Technical Paper

Digital Technology in the Wax Room

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Abstract

There is little question that we live in a digital world. The question becomes how can we put the information to work. This paper serves to answer that question specifically as digital data exists in the wax room of an investment casting foundry. Meeting customer expectations has been a driving force for decades and many different quality management systems have evolved to achieve this requirement. Business management dictates that any successful program provides a sound ROI. A common theme with these programs is data collection and analysis. Our digital world makes both the collection of key metrics and the analysis of those metrics more much more economical. All this effort has lead toward more robust process control. The core of this paper deals with how to collect appropriate data and analyze that data for the highest levels of process control in the wax room. Using the latest model wax injection and assembly equipment allows this level of process control and data collection for both qualitative and quantitative analysis. In turn, this leads to sound operational decision netting the most efficient production of both wax patterns and assemblies.

Digital Technology in the Wax Room

Thank you for the opportunity to present to you today. Preparing for this paper has been a trip down memory lane. When I entered this industry forty years ago, there were minimal controls in the wax room. Today we have the opportunity to use digital controls and for the first time we can visually see what is happening with the wax temperature, flow, and pressure each and every injection. Digital technology allows you to have tighter tolerances, less variability. However, one thing I have learned over the past forty years; no matter how sophisticated the instrumentation, the application of that instrumentation and how it is used to control the process is the real challenge. With this paper, I will review the information you can gather with digital controls and how you can apply this information to reduce wax room scrap to achieve higher casting yields

Key input variables are temperature, flow, pressure, time and the wax itself. Let us take a look at these variables and how they have changed over the years.

Manual Control:

There have been many changes in our industry during the past 40 years. I look back at the variability of the process control devices when I started.

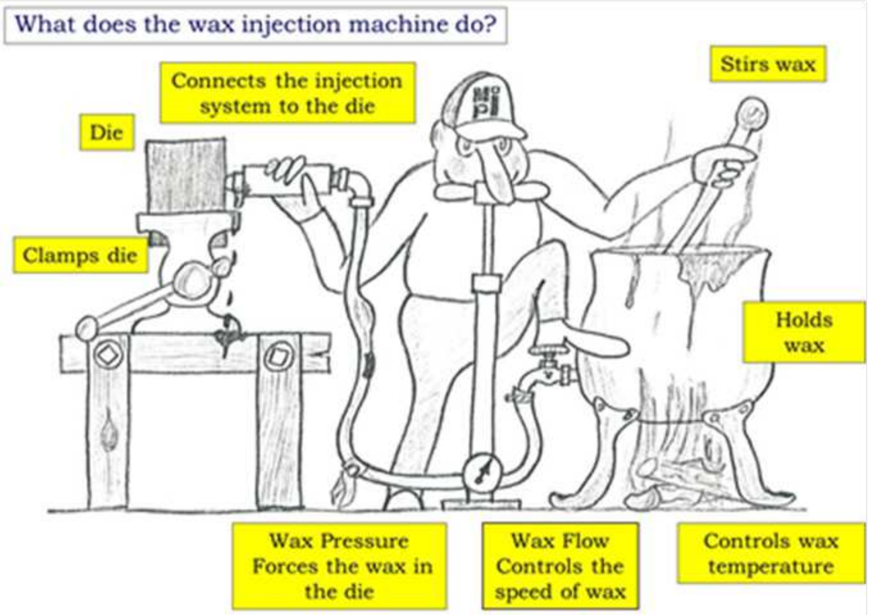


Illustration 1

Old technology Wax Injection Machine controls (See illustration 1):

Wax Temperature Control: Was achieved using liquid filled, bulb type, on/off temperature controllers with swings of ±5° C being the norm. Setting the instrument varied by operator. Each operator would set the instruments differently depending on their vantage point or eyeball position to the instrument.

Wax Flow Control: There was not a “Flow Control” device on the machine, no knob labeled flow control. Flow was controlled by the manually operated wax valve. The more the operator opened the valve the faster the wax entered the die. There was no flow read out only the luck of the draw and the ability of the operator to repeat.

Wax Pressure Control: Manually adjusted non-compensated hydraulic pressure reducing valves had large variations in pressure from cold to hot hydraulic oil. Pressure adjustment accuracy was again up to the vantage point of the operator. The wax pressure was used as a flow control device; the higher the pressure the higher the flow.

Die Temperature Control: There was no way to control the die temperature. In most cases there was no cold water even flowing in the platens. In fact, there were no platens.   If cooling was required, dry ice was used on top of the die. It was very common in the golf industry back in the 70’s to see soft metal or epoxy dies made in multiples being run in sequence: one die being injected, one die sitting cooling the pattern using dry ice another die having the pattern removed by the operator. Control of the die temperature was never considered.

Injection Time: There was no measure, after all the operator could count! In addition, the operator would get into a rhythm.

The Wax Material: There were also changes in the wax. We were forced to make some major changes when PCBs were removed from the wax. It took a while to get a wax pattern with a good surface finish again.

