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Linearization on non-linear switched reluctance actuator for precision motion

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ABSTRACT – In order to analyze a Switched Reluctance (SR) Actuator performances for high precision and accuracy, a SR Actuator prototype was developed. Many past researchers focused only on high generated torque SR actuators. However, the motion characteristics was less to be discussed due to the lack of attention given in terms of precision accuracy. High generated torque may result in high overshoot, while too low generated torque may incapable of initiating rotations. In theory, characterization of SR Actuator may capable of delivering high precision control and accuracy at high magnitudes of current, with the correct input-output relationship. For a SR Actuator, the generated torque has a strong relationship to the motion characteristics. Therefore, in this paper the predetermined characteristics of the SR Actuator will be presented as a linearizer unit through experimental characterization of the SR Actuator prototype. The linearizer unit is expected to cancel the nonlinear characteristics between the input current and the thrust force, thus improving precision and accuracy.

1. INTRODUCTION

Feedback linearization is frequently used in designing position control units for electromagnetic applications. Its high nonlinear characteristic had increase the research method of linearization [1]. It is also implemented in other non-linear actuator type such as pneumatic actuator [2] and electrostatic actuator [3]. The linearizer is required to suppress and cancel out the nonlinearities characteristic of electromagnetic which is due to the hysteresis and uncontrolled magnetic flux distributions [4]. The linearizer will provide the predetermined characteristic data through look up table which relates the thrust force, mover position and excitation current. By adopting the linearizer unit, it was found that the steady state error and standard deviation were reduced about 80% for both properties [4]. The significant performances improvement is due to the constructed linearizer unit which based on the pre-configured open-loop experimental work characteristics which considering the effects of frictional force. Hence in this work, the predetermined characteristic of the SR Actuator will be presented as a linearizer unit through experimental characterization to enhance high precision accuracy.

2. METHODOLOGY

To evaluate the precision motion accuracy of the non-linear SR Actuator, the linearizer unit was evaluated based on several experimental works using the prototype shown in Figure 1. The linearizer unit will be used to linearize the non-linear characteristics of the SR Actuator, based on a specific initial position, which in this research the position is at 0° and 80°, respectively. In practical, the linearizer is used for feedback controller as shown in Figure 2. Since the actuator's performance was measured from the accuracy of rotational motion, the linearizer unit will able to improve the controlling performances based on the amplitude of the excitation current and the rotary motion characteristics, thus cancelling the non-linearity of the SR Actuator. The signal waveform block in Figure 2 is selected from the open-loop experimental work, where the suitable waveform will be based on the waveform that generated the stable and highest torque. The linearizer is expected to improve the controller performances since the controller will be better tuned over the complete operating range.

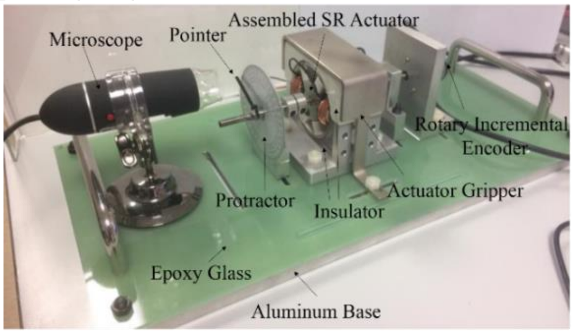

Figure 1 SR Actuator prototype

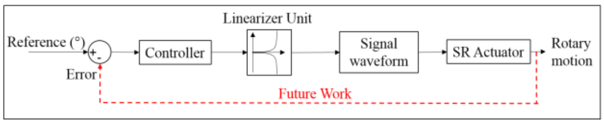

Figure 2 Application of linearizer unit in control system

For the signal wavefrom block, three (3) types of driving signal waveforms were applied; i.e.: (i) step input signal; (ii) sinewave signal and; (ii) pulse input signal. All the signals were applied with 1A excitation current magnitudes for 6 seconds including a 2 seconds delay. Rotor position at 0° is selected as the critical self-starting conditions due to its fully unaligned position. Each of the signal were assigned with several different frequency from 1Hz to 20Hz. Due to the high current amplifier operating limitation, further increases in frequency is not permissible. However, for the linearizer characterization, only the step input signal will be discussed.

