Sculpting Efficiency:

Integrating Automation into

the No-Bake Casting Process

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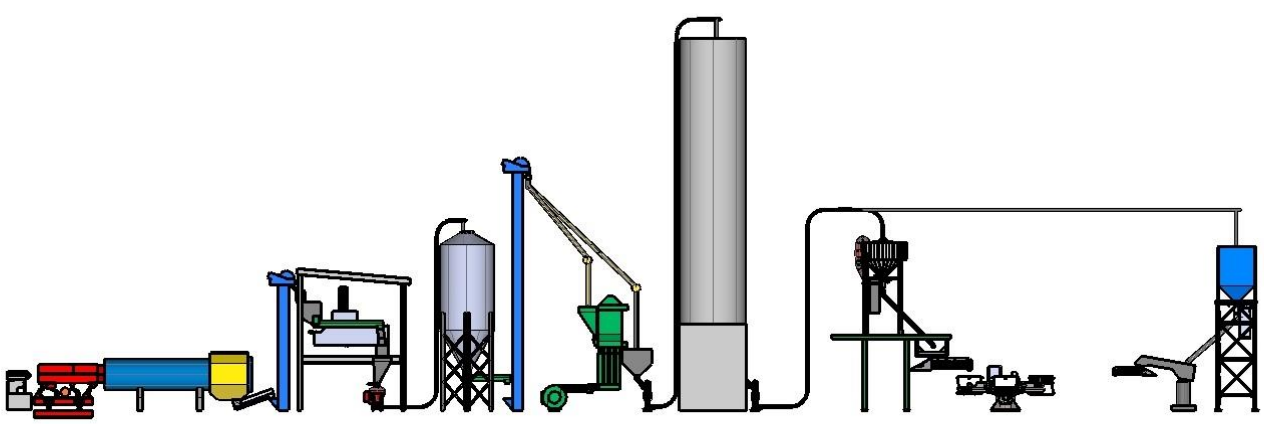


Abstract

This paper covers recent upgrades to our steel foundry as we continue to automate our no-bake molding line. In November of 2022 we installed a Palmer Flip Molding Machine (FMM), as well as the required support equipment into our mold-making processes. We will look at some of the historical challenges of foundry work and delve into the possibilities for automation to make the work more bearable. Given the steel industries pressing need to attract and retain employees, our story highlights the delicate balance between manual labor and technology. We strive to improve efficiency, consistency, speed, and safety while remaining competitive in a demanding industry.

Introduction

I would like to begin with a passage from Vannoccio Biringuccio's treatise "De la Pirotechnica"; published in 1540 it is one of the earliest printed books on metallurgy. Concerning the art of the foundry Biringuccio writes "He who wishes to practice this art must not be of weak nature, either from age or constitution, but must be strong, young, and vigorous, so as to be able to handle things, as you almost always have to, that are heavy and inconvenient because of their weight--- things such as bronze, iron tools, wood, water, clay, rocks, bricks, and the like. Nor do I doubt that whoever considers this art well will fail to recognize a certain brutishness in it, for the founder is always like a chimney sweep, covered with charcoal and distasteful sooty smoke, his clothing dusty and half burned by the fire, his hands and face all plastered with soft, muddy earth. To this is added the fact that for this work a violent and continuous straining of all a man's strength is required, which brings great harm to his body and holds many definite dangers to his life. In addition, this art holds the mind of the artificer in suspense and fear regarding the outcome and keeps his spirit disturbed and almost continually anxious."

After almost 500 years Biringuccio's description of the foundry worker is still accurate. The metal casters that came before us were true giants of industry and innovation. However, even with the advancements made over the past century I still see workers that look like they're coming out of a coal mine. And unfortunately, I see far too many injuries as well. The nature of foundry work is unforgiving and historically that seems unchangeable, so I tread carefully in my optimism because to think that we're going to be the generation of engineers that cures all the foundry worker's woes is a level of arrogance that I am not quite ready to embrace. But I will say that the current technology available to us in both mechanical and digital systems has given us the best chance to make improvements that anyone has had since the art of metal casting began.

Identifying a Need

Like most businesses we have been dealing with a shortage of employees in the last few years. Given the intensive labor and difficult, dirty work we do in foundries, we perhaps have an even more difficult time finding workers. We do not see a solution to the worker availability problems anytime soon, so as we modernize our facility, we must plan to do more with less. Our challenge is to make foundry work more attractive to employees so that they stay long term while at the same time increasing productivity and making more sand molds, and therefore parts, per hour.

