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Elliptical curve machining with variable feed rate for shape accuracy

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ABSTRACT

Generally, tool path deviates from curved geometry as tool path interpolates linearly between two successive cutter location points. Deviation of the tool is directly proportionate with a curvature of the geometry. Any approach improving the shape accuracy is laborious and time consuming. The main objective of the present study is to reduce the problem of shape accuracy. This required generating a curved profile from a set of control points such that the tool moves smooth from one point to another point. Various methods are studied for the interpolation of elliptical curve by deciding a number of control points as per curvature. The control points can be decided by two ways: a) Minimizing difference between arc length and chord length between two cutter location points. b) Minimizing chordal height between two successive cutter location points on the curve. The novel approach, finding shape error by the intersection of lines, is suggested to determine the number of control points to improve shape accuracy. Variable feed rate is proposed as per the number of control points considering the curvature effect of the tool path. The shape accuracy of elliptical curve of the present approach is compared with the earlier studies and reported.

1. Introduction

Tool deviation from predetermined curved geometry is a main cause that affects manufacturing quality. Generally, two successive cutter location (CL) points on the curved profile are interpolated linearly. The tool path is generated by approximating the curve using line segments. Straight line segments are used to connect consecutive cutter location (CL) points of the tool path. These segments deviate from the desirable curve profile, which results in non-linearity error (i.e. Shape error) for every interpolation. At specified feed rate, commercial CNC interpolators for curvilinear tool path can't achieve desired position accuracy as massive data are communicated between CAD software and CAM systems. The aim is to propose a tool path to minimize machining time and increase shape accuracy by adapting the geometry of the curve. The curve consists of series of straight line with variable slopes. The discontinuity amongst linear tool path is the main reason of feed variation. The curvature of the tool path influences in selection of the appropriate feed rate to attain required shape accuracy. The feed rate required to be reduced as the cutter approaches the corner having larger curvature and to be increased as tool approaches to the smaller curvature of curved geometry.

The current paper proposes variable feed rate as per curvature of the tool path for the desired shape accuracy. A method is described for the compensation of the shape error associated with tool path generation. It is also proposed to have linear interpolation of elliptical profile with reduced number of control points. An interval between two consecutive cutter location (CL) points (i.e. control points) is known as the step size, it is an important parameter to determine shape accuracy of the curvilinear profile. The smaller step size requires more machining time and on the other ends the larger step size requires less machining time but results into the poor surface quality with the deviated curvilinear profile.

For an elliptical tool path, chord error is calculated to reduce the shape error as per predetermined value. Maximum allowable feed is determined considering the effect of the curvature of the tool path.

2. Research related to geometrical error

Good amount of work has been carried by various researchers to reduce chord error and to develop algorithms to compensate deviation from tool path. Habibi and Arezoo [1] have suggested that geometrical errors have a big portion of total error. Machining code is modified to improve precision of the work piece. Geometrical errors are analyzed and compensated with complementary algorithm. Initial tool path is traced by software to compensate geometrical deviation. Due to free form shape, spline profile is chosen to interpolate curvilinear path point to point to reduce machining time significantly. Omirou [2] have put forward that a tool path cannot be programmed directly each time by the standard CNC motions. Presented interpolator avoids the shortcom-

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ings of the linear approximation adopted by the standard CAD/CAM software. Zhang and Liang [3] have described that CAD/CAM system decomposing a free form surface represented into a set of straight lines. The algorithm with Non Uniform Rational B Spline (NURBS) interpolation is executed. Cutter location (CL) points are generated by the algorithm. Proposed NURBS surface interpolator can achieve higher machining accuracy compared with the conventional interpolator. Liu and Jin [4] have explained that interpolation algorithm is the largely responsible factor affecting the machining accuracy of computer numerical control (CNC) machine tools. A real-time machine high-precision interpolation algorithm for a general-typed parametric curve is proposed. The algorithm is general, and applicable to any smooth curve that can be formulated by parametric equations. Pateloup and Duc [5] have defined the tool path by circle arcs and line segments that introduce slowdowns during machining. B spline curve is proposed for approximating a sequence of line segments and circle arcs. The numbers of control points have been reduced. The curvature has been optimized to smooth tool path to reduce the machining time. Sun and Wang [6] have proposed a novel parametric interpolator based on guide curve considering the effect of the curvature of curvilinear path. A formula has been described the relation of the maximum allowed feed and the maximum allowed rate of change of curvature of paths. The feedrate has been varied with a guide curve associated with the path curvature to restrict chord errors to predetermined tolerances. C.H. Chu and Huang [7] have explained that machining errors are induced by linear interpolation between cutter location (CL) points. Machining quality is depreciated considerably at feedrate sensitive corners. Feed rate adjustment has been proposed to control the tool motion automatically at these feed rate sensitive corners for limiting the machining errors in the region with large curvature. Emami and Arezoo [8] have explained that the rapid direction changes of the cutter at curved portion create vibrations in the machine resulting in poor surface finish. Therefore, in order to maintain surface quality and accuracy, processing speed must be reduced to maintain surface quality in this region. Parametric functions have been used in order to overcome such limitations to reduce feedrate discontinuities among blocks. Bi and Jin [9] have suggested that curvature and tangent discontinuities are the most important sources of feed fluctuation. The new curvature-continuous tool path is suggested to avoid these curvature and tangent discontinuities. The analytical computation has been carried out to determine control points of the cubic Be´zier transition curves. Actual machining has shown that the curvature-continuous tool path generates smoother feed to consume shorter machining time compared to original linear tool path. Bjoèrklund and Bjurstam [10] have presented a method for the compensation of errors associated with tool path generation by modification of an NC program. The suggested method has maintained maximum feed rate despite of tool path changes, even at corners. Pateloup and Duc [11] have described that corner radii can be modified and length of tool path can be reduced to increase real feed rate. Machine time has significantly reduced when B spline has been used instead of straight lines and circle arcs. Choi and Yang [12] have developed a curve interpolation algorithm for generating feed rate commands to control the roughness of a curved surface. NURBS curve interpolation scheme with a variable feed rate for the surface requirement has been presented. Ülker et al. [13] have suggested that machining time and accuracy are very important when producing complicated parts. So, step-size and tool-path interval are essential components in high-speed and high-resolution machining. If they are too small, the machining time will increase, whereas if they are too large, rough surfaces will result. The machining time is a key factor in high-speed machining and affected by the tool-path interval more than the step size. A software has been developed to reduce machining time and increased accuracy with Non-Uniform Rational B-Spline (NURBS) patches. The methodology is developed to optimize tool path. Lin et al. [14] have calculated the next CC point by an accurate chord evaluation method to develop the cutting simulation process. With this method, the chord errors between CC points are controlled uniform along the tool path. The results have shown that the proposed algorithm can significantly reduce the number of cutter locations meanwhile confine the chord error. Fountas et al. [15] have made an effort to ensure the quality of machined products at minimum cost and maximum effectiveness. Selection of optimum machining parameters should be done when computer numerically controlled (CNC) machine tools technology is employed. The algorithm has been developed as a hosted application to a cutting-edge CAD/CAM system. Collaboration among applications has been achieved through programming for software automation by utilising the application programme interface of the system. The methodology is capable of providing optimum values for process parameters on its way to maintain both productivity and high quality. Fountas et al. [16] have computed optimal tool paths with reference to ideally designed CAD models to suggest machining improvements in terms of high quality and productivity. The problem have involved surface machining error as the first quality objective, represented via the mean value of chordal deviations that tool path interpolation yields and effective radius of inclined tools that affects scallop. Machining time has been considered as the second quality objective entering the problem to assess productivity; whereas the number of cutter location points created for each tool path evaluation has also been considered. Fountas et al. [17] have proposed a simple philosophy of machining 2D spiral-type sculptured surfaces by analysing a given mathematical expression and then generating a shape interpolator via the implementation of known numerical techniques for CNC machining such as linear and circular approximation. An algorithm discretises the ideal curve of a given surface so as to maintain the lowest possible value in terms of chordal deviation existed between the theoretical curve and the real tool path trajectory.

Thus, feed rate is a main concern of study by many authors. The acceleration and deceleration of the tool motion can be suggested as per curvature of the tool path. It is an important parameter to maintain surface quality. Inspiring from the above literature, an attempt is made to study various existing approaches to reduce shape error. On the basis of various existing approaches a novel method (i.e. Joshi approach) is suggested to reduce shape error for variable feed rate as per predetermined value.

3. Shape error for elliptical tool path

The radial distance between the chord and arc is known as chord height. It is clear that chord height is to be kept as per tolerance value to achieve required shape accuracy. This is possible by varying the numbers of control points and feed rate as per curvature of the tool path. Various approaches to determine the chord height are considered and compared. The elliptical tool path is taken as a case study and new method to reduce the shape error is proposed.

The elliptical tool path is a curvilinear tool path (AA). During interpolation of such curvilinear path, the various cutter location (CL) points are connected linearly by G01 command. The curve AA can be obtained by segmental linear path AA′, A′A″, etc. (Fig. 1). The chord height (LM, PQ, ST…) is a radial gap between arc due to elliptical tool path and chord due to linear interpolation. The shape accuracy of curved geometry depends on the magnitude of these chord heights. Lesser the chord height better would be shape accuracy. The chord height can be minimized by selecting cutter location (CL) points nearer. This will lead to larger number of cutter location (CL) points. Further, every cutter location points (CL) will add the processing time. However, it is desirable to position cutter location (CL) points as near as possible to reduce chord height. Numbers of different research have proposed various approaches to minimize shape error. One of the approaches is to minimize the difference between arc length and chord length for the fixed angular position, by reducing the chord height (LM, PQ, ST…) close to zero. The arc length and the chord length must be same. It means length of $\overline{AA'}$ is to be a length of $\widehat{AA'}$. Same way, the length of $\overline{A'A''}$ should be same as length of $\widehat{A'A''}$. To reduce the difference between arc length and chord