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Robotic Finishing Applications

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This paper surveys Robotic Finishing applications utilizing abrasive and synthetic belts, flap and buff wheels. The primary emphasis is placed on the polishing of parts to achieve a surface finish for preparation to paint or plate.

COMPLETE STORY

Introduction

Provided is an overview of what components comprise a robotic finishing system, how the pieces fit together and work. Also covered is what factors influence cost, and guidelines to help potential users conduct an in-house survey of existing polishing, buffing or deburring applications. Specific examples are provided to help determine the system requirements to successfully implement a robotic finishing solution.

Robotic Buffing Large Awkward Part


Typical Manual Finishing Station

Evolution of Automated Polishing Applications

Since the advent of modern polishing techniques in the early 1900's, the majority of all polishing has been accomplished by hand. Advances in technology have led to developments and improvements in media, semi automatic stations and fully automatic work cells. These advancements have allowed equipment builders to develop automated equipment to process more complex shape parts. Buffing, because of the nature of its process, (cloth and compound) was the first early user of automated finishing applications.

In the fifties, sixties and seventies some automated polishing applications were attempted. Success was limited to simple shaped high volume parts. More complex shaped parts required many media processing heads, each head working on a specific part area. Each head was tediously set-up to perform its operation in conjunction with sister heads up and down line. Even slight part variations could adversely affect the part quality.


OB Lower Unit Belting Line 1969 Vintage


CNC Finishing Cell

CNC Polishing Technology

These automated polishing systems were targeted for high volume simple shaped part styles. The introduction of the CNC style polishing cell opened the door to belt process more complex shaped parts. Most CNC technologies were limited to a single belt grit. The CNC cells also supported five axes of motion, allowing only limited access to complex shaped parts. In many cases the complex shaped parts had to be re-loaded in fixtures to complete the processing.

CNC belt polishing was well suited for gate grinding and flap wheel applications where two to four parts could be set-up and run simultaneously. The primary advantage of the CNC over the traditional automated line was in part changeover. The computerized CNC control allowed the operator to call a program from memory, change two to four fixtures and be up and running production in a matter of minutes.


Traditional Automated Finishing Line

Both the traditional automation line and the CNC are best suited for the more forgiving buffing process. Polishing with abrasive media remained primarily a hand operation, for complex part shapes people were used to manipulating parts under wheels and belts to complete the required finishing tasks.

Robots Yield More Finishing Applications
The development of robotic technology has opened the door to automation of finishing applications for both simple and complex shape parts. The industrial robot can replicate the motions a human would make during the manual finishing process. Robots, while lacking the human senses of sight and touch, do possess the ability to replay their programmed path with a great deal of repeatability. Their path replay repeatability makes them ideal for process delivery applications such as Mig welding, water jet cutting, sealant dispensing, paint spraying and finishing.

The robot, when integrated into a system with a part presentation device, finishing heads, and system software, can make an excellent automated polishing system. The robot with its six axes of motion can maneuver complex shaped parts, and with the proper head and tooling design can successfully polish six sides of most part surfaces.

While the robot cannot keep the same production rate as the traditional multi-head finishing line or multi spindle CNC cells, it can perform multiple finishing operations in a single part handling. When one factors in the ability of the robot cell to run unattended and quick part changeover, the robot cell can keep pace with most manual polishing rates.

Buffing on the other hand, is probably an application that is best handled by traditional or CNC methods. The robots can only maintain the same production pace as a human operator, usually well short of the production capabilities of other automation methods. In rare cases when combining both belt finishing and buffing in the same cell, robots show promise by eliminating secondary part handling and operations.

Industries
Almost all U.S. manufacturing operations are involved in some sort of hand finishing. These applications range from the simple filing of the sharp edges on machined surfaces, to the most complex of polishing requirements to finish and size jet engine fan blades or artificial hip and knee implants.

The following is a list of a few industries that have successfully automated hand-finishing applications with robots.

<u>Aerospace</u>
Airframe spars, stringers, skins.
Engine fan vain, blade root, disks, and combustion housings.

<u>Cookware</u>
Pots, pans, knives, forks, utensils.

House ware
Die cast lamp bases, vacuum cleaner trim.

Plumbing
Sinks, faucets, bases, handles.

Marine
Deck hardware, propellers, drive housings.

Automotive
Trim components, engine, transmission, plastic trim, bumpers, motorcycle suspension, engine details, trim components, gas tanks and fenders.

Lock Hardware
Locksets, knobs, levers, and hinges, trim components.

