Optimal control of CNC machining tool movement

Ning Dong[1, a], Hang Meng[2, b]

[1]School of Energy Power and Mechanical Engineering,North China Electric Power University,Baoding 071000,China;

[2]School of Energy Power and Mechanical Engineering,North China Electric Power University,Baoding 071000,China;

[a]2991415515@qq.com, [b]807055224@qq.com

Keywords: CNC machine tools, Optimal Control, S-shape acceleration and deceleration control, k-ahead Algorithm for Velocity, Multi interpolation period algorithm,simulink simulation, Time optimization.

Abstract. The CNC machining technology is of great significance to the modern manufacturing industry. In this paper, the motion of the CNC machining tool is optimized. In order to solve this problem, we divided into steps as follows: firstly, we take a look ahead velocity curve and deceleration control algorithm and interpolation algorithm based on multi cycle in speed control. The optimization model is established in which taking the establishment of the processing time as the objective function, taking the interpolation velocity as the decision variable, and satisfying the error requirements .Then, the influence of the cutting tool"s radius on the angle between the patch and the two adjacent straight line is analyzed, and the working efficiency is affected by the change of the machining time under the condition of equal arc length. Study found that the greater the radius of the arc, the smaller the curvature, and the speed is relatively high after the inflection point. In addition, considering the influence of the instantaneous starting acceleration and the instantaneous starting speed on the model, the initial velocity is not zero and the minimum speed limit exists in the whole process. Finally, we using the Simulink component of MATLAB to model the processing line for the case of line and arc, which further confirms the accuracy of our model.

Introduction

CNC machining technology as support for the key technology of modern equipment manufacturing industry, the development of aerospace, automobile and ship manufacturing industry plays a crucial role, plays a decisive role in the function and performance of the equipment manufacturing. Today, NC machining technology is moving towards high speed, high efficiency and high precision, high speed machining requirements of motion of the machine shaft can in a very short period of time to high speed running state and to achieve rapid and accurate stop. The sharp corners and high curvature of NC machining path can easily lead to over cutting, machine tool vibration and data starvation, which seriously affect the processing quality and processing speed. Research and development of CNC machining tool to meet the high speed, high accuracy requirements, effective and flexible acceleration and deceleration control method, has become the focus of modern high-performance CNC system research.

We make use of the speed ahead algorithm and the multi interpolation cycle algorithm based on the model curve plus deceleration control, and establish the real-time processing optimization control model, and analyze the optimization control problem of the NC machining tool movement.

Real time processing optimization control algorithm for machining line

Research on multi interpolation period transition algorithm. In the continuous processing line segment, corner speed and direction will change suddenly, if high speed through the corner for exceeding maximum acceleration caused by the vibration of the machine tool, if the low will reduce the processing speed. In order to improve the processing speed to meet the machining accuracy and the machine tool drive shaft maximum acceleration capability, based on the corner according to the accelerated bounded acceleration deceleration method of multiple interpolation cycle transition.

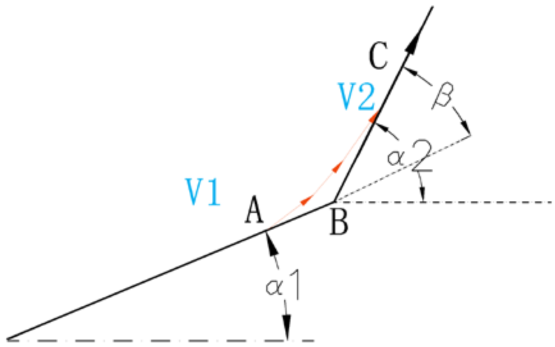

Fig. 1 Principle diagram of multiple interpolation period transition algorithm

The basic principle of S type curve plus deceleration control. The movement process can be divided into 7 sections, that is, the acceleration phase, the uniform acceleration phase, the deceleration phase, the uniform stage, the acceleration and deceleration phase, the uniform deceleration phase, the deceleration phase.

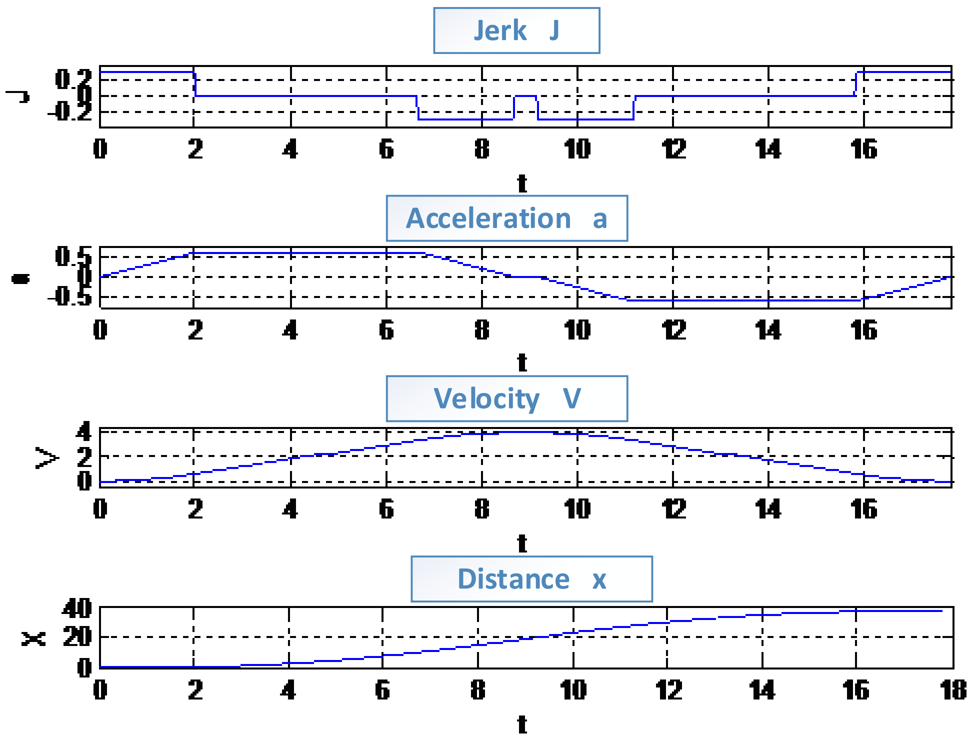

Fig. 2 Schematic diagram of S type curve plus deceleration process

Speed forward control algorithm. In the NC machining, the corner of the machining path and the high curvature arc are easy to cause the phenomenon of over cutting, the vibration of the machine tool and the data starvation, which seriously affect the machining quality and efficiency. In this paper, the CNC machining speed control algorithm is proposed, which can automatically analyze the machining path, which can effectively guarantee the higher machining efficiency and machining accuracy.

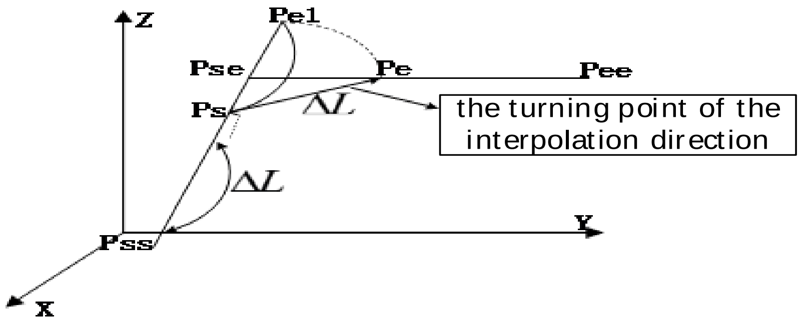

Fig. 3 Schematic diagram of speed control algorithm

In the form of interpolation operation, the distance between each step is determined according to the combination of the interpolation period and the movement speed. The prediction and processing method of the turning point can ensure the speed can not fluctuate, make it smooth change, improve the actual running speed and the efficiency of the process.

Optimal control model for real time processing. In other conditions and requirements of error control, based on the processing time as objective function optimization:

$$\min t = \sum_{i=1}^{n} \left(\frac{\left\lceil \frac{l_i}{\rho} \right\rceil - S_{(i)}}{V\max(i)} + t_{7d(i)} \right) + \sum_{j=1}^{n-1} \frac{\varepsilon}{V_{g(j,j+1)}} \tag{1}$$

Constraint conditions of objective function:

$$s.t.\begin{cases} V\max(i) \le V\max \\ V\max(i) \ge 0 \\ V_{g(j,j+1)} \le \dfrac{a_{\max}T}{2\sin(|\alpha_j/2|)} \\ \max\left\{\sqrt{(f(i1)-g(i1))^2+(f(i2)-g(i2))^2+(f(i3)-g(i3))^2}\right\} \le \varepsilon \\ S_{(i)} \le \left\lceil \dfrac{l_i}{\rho} \right\rceil \\ t_{7d(i)} = \sum\limits_{m=1,m\ne 4}^{7} t_{m(i)} \\ \int_0^{t_{7d(i)}} V dt = S_{(i)} \end{cases} \tag{2}$$

When the motion is two dimensional, the objective function is:

$$\min t = t_{l1} + t_{l2} + t_g = \frac{\left\lceil \frac{l1}{\rho} \right\rceil - S_{(1)}}{V\max(1)} + t_{7d(1)} + \frac{\left\lceil \frac{l2}{\rho} \right\rceil - S_{(2)}}{V\max(2)} + t_{7d(2)} + \frac{\varepsilon}{V_{g(1,2)}} \tag{3}$$

According to the model, we can conclude that: the angle between the line, which is close to 180 degrees, the angle between the relative speed of the tool more quickly, when the angle is 180 degrees, two line smooth transition can be seen as a processing line, this does not need to consider the velocity sensitive point in the algorithm when the speed forward; the processing line is 90 degree line, if one line is an integer multiple of the resolution, then the theory can achieve zero error at the corner, the inflection point when the need for a shaft speed of 0, which reduced the processing efficiency, so, in the error range, you can still use the forward speed acceleration and deceleration control method to realize the inflection point of the transition to improve the processing efficiency.

Optimal control algorithm for real-time processing of machining line for linear and arc connecting

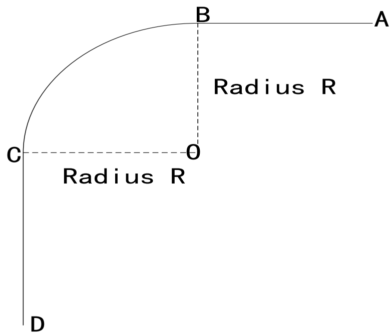

Fig. 4 Sketch map of the processing line is a circular arc

Machine tool from the B movement to the C process, the application of S type curve acceleration and deceleration control method, plus the time required to accelerate the stage, the time required: uniform phase,: the required time required to reduce the acceleration phase: the time required for the machine tool through the arc.

$$\begin{cases} T = T_1 + T_2 + T_3 \\ T_1 = \dfrac{a_m}{J_{const}} \\ V_m = \dfrac{1}{2} J T_1^2 + a_m T_2 + a_m T_3 - \dfrac{1}{2} J T_3^2 \\ R = \int_0^{T_1} \dfrac{1}{2} J t^2 dt + \dfrac{1}{2} a_m T_2^2 + \dfrac{1}{2} J T_1^2 T_2 + \int_0^{T_3} \left(\dfrac{1}{2} J T_1^2 + a_m T_2 + a_m t - \dfrac{1}{2} J t^2 \right) dt \end{cases} \tag{4}$$

When $V_{mx} = V_{my} = 0.1 m/s$, $a_{mx} = a_{my} = 0.1 m/s^2$, $J_{constx} = J_{consty} = 0.3 m/s^3$. By using MATLAB to solve the solution of nonlinear equations, the relationship between the solution and the solution is obtained:

$$r = \left(\frac{109}{2160} - \frac{1}{20} \times \sqrt{\frac{2}{3} \times \left(\frac{7}{6} - T \right)} \right)^3 - \frac{1}{10} \times \left(\frac{7}{6} - T \right) + \frac{3}{40} \times \left(\frac{7}{6} - T \right)^2 \tag{5}$$

With the increase of the radius, the processing time is increasing, but the efficiency of the investigation is under the condition of equal arc length, obviously, the greater the radius, the higher the machining efficiency of the machine tool.

Optimal control algorithm for real-time processing of machining line for linear and circular arcs (with instantaneous starting acceleration and instantaneous starting speed)

Considering the influence of the instantaneous starting acceleration and the instantaneous starting speed on the model, the motion of each axis of the machine tool is no longer from zero, and it has an initial value.

$$\begin{cases} T = T_1 + T_2 + T_3 \\ T_1 = \dfrac{a_m - a_0}{J_{const}} \\ V_m = V_0 + a_0 T_1 + \dfrac{1}{2} J T_1^2 + a_m T_2 + a_m T_3 - \dfrac{1}{2} J T_3^2 \\ R = \int_0^{T_1} \left(V_0 + a_0 t + \dfrac{1}{2} J t^2 \right) dt + \dfrac{1}{2} a_m T_2^2 + T_2 \left(V_0 + a_0 T_1 + \dfrac{1}{2} J T_1^2 \right) + \\ \int_0^{T_3} \left(V_0 + a_0 T_1 + \dfrac{1}{2} J T_1^2 + a_m T_2 + a_m t - \dfrac{1}{2} J t^2 \right) dt \end{cases} \tag{6}$$

when $a_0 = 0.02\,m/s^2$, $V_0 = 0.00216\,m/s$, V_{mx}=V_{my}=$0.1\,m/s$, a_{mx}=a_{my}=$0.1\,m/s^2$, J_{constx}=J_{consty} $= 0.3\,m/s^3$ .By using MATLAB to solve the nonlinear equations, the function relationship between R and T is obtained:

$$r = \left(\frac{40471}{800000} - \frac{3}{20} \times \sqrt{\frac{2}{3} \times \left(\frac{217}{200} - T\right)}\right)^3 + \frac{3}{50000} \times \sqrt{\frac{2}{3} \times \left(\frac{217}{200} - T\right)} + \frac{9}{80} \times \left(\frac{2}{3} \times \left(\frac{217}{200} - T\right)\right)^2 - \frac{1}{20} \times \left(\times \sqrt{\frac{2}{3} \times \left(\frac{217}{200} - T\right)}\right)^3 \quad (7)$$

S curve acceleration and deceleration control model simulation

Of CNC machine tools go knife position, designated processing line and the real trajectory of the tool error analysis and line angle analysis of the coordinate trajectory based on, the standard module of MATLAB / Simulink to build simulation model of the position controller of CNC machine tools, the simulation was chosen for numerical control machine tool position controller is used as an example for calculation, the parameters respectively: angular frequency, damping coefficient, interpolation cycle, the location of the gain. The closed loop link in the model is the position controller for tracking the input command. The model of the position controller is as follows:

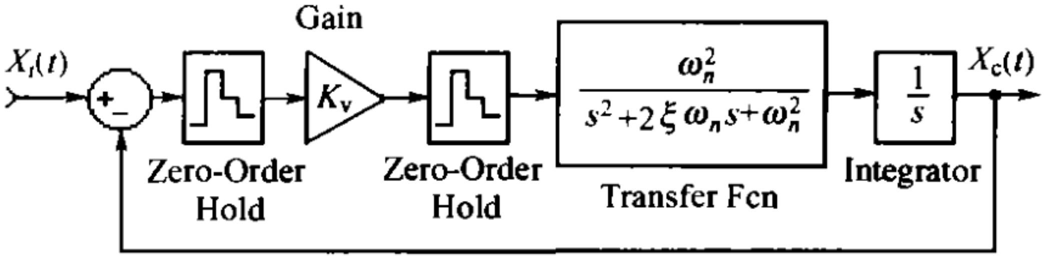

Fig. 5 X coordinate position controller

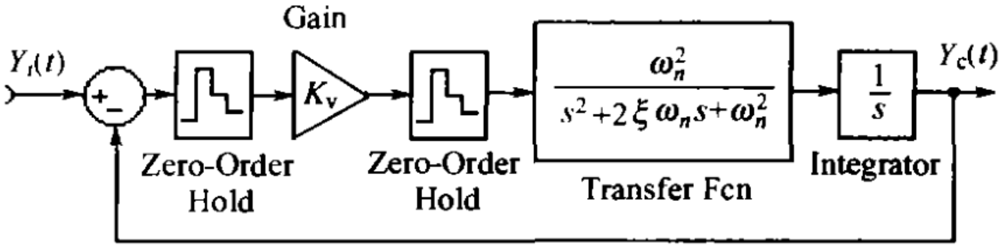

Fig. 6 Y coordinate position controller

Simulation of machining line. The instruction function of the input is shown in:

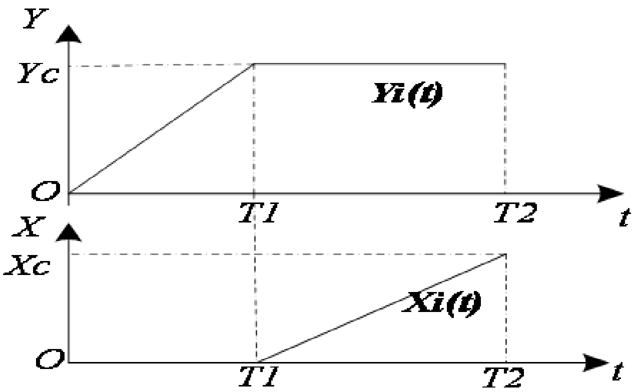

Fig. 7 The instruction function of the processing line when the line is broken

The simulation results are shown below:

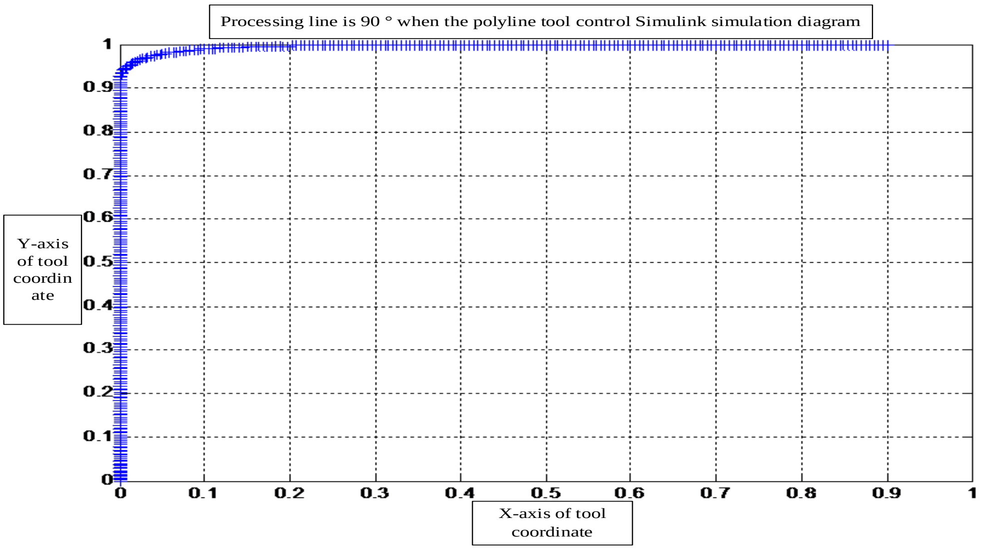

Fig. 8 Simulink simulation diagram of tool position control for machining line at 90 degree

Simulation of machining line for arc. The instruction function of the input is shown in :

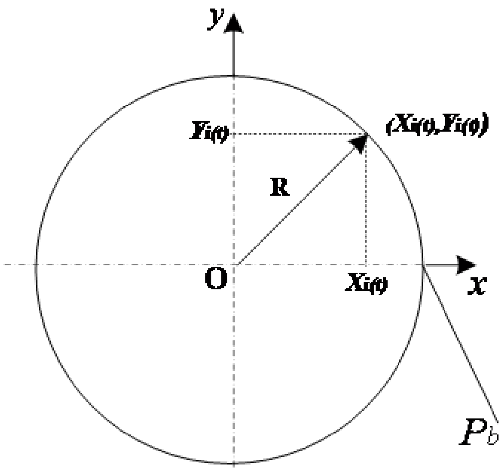

Fig. 9 The instruction function of the machining line is a circular arc

The simulation results are shown below:

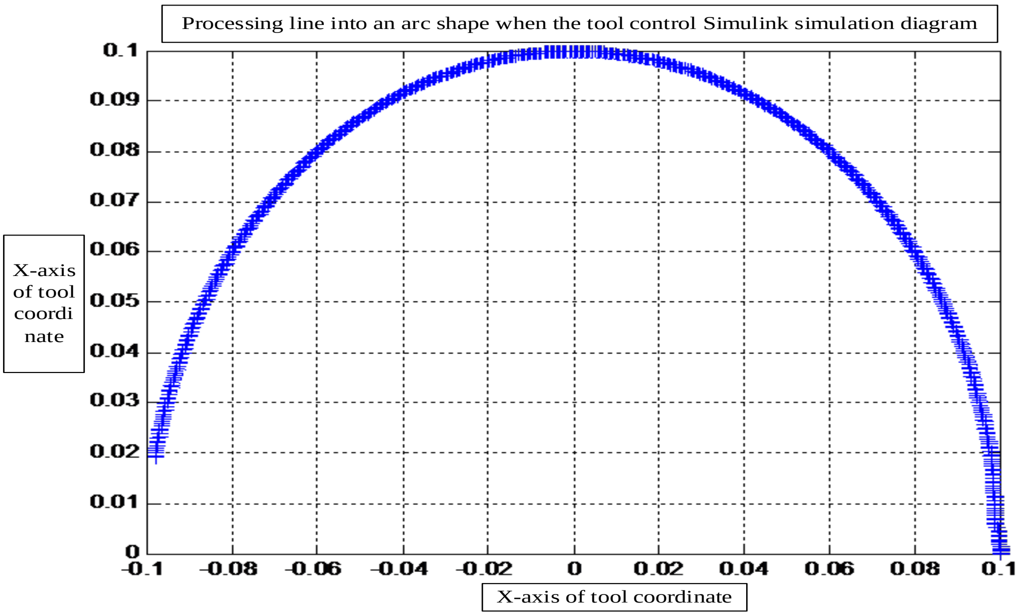

Fig. 10 Simulink simulation of tool position control for machining line

It can be found that the simulation results are consistent with the previous model, and the correctness of the model is verified by both the processing line and the arc.

Conclusion and Suggestion

Aiming at the optimization control problem of cutting tool movement in CNC machine tools, the optimization model of the processing time as the objective function and the velocity of each stage as the decision variables is presented. In the design of the algorithm, we apply speed ahead algorithm based on curve plus deceleration control, in order to study the processing line for line and curve, and the line angle and the radius of the circular arc in meeting the precision requirements on the processing rate is analyzed.

Strengths. 1.The speed ahead algorithm based on curve and deceleration control not only can prevent the vibration of the machine tool, but also can improve the machining precision effectively and prevent the phenomenon of over cutting.

2.The constraint conditions in the process of the model are fully considered, and the established model is in line with the actual situation.

3.Using Simulink to simulate the system, to verify the accuracy of the model, to further improve the credibility of the model and algorithm.

4.Fully considering the processing precision, using the multi interpolation period transition algorithm can achieve higher accuracy.

Weaknesses. 1.Although the three-dimensional model is established in this paper, the process of inspection has been used in the two-dimensional example.

2.The model we have built is not a good method to improve the stability of machine tools, which can be further studied by reading the literature.

Suggestions. Through the study of in the running process of the NC machine tool motion that conclusions are as follows: for the purpose of improving the machining accuracy, the machine"s resolution need to be further reduced, and take more reasonable algorithm, so that the tool in the turning point of the time is a flat line or arc; for the purpose of improving the processing efficiency, not only to further strengthen calculation speed sensitive points in the algorithm, but also to study machine three axis linkage technology, enables that the tool can be processed simultaneously in a multidimensional manner.

References

[1] Kun Ren. High speed machining control forward control theory and key technology research of [D]. Zhejiang University, 2008.

[2] Lixian Zhang, Hongbo Li, Xizoshan Gao, Ruiyong Sun. High speed CNC processing S type deceleration mode continuous micro line interpolation algorithm [J]. Mathematics Mechanization Research Preprints, 2010,09: 228-238.

[3] Qingjian Liu. Real time optimization and control of NC machine tool [D]. Tianjin University, 2010.

[4] Xingui Guo, Congxin Li. Research on acceleration and deceleration algorithm of S curve [J]. Machine Tool and Hydraulic, 2002,5: 60-62.

[5] Ji Xun, Weimin Ma. The dynamic path error of NC machine tools of MATLAB simulation calculation method [J]. Journal of Beijing University of Aeronautics and Astronautics, 2003,04: the 299-302.

[6] Xiaochun Wang, Wei Ye. The turning point of the high speed machining of small segment of the numerical control system [J]. Journal of Beijing Jiaotong University, 2010,34: 158-160.

[7] Wright P K, Greenfeld I, Hayes C. A prototype of a next generation-control environment:expert systems for planning and sensor integration[J]. Transaction of the North American Manufacture Research Institution, 1990:332~328.