Digital Control:

Digital Technology allows us to control the key input variables – temperature, flow, pressure and time - accurately, thereby achieving dimensionally repeatable wax patterns. Remember, the goal of wax injection is to replace 100% of the air that is in the die with wax. If you achieve this goal, you will get a perfect wax pattern. In order to be successful, you need control of temperature, flow, pressure, time and the wax itself - repeatedly. Having this foundation, a dimensionally repeatable pattern, allows you to be able to achieve dimensionally repeatable castings.

Wax Temperature Control: Wax temperature controls viscosity, and viscosity controls the flow ability of the wax in the die. Today there are electronic temperature controllers, which are tuned to each temperature zone. The accuracy and repeatability of the instruments is extremely tight, less than +/- .5°C.

Wax Flow Control and Wax Pressure Control: Flow and Pressure are controlled with either electronically controlled hydraulic servo or proportional valves. The valve’s position or opening is controlled by varying the input voltage through a programmable DC driver card. These devices are closed loop and they continually monitor and correct the flow and pressure during the injection cycle. Digital technology has allowed us to see the interaction of flow and pressure in a graphical format.   This is the first time an operator is able to see the relationship between wax flow and wax pressure live during an injection and first time they are able to adjust flow and pressure and understand the effects the change has on the wax pattern.

Die Temperature Controls: We now have closed loop temperature controlled water circulating in the platens and the dies. Wax enters the die as a liquid, and must be brought down in temperature to a solid before the pattern can be removed from the die. We now have control of the die temperature and the process of heat removal from the wax pattern.

Injection Time: We now have a timer which is initiated by the automated injection cycle – maybe not as accurate as the timers used in the Olympics but a lot better than the operator counting!

Digital Technology allows all the key process control devices set points to be stored as part of the recipe. The operator simply loads the recipe from the machine's memory; no more variability caused by the operator during the setup of a new job.

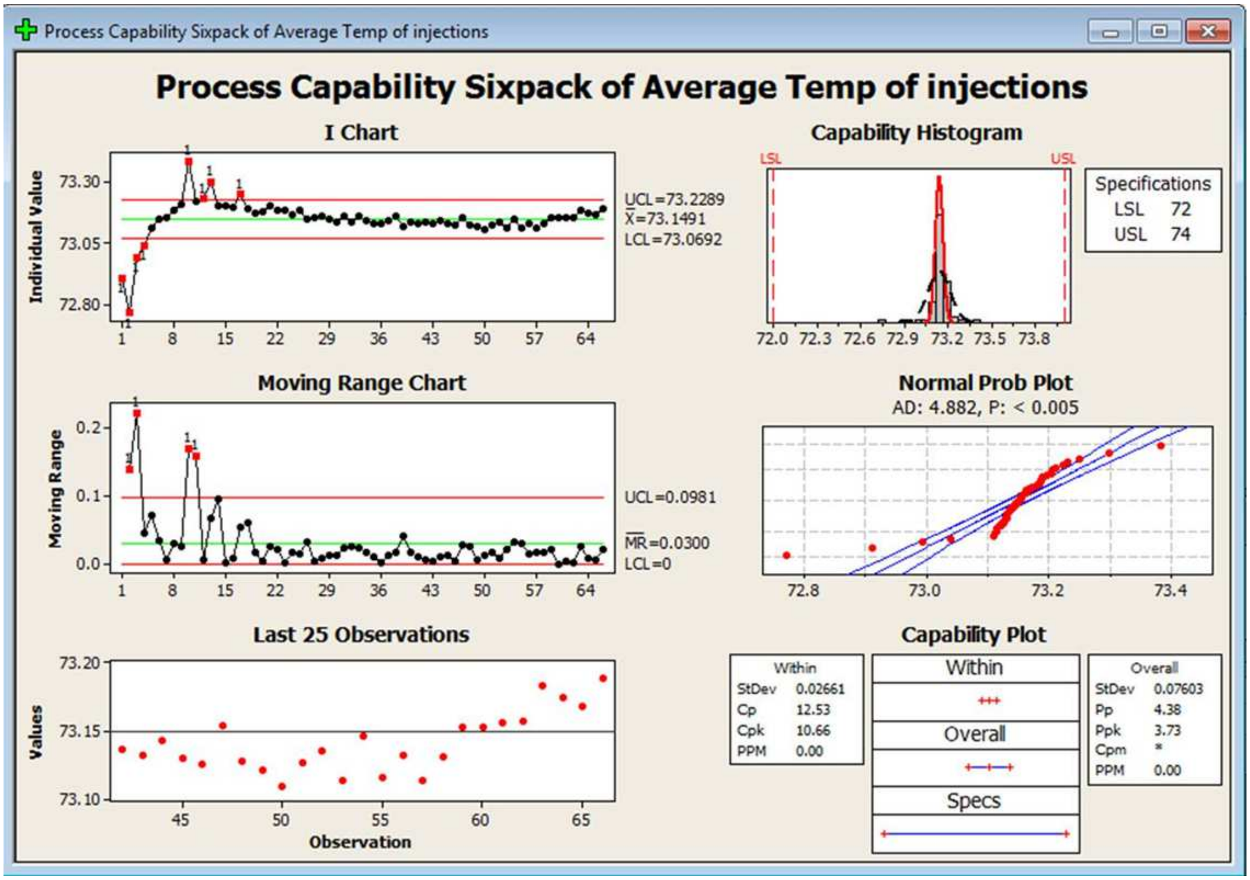
Now, with all these digital controls you have the ability to control and analyze wax temperature, flow, pressure and time. You also have the ability to store a recipe so that you can repeat the process on every shift with every operator. You have the ability to control who can make changes to the recipes. You are able to analyze the drift of your process, and bring it back in line before it goes out of tolerance and makes a bad part. The electronically controlled valves used for flow and pressure control, have the capability to be programmed to vary the flow and pressure during the injection cycle offering the ability to fine-tune a complicated injection profile - such as injecting around a fragile ceramic core for a single crystal turbine blade. The controls have the ability to give you a perfect pattern each time. Why isn't every foundry with these controls creating perfect patterns? Why haven't pattern defects been eliminated? In order to achieve these results, the wax department must understand the interaction of the key input variables and implement rules for managing this technology. Let me repeat: no matter how sophisticated the instrumentation is, the application of that instrumentation and how it is used to control the process is the real challenge.