Medical
Implants (knees, hip), instruments.

Justification Factors

When surveying a facility for robotic finishing potential, one must take into consideration a number of factors that could help or hinder the justification of the application. Some factors to consider include the following:

Labor Cost

- What is your direct finishing cost of labor; how many hand finishers work on each shift?
- What is their hourly rate and benefit cost?
- Many shops run only single shift finishing operations. It is very difficult to cost justify any type of automation on a single shift basis.

Workmen's Compensation Cost

- Are the parts large or heavy; is there a chance of back injury?
- Are the parts small and difficult to hold, requiring repetitive hand motions to process, adding to the potential of ‘‘Carpal Tunnel Syndrome’‘?
- Is the environment noisy, and/or dirty, contributing to health risk factors?
- Is the work tedious or boring leading to worker apathy and safety problems?
- Workmen's Compensation Claims are on the rise. The manual processing of both small and large parts could be a significant factor in future rising benefit cost. An automated robotic finishing cell could greatly minimize this type of exposure by removing the operator from the health risk associated with the tedious, dirty and noisy environment of manual finishing.

Governmental Regulations

- Will the manual polishing equipment meet OSHA standards?
- Will future air quality requirements allow open area finishing?
- Disposal of polishing debris (hazardous material).

Just-In-Time Manufacturing

- What are your corporate goals regarding product inventory?
- Will your product mix expand or reduce in the future?
- Will your competition require you to reduce product cost and improve delivery to stay competitive?

Quality Control

- Will the demands of the consumer require the improvements in quality only automation can provide?

Available Work Force

- What is the availability of hand finishers in your region?
- If you need to expand production, can you hire and train the required work force in an ample time?
- Does your finishing department control your quality and productivity?
- Do work rules affect your ability to respond to market conditions?
- Will the elimination of hand finishing improve your overall competitiveness in your market?
- In many plants, the finishing department controls the productivity and quality of the finished goods. To increase production capacity, you will have to hire and train additional hand finishers.
- Approximately three of ten finishers will last one year on the job.

Perishable Cost

- Media (Belt) Cost

The implementation of a robot cells has reduced media cost from 50 to 88% of the manual operation.

Safety Equipment
Operator gloves, aprons, earplugs, leg and shin protectors, and safety glasses are all items most companies provide to their manual finisher to meet OSHA and local safety codes. A typical manual finisher can use two pairs of gloves a shift and one pair of safety glasses a week. This

could easily account for $2,000.00 or more of indirect cost per manual polishing station a year. The robot, of course, does not require any of the above safety items.

Advantages of Robotic Finishing


Robotic OB Lower Unit Processing 1989 Vintage

Man has a great ability to adapt to change. In finishing, a manual processor can quickly and effectively process a variety of part shapes, style and process set-ups in lot runs of one with little set-up or no changeover. Most fixed automation systems are best suited to large lot runs, days and even weeks of continuously running the same part style, production is only stopped to replenish media set-ups. Part changeover can be time consuming and difficult. The CNC style machine handles medium to large runs effectively. Part changeover is usually quick, requiring only fixture change and loading a new program from memory. However, the CNC cell is usually limited to a single operation and is best suited to simple belt grinding operations or the more forgiving flap wheel or buffing applications.

The robotic cell falls somewhere between the flexibility of the human, with rapid part changeover and multiple operations, and the medium volume of the CNC cell. The robot, like man, picks up the part and moves the part under the media to complete the required finishing. The robot cell can handle up to eight individual operations such as abrasive or synthetic belts, flap wheels, wire brushes, synthetic wheels and buffs with compound.

Most cells can be set-up to run any combination of operations with their sequence and process parameters determined by the part program. Part queuing and fixturing techniques adapted for robotic processing can be set-up for rapid changeover of part styles when quick-change cell tooling concepts are employed.


Mass Part Storage

To complete a part style changeover, the operator runs out the current lot of parts from the queue, selects and loads the new part number from storage memory, replaces the part queuing trays and exchanges the robot EOAT with the new part fixture to be run. In some cases the media set-up or contact wheels will have to be changed for the new part process set-up. This changeover can usually be accomplished in ten minutes or less. When the cell hardware and part program are loaded, the operator simply loads the new part styles into the queuing trays and initiates the automatic cycle. The robot will then move to pick-up the first part from the queue and process it through up to eight pre-taught operations.

