proper stripping parameters are used for the specific part to be stripped.

LASER STRIPPING CONCEPTS

The following subsections present actual operational systems and potential concepts for stripping facilities. These subsections are broken down into three main areas of:

- Portable systems for field and floor operations that require either small-area cleanup or at-the-site coating removal,
- Component stripping facilities to replace CS or PMB component stripping facilities, and
- Large assembly stripping facilities to replace CS or PMB facilities

The concepts and examples that follow are based on the experience base of the authors. The purpose of these concepts is to demonstrate potential implementation skeems which will provide background to enable the transformation of these concepts to any coating removal or overspray/flash removal situation seen in a production or maintenance operation.

Portable Stripping Concepts

Two pioneers in laser stripping were Plasmatronics, responsible for the current LADS at Hill AFB, and F2, involved in a number of DoE applications, began operations in the early 90s. Promise shown by the LADS in particular stimulated interest within DoD circles in transitioning this environmentally friendly technology into a portable, field-deployable configuration. A portable configuration would not require bringing the parts to be stripped or cleaned to the laser facility. In the mid-90s, General Lasertronics Corporation (GLC) was able to successfully transmit laser energy to the work surface via fiber optic cable. At the same time, laser vendors were providing higher-power laser configurations of small enough size they could be trailer-mounted.

Combining these features, GLC was able to develop the industry's first portable laser configuration that employed fiber optics beam delivery to power a hand-held workhead tool. The portable GLC system was installed into a small single-axle 'pony trailer' and incorporated a 50-foot umbilical assembly housing the fiber optical cable, control electronics and evacuation air flow to bring the laser energy and its control features to a hand-held workhead tool. The beam delivery incorporated x-y scanners to direct the laser beam over the work surface. The scanners were designed to keep the laser pulses striking the work surface in constant motion to prevent substrate damage that might be caused by excessive dwell. The workhead also incorporated a small screen video monitor providing a direct view of the work surface to the user. This monitor allowed the user to see the actual laser stripping process without risk of eye damage.

The entire beam delivery subsystem was interchangeable, and could be replaced with various workheads configured to the stripping task requirements. The evolution of this basic configuration continues with a wide range of workhead tool/umbilical configurations available for a variety of applications, including automatic surface monitoring configurations with both 'standard' and color selective options.

<u>Glove Box Concepts</u>

The first laser glove box was conceived and designed by Col. Terry Fuchser (USAF retired) and Mr. Dave Ellicks, of the USAF Corrosion Prevention and Control Office at Warner Robins Air Logistic Center (WR-ALC). Lasertronics, developed a prototype glove box in-house that led to demonstration and development of a laser actuated glovebox used by the nuclear industry for safe decontamination of tools and small parts.

Two example projects are mentioned here:

Three Mile Island Sample – A contaminated steel manway backing plate was transported to the Framatome Lynchburg nuclear facility for safe disposal. This item was selected for an initial evaluation of the laser's potential as a decontamination tool. Utilization inside a 'nuclear-qualified' glovebox offers an extra layer of shielding for the user. For this test the GLC hand-held workhead was placed inside the glovebox, and the tool's on-board video feedback was used to direct the laser beam over the contaminated work surface. Results are summarized here from the Framatome engineering notes:

"…The tool cleans a 2" x 4" area and is equipped with video (monitor) that allows the user to see the work through the toolhead. The user actually sees the laser firing and the path (scan pattern) it takes. A single pass appeared to almost completely clean the surface, a second pass finished the process, then the operator doubled the number of passes to ensure proper cleaning (1, 2, or 3 passes may have been plenty). The process completely cleaned the surface back to a shiny metal finish; we used this change in (surface) color to move/position the tool for the next cleaning location (an indexing fixture would have ensured uniform coverage and decreased our positioning times).

Results:

Pre-Decon: 2000 mr/hr-beta/gamma
600 mr/hr-gamma
800,000 dpm/100 cm squared loose contamination
Post-Decon: 500 mr/hr-beta/gamma
200 mr/hr-gamma
15,000 dpm/100 cm squared loose contamination
(blue filter canister 80 mr/hr)

It is believed that some of the dose readings are being affected by the uncleaned area and by areas missed due to our manual positioning technique. Also, a stronger vacuum may be required to pull all of the contamination out…"

Tennessee Valley Authority (TVA) Field Evaluation – In response to an Electric Power Research Institute (EPRI) program, one of GLC's laser glovebox designs was delivered to the TVA facility at Muscle Shoals, Alabama, and was subjected to extensive field evaluations. Initial test trials randomly selected three small parts for decontamination.