How do you know that your machine is doing what it is supposed to do? Do you have jobs that are dedicated to a particular wax injector because a job runs better on one machine than another because your machines have personalities? This is a production nightmare because you cannot switch a job from one machine to another machine. How do you compare one manufacturer's machine to another when different manufactures apply these controls differently? For instance, one manufacturer will monitor and control the wax pressure in the wax and another manufacturer will control the wax pressure in the hydraulic system. How do you know that what you set on a machine is in fact what you are getting out of your nozzle?

Now through the use of digital data collection devices, such as MPI's 20-20 Process Vision, you can gather real time wax temperature, flow and pressure for each injection, from any manufacturer's machine and compare the differences from machine to machine. The data the 20-20 collects from each manufacturer's machine is the same no matter how the manufacturer controls their machine. You can now put known offsets into the machines and make all machines match. You can eliminate your machines personality and get repeatability from all of your machines.

Here is an example of how a large foundry benefited from the use of a data collection device. The Foundry had several injection machines ranging in vintage from five to 40 years and from different manufacturers. The newest included a digitally controlled wax injection machine. They used an engineer to collect injection data using MPI's 20-20 Process Vision digital data collection device and compared each machines pattern quality and repeatability. They saw machine-to-machine variability and variability within each machine. They rebuilt one of the older manual machines, brought it back to its "as new condition" and reduced the variability. They then compared the digital data from the rebuilt machine to their newest electronically controlled machine and were able to make informed decisions, based on real injection data, as to what would give them the best ROI.

In the above example, one of the data points being collected was the wax temperature. They used the data collected from the MPI 20-20 to analyze, through Statistical Process Control, the wax temperature variation at the nozzle. Using the data set for one machine and a run of 66 injections, the customer performed a Statistical Process Control analysis. The data was gathered at intervals of every .1 second for the duration of each 9-second injection. The average of each sample is taken and then used to make the SPC chart included as illustration 2.



Specifications	
LSL	72
USL	74

Within	
StDev	0.02661
Cp	12.53
Cpk	10.66
PPM	0.00

Overall	
StDev	0.07603
Pp	4.38
Ppk	3.73
Cpm	*
PPM	0.00

Illustration 2

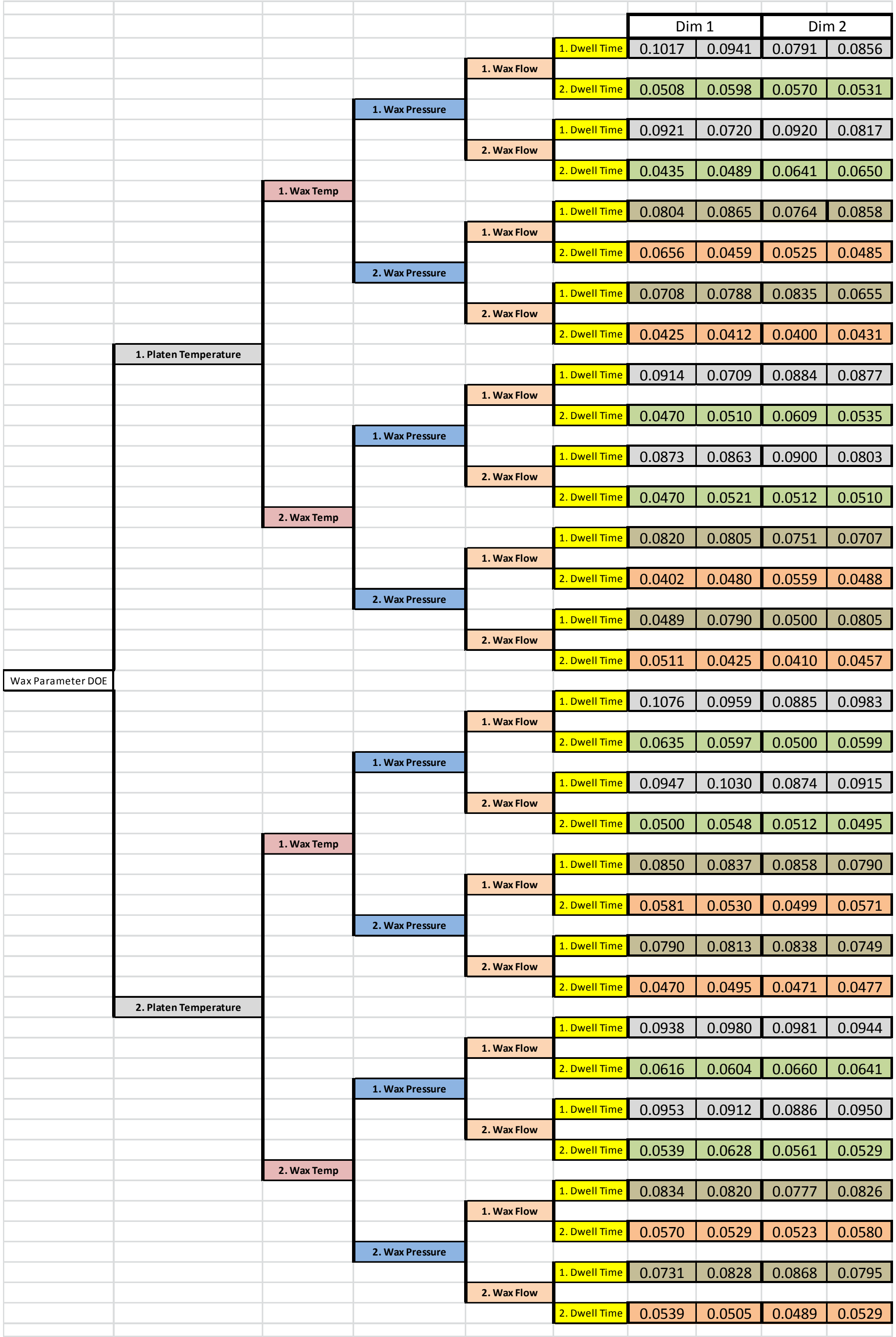
Here we can see from the I-MR charts and the last 25 observations that our process is mostly in control and stable. We see both common cause and special cause variation. This customer evaluated the specific special cause variations at the beginning of the run and determined the cause was due to the machine sitting idle for a time period. This machine did not have fixed purge of the injection nozzle and suffered from wax changing temperature in the nozzle. After numerous evaluations, the customer determined the value of adding fixed purge and has ordered all new machines with that feature.

Further analysis of this data using both the histogram and the Capability information clearly shows the process is very robust and can meet their requirements of plus or minus one degree Fahrenheit. It would be prudent to also analyze the other special cause variation injections to see if it can be determined what caused that variation.

Using Data to Drive the Recipe:

For years, engineers have been frustrated with the ability, or inability as better stated, to accurately predict the outcome of a wax injection recipe. The best way to start injecting a new part is to take the recipe of a similarly sized part already in production. From there the recipe is adjusted to achieve an acceptable part. What do you do if the part you end up with has a dimensional variance from specification? How about do a 2k full factorial Design of Experiment (DOE) to develop a dimension prediction formula? One of MPI's customers recently conducted just such an experiment at MPI's Pattern Production facility.

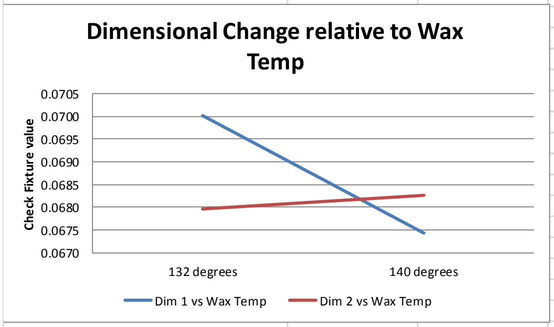
The customer provided a die and wax to conduct the experiment. Five factors were analyzed and all data was collected to perform the DOE. The length and width of the part was evaluated under the various parameters and a formula developed that can accurately predict the length and width for various combinations of the factors. The factors evaluated included: wax temperature, flow, pressure, die temperature and dwell (hold) time. Each factor was established by selecting a high and low value that when used produced a visibly good part. Illustration 3 and 4 shows the results of the experiment as well as the relationship of the various factors.



