IOP Conference Series: Materials Science and Engineering

Review on CNC-Rapid Prototyping

Review on CNC-Rapid Prototyping

M Nafis O Z, Nafrizuan M Y, Munira M A, Kartina J
Faculty of Manufacturing Engineering,
Universiti Malaysia Pahang,
26600 Pekan, Pahang,

Email: nafis@ump.edu.my

Abstract. This article reviewed developments of Computerized Numerical Control (CNC) technology in rapid prototyping process. Rapid prototyping (RP) can be classified into three major groups; subtractive, additive and virtual. CNC rapid prototyping is grouped under the subtractive category which involves material removal from the workpiece that is larger than the final part. Richard Wysk established the use of CNC machines for rapid prototyping using sets of 2½-D tool paths from various orientations about a rotary axis to machine parts without refixturing. Since then, there are few developments on this process mainly aimed to optimized the operation and increase the process capabilities to stand equal with common additive type of RP. These developments include the integration between machining and deposition process (hybrid RP), adoption of RP to the conventional machine and optimization of the CNC rapid prototyping process based on controlled parameters. The article ended by concluding that the CNC rapid prototyping research area has a vast space for improvement as in the conventional machining processes. Further developments and findings will enhance the usage of this method and minimize the limitation of current approach in building a prototype.

1. Introduction

Rapid prototyping (RP) can be defined as an automatic fabrication process of three dimensional physical models directly from computer-aided design (CAD)[1]. In designing processes, generating solution is largely associated with the use of external representations such as sketch and physical model [2]. The physical model does not only serve as external information storages but also act as example, solution development, testing and communication. Current rapid prototyping techniques are capable of automatically constructing physical models with minimal planning time, the ‘3D printing’ concept where there is no human intervention. Additive layer-based manufacturing approaches are commonly adopted to automatically produce complex shapes. The promise of minimal process engineering is a major factor that has driven the use of free- form rapid prototyping (RP) techniques. Unfortunately, many of these processes have been restricted to a small variety of materials with limited geometric accuracy. Therefore, a new approach is developed aimed to produce quality parts with little or no human intervention by combining the important attributes of CNC machining and the existing rapid prototyping technologies.

2. Hybrid Rapid Prototyping

RP has proven to be an effective tool to reduce the time and expense involved in the realization of a new product. However, the fields of application are currently saturated. The current need is to produce the finished parts of required quality in the shortest possible time. This led to the focus of improvement in production speed, accuracy, variety of materials and cost [3].

The current additive RP fabricated the part layer by layer until the final part produce. This layered approach generates the stair-step effect which limits the accuracy of final part. Another limitation concerns on range of materials used in the process. Initially, RP used for visualization and assemblability test and none of these applications impose structural requirements on the part.

CNC process becomes a new substantial solution to the limitations of RP process. Modern CNC capable to operate at high speed, high precision and high flexibility. Consequently, the effective combination of RP and CNC technologies could bring a new hybrid manufacturing system that completely meets the requirements of the next generation of production systems, especially for short run production [3]. Figure 1 indicates the convergence between RP that is appropriate to meet the rapid manufacturing goals, and CNC that produces high accuracy final part.

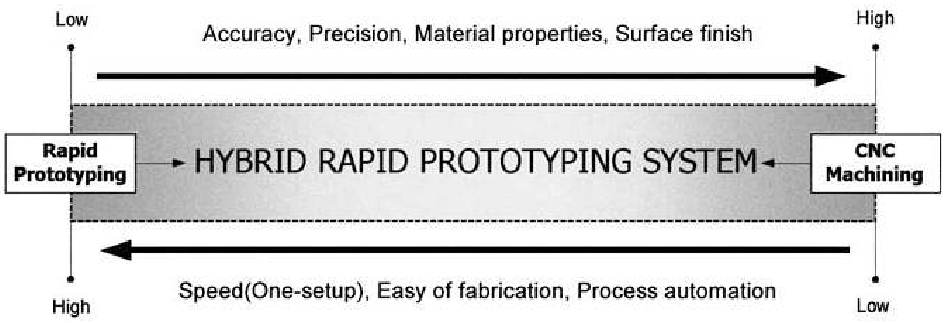

Figure 1. Convergence between RP & CNC [3]