- One large carbon steel crescent (adjustable) wrench - 300 counts
- One large (long-handle) chrome-plated ½-inch drive ratchet - 350 counts
- One piece of angle-iron (pylon or structural bracing) that, in addition to contamination had both rust and heavy paint – 500 counts.

All three test items were easily cleaned to 'free-release' status, meaning no detectible radiation remained after laser cleaning. Reduction to zero counts for the carbon steel is of particular interest, because TVA suggests this material is too porous for the laser to be completely effective.

During the EPRI-directed laser field-evaluation period at TVA, more than 50 utility-supplied components, with a variety of coatings and surface contaminants, were successfully cleaned using the laser glove box. In addition to the evaluation at TVA, decontamination, along with more conventional paint and/or corrosion removal, was successfully demonstrated at the Westinghouse Waltz Mill facility, at the Portsmouth Naval Shipyard, at the R Brooks service facility in New York, and at the EPRI facility in North Carolina.

Field/Work Floor Concepts

The advent of the smaller, more portable systems has suggested a logical division of labor between these and the larger, higher throughput configurations, such as the LADS. The high throughput systems are virtually all fixed platform, non-portable configurations, and cannot easily be used in nooks and crannies, confined spaces, and in fuselage areas that are close to the ground. The smaller portable systems can reach these difficult access areas, but are unacceptably slow for decoating large areas. Combining the features of both laser system types can provide a full set of capabilities, with an acceptable production throughput.

Future fixed-base, high-throughput systems should be installed inside the aircraft depaint hangar, with appropriate logistical support and safety features. In this environment, the larger system can be easily supported, or supplemented, by the smaller, portable units capable of addressing difficult confined areas. Two successful field/work floor concept implementations are given below.

Philadelphia's City Hall Tower Statue Corrosion Cleaning Example (See Figure 1) - Corrosion products on bronze sculptures are the typical green and black bronze corrosion. Black corrosion is, in general, classified as copper sulfide. Many of the green corrosion areas and most of the black areas also contained a large amount of chlorides. In addition, the black crust was found to contain large amounts of carbon, silica, sulfides and sulfates, as well as tar-like materials. These corrosion products are created by environmental pollution such as by-products from cement or plastics factories, petroleum refineries, chemical plants, automobile traffic, and dust particles. This combination creates a very hard and dense corrosion crust.

Figure 1. Philadelphia City Hall Tower Statue Corrosion Cleaning

Figure 2. Fiber Optic Delivery

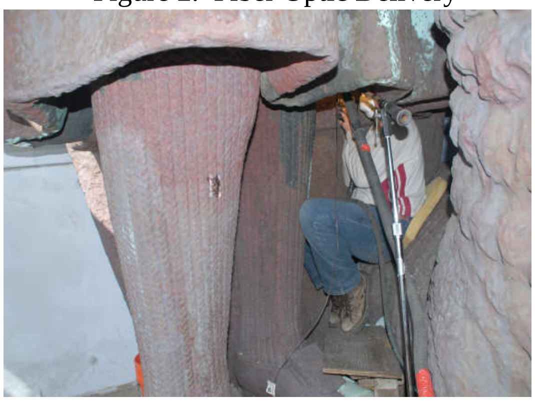

Figure 3. Fiber Optic Delivery

Using a laser-based stripping system provides the opportunity to treat monuments just above pedestrians. The ablation process surface cleaning byproducts can be extracted by vacuuming to prevent contamination of surrounding areas.

The use of traditional surface cleaning methods cannot provide the desired level of corrosion removal without damaging the substrate or contaminating the surrounding area. All blasting methods using solid media were discarded due to the possible surface damage and contamination of the surroundings. When used in chloride contaminated areas, blasting removed only the superficial corrosion and pinned over and sealed the corrosion in the crevices. Chemical methods required a lot of time, did not provide the desired level of chloride removal, and could potentially cause run-offs that could stain the building below. Water jet blasting provided a similar level of chloride removal as the laser, but was the most surface damaging technique tested.

