Creating Rapid Prototyped Enterprise Quality Molds that can Produce Fully Functional, Testable Parts

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Abstract

Rapid prototyping (RP) is a powerful tool and a best practice used in industry to develop a product's fit, form, and function. This technology is becoming a critical step in the design process. Although it has its own quality issues, this new technology is now being used to develop complex molds that can create fully functional parts from the rapid injection molding (RIM) process. Strategies are being developed to process the RP machines material for injection molding and combat the intrinsic process control quality issues. Work is directed towards enhancing the quality level of the RP machine (i.e. precision and variability) so that precise bolt on molds can be tested and built in short runs.

Introduction

With the advancement of technology, rapid prototyping (RP) has now become the staple for product design. In this day and age, information reigns supreme. It is a fact that our society is living in an information age. When our products, at times, can almost be as smart as we are, the consumer will demand precision and reliability in the goods they purchase. This can be seen in Figure 1 which shows that an increasing number of manufacturers are turning to RP with the largest sector being consumer products. This trend has increased in popularity over the years. By 2001 some 3.55 million models were produced with the United States leading in production (Figure 2 below and Figure 3 on next page)[1].

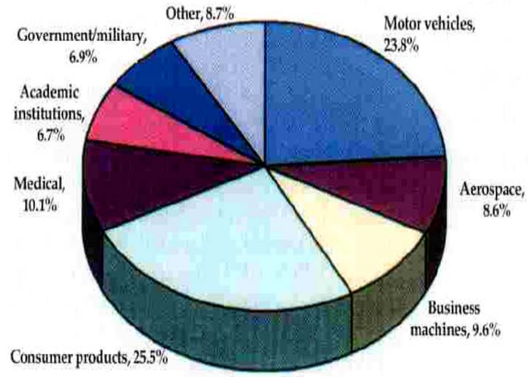


Figure 1 Manufacturing Breakdown of RP Use

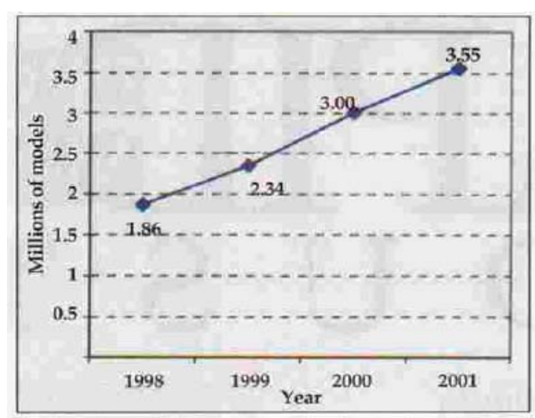


Figure 2 Worldwide Increase in RP Production

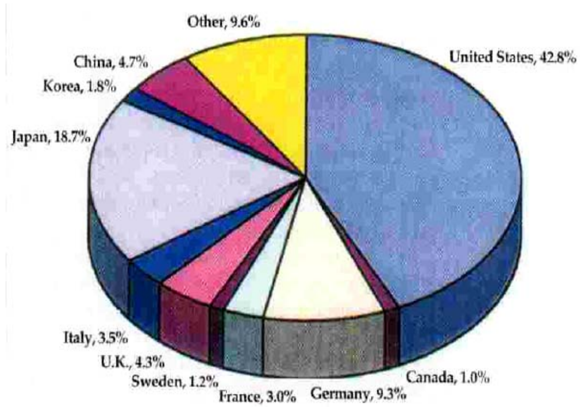


Figure 3 Worldwide Production Rates

This precision and reliability is obtained by creating a robust design, or developing a product that can withstand a certain degree of process/manufacturing noise. This is where RP comes into play. Its purpose is to provide the design and manufacturing team valuable information they can use to hone the products development, giving the final product its desired fit, form, and function.

Discussion & Analysis

RP allows the manufacturing and engineering team to reduce lead times of product development cycles. The key here is its simplicity. Industry has come a long way since the theory of build-test-fix. Now many companies are opting to spend quality time on the development stage. This goes along with the theories held by Six Sigma and lean manufacturing. However, along with its simplicity, should come the understanding that RP is a relatively new process, comparative to other more developed processes such as molding, CNCs, or lathes. With this understanding it should be noted that not all RP machines are created equal. Each RP machine has its own precision and variance issues, all of which are expected to meet enterprise quality. For example, Zcorp's Spectrum 510 RP machine creates parts that are oversized .01 inch/inch where as the Dimension BST has an overall tolerance of .005 inches.

