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Position Control of Double Sided Linear Switched Reluctance Motor Based on PSO

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Abstract

The movement of the double-sided linear switched reluctance motor (LSRM) has high overshoots and oscillations because the magnetic circuit of the LSRM has nonlinear characteristics. The traditional PID controller is insufficient in LSRM due to the nonlinear magnetic circuit of the LSRM. Therefore, the closed-loop PID controller based on a particle swarm algorithm (PSO) is designed and implemented using Matlab/Simulink to achieve the best characteristics of the LSRM.

Keywords: LSRM, PID controller, PSO, and Current Controller.

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1. Introduction

The linear switched reluctance motor (LSRM) provides one-dimensional movement without using a rotary transformation mechanism. Compared to the traditional linear motor that uses a belt with the rotary motor to establish the one-dimensional movement. The LSRM motor has advantages such as a simple structure, low cost, and direct drive without mechanical transformation **[1-4]**. The LSRM is based on switched reluctance motors (SRMs), which have high reliability, ease of making, great precision, and easy installation **[5]**. The LSRM is used electromagnetic force to achieve linear motion. On the contrary, the linear movement of the LSRM has overshoots and oscillations and it needs an accurate control method to remove the oscillations **[6]**.

In **[2]**, established a model of the LSRM model, and designed a PD controller for position control of LSRM. The experimental results show the effective controller and model of LSRM. But the oscillation of linear movement is not eliminated. In **[8]**, the LSRM structure is optimized to enhance thrust force. The width of the translator core is increased to reduce the resistance of the magnetic circuit. The results showed that the new LSRM design improves the thrust compared to the old LSRM design. Also, a suitable controller was used for precise positioning. The results show the position error of the LSRM with a controller is less than 0.25 mm. In **[6],** introduced modeling of the LSRM that consists of three phases of the SRM. The proposed model of LSRM has studied the end-effect of the LSRM. The results of the simulation were proving the validity of the modeling. In **[7]**, used fuzzy logic to control the speed of an LSRM that consists of four phases SRM. The results show that the LSRM speed can track the desired speed precisely.

The error in position response is not completely removed in previous research. The current work uses a PID based on a particle swarm algorithm (PSO) to remove the position error of LSRM through step movement.

2. The modeling of the LSRM

The structure of LSRM composes of two stators and a translator (mover) as shown in figure 1. In this work, the double-sided LSRM composes of four stages of the SRM.

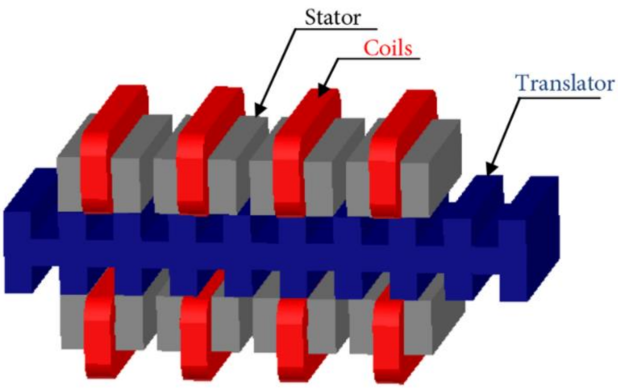

Fig.1 The structure of the LSRM.

The mathematical model of the LSRM for one stage that is given in **[6, 9]** is implemented using Matlab/Simulink as shown in figure 2. The other phases of the LSRM is implemented in the same way.

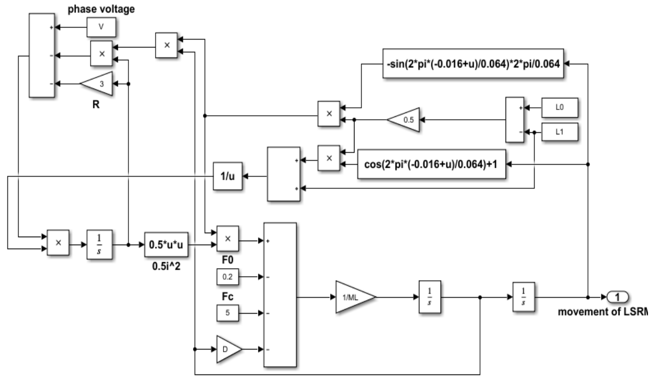

Fig.2 The modeling of the LSRM for one stage.