Testing various lasers demonstrated that a fiber optic cable beam delivery was more practical than a mirror delivery system. The fiber optic delivery can be seen in Figures 2 and 3. The GLC 200W laser system with a 45m GLC fiber optic cable enabled work in hard to reach areas without moving the laser unit. This system also employs purge air to provide positive pressure past the lens preventing lens contaminating resulting in virtually non-stop operation.

Figure 4. Before Corrosion Removal Process

Laser ablation was demonstrated appropriate for carrion removal from copper alloy sculptures with significant advantages over other techniques. Ablation is a very effective technique for addressing corrosion and chloride contamination on bronzes of any size. The laser is a very dynamic tool that can be adjusted to produce a variety of results. Results of the corrosion removal process can be seen in Figures 4 and 5.

Figure 5. After Corrosion Removal Process

Federal Aviation Administration (FAA) Approved Removal Method – A GLC laser system has received FAA Alternate Method of Compliance (AMOC) approval to removal of paint, sealant, corrosion and rust on metal substrates listed in SAE MA4872 Annex D, regardless of aircraft manufacturer. Some of the substrates identified in MA4872 Annex D include 2024 T3, clad and unclad, 7150 T351 unclad, 7175 T7351 unclad, AZ31B Magnesium, Ti6A1 – 4V Titanium, and 4340 Sheet Steel.

A unique advantage of the laser process is that it is a 'zero-added-waste' technology.

The approval itself was predicated upon the results of a five-cycle laser stripping process conducted on thin aluminum sheets (0.032 inches) used in commercial aircraft 'skins.' After the five coating removal cycles were completed, the samples were fatigue tested to failure at an FAA-approved test laboratory in the Seattle area. Test results showed neither adverse structural impact on the substrate materials, nor any evidence of unacceptable temperature excursions. As an approved AMOC, the GLC laser process will support Nondestructive Evaluation/Inspection (NDI/NDE) associated with locating scribe marks known to occur on commercial aircraft, these being subject to a recent airworthiness directive aimed at the Boeing 737, but likely to be extended to other metal structure aircraft.

Figure 6. FAA-approved Laser Process

The FAA-approved laser process was implemented using the GLC model shown in Figure 6. This particular configuration is installed in the new maintenance hangar for the next-generation presidential helicopter located at NAS Patuxent River, Maryland.

COMPONENT STRIPPING –FACILITY CONCEPTS

The authors have developed laser stripping facility tools and concepts for components (e.g., off-aircraft parts) and other smaller parts. Capabilities can be provided that greatly extend beyond those of current production stripping facilities. Representative components are shown in Figures 7 and 8. These parts range in size from two feet by four feet to 15 feet by 30 feet. The shapes range from basically flat panels to semi-conical shapes.

Figure 7. Typical Aircraft Flap

The research completed in developing these concepts has allowed the identification of a variety of acceptable commercially available laser systems. These are laser systems that are specifically configured for stripping or ablation operations, and that are easily integrated into stripping facility designs. This research also shows that there are a multitude of possible laser and facility concepts and configurations available to meet both current and future needs. The primary issue that the user/operator has to define is straight-forward – What are the real production requirements for the proposed facility? Above any other issue, this is what drives the design of the stripping facility, as discussed in Section 1.

Figure 8. Typical Aircraft Engine Nacell

The concepts presented below are built around facilities containing one or more laser systems, one or more stripping rooms, and in all cases, the use of handheld laser stripping systems for touch-up, as required. The use of these concepts will result in a 95% reduction of hazardous waste generation. The integration of a comprehensive maintenance concept will enable these facilities to maintain a 95% + operational time.

Component Stripping Concept 1

The Concept 1 facility was developed with emphasis on maximum throughput and is illustrated in Figure 9.