Research for rapid development of products was performed on a Zcorp Spectrum 510 RP machine. This machine is a three dimensional color printer that prints by spraying binder on a gypsum based powder. In developing these complex molds it was noted that the powder encountered a certain degree of swell, more formally known as its "Swell factor." The swell factor is the drying of the binder and the shift of the parts dimensions towards the parts upper control limit, usually if unaccounted for it causes the RP part to go out of specification. Based on the swell factor it was concluded that more research needed to be done to determine the variance of the machine while in mid-process. With this machine it is not known whether or not build orientation has a contributing factor to overall variance of the molds. Build orientation is whether the mold was built with the smallest thickness in the Z-direction.

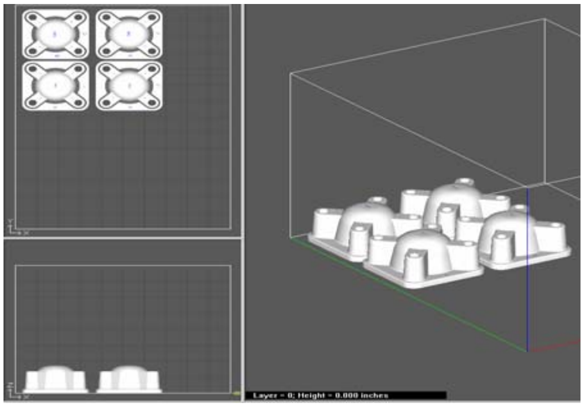


Figure 4 Build Orientation (horizontal)

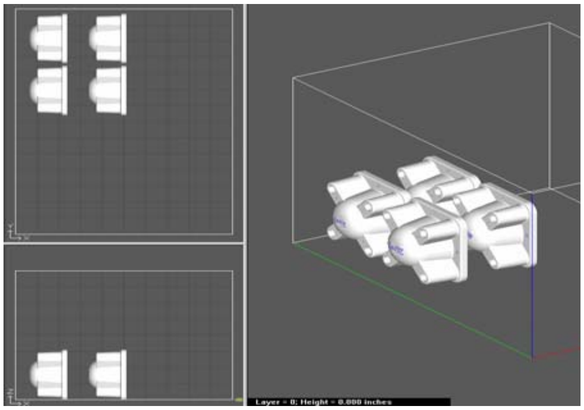


Figure 5 Build Orientation (vertical)

Figures 4 and 5 show their respective build orientations for the Statistical Process Control (SPC).The most efficient build orientation is usually with the smallest Z-direction distance. This will allow the part to build more quickly and not allow the powder's own weight to skew the dimensions of the part. A set of four parts are run six times, three being built horizontally, the remaining three being built vertically

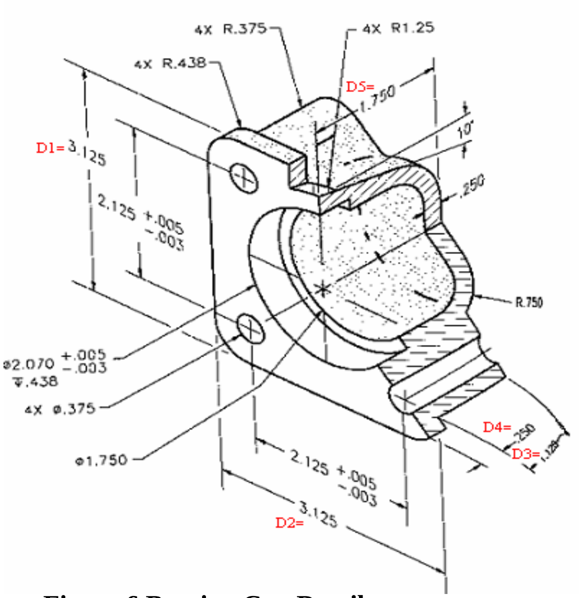


Figure 6 Bearing Cap Detail

Table 1 SPC Input values

Name	Dimension (In.)	Tolerance (In.)
D1=	3.125	(-.003/+.005)
D2=	3.125	(-.003/+.005)
D3(all legs)=	1.125	(±.005)
D4=	0.250	(±.005)
D5=	1.750	(±.005)

Figure 6 displays a schematic of the part (a bearing cap) under study. This bearing cap was chosen for SPC analysis because the part was of sufficient complexity and addresses most common manufacturing issues. Table 1 gives the dimensional breakdown of the values used to perform the SPC analysis.

