Automation and Chemical Milling

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In 1992 Boeing's Fabrication Division moved its chemical milling operation from an old facility in Seattle to a new sheet metal facility in Auburn. The main goals of the project were to decrease operating costs and down time and increase capacity and safety. This paper is about the design and start-up of this new partially automated chemical milling tankline, regeneration system and masking facility. This includes discussions on the approach used, areas automated (repetitive versus difficult), start-up, manufacturing difficulties, lessons learned, and some future improvements.

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1 Overview

In the summer of 1991 a team was formed to design and start-up a chemical milling facility in a new aluminum sheet metal factory. The production from the old facility was to be transferred by the end of 1992. The design constraints were to fit the operation into the previously designated foot print and constructed secondary containment. A preliminary layout and design concept had been established (that is how the secondary containment was located and built), but required revising based on lessons learned from the construction and start-up of an associated aluminum finishing tank line. The team's charter was to write a requirements document, define layouts, start-up, and qualify and the facility.

2 Design Process

2.1 Document Processes

In order to understand the processes the team reviewed the current operation and determined the basic flow of parts. The following are the basic operations that were to be performed in the new facility:

- Chemical Milling
- Gage Reduction
- Cleaning
- Cleaning/Deoxidizing
- Etch Cleaning for Mechanical Finishing
- Masking
- Scribing

Figure 1 is a flow chart for the chemical milling process and is an example of a typical process flow chart.

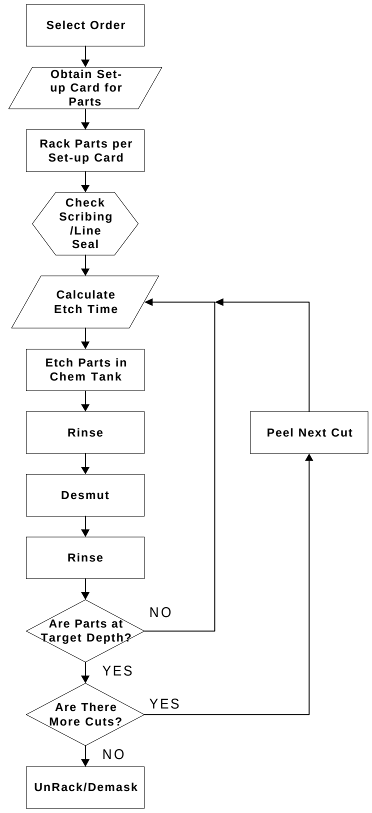

Figure 1 Chemical Milling Chart Flow Chart

2.2 Design Objective

The overall goals of the project were to move the operation to the new facility and reduce operating costs. The following is a summary of specific objectives that would meet the overall goals (they are not listed in any order of importance):

- Decrease Operating Costs
- Improve Part Flow (reduce cycle time)
- Reduce Down Time
- Increase Capacity
- Increase Safety by Reducing Employee Exposure to Chemicals
- Maintain Operational Flexibility
- Improve Process Reliability
- Eliminate Process Short-cuts

2.3 Design Philosophy

Below are the main system designs that were chosen to meet the above objectives:

2.3.1 Automate the repetitive

The general philosophy was to automate the repetitive and leave the unique/complex manual.

Some of the repetitive tasks that were automated were crane movement, tank controls, and maskant dipping application.

- **Automated Crane Movement:** Since chemical milling is an iterative process, only the repetitive parts of the recipe were automated. Some examples of repetitive functions are rinse and deox times, drip times, opening and closing lids, and crane movement. The operator calculates the desired time and enters it into a recipe. The control system then takes over the process. The operator can stop and/or resume the recipe.

- **Tank Controls:** The tank controls that were automated included continuous level control, temperature control (always had been), and air agitation.

- **Maskant Dipping Process:** The maskant application process was automated using a power and free conveyor system with a lowerator. This was set up to accommodate the requirements of the water-based maskant. The previous facility applied solvent-based maskant using a manual flow coater. With the new system the operator racks the parts, pushes a button, and comes back later when the parts are completed.