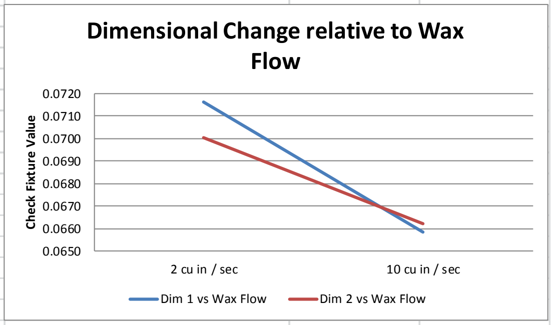
						Dim 1		Dim 2	
Wax Parameter DOE	1. Platen Temperature	1. Wax Temp	1. Wax Pressure	1. Wax Flow	1. Dwell Time	0.1017	0.0941	0.0791	0.0856
					2. Dwell Time	0.0508	0.0598	0.0570	0.0531
				2. Wax Flow	1. Dwell Time	0.0921	0.0720	0.0920	0.0817
					2. Dwell Time	0.0435	0.0489	0.0641	0.0650
			2. Wax Pressure	1. Wax Flow	1. Dwell Time	0.0804	0.0865	0.0764	0.0858
					2. Dwell Time	0.0656	0.0459	0.0525	0.0485
				2. Wax Flow	1. Dwell Time	0.0708	0.0788	0.0835	0.0655
					2. Dwell Time	0.0425	0.0412	0.0400	0.0431
		2. Wax Temp	1. Wax Pressure	1. Wax Flow	1. Dwell Time	0.0914	0.0709	0.0884	0.0877
					2. Dwell Time	0.0470	0.0510	0.0609	0.0535
				2. Wax Flow	1. Dwell Time	0.0873	0.0863	0.0900	0.0803
					2. Dwell Time	0.0470	0.0521	0.0512	0.0510
			2. Wax Pressure	1. Wax Flow	1. Dwell Time	0.0820	0.0805	0.0751	0.0707
					2. Dwell Time	0.0402	0.0480	0.0559	0.0488
				2. Wax Flow	1. Dwell Time	0.0489	0.0790	0.0500	0.0805
					2. Dwell Time	0.0511	0.0425	0.0410	0.0457
	2. Platen Temperature	1. Wax Temp	1. Wax Pressure	1. Wax Flow	1. Dwell Time	0.1076	0.0959	0.0885	0.0983
					2. Dwell Time	0.0635	0.0597	0.0500	0.0599
				2. Wax Flow	1. Dwell Time	0.0947	0.1030	0.0874	0.0915
					2. Dwell Time	0.0500	0.0548	0.0512	0.0495
			2. Wax Pressure	1. Wax Flow	1. Dwell Time	0.0850	0.0837	0.0858	0.0790
					2. Dwell Time	0.0581	0.0530	0.0499	0.0571
				2. Wax Flow	1. Dwell Time	0.0790	0.0813	0.0838	0.0749
					2. Dwell Time	0.0470	0.0495	0.0471	0.0477
		2. Wax Temp	1. Wax Pressure	1. Wax Flow	1. Dwell Time	0.0938	0.0980	0.0981	0.0944
					2. Dwell Time	0.0616	0.0604	0.0660	0.0641
				2. Wax Flow	1. Dwell Time	0.0953	0.0912	0.0886	0.0950
					2. Dwell Time	0.0539	0.0628	0.0561	0.0529
			2. Wax Pressure	1. Wax Flow	1. Dwell Time	0.0834	0.0820	0.0777	0.0826
					2. Dwell Time	0.0570	0.0529	0.0523	0.0580
				2. Wax Flow	1. Dwell Time	0.0731	0.0828	0.0868	0.0795
					2. Dwell Time	0.0539	0.0505	0.0489	0.0529

Illustration 3

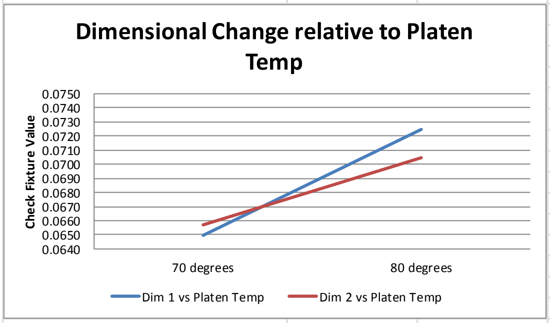
	132 degrees	140 degrees
Dim 1 vs Wax Temp	0.0700	0.0674
Dim 2 vs Wax Temp	0.0680	0.0683



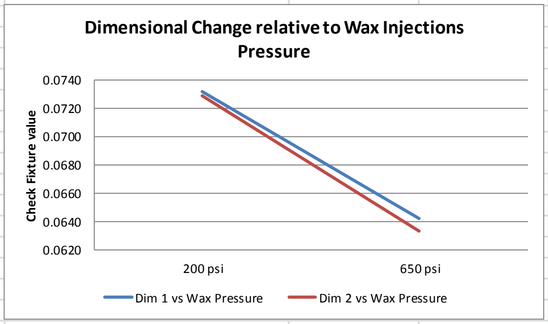
	2 cu in / sec	10 cu in / sec
Dim 1 vs Wax Flow	0.0716	0.0658
Dim 2 vs Wax Flow	0.0700	0.0662



