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Rotor positioning characterization for a non-linear switched reluctance actuator

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ABSTRACT – Recently, researchers have conducted rapid researches on Switched Reluctance (SR) Actuator to replace the conventional continuous-drive motor; i.e. Interior Permanent Magnet motor in electric vehicles. These researches portrays that the much researches are focus towards high torque generation, in which precise positioning researches are very minor. High precision positioning is less to be conducted due to the highly nonlinearity characteristics of the SR Actuator, in which it's difficult to be controlled. However, the SR Actuator can be the future low-cost high precision actuator since the design is highly simpler and robust. The disadvantage is that it will requires linearization to cancel out its nonlinearity characteristics. In order to develop a high precision SR Actuator, the rotor positioning characterization is important in order to provide the predetermined characteristics in terms of the non-linearity of the SR Actuator motion with respect to the excitation current.

1. INTRODUCTION

Important rotor positioning for high torque generation using conventional Switched Reluctance (SR) Actuator configuration has been researched since few years back [1]. There are five important positions, illustrated in Figure 1. This configuration represents the counter-clockwise (CCW) rotational direction. Each of the position indicates the inductance characteristics as shown in Figure 2. Typically, the second phase was excited after the dead time which is at position θ_3. It is to ensure continuity of rotational since the rotor is at stable position during the dead time.

Based on the previous research [1, 2], it was found that the ideal position for self-starting condition was during the partial aligned between the poles. This position provides the predetermined pathway for the magnetic flux and creates tendency of rotational through accumulated magnetic flux. A decent SR Actuator must be capable of generating high torque at small aligned position since it is the critical position for self-starting. Therefore, in this work it is important to define the characteristic of the SR Actuator at different rotor's position for performance evaluation.

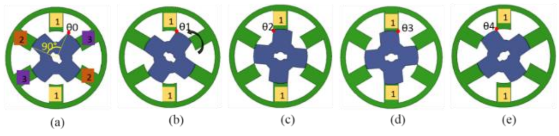


Figure 1 Rotor position to derive the inductance [1]

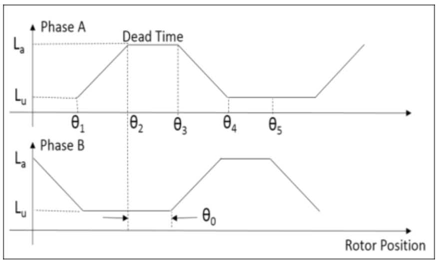


Figure 2 Typical overlapping inductance profile [1]

The rotor positioning will also determine the characteristic of rotary motion as both have direct relationship between each other. A high generated torque may result in high overshoot, while too low generated torque may incapable of initiating rotations [2]. For the characterization of SR Actuator, the rotary motion must be capable of delivering high precision and accuracy at high magnitudes of current [3,4]. The characterization is important as it will determine the linearizer unit for the controlled systems in future work.

2. METHODOLOGY

To evaluate the rotor positioning characteristics, the measurement setup and the SR Actuator prototype for validating the experimental works are shown in Figure 3. The experiments were carried out by applying signal waveform to the SR Actuator, amplified by the Programmable Bipolar Power Supply, Model PBZ60-6.7. The current magnitude was varied from 0 to 2A with the interval of 0.5A for each signal configuration and underwent the 20 repetitions. On each repetition, the rotor was manually adjusted to the initial position. In order to ensure the accuracy of initial position during each repetitions, the position is observed through the microscope. For every repeated experiment, a 10 seconds time delay was applied to ensure the current was fully disconnected from the mechanism. This will allow the discharging process, hence reducing the accumulated magnetic flux within the core. Since, the ferromagnetic material was exposed to the saturation effects, a continuous repetition is not recommended. Therefore, it is assumed that the given 10 seconds delay time able to sustain the magnitude of magnetic flux below saturation level.

