AC 2007-2505: PROCESS CAPABILITIES OF RP SYSTEMS AND THEIR IMPLEMENTATION IN ACADEMICS AND INDUSTRIAL OUTREACH

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Process Capabilities of RP Systems and Their Implementation in Academics and Industrial Outreach

abstract

Rapid Prototyping (RP) is widely used as a tool to create cosmetic parts and non-working models in disciplines from Industrial Design to Engineering. With the maturity of RP, there is an impetus to further use this technology in Manufacturing. One use is exposing fabrication problems not readily observed either on-screen or in print. Another use for RP is to provide functional parts for assemblies before permanent tooling is made. This allows problems in the field to be quickly addressed providing faster response time and greater customer satisfaction. There is a need to better understand the tolerance capabilities of RP. The experimental focus is on Rochester Institute of Technology's (RIT) experience using Z-Corporation's Spectrum Z510 RP system in the Center for Product Innovation and Commercialization (CPIC). The process capabilities of this system, using statistical process control charts, will lead to better understanding of part accuracy. Typical problems experienced and the techniques used to overcome these problems will be addressed. Issues such as costs, feasibility of use, and benefits within the academic environment and industrial outreach will be explored.

introduction

In the past twenty years RP has seen an increase in use amongst product design disciplines. In an evolving global market a paradigm shift has facilitated the need for rapid product development (RPD). RPD can be defined as an interdisciplinary methodology to combine all influences of engineering to an iterative product development process.[1] RP machines offer the ability to quickly build physical models from concept. Prototyping allows developers to address design issues before considering manufacturing processes. This aligns with quality assurance programs in that the design process is front loaded, exposing mistakes before capital is invested in manufacturing. Introduction to the tools and best practices used in industry will enhance the development of educated students.

The roles of designers, engineers and manufactures are being fused. With cross-functional teams being more prevalent in industry, tools such as RP machines are increasing productivity. RIT's Mechanical Engineering Technology (MET) Department has developed the CPIC through funds provided by a National Science Foundation (NSF) grant. The center is intended to strengthen RIT's academic environment and provide industrial and educational outreach to neighboring colleges. Allowing students access to state of the art technology gives them an advantage in product development and manufacturing. This boosts interest in academic and personal entrepreneurial projects while at the same time offers exposure to multiple fields of study.

The CPIC currently houses two fully-functional RP machines. One is Z-Corp.'s Spectrum Z510 color system which uses a gypsum-based powder and liquid binder. This machine is the focal point for current experimentation. The center offers students hands-on experience with technology that is becoming as commonplace as the inkjet printer. So far, the CPIC has been used by students for a multitude of educational endeavors.

discussion and analysis

The role of Industrial Designers is evolving, requiring a multidisciplinary understanding of product development. In a recent article written for the Industrial Design Society of America (IDSA), entitled "*New Models for Design Education: beyond the university",* the author suggests students take advantage of a flexible curriculum, selecting the learning types that meet their demands and situations.[2] Before the advent of RP machines, days were spent generating appearance models for presentation. The ability to print a 3D model quickly and effectively allows time to be spent analyzing aesthetics and ergonomics of a project before considering its manufacturability; allowing time to be allocated to Design for Manufacturing and Assembly (DFMA). DFMA shortens overall development time, cost and waste by offering a means for effective information change between designer, engineer, manufacturer and assembler.[3]

An industry shift is moving away from "*throw it over the wall*" approach to design through the implementation of cross functional teams.[4] RP is helping to knock down that wall. With CAD software making giant leaps in design, engineering and manufacturing capabilities, multiple disciplines can communicate in the "same language." RP is the means for that communication. British Scientist and Novelist C. P. Snow expressed in his now famous 'two cultures' lecture at Cambridge University in 1959 that the relationship between design and engineering is quite difficult. He was noted for exploring the difference between the scientific and artistic community blaming the breakdown in communication between them as a major hindrance to solving the worlds problems.[5] The success of the CPIC rests in its ability to attract students from different colleges (design, engineering, sciences and manufacturing) offering involvement in cross-disciplinary projects.

