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Enhancement of the Capabilities of CNC Machines via the Addition of a New Counter boring Cycle with a Milling Cutter

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Abstract

The operations of the machine, such as milling or drilling are the processes of shape transformation in which the metal is removed from the material stock to generate a part. The contact amongst the work piece and the generating tool creates substantial force. The study intends to examine and analyze different techniques of the model-based procedure control. Moreover, this research also aims at assessing a feature based approach, i.e., CNC approach. The program of CNC consists of a combination of machine specific instructions and machine specific codes. After reviewing the manuals of all modern CNC units from the different manufacturers, no efficient cycle was found for boring and counter-boring holes using a milling cutter. This research encapsulates the an investigation for the development of general programming algorithm, which is applied for boring or counter-boring many holes of different diameters using only one standard milling cutter. This algorithm has been integrated to produce a user-defined cycle (G888) and a subroutine for boring or counter-boring holes to achieve specific counter-bore diameters with accurate tolerance and good surface finishing. This programming algorithm can be equipped with our user-defined cycle (G881) to enable the machining of many counter-bore holes lying in a straight line (row/column/diagonal) or holes lying in regular or inclined matrix form. The algorithm can also be equipped with the presented user-defined cycle (G890) to machine counter-bore holes that form a circular pattern.

Keywords: user-defined cycles, canned cycles, NC programming algorithms, CNC Machining

1. Introduction

Machine tools, which are automated for operations using encoded program commands, rather than using cams for mechanical automation or levers/ hand wheels for manual control, is referred as numerical control or NC. During the previous years, like 1940 and 1950, NC machines were first built by modifying the existing tools, which integrate motors and moving system controls over punched tape, following points fed. Servo mechanism of these machines was based on analog and digital computers for rapid argumentation; hence, creating the revolutionary process of manufacturing, computer numerical control (CNC). The modern CNC are highly automated in nature, as it possess contemporary programs (Anderberg & Kara, 2009). In addition to this, these systems also integrate CAD (computer aided design) and CAM (computer aided manufacturing), along with the end-to-end designs of the components.

It has been analyzed that in order to operate this type of machine, a computer file is generated with a program, which is used for the interpretation of the command via postprocessor; hence, leading CNC machine to load a file for the production of the command. A number of steps are found to be involved in the production of the command, which are highly automated and complex. More so, it is also observed that the entire process also matches with original design of CAD (Luggen, 1983; Groover & Zimmers, 1984).

Modern computer numerical control machines allow the programmer, among other things, to call up fixed manufacturing routines, which are usually known as cycles. These routines automatically perform pre-programmed tasks; hence, making the manufacturing process easier and more efficient. It is significant to bring into the notice that there are different cycles on machining centers, horizontal boring machines, milling machines, turning machines, drilling machines, and grinding machines, depending on their jobs. There are two types of cycles. The first type of cycle is known as canned cycles, which are pre-prepared by the CNC unit manufacturer. It has been established that there are a number of different canned cycles, which are available in drilling and milling machines for different purposes. These include drilling holes, deep drilling, boring, reaming, and tapping (Anderberg et al., 2012). In milling machines, there are many canned cycles for the purpose of face milling, contour milling, thread cutting, rectangular stud milling, and circular stud milling. In addition to this, they are also available for making a long hole on a circle, a slot on a circle, a circular slot, a rectangular pocket, and a circular pocket.

Different types of canned cycles are also available for a turning machine, such as a grooving cycle, an undercut cycle, a stock removal cycle, a thread cutting cycle, and chaining of thread. The use of canned cycles is found to be a good programming method, which can be adopted to drill one hole in a single block. In this method, the programmer has to calculate the center coordinate for each hole, while drilling many holes, which lie in a straight line (row/column/diagonal) or holes lie in a regular matrix form. It has been assessed that such calculations increase the risk of different programming errors and are also found to be time consuming in nature (Ernesto & Farouki, 2012). In most of the industrial cases, these holes do not only lie in a regular matrix form, but also may be lying in an inclined matrix form. In this case, the programmers need to have large amount of time, in order to calculate the coordinate centers for each hole; thus, the program will require a large amount of memory storage (Gidding & Lewis, 2000; Siemens, 2012; Gidding & Lewis, 2000; Siemens, 2012; Siemens, 2012)

This research intends to include and discuss some of the major techniques, which are being used for monitoring and controlling the phenomenon, which is usually occurred from the contact of the cutting tools and work piece. It has been established that modern CNC units are capable enough to create a second type of cycle that is similar to canned cycles, which is known as user-defined cycles, for diverse operations of machining. The user-defined cycles are prepared and developed by CNC researchers or professional programmers, in accordance with their experience and the requirements of their products. It is a notable aspect that the task of producing user-defined cycles is not easy. It is due to the fact that this process is highly complicated in nature and requires special experience. More so, it also needs to have significant efforts for validation and verification of the cycle, before its installation into the CNC unit and to ensure that the cycle is ready for the programmer to use (Conway et al., 2012). On the other hand, if all of these parameters are not fulfilled, the cycle may produce a machine error or machine crash.

In this study, the capabilities of the algorithm were tested by the help of two case studies. The first case study was developed for a Numeripth8000 -B- CNC unit, equipped with a horizontal Orion-500 machining center. However, the second case study was developed for a Sinumeric 840-D, equipped with a vertical EMCO machining center. During this activity, several work-pieces showed satisfactory outcomes, with an accuracy of up to 0.15 mm for the diameter and 0.80 micron for the surface finishing. The developed algorithm saves approximately 80% of the special boring tools, while saving 95% of the preparation time, which is usually needed for the part program and reduction in the errors of program. Abbas (1996) has discussed the preparation of a custom macro in modern CNC machines and its effect on time, which is usually required to prepare the CNC part programs and error reducing techniques, within the program.

Omirou et al. (2012) has presented an algorithm, in order to improve the turning operations' interpolation accuracies. The free-form profiles are resolved within the parts that are considered in the implementation of the Bezier formulation, turning in the region of a center linear axis. The production of parts through forging and casting plays a major role in meeting the demand to manufacture the geometric shapes. Furthermore, it has also been established that computer numerical control (CNC) is used as a method for turning machine, which works on the concept of locus tracing (Kadir et al., 2011). The potential algorithm applies a CNC interpolator on real-time, which supplies the turning machine with the highest possible capability and accuracy. This task of machining is programmed for a canned cycle, which tends to extend the existing capability of G70/G73 CNC for turning fixed cycles and feature-generation.

Sheth and Rathour (2014), applied macro parametric programming for developing a Bezier surface and canned cycle with hypo cycloid, which is merged with EP-hypo cycloid curve. It has also been established that the developed algorithm was useful in canned cycle and for a variety of applications including, surface milling, a lobe pump rotor, and a cycloidal speed reducer, which is exclusive of an arrangement of external CNC interpolator or CAD modeling.

Abbas (2003) has presented an approach that high tolerance and good surface finishing can be obtained by using CNC grinding machines. However, due to the high cost of these machines, manufacturers often consider interchanging boring bar or add a grinding spindle, for a turning lathe. Complex software is usually used to facilitate this addition as the programmer ought to have control over the complete grinding wheel surface and not only on the tip of the cutter or tool, in contrast to milling or turning (Lasemi et al., 2010). This paper aims at presenting simplification of the grinding program by using this general algorithm, which is applied by the programmer for generating a suitable machine subroutine. Afterwards, this subroutine can be applied to all the operations of grinding machine. In this algorithm, it is essential for the programmer to describe each work piece separately for the contour within a small program, as similar with the program of CNC lathe.

There experimentation generated satisfactory results, when this algorithm was applied to a numerical control, Sinumeric 840 C through a hollow spindle lathe as well as many gun barrels were turned and grounded with the suggested approach. Abbas (2004) observed a significant development within the technology of grinding complex geometrical parts. Nowadays, many factories consider additional grinding spindle within a turning lathe for avoiding the purchase of additional and expensive grinding machines.

There are two types of software, which are required for interchangeable use of grinding spindle, along with a turning boring bar. The first software to be used is a program that includes subroutine for controlling the movement of machine, through the work-piece profile of the grinding wheels. The first software to be used is a program, which generates a subroutine that are essential for creating profile of the wheels for new grinding with the respective work-piece of the grinding profiles and dressing them, after using the grinding wheels (Newman & Nassehi, 2009). A long-term programming is needed when the cut is very small in depth. Different software will be required for each of the grinding wheels, having different shape. The machine manuals and literature research has not provided that the detailed description of such problem, within the machine.

Thus, this paper aims at representing a description of a general algorithm for dressing programs and profile production, more simply for the subsequent wheel grinding. This algorithm will be implemented to create appropriate subroutine in the programming for the system of machine dressing. The algorithm can be integrated on the grinding machines as well as on the hollow spindle lathe of additional grinding spindle. The subsequent subroutine will be integrated for profiles of grinding wheels and dressing of the commonly shaped grinding wheels (Ridwan & Xu, 2013). The grinding wheel contour will only be needed by the programmer, in order to have clear and detailed description. Hollow spindle lathe has also undergone the implementation of this algorithm, which is applied on a numerical Sinumeric 840C control. Satisfactory results have been demonstrated with the implementation of this approach for many grinding wheels that were profiled and dressed through its application.

It has been indicated by Abbas (2004) that CNC programs involve complex task for grinding parts, involving different shapes. These are long programs that go through problematical calculations as the programmer need to have control over the grinding wheel's surface and not only on the tip of the cutter or the tool diameter like, milling or turning. Furthermore, there is additional software, which is required for grinding wheels' profiling and dressing. It observed that no detailed description has been provided in the literature and machine manuals, about the resolution of this issue. This paper represents a simple way for producing the programs for dressing and profile via general algorithm for grinding wheels with complex shape.

The programmer needs to apply this simple algorithm to produce a subroutine, which is applicable on CNC grinding machines and spindle on CNC lathes that are additional. When subroutine is stored in the CNC unit, than the programmer will describe the contour by filling in the grinding wheels parameters. The algorithm was implemented on an "add-on grinding spindle" along with a numerical control, Sinumeric 840C and a hollow spindle lathe. When the proposed approach was implemented it gave satisfactory results for many grinding wheels, having complicated shape that were profiled and dressed.

Abbas and Megahed (2005) described an examination of developing a programming algorithm, which is employed for drilling holes, which usually lie in a form of regular matrix. This paper explains the examination the process, which deals with developing a general programming algorithm to drill holes that lie within a general matrix or an inclined matrix form in G-code. The algorithm will be applied to develop cycles that are user-defined or subroutines to drill holes that are lying in an inclined matrix form, staggered matrix, regular matrix, column, sole row, and diagonal.

The programmed algorithm is helpful for machining drum and trammels screen, separators, and boiler-plates. To test the capabilities of the examined algorithm, there are many work-pieces, which have projected the satisfactory results. Therefore, some examples of these machined pieces are given. The study recognizes that the fundamental objective of the two sub-problems of finding tool path (CL) points and tool orientations is to completely and correctly machine the work piece, in order to obtain the design surface.