3. RESULTS AND DISCUSSION

For the rotary motion characteristics, the SR Actuator was evaluated experimentally. Figure 3 shows the example of rotary motion characteristic for a single initial position at excitation current magnitude, i = 1A. The maximum rotary angle indicates the overshoot angle for the SR Actuator while the final rotary angle indicates the settled rotor's position. Based on different rotor's position data with respect to applied step input signal, the maximum rotary angle of the SR Actuator with regards of position and excitation current is plotted in Figure 4.

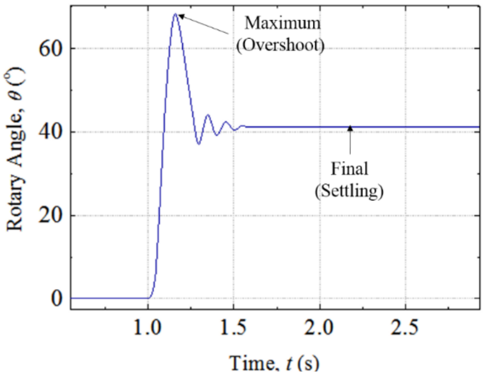

Figure 3 Rotary motion characteristic of i =1A at initial position 0°

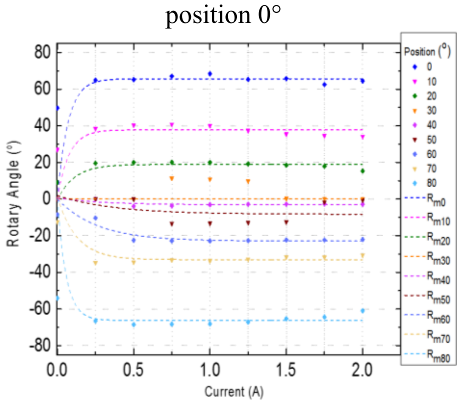

Figure 4 Experimental works rotational motion result of varying rotor position at maximum rotation

In overall, the overshoot is observed by most of the initial positions. The overshoot motion occurred due to the resultant high momentum exerts by the rotor. In conclusion, the rotary motion characteristic is highly dependent on the position and excitation current applied to the SR Actuator. Based on the characterization of SR Actuator's rotary motion, the final rotary angle at position 0° in Figure 4 was plotted with respect to the excitation current; i.e.: linearizer unit. The output function of the linearizer is determined from the rotary motion characteristics shown in Fig. 5. The linearizer is used to cancel the nonlinear characteristics between the input current and the thrust force. The linearizer unit was assigned at this position as it is the critical position for the self-starting conditions due to the fully unaligned. The symbols indicate the measured value while the solid line is the approximate linearizer unit. The added linearizer unit in a non-linear control system is critical to cancel the non-linear characteristic of the electromagnetism in the SR Actuator and predetermined the suitable excitation current to achieve precision accuracy. This linearizer unit function will be implemented in the future work as shown in Figure 2.

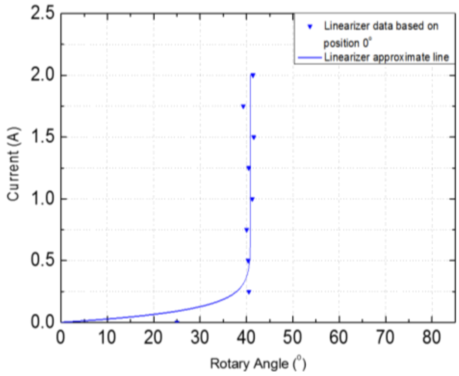

Figure 5 Linearizer unit based on rotary motion characteristic at position 0° with respect to applied step input signal

4. CONCLUSION

As a conclusion, in order to design the linearizer unit, the motion characteristics of SR Actuator were first analyzed by applying excitation currents; i.e. the step input signal waveform for different rotor's position; position at 0° to 80°, respectively. The linearizer unit was successfully designed for the Switched Reluctance (SR) Actuator prototype, where the linearizer unit defines the relationship between the final rotary angle and the excitation current. It was expected from the designed linearizer unit that the non-linearity characteristic exhibits by the SR Actuator will be cancelled out and high precision positioning could be developed and improved in future research works.

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