Each control chart (Figures 7-11 on the following pages) takes into account one dimension of the five possible. Taken together they convey the over all process limits of the machine. From there, a series of measurements are taken and entered into a statistical control chart. An analysis can be performed to determine machine variability.

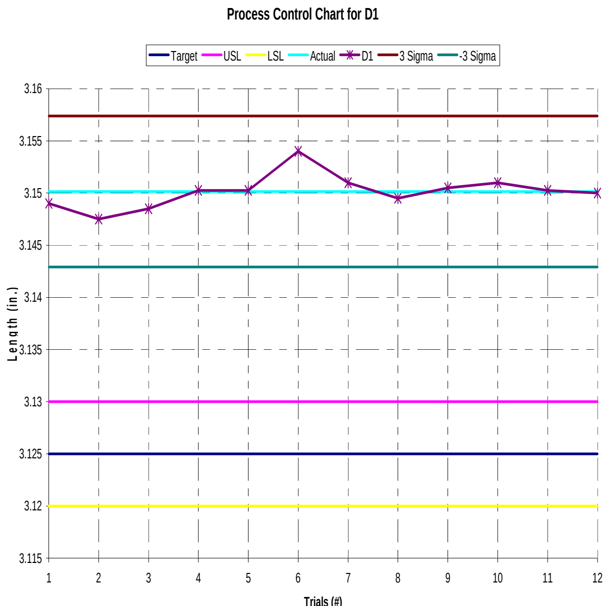


Figure 7 Base Control Chart for the D1

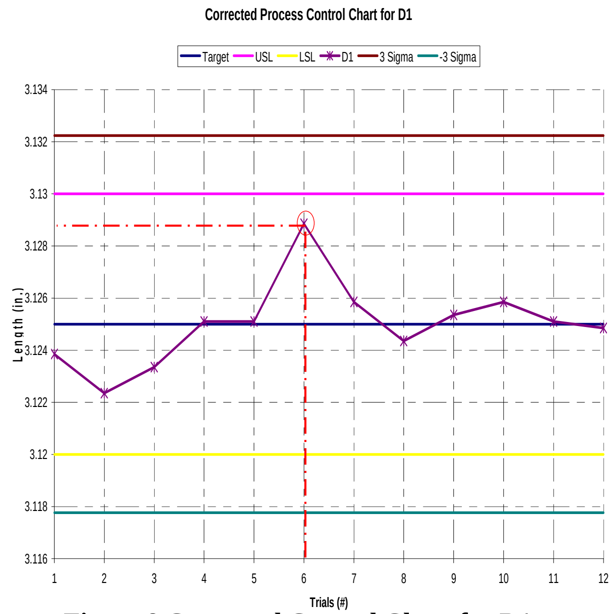


Figure 8 Corrected Control Chart for D1

Figure 7 indicates that the RP 510 machine is precise but not accurate. All data points seem to gather randomly around the mean measured value and have no apparent indication of skewing toward its upper or lower limits. Figure 8 shows the corrected process control chart. This was done by subtracting the skew of the process. Clearly this indicates that the machine is capable of making parts that fall within the part tolerance. This is not always the case as in trial six (Figure 8) where the print head failed and had to be replaced immediately.

The process control chart for D2 (Figure 9) shows a trend that is leading toward the upper control limit. This signals that the process is moving out of specification. As shown by the process control charts, the upper and lower specification limits are too tight for the process to meet.

