Design of Motor Starting Device Based on Principle of Winder Energy Storage

Yan Lu Zishun Wang Luzhou Shentu Weigang Zheng*

School of Mechanical and Electrical Engineering, Wuhan University of Technology
zfeidiao@126.com

Abstract. In order to solve the problems of short service life, high energy consumption, and low efficiency of small and medium-sized motors due to the continuous heating by frequent start-stop, we designed a motor starting device based on the principle of winding springs to assist motor starting. The device uses a clockwork to recover the remaining kinetic energy after the motor is de-energized. When the motor is started again, the clockwork releases the elastic potential energy driving the motor to rotate to a certain speed, and then turns on the motor power, this can achieve the purpose of “current reduction and torque protection”. The device has the advantages of high energy conversion efficiency and low cost, can be used without changing the overall layout of the original equipment and does not affect the normal operation of the motor, and is easy to promote.

1. Introduction

As a power source for various electromechanical devices, motors have been widely used in various industries, among which the use of small and medium-sized AC motors dominates. The volume of AC motor market growth is alarming. In actual production, in many cases, it is required that the motor should be frequently started and braked. This would cause serious energy waste for ordinary motors. When the motor is frequently started, excessive starting current will cause the motor to continue to heat up, reducing the production efficiency as well as the number of times that the motor is allowed to start and stop. At present, the common motor starting modes are divided into three types: full-voltage start, step-down start, and soft start. The advantages and disadvantages are compared as follows:

| Motor starting mode | Advantages | Disadvantages |
|---------------------|------------|---------------|
| Full-voltage startup | Simple and low-cost | Large start-up current, many influencing factors and restrictions, no recovery. |
| Step-down startup | Small start-up current and small starting torque | Only be used to connect the motor with Δ, can not start with the load or recover excess energy. |
| Soft start | Small start-up current and small impact on the grid | No energy recovery, long startup time and high cost, can not be started frequently. |

To solve the problems above, we design a motor starting device based on the principle of winder energy storage. Compared with the existed motor starting mode, this device has the following advantages: 1. No complicated starting and braking circuits; 2. Using the clockwork to store the remaining kinetic energy of the motor with high energy storage efficiency and long storage time; 3. Use
the remaining kinetic energy stored in the clockwork to start the motor, obtaining a certain initial rotation speed as well as reducing the starting current.

2. The design

2.1. Device operating principle
Curves in Fig. 1 is based on the relationship between the motor rotor current $I_2$ and the slip rate $S$.

$$I_2 = \frac{E_2}{\sqrt{R_2^2 + X_2^2}} = \frac{SE_{so}}{\sqrt{R_2^2 + (SX_{so})^2}}$$

When the motor starts, the slip rate is at the maximum and the rotor current is at the maximum. As the speed of motor increases, the relative speed between the rotor and the rotating magnetic field decreases, the rotor's induced electromotive force decreases, and the rotor current also decreases. Based on the principle above, the device uses a spring to store the remaining kinetic energy when the motor is de-energized, and releases it when the motor is started again, and provides an initial rotation speed at a certain range for the motor rotor, so that the motor slip can decrease from a relatively smaller value reducing the motor starting current and the heat loss of the motor.

![Fig. 1](image)

2.2. Structural design
The structure design of the device is worthy of attention for the following four aspects: 1. Do not change the overall layout of the original equipment or affect the normal operation of the motor; 2. The device can be perfectly installed on the transmission mechanism of the original equipment; 3. Do not interfere with the mechanism of the original equipment; 4. While achieving the recovery and control of the braking energy, the number of transmission stages should be reduced as much as possible, thereby reducing the energy loss caused by gear friction. The device is divided into an energy release module and an energy storage module according to its functions. The overall device diagram is shown in Figure 2.

![Fig. 2 Overall diagram of the device](image)

The working process of this device is divided into energy release process and energy storage process. The schematic diagram of the organization is shown in Figure 2 left. In the energy release process, the motor power is turned on, and the MCU controls 9 to release 10 while the control 5 is closed. In 10, the
spring releases the stored elastic potential energy, driving 13 to rotate, and transmits the power to 2 by 4 to drive the motor to a certain rotation speed. After the energy is released, 5 is disconnected, 9 is used to lock 10 shell, and then the motor starts. In the energy storage process, the power of the motor is turned off, the MCU control 17 is closed to transmit the remaining kinetic energy of the motor to 15 by 18, making itself stored in 11 through the process of driving the spring in 11. In the energy storage process, 9 is in the locked state; after the energy storage is completed, under the effect of 16, 11 will not release energy by itself.

2.3. Energy storage unit design
The energy storage unit (characteristics shown in Fig.3-c) is mainly composed of a spring and a shell. The device uses the Fig.3-a method to connect the inner ring of the spring and the mandrel. The device uses the Fig.3-b method to connect the outer barrel of the mainspring with the outer shell of the spring energy storage unit. For the fixing of the shell, it is screwed to the transmission mechanism to facilitate the energy storage and release process of the device.

![Spring fixing method](image)

2.4. Control part design
The overall control system of the device is shown in Figure 4-a below. The STC12 MCU is used as the control core. After the MCU receives the input signal from the button and the rotation speed measurement module, the signal of the control relay module is output through its internal clock and interrupt process in order to control the opening and closing of electromagnetic clutch as well as the motor power supply. This cooperates with the mechanical transmission part to facilitate the recovery and utilization of the remaining kinetic energy of the motor, achieving the purpose of reducing the starting current of the motor.

| parameter | parameter | Clockwork thickness h/mm | Clockwork Width b/mm | Clockwork length L/mm | Clockwork elastic Modulus E/GPa | Clockwork tensile strength σ/MPa | Mandrel diameter d₁/mm | Shell inner diameter d₂/mm |
|-----------|-----------|-------------------------|---------------------|----------------------|---------------------------------|---------------------------------|------------------------|--------------------|
| Value     | value     | 1                       | 16                  | 1800                 | 206                             | 1573                            | 15                     | 71                 |
| parameter | parameter | Clockwork coils in the free state r₀/r | Clockwork coils in the fully tight state r₁/r | Clockwork Effective coils Δr/r | effective coefficient | Mandrel angular speed ω (r/min) | Fixed coefficient between Clockwork and shell |
| Value     | value     | 10                      | 15                  | 5                    | 1/3                             | 1400                            | 0.9                   |
The control part of the hardware circuit is shown in Figure 4. The device uses AC-DC module to convert 220V AC power to 24V DC output to supply for electromagnetic clutch. Taking into account that if the 24V voltage is directly transferred to the 5V output power supply for the MCU, the aging of components will be accelerated due to the heat caused by varied voltage difference, so hierarchical buck mode is used to reduce the circuit heat. In addition, fuses are added to prevent safety accidents caused by excessive current in the circuit.

3. Performance test and experimental verification

We selected the motor of the industrial washing machine as the experimental object for its characteristic of starting and stopping frequency to detect the effect of the device. Through analysis and comparison, combined with the actual situation, the device used XGQ-20 model industrial washing machine as the experimental object. Its motor rated power is 2.2kw, rated capacity is 20kg, starting and stopping times is 8 times / min, experimental platform is shown in Figure 5. In order to make the experimental data closer to the real situation, we select the single-phase asynchronous motor model YL90-4 as the experimental object to study the starting current, rotation speed and heat generation of the motor. The rated power of the motor is 2.2kw and the rated rotation speed is 1430r / min. The experimental results are as follows:

3.1. Motor start-up current comparison experiment

In order to verify the influence of the device on the motor start-up current, an AC mutual inductor is used to measure the no-load start-up current of the YL90-4 single-phase asynchronous motor with or without the installation of this device.

![Fig. 5 Device experimental platform](image)

![Fig. 6 Starting current comparison chart](image)

The drawing based on the measured data from multiple experiments is shown in Figure 6. The red and blue curves are the starting current change curves of the motor with or without the installation of the starting device. In the drawing, the maximum starting current of the motor without the starting device is 64.4A, which is much larger than the current during normal operation of the motor. After the device is set, the maximum starting current of the motor is 53.2A, and the starting current is obviously reduced. It can be seen that the starting device can significantly reduce the starting current of the motor.

3.2. the Start speed measurement experiment

The initial speed provided by the device when the motor is started is also an important indicator to measure the performance of the device. We use the Omron E6A2-CW3C encoder to detect the initial speed provided by the starting device with the motor. To make the data more reliable, a total of 10 times measurement are performed, we take the average from the data without the maximum or minimum
values. The initial rotation speed of the motor spindle driven by the starting device during the energy release process was 247 r/min. The experimental data is shown in Table 3:

Table 3. The device provides the maximum speed

| Experiment times | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|------------------|---|---|---|---|---|---|---|---|---|----|
| Speed r/min      | 235 | 262 | 253 | 241 | 238 | 221 | 268 | 221 | 260 | 273 |

4. The theoretical calculation of saving electricity

Clockwork torque formula\(^6\): \(M_{\text{max}} = \frac{bh^2}{6}k\sigma_P\times\frac{16\times\pi^2}{6}\times 180 = 4.7\text{N\cdot m}

(When the pin is fixed: \(k\sigma_P=180\text{kg/mm}^2\))

The changing rate of torque formula: \(B = \frac{\pi}{\sigma_P} = \frac{\pi\times4.6}{1750} \times 100 = 0.82

(Silicon-manganese spring: \(\sigma_P=90-110\))

\(M_{\text{min}} = M_{\text{max}} - BM_{\text{max}} = 4.7-0.82 \times 4.7=1.3\text{N\cdot m}

Output work formula: \(W = M\varphi = \frac{4.7+1.3}{2} \times 5 \times 2\pi = 197.4\text{J}

From the mechanical design manual: The efficiency of deep groove ball bearing mechanical is 0.99. The efficiency of 7-level precision gear mechanical is 0.98. \(^7\) Combined with the mechanical structure shown in Figure 2, it can be calculated that the energy release transmission efficiency of the device is 0.895 and the energy storage transmission efficiency is 0.90. Therefore, the energy released by the energy storage unit is up to 176.7J at once.

5. Conclusion

We conduct a performance test of the finished prototype and find that the maximum starting current of the motor can be considerably reduced by 11.1A to 82.6% of the original starting current. Meanwhile the device can reduce the heat loss in the starting process of the machine by providing it with an initial 247r/min rotational speed. The feasibility of the application of the device is mainly presented in the following aspects: 1. In principle: the design of the device makes use of the starting principle of the AC motor; according to the principle of machinery, the winder owns the advantages of easily use, low price and high energy recovery rate, and high security and small size; 2. Process: all parts of this device are standard parts, which can be manufactured by ordinary lathes and related tools; 3. Economically: The materials needed for this device are available in the market with affordable prices. Therefore, advocating the use of this motor-based starter device based on the principle of winding energy storage is of great significance for energy conservation and emission reduction.

References

[1] Cao Limin. Analysis of economic operation of small and medium-sized motor industry in 2015 and strategic focus in 2016 [J]. Electrical Appliance Industry, 2016, 09:1-4.
[2] Deng Xingzhong, Zhou Zude, Deng Jian, and Feng Qingxiu. Electromechanical Transmission Control (Fourth Edition) [M]. Wuhan: Huazhong University of Science and Technology Press, 2007:51-55.
[3] Lei Shaochong. Testing and analysis of motor starting current [J]. Small and Medium-sized Electric Machines, 2001, 28(01): 53-54.
[4] Xu Yikun. Optimum design and grid-connected control of energy storage box of permanent magnet motor type mechanical elastic energy storage unit [D]. Beijing: North China Electric Power University, 2015:12-15.
[5] Yang Yizhou, You Wenming, Gao Yan. Research on Life Prediction Method of Class B Insulated
Spindle Motor [J]. Coal Mining Machinery, 2016, 37(01): 201-202.

[6] Fu Xionggang. Design and Calculation of Meter Clocking [J]. Instrument Manufacturing, 1978, 03: 24-26.

[7] Cheng Daxian. Mechanical Design Manual (Fifth Edition) Volume II and III [M]. Beijing: Mechanical Industry Press, 2010.