Additionally, due to economical and ecological constrains, the machining process must also be optimized for its performance and environmental footprint. Performance of a machining process is indicated by several parameters such as cycle time, cost, and tool life. However, the environmental footprint is characterized by its energy use, emissions, coolant use, etc. The common constraints include those, which are related to the gouging prevention, scallop height limit, and kinematic limits (Overby, 2010). The research has exploited these similarities in the sub-problem objectives and constraints by expressing them as those of a single optimization problem. Also, the optimization problem was defined in the combined parameter space, which is the full configuration space (C-space) of the cutter.

Abbas et al. (2011), explored the drilling machines for CNC with respect to optimum path planning, while considering products of a special class that include numerous holes, which are usually placed in a form of rectangular matrix. Some of these examples include different products, such as trammel screens, drum, and boiler plates, steel structures with connection flanges, and separators of food-processing, in addition to definite parts of printed circuit boards. CAD software packages that are mostly used for commercial purposes include modules that results in CNC code auto-generation.

The plan, which is generated for tool path using the commercial software CAD, is not found to be optimized, in terms of considering the distance for tool travel and allocated time for total machining. This process of optimization is usually incomplete, as the distance of tool travelling is minimized, which is known as travelling salesman problem (TSP). In the context of programming, TSP is found to be the most difficult problem for solution, without having any identified solution, which can be attained in polynomial time (Sarhan & Matsubara, 2014). A number of heuristic optimization algorithms are explained to solve the TSP, with diverse success factors. ACO (Ant colony optimization) is recognized as an integrated and one of the most successful algorithms, which assists in addressing the concerns in TSP; hence imitating the nature of ants' behavior.

This paper has applied the ACO algorithm to the CNC drilling tool path planning between rectangular matrixes of holes. Taking a benefit of the rectangular design of the holes, there were two variations, which were proposed for the basic ACO algorithm. Different case studies on simulation, point out the average path through modification of ACO algorithms, which displays a major decrease in the total distance, traveled by the tool.

A common algorithm has been developed, which is practical to allow the drilling of holes and is circularly organized within multiple patterns. This potential algorithm can be simply adapted by using program within any modern CNC unit, just by creating a cycle of user-defined subroutine (Yusof et al., 2009). In order to test the effectiveness of the potential algorithm, there were two cases that enhanced understanding of the algorithm. The first used the Nwneripth800-B CNC unit, which was equipped with a horizontal Orion-500 machining center. On the other hand, the second case study was developed by using the Sinumeric 840-D, which was equipped with a vertical EMCO machining center. During this process, the production of few samples was successful. This original algorithm exhibits potential competence in the part program development and proposes the benefit of diminishing the errors in encoding.

Several research have been performed, which were based on the optimization of the path-planning within a computer numerical control (CNC), where machining jobs takes place in machining center and involve many concentric holes for drilling, which are typically organized within circular patterns. It is assumed that this research may contribute to great benefits, while reducing the machining time for some components, which are utilized in the food separators, trammel screens, condensers, boilers, and heat exchangers (Conway et al., 2012; Omirou et al., 2012). The cost of machining and tool optimization are the two aspects that are typically overlooked when paths are generated for tool and CNC codes, with respect to the CAD software packages, which are commercially available (Ridwan & Xu, 2013). This problem of achieving minimum travelling distance for tool path can be represented as the travelling salesman problem (TSP).

A varied level of success has been achieved for this optimization problem of solving TSP, which is based on the literature. TSP problem is also addressed by using Ant Colony Optimization (ACO). ACO is found to be a prominent approach, which is established on the basis of imitating the natural behavior of the ant colonies. This research recommends a study by using hybrid ACO, which takes an advantage with biasing mechanic design of a local search and the hole, which is arranged in geometric pattern. The examples of simulation indicate that this approach comprises of better performance when compared with the classical approach of ACO, considering the use of commercial CAD software to generate simple spiral path as well as the approach of genetic algorithm (GA). This approach is then implemented within the food-industry for the planning of drilling path, which consists of a separator plate with two-thousand-hole.

(Majerik et al., 2015) the objective of the article was to suggest the possibility of creating CNC program production process components on a rotary chuck, or with minimal handling. This is achieved by shortening the time of the final machining while eliminating inaccuracies caused by manual switching of the workpiece. The results presented in this paper can be further exploited in the process of teaching courses and programming CNC machines and technical practice for upgrading older solutions and processes of the main and additional times, while maintaining the dimensional accuracy of machine parts. In our future research plans e.g. comparing to the existing workshop CNC machining centers, have the presented simulation methodology have a number of advantages. First, with the same interpolation steps, the contour accuracy is significantly higher. Second, the programming module is easier to use more simple G code lines. And last, machining cost is lower because of the reduced machining time.

Usually, CNC unit manufacturers may not provide satisfactory explanation for cycles in a user-defined CNC program. User-defined cycles are considered as the black box in CNC manufacturing unit manufacturers, i.e., CNC programmer is only aware of the input and the results. Thus, this research develops a simple way of boring or counter-boring with a general programming algorithm and only one standard milling cutter, comprising of numerous holes with various diameters. This algorithm is used for achieving specific counter-bore diameters to create a new cycle of subroutine or user-defined (G888), applied for the accuracy, tolerance, and good surface finish.

2. Algorithm of User-Defined Cycle

The G-code (G81-G89) is used within standard canned cycles and they are cancelled by (G80), while activation within user-defined cycles takes place by means of the G-code (G801-G899) and cancelled by (G800). This algorithm is used by the programmer, in order to create suitable machine subroutine or G888 (user-defined cycle) that fits to the machine. These cycles applied for boring or counter-boring holes. This cycle can be equipped with our user-defined cycle (G881) to bore or counter-bore holes that lie within a regular matrix, an inclined matrix, a single row, a staggered matrix, a column, and a diagonal. In addition, this cycle can be equipped with our user-defined cycle (G890) for boring or counter-boring holes, which lie within a circular form.