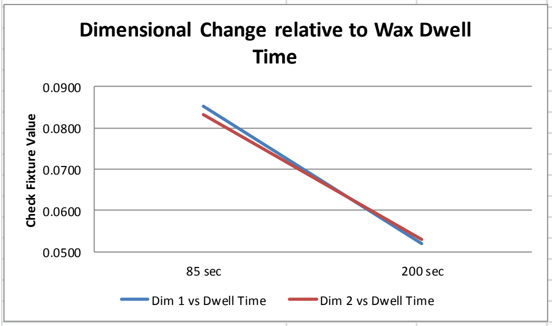
	70 degrees	80 degrees
Dim 1 vs Platen Temp	0.0650	0.0725
Dim 2 vs Platen Temp	0.0657	0.0705



	200 psi	650 psi
Dim 1 vs Wax Pressure	0.0732	0.0643
Dim 2 vs Wax Pressure	0.0729	0.0633

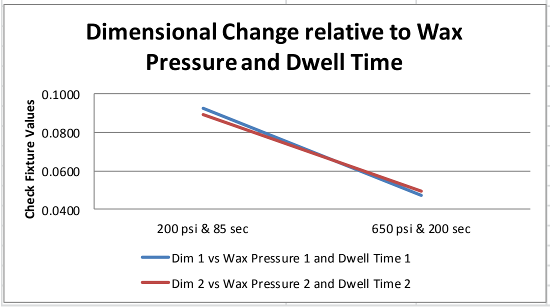


	85 sec	200 sec
Dim 1 vs Dwell Time	0.0854	0.0521
Dim 2 vs Dwell Time	0.0833	0.0530



Note: The larger number denotes a smaller part

	200 psi & 85 sec	650 psi & 200 sec
Dim 1 vs Wax Pressure 1 and Dwell Time 1	0.0922	0.0473
Dim 2 vs Wax Pressure 2 and Dwell Time 2	0.0892	0.0493



	200 psi & 200 sec	650 psi & 85 sec
Dim 1 vs Wax Pressure 1 and Dwell Time 2	0.0542	0.0786
Dim 2 vs Wax Pressure 2 and Dwell Time 1	0.0416	0.0774

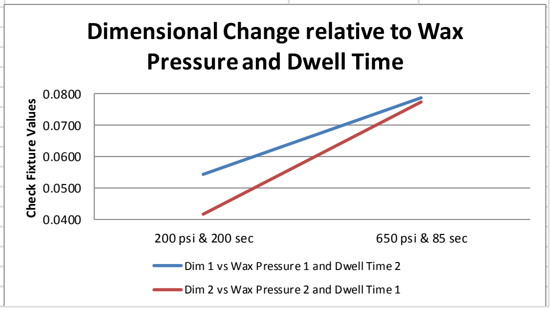


Illustration 4

From this data predictive models were developed. I believe you can appreciate the value gained by being able to accurately predict how changes in your recipe will affect critical dimensions on parts. Without digital equipment capable of maintaining the low level of variation, this type of experiment is not possible.

Train the personnel:

Having your personnel adapt to the new digital technology of the wax room is key to success. They need to be properly trained in the operation and maintenance of the equipment. They need to understand how a new digitally controlled machine differs from the older machines. It is very often difficult for an operator to give up his old ways without understanding why. Often we find the wax machine with the newest controls being set like the older equipment in the wax room because an untrained operator has been given access to the program and can make changes to the recipe.

Example #1: Oftentimes in older machines, the accuracy of the temperature control of the injection nozzle was not there. To overcome this nozzle temperature difference the operator increased the nozzle temperature to achieve a more accurate wax temperature. The operator through experience made the decision to increase the nozzle temperature and they determined how much to increase it. It was the operator controlling the temperature, not the machine controlling the temperature. This was the norm; this is what was required of the operator. In the new digitally controlled machines, if they do change the temperature of the nozzle, as they are used to doing, they are actually throwing the machine out of control. They are introducing a temperature variable, which is giving them a pattern-to-pattern variation. The machine is not being used as it was designed. To overcome this, only give access to the process controls to someone who has been trained and understands how the new machine is meant to function.

Example #2: Management purchases a machine that has paste capability and has projected an ROI based on cycle time reduction. The machine is installed in the wax room with operators used to using liquid wax machines. The operator does not know about the benefits of paste wax, and the testing that was done to achieve the cycle time reduction, they use it as a liquid machine with no cycle time improvements. Parts are being made, they are good parts, but they have not benefited from the projected ROI because the cycle time has not been reduced. Again, the machine is not being used as it was designed.

Example #3: The wax pressure control graph is showing spikes, an over pressure spike, at the beginning of the pressure curve. Chances are the operator is not able to analyze this information. The spikes mean that the machine is controlling the flow by pressure - which gives variation in the flow or an unstable flow curve. The operator should be able to get the machine into flow control mode, but they must be trained to understand the meaning of the data the machine gives them.

