Vibration Torque Measurement and Mechanism Analysis of Rotary Stepping Motor

Hao Zhao[1]
Jiaxing University, Jiaxing Zhejiang China 314001

E-mail: zhaohao204@163.com

Abstract. Vibration torque are existence obviously during operation of stepping motor, it is a periodic structure vibration problem. In this paper, the actual vibration torque testing of stepper motor is executed through a self-made vibration torque sensor, the experimental results show that the stepping motor vibration torque of single three shot operation is more bigger than the six shot, and obvious reply oscillation existence in two operations; sharp vibration torque is generated on low frequency lost step oscillation; Last, the generation of these experimental phenomena are analyzed, it can provide a certain reference for controller or control algorithm designation of stepper motor.

1. Introduction

Stepper motor is a kind of micro motor which convert electric pulse into angular displacement or line displacement, its angular displacement is proportional to the number of pulses and has no relation to voltage or out condition in the load capacity scope, and it is used mainly as the implementation components in the open-loop control system, such as printers, NC machine tools, robots and other places where needs to be located accurately [1-4]. But the stepper motor exist obvious oscillation in operation process, it is manifested as the motor speed fluctuation (resonance or jitter), even cause displacement and vibration on extremely cases, and it is the main factors for step motor speed stability, because the torque angle characteristic of stepper motor is nearly sine function, and the magnetic field of the stator turning as jumping.

In recent years, the torque fluctuation or speed fluctuation of stepper motor is studied by some experts and scholars. According to the starting out-of-step and mechanical impact of stroke termination effectively on linear stepper motor, a control system based on DSP2407 was proposed by HongMin Zheng [5]; A new type of stepper motor controller is designed by Bo Qu [6], the performance of the microprocessor STM32F103RBT6 and the driving principle of stepper motor driver chip L6208 are analyzed; To solve the problems existed in traditional stepper speed control algorithm, a novel algorithm based on space control instead of time control was introduced by Baoshan You [7]; The measurement of the stepper motor rotation stability by optical encoder and its evaluation criterion were presented by Pan Jin-yu [8], it is based on the analysis of effect for rotation performance of stepping motor in low-speed scan. Based on repetitive control of time-varying periodic signals, a new method of restraining toque ripple for 5-phase hybrid stepping motor system is proposed [9], and the principle of torque ripple is analyzed.

In this paper, a self-made vibration torque sensor is used for measuring the stepper motor torque fluctuation [10]. The sensor is able to detect instantaneous torque fluctuation relative to the grating and photoelectric encoder method in the reference. Last, the experimental results are analyzed and studied, it can provide a certain reference for controller or algorithm designation of stepping motor.

2. Experimental results and mechanism Analysis

The experimental platform is made by fangyuan industrial technology co.LTD. of zhejiang university, its type is *NMCL–II*, stepping motor model is *M*10, the DC resistance of each phase windings are

---

[1] To whom any correspondence should be addressed.

45 Ω, and the supporting drive power type is *NMEL*–10.

2.1. Experiment 1

Stepping motor and homemade vibration torque sensor are connected coaxially, three phase three clap and six clap of single step operation without load, the vibration torque of motor are shown in figures 1 and 2 respectively.

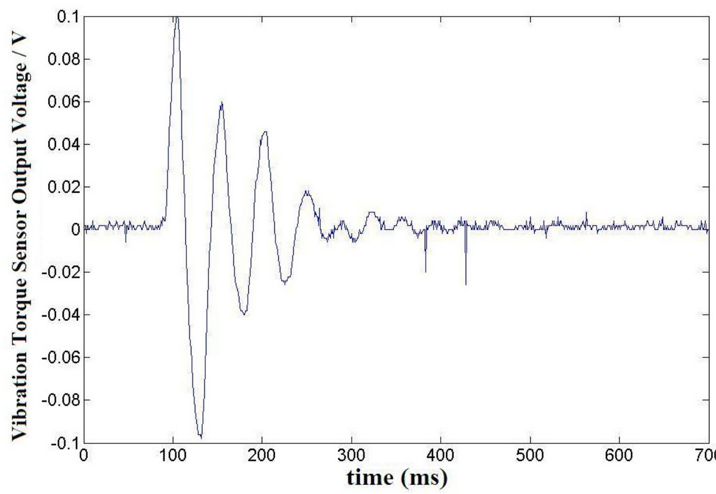

Figure 1. Vibration torque on three phases single three clap.