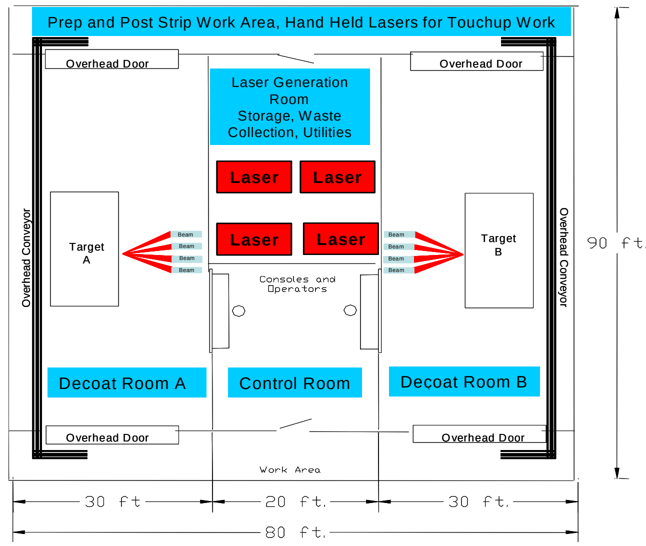

Figure 9. Component Stripping Concept 1

In Concept 1, only the motion control system for the target part requires automatic or robotic capabilities in the facility. If three-dimensional motion control can be provided, complex part shapes can be effectively and efficiently stripped. The advantage of moving the part instead of the laser beam is that the laser generation component, the beam delivery subsystem, and the waste collection subsystem are all stationary, which makes these components less complicated, more reliable and easier to maintain. The disadvantage of moving the part is the required range of motion in each axis. The facility (or workcell) housing the part has to be three times larger than the dimensions of the largest part. Also, with a need to keep the part moving, the motion-control fixturing is more complex.

As seen in Figure 9, the conceptualized facility incorporates two decoating rooms and employs four lasers stripping the target parts. If the four lasers are focused on a single part at the same time, the strip rate would be about 400 square feet per hour. Based on LADS experience with stripping radomes, it would take the same amount of time to unload a decoated radome and load a new one in target room A as it would to decoat a radome in target room B. The ability to switch the beam delivery between the decoating rooms combined with improved part handling and a crew dedicated to the loading and unloading of the parts increases the part throughput an estimated 6 to 10 times that over the current LADS facility capabilities.

Component Stripping Concept 2

Concept 2 was developed by SLCR[1] and is based on one of their commercial laser systems. This concept holds the part stationary while the laser delivery system and portions of the waste collection system are moved with a robotic arm system mounted to a rail system. The robotic [1]arm is illustrated in Figure 10. Note in Figure 10 that both the end effecter for the laser and the waste collection system are attached to the end of the robotic arm. For this concept, the laser generation system and the main components of the waste collection system are stationary. The advantage of this concept is the reduced facility size over that of Concept 1. The part size that can be decoated is dependent on the range of motion of the robotic arm

Figure 10. Component Stripping Concept 2

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[1] SLCR Laser Technik Gmbh is a commercial laser system company in Germany. Website: www.slcr.de/English/index.htm

system and the length of the rail system supporting the robot. There are practical limits on the implementation size of this concept. This concept has the ability to strip complex shaped parts with an anticipated strip rate of about 80 square feet per hour. The cost of implementing this concept into a decoating facility would be significantly less than the cost of the facility implementing Concept 1.

Component Stripping Concept 3

In Concept 3 the part, the waste collection system, and the laser generation system are stationary, and the beam delivery system and the waste collection system end effecter are all motion controlled. The motion controlled part of this concept enables X, Y, and Z motion of the beam delivery and waste collection end effecters. The motion control system implements X and Y motion through a platform that contains the beam delivery system, and the waste collection system end effecter, and enables the Z axis motion by mounting this platform on a rail system similar to the one used in Concept 2. This concept is illustrated in Figure 11.

The advantage of this concept is the reduced facility size over that of Concept 1. The part size that can be stripped is dependent on the range of motion of the motion control system. There are practical limits on the implementation size of this concept.

This concept has the ability to strip complexly- shaped parts with an anticipated maximum strip rate of about 220 square feet per hour. The complexity of the parts that can be addressed is limited by the X and Y motion and the size of the laser and waste collection end effecters. The throughput rate would be somewhat less than that of the current LADS facility due to the time consumed in part handling, which is required to strip both sides. The cost of implementing this concept into a decoating facility would be less than the cost of the facility implementing Concept 1. The strip rate and throughput rate could be doubled by implementing a laser platform on both sides of the part. However, the part shape itself might limit the ability of this double laser approach.

