MOTOR SPEED SENSING TECHNIQUES FOR INDUCTION MOTORS

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Abstract
Correct sensing, transmission and display of revolution per minute (rpm) speed of shafts is very important for smooth running and control of induction motors. Speed sensors sense shaft speed. Therefore, sensors are a critical component in a motor control system. When speed sensors are used in closed loop for feedback in a motor control system, it enables the designer to adjust the stator voltage/frequency relationship to realize the desired speed with minimal losses and improve the motor's reliability by detecting fault conditions that may damage the motor. RPM sensors that can be used to feedback information to microcontroller include shaft encoders, proximity sensors, photoelectric sensors, sitrans WS300, quadrature encoder and Hall Effect tachometer. When choosing sensors, it is necessary to make sure the resolution of the sensor is appropriate for the speed of the shaft. Two factors that affect the quality of speed data (which are in form of pulses) are number of pulses per revolution (PPR) of the shaft and symmetry of the pulses.

Key words: RPM, PPR, Closed Loop, Feedback

1.0 INTRODUCTION

Sensors, especially speed sensors, are a critical component in a motor control system. Motor speed sensing techniques involves ways of detecting and measuring the rotational speed of a motor shaft in revolutions per minute (rpm) for the purposes of feedback and control of motor speed. RPM measurement is important when controlling the speed of motors, conveyors, turbines, etc. This act is carried out by an rpm sensor which function is to sense shaft speed. Sensors are used to provide feedback information on the motor, in a closed loop control system. With this advantage, the designer is able to adjust the stator voltage/frequency relationship to realize the desired speed with minimal losses and improve the motor's reliability by detecting fault conditions that may damage the motor. As an example, Figure 1 provides block diagram of a 3-phase 15kW squirrel cage induction motor control system to show the sensor feedback provided for a typical motor control. Information, in the form of electrical signal, or pulses, is fed back from the motor to the microcontroller (AT89C52) by Sitrans WS300 rpm sensor. This information is processed by the microcontroller, using the program uploaded to it, to give out an error signal instructing the 3-phase Mos-Controlled Thyristor Inverter (MCT-inverter) on which switching frequency to adopt at each time. The feedback sensor (Sitrans WS300) has the duty of transmitting the output rpm to the microcontroller which serves as an error amplifier. Where the output rpm does not match the command signal or expected output, the microcontroller compares the input and feedback signal and gives out an error signal (or actuating signal) that controls the switching of the 3-phase MCT-inverter. The switching of the MCTs determines the stator voltage/frequency balance which in turn determines the torque and speed of the motor, and so correction is made automatically. Simulation results from the experiment are shown in tables 1. The readings show a consistent and accurate rpm values, as copied from the LCD. This is a demonstration of a good motor sensing technique made possible by sitrans WS300 sensor. In order to have closed loop control of motor shaft speed, a speed error signal is required between the desired set speed and the actual measured speed. Speed sensors play a critical role in a control loop. Several solutions are possible to obtain the speed and direction of the rotor. The most precise, but also the most expensive, is to use absolute or incremental encoders. These optical sensors may be expensive as the induction motor itself. Another solution that can be used is to use the output of a tachometer generator that is connected to the rotor shaft. An analog-to-digital converter is needed to interface the output of this sensor with the microcontroller. A third solution is to use Hall effect sensors. These cheap non-contact sensors are now proposed in small IC packages. Yet another option is to use sitrans WS300. This is the sensor used in this work. Siemens (2014) explains that sitrans WS300 is a low- to high resolution shaft-driven speed sensor and operates in conjunction with a conveyor belt scale. It is directly coupled to a rotating motor shaft to ensure accurate belt-travel read-out, eliminating problems of belt slippage or material build-up. The sitrans WS300 converts shaft rotation into a pulse train of 32,256, 1000, or 2000 pulses per revolution using a high precision rotary optical encoder. The digital signal is transmitted as speed input to an integrator in the microcontroller for calculation of belt speed or motor speed. It provides a frequency signal proportional to the shaft speed, enabling a range of speeds to be read accurately. The benefits of WS300 speed sensor are that it is compact and economical. It is easy and has low-cost installation. It has accurate belt speed detection. It has optional resolutions for measurement over a range of belt speeds and it is corrosion resistant. It then follows that for a balanced voltage-frequency (v/f) ratio, the speed of the motor can be sensed through the applied stator voltage or vice-versa, since the v/f ratio determines the torque of the motor.

2.0 MATERIAL and METHOD

Design of induction motor drives frequently meets problems of speed measurement. Speed in closed loop control system is a controlled value and appear in the feedback loops. There are some methods to evaluate motor speed: to measure directly or to apply models, calculating that. Modern induction motor drives use observers, calculating speed according to mathematical models of induction motors. Adequacy of the model in all speed range remains the problem. Petrovas et al (2010) developed equipment for experimental speed measurement of induction motors. In their procedure, they made experiments at starting of motor on no load. The current transients were measured also.