3. The LSRM controller

The LSRM is a non-linear system. Thus, the linear control method does not give accurate results by using the trial and error method **[9]**. In this work, the PSO is utilized to estimate the parameters of the PID controller online to realize an accurate position response of the LSRM. The proposed control system with the LSRM is shown in figure 3. Where, X_d is the desire position in (mm), X_m is the actual (motor) position in (mm), and e is the position error.

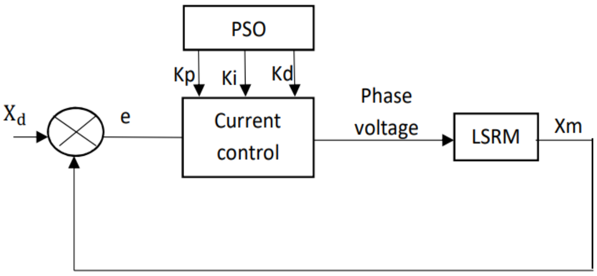

Fig.3 The LSRM with Controller.

3.1 Current controller

In this controller, the motor current is limited between two levels of currents that are equal to $I_d \pm \Delta I$, where, Id is the desired current and ΔI is the ripple width current. The position error is estimated by comparing the desired position with the motor position. This error is supplied to the PID controller, which is used to produce the desired current. The actual current of LSRM compares with the desired current to produce switching voltage. This voltage supply to the Matlab function that used to compare the motor position (Xm), the demagnetization position (Xq), on position (Xon), and off position (Xoff) to supply an appropriate voltage to the LSRM as shown in figure 4. Where Xon is the position that voltage supply to LSRM, Xoff is the position that voltage remove of motor and Xq is the position when flux becomes zero is the voltage **[9]**.

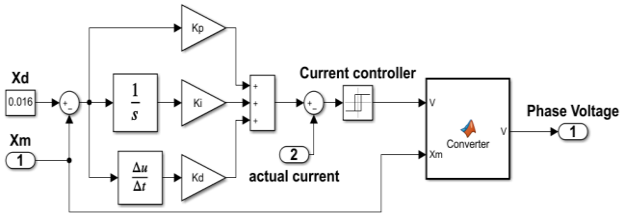

Fig. 4. The LSRM with the controller.

3.2 PID based on PSO

Particle swarm optimization is an optimization algorithm which has been used in many applications. This approach focused on the movement of particles throughout the search space. All particles indicate their current location as well as the velocity of a particle in a PSO flies in a limited space with an adjustable speed that is dynamically updated on the basis of its own flying knowledge besides the flight experience of all other elements. Particles take full advantage of their peers just like particles attempts to improve by imitating the properties of their peers succeed. In addition, every element is able to remember the best position ever reached throughout the search space by itself **[10-12]**. The PSO is used to adjust the parameters (Kp, Ki, and Kd). The mathematical equation that is used to implement the PSO can be driven as follow **[13 -15]**:

$$V_i^{t+1} = W * V_i^t + C_1 * \mathrm{rand}(.)[P_{best_i}{}^t - P_{current_i}{}^t] + C_2 * \mathrm{rand}(.)[g_{best_i}{}^t - g_{current_i}{}^t] \quad (1)$$

$$W = W_{max} - \frac{(W_{max} - W_{min})}{T_{max}} * t \quad (2)$$

Where,

V_i^{t+1}: : New speed of element i.

V_i^t: Old speed of element i.

C_1: Cognitive weighting factor is acceleration coefficients.

C_2: Social weighting factors is acceleration coefficients.

rand(.): stochastic components of the algorithm.