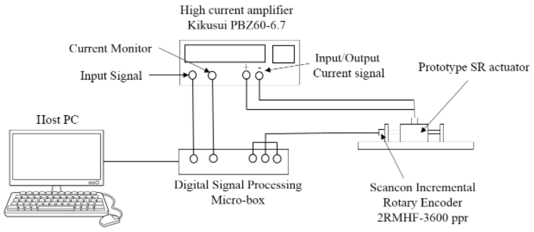


Figure 3 Measurement setup

3. RESULTS AND DISCUSSION

The analysis of different initial rotor position is required due to the correlation of changes in generated torque based on Equation 1. The rotor position was varied from position 0° to 80° in the FEM analysis and experimental work as shown in Figure 4. The rotor was rotated by an interval of 10° towards the counter-clockwise directions and nine (9) different positions were evaluated. A constant step input signal, 1A to 2A was applied at all respective position to obtain the generated torque and rotary motion characteristic.

$$\frac{N_r}{N_s/N_{ph}} = Integer \qquad (1)$$

Where,

N_r = Rotor pole number
N_s = Stator pole number
N_{ph} = Phase number

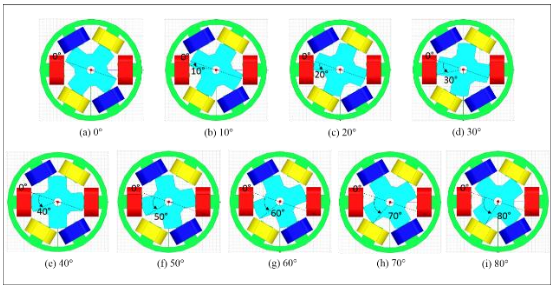
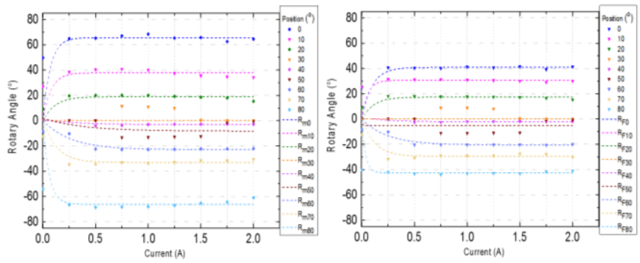


Figure 4 Initial position of the rotor from 0° to 80° with interval of 10°

For the rotary motion characteristics, the SR Actuator was evaluated experimentally. Figure 5 presents the maximum and final rotary angle of the SR Actuator with regards of position and excitation current. The maximum rotary angle indicates the overshoot angle while the final rotary angle indicates the settled rotor's position. It can be observed that the maximum generated torque at position 0° and 80° have resulted in the highest rotary angle for both positions but with opposite direction of rotation.

Based on the rotary positioning characteristics, the equation with regards to the rotor position and excitation current was obtained. The equation defines the characteristic of the SR Actuator design for the respective position configuration. This equation will later be used for designing the linearizer unit in future work as shown in Figure 6. The linearizer unit will be useful for controlling the SR Actuator with precise motion.



(a) Maximum rotation (b) Final rotation

Figure 5 Experimental works rotational motion result of varying rotor position

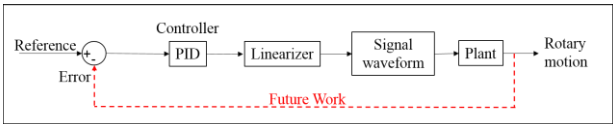


Figure 6 Application of linearizer unit in control system

4. CONCLUSION

As a conclusion, the rotor positioning characterization of the SR Actuator were authenticated in order to further validate the control performances of the SR Actuator for precise motion in future work. The rotary motion overshoot behavior was observed at most of the positions; 0° to 80° for the applied step input signal waveform. It is found that the percentage overshoot, %OS produces is within the acceptable range of stepper motor; maximum up to 80%. It proves the credibility of SR Actuator to be comparable with the characteristic of conventional Hybrid Stepper motor that available in market today.

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