Figuring out how to make our employees' work easier was not merely an act of altruism, it was necessary for our survival. Our experienced workers were being lost due to injuries and attrition, and new workers wanted no part of the hard labor. Our no-bake system was based on a closed loop molding line for many years. Molds were hand packed and after setting up they were manually flipped over; large mold halves were flipped using an overhead crane. Many of our smaller molds ranged from 10 to 150 lbs. and large ones weigh several thousand pounds. Back injuries were common, as were crushed fingers and ankle injuries due to chunks of sand creating tripping hazards. I saw many new employees excited to start work only to get a taste of the mold line and never return for their second day.

We knew we had to automate a large part of our molding process but a clear-cut solution had yet to present itself. Successful upgrades can bring high rewards, but a failed one can bring financial ruin. It is a stressful decision to make.

Efficient Design

We considered many different options including a traditional carousel with a mold rollover. This setup could have added the automation we wanted but the system had a large footprint and the rollover was too slow, maxing out at around 20 molds per hour. After consulting with Palmer Manufacturing about our needs, they recommended their Flip Molding Machine (FMM). Palmer had previously built and installed a smaller FMM at another foundry as a proof of concept, and it had been very successful. Our FMM would be considerably larger so we were worried about the risk of being the second test bed for the concept. However, after visiting the other foundry and seeing their machine in action, we were convinced that this would be the best solution for our foundry. The other foundry's employees looked calm and relaxed as they made molds; it made me wonder if they knew how easy they had it.

The FMM combines the traditional carousel and rollover into a single machine. It has four platens that revolve like the carousel; however, the stations also take on the function of the roll-over by inverting the mold as they arrive at the final draw station. Pricewise the FMM, as a single machine, was more cost effective than buying a separate carousel and rollover, in fact it was comparable to the rollover alone.

Another requirement for us was rapid pattern changes, since we must swap patterns several times per shift. We worked with Palmer to design platens for the FMM that would be adaptable to a wide variety of pattern shapes. Our engineering team designed a clamping system that mounts in different configurations to the platens allowing for rapid changes. We kept everything as robust and simple as possible.