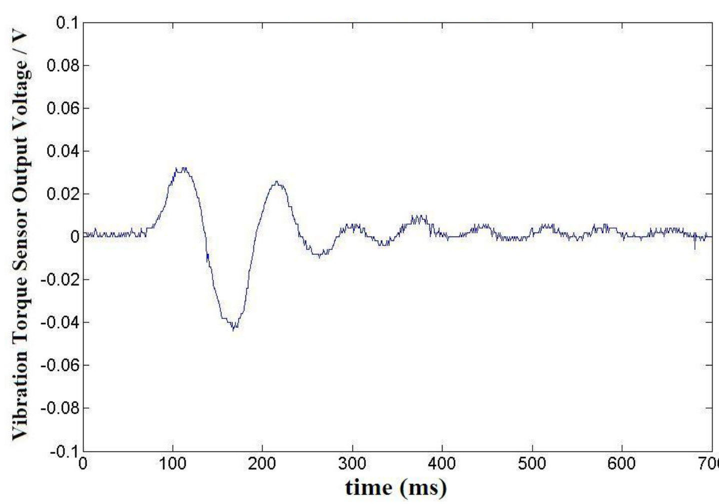

Figure 2. Vibration torque on three phases six clap.

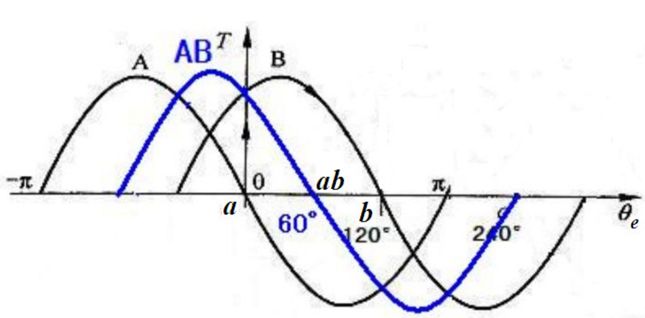

Figure 3. Torque angle characteristic of stepping motor.

From the experimental results, the vibration torque amplitude of stepper motor operation in three-phase three beat is greater than six beat, the reasons are shown in figure 3.

In figure 3, sine wave A is the torque angle characteristic of stepping motor when A phase windings going through DC current; sine wave B is the torque angle characteristic of stepping motor when B phase windings going through DC current; sine wave AB is the torque angle characteristic of stepping motor when A phase windings and B phase windings going through DC current at the same time; then:

$$\begin{cases} T_A = -T_{\max}\sin\theta_e \\ T_B = -T_{\max}\sin(\theta_e - 120) \\ T_{AB} = -T_{\max}\sin(\theta_e - 60) \end{cases} \tag{1}$$

Energizing sequence for stepping motor working on single three clap is $A \rightarrow B$; and six clap is $A \rightarrow AB$. The staring position is a, which is the balance position of angle characteristic A, and this time $\theta_e = 0$; if B phase windings going through DC current, the angle characteristic change into B instantaneously, and the static torque is:

$$T_B = -T_{\max}\times\sin(-120) = T_{\max}\frac{\sqrt{3}}{2} \tag{2}$$

If A and B phase windings going through DC current simultaneously, the angle characteristic change into AB instantaneously, and the static torque is:

$$T_{AB} = -T_{\max}\times\sin(-60) = T_{\max}\frac{\sqrt{3}}{2} \tag{3}$$

Therefore, if stepping motor operation on single step, the torque fluctuation amplitude of three clap and six clap are same in theoretically when take changing electric pulses, but due to the rotor must be turning and then the sensor output signals, it is namely the stepping motor rotor has turned certain angles, As shown in figure 3, it is known that the static torque of three clap is bigger than six clap, then leading to the large vibration torque.

