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Simulation of AC Variable Frequency Asynchronous Electric Dynamometer System

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An AC asynchronous electric dynamometer system based on a motorcycle engine test bench to better determine the performance of the machine is studied in this paper. The constitution and control strategy of the dynamometer system are discussed. The principle of AC asynchronous electric dynamometer is described, and the conditions for stable operation of the system are discussed. A simplified mathematical model of the frequency inverter is proposed based on the analysis and establishment of the mathematical model of AC asynchronous dynamometer, and the mathematical model of the whole test system is established. The experimental results show that the control system has good performance and can meet the requirements of dynamic test and control. It is concluded that, with the AC asynchronous dynamometer system, the machine can run stable, and the cost is low.

1. Introduction

The electric dynamometer has been widely used with the application of power electronic technology, sensors, computers and control technology (Baradar and Ghandhari, 2013). Compared with other types of dynamometers, the electric dynamometer can not only achieve energy feedback, but be used as a motor to drive DUT rotate (Bilodeau et al., 2016). Early electric dynamometers are DC type, DC motors have good speed and the control technology is simple and mature. However, DC electric dynamometers are not suitable for high speed applications due to the influence of commutator. As the DUT runs at high speed, a mechanical reducer is required for the DC electric dynamometer system, complex, high noise, high friction torque, affecting the accuracy of the measurement.
At present, the research on AC electric dynamometer mainly focuses on two aspects: design of control system, and torque/speed measuring method (Bu et al., 2012). This paper studied the AC asynchronous dynamometer system, which will become the mainstream of dynamometer. A soft torque/speed measurement model is studied and established based on its components and control algorithm. The research work and achievements of this paper have certain engineering value, significant to simplify the AC asynchronous electric dynamometer system and reduce the cost (Christopoulos et al., 2016).
This paper studied an AC asynchronous electric dynamometer system based on a motorcycle engine test bench to better determine the performance of the machine. The constitution and control strategy of the dynamometer system are discussed. The principle of AC asynchronous electric dynamometer is described, and the conditions for stable operation of the system are discussed. A simplified mathematical model of the frequency inverter is proposed based on the analysis and establishment of the mathematical model of AC asynchronous dynamometer, and the mathematical model of the whole test system is established. The experimental results show that the control system has good performance and can meet the requirements of dynamic test and control. It is concluded that, with the AC asynchronous dynamometer system, the machine can run stable, and the cost is low.

2. Structure of AC asynchronous electric dynamometer system

AC asynchronous electric dynamometers have been widely used in recent years for its simple structure, wide measurement range and high accuracy. The test system with AC asynchronous electric dynamometer as its

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core is a key part of various power equipment test benches. In this chapter, a motorcycle engine test bench is taken as an example to analyze the principle and composition of AC asynchronous electric dynamometer and carry out the research of mathematical model and control strategy (Dehghan-Azad et al., 2017).

2.1 Composition of AC asynchronous electric dynamometer system

The AC asynchronous electric dynamometer system usually consists of the DUT, AC asynchronous electric dynamometer, inverter, energy consumption device (or feedback device) and the measuring and control system for torque/speed test and control (Dong et al. 2017). The composition of the system is discussed based on the motorcycle engine test bench (Haileselassie and Uhlen, 2013).

The motorcycle engine test bench consists of the electric dynamometer main loop and the measuring and control system (Jia and Rajashekara, 2017). The electric dynamometer main loop includes the engine under test, balanced AC asynchronous electric dynamometer, frequency converter and load resistor. The motorcycle engine is connected to the AC asynchronous electric dynamometer through a coupling (Lin et al., 2008). While doing experiments such as cold running-in and so on, the AC asynchronous electric dynamometer drives the engine to rotate as a motor; in power measuring state, the AC asynchronous electric dynamometer provides load torque of the tested engine under the control of the frequency converter, absorbing the output mechanical energy, converting it into electrical energy and feeding into the frequency inverter for rectifying into DC power (Lin et al., 2009). The output power of the motorcycle engine is only 10 kW. To reduce the investment, a metal DC resistance is used in the system to consume DC energy.