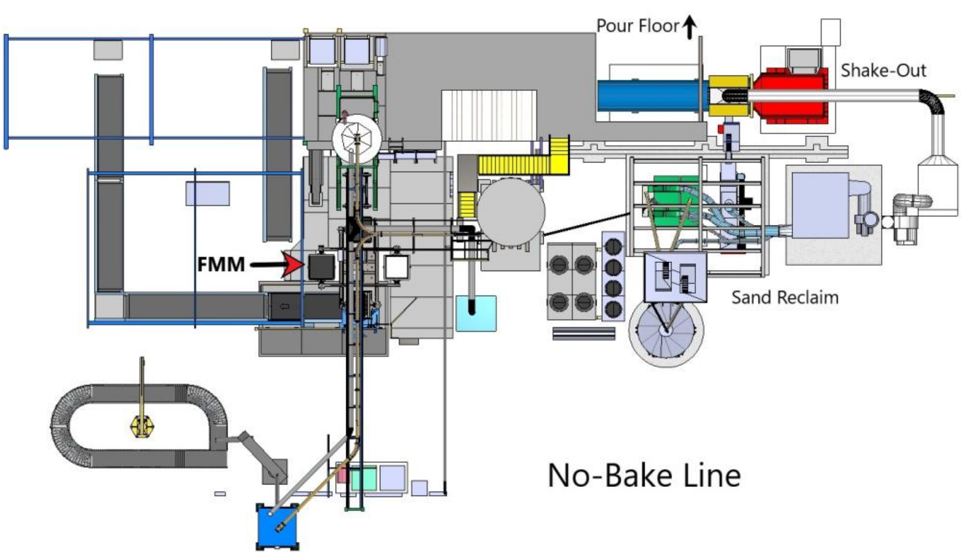
Sizing the Machine

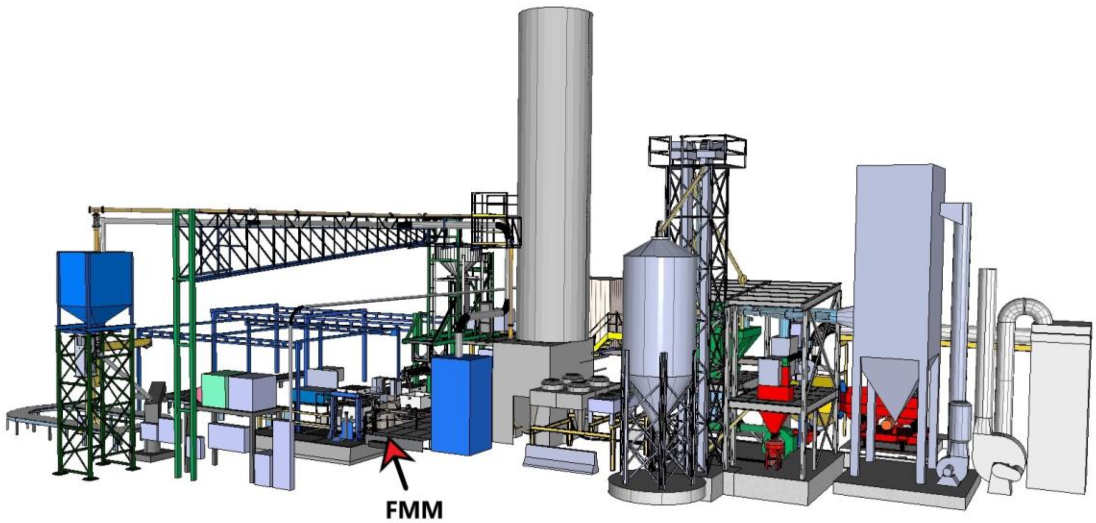
Sizing the machine for our needs was a tedious process. Palmer kept telling us that larger platens add very little additional cost, but while we didn't want to undersize our FMM we didn't want a behemoth either. We had a large warehouse filled floor to ceiling with patterns, but no list of their exact dimensions. Each pattern was measured and logged onto a spreadsheet.

Our first instinct was to aim for a machine that was large enough to accommodate 90% of our patterns. However, we came to the realization that this was the wrong metric to use. Some patterns were only used for a few molds a year, while others were used for thousands of molds. So, to arrive at the final size, we pulled production numbers for the previous 5 years and calculated the percentage of molds we produce that could fit on various size platens. The final decision was made to go with 48"x48" which would accommodate 95% of our molds produced. For reference, if we chose to go with 42"x42" platens we would have been able to get approximately 88% of our molds made on the FMM, but the extra 6" per side was deemed to be worth the extra cost and space.

A 14" draw capacity would have also worked for 95% of our molds, but instead we chose to go with a 24" draw capacity. The increased draw was virtually the same price and provided more potential usage in the future. We also considered rectangular, rather than square, platens, but that didn't make sense due to our pattern sizes and the nature of the rotating set-up. Another thing that we took into consideration was the size of our pour carts and maneuverability of moving molds/carts to the pouring area. We have 2 sizes of pouring carts, 54"x36" and 63"x43".

We had a lot of numbers to look at and on paper things seemed pretty good. However, there was a lot of concern from management and from Palmer about how the system would fit into our existing infrastructure and how well the workflow would function once you added employees and forklifts constantly navigating around the machinery. Luckily, we have a detailed 3D model of our facility that is constantly updated as we make modifications and install new equipment. Palmer provided us with 3D models of their proposed equipment, and we were able place the models into our facility layout as well as try them out in different configurations.





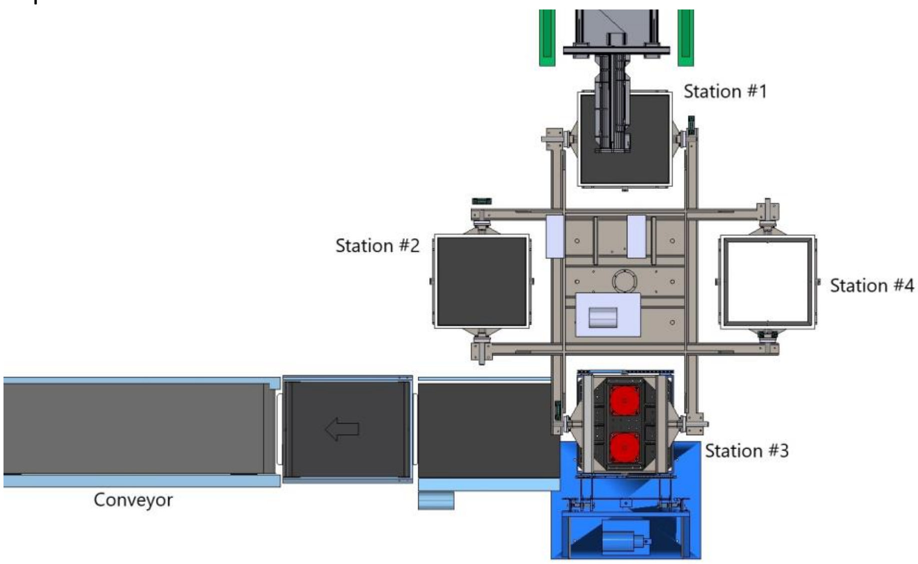
Once we felt confident about the setup, management reviewed our design, but there was still concern. A slight miscalculation at this stage could have dire consequences when it came to the installation and productivity of the equipment. I ended up putting the equipment into an augmented reality program that allowed us to take a tablet out to the foundry, set a few reference points to the building, and then take a virtual tour of the work area. Management was able to hold up the tablet and view the equipment as they walked around it to make sure there were no obstacles and pathways were wide enough for forklifts to safely operate. This visualization alleviated everyone's concerns and we were given the greenlight to move forward with the project.

