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FIELD TESTING OF AN AUTOMATED SURFACE FINISHING SYSTEM FOR LARGE DIAMETER STORAGE TANKS

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Abstract

Surface finishing of large storage tanks represents a typical area in which construction automation techniques can yield significant improvements over conventional methods. Current techniques are costly and laborious, and they expose workers to significant health and safety risks. Automation offers potential improvements in each of these areas and is well suited to the large, uniform surfaces of the tank wall. The University of Texas has developed a prototype automated surface finishing system for use on large diameter tanks. This system uses a computer-controlled motion module to refinish the vertical exterior walls of a tank. The module is configurable for both blasting and painting and utilizes conventional surface finishing equipment for these processes. The University of Texas' automated paint sprayer was field tested in January, 1992 at an Amoco pipeline facility in Alvin, Texas. These tests, which were used to demonstrate automation techniques to members of the construction community, are described in this paper. The successes of the system are reported along with the problems, and recommendations are given for improving the system. An economic analysis is presented along with future plans for the system.

1.0 INTRODUCTION

Automation of surface finishing techniques for large storage tanks can yield significant improvements over conventional methods. Current techniques are costly and laborious, and they expose workers to significant health and safety risks. A typical refinishing operation involves sandblasting a tank to remove old paint and rust, and then painting it to protect the surface from the environment. This work is performed manually using a painting scaffold or similar device to access elevated work areas. Heavy equipment and protective clothing are required, and process byproducts are released into the environment. The procedures are hazardous, exposing workers to silica dust, harmful paint components, and possible injuries due to falls. Strenuous working conditions and worker fatigue contribute to an inconsistent quality of the applied coating. This hazardous surface finishing procedure is well suited for automation techniques. The large, uniform working areas are accessible with remotely operated equipment. Development in this area of construction automation can be justified by the potential improvements in working conditions, surface finish quality, and reduction in cost. Reduced environmental contamination serves as additional incentive.

The University of Texas has developed a prototype automated surface finishing system for use on large diameter tanks. This system uses a computer-controlled motion module to refinish the vertical exterior walls of a tank. The module is configurable for both blasting and painting and utilizes conventional surface finishing equipment for these processes. An overspray hood is included to reduce contamination of the surrounding environment during painting. The module attaches to a tank's wind girts with steel cables, and its position and velocity are controlled by servo-driven hoists. This automated system also controls the initialization and termination of the blasting and painting operations. This system replaces one person of the three-person crew generally required to refinish a tank and removes the operators from the immediate vicinity of the work area. A description of the automated paint sprayer and the results of preliminary tests were presented at the 8th ISARC.[1]

The University of Texas' automated paint sprayer was field tested in January, 1992 at an Amoco pipeline facility in Alvin, Texas. These tests were used to demonstrate automation techniques to members of the construction community. The field test results were favorable, revealing that automation of surface finishing techniques for large uniform structures is feasible and represents considerable improvements in worker safety. A consistent, high quality surface finish was obtained with minimal risks to the operators. The system has the potential to reduce the costs required to refinish a tank. The field tests of the automated paint sprayer are described in this paper. The successes of the system are reported along with the problems, and recommendations are given for improving the system. An economic feasibility analysis is presented, and future plans for the system are discussed.

2.0 MOTIVATION FOR AUTOMATING THE TANK PAINTING PROCESS

There are five commonly recognized primary motives for automating construction operations: (1) increased productivity/reduced cost, (2) increased quality, (3) safety - minimization or elimination of a hazard (to humans), (4) the need for super-human capabilities (such as lifting heavy objects, or ability to withstand severe work environments, such as arctic conditions), and (5) worker substitution given an inadequate supply of labor. In this development, the primary motives for automating tank spraying are increased productivity, reduced cost, and increased safety.