In addition, when the stepper motor operating on no-load, as shown in figure 3, the acceleration interval of three clap is 120 electrical degrees, and the acceleration is increased firstly and then decreased; the acceleration interval of six clap is 120 electrical degrees, and the acceleration is always decreased.

The rotor is effected not only by the static torque, but also by the air friction resistance torque and bearing friction resistance torque during actual operation, so the acceleration interval is less than the theoretical value, and we still know that acceleration interval of three clap is greater than six clap. So, the rotor speed at balance position b of three clap operation is greater than at the balance position ab of six clap operation. Due to the inertia, the rotor is not stop immediately when reaches the equilibrium position, and its rotation direction will away from the equilibrium position, which is similar to the pendulum motion process. The function of static torque is drive the rotor to return the balance position, so stepping motor rotor will produce reciprocating motion, and the six clap operation will generate obvious reciprocating oscillation than three clap operation.

2.2. Experiment 2

Stepping motor and homemade vibration torque sensor are connected coaxially , three claps of single step operation without load, and the frequency of pluses are about 170Hz, the vibration torque is shown in figure 4.

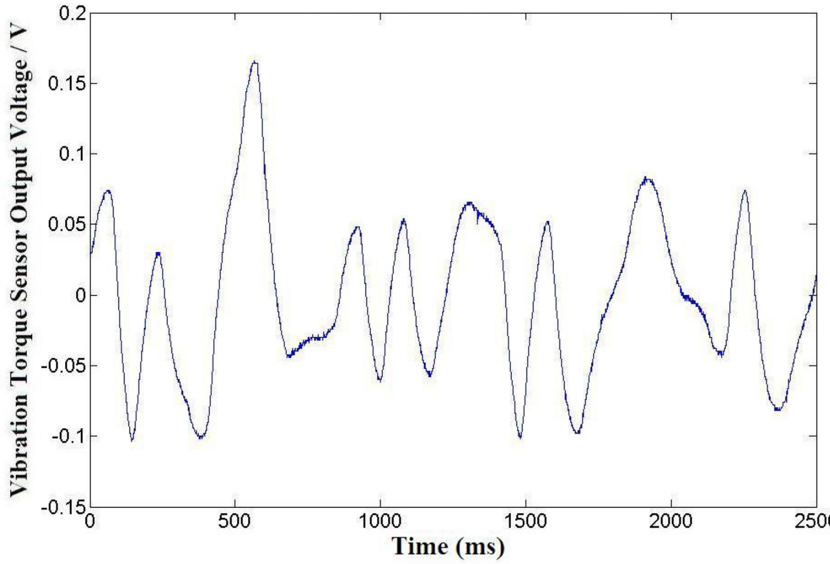

Figure 4. Vibration torque on low frequency oscillation of lost step.

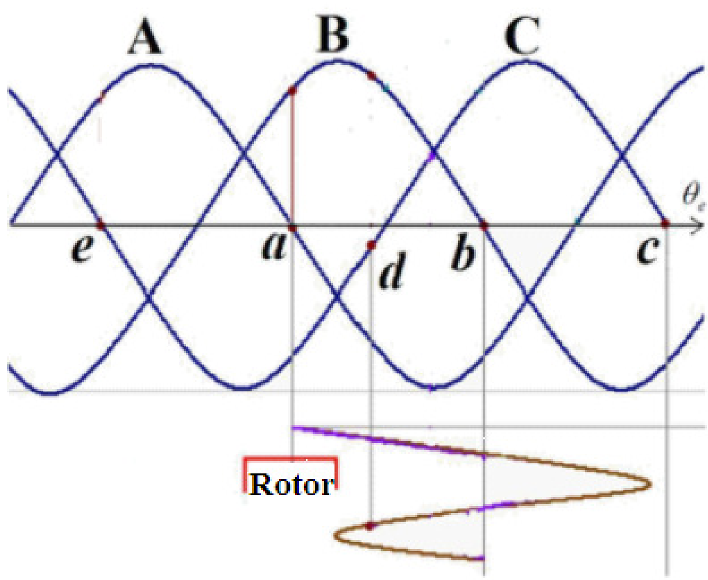

Figure 5. Principle analysis of low frequency lost step oscillation.

The reason of stepper motor lost steps is shown in figure 5, the stepper motor rotor is located in the equilibrium position a when the A phase windings going through DC current, then the A phase windings power cut off and B phase windings power turn on, the rotor is turning to balance position b under the affection of static torque, and it is an accelerated state in the process; when the rotor reaches balance position b, a reply oscillation will be generated on the rotor due to the inertia; if the rotor is at the position d, then B phase windings power cut off and C phase windings power turn on, the rotor is subjected to static torque which direction is negative as shown in figure 5, and the speed at the same direction, so the rotor is to acceleration at negative direction, which causes the stepping motor generates lost step; and according to the graph 5, there is a static torque jump at position d ,which changes static torque positive into negative, and it is always negative in the location process $d \to e$; if the A phase windings going through DC current at this process, there will generate another static torque jump, which driving the static torque from negative to positive; and the stepper motor is generated intense torque fluctuation if this processes are repeat.

3. Conclusion

The torque fluctuations of stepper motor were tested, including single-step operation and low frequency lost step operation, the test results are analyzed, and the corresponding conclusion are received. In order to reduce the torque fluctuation of motor on the practical operation, the following work and research is to design a new step motor controller, which controls the winding current input according to the torque fluctuations, it can improve the performance and extend the application range of stepping motor.

Acknowledgment

The work was sponsored by in part by the Jiaxing Science and Technology Research Project of China under Grant (2012AY1021) and in part by the Zhejiang Provincial Department of Education Scientific Research Project of China under Grant (Y201226082).

References

[1] P Krishnamurthy and F Khorrami 2008 TriM: An Ultra-Accurate High-Speed Six Degree of Freedom Manipulator Using Planar Stepper Motors *Journal of Intelligent and Robotic Systems* **51(2)** 137–57

[2] Maki K Rashid and Zahi A Khalil 2004 Configuration Design and Intelligent Stepping of a Spherical Motor in Robotic Joint *Journal of Intelligent and Robotic Systems* **40(2)** 165–81

[3] P Melin and O Castillo 2004 Intelligent control of a stepping motor drive using a hybrid neuro-fuzzy approach *Soft Computing* **8(8)** 546–55

[4] Tomoaki Yano 2010 Simulation results of a hexahedron octahedron based spherical stepping motor *Journal of Mechanical Science and Technology* **24(1)** 33–6

[5] HongMin Zheng and WenFeng Cui 2012 Design of Controlling System for Linear Stepper Motor Based on DSP2407. Advances in Electronic Commerce *Web Application and Communication Advances in Intelligent and Soft Computing* **149** 335–41

[6] Bo Qu and Hong Lin 2011 Design of the Stepper Motor Controller. Electronics and Signal Processing *Lecture Notes in Electrical Engineering* **97** 525–31

[7] Baoshan You and Liying Pei 2011 A Novel Stepper Speed Control Algorithm Based on FPGA. Advances in Computer Science and Education Applications *Communications in Computer and Information Science* **202** 205–9

[8] Pan Jin-yu 2005 Analysis and Determination of Stepping Motor Rotation Stability *Aerospace Shanghai* **22(5)** 54–7

[9] Sun Yao-jie, Zuo He and Kang Long-yun 2004 Time-Varying Repetitive Control of Restraining Torque Ripple for Hybrid Stepping Motor System *Proceedings of me CSEE* **24(11)** 183–7

[10] Zhao Hao, Feng Hao 2012 Research of a New Permanent Magnet Angular Acceleration Sensor Based on Electromagnetic Induction *Chinese Journal of Sensors and Actuators* **25(9)** 1257–61