2.3.2 Simplify the System (passive lifts)

The system was simplified by using passive attachments of the rack to the crane. The other automated tankline in the facility had active hooks for lifting loads. This added unnecessary complications to the programming, mechanical systems and overall reliability. The passive lift systems greatly simplify the automated cranes and their reliability by removing a potentially complex and hardware dependent system.

2.3.3 Regenerate Solutions

About a year after start-up, a sodium hydroxide regeneration system was purchased and installed. Although it took a couple years, once it was fully operational it eliminated the need to dump the milling solution. This saves in down time, labor, chemical and disposal costs.

2.3.4 Tank Lids

The addition of bi-fold lids to the processing tanks reduces employee exposure to chemicals, energy consumption, and the scrubber size required. Figure 2 is a picture of the bi-fold tank lids.

Figure 2 Bi-Fould Tank Lids

2.3.5 Lay-out, Maximize Floor Space

In order to increase usable floor space from the original design, the material handling between the masking area and the scribing area was eliminated. Since parts had to be taken off the racks to be scribed the originally planned conveyor between the maskant system, scribe area and tankline was eliminated. Carts for the racks were used instead. The other improvement was to elevate the oven. This allowed the space under it to be used for scribing and storage.

3 Start-up Equipment/Process

3.1 Charge Tanks

Before the equipment was bought off the tanks were leak tested and the temperature controllers tested using water. No leaks were found. The temperature test was suspended due to scale build up on the tanks. Hard water and high evaporation rate of water caused the scale build up . The desmut tanks were the first tanks charged.

The desmut tanks contain primarily nitric acid and were filled using a tanker. After they were charged with nitric acid and water the solution was recirculated before the other chemicals were added. While the solution was recirculating through the pipes, a mild steel plug that a contractor installed to replace a bad flow probe dissolved causing nitric acid to be sprayed on the support structure of the pit. The reaction of the nitric acid produced NOx fumes (yellow cloud) and damaged support structure.

After the area was cleaned up and the damaged structure was repaired, the remaining tanks were charged without incident. The chemical milling and alkaline clean tanks were also charged without any complication.

The maskant tank was charged with the maskant manufacturer present. This is a process where the prevention of bubbles is important. As anticipated there were a significant amount of bubbles in the maskant after charging. To accelerate the removal of the bubbles the maskant viscosity was lowered and continuously recirculated.

3.2 Pre-production Tests

Test plans were developed under the assumption that the system would be debugged prior to acceptance. As it turned out this was not the case. In order to expedite the delivery of the systems the pre-production tests were used to de-bug the equipment. This made the plans obsolete. The two automated systems that required the most testing were the maskant application system and the tankline and cranes.

3.2.1 Maskant Application System

The maskant application system was tested first using sheets of aluminum, representing the simplest parts. The first part through the system was nearly blown off the rack by the oven. The part was blown into the wall, which caused the maskant to be damaged. This pointed out an oversight in the oven set-up. In order to increase temperature uniformity, the oven airflow had been increased to turbulent velocities. By closing the baffling in the oven the airflow was decreased and the parts made it through the system successfully. Figure 3 is a picture of the maskant dip tank.

Figure 3 Maskant Dip Tank

3.2.2 Tankline

The tankline pre-production testing started by verifying that all the tank controls worked. This included verifying temperature uniformity, ventilation states, agitation set-up, recirculation, tank level/make-up, and conductivity. From the beginning all the controls seemed to work adequately, but the monitoring system was unreliable. The supervisory controller did not always accurately represent the state of the equipment as controlled by the PLC (programmable logic controller). This did not actually effect the operation that much, but it was a nuisance.