Sandblasting and painting operations present a multitude of potential health hazards to the workers. Perhaps the most obvious safety hazard is the inherent danger of working above grade on scaffolding. With this approach, workers are exposed to the risk of fall at all times. According to the National Safety Council, 70% of all serious injuries to coating crews are caused by falls. [2]

In addition to the risk of falls, blasting and painting crews are exposed to long-term health hazards posed by process by-products. These include silica dust (from blasting), old surface paint, air-borne atomized paint particles, and the chemical fumes of curing paint. Crew protection methods include auxiliary breathing equipment, protective helmets, heavy clothing, and safety lines and lanyards. The automation of surface finishing can significantly reduce many of these safety risks.

In addition to eliminating or minimizing safety concerns, labor costs and task duration can also be significantly reduced with an automated operation. With current manual methods, human labor contributes significantly to the overall cost of operations. The labor costs alone of blast cleaning and painting a square meter of tank surface in 1990 ranged from \$9 to \$17. [3] Of course, with an automated approach, much of this required labor can be eliminated. Considering the vast amount of surface area to be coated, the cost savings can be substantial.

Increased productivity can also serve to reduce task duration. With conventional methods, the daily productivity rate of a three-person crew is approximately 100 square meters for blasting or 200 square meters for spray painting. Preliminary estimates of daily productivity for the proposed automated system are 220 square meters for blasting and 2000 square meters for painting, assuming a 90% duty cycle. This assumes a two-person crew which is primarily responsible for equipment set-up and monitoring. [4]

3.0 FIELD TESTS

3.1 Prototype Description

The automated paint sprayer consists of an aluminum motion module which rolls on the surface of a tank (Figure 1). The module attaches to the wind girt of a tank via two 1.0 cm diameter steel cables. The position and velocity of the module are determined by the amount and speed of the cable splayed through two hoists located at the rear of the module. Squirrel cage assemblies mounted beneath the motion module retain the excess cable from the hoists. [5, 6]

A closed loop system is used to control the operation of the hoists. An IBM PC provides a means to create a control program for either a blasting or a painting operation. The program is sent to an axis controller which performs the control operation using feedback from a motor-mounted encoder. An amplifier is included to boost the control signal to the motors. All computer components are mounted in a portable console which remains on the ground during operation of the unit.

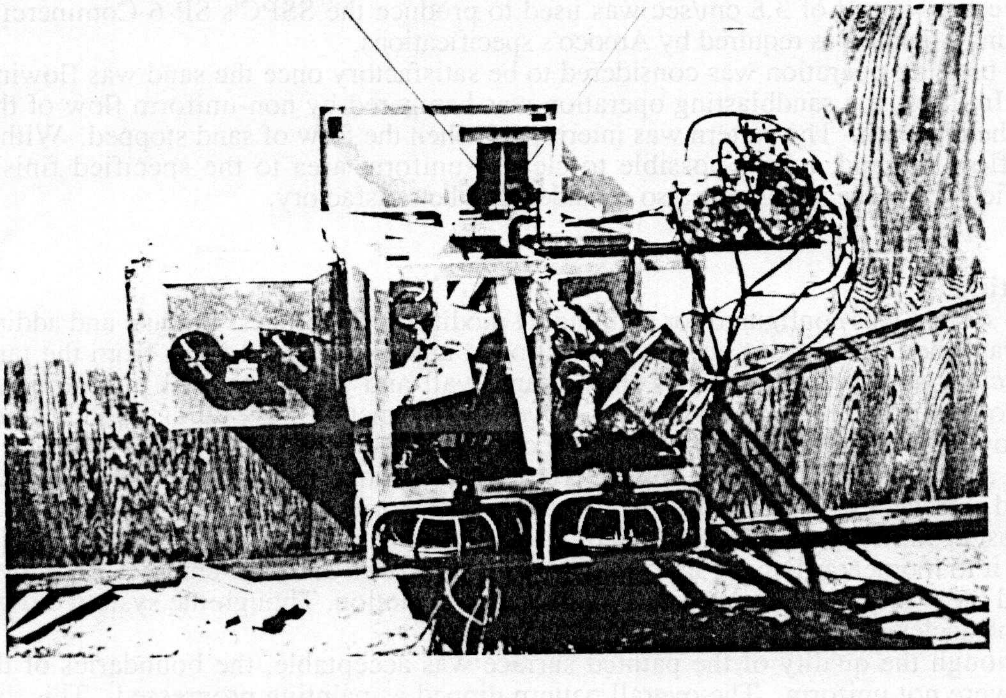

Figure 1. Automated Paint Sprayer

The paint system can be configured for either blasting or painting by modifying the process module attached to the left side of the motion module. This process module contains the linkages and motor used to oscillate the nozzles for the blasting and painting processes. A separate set of linkages is used for each process, and the system must be configured accordingly. An overspray unit, used for the painting process, mounts to the back side of the process module.

The automated paint sprayer is used to refinish the large uniform areas of the tank. The top and bottom of the tank, as well as the areas around the piping and gauge lines, are still refinished using conventional, manual methods.

3.2 Setup

The field tests were conducted in January, 1992. The automated paint sprayer was delivered to the site and positioned in an accessible area inside the tank dike. Special anchors were fabricated to attach the cable ends to the wind girts. Electric power for the controllers and hoists was supplied by Amoco, and a 750 SCFM diesel-powered compressor was rented to supply the air for process equipment operation.

The distance between the cable mounts was approximately nine meters, allowing a work area six meters wide and six meters high. While this was smaller than the area desired for final production, it was a good size to test the functionality of the components. The system was configured for sandblasting and attached to the tank. Counterweights were added to balance and stabilize the motion module.

3.3 Sandblasting

The blasting nozzles were positioned 66 cm from the surface of the tank, providing a vertical path 51 cm wide. A coarse, sharp-edged blasting slag was selected as the blasting medium. The speed of the motion module was adjusted to produce the specified surface finish. A vertical speed of 3.8 cm/sec was used to produce the SSPC's SP-6 Commercial Blast Cleaning Standard as required by Amoco's specifications.

The blasting operation was considered to be satisfactory once the sand was flowing smoothly. Initially, the sandblasting operation was hampered by non-uniform flow of the sand from the blast pot. The pattern was interrupted when the flow of sand stopped. With a consistent flow of sand, it was possible to clean a uniform area to the specified finish. Blasting efficiency at the welds was also considered to be satisfactory.

3.4 Painting

The system was configured for painting by modifying the process module and adding the overspray hood. The paint hood was positioned approximately 2.5 cm from the tank surface to clear surface irregularities in the tank wall and a new control program was generated to facilitate the painting process. Overlap parameters were adjusted to provide sufficient coverage of the tank surface and the module speed was adjusted to 15.2 cm/sec.

The automated paint sprayer applied a uniform, high-quality coating 0.076 mm thick as specified. In general, the system performed satisfactorily. The wheels were able to traverse most of the welds with little difficulty. The system did encounter several obstacles that caused it to momentarily hang up. A warp in the tank wall and a 12 cm thick port cover both caused the system to deviate from its programmed motion. Though the system did get over these obstacles, the painting pattern was interrupted.

Although the quality of the painted surface was acceptable, the boundaries of the work area were not uniform. The overall pattern dipped as painting progressed. This dip, shown in Figure 2, was severe enough that painting operations were halted to prevent the system from hitting the ground. This problem was traced to the design of the drive pulleys on the hoists. The effective radius of these pulleys varies as the applied load varies. Since the system controller monitored the position of the hoists and not the position of the motion module, no compensation was made for the deviations between the desired and actual positions.