When the user-defined cycle (G888) is stored for the CNC unit, then the programmer just needs to call out for the particular cycle and filling within one block of parameters, in contrast to write several blocks to describe the route of milling cutter. The buffer page or the directory does not display the subroutine when the execution of the program takes place; as a result, the operator cannot adjust the contents of the subroutine. To pass the values within the global parameters of the user-defined cycle, letter addresses are used (indicated by A through Z); such as, the letter address A is a value which is stored within parameter (P201) and the letter address B is a value, which is stored in (P202). Therefore, the potential algorithm precisely and clearly describes method, which is used in the creation of statements for user-defined cycle (G888) for boring or counter-boring many holes with one standard milling cutter. In concurrent algorithm, parameters to be input are similar to the following:

A = Milling-cutter diameter or End-mill diameter (P201).

B= Initial hole diameter (P202).

D = Final counter-bore diameter (P204).

X = Coordinate center of the initial hole in the X-axis direction (P224).

Y= Coordinate center of the initial hole in the Y-axis direction (P225).

R= Level of Approach within the Z-axis direction (P218).

Z= Depth of the counter-bore diameter in the Z-axis direction (P226).

E= Level of Retraction within the Z-axis direction (P205).

This system will create three calculated points, i.e., P1, P2 and P3. Figure 1 displays all of the features of a general algorithm, which is appropriate to generate a subroutine or a user-defined cycle (G888) for its use on any modified CNC controls. The prime focus of the potential algorithm is to take all of the calculations and complicated formula as input, which are required for controlling the center of the milling cutter movements, according to the diameter of the milling cutter or the end-mill, the initial diameter of the hole, and the final diameter of the counter-bore hole. The subroutine will start to move the center of the milling cutter with rapid motion to the center of the hole, according to input data in parameters X = P224 and Y = P225. Next, the front of the milling cutter will move with rapid motion to approach the level in the Z direction where, R = P218. Subsequently, the algorithm will have three routes:

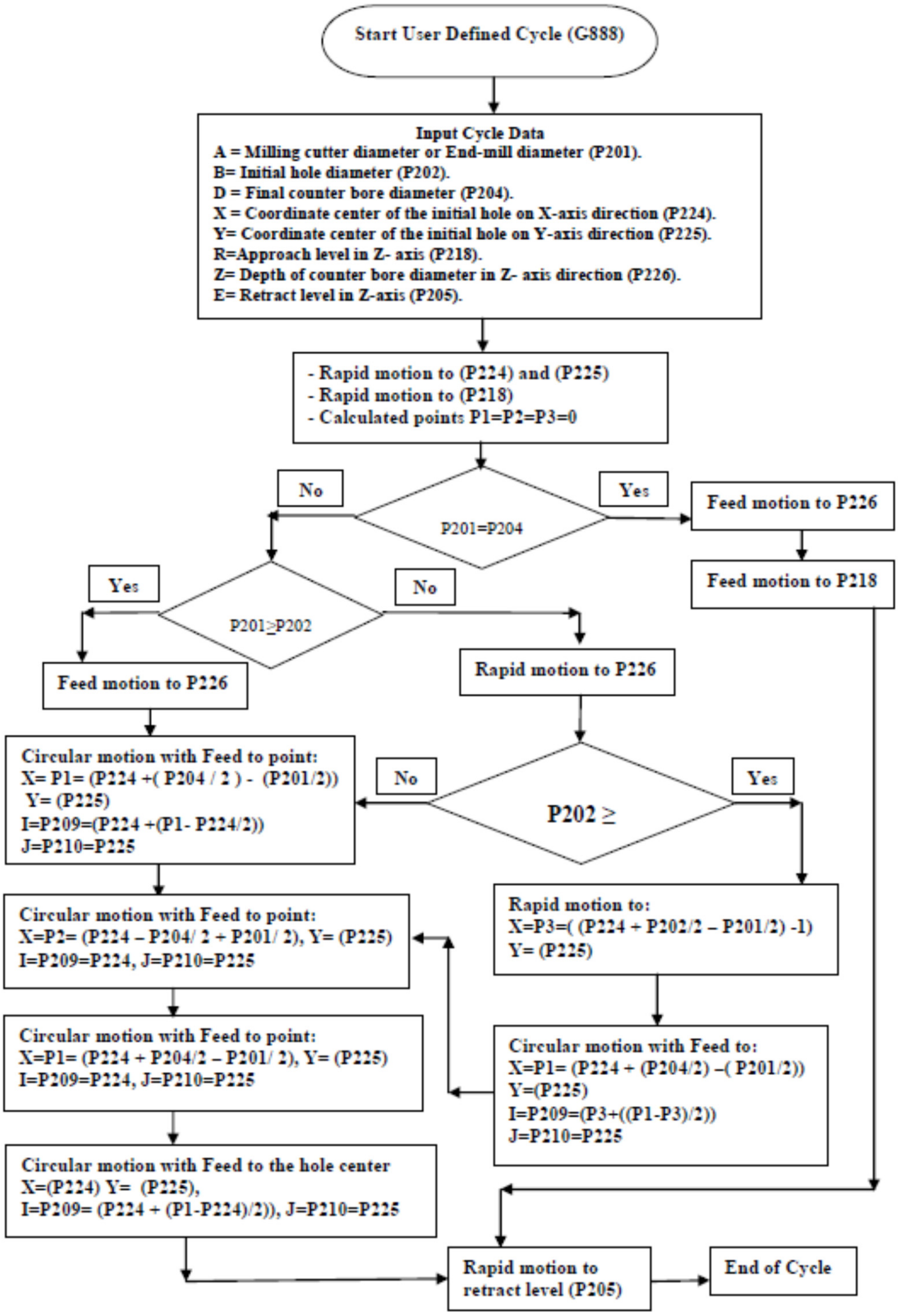

Figure 1. A General Algorithm for User-Defined Cycle (G888)