In addition to the location of machinery, it was crucial at this stage of the design to take into consideration how the machinery would be transported, unloaded, and moved into the foundry. The FMM has a width of 16.5’ making it too wide for a Semi-trailer and also too wide to fit into our roll up door. Palmer was able to design the FMM so that two opposing platens were removable and could be shipped separately. This brought the width down to just under 12’. The FMM was shipped on a Semi-trailer as an oversized load, and it fit into our foundry doors with about 1” of clearance on each side. We were able to unload the FMM with a large forklift that we rented. I try to avoid hiring a crane whenever possible as that dramatically increases installation costs.

Installation

While our equipment was being built, we did as much preparation work as possible. It is always a challenge when you're working around a running production line. Every minute they cannot produce is lost revenue, so we went to great lengths to not interfere. We were able to install our new sand tank and sand heater, relocate our resin totes, and install new transporter piping on the roof. Most of this happened during the work week but we also utilized every Sunday possible, the one day with no production, to install big stuff. Occasionally we did have to block off production areas, such as when we poured our concrete footings, but we scheduled this time with production leaders to figure out how to keep them partially operational and minimize losses.

Once the FMM was on site and we were ready for the main installation we shut down completely for 1 week. During this time, we reconfigured our old line into a new space and got it operational so that production could resume there, albeit in a diminished form. We then focused on installing the FMM and conveyor system which took about two weeks including testing and debugging. Once we handed everything over to production it took another few weeks to optimize the system, although this is an ongoing and probably never-ending process. All things considered the installation had minimal impact on our production schedule.



Operation of the FMM

The FMM has four platens that revolve around a central base. The platens revolve together, indexing 90 degrees at a time to move through progressive stations.

Station #1 - Patterns are filled with sand via a Palmer M500XLD sand mixer and excess sand manually struck off. Vibrators mounted under the platen help with compaction while the patterns are filled.

Station #2 - The sand mold cures while it sits at this station.

Station #3 - The platen is inverted as it arrives at this station. Once it has fully inverted a conveyor raises up from a pit below it and stops precisely at a position just underneath the mold. The vibrators then activate allowing the mold to slide out of the pattern and onto the conveyor. The mold is lowered and transported away while the platen is turned back over and moves to the next station.

Station #4 - Sleeves can be placed at this position during regular cycles, or the patterns can be swapped out quickly when required.

Every station is active at the same time so coordinated teamwork is necessary. Station #1 has the main operations control panel while Station #3 has a secondary panel which allows operators to control the draw cycle in case a mold doesn't release and needs manual intervention. There are separate PLCs for the mixer, FMM, and conveyors. The PLCs and their corresponding HMIs are all located next to the FMM for ease of access and to allow the operator to change parameters as needed.

Challenges

The FMM is capable of running very fast cycles so we needed a binder system that could keep up with it. Our average FMM cycle time is 90 seconds and there is a narrow window that is ideal to strip the mold from the pattern. If the platen rotates before we have a full cure the mold will slump and fall out of its box. This is annoying with smaller molds but unnerving with larger molds. Weighing in at hundreds of pounds, a large mold falling four feet and impacting our lift conveyor can damage rollers and even the conveyor frame itself. On the other hand, when a mold kicks off too early and has no flexibility, it becomes extremely difficult to vibrate out of its pattern, resulting in an employee pounding the backside of the platen with a hammer until the mold releases.

We run Poly Urethane as a binder system because of the amount of control it gives us over the curing reaction. We use 0.7% binder at a 60/40 ratio, and we changed to a much faster catalyst than we were running on our manual line. For consistent results we had to reduce any and all variables in our sand and binder. Our sand goes through a heater to keep it at a consistent temperature as it enters the mixer. The two binder totes are also constantly pumped through closed loop heating systems so that they maintain a uniform temperature.