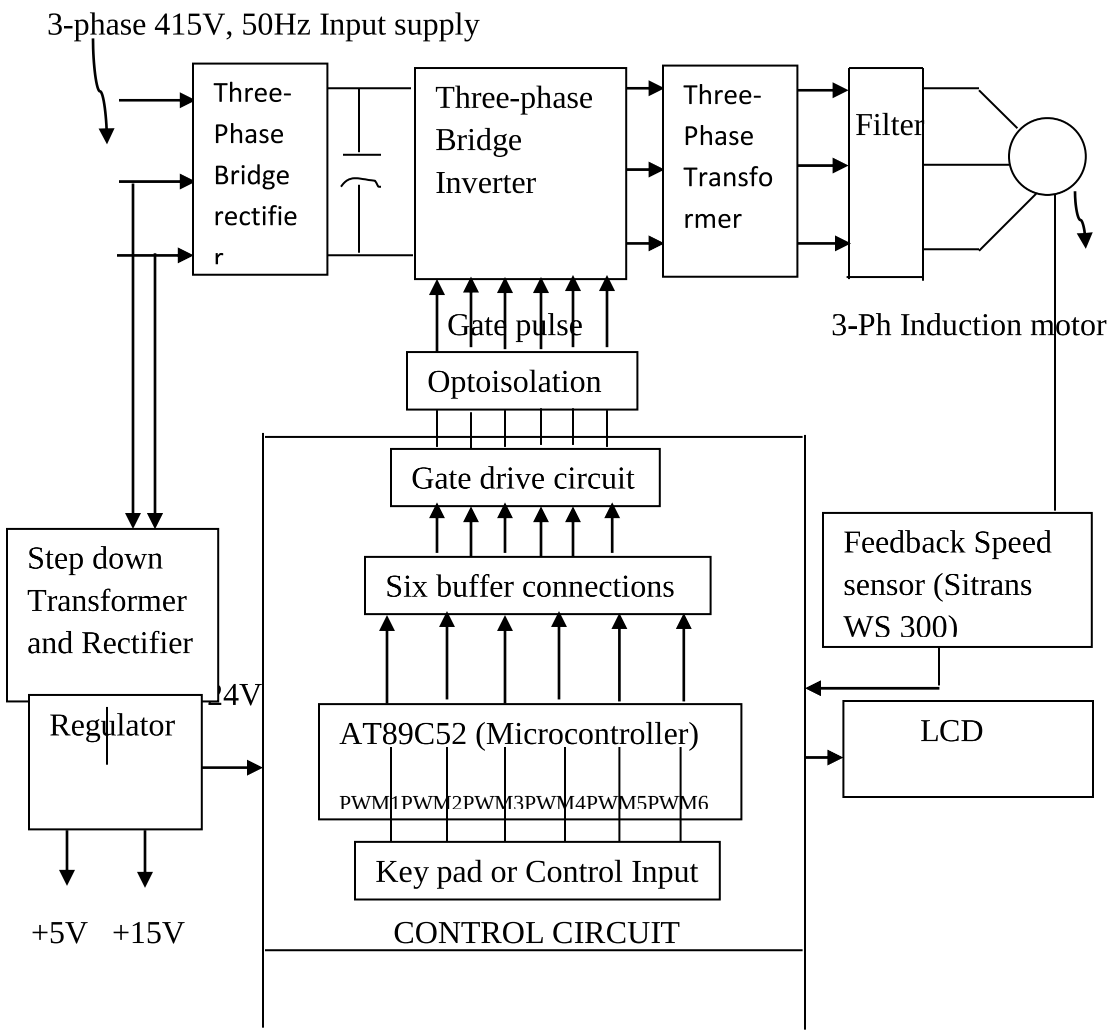

Figure 1: The system block diagram of speed control of 3-phase ac squirrel cage induction motor showing the position of feedback sensor.

Table 1: Result for variable speed/frequency and fixed load: 10N

S/No.	Reference Speed (r.p.m.)	Frequency (Hertz) (Hz)	Stator Voltage (V)	V/f ratio	Actual Speed (r.p.m.)
1.	1450	50	350	7.0	1450
2.	1510	52	364	7.0	1510
3.	1570	54	378	7.0	1570
4.	1630	56	392	7.0	1630

5.	1690	58	406	7.0	1690
6.	1750	60	411	6.9	1750

The goal of developing such measuring equipment is obtaining results and comparing that with simulation results. Yu et al (1998), in their experimentation, used a low cost shaft sprocket with 25 teeth and a Hall Effect gear tooth sensor to measure induction motor speed and got good results. The need of the measurement of induction motors working in the inaccessible and important places is often necessary. The possibility of on-line digital processing of voltage and current measurement signals caused rapid development of the induction motor speed measuring methods. According to Bien et al (2011), the methods for the induction motor speed measurement described in scientific literature and patents are based on the following procedures:

- Spectral analysis around the current induction motor main frequency (electricity) or detection of its envelope.
- Spectral analysis in the frequency domain connected with heterogeneity of rotor construction-cage bars.