Having a model in hand, one is able to evaluate manufacturing capabilities. Recently, a project was undertaken by students in a composite construction course at RIT. An ice scraper was designed in SolidWorks^{tm}, printed on the Spectrum Z510, and used as a plug to create a silicone-rubber mold (Figure 1). A series of fiber reinforced plastic parts was made from that mold (Figure 2). Each part was created using different combinations of carbon fiber, resin and methods of resin injection. The end result attained is the level of quality desired (Figure 3). The students use RP machines as a tool to front-load the design and engineering process, leaving more time for manufacturing considerations. Offline quality control allows changes to be made without capital loss in retooling.

Figure 1 – RP base for rubber mold

Figure 2 - Laying up carbon fiber over silicone-rubber mold

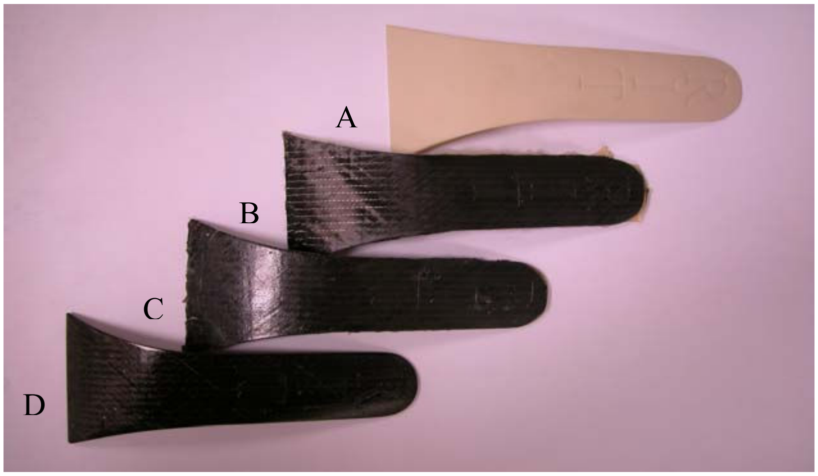

Figure 3 - Results of three different methods of fabrication

Method A – RP'd ice scraper used as a plug to create mold

Method B – Vinyl-ester with resin injection method

Method C – Vinyl ester resin with wet lay up

Method D – 3:1 Epoxy with wt lay-up

Student exposure to evolving industry practices is the intent of the CPIC. Projects like the ice scraper can now be completed faster, by eliminating the time required to hand make mold, providing an increase in customer and worker satisfaction by reducing lead time. In this case the students tested three different fabrication methods, determining that the Method D was best suited to their needs. Once the process is understood by students, it can be repeated for any project. In four days, students can take an idea from conceptualization to functional prototype, ready for evaluation. Previously overlooked design issues such as ergonomics and aesthetics can now be evaluated with the physical model in hand. Students with minimal machine shop experience are no longer held back by their lack of experience.

Special attention should be paid to tolerancing of projects requiring assemblies and sub-assemblies. Initial student research revealed that prototyped pieces can deviate as much as ±0.010 inch per inch from target dimensions.[6] For cosmetic non-working models this is of little concern. When a pin is to align with a hole, however, dimensions exceeding the upper and lower tolerance limits (UTL and LTL) result in interferences, which require secondary operations prior to assembly. To address this situation, experiments owned by students of a quality engineering course were performed to define and control the variance of the machine. Statistical Process Control (SPC) charts were generated using dimension measurements taken from a series of bearing caps printed by the Spectrum Z510 (Figures 4 through 6).