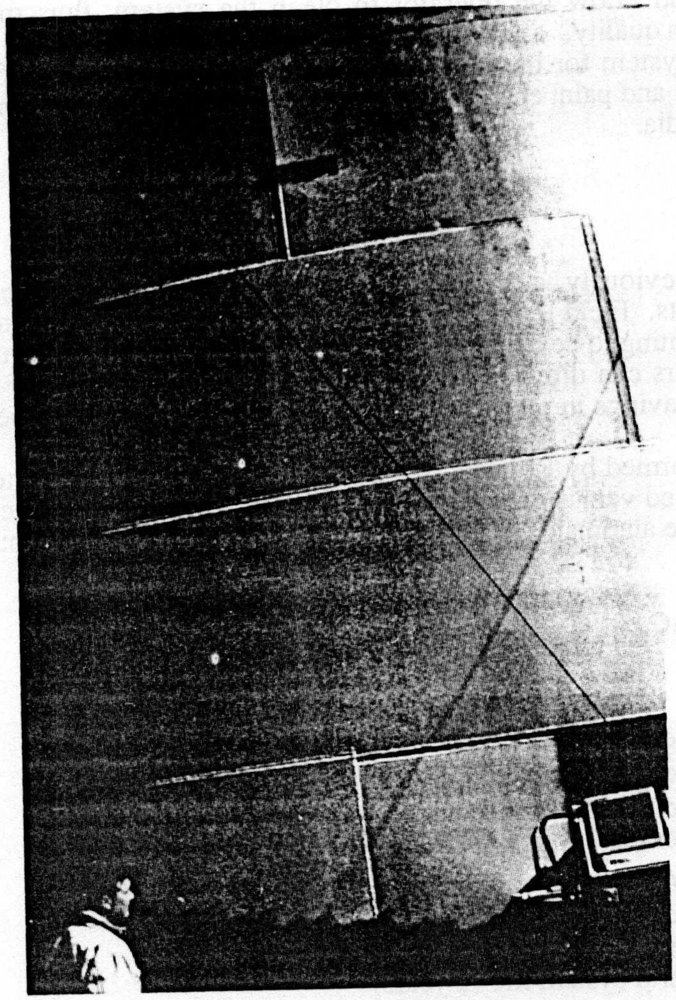

Figure 2. Paint Pattern

3.5 Results/Future Plans

The automated paint sprayer worked as expected and proved the design and process concepts. Both sandblasting and painting were accomplished with proper adjustment of the parameters. The problems identified during the tests served as a good indication of the general problems with automation of construction processes.

Future plans for the system include direct monitoring of the position of the motion module to compensate for the dip in the pattern. Plans also exist to monitor the paint pressure to predict clogging of the nozzles. An increase in pressure would immediately halt the painting process and allow the operator to clean the system, thus minimizing the interruptions in paint film quality.

A containment system for the blasting byproducts is also planned. Such a system would prevent silica dust and paint chips from being released into the environment and allow recycling of the blast media.

4.0 ECONOMICS

As mentioned previously, a primary motive for automation of the blast and paint processes is reduced costs. Field tests of the automated paint sprayer indicate productivity rates for blasting and painting to be better than the initial specifications. One automated paint sprayer and two operators can directly replace two standard work crews of three persons each and produce a net savings in production costs of approximately \$0.45 per square foot. [4]

An analysis performed by Rowland [4] uses a hypothetical scenario to evaluate the relative worth of automated versus manual surface finishing methods. The increased annual cash flow generated by the automated system was calculated using the equation:

$$\text{Annual Cash Flow} = (\Delta C_{\alpha} - \frac{\Delta C_{OH}}{\alpha_{ave}})\alpha - \Delta C_{year} - \Delta P\left(\frac{i(1+i)^n}{(1+i)^n - 1}\right)$$

where ΔC_{α} = Operating cost reduction (\$ 0.45 per square foot)
ΔC_{OH} = Additional overhead costs (\$ 500)
ΔC_{year} = Additional annual costs (\$ 1500)
α_{ave} = Average job size (30,000 square feet)
α = Annual system production (100,000 square feet)
ΔP = Additional purchase price (\$ 50,000)
i = Interest rate (10%)
n = Useful system life (2 years)

A baseline case which used the parenthetical values above revealed an increase in annual cash flow of \$13,000. A sensitivity analysis was performed by systematic variation of ΔC_{α}, ΔP, α, and n in the economic model. The results showed the most significant factors in the economic viability of the system to be yearly production volume and savings in operating costs. Variations in the purchase price and useful life of the system had moderate impact on system economics. Effective interest rates, which were independently varied, had a marginal effect on the cash flow generated by the automated paint system.