The first method can be implemented in a very easy way even without digital signal processing for the noticeable eccentricity motors. However, its application makes the dynamical speed changes observation impossible and the measurement lasts relatively long, the envelope oscillation frequencies are low (about 1Hz or smaller). The second method gives the possibility of dynamical speed changes observation. It is more frequent in the modern measurement system solution. It requires the acquaintance of the engine construction parameters and motor current main frequency. RPM sensors that can be used to feedback information to microcontroller include shaft encoders, proximity sensors, photoelectric sensors, sitrans WS300, quadrature encoder and Hall Effect tachometer, some of which mechanism are described as follows:

2.1 SHAFT ENCODERS

Shaft encoders are among the best solutions for speed sensing devices. They offer high resolution capacity (typically 1 to 5000 Pulses per Revolutions) and symmetrical pulses. However, sometimes it is not possible to mount an encoder to the shaft being monitored.

2.2 QUADRATURE ENCODERS

Lepkowski (2003) explained that quadrature encoder can be used to provide the speed, direction and shaft position of a rotating motor. A typical quadrature encoder can be optical and is packaged inside the motor assembly and provides three logic-level signals that can be directly connected to the microcontroller. Motor speed can be determined by the frequency of the first two logic-level signals known as channels A and B. The counts-per-revolution (CPR) depends on the location of the encoder and whether motor-gearing is used. The phase relationship between the two channels can be used to determine if the motor is turning in either in either a forward or reverse direction. The third logic-level, known as the index signal, provides the position of the motor and, typically, a single phase is generated for every 360 degrees of shaft position. The quadrature encoder's speed and direction information can be determined either with discrete logic, a quadrature encoder logic IC or a

PICmicro® microcontroller. Vendors, such as LSI Computer Systems, offer an IC that converts the three encoder signals to a signal that represents the velocity, position and distance that the motor has moved.

2.3 HALL EFFECT TACHOMETERS

Hall Effect tachometer sensors can be used to sense the speed and position of a rotating motor. This type of speed sensors use hall element to sense the change influx in the air gap between a magnet and a notch in a rotating shaft or a passing ferrous gear tooth. An advantage of Hall Effect tachometers is that they are non-contact sensors that are not limited by mechanical wear. Hall effect tachometers that integrate the sensor and sensor-conditioning circuit in a small IC package contains circuitry inside the sensor that typically consists of a comparator or Schmitt trigger to provide a digital output signal that can be directly connected to the microcontroller.

2.4 PROXIMITY AND HALL EFFECT SENSORS

According to Opto 22 (2016), proximity sensors provide medium- or low-resolution sensing, depending on the number of pulses measured per revolution. The best method of using proximity sensor is to sense the teeth on a gear. This type of sensing typically has options for 60, 120, or 240 PPR, and the pulses are symmetrical. Photoelectric sensors usually provide low resolution, due to the low number of pulses measured per revolution. A photoelectric sensor must sense a reflection target on the shaft. If more than one target is used to increase the PPR, then the symmetry from one pulse to the next is likely to be poor.

3.0 METHODS OF DETERMINNING RPM OF MOTOR SHAFT

The two methods of determining rpm of motor shaft are frequency measurement method and period measurement method. Frequency measurement is better for fast-moving devices such as motors and turbines that typically turn in thousands of revolutions per minute. When using frequency measurement as a method of monitoring rpm, the key factor is the number of pulses being sensed per revolution (PPR). This method works well with high PPR sensors such as shaft encoders or proximity sensors sensing gear teeth and works poorly for low PPR sensors such as photoelectric sensors. The formula for determining rpm under this method is given by

$$RPM = \frac{Pulse\ Frequency \times 60}{PPR} \quad (1)$$

where RPM = Revolutions per Minute

and PPR = Pulses per Revolution

Period measurement is better for devices that move more slowly, such as shafts that turn in less than 10 rpm. Period is the time from the start of one pulse to the start of the next pulse. Knowing that period is the inverse of frequency, the formula for determining rpm under period measurement method is

$$RPM = \frac{60}{Pulse\ Period \times PPR} \quad (2)$$

Each of these devices sends speed data in the form of pulses. The quality of these data is determined by the number of pulses per revolution (PPR) of the shaft and the symmetry of the pulses. Higher PPR values result in better solution. The symmetry of one pulse to the next pulse determines the consistency and accuracy of the rpm readings. Choosing sensors for motor operation requires that the resolution of the sensor matches the speed of the shaft. Whenever the motor system needs to sense current, current sensors like shunt resistor, current-sensing transformer and Hall effect current sensors are used.

3.1 ZERO SPEED DETECTION

Detecting when the shaft has stopped is important in many applications, for example, to determine whether a conveyor has failed. Using the frequency method entails determining how much time to allow between pulses before deciding that the shaft has stopped. If a pulse is not received before the timer expires, then the shaft has stopped.

CONCLUSION

The complexity of induction motor faults requires that effective motor speed sensing method be adopted by choosing speed sensors that match with the speed of motor shafts. By this, the pulse per revolution and symmetry of pulses will be okay with the speed of the shafts and make the rpm readings consistent and accurate. This can be seen in the readings of the speed control of 3-phase induction motor shown in table 1. Industries should consult and co-operate with relevant research institutes and universities to know the latest motor sensing techniques and comply accordingly, in order to boost productivity.

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