Figure 11. Component stripping Concept 3

Component Stripping Concept Comparison

A quick reference comparison of these three off-aircraft component decoating facilities is given in the following table. Through the integration of commercially available components, each of these laser decoating facility concepts is realizable today.

TABLE 1
COMPARISON OF COMPONENT STRIPPING CONCEPTS

Concept Number	Max Strip Rate	Facility Size	Throughput	ROM Cost
1	1,000 Sq Ft per hr	Largest	6 to 10 times LADS	$12 Million
2	220 Sq Ft per hr	About half the size of Concept 1	Equal to LADS	$5 Million

3	220 Sq Ft per hr, or 440 Sq Ft per hr	About half the size of Concept 1	Equal to LADS (one laser) or better than LADS (two lasers)	$5/$7 Million

LARGE ASSEMBLY STRIPPING – FACILITES CONCEPTS

The authors have developed large area stripping concepts and use stripping situations appropriate to aircraft surface configurations to demonstrate these concepts. The aim is to eliminate the need for PMB or chemical stripping of aircraft, with their attendant cleanup and disposal costs. These full aircraft laser stripping concepts will not only reduce the labor hours associated with currently used decoating methods, but also will increase the quality, flexibility, and controllability of the decoating processes that will be required for the aircraft of the future. Combining today's operational robotic systems for full aircraft PMB decoating and full aircraft NDI systems with extensions of the off-aircraft decoating concepts defined above can be accomplished by relying directly on the concepts identified below.

Figure 12. Large Assembly Stripping Concept 1

- Robotic laser delivery system
- Laser generation system on a cart
- One or more laser stripping units per assembly
- Handheld lasers for touch-up finishing

The anticipated results from implementation of these concepts include:

- Strip rate – 1 Laser – up to 220 ft^2/hour; X Lasers X times ft^2/hour
- Elimination of blast mask and demask/cleanup labor
- Reduced FOD introduction
- Reduced labor for stripping operation
- Reduced worker injury
- Reduced real estate required for assembly stripping facility

Large Assembly Stripping Concept 1

The first concept utilizes a platform-based system with a three-dimensional robotic system to achieve the mobility to navigate around an entire aircraft. This concept is notionally illustrated in Figure 12.

In this case the aircraft is stationary and the laser generation system, the beam delivery system, and the waste collection system end effecter are all motion controlled. This motion control enables X, Y, and Z motion of the beam delivery and waste collection end effecters. The motion control system implements motion in the X, Y, and Z axes over a specific section of the aircraft through activation of the platform containing the laser generation, beam delivery, and the waste collection subsystems. The robotic motion of the entire system enables decoating of practically the entire aircraft.

Large Assembly Stripping Concept 2

Concept 2 starts with a platform-based system installed on a rail system. With the capability to rotate the platform, and the vertical control component, you can achieve the mobility required to navigate along large curved sections from the top to the bottom. This concept is notionally illustrated in Figure 13.

This motion control concept enables X, Y, and Z motion of the beam delivery and waste collection end effecters. The motion control system also implements 'longitudinal' motion along the major axis of the part through the rail system to which the platform is attached.

Large Assembly Stripping Summary

A large assembly stripping facility will most likely contain more than a single robotic laser stripping unit. One can easily take the two concepts presented and visualize specialized units for stripping aircraft and other large assemblies. The bottom line is that the technology is available for laser stripping large assemblies now. In terms of the technologies needed, the future is here now.

LASER FACILITY MAINTENANCE APPROACH

For any production facility to be successful, the operation time of that facility has to exceed, at a minimum, the production time required to meet the production output requirements. In today's production world where lean/Continuous Process Improvement (CPI) rules, production operational time needs to exceed 90%. One of the keys for a laser based facility to meet these requirements is a solid preventive and emergency repair maintenance concept.

In March of 2001 a new approach was adopted for maintaining the LADS facility. The success metric for this maintenance approach was facility production time – uptime. The initial production objective was to establish a total maintenance program that would lead to LADS operational time exceeding 80%.

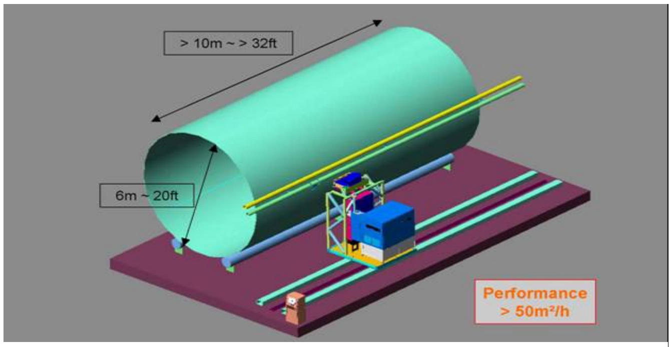

Figure 13. Large Assembly Stripping Concept 2

The maintenance concept developed and implemented for the LADS facility from March 2001 to August 2006 provided a laser decoating facility capable of production time that exceeded 90%. Anyone considering a laser decoating system needs to study the LADS maintenance concept and implementing such a robust maintenance plan. The history of laser decoating facilities demonstrates that failure will beset the facility, without such an aggressive maintenance plan.

Basic elements in the LADS maintenance concept:

The critical tendons in the maintenance concept include:

- Developing and maintaining up-to-date system drawings
- Documenting assembly and disassembly procedures
- Implementing and continually improving the Preventive Maintenance and Inspection program for the entire LADS facility
- Requiring a four-hour initial response to unscheduled repair
- Requiring repairs accomplished within 48 hours of receiving parts

- Solving system failures with commercial off the shelf components
- Implementing on-line, real-time incident reporting detailing all system failures, solutions, and lessons learned
- Defining critical components
- Implementing process to insure proper stocking of all critical components
- Implementing failure analysis and developing system diagnostics and prognostics procedures to enable Condition Based Maintenance
- Define and implement potential system upgrades to enhance system capability, reliability, and maintainability
- Installation of remote sensors and monitoring technology to assess the health of system during operation

The resulting operational improvement of this maintenance concept can be seen in Table 2.

TABLE 2

LADS UPTIME DATA

Year	2001	2002	2003	2004	2005	2006 (Jan. – Oct.)
Uptime %	27	53	64	94	96	90

This data illustrates the uptime improvement and the value of having critical components properly spared. In March 2002 LADS started a period of solid uptime of **zero** that resulted from blowing the peaking capacitor. This capacitor had been identified as a critical component. However, we had ranked it as a low-priority critical component. There was a six-week lead-time to replace the capacitor. Upon the delivery and installation of the initial replacement, we discovered a manufacturing fault in the capacitor. We sent this capacitor back for replacement and ordered an additional spare at the same time. However, we were down an additional six weeks as we waited for the replacement capacitor. It was these types of situations that kept the operational time below 90% until 2004 when all the critical spares had been purchased. Further demonstrating the effectiveness of having critical spares available was the two hour down time that resulted from the next peaking capacitor failure.

CONCLUSIONS

Combining the operational cost-effective success of laser based facilities, like the LADS, and the advantages of laser coating removal over the traditional methods demonstrates that laser based removal facilities are ready for production facility implementation from a technology, reliability, and economic standpoint.

The proven advantages of laser coating removal include:

- Reduced worker injuries
- Reduced floor space required to house the equipment
- Reduced hazardous waste generation
- Reduced volume of coatings residues
- Reduced hazardous material use

- Reduced labor hours to complete stripping
- Reduced or no damage to substrate materials – yielding increased component life
- Reduced stripping operation life cycle costs

Incorporating current technology into future coating removal facility concepts will improve operational flexibility and effectiveness, cost-effectiveness, and durability/maintainability. The facility must be designed to match the production requirements. Success is determined by the right design and comprehensive maintenance and available logistics support.

Laser ablation equipment available today incorporates essential safety features:

- Explosion safety
- Color selective stripping that is automated, not operator initiated
- Documented substrate safety and appropriate approvals
- Improving throughput and reliability

BIBLIOGRAPHY

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