The next tests involved verifying crane movements and timing in the two main modes of operation, semi-automatic and automatic. In semi-automatic, the ability of the cranes to take directions was verified. In automatic, the ability of the system to execute a recipe with the appropriate timing was evaluated. In addition, the system interlocks were tested. There were no major problems here. The biggest difficulty was the photo eyes down the length of the tankline to check for crane clearance were frequently being accidentally set off. As a result the recipe was frequently interrupted. This was resolved by removing the sensors from non-essential areas and relying on manual e-stops. Figure 4 is a picture of the tankline and cranes.

Figure 4 Tankline and Cranes

3.3 Line Qualification

In order to process parts, the system had to pass qualification tests. The test panels and results were submitted for acceptance on the Qualification Processors List. The tests run were surface roughness, endgrain pitting and intergranular attack. In addition proof of certification of temperature and chemistry had to be presented.

3.4 Start-up New Process

Once the equipment was ready and the line was qualified the operating personnel began the transition from the old facility to the new one. The plan was for a 3-month transition period where each week a few more people would make the move. After the first month factory management decided to bring them all down. This was somewhat risky considering there were still some equipment safety issues to be worked out. As it turned out the move went smoothly.

During the first 6 months two processing problems appeared:

- **Wash-board appearance**: This problem showed up after 3 months and was probably caused by continuous air agitation, increased tank life due to the larger tanks, and the reduced amount of parts per volume of solution. Once the air was reduced the problem went away.

- **Endgrain Pitting:** This problem also showed up after 3 months. Originally it was felt that the endgrain pitting and the washboard problem were related. This was later found not to be the case. The endgrain pitting was caused by a bad test method, which had not shown up because the tests were previously run on new tanks. The test is normally run on a monthly basis or when a new solution was tested. At the old facility tanks only lasted 3 weeks on average, so tanks were always new when they were tested. The original test method used a piece of extruded material with the endgrain polished. The flaws in the test method were that we don't etch the endgrain of extrusions or use the alloy of the test panel. The test method was changed to use the standard 40 and 80 mil surface roughness panel. The fillet of the deeper cut was then analyzed for endgrain pitting.

3.5 Start-up Regenerator

The purpose of the regenerator is to remove the aluminum from the solution and recover the sodium hydroxide. The regenerator was installed after the tankline was running. It was designed to run 24 hours a day seven days a week. The equipment was ready to start during through the washboard and endgrain pitting problems.

Production was initially fearful that plugging all the tanks into the system at once could cause all the tanks to go bad at the same time. Because of this the tanks were cycled through the regenerator in a batch mode. This made it difficult for the regenerator to reach steady state. After a couple years of successful operation, production had the confidence to plug all the tanks at the same time into the system. Since then no tanks have been dumped.

4 Successful Changes

- **Automated Crane Movement:** The switch from manual pendant cranes to PLC controlled cranes went smoothly. The pendant cranes required the operator to walk with the crane as it moved and position it as required to get the load in and out of the tank. In semi-automatic mode the operator can give the crane commands from the supervisory computer or a push button station or walk with the crane and use a joystick to give the commands. Either way crane positioning is controlled by the PLC. In automatic mode the operator enters a recipe, which executes all the crane movements. This can be interrupted and resumed if circumstances require. The main benefits from these changes are allowing the operators to be away from the chemical fumes and permitting one operator run two cranes. Figure 6 is a picture of the tank and crane control console.

Figure 6 Tank and Crane Control Console

- **Automated Tank Controls:** Although the old tankline had temperature controllers, they could not do remote temperature monitoring, and all the water adds had to be done by an operator. The new system has automated temperature and level controls. Another feature designed in, but never completed, was automatic control of the air agitation. The design was to schedule the frequency and agitation time.

- **New Maskant:** Part of the design considerations while building the area was to use water-based instead of solvent-based maskant. The transition from the old easy to peel solvent-based maskant to a new, harder to peel water-based maskant was difficult on employee morale, but the material performs adequately. Most parts are being processed with water-based maskant.

- **Automated Maskant Dipping/curing:** The previous maskant application process was a flow coat system. By switching to dipping we were able to reduce the amount or labor. Parts are now racked, cleaned and then sent through an automated material handling system where they are dip coated and cured.

- **Increased tank life (regenerator):** When the regenerator was fully operational, the life of the tanks went from about three months to indefinite. Also with the regeneration of the sodium hydroxide, the amount added during the life of the tank decreased. Since the regenerator is constantly running the etch rate in the tanks is much more stable. Although it is not stable enough to predict the etch time on the first try, the first cut can be closer to the targeted depth.

- **More Reliable Process:** With all these equipment changes (as well as some processing changes) taking place, the average surface roughness decreased from a roughness average of about 45 to 32 microinches. Figure 7 below shows the change in surface roughness average over time. This reduction in surface roughness may ultimately improve the fatigue life of the parts.

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Figure 7 Surface Roughness

5 Unsuccessful Changes

The following are changes that were made that did not work or have the desired effect:

- **Spray Rings:** In addition to double counter current rinse tanks spray rings were put on the milling tank to cool the parts and rinse some of the solution back into the tanks. Manufacturing did not buy into this and never used them. Eventually they all plugged and quit working.

- **Conductivity Meters:** Conductivity meters were installed on all the clean rinse tanks to control water additions. Although they worked to some degree, it was difficult to keep them calibrated.

- **Reduced Number of Chem Millers:** It was expected that with the automated cranes, the tankline could be run with two chemical milling operators. Due to issues unrelated to the system the number of operators was never decreased.

6 Lessons Learned

The following are lessons learned during the process.

- **More Up-front Design Work:** The more effort put in to defining the requirements and during the actual designs the better. During these phases, changes are much less costly and are easily incorporated. In order to do this more time should be spent finding experienced participants willing to voice their opinions and explore options. These portions of the project can be painful, but the more areas that can be covered, the more likely the objectives can be met and the less the project will cost. Below are some specific areas that were missed or under designed.

    - **Simplify System:** One area that could have been made less complicated was the re-circulation on some of the tanks. The system as designed had re-circulation pumps and piping on all tanks. More effort should have been made in defining the processes. This was done at a later date and re-circulation systems were removed from all non-heated tanks.

    - **Free Board:** Chemical-milling solutions produce a lot of foam, especially when operated at the higher temperature ranges, and when there are large loads in the tanks. The design only called for one foot of free board. There should have been two to three feet of free board.

- **Material Handling/Tank Integration:** The original design called for the cranes to move past a tank when the lids were open. This was to enable the parts to drip into the tank and not on the lids. During the crane and tank design there was not enough attention paid to this feature. As a result the tank lids must be closed for the cranes to pass.

- **Software/Controls Definition:** The software was left entirely to the supplier, with little review. It would have prevented problems and improved maintainability if there were written descriptions of all the control loops. This was done for the regenerator, which simplified the start-up and maintainability.

- **Equipment Ownership:** Work hand in hand with the designers and contractors. Make sure they understand and communicate information to the subcontractors (i.e. mild steel is not compatible with nitric acid)

7 Future Improvement Efforts

The following is a list of areas where future improvements and projects will be directed:

- **Simplify the Hardware:** Simplifying the hardware reduces the maintenance requirements of the line, and increases space. Some of the hardware being evaluated are the level sensors, the need for pumps and some of the piping runs.

- **Improve the Controls/Alarm system:** Currently the system controls have to be frequently re-booted, there are many alarms and no data collection, and some of the supervisory controller information is inaccurate. The improved system will improve supervisory control accuracy, reduce the maintenance of the system and include data collection for troubleshooting and logging system problems. It will also include redoing the alarming systems to eliminate nuisance alarms.

- **Reduced Fatigue Life:** Future projects will investigate the desire for increasing the fatigue life by lowering the surface roughness on the parts.