The measuring and control system consists of core industrial PC and peripheral devices, such as speed/torque sensors and signal processor, throttle control system consisting of DC torque motor and data acquisition card (Moursi et al., 2013). The signal processor comprises a plurality of self-designed signal processing circuit boards. The signals output from the sensor are input into the acquisition card in PC after being processed by the signal processor, and detected by the signal acquisition module of the control program. The magnetic speed sensor installed on the dynamometer rotor shaft is used as the speed measuring device of the test bench; a tension sensor is used to measure the torque. The computer obtains the sampled data and processes. Then the PC sends control commands or variables to the actuator (frequency inverter and throttle control system) by the corresponding control algorithm to adjust the working status of AC asynchronous electric dynamometer (Pereira et al., 2014).

2.2 Principle of AC asynchronous electric dynamometer

AC asynchronous electric dynamometer is the load of the DUT in power measuring state, and an AC asynchronous induction motor in power generation state. Under the control of the frequency inverter, it adjusts the electromagnetic torque to change the load and speed of the engine, absorbs the mechanical work output from the tested engine, and converts it into electric energy (Tani et al., 2012). The DUT cannot directly measure the output torque due to its structure. In general, the speed and the torque of the motor shaft are measured so as to measure the output torque and power of the engine indirectly. When the dynamometer runs as a motor, it can be used as an ordinary three-phase asynchronous motor to drive the DUT for start, cold running-in and determine the mechanical loss (Teng et al., 2009).

For example, p denotes the effective output power (N • m). M_p denotes the effective output torque (N·m). n denotes the speed (r/min), then the relationship among the three is:

$$P = \frac{M_p \times \mathrm{n}}{9550} \tag{1}$$

In expression (1): The effective power p is calculated by measuring the output torque M_p and speed n of the engine under test under certain operating conditions. The shaft load torque M_p and speed n of the AC asynchronous electric dynamometer are two key measurements of the dynamometer system (Zhang et al., 2017).

3. Analysis of AC asynchronous electric dynamometer system

3.1 Controlling of AC asynchronous electric dynamometer system

To test the engine speed, the load of the engine under test is adjusted, so that the electric dynamometer system runs stably at required speed; to test the load, the engine throttle opening is adjusted to keep stable speed. The electric dynamometer load torque is given by the PC via the frequency inverter according to the control algorithm.

Speed control: In control mode, the electric dynamometer is in power generation state and the throttle setting u_δ is constant. In this case, the difference $e_n(t)$ between the set speed n_{ref} and the current speed sampling value n(t) is used as the input of the constant speed controller, and the output of the controller is the given torque M_e^* of the frequency inverter. The frequency inverter applies the voltage u_s to the electric dynamometer according to the given value to adjust the engine speed, constituting a closed-loop speed control. In applications, the engine speed shall be tested continuously for multiple throttle openings. The control algorithm always adjust the torque of the dynamometer based on the difference $e_n(t)$ between the detected feedback speed and the given speed for any throttle opening, so as to keep the stable speed. Figure 1 shows the control block diagram of speed characteristics.

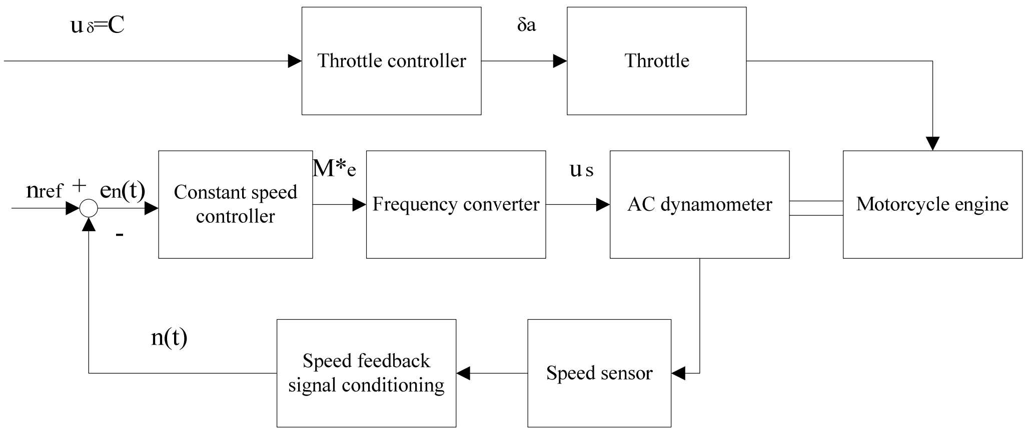


Figure 1: Control block diagram of speed characteristics

Load control: the electric dynamometer is in power generation state. The setting of frequency inverter M_e^* is constant. The constant speed controller outputs the given throttle voltage u_δ based on the difference $e_n(t)$ between the detected feedback speed and the given speed to adjust the throttle opening δ_a, so as to keep the stable speed. Figure 2 shows the control block diagram of load characteristics.