These are just a few examples of problems we have seen in the field - the inability to integrate the digital technology into the wax room and achieve superior wax patterns on a repetitive basis.

Robotic Integration:

So far, we have been talking about digitization of the wax injector. There are other areas in the wax room where digitization can improve the wax room process: through the use of robots.

We are all familiar with the use of robots in your shell room. How they have reduced manual labor and added repeatability to the shell building operation. Robots have now entered the wax room and they are here to stay. Robots reduce labor and improve the pattern-to-pattern repeatability as well as the assembly-to-assembly repeatability.

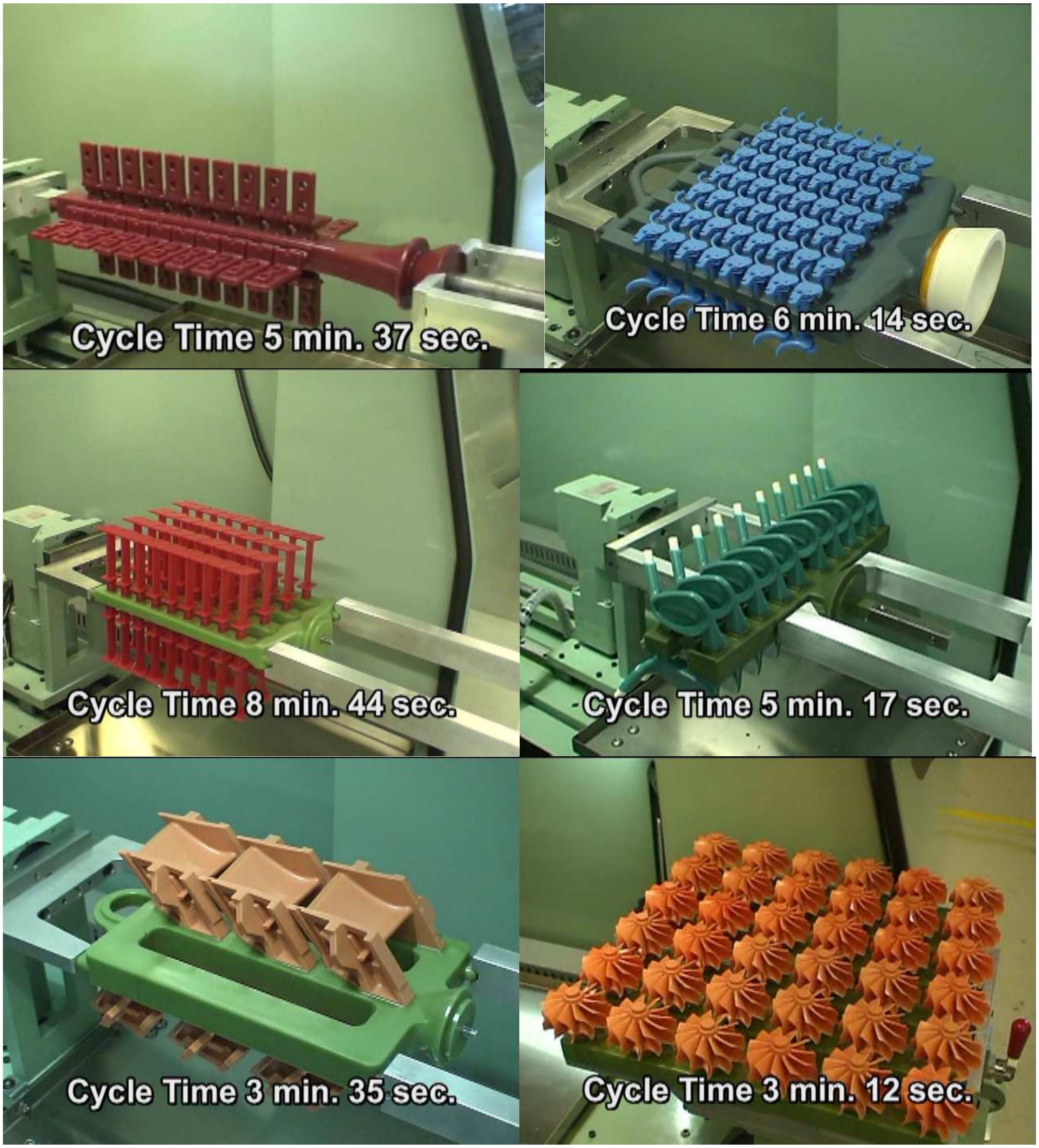
A wax Injector Integrated to a six axis Robot

Another area of digitization is an automated wax injection cell, combining the accuracy of the digitally controlled wax injector with the accuracy of the digitally controlled robot. The robot can load the core, unload the pattern and perform all secondary operations that are normally done by an operator with the advantage of removing the variability of the operator. Not only is the same operation done each and every time, but the time it takes to do the operation is repeated. If the machine is set to perform in 1 minute 52 seconds, it does so every time. It is boringly accurate. Let us take a look at a cell in action.