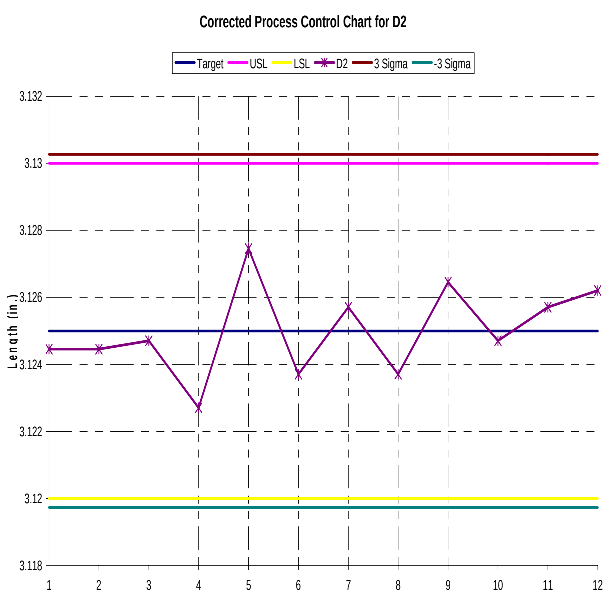
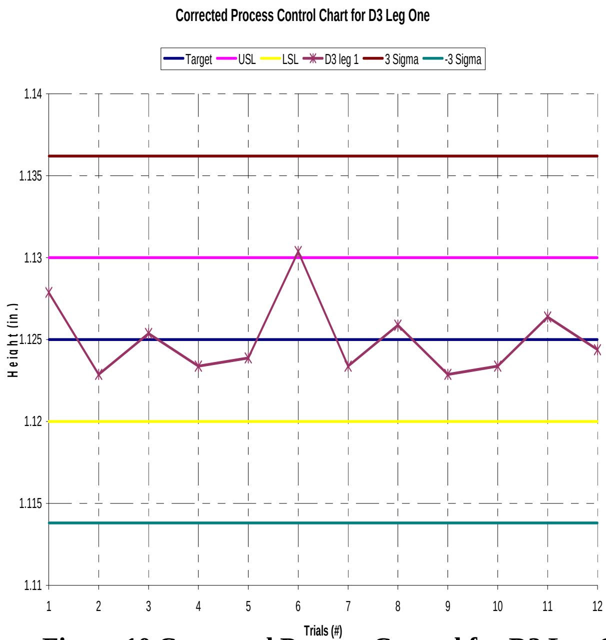


Figure 9 Corrected Control Chart for D2



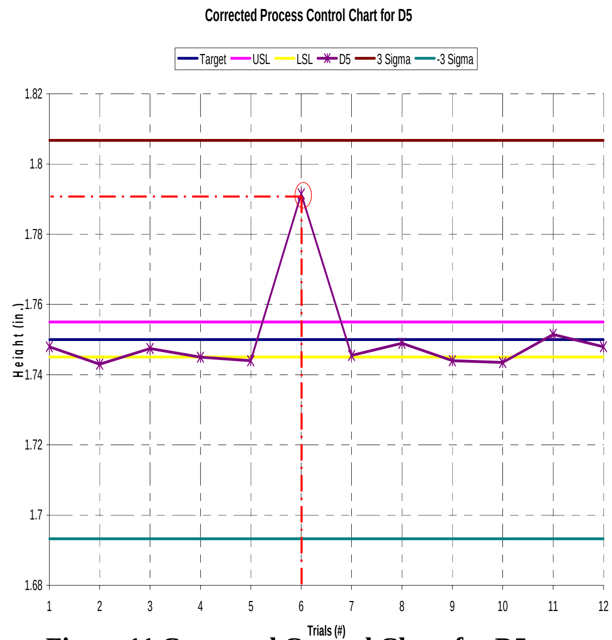


Figure 10 Corrected Process Control for D3 Leg One **Figure 11 Corrected Control Chart for D5**

Consequently the tolerance must be expanded. In trying to make molds that meet more specific specification limits then the process could provide, it was found that this was a failing process (as shown in Figure 10 of the corrected D3 leg one).

When the print head failed it was an immediate occurance and was displayed by a large spike in the data set as indicated by Figure 11 trial number six. One potential reason for print head failure is the presence of air bubbles in the lines. If bubbles are present it will cause missed layers and the print head to fail prematurely. If air bubbles are noticed, the system must be bled, then rechecked. This procedure may need to be repeated several times In light of these events, a log was created to track the varying machine and part characteristics. Along with random samples, this gives a good indication of when a print head will fail. This allows for the anticipation and prevention of "out of tolerance, out of process" parts due to print head failure.

In the case of the Zcorp 510 RP, a log of print head binder use is known. This information was used in conjunction with dimensional accuracy. It was noted that after 1000 milliliters of clear binder use, parts were produced that were dimensionally inaccurate. A sharp drop in accuracy happens as the print head moved toward 1000 milliliters as shown in Figure 11 trial six.

A continual feedback loop can be obtained by recording and plotting data. A measure of machine quality is calculated by SPC. This provides users with a form of process audit and allows the verification of required process conditions. Mistake proofing is accomplished with a detailed training strategy.