Initial field tests of the automated paint system validated the hypothesis predicting the economic advantages of automation. These advantages, along with improvements in worker safety and product quality, augment the initiative for development in this area of construction automation. [4]

5.0 CONCLUSIONS

The work done so far has been carried out by a small cadre of engineering graduate student operators. The characteristics and performance of these individuals may not be typical of the people who would normally perform these operations. The conclusions that we have been able to draw from our design and test experience to date are summarized below:

• It is quite easy to produce acceptable blast cleaning with automated equipment; the quality of the finished surface is high and the improvement in the operator's work environment is dramatic. No insurmountable obstacles have been encountered thus far.

• A sand pot vibrator improves the flow of the sand and should be included as a component of any blast cleaning system. Careful storage and handling of the sand improves the flow characteristics of the sand and results in higher productivity.

• A larger sand pot would improve the productivity of the blast cleaning operation but would require a heavier vehicle. A heavier vehicle is potentially troublesome around some tank berms and the muddy low lying areas within the berms. A larger sand pot will require a greater capital investment for both the tank and vehicle.

• The high noise level associated with blast cleaning requires ear protection even with a remote operator station. "No hands" radio communication between crew members would be helpful.

• The blast cleaning operation should include a test procedure for lead and other toxins. The remote operator station enabled the crew to stay upwind of the blast effluent; the operators felt that this alone made the automation worthwhile. Lack of a natural breeze might require use of a respirator at times; but with a modest breeze the operators felt no need for a respirator. The system should include a simple test or alarm to insure against operator complacency.

• The development of a blast cleaning effluent system will require a system that can process large air volumes and extract large amounts of sand. The size distribution of the blast effluent is widely distributed.

• It is possible to produce a uniform high quality paint film with automated equipment.

• The paint over-spray containment system worked well. The small amount of air handled and the lack of detectable overspray were encouraging. A roll type filter for continuous filter renewal should be a part of any commercial system.

• The air assisted-airless paint spray system produces a good quality job, is easily controlled and gives efficient paint deposition.

• The high solid epoxy paint favored by the petroleum company-owners is more difficult to work with than some other paints. A search for a more easily managed paint might be worthwhile. Stable single component paints with a long pot life would be easier to handle and reduce the time required for clean up.

• The current control system was able to provide usable accuracy. Greater accuracy, while desirable, is not essential, and should be achievable.

• Graphical pre-processing would be a significant programming aid. The controller needs to be able to switch modes in the middle of a job. The operator would like to be able to interrupt and redirect the machine in the middle of a control sequence.

• The process is insensitive to winch location. Productivity of the crew would be enhanced by developing cable latching and anchor point hardware to minimize the time required when setting up.

• Significant market appeal to owners would result if they could be given the assurance of uniform paint film quality by incorporating on-line monitoring and self shut down feature so that their time and attention could be more easily utilized in support activities while the operation is underway.

• Generous allowance for cooling of the electronic motor drive circuits is needed to deal with operating and environmental conditions encountered.

• While most of the economic potential of the system lies in the huge number of existing tanks world wide, new tanks designed with automated surface finishing in mind will reap the benefits from this new technology.

Development of the automated paint sprayer is ongoing. Research efforts are continuing to refine the system and enhance quality and productivity. The advantages realized by automation of the prototype surface finishing system are encouraging and industry interest in automation is increasing.

ACKNOWLEDGMENTS

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