The interesting features of these Hybrid-RP systems is that the integration of advantages and capabilities between the conventional RP, i.e. rapid process planning & independence geometry and CNC machining, i.e. accuracy, precision and good surface finish. Thus, some hybrid systems have ever been applied to the real manufacturing process such as mold making and tooling [4]

In addition, to assure the operation of the hybrid system, a test bench system, called ECLIPSE-RP has been developed used to verify the proposed approach [5]. The main features of the test bench system can be summarized into six core concepts. First, the ECLIPSE-RP system is a also a hybrid-RP system performing both deposition and machining. Second, ECLIPSE-RP builds a model by stacking thick layers with full three dimensional shapes. Third, each sheet is inverted to allow two machining setups in a building cycle. Fourth, a machining feature concept is adopted to maximize process efficiency. Fifth, ECLIPSE-RP uses a specially developed machining center based on a 6-axis parallel mechanism as a cutting station. Finally, this hybrid system imports the shape information through a physical file which carries exact geometry. Hence, the shape error does not occur and high accuracy model can be produced.

As the hybrid-RP system performs both deposition and machining, this technology is expected to become a new cost effective manufacturing technique that will produce completely finish quality parts in a very short time.

3. Development of CNC-Rapid Prototyping

Additive layer-based manufacturing approaches are commonly adopted to automatically produce complex shapes that would be difficult or impossible to create using conventional methods. These models are used as prototypes to evaluate form and function but RP is increasingly being used for production parts. Many different RP processes are available including Stereolithography, Fused Deposition Modelling and Selective Layer Sintering.

Some exploration into the use of CNC machines for rapid prototyping has been published. Layer-based robot machining for rapid prototyping have been developed using machined layers that are laminated during the process. The process is demonstrated using laminated slabs of plastic, machined as individual layers upon gluing to previous layers [6].

A hybrid approach using both deposition and machining called shape deposition manufacturing (SDM) continues to be developed [7]. For each layer, both support and build material is deposited and machined in a combined additive and subtractive process. This Shape Deposition Manufacturing (SDM) process integrates material layer deposition with CNC material removal processes. Recently, a hybrid layered manufacturing process is develop further which combines the features of subtractive and additive manufacturing to build near-net shape metallic prototypes using arc weld deposition [8].

Reference Free Part Encapsulation (RFPE) as the use of CNC machines for rapid prototyping has also been explored [9]. The approach was discussed recently in conjunction with high-speed machining (HisRP) [10]. RFPE in combination with feature-based CAD/CAM was proposed as an RP system [11]. Another approach is to use CNC machining for prototyping dies, an area called rapid tooling [12]. One approach to rapid tooling uses machined metal laminates stacked to form dies [13][14].

Many of these methods utilize CNC machining but do not address the fundamental problems of automating a fully subtractive rapid machining approach. Methods have been developed to cover all aspects of process planning for rapid machining, including toolpath planning, choosing tool geometries, calculating setup orientations and a concept for a universal approach to fixturing.

With regard to toolpath planning, the presented method borrows from layer-based RP methods. The general idea is to machine the visible surfaces of the part from each of a plurality of orientations. From each orientation, some but not all of the part surfaces will be visible. Only parts whose entire external surface is visible can be completely machined with this methodology. In some ways, this limits what can be done when comparing the methodology described herein to traditional RP techniques, but in no way reduces the flexibility when compared to traditional CNC machining [15].

The goal is to machine the part from enough orientations such that, after all toolpaths are complete, all surfaces have been fully machined from at least one orientation. For each orientation, there is not a particular plan for a set of feature machining operations; rather, each orientation is machined using simple 2½D layer-based toolpaths. This is very similar to the existing rapid prototyping systems; however, in this case, one is limited to removing only visible layers from each orientation instead of creating and stacking all of the true cross sections of the part from just one orientation.

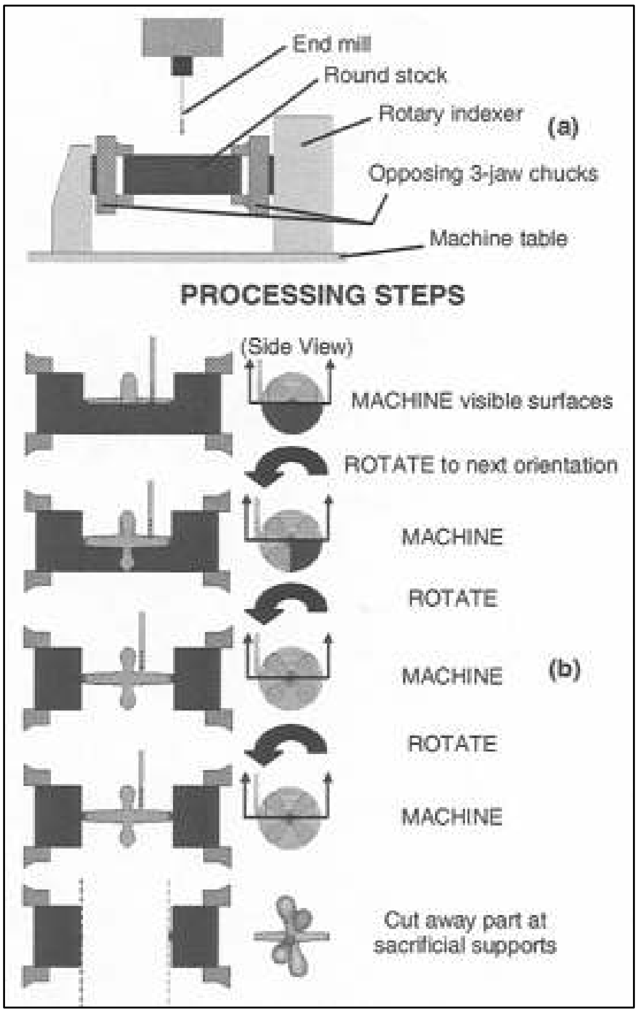

Figure 2. CNC-Rapid Prototyping processing steps[15]

Designing a fixture scheme for CNC machining is a difficult task that requires a significant amount of work from a highly skilled technician. In general, fixturing or workholding serves three primary functions: location, clamping, and support [16]. Currently, the approach to fixturing for CNC-RP adopts from the general idea of sacrificial supports, which are used in existing RP systems. In this work, the general intention is retained, however, the requirements for the support structures are different. The goal is to have a fixture solution that is created in process and is customized for each part. Specific to this work, the fixture supports need to allow the part to be rotated about the axis while providing access to as much of the part surface as possible [15].

The 'staircase' effect as seen on common RP method is still created on part surface contours. However, due to the capability of machining to make very shallow depths of cut, rapid machining able to produce very thin layer thickness. This reduction of layer thickness tends to increase the machining time but it does not necessarily do so proportionally because shallower depths of cut enable higher feed rates.

4. Optimization of CNC-Rapid Prototyping Process

The basic concept of CNC-RP involves machining all visible surfaces of a part from a particular orientation using a 3-axis vertical machining centre. Visible surfaces are those surfaces that can be 'seen' when looking down the axis of the cutting tool – the z-axis. Not all surfaces will be visible in a particular orientation and therefore a number of orientations are normally needed in order to machine all part surfaces but without refixturing. This reorientation is achieved by the use of two opposing fourth axis indexers. This removal of visible cross sections of the part using simple 2½ D layer-based tool paths is similar to a roughing process in traditional machining operations (Balasubranmaniam, 1999).