2.1 The First Route

If the size of the milling cutter diameter is equal to the final diameter of the hole, then the cutter will move with feed motion until, the boring depth in the (Z) direction where, (Z=P226). Next, the cutter will return to the approach level in the (Z) direction where, (R=P218), with feed to produce a good surface finish. Finally, the cutter will move with rapid motion in the (Z) direction to retract to the level where (E=P205) to save time. This route will be similar to the regular boring operation.

2.2 The Second Route

If the diameter of the cutter is not equal to the final diameter of the bore and is larger than the initial hole diameter, then the cutter will proceed with feed motion until the counter-bore depth in the (Z) direction where, (Z= P226), to avoid the tool crashing with the work-piece and to enlarge the hole diameter; subsequently, the center of the cutter will move with a circular motion to point (P1) to position the outside surface of the cutter to be tangent with the final diameter, followed by another circular movement to point (P2), and then a circular movement to point (P1) again. Next, the center of the cutter will return back to the hole center, as shown in figure 2a . Finally, the cutter will rapidly move to the retracting level in the (Z) direction where, (E= P205).

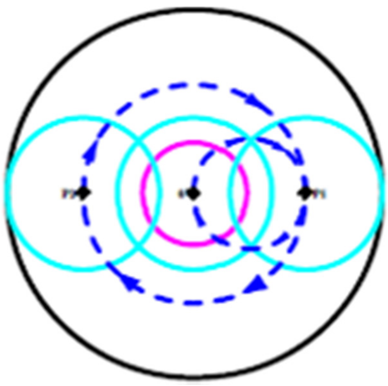

Figure 2a. Milling Tool Path for the Second Route

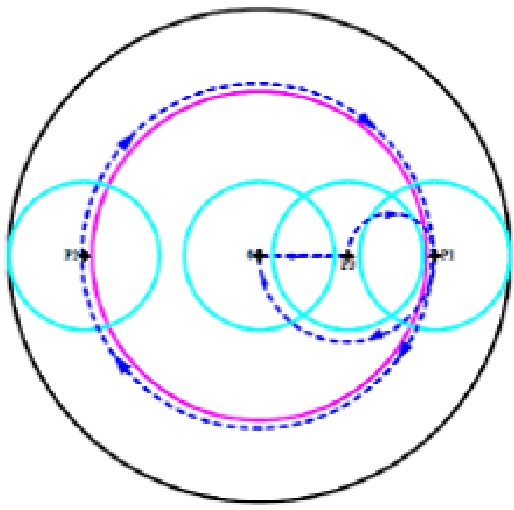

Figure 2b. Milling Tool Path for the Third Route (First Sub Route)

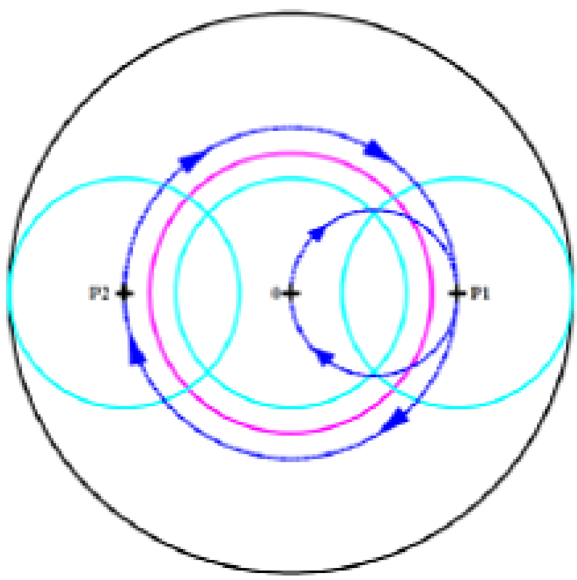

Figure 2c. Milling Tool Path for the Third Route (Second Sub Route)

2.3 The Third Route

If the diameter of the cutter is less than the initial diameter of the hole, then the cutter will move with rapid motion in the (Z) direction until, reaching the counter-bore depth where, (Z= P226) to save time. Next, the cutter has two sub-routes of movements.

2.3.1 The First Sub-Route

If the initial diameter is greater than twice the cutter diameter, then the cutter will be moved to the side with rapid linear motion in the (X) direction to the calculated point (P3), in order to save the time. Next, the cutter will move with feed by circular movement to the calculated point (P1) to be a tangent with the final diameter of the counter-bore, followed by circular movement to point (P2), circular movement to point (P1), and then returning to the hole center, as shown in figure 2b.

2.3.2 The Second Sub-Route

If the initial diameter is smaller than the twice of the cutter diameter, then the cutter will move directly with feed by circular movement to the calculated point (P1), followed by circular movement to point (P2), by circular movement to point (P1), and then returning to the hole center, as shown in figure 2c. The objective for all of the above circular movements is to achieve a smooth touch or smooth retract with the final surface to avoid the tool gauche.

3. Applications

The developed algorithm in the subsequent part of the research is applied for creating an appropriate user-defined cycle (G888) with a horizontal milling machine for Lewis machining center and grinding, which is equipped with an Vertical Machining Center, EMCO with Sinumeric 840-D and CNC unit Numeripath 800. Figures 3 and 4 provide the details of such a cycle (G888) for the respective control units. The modification of parameters can be obtained, with respect to a suitable Fanuc control unit, integrating a change in Parameter P1 to be #1 and Parameter P2 to be #2, etc. When the software to be utilized for the user-defined cycle (G888) is uploaded in the CNC unit, the CNC memory stores the software. The machine operator or programmer is unable to view the subroutine and they cannot change it.

```
%
N01 (PGM, G888, COUNTER BORE  HOLES)
N02 ! A = Milling cutter diameter or End-mill diameter (P201).
N03 ! B= Initial hole diameter (P202).
N04 ! D = Final counter bore diameter (P204).
N05 ! X = Coordinate center of the initial hole on X-axis direction (P224).
N06 ! Y= Coordinate center of the initial hole on Y-axis direction (P225).
N07 ! R=Approach level in Z- axis (P218).
N08 !  Z= Depth of counter bore diameter in Z- axis direction (P226).
N09 !  E= Retract level in Z-axis (P205).
N10 ! P1, P2, P3= Calculated Points
N11 (LET, P1=0)
N12 (LET, P2=0)
N13 (LET, P3=0)
N14 G00 X=P224, Y=P225
N15 G00 Z=P218
N16 (IFS, P201 = P204) GO TO N32
N17 (IFS, P201 GE P202) GO TO (G01 Z=P226) (GTO, N20)
N18 G00 Z=P226
N19 (IFS, P202 GE 2*P201) (LET, P3= (P224 + P202/2 – P201/2) -1) (GTO,
N29)
N20 (LET, P1= (P224 + P204 / 2  -  P201/2))
N21 G02 (LET X=P1 , Y=P225, I=P209=(P224 +(P1- P224/2)) J=P210=P2)
N22 (LET, P2= (P224 – P204/ 2 + P201/ 2))
N23 G02 (LET, X=P2, Y=P225, I=P209=P224, J=P210=P225)
N24 (LET, P1= (P224 + P204/2 – P201/ 2) )
N25 G02 (LET, X=P1, Y225 I=P209=P224, J=P210=P225)
N26 G02 (LET, X=224, Y225, I=P209= (P224 + (P1-P224)/2)), J=P210=P225)
N27 G00 (LET, Z=P205)
N28GTO N100
N29 G00 (LET, X=P3, Y=P225)
N30 G02 (LET, X=P1, Y=P225,  I=P209=(P3+((P1-P3)/2))), J=P210=P225
N31 GTO N23
```

Figure 3. User defined cycle (G888) Numeripath 8000-B – Giddings & Lewis Control

```
Program CYCLE888.SPF
PROC CYCLE888(REAL _X,REAL _Y,REAL _Z,INT _E,INT _R,INT _A,INT
_B,INT _D), SAVE SBLOF
;Input cycle data
N0  ;_X = Coordinate center of the initial hole on X-axis direction
N01 ;_Y= Coordinate center of the initial hole on Y-axis direction
N02 ;_Z= Depth of counter bore diameter in Z- axis direction
N03 ;_E = Retract level in Z-axis
N04 ;_R = Approach level in Z- axis
N05 ; A = Milling cutter diameter or End-mill diameter
N06 ; B= Initial hole diameter
N07 ; D = Final counter bore diameter;_
N08 ;_P1= Calculated point
N09 ; P2= Calculated point
N10; P3= Calculated point
N11 P1=0
N12 P2=0
N13 P3=0
N14 G00 X=_X  Y=_Y
N15 G00 Z=_R
N16 IF ( _A= _D ) GOTO N32
N17 IF ( _A ≥ _B  ) GOTO (G01 Z=_Z) (GOTO, N20)
N18 G00 Z=_Z
N19 IF (_B ≥ 2*_A) (P3= (X + B/2 – A/2) -1) (GOTO, N29)
N20 P1= (X + D / 2  -  A/2)
N21 G02 X=P1  Y=_Y CR= (P1-_X) /2
N22 P2= (X – D/ 2 + A/ 2)
N23 G02 X=P2  Y=_Y  CR= (_X-P2)/2
N24 P1= X + _D/2 – _A/ 2)
N25 G02 X=P1  Y=_Y CR=(P1-P2) / 2
N26 G02 X=_X   Y=_Y CR= (P1-_X)/ 2
N27 G00 Z=_E
N28GOTO N100
N29 G00  X=P3  Y=_Y
N30 G02  X=P1 Y=_Y  CR= (P1-P3)/2
N31 GOTO N23
N32 G01 Z=_Z
N33 G01 Z=_R
N34 G00 Z=_E
N100 M17
```

Figure 4. User defined cycle (G888) for boring or counter boring with milling cutter suitable for Sinumeric 840-D-Siemens

This software comprises of all defined parameters and potential calculations, which are needed in machine motions. Then, the programmer can call the cycle by filling in the addresses, which are similar to the canned cycle. In order to test the validation and verification of the cycle (G888), many parts from the work-piece model shown in figure 5 with specifications in table 1, were machined with accuracies of up to 0.15 mm in diameter and 0.80 microns in surface finish, and satisfactory results were obtained. The CNC part programs required for counter-boring this part with one standard milling cutter are shown in figure 6 and figure 7 for Numeripath8000-B and Sinumeric 840-D, respectively.