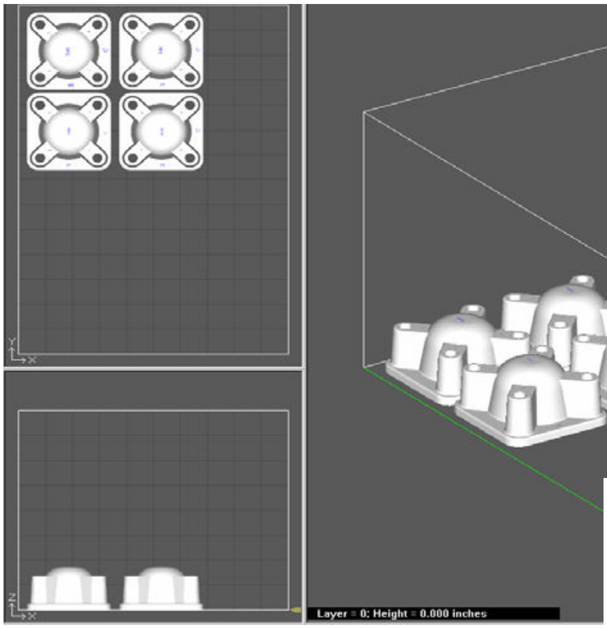
Layer = 0: Height = 0.000 inches

Figure 4 – Screen shot of print orientation

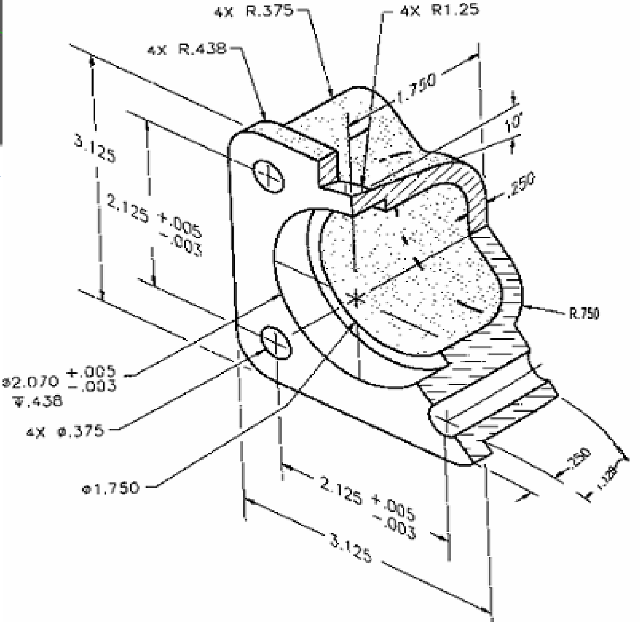

Figure 5 – Part dimensions

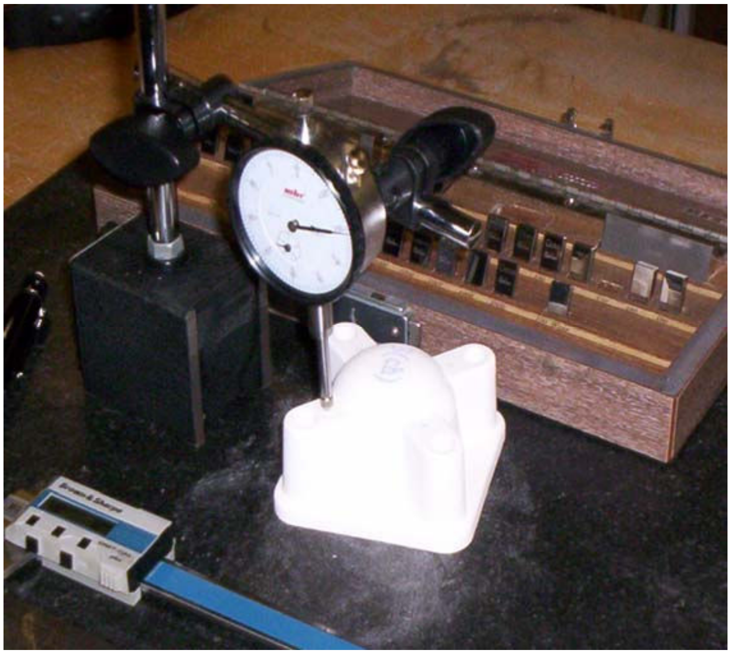

Figure 6 – Measurement method

These dimensions appear to cluster around the mean measured value, usually skewing towards the UTL. Figure 7 illustrates one of these dimensions. All SPC charts indicate the machine is precise, but not accurate. To account for the inaccuracy in the design process, CAD dimensions need to be adjusted as much as 0.010 inch per inch if assembly is desired. It has been determined that the cause of the skew is due to the powder/binder interaction during cure.[6] Student projects such as this not only enhance understanding of quality engineering, but at the same time offer some insight into the process capabilities of the machine. Such knowledge is useful to future students who choose to take advantage of the CPIC.

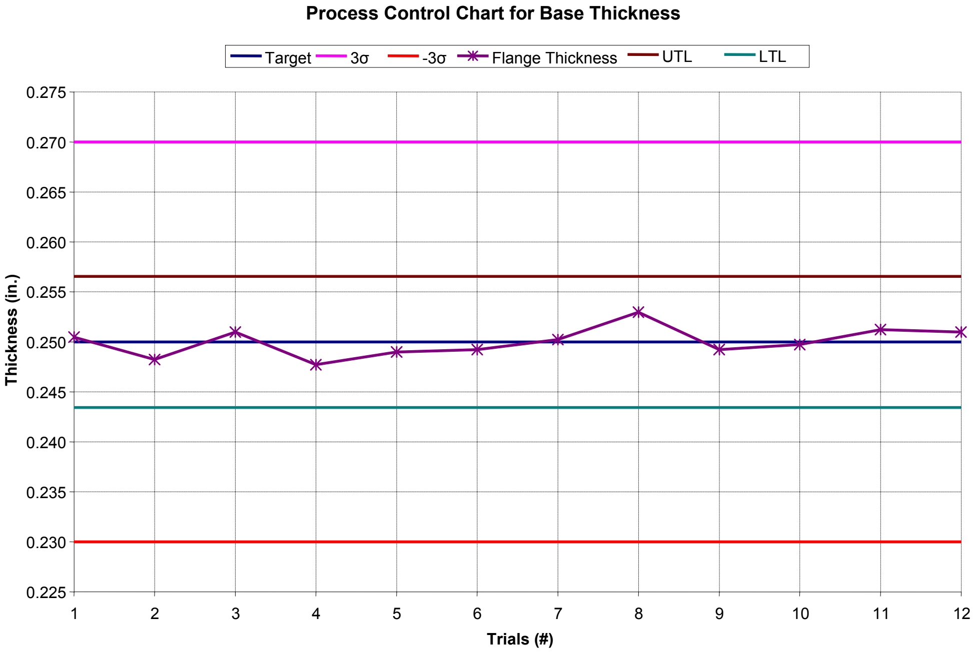

Figure 7 - SPC Chart illustrating measurements taken from the bearing cap

Understanding RP process capabilities ensures the CPIC success in developing enterprise quality parts. SPC methods provide users with a form of process audit allowing verification of required process conditions. To better understand the effects of noise on the production of robust quality parts, students of a robust design course used the Z-Corp machine to perform a Taguchi analysis. Table 1 illustrates the factor and level settings used to plan the experiment. Figure 8 represents the build orientation of experiments 1-3 in Table 2. The Optimal level settings were found using calculations in Minitab$^{\text{tm}}$. An ANOVA was used to create main effect plots displaying the mean and S/N ratio. The level settings highlighted in Table 1 indicate the optimal control factors, later verified by a confirmation run.

Table 1 – Factor and Level settings for Taguchi

Control Factors	L9 Array		
Factor	**Level I**	**Level II**	**Level III**
Rotation-x	0˚	45°	90°
Rotation-y	0˚	45°	90°
Position	Top Left	Center	Lower Right
Depth	Low	Medium	High

Table 2 – Level Settings for each experiment

Exp#	**Settings**			
1	0°	0°	Top Left	Low
2	0°	45°	Center	Medium
3	0°	90°	Lower Right	High
4	45°	0°	Center	High
5	45°	45°	Lower Right	Low
6	45°	90°	Top Left	Medium
7	90°	0°	Lower Right	Medium
8	90°	45°	Top Left	High
9	90°	90°	Center	Low

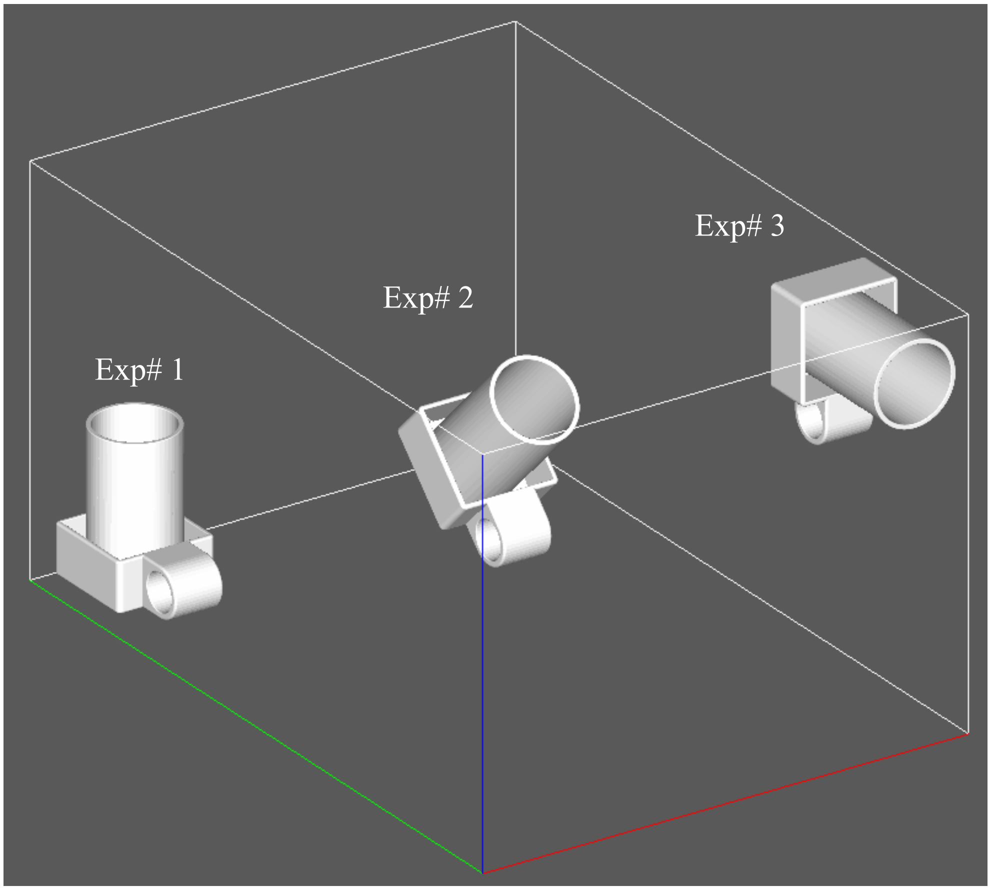

Figure 8 – Example of build orientations1-3 from Table 2

Performing statistical analysis on the RP machines gives students who use the CPIC assurance that a project will meet or exceed the desired level of quality. In an effort to maintain usability of the center, it is essential for machines to be self-sustaining. Students are involved in the management of the queued projects as well as producing invoices and other managerial duties. Funds are collected from users to cover the cost of materials and depreciation of the machines. As a form of statistical quality control, the student managing the projects keeps documented accounts of everything printed and is therefore able to track and record all consumables. Published information provided by Spectrum estimated cost of use at \$1.00 per cubic inch. According to an analysis of in house research, performed by the student manager, the actual cost is approximately \$9.00/in^3 including labor (Table 3).

Table 3 – Cost Break Down for Ice Scraper Project

Direct Consumables

Material		Price		Consumed		Total Cost
ZP-130	Powder	\$4.00	/in^3	19.89 in^3	=	\$79.56
ZB-58	Binder	\$0.13	/ml	177.2 ml	=	\$23.04
ZP-120	Wax Dip	\$0.20	/in^3	19.89 in^3	=	\$3.98
	Wated material accounts for 5% of total cost				=	\$5.33

Indirect Consumables

Material	Price		Consumed		Total Cost
Machine Depretitation	\$15.00	/hour	3 hr	=	\$45.00
Print Head	\$0.05	/ml	177.2 ml	=	\$8.86
Wash fluid accounts for 6% print head cost				=	\$0.53

Labor

Material	Price		Consumed		Total Cost
Machine Set-Up	\$10.00	/hour	0.5 hr	=	\$5.00
Part De-powdering	\$10.00	/hour	0.5 hr	=	\$5.00
Infiltrant time	\$10.00	/hour	0.5 hr	=	\$5.00
			Total Cost to Customer		\$181.29
			Dollars per in^3		\$9.11

The future role of the CPIC will be as an educational center continually adding to the knowledge and experience of students. Multidisciplinary student research similar to what is outlined here will assist to understand and make viable this emerging technology. Maintaining documented accounts of continuing research projects will facilitate the evolution and interest in the CPIC.

The Department of Defense (DOD) has requested that the National Research Council (NRC) conduct a study to develop and define a coherent framework for bridging communication gaps between design and manufacturing. One recommendation made by the NRC is that *"[the DoD] should invest in the educational and training of future generations of engineers who will have a thorough understanding of the concepts and tools necessary to bridge design and manufacturing."*[3] The CPIC is a valuable resource available to students that will help them bridge the gap between design and manufacturing.

acknowledgments

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