Our workers were another variable, so we installed a large digital timer on the wall that resets at the start of every cycle. This helped the workers keep track of the FMM cycle and the simple change really helped them keep consistent times. They view it as a challenge to be fast and efficient and they take pride in doing so.

Our mold take-away conveyor system was another challenge. Creating molds at a fast pace meant we risked having a bottleneck downstream if the molds couldn't be assembled fast enough. We chose to install an automated conveyor belt system that would stay in sync with the FMM. As the molds progress down the conveyor cores are set in place, the molds are sprayed with an alcohol-based coating, and finally the cope and drag are assembled and set onto steel pouring carts which are moved by forklift onto the pour floor. A series of optical sensors are used on the conveyors so that our PLC knows when a mold has been cleared and another is ready to move down the line.

Results Matter

It took us several weeks to get everyone synchronized so that we could utilize the full output of the FMM. We are still working on ways to improve the performance of both the machine and the employees; only now it is an orchestrated dance rather than a brutish fight. No more heavy lifting and crushed fingers, instead there is a multitude of hand signals and emphatic yelling as each station gives all clear to signal the FMM to rotate.

If we look at the number of molds per hour that we are making with the FMM it can be a little deceiving. Our old line was making 16 molds per hour on average. Now we average 21 molds per hour from the FMM with our fastest shift on record making 32 molds per hour. It may not look like a huge improvement, but the FMM has allowed us to change our molding workflow in ways not possible before.

Previously, with large patterns we could only make one or two molds per hour and we would run several smaller patterns in between them. But the FMM does not care what size the pattern is, it does not get fatigued or slow down. We can now run the pattern and make 20 or more molds per hour, regardless of whether they are large or small. With smaller patterns we are able to double them up on the platen, producing the cope and drag at the same time. Also, we have started to optimize patterns from which we make a large volume of castings. For example, patterns that previously produced four castings have been changed to now produce eight castings, making each mold from the pattern twice as productive. Previously the optimized patterns would have been awkward to manually flip over but the FMM has no issues.

This increased productivity has allowed us to reduce our mold making from three shifts working around the clock to a single shift running the FMM. Odd sized patterns and ones that only require a few molds are still made on a separate closed loop line that also runs one shift per day with minimal staffing and much safer working conditions.

Plans for Future Upgrades

Upgrades are a double-edged sword, since success reveals your next weak point... or several. Even though we can match our old output of three shifts on a single shift, wouldn't it be wonderful to still run three shifts and make a lot more castings! That is certainly our long-term goal, but we have a bottle neck in our melting capacity first and in our sand reclamation system second. As for our melting capacity, we recently purchased a 600kw power supply to add to our existing power cabinets and we are looking at an installation date in the summer of 2024. To handle our second bottleneck, in October 2023 we finished updating part of our reclaim system with a new rotary lump crusher to break down our molds. We also modified our sand cooler and added another transporter. These upgrades have more than doubled our capacity to break down sand molds. However, to really handle the FMM's molding capacity we still need to install another machine to remove resin from the sand to keep our LOI's low. We currently use a pneumatic reclaimer to scrub the no-bake sand and I hope we can install a second reclaimer in 2024.

Conclusion

Our Foundry Manager, Jake Reynolds, recently told me that without the FMM upgrade, he feels like we would have been moving backwards as a company. The pandemic brought about a lot of hurdles for companies to jump, and we were able to mitigate the employee retention problems we were already having by automating our no-bake molding process. For me personally, I knew we were going to be successful when I saw one of our long-time employees bring his 5 kids in on a Saturday to show them what we were building. I was used to hearing people complain about foundry work and sometimes dismiss it as a dead-end job, but as I watched this employee show his kids around you could see the pride and excitement in his face. After installing the FMM, employee morale has been high and we experienced an 18 month run of profitable months, even with all the supply chain turmoil. It is still a tough dirty environment, but the improvements are leaps and bounds beyond the physical work we were asking people to do before.

I see the FMM as being the core of our no-bake line for at least the next decade. However, I also know that to stop upgrading is stagnation. The practices that are profitable today aren't necessarily going to be tomorrow. Without upgrades competitiveness declines, workers motivation evaporates and soon the furnaces will go cold. I have faith that the metal casting industry will continue to innovate in ways that are beyond my imagination. The final line of Birringuchio's passage seems a fitting way to end this paper. After his colorful description of the sufferings of the foundry profession he simply concludes "But, with all this, it is a profitable and skillful art and in the large part delightful." I couldn't agree more.