Table 1. Work piece Specifications for Testing Cycle (G888) Capabilities

	Milling Cutter Diameter = A = P201=45 mm						
Hole No.	Hole Center		Counter bore Hole depth	Approach level	Retract level	Initial hole diameter	Final hole diameter
	X=P224	Y=P225	Z = P226	R=P218	E=P205	B=P202	D=P204
1	60	60	-20	5	100	40	$45^{+0.15}$
2	180	80	-20	5	100	45	$60^{+0.15}$
3	320	120	-20	5	100	60	$75^{+0.15}$
4	185	205	-20	5	100	90	$130^{+0.20}$
5	80	310	-20	5	100	100	$140^{+0.20}$
6	310	310	-20	5	100	100	$150^{+0.20}$

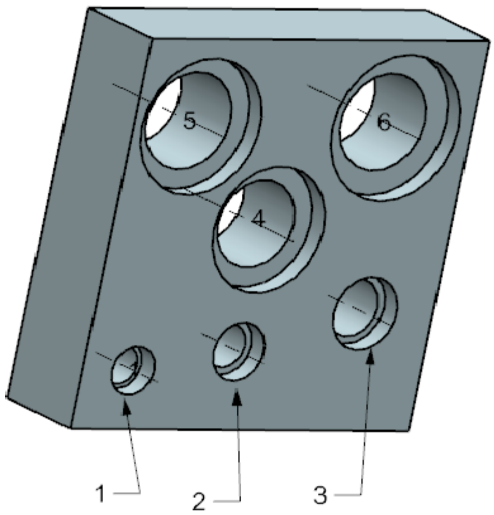

Figure 5. Work piece drawing for testing the user defined cycle capabilities

```
%
N10 (PGM, Counter Boring, Boring and Counter Boring Cycle-
G888)
N20 T01 M06 S500 M08 F0.25
N30 G00 G90 G95 Z200 M03
N40 G888 X60 Y60 Z-20 R5 E100 A45 B40 D45   (Hole-1)
N50    X180 Y80 B45 D60   (Hole-2)
N60   X320 Y120 B60 D75 (Hole-3)
N70    X185 Y205 B90 D130 (Hole-4)
N80    X80 Y310 B100 D140 (Hole-5)
N90   X310 Y310 B100 D150 (Hole-6)
N100 G800 Z500 M05 M09
N70 M02
```

Figure 6. Part program for boring or counter boring with milling cutter for Numeripath 8000-B – Giddings & Lewis Control

```
%
;Program main.mpf
N10 G54
N20 M06 T1 D1
S500 M3 F100
N40 CYCLE888(60,60,-20,100,5,45,40,45)
N50 CYCLE888(180,80,-20,100,5,45,45,60)
N60 CYCLE888(320,120,-20,100,5,45,60,75)
N70 CYCLE888(185,205,-20,100,5,45,90,130)
N80 CYCLE888(80,310,-20,100,5,45,100,140)
N90 CYCLE888(310,310,-
20,100,5,45,100,150)
N100 G00 Z500 M05 M09
N110 M30
```

Figure 7. Part program for boring or counter boring with milling cutter for Sinumeric 840-D- Siemens

4. Feature Based Procedure Planning and Automatic Numerical control Part Programming

It is assumed that a well-integrated manufacturing and design system will provide a rich set of features; therefore a designer can manufacture the critical parts with utmost flexibility. Many systems of CAM/ CAD incorporate very few and limited set of design. In the research, the feature based-approach with respect to the integration of manufacturing and design is used. One of major objective behind this activity is to inculcate the sculptured surface as the features of higher order, which includes both computer-aided procedures and parametric design paradigm techniques (Sarhan & Matsubara, 2014). The advantage of the decomposition of tool-driven is the possibility of deploying multiple tools for the optimization of the milling operations. The figure 8 shows the decomposition of the pocket of hand-shaped into di roughing operations.

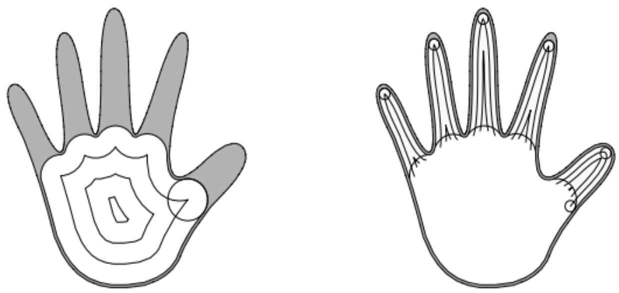

Figure 8. Feature Based Procedure Planning and Automatic Numerical control Part Programming

The left side indicates that the big tool is first deployed to machine, and away the area of the palm, it can be easily fixed. The shaded area represents the uncut region by the gigantic tool. However, the right figure represents the small tool that is deployed to cut the enduring figure area. The approach adopts several procedures so as to find the combination of tool diameters for the machine a milling feature, within a short span of time (Vichare et al., 2009). The tool, however, depends on the overhead time and the features. Therefore, a simplified linear overhead per-tool overhead is espoused so as to roughly approximate the component.

5. Process Control

The term “process control” can be understood as the operation of the process variables such as speed, depth-of-cut, and feed for the regulation of the processes. The operations of the machine tools, which are perform on-line and off-line, are governed by the adjustments of the speed and feeds to destroy chatter, while initiating an emergency termination in response against an event breakage of tool. It also performs the regeneration of the program so as to increase the depth-of-cut, in order to suppress burr development. Computer aided process of planning is found to be more cultured procedure, which utilizes process models off-line set in various different models for the selection of the variable (Tobon-Mejia et al., 2012). However, advancement in the modeling of the cutting mechanics is obligatory. Recently, models are resolute and empirically contain terms of non-linear that account the effects of unmolded. However, the biggest hindrances in its implementation include limited applicability and low reliability.

6. Discussion

This paper illustrates that the capabilities of CNC Machines using an additional counter boring cycle can be improved, which is currently saving 95% time for preparation and 80% cost for the special tools via milling cutter. The results of the current study are practical and consistent with the outcomes, which were established by (Abbas, 2012). Sona et al (2009) signifies the use of Numeripth800-B CNC unit within the machining center (Orion-500) through a case study that demonstrated the algorithm’s capability, which has high academic value. The current study analyzes the capabilities of the CNC machine by using the user-defined cycle (G888) and attained results have shown great accuracy up to 0.15 mm for surface finishing.

Sona et al. (2009) presented a hybrid design for 5 axis CNC milling machine that can avoid substantial pitfalls and has several benefits for both mechanisms (parallel and serial). A further extension of the present research study involves the implication of same method to other kinds of five-axis CNC milling centers, while table tilting comprises of two rotations on each of the spindle tilting or tables (Yusof et al., 2009). Also, it can work with one rotation for each of the table and spindle types. Moreover, the same technique can be applied to develop a post processor for industrial robots. The compensation vectors can also be determined for same robot using principle of inverse kinematic transformation.

The current study is consistent with Sona et al. (2009), considering the high tolerance and capability advantage of the milling cutter. Another study by Anderberg (2012), demonstrated the method to improve CNC machining by improving its process planning. In this paper, we address same issue and improve efficiency of the CNC milling machines utilizing the milling cutter. To improve efficiency of the CNC machine, we focused on a new cycle in the boring for the milling. This study has identified and illustrated the inherent differences in between the current study and by the research of Anderberg (2012), as it was intended to achieve reduction in energy consumption behaviors using an efficient process. On the other hand, Sona et al. (2009) examined the 5-axis CNC machines; thus, treat them differently, to analyze, model, and suggest ways to improve efficiency of the machine consumption behavior.

The knowledge, techniques, and software tools developed by Abuthakeer et al. (2011) are used in manufacturing industry at various stages, in order to save energy (electricity). CNC machining encompasses a variety of manufacturing processes including cutting, milling, turning, and grinding. However, in this study we focused on CNC point-milling for analysis and modeling of the method, when new cycle is added to improve its capability. This research has a significant academic value, as it can be readily extended to other CNC manufacturing processes to improve their performance and energy usage. Sona et al. (2009) proposed a strategy to formulate the full 5-axis tool path planning problem by transforming it to a multi-objective non-linear optimization problem in the C-space of the cutter. The researcher has identified that an optimal solution to the 5-axis tool path planning problem necessitates simultaneous solutions of involving sub-problems, but none of the existing approaches address the inherent complexities.

The formulation method used in the study considers all the cutters simultaneously, without making any simplifying assumptions. A 5-axis tool path planning system based on our formulation may be able to find the optimal tool path solution in the full C-space of feasible solutions. It is impossible with the existing approaches to completely provide the solution and address all the complexities of the current algorithms and methods. However, the proposed approach can provide solution to the two sub-problems of cutter locations and cutter orientations simultaneously. Reducing energy consumption in CNC machining has been the ultimate achievement of the research, which was conducted by (Sona et al., 2009).

On the other hand, in this research has proposed and implemented few ideas, related to the CNC process planning. The proposed planning has demonstrated the need for considering the use of additional counter boring cycle during designing and comparing of manufacturing operations, along with the conventionally considered metrics of process productivity and cycle time. Sona et al. (2009) and Anderberg (2012) reported in their work a novel foundation over which, advanced 5-axis tool path planning systems may be built to obtain tool paths that minimize several, often conflicting objectives, simultaneously.

These studies highlighted the various other dimensions for the future research work in the field. Similarly, using the current research study further researches can be carried out in future and several other methods can be implemented, which enhances the theoretical value of the current study. With standards, requiring tangible progress toward saving energy, equipment cost, and offering substantial advantages for time effectiveness this study has a practical value for the industrial operations, as well as academic value for the further research work in the current field of study. Zhu et al. (2010) conducted the study using the CNC machine tools, specifically to gain capability advantages within the industrial product-service system.

The comparison with previous studies indicates that previous studies did not use the traditional milling cutter to transform the workability of the CNC machine. Therefore, this research has been added to the existing knowledge, which is available on this topic. Furthermore, the addition of a new counter boring cycle with a milling cutter has lead to significant improvements in the capabilities of CNC machines in comparison to the previous work done by researchers in this area. Future researchers can build on this study and research in other areas. The knowledge and the tools, developed in this research can be readily used, especially because they do not require any changes to the existing practices or infrastructure. As the research work extends for the sustainability, it is expected that the present work will contribute in saving energy, specifically in manufacturing sector. The future researches need to offer more advantage regarding time safety in the process of preparation and greater efficiencies regarding the use of equipment and cost advantages.

7. Conclusion

This paper describes an easy method to create subroutine or user-defined cycles (G888) for boring and counter-boring holes with different diameters using one standard milling cutter. These holes may be in random positions or lying in a row, a column, a rectangular matrix, or in circular patterns. This cycle is suitable for all modern CNC units or may require very slight modifications, depending on the names of the parameters, which are used in the CNC unit. This cycle can be used to counter-bore parts with an accuracy of up to 0.15 mm in diameter and 0.80 microns in surface finish. The cycle saves approximately 80% of the special boring tools, as well as saving 95% of the preparation time needed for the part program, additionally for reduction in the errors of the programming.

This research study has a significant practical and academic relevance, as the methods, procedures, and tools used to conduct the research work are practical and can be implemented easily. More so, the current study can also be considered as an imperative addition to the literature and further researches, which intends to understand CNC machining and ways to improve its capabilities, new implications of tool, methods, or procedures to enhance its efficiency, cost reduction within the process implementation, and time or energy consumption for carrying out the procedure. The current study offers a significant enhancement in performance of CNC machine, specifically when they are implemented with an additional counter boring cycle.

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