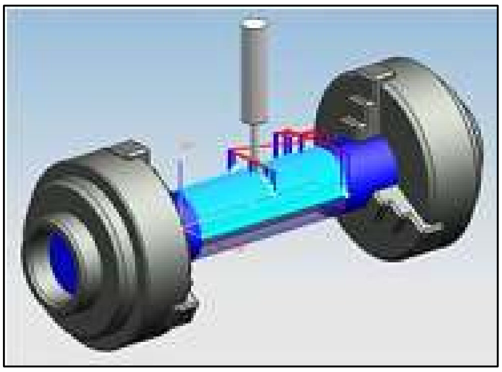

Figure 3. Setup for CNC-RP [16]

This process is feature free and successfully eliminates feature recognition and feature based process planning [18], as there is no need to plan the manufacture of each feature independently. Since only 2½ dimensional tool paths are to be machined and no feature information is required, a generic approach using a small diameter flat-end mill cutter is feasible. However, there are some draw-backs in using a small diameter tool. Avoiding tool deflection or breakage requires relatively low feed rates and depths of cut are limited by the required precision of machined surfaces and so material removal rates are low and machining times are consequently high.

The objective is however that overall efficiency is improved through the removal or very significant reduction of process planning and setup efforts [15]. Tool selection is very important to avoid collisions. The tool length must greater than the distance to the furthest visible surface for each orientation [18] so that the tool holder does not collide with the stock material. The tool diameter is defined by the need to manufacture the smallest features of the part.

Comparison study has been carried out to estimate process planning times for different machining approaches and to identify the suitability of the tool types to be used in CNC rapid prototyping [19]. Surface finish of the machined part was also observed and analysed. The three machining approaches considered were (i) conventional roughing, semi-finishing, and finishing using Ø8 endmill and Ø8 ballnose cutters (ii) single Ø8 endmill cutter and (iii) single Ø8 ballnose cutter. The results clearly demonstrated that the Roughing, Semi-finishing and Finishing approach offers shorter machining time but required intensive labour and time in process planning. The finishing approach using a single cutter gave longer machining time but reduced process planning. The study also showed that a single endmill cutter approach was the best option because it offered reasonably good dimensional control, simpler tool path strategy and no tool change was needed. Table 1 indicates the comparison of three machining approaches for CNC-RP.

Table 1. Comparison data on three machining approaches in CNC-RP

	Roughing/Finishing		**Finishing**		**Finishing**	
Material	Aluminium		Aluminium		Aluminium	
Tool	Endmill & Ballnose		Endmill		Ballnose	
Cutting Speed (m/min)	150-300		150-300		150-300	
Number of operations	8		4		4	
Type of operations	Rough Follow		Rest Milling		Rest Milling	
	Rest Milling					
	Countour Area					
Estimated Process Planning Time (minutes)	**Steps**	**Time**	**Steps**	**Time**	**Steps**	**Time**
	Operations selection	5	Operations selection	2	Operations selection	2
	Identify geometries	12	Identify geometries	4	Identify geometries	4
	Tool setup	6	Tool setup	3	Tool setup	3
	Path settings	25	Path settings	8	Path settings	8
	Post processing	6	Post processing	2	Post processing	2
	Program editing	8	Program editing	4	Program editing	4
	Machining setup	20	Machining setup	20	Machining setup	20
	Tool changes	2	Tool changes	0	Tool changes	0
	Total	84	**Total**	43	**Total**	43
Depth of Cut (mm)	Roughing	1	Finishing	0.1	Finishing	0.1
	Finishing	0.1				
Stepover	**Method**	**%**	**Method**	**%**	**Method**	**Height**
	Tool diameter (Endmill)	20	Tool diameter (Endmill)	20	Scallop (Ballnose)	0.1
	Method	**Height**				
	Scallop (Ballnose)	0.1				
Number of Tool Change	6		0		0	
Machining Time (hours)	4.57		37.73		23.95	
Total Time (hours)	**5.97**		**38.45**		**24.67**	

5. Conclusion

CNC Rapid Prototyping has been described in this paper as the significant solution to the limitation of RP process where it is able to meet the rapid manufacturing goals and also to produce high accuracy final part. CNC Rapid Prototyping has been highlighted as the new cost effective manufacturing technique that will maximize the process efficiency in terms of quality and also time of completion.

There are several approaches have been discussed in a number of researches on the development of CNC Rapid Prototyping where various RP processes were integrated with the use of CNC machine. However, the effectiveness of this techniques are still depending on a few factors which are the different types of machining approach that will give different effect on the machining time and process planning, the tools selection to avoid collision and also the highly skilled technician or operator to run this process since designing the fixture scheme for CNC machining is a difficult task.