$P_{best_i}{}^t$: is the particles best position.

$P_{current_i}{}^t$: is the particles current position.

$g_{best_i}{}^t$: is the group best position.

$g_{current_i}{}^t$:is the group current position.

i=1,2,3…….Npop.

Npop: is the size of the population.

W: represented the weight of inertia which is set by the equation.

W_{max}: Maximum inertia weight.

M_{min} : Minimum inertia weight

T_{max}: Maximum number of iterations.

t : the current iteration.

The position of each particle updates as below:

$$X_i^{t+1} = X_i^t + V_i^{t+1} \quad (3)$$

Where,

X_i^{t+1}: New position value.

X_i^t: Old position value.

The principle operation of PSO can be explained using the flowchart that is shown in figure 5.

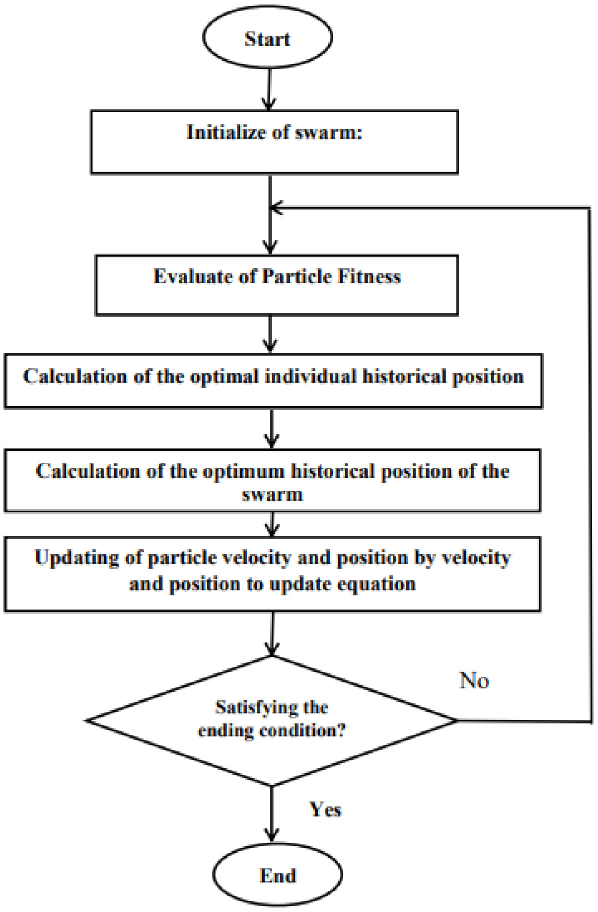

Fig.5 Flow chart of the PSO training.

4. Simulation results

The modeling of the LSRM with a control system for one stage of the SRM is verified and implemented by using Matlab/Simulink 2020. The motor parameters are listed in Table 1. The results of the LSRM for one phase are approved, and all the results of the other phases of the LSRM are identical. Each phase of the LSRM can be moved 16 mm when is energized which equals ¼ tooth pitch. Figure 6 shows the step movement of the LSRM is smooth without oscillation when using the PSO base PID controller. Figure7 shows The LSRM force that needs to drive the LSRM to the desired position. Figure 8 shows the current response of the LSRM for one stage. Moreover, one can note that the controller is used to limit the output current to control the motive force to remove the oscillation during the movement. Figure 9 and 10 show that the ability of the proposed controller to drive the motor to desire position (0.016 mm) at different load conditions.

Table 1 The LSRM Parameters.

Parameters	Description	Value
V	Applied voltage	*24V*
i	Phase current	*8A*
R	Resistance	*3 Ω*
X	Displacement	*16mm*
λ	Tooth pitch	*64mm*
L_0	Minimum inductance	*23mH*
L_1	Maximum inductance	*15mH*
Fc	Load force	*5N*
F_0	Friction force	*0.2N*
ML	Mover load	*6 Kg*
D	Damping coefficient	*65 Nm/ s*