The robot program sets the proper robot process speed, force, and SFPM for the application. The program also keeps track of media wear factors, such as belt life by increasing the process force or SFPM at a predetermined part count or worn wheel by adjusting the programmed path and SFPM for the new smaller diameter wheel base on the horsepower loading of the process. Upon completing the processing, the robot returns the completed part to its position in the queue and moves to pick the next part. The robot will continue to run all parts from the queue, stopping only when a fault occurs, such as broken, worn belt or wheel, dropped part from EOAT, air pressure loss, or when system fault occurs.

Robotic systems for polishing are not well suited for single piece runs, although they do handle smaller lot runs of ten to 50 pieces very well. When robotic finishing cells are designed and implemented properly, a single operator can attend up to four cells simultaneously. When large part queues are designed into the cell through the use of conveyors or other methods of automated material handling such as AGV's, unattended production capabilities through breaks, lunch, and shift change are normal. Unattended run time can account for 10% improvement in productivity per shift.

Implementation of process control software to monitor and adjust process parameters has extended the media life allowing up to eight hours of unattended automated operations. This has allowed users to run a third shift of unattended production. This feature can add to the benefits of automation, by not only reducing media costs, but also allowing up to 23 hours of production capability with only 16 hours of manning. The additional available unmanned production capability could help justify the cost of implementing the robotic finishing cell.

Part Selection

When evaluating parts to be processed, it is best to set up categories such as shape, size, weight, process requirements, material and volume. Parts with similar characteristics should be grouped and families of parts should be established. Any one robotic cell configuration may not be able to process a full range of part sizes or weights. Some part styles such as levers and faucets require processing on six sides, making part presentation, gripping and head configuration all critical. Six-side processing may require special head design and grippers with part reorientation concepts that will make that cell design special. Sufficient part volume must be found to justify the development of any special cell features.

Cell Considerations

When deciding to design in-house technology or look for a system integrator, one must consider a number of factors. The selection of each component in the cell is critical; robots, heads, arrangement, software, tooling and safety are all items that must be evaluated. The robot selection may be the easiest to make. A well-supported and field proven vendor should be considered. A vendor with a broad range of products with common controls through the product line will prove to be beneficial. This is helpful when different size cells are required to meet your part selection and production requirements.

Robotic products come in many shapes and sizes, polishing and buffing applications usually fit into a 6-axes, 22 to 99 lb. payload robot. Great caution should be taken should you decide to use a less than 6-axes or 22 lb. robot. While they may meet your current requirements, they may fall short in capability when your part size or style changes.

Process Heads

The selection and placement of the heads is a critical part of the design and implementation of a robotic finishing cell. Many first time users select a standard hand buffing or polishing jack. This choice seldom meets the long-term robotic finishing cell objectives.


Finishing Head Set-up

Most robotic system integrators have a family of head designs that have evolved over the years to meet a wide variety of application and processing requirements. The heads should be flexible. Many contact wheel styles and sizes may be required to process a group of parts. Quick-change wheels, floating wheel design, force and speed control capabilities are a few of the head selection considerations. Heads with both vertical and horizontal running belts may be required to better process a variety of part shapes.

Modern head designs have been developed with the greatest of process flexibility in mind. A single head design can accommodate belts, wheels, and buffs; with software to control belt and/or buff wheel wear factors. Selecting a single purpose head, one that only allows belt or wheel operations, can significantly limit the future process capability of the flexible robotic finishing cell.

End-Of-Arm Tooling

The parts selected for processing will dictate the type of gripper design required. The market supports a large variety of ‘‘off-the-shelf’‘ pneumatic actuated products. Parallel and three jaw styles with gripping forces of 30 to 330 lbs. are most popular for robotic finishing applications.

When selecting a gripper design for a specific part, one must consider the amount of gripping force required to hold the part suitably for the process to be completed. Belt polishing usually requires moderate amounts of holding forces, 30 to 100 lbs., depending on part size, shape and finger holding surfaces. Flap wheel, wire brushes and synthetic wheels usually require some type of finger locking design to lock in part features to the fingers to prevent the part from stripping off during the process. Buffing applications present the most difficult gripper design. The buff tends to grab at part edges and pulls the part away from the gripper. When buff is part of the process, the gripper unit should be of a heavy duty holding capacity, 100 to 300 lbs., with locking finger design incorporated.

Many times parts do not lend themselves to off-the-shelf products, in this case the designer will have to resort to an in-house design, employing pneumatic actuated cylinders, collets, mandrels, and other custom designed devices to hold the part.

The primary purpose of the gripper is to hold the part with suitable force for the intended operation. The gripper must not scratch or deform the part, and cannot interfere with the process. The gripper must also be designed to pick-up the raw part from its queuing nest and return the finished part to its nest without damaging the finished surface.

The gripper part touching details should be considered perishable. It is advisable to make the finger and locator details easily field replaceable. It is almost impossible to design a gripper with fingers that do not contact the media during the process. The gripper must also communicate with the cell during the cycle. Switches or sensors to indicate open/closed positions and part present will be a great benefit to the reliable unattended operation of the cell.

When planning the design of a gripper, it is advisable to avoid spring actuated single acting units, and vacuum actuated designs at all costs. Both springs and vacuum are not as reliable as the pneumatic double acting mechanical designs and should be avoided if possible. Safety spring designs, where a spring assists the air pressure and supplies gripping force if pressure is lost, should be considered where dropping parts can cause costly problems if air pressure is lost.

Manual Quick Change EOAT

When a user requires a number of part changes a shift, the tool change modules should be employed. These units allow the user to rapidly replace a gripper from the arm without the use of tools. The operator can accomplish this as part of the automatic cycle or manually. In either case the gripper is pre-wired and piped to a tool adaptor that is located and clamped via a pneumatic device to lock the tool in place on the robot arm. This device can allow tool change in one minute or less. Normally an operator would require 10 to 15 minutes to detach and reattach a bolt on type tool.

When the processing requires a part to be completely finished, auxiliary devices that work in conjunction with the gripper are employed. A common device such as a part reorientation station, where the part is placed in a nest and re-picked in a different orientation to access other part surfaces. This technique is used on parts such as hip and knee implants, where critical polishing is not accessible from a single holding position.

Part Presentation

The selection of the type of raw part's presentation method is critical to the productivity of the cell. Many first time users opt to have an operator load each part to the robot EOAT. This very seldom proves to be a productive method of loading, and operator paces the robot.

Most production cells have evolved to a raw part queue of from six to 30 parts. This queue allows the cell to run unattended for the amount of queue available.

The parts queue station can take a number of forms. Single and double drawer stations are popular because they allow the operator the ability to inspect, load or changeover part styles without interrupting the cell's production. Palletized conveyors can provide up to eight hours of parts queue and have been provided to customers who have medium to high size lot runs, this has provided the ability to run a full third shift unattended. Those customers have benefited by the ability to run a third shift of production unattended.

When selecting the capacity of the queue, one should consider the following:

- What is the anticipated media life? The parts in queue should not exceed the number of parts run through one set of media. The cell will stop when the media life is exceeded and the cost of the additional parts in queue may be wasted.
- Tooling cost for large queue capacity is expensive.

- Lot sizes, providing a queue of (30) parts is not necessary, if a typical lot run is (12).

Cell Arrangement
The components in the cell should be arranged with consideration of service, programming and operation. Floor space is a premium in most plants, but designing a cell where the components are packed together may result in a cell that is too hard to program and service. Placing components on a common base and the use of plug-in connectors are added costs, which will pay the user dividends the first time the cell is moved.

Cells are designed with fence style barriers and total walled enclosures. The fences provide a simple inexpensive barrier between the robot and the operator. The fence does protect the outside from thrown or dropped parts, but does little to contain the airborne dust created by the process. In the case of the fenced cell, the heads must be fitted with proper safety guards and dust collector hoods to contain and collect the debris.

Recent cell designs have incorporated total cell enclosures. These enclosures are constructed of sheet metal with windowed wall sections and access doors. The total enclosure provides the additional benefit of containing all the airborne debris within the confines of the cell. The total enclosure requires dust collection, usually built into the floor of the base. The heads normally need no elaborate guards or dust hoods, making the media fully accessible to any operation. An independent lighting transformer to fluorescent or adjustable flood light fixtures normally provide cell lighting.

Safety should be a primary consideration in any robot application. Governmental standards and good common sense require the enclosure or fence to have interlocked doors to limit access to the robot work area. Provisions must also be made to allow the attending operator access to the parts in queue, without interrupting production. The RIA safety committee has outlined standards for safety, which allows users and robots to coexist safely.

Software
Robot polishing systems bear little functional resemblance to any other robotic applications in industry. Finishing robots not only deliver a process, but also deliver the process at multiple locations (heads). Each process head requires different paths, with process parameters such as SFPM, IPM, force, dressing and compensation factors. To complicate matters, the robot also can act in a material handling capacity picking up, (palletizing) and depositing (depalletizing) parts from the queue as part of the process cycle.

The program logic to complete a process sequence for six separate media operations could involve the firing and monitoring of over 60 I/O's and up to eight analog signals. Typically one user frame and user tool are employed for each head, requiring 40 to 60 process points. This results into a complex structure to control, even for the most experienced programmer.

If robotic finishing cells are to be a useful plant process tool, they must be made ‘‘user friendly’‘. The burden of supporting complex software structures for each part program must be eliminated by a simple ‘‘polisher friendly’‘ menu system. The system has to support floor process and path changes without the user operator becoming an expert robot programmer.

The menu system outlined allows the user to develop the process sequence with user named process paths, giving the task programmer control over all process parameters from an object oriented menu. All user inputs will be in response to prompts from the system CRT/Keyboard. All modes of cell operation are initiated via menu selections, with sequence status, part count, cycle time and faults displayed on the monitor. The user never has to write a line of code, command an I/O on or off, or even understand the robot native language to develop a part task program. All the complex programming is supported by executive software, invisible to the user. Employing this type of cell software allows the user to concentrate his efforts on production, process and quality issues, not complex robotic programming.

When developing software for a robotic finishing cell, the following are the minimum features that should be considered:

- Automated palletizing/depalletizing routines
- Flexible sequence control
- Robot IPM, head force, SFPM overrides
- Media wear compensation (force, SFPM or IPM)
- Media life monitor
- Path shut-off or multiple repeat
- Path test run
- Frame offsets
- System fault screen
- Cycle timer/watch dog timer
- File management utilities

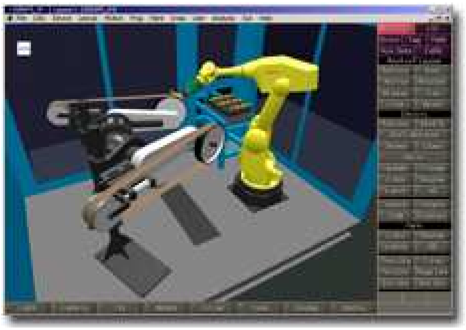
Process Programming

The process or task program is taught by the user via the teach pendant. The user moves the part to the media with the robot replicating the moves a hand polisher would make to finish the part. During the teach process, the user could set the process parameters based on the media being used and the area of the part being processed. A good software program would allow the user to alter the process parameters (SFPM, IPM, Force) on a point-by-point basis.

Polisher Friendly Software Menu Selection

Task programming a robotic finishing cell is a complicated and time-consuming job. Much time is spent establishing the required points, setting the process parameters, and test running the cell to see the finish results. The job becomes even more difficult when the robot is required to pick and deposit raw and finished parts from the queue as part of the automatic cycle. One cannot really appreciate the value of the menu driven software package until he attempts to program a cell in the native robot language, without the availability of the ‘‘Polisher Friendly’‘ software package.

Technology Advances



Computerized simulation of robotic applications has been used for years to evaluate potential applications for reach, tool design and cycle time. Finishing applications are no different. Simulation methods have been successfully used to establish equipment arrangement, evaluate EOAT design and estimate cycle time.

The greatest benefit to using simulation on a polishing cell is to reduce the amount of process teach time. Being able to establish process points off-line frees the cell to run production when new parts are added. Field experience has proven that an off-line taught program can be launched into production in 20% of the time it would take to develop the on-line program. The amount of time spent on the simulation workstation is approximately the same as the time one would spend on the floor. However, using off-line techniques, the robot cell would be available to run 80% more production during the programming process.

Simulation techniques rely on 3-D CAD models for all the elements of the robotic cell to be successful. Customer parts are difficult to model, and when modeled in some cases bear little resemblance to the actual parts. Processes used to manufacture raw parts such as casting, forging or molding do not always produce a part to print tolerances. This can be caused by use of multiple molds and die placed gated risers and other features in different locations for each part cavity.

This factor raises the on-line and off-line programming complexity. Simulation vendors have developed software to support hand held, low cost CMM probes. This probe allows users to gather part surface data and even establish process points from actual production parts. This method of gathering part information from simulation models has shown a great deal of promise to cost effectively improves process programming.

Robots have presented a new dimension to polishing. While no robot will ever have human dexterity or sensory ability, robot arms today with their computer controls and continuous path motions have been able to be programmed to duplicate the hand motions required to successfully polish many complex part surfaces. As robotic integrators and users gain more practical robotic finishing experience, software, simulation and other advancements in system and processing will evolve. This evolution in technology will provide users with further cost effective solutions to many finishing applications.

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