Overall, there are still a lot of rooms for improvement in this CNC rapid prototyping research area. Future research needs to be done to enhance the usage of this method and minimize the limitation of current approach in building a prototype. Another interesting extension of this research would be the application of this method in other areas of the manufacturing decision making process such as material or tooling selection.

References

[1] Cooper K G 2001 *What is Rapid Prototyping? In Rapid Prototyping Technology Selection and Application*, ed. L.L.Faulkner, 1-10. Marcel Dekker, New York.

[2] Anne Ro¨mer, Guido Weißhahn and Winfried Hacker 2001 *Effort-saving product representations in design-results of a questionnaire survey* (aTechnische Universita¨t Dresden, Germany)

[3] Junghoon H, Kunwoo L, Zhu-hu and Jongwon K 2002 Hybrid rapid prototyping system using machining and deposition, *Computer-Aided Design* **34** 741-745

[4] Jeng J Y and Lin M C 2001 Mold fabrication and modification using hybrid processes of selective laser cladding and milling, *J Mater Process Technology*; **110(1)** :98-103

[5] Hur J H et al. 2000 Development of hybrid rapid prototyping system - hardware and software*, Proc of the Third World Congress on Intelligent Manufacturing Process and Systems*. Cambridge, Massachusetts, USA, Jun 28-30

[6] Chen Y H and Song Y 2001 The development of a layer based machining system. *Computer Aided Design* **33**, pp331-342

[7] Merz R, Prinz E B, Ramaswami, K Terk, M and Weiss L E 1994 Shape deposition manufacturing. *Proc of Solid Freeform Fabrication Syrup*. Austin, TX: Univ. of Texas at Austin, ppl-8

[8] Karunakaran K P, Suryakumar S, Pushpa V and Akula S 2009 Retrofitment of a CNC machine for Hybrid layered manufacturing*. The International Journal of Advanced Manufacturing Technology.* **45**:690-703

[9] Sarma S E and Wright E K 1997 Reference Free Part Encapsulation: a new universal fixturing concept. *Journal of Manufacturing Systems.* **l6**, pp35-47

[10] Shin B S, Yang D Y, Choi D S, Lee E S, Je T J and Whang K H 2002 Development of rapid manufacturing process by high-speed machining with automatic fixturing. *Journal of Materials Processing Technology.* **130**, pp363-371

[11] Choi D S, Lee S H, Shin B S, Whang K H, Yoon K K and Sarma S E 2001 A new rapid prototyping system using universal automated fixturing with feature-based CAD/CAM. *Journal of Materials Processing Technology.* **113**, pp285-290

[12] Radstok E. 1999 Rapid tooling. *Journal of Rapid Prototyping.* **5**, pp164-168

[13] Vouzelaud E A, Bagchi A and Sferro E E 1992 Adaptive laminated machining for prototyping of dies and molds *Proc of 3rd Solid Freeform Fabrication Syrnp*., pp291-300

[14] Walczyk D E and Hardt D E 1998 Rapid tooling for sheet metal forming using profiled edge laminations-design principles and demonstration. *Journal of Mfg. Science attd Engg., Trans. of ASME* **120**, pp746-754

[15] Frank M C, Wysk R A and Joshi S B 2004 Rapid Planning for CNC Milling - A New Approach for Rapid Prototyping. *Journal of Manufacturing Systems,* **23**:242-255

[16] Chang T C, Wysk R A and Wang H P 1998 *Computer-Aided Manufacturing* (Englewood Cliffs, NJ: Prentice-Hall)

[17] Balasubranmaniam M 1999 Tool selection and path planning for 3 axis rough cutting (Ph.D. thesis Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge)

[18] Kamrani A K and Nasr E A 2006 Subtractive Rapid Prototyping: creating a completely automated process for rapid machining. Rapid Prototyping Theory and Practice (New York: Springer Science Business Media, New York) p 165-196

[19] Keat L L, Case K. 2010 Rapid Prototyping using Conventional 3-Axis Milling. *8th International Conference on Manufacturing Research ICMR*