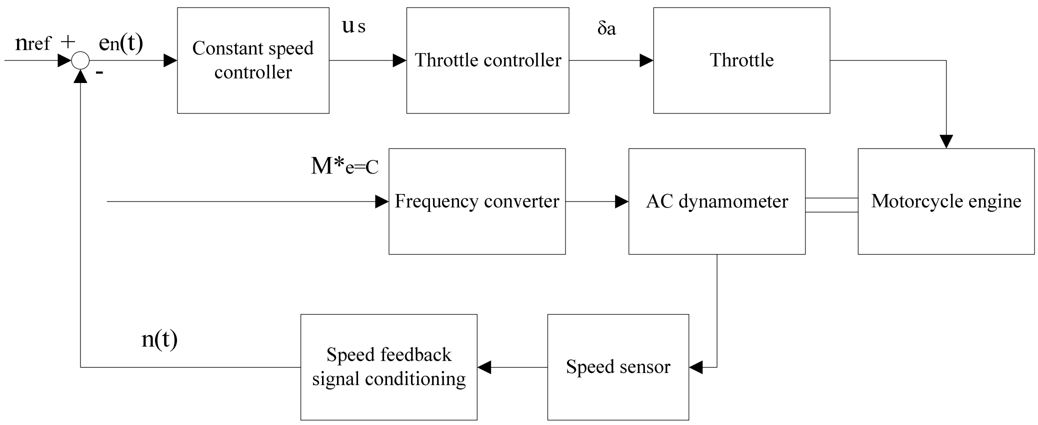
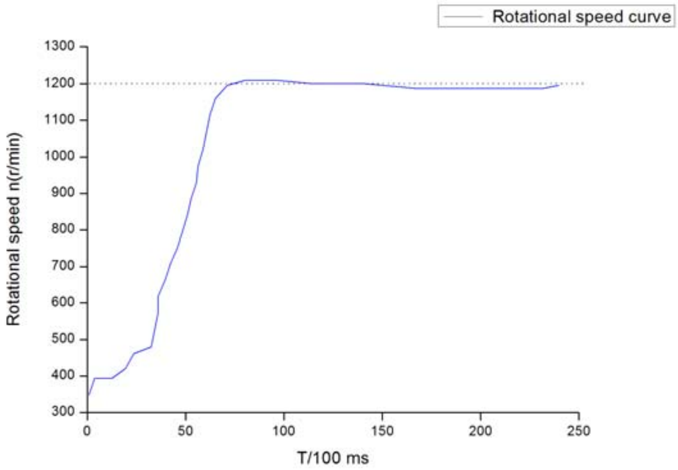


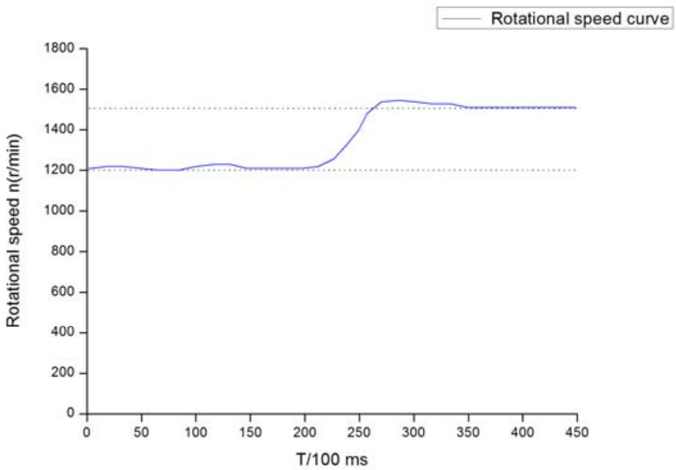
Figure 2: Control block diagram of load characteristics

3.2 Experimental results and analysis

To verify the performance of the fuzzy PID constant speed controller, speed and load characteristics experiments were carried out on the motorcycle engine test bench. The speed characteristic experiment includes two parts: Initial state speed control experiment and sudden speed change control experiment. In the initial state speed control experiment, set the speed to 1200r/min and throttle opening to 50070; in the sudden speed change control experiment, set the stable speed to 1200 r/min and keep the engine throttle opening unchanged. Change the speed setting to 1500 r/min. Figure 3 (a) - (b) shows the experimental results.



(a) Initial state speed control experiment

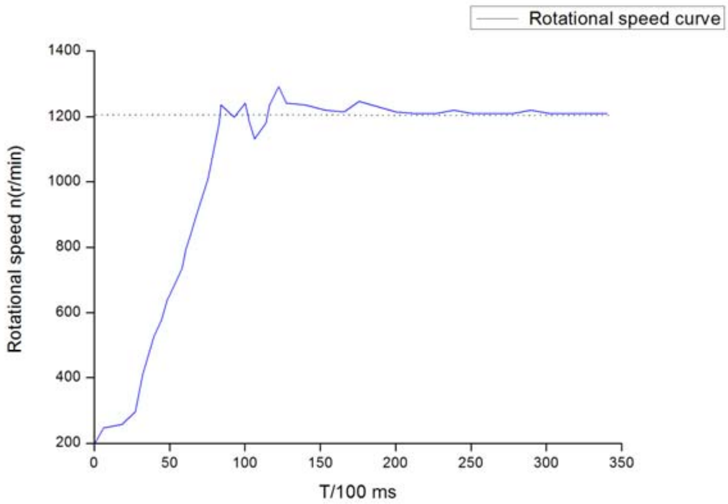


(b) Sudden speed change control experiment

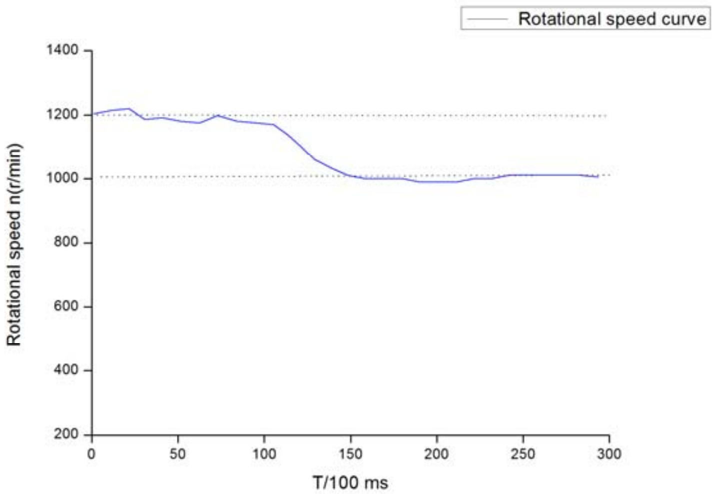
Figure 3: Speed characteristic control experiment

The initial state speed control experiment results show that the speed overshoot is controlled within 60 r/min. After stabilization, the speed is controlled within 1200±5 r/min. The sudden speed change control experimental results show that, the system can quickly track the change of the given value and stabilize at the new speed of 1500 ± 5 r/min, and the control system shows good performance. Figure 4 (a) - (b) shows the experimental results.

Load characteristics experiments also include the initial state speed control experiment and the sudden speed change control experiment. In the initial state speed control experiment, set the speed to 1200 r/min and the electric dynamometer torque to 25 Nm; In the sudden speed change control experiment, after the speed is stabilized at 1200 r/min, keep the torque of electric dynamometer motor unchanged, and change the speed to 1000 r/min. The experimental results show that in the initial state control experiment, although the speed overshoot is slightly high, reaching 110 r/min, the stable speed is still 1200±5 r/min. The sudden speed change control experimental results show that, the system can quickly track the change of speed and stabilize at the new speed of 1000±5 r/min, and the control system shows good performance.



(a) Initial state speed control experiment



(b) Sudden speed change control experiment

Figure 4: Load characteristic control experiment

4. Conclusion

This paper takes a motorcycle engine test bench as an example. The principle of AC asynchronous electric dynamometer is described, and the conditions for stable operation of the system are discussed. The issues on power matching are analysed. A mathematical model of AC asynchronous dynamometer is established based on the analysis and a simplified mathematical model of the frequency inverter is proposed, and the mathematical model of the whole test system is established, laying a foundation for research of the soft measurement technology. Finally, in view of the disadvantages of the traditional PID controller, the AC asynchronous electric dynamometer control system based on the fuzzy PID constant speed controller is designed and the related experimental results are given. The experimental results show that the control system has good performance and can meet the requirements of power system test and control.

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