Over View of Injection Cell from Video #1

Pattern Assembly using robots:

Because of the accuracy of the robots and their ability to work together, we are able to assemble more patterns per runner bar and create more accurate assemblies than what can be done manually. Here are some examples of different parts, runner bars and finished assemblies done robotically.

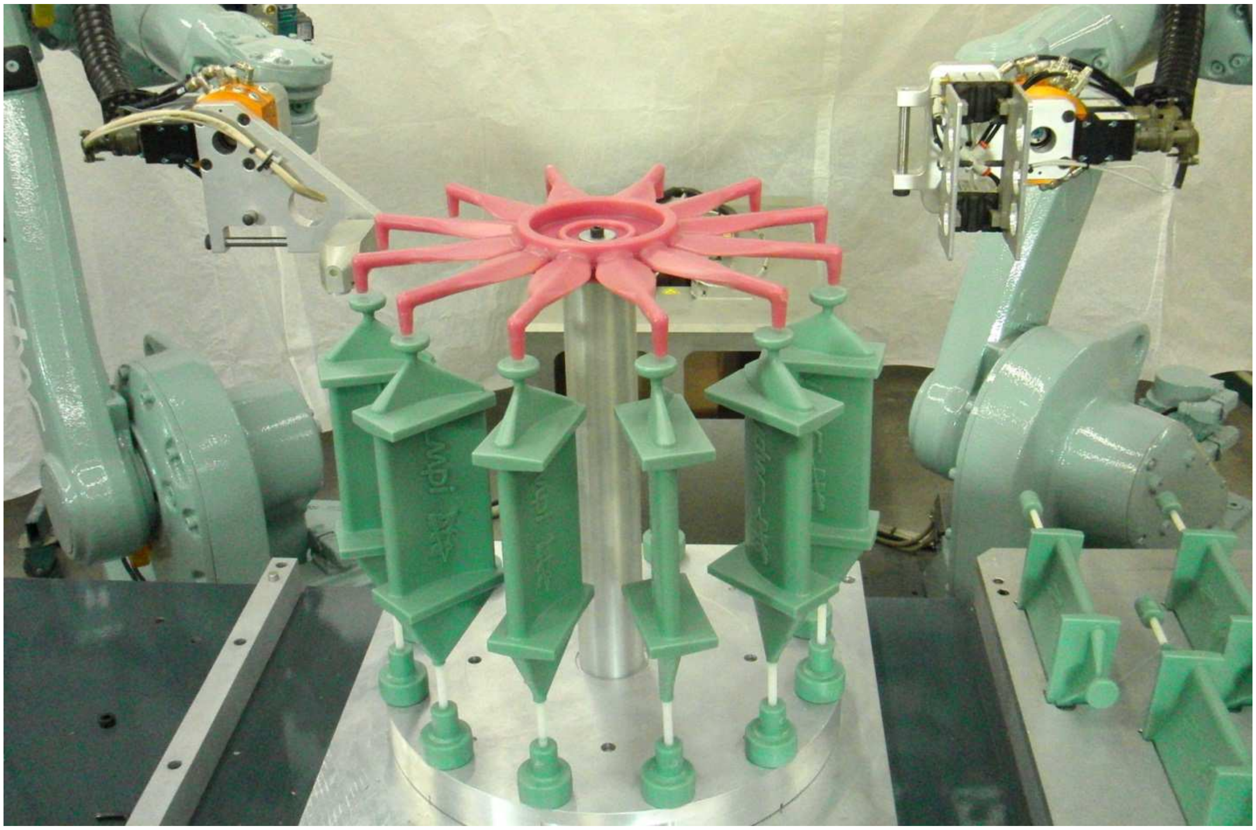


Stills from Video #2

All of the parts shown had the advantage of being able to be assembled in groups of patterns, offering reduced cycle times compared to assembling them one at a time. There are other applications where robotic assembly offers significant advantages even when assembling only one pattern at a time. An example of this is in Single Crystal Turbine Blades.

Single Crystal Turbine Blade using two - six axis Robots

A single crystal turbine blade assembly is created as a circular assembly with the blades positioned radially around the downpour. In order to achieve repeatable single crystal grain growth it is critical that the radial and angular position of the blade and the position of the baffling around the center downpour are accurately positioned. The electronically controlled robots can accurately position the patterns to create that position and angle for each and every assembly. The results are a much higher metal casting yield of single crystal turbine blades. Take a look at a mockup of a single crystal assembly.



Still from Video #3

Conclusion: The digital technology that we have available to us today is awesome. Yes, it can be frustrating, we have all experienced the wins and the setbacks of the digital age in our everyday work life and we know that when we get it right the benefits can be significant. Wax injection and pattern assembly is just coming into the spotlight of the digital age. Once you embrace it, apply the technology correctly, and truly control your process, you will see huge gains. Remember it is more than just a piece of equipment, if implemented correctly it can be a valuable tool your people can use to increase your bottom line through casting yield improvements.

Thank you.