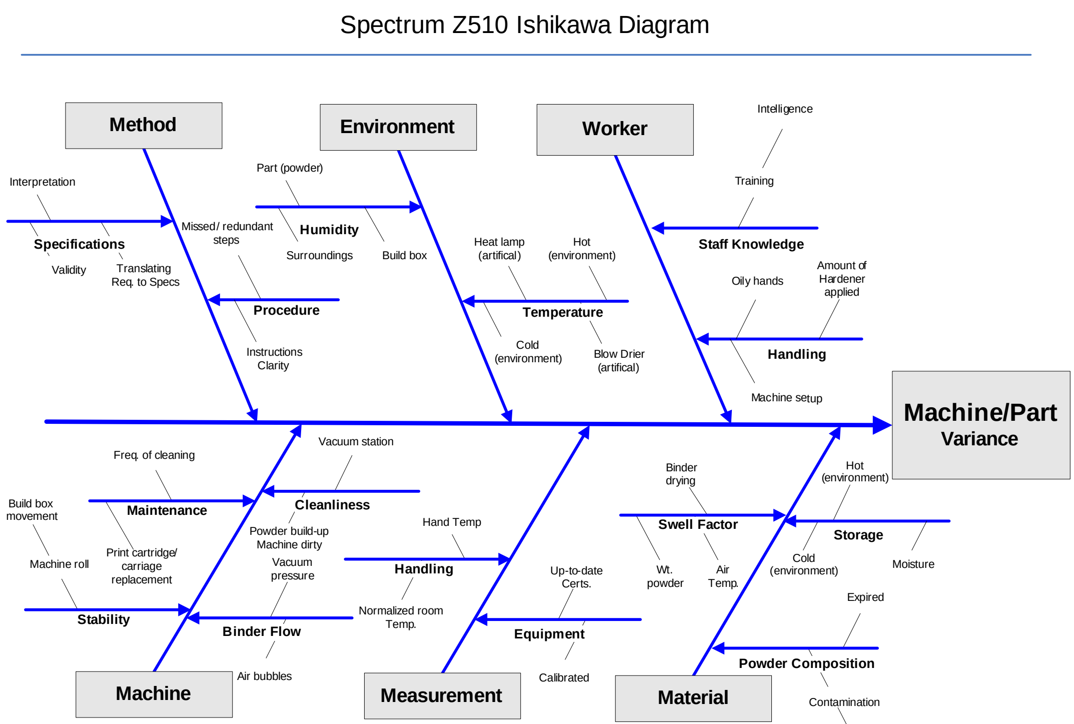


Figure 12 Ishikawa Cause and Effect Diagram

This training strategy limited the amount of variability in the machine and was developed to support setup and running of the machine. It was identified in a cause and effect diagram (Figure 12) that along with print head failure, human error contributed just as much to the overall error. Both were equally limiting in supporting enterprise quality. This consists of process regulation in trying to meet such standards as ISO 9000:2000 or Malcolm Baldrige criteria.

In keeping with such process regulations a much better mold can be made from the Zcorp machine. With the combination of quality standards and the success of rapid injection molding (RIM), fully functional parts are now being developed from RP machines. The success of RIM is attributed to two main factors. First, there is low tooling cost for producing large parts and the RIM machine requires very little adjustment to run. Secondly, Nylon has low viscosity that allows material to flow under lower pressures and temperatures, approximately 145 to 450 psi and 160 to 285 °F for the whole process respectively [2]. It should be noted that this process is patented by Matt Holtzberg, president of Compcast Technologies, LLC of Barnegat Light, N.J[3].

While actually developing injection molds for the RP machine a number of different products were tested as potential seal treatments for the gypsum based powder. The desire is to create working molds that Nylon can be poured into. One product tested was wood hardener but it was quickly discovered that this product merely gave the powder more rigidity but did not seal. Another attempt was performed with Zcorps very own merchandise, called Zbond which is debloomed Cyanoacrylate. It can also be noted that a combination of wood hardener and Zbond, performed poorly, with minimal success. Finally, an enamel based paint called Hard-As-Nails, which contains Nylon 6/6, was experimented with. All attempts to date have failed to create a proper seal and more importantly added secondary operations to the process.

Future work

In continuing efforts, it has been suggested that a urethane coating be used to seal and create part rigidity. In conjunction with the urethane, a sort of plating process should be looked into such as the method of vapor deposition. This will allow for the control of thickness of the plate and give the mold its desired characteristics. However, in order to keep with enterprise quality standards such as the ones held by ISO 9000:2000, Malcolm Baldrige, and Six Sigma a reduction in secondary operations is needed. Experimentation with Zcorp's own Zcast material or some other carbide material should be explored to reduce secondary operations. Other than machine functions, the Nylon RIM machine should be integrated into the RP mold making process to form one continues motion of processes in order to eliminate intrinsic quality control issues.

Reference

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[2] Schneider, P., and Wagner, P., 1984, "MOLDING NYLON PARTS BY THE RIM PROCESS," Plastics Engineering, 40(10) pp. 39-41.

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Acknowledgements

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