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Single Phase Induction Motor Speed Regulation Using a PID Controller for Rotary Forcespinning Apparatus

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Abstract

Rotary forcespinning (RFS) is a simple method of fabricating fibers with a high production rate and low production cost. It can modify fibers morphology by varying polymer concentration, the solution flow rate, and the speed of induction motor. The change in the motor speed affects fibers diameter distribution. Therefore, it is necessary to implement a PID (proportional-integral-derivative) controller to maintain the stability of the speed during fibers production. A dimmer circuit to control the AC voltage supplied to the induction motor and a rotary encoder with a signal conditioner to measure the motor speed were used to regulate the motor speed. By applying the second Ziegler-Nichols tuning method, the PID controller constants, which are K_p, T_i, and T_d, were obtained; Their values were 0.001242, 5, and 1.25, respectively. From the control system responses for the set points in the range of 16,000 to 28,000 rpm, it was shown that the control system has a fast response. In addition, a maximum overshoot of 345 rpm at the set point of 24,000 rpm and a maximum steady-state error of 335 rpm at the set point of 28,000 rpm were also obtained by the control system. Under a disturbance of 5 s given to the control system, the speed could be restored back to its original state within 34 s. Therefore, the speed regulation system was regarded as a good control system.

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Keywords: speed regulation; single phase induction motor; dimmer; proportional-integral-derivative; rotary forcespinning.

1. Introduction

Rotary forcespinning (RFS), which is a relatively new method of fabricating fibers, offers a high production rate and low production cost, so that it suits for the mass production of fibers [1]. Additionally, the components of RFS method are simple and the conductivity of precursor solution does not affect the fibers formed, which are in contradiction with the electrospinning [2]. The method can manipulate the fibers morphology by varying polymer concentration, the solution flow rate, and the speed of induction motor. Besides, the polymer concentration variation can affect the diameter of fibers, while the change in the motor speed influences its diameter distribution [3].

However, because it has limited control parameters to manipulate the morphology of the fiber, there is a need to do optimization of these parameters to obtain high-quality fibers. One of the parameters that can be optimized is the induction motor speed, which can be regulated by changing the supply of AC voltage [4]. Moreover, since the fibers diameter distribution is influenced by the stability of induction motor speed, it is necessary to control the induction motor speed. Therefore, a proper control system is required to regulate the speed of the induction motor. To maintain the desired system output, the PID (proportional-integral-derivative) controller can be used [5-7].

This paper reports the design and development of a speed regulation system for a single-phase induction motor used in RFS. For regulating the AC voltage that is supplied to the induction motor, a dimmer circuit with phase-cutting method was used. The

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PID controller was employed to make the induction motor speed stable. The controller constants were determined using the second Ziegler-Nichols tuning method. The ability of the speed regulation system to maintain its speed was also tested by giving disturbance to the motor.

2. Design of Speed Regulation System

A speed regulation system that would be applied to RFS is shown in Figure 1. The system had a plant that consists of a single phase induction motor (220V, 50Hz, 350W) and a rotary encoder, which uses an optocoupler as a detector, supported by an operational amplifier LM 358-based signal conditioner. The system also has a dimmer circuit using a microcontroller (ATmega 8A, Atmel), a minimum system (Mikro AVR 8535, Creative Vision) generating PWM (pulse width modulation), a DAC (digital to analog converter) circuit using a 100kΩ resistor and 1μF capacitor, and a display (computer).

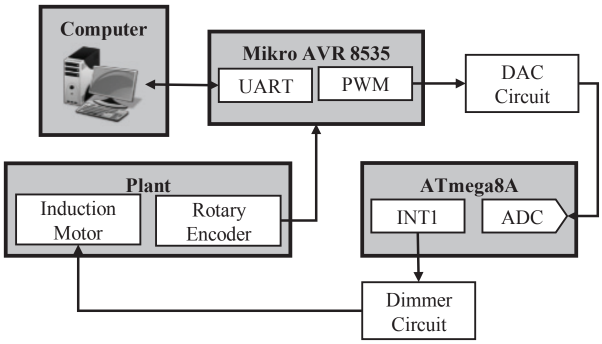


Figure 1. The block diagram of speed regulation system

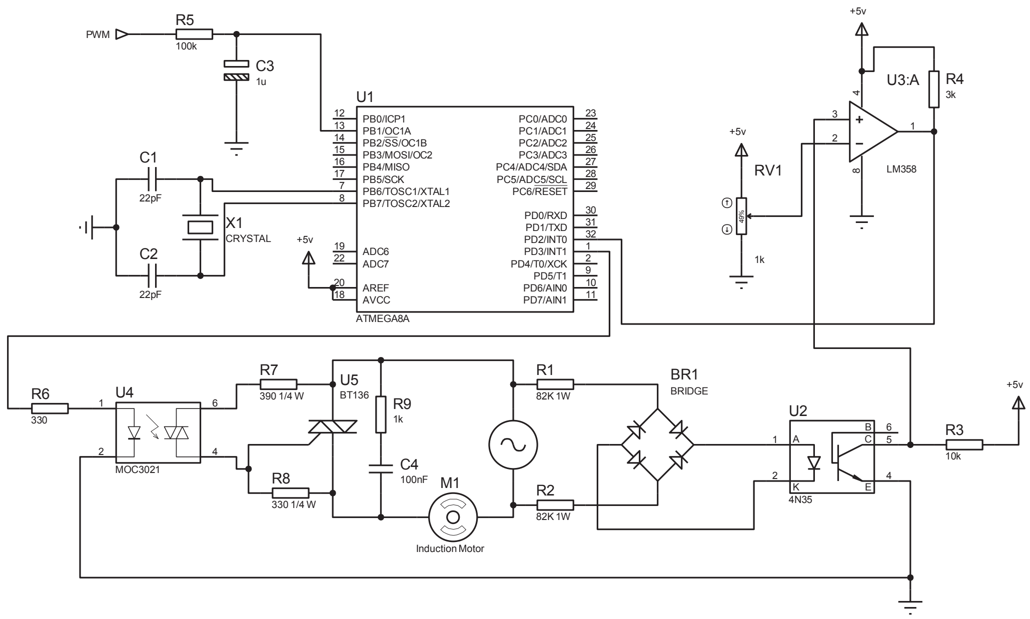


Figure 2. The dimmer circuit.

The dimmer circuit that was used in the speed regulation system is shown in Figure 2. The dimmer circuit was modified from a commonly provided circuit [8]. This circuit was used to adjust an AC voltage that is supplied to the induction motor. Its operation is as follows: the 220V AC voltage is rectified by the diode bridge (BR1) to form a full wave rectified DC voltage with a peak of 220V. The full wave rectified DC voltage is converted into 5V pulses by the 4N35 optocoupler (U2). The LM358 comparator (U3: A) is used to reduce the width of the pulses. The diode bridge (BR1) along with the 4N35 optocoupler (U2) and the LM358 comparator is called as a zero-crossing detector. A 5V pulse generated by the LM358 comparator becomes an external interrupt signal for ATmega 8A (U1) to start a phase cutting process. In the phase cutting process, MOC3021 triac driver (U4) and BT136 triac (U5) are functioned as a switch to give the AC voltage to the induction motor (M1) and control its power. To trigger the triac driver (U4), a signal from INT 1 port of the Atmega 8A is used. The snubber circuit, which consists of the 1kΩ resistor (R9) and 100nF capacitor (C4), is used to protect the triac from induction current produced by the motor. A low pass filter (LPF), which consists of the 100kΩ resistor (R5) and 1μF capacitor (C3), functions as the DAC circuit given in Figure 1.

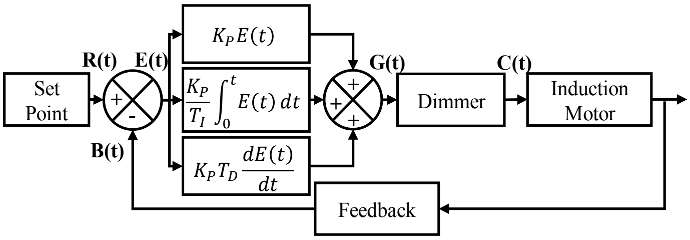
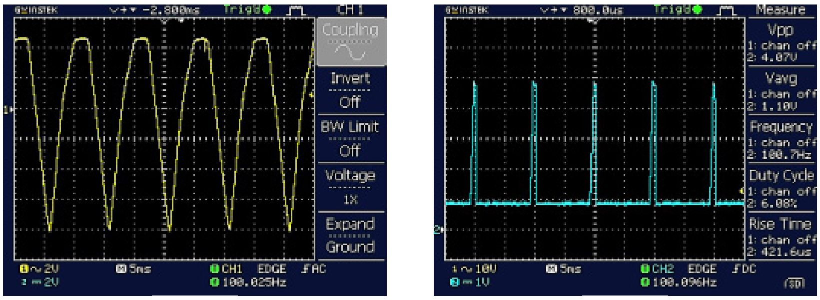


Figure 3. The block diagram of a PID controller.

A PID controller, which is applied to the speed regulation system, is illustrated in Figure 3. E(t) represents the difference between the measured speed B(t) and the desired speed R(t). G(t) represents the controller output, which is the summing result of proportional, integral and derivative control actions. The change of AC voltage from the dimmer is represented by C(t). To get controller constants used in the PID controller, the second Ziegler-Nichols tuning method was employed.

3. Testing Results and Discussion

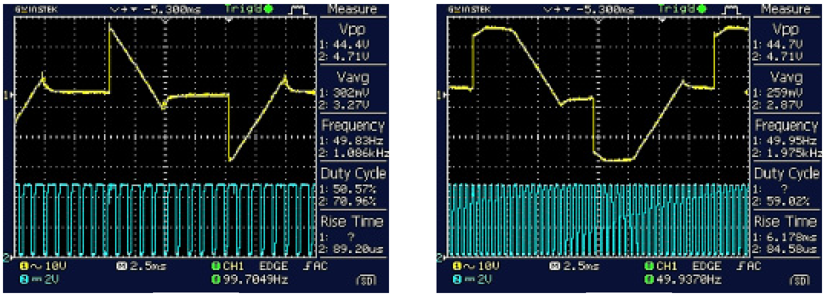
The diode bridge and zero-crossing detector were examined by supplying an AC power line with 220V voltage and 50Hz frequency. A pair of resistors R1 and R2 (see Figure 2) limits the AC power that was applied to the diode bridge. Figures 4 (a) and (b) show the outputs of the diode bridge (BR1) and the zero-crossing detector (LM358), respectively. An oscilloscope with a step-down transformer was used to reduce its peak due to safety reason for capturing the full wave rectified DC voltage given in Figure 4 (a). It is given in Figure 4 (a) that the full wave rectified DC voltage has a frequency of 100 Hz. Figure 4 (b) gives a series of pulses with a peak of 5V and a frequency of 100Hz. Therefore, Figures 4 (a) and 4 (b) has confirmed that the diode bridge and the zero-crossing detector work well as assumed.



(a) (b)

Figure 4. (a) Full wave rectified DC voltage and (b) zero-crossing pulses

The dimmer circuit and rotary encoder have been tested by varying the induction motor speed. Figure 5 (a) shows the dimmer circuit output AC voltage (yellow/upper line) and the rotary encoder output signal (blue/lower line) at a low speed. Figure 5 (b) also shows the dimmer circuit output AC voltage and rotary encoder output signal but at a high speed. The change of induction motor speed has been confirmed by the rotary encoder output signal. By comparing Figures 5 (a) and 5 (b), when the induction motor speed became greater, the frequency of rotary encoder output signal became higher and the power supplied to the induction motor increased. The difference in power at high speed and low speed is caused by the phase of AC voltage that was cut in which the cut phase at the low speed is more than that at the high speed. When the cut phase of AC voltage is more, the power supplied to the induction motor becomes less.



(a) (b)

Figure 5. Outputs of dimmer circuit (yellow/upper line) and rotary encoder (blue/lower line) at (a) a low speed and (b) a high speed.

The set point (desired speed) is determined by the computer, while the measured speed is sent to the computer. The PID controller is run to determine the AC voltage that is supplied to the induction motor according to the error, which is the difference between the set point and the measured speed. If the measured speed is lower than the set point, the cut phase of the AC voltage becomes less, and the power that is supplied to the induction motor becomes larger. While the induction motor speed increases with increasing the supplied power, the speed will be approaching the set point. When the induction motor speed has approached the set point, the power that is supplied to the motor will decrease until the induction motor speed reaches the set point. The time to reach set point, overshoot, and steady-state error in the speed adjustment are affected by the PID controller constants. The second Ziegler-Nichols tuning method was employed to obtain suitable PID controller constants.

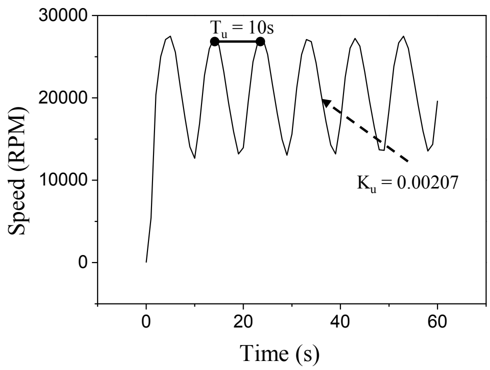


Figure 6. The system response at the value of K_p of 0.00207 that was used for tuning the PD controller.

In determining the PID controller constants, the first thing to do was to test the system response by changing the value of the proportional constant (K_p) by the trial and error method. The obtained system response must be in the form of a periodic wave as illustrated in Figure 6. The tests of the speed regulation system response were conducted by varying the values of K_p of 0.001, 0.002, 0.00205, 0.00207, 0.0021, and 0.003 at the set point of 20,000 rpm. The system response was a periodic wave at each value of K_p, but the stable periodic wave was obtained at the value of K_p of 0.00207 as shown in Figure 6. This result was used to tune the controller constants so that the control system output has small overshoot with a short time to achieve the set point. From the stable periodic wave, it was determined that the ultimate gain (K_u) was 0.00207 and the ultimate period (T_u) was 10 s. By using formulas that are given by the second Ziegler-Nichols tuning method [7], the values of PID controller constants could be obtained. Table 1 shows the obtained PID controller constants.

Table 1. The PID controller constants

Controller Constant		
K_p	T_i	T_d
0.001242	5	1.25

The obtained PID controller constants were then applied to the PID controller. The control system responses for the set points of 16,000, 20,000, 24,000, and 28,000 rpm are shown in Figure 7. It was found that the times to achieve the stability were 25, 36, 50, and 69 s with the rise times of 23, 28, 35 and 47 s, respectively. The control system also has a maximum overshoot of 345 rpm at the set point of 24,000 rpm and the steady-state error of 335 rpm at the set point of 28,000 rpm. Since they have a short time to achieve the stability, it means that the control system has a fast response and it can be regarded as a good control system [6].

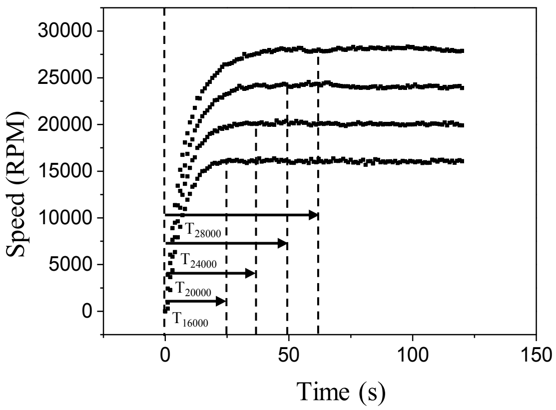


Figure 7. The control system responses for the set points of 16,000, 20,000, 24,000, and 28,000 rpm.

Figure 8 shows the speed regulation system immunity when it is given a disturbance. The control system was set at the speed of 20,000 rpm and the disturbance of 5 s was given at the time of 50 s. The induction motor speed reduces to 65% of its initial speed and it can be restored back to its original state within 34 s. Due to its fast restoration, it was proven that the control system is good.

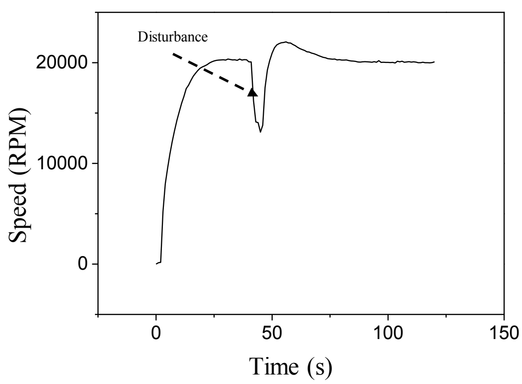


Figure 8. The control system response with a disturbance.

4. Conclusion

A speed regulation system for a single phase induction motor used in rotary forcespinning apparatus has successfully been developed. A PID (proportional-integral-derivative) controller was applied to maintain the induction motor speed at a desired value. By using the second Ziegler-Nichols tuning method, the PID controller constants (K_p, T_i, and T_d) were obtained; they are 0.001242, 5, and 1.25, respectively. The control system responses for the set points in the range of 16,000 to 28,000 rpm were observed and it was found that the control system has a fast response. Moreover, the control system also had a maximum overshoot of 345 rpm at the set point of 24,000 rpm and a maximum steady-state error of 335 rpm at the set point of 28,000 rpm. When a disturbance of 5 s was given to the control system, the speed could be restored back to its original state within 34 s. Therefore, the speed regulation system was regarded as a good control system.

Acknowledgements

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