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A new method based on improved ant colony algorithm to configure friction compensation pulse characteristic parameters

Xiaoyong Huang[a,c], Xuesong Mei[a,b,c,*], Tao Tao[a,b,c], Dongshen Zhang[a,b,c]

[a]Xi'an Jiaotong Univeristy, No.28 Xianning West Road, Xi'an 710049, P.R.China
[b]State Key Laboratory for Manufacturing Systems Engineering, No.99 Yanxiang Road, Xi'an 710049, P.R.China
[c]Shaanxi Key Laboratory of Intelligent Robots, No.28 Xianning West Road, Xi'an 710049, P.R.China

* Corresponding author. Tel.: +86-29-8266-3870; fax: +86-29-8266-8604. E-mail address: xsmei@xjtu.edu.com

Abstract

Friction is one of the disadvantages to obtain high speed and high accuracy in servo feed system. A new optimal method based on ant colony algorithm is proposed to overcome the problem of time-consuming and poor result when determining friction compensation pulse sequences parameters at reverse points in this paper. The intelligent process can be rapidly realized by evaluating fitness function, which is composed of peak and mean errors of quadrant friction errors. An improved version of roulette strategy is introduced to improve search efficiency and avoid encountering local optimization, called improved ant colony algorithm (IACO). In addition, because of its openness and universality, it is easily embedded in CNC System. The experimental result is presented to illustrate the effectiveness of this approach in suppressing mean and peak errors at the reverse point. It is shown that the improved method has advantages of strong convergence, remarkable effect and better robustness, which promotes contour accuracy around reverse points.

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Keywords: Optimization method ;Ant colony algorithm; Friction compensation.

1. Introduction

The machining accuracy is directly affected by the motion precision of the feed system. Friction errors is one of the important disadvantageous factors in the high speed and high precision servo feed system, especially in low-speed or reverse motion. However, it would take high cost to remove friction phenomenon by improving the lubrication conditions, reducing the surface roughness and modify the structural design of the tribological inhibition. Therefore, it is necessary to take other effective measures to eliminate friction effect.

The method of improving the control strategy is often used to suppress the friction error in the servo feed system with definite mechanical structure. Some Researchers have focused on improving the bandwidth of servomechanism, feed forward friction error compensation based on friction model and friction compensation with compensation pulse. In improving the bandwidth of servomechanism, friction is regarded as disturbance and which needs to be held down by advanced controller[1], disturbance observer[2] or optimizing control parameters[3]. In feed forward compensation which is based on friction model, the friction compensation will be realized by predicted compensation force base on the friction model[4]. Common friction models include Stribeck model[5] , Dahl model[6] and LuGre model[7]. It is not a good method in actual use because of the worse compensation effect caused by complexity and inaccurate friction model [8]. For the method of pulse compensation, the pulse is added to the control loop to overcome friction force. Xuesong Mei[9] effectively suppressed the friction error by the reasonable compensation pulse sequence, but it is a hard work to establish the parameters of compensation pulse. Bin Feng[10] obtained effective parameters of compensation pulse with the study of pulse parameters. However, there still exist some disadvantages, such as wide range of optimization parameters, too much learning time and so on. In the commercial CNC systems, the friction compensation parameters are usually established by engineers according to his experience, which are not so efficient.

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With the development of the optimization theory, the complex engineering problems have been transformed into parameter optimization by biological intelligent algorithm, such as genetic algorithm[11],particle swarm optimization[12] and ant colony algorithm[13]. These methods greatly simplified the problems, so they have been rapidly developed and widely used. Compared with other intelligent optimal algorithms, ant colony algorithm has many advantages such as high efficiency, low time complexity and good robustness, which attracted the attention of many scholars. Dorigo Macro[14] proposed ant colony algorithm by simulating the routing behavior of ant colony and solved the traveling salesman problem (TSP) successfully. L.M.Gambardella and M.Dorigo[15] introduced the global and local pheromone updating strategy in their Ant-Q algorithm; Stuzle and Hoss[16] proposed the MAX-MIN Ant System (MMAS), which avoided premature stagnation and local optimality by setting the upper and lower limits for pheromone; Bullnheimer[17] designed the rank-based version of ant system in which the weight, in inverse proportion of the path's length, was updated after each iteration, which made the search behavior of ants more concentrated in the optimal solution.

To solve the problems of determining characteristic parameters with long adjustment time and poor compensation effect, a novel characteristic parameters self-tuning strategy based on ant colony algorithm is proposed in this paper. The experimental results show that using this method can realize the friction compensation effectively.

2. Analysis of Friction Errors and Friction Compensation

2.1. Analysis of Friction Errors

To study the dynamic features of servo feed system at reversing position, the open CNC system is established in this paper, and its dynamic model is shown in Fig. 1. X_r and X_l are command position and actual position, respectively. K_{fv} is the gain of velocity feedforward. K_p is the gain of position loop. K_{vp} and K_{vi} are proportional and integral gain of velocity loop. K_t is the constant of motor torque. J and B are inertia and damping of mechanical system, respectively. r_g is the drive ratio and T_f is the friction force. Fig. 2 shows the dynamic reverse motion process of servo feed system with the feed rate F = 1m·min^{-1} and the radius R = 25 mm. The whole process of dynamic motion is introduced as follows. When the worktable is close to the reverse point, the speed of worktable would gradually decline from V to zero while friction force T_f increases rapidly. When the driving force is not enough to overcome the maximum static friction T_f^{max}, the worktable would stop moving and enter the stop phase. During the stop phase, X_l and θ_l are constant and control system which be regarded as open loop at the position of the quadrant. Moreover, position command X_r and position error E_{rr} would be increased .The driving torque T_m would also increase but yet less than the maximum static friction T_f^{max}. The worktable will produce a slight pre-slide. The worktable begins to move when the error E_{rr} accumulating gradually as the driving force T_m reaching the maximum static friction T_f^{max} . Due to the dynamic friction and static friction have the large difference and the friction T_f decreases sharply. As a result, the resultant

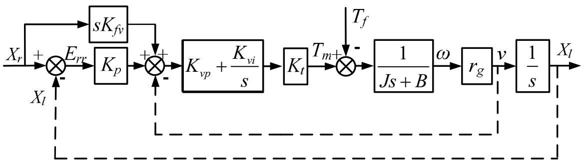

Fig. 1. The modelling of servo feed system.

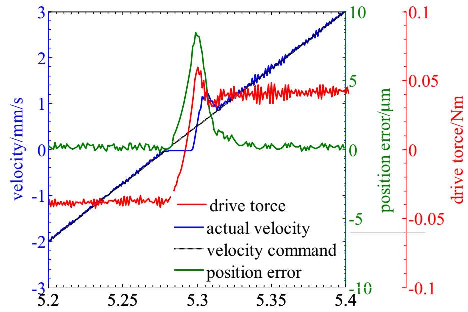

Fig. 2. Dynamic reverse motion process of servo feed system.

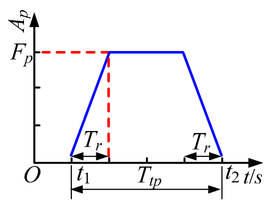

Fig. 3. Trapezoidal compensation pulse.

force of the driving force and friction on the mechanical system increases rapidly, and the speed V_l of the mechanical system also increases rapidly. Because the speed of the worktable is lower than command speed which is shown as $|V_l|<|V_r|$ in the initial separation phase, the position error E_{rr} increases and the mechanical system moves faster and faster. At the moment 5.307s, when the friction error E_{rr} reaches the peak value E_p and the actual speed V_l is equal to command speed V_r. Subsequently, the mechanical system enters the adjustment phase. In this stage, the followed error E_{rr} begins to decrease with the fluctuations of driving torque T_m and the table speed V_l . Finally, the error is adjusted to the normal rang and the motion state returns to normal movement.

2.2. Friction Compensation Pulse

It will limit the compensation effect since the bandwidth of the position loop is relatively low, and it also causes impact on inappropriately compensation pulse in current loop. However, the speed loop has the characteristics of good openness and high bandwidth. Therefore, the compensation pulse is added to the speed loop in this paper. Compared with the traditional rectangular pulse sequence, the change of trapezoidal pulse sequence is more smooth in rising and falling phases. It has less impact and better compensation effect. The friction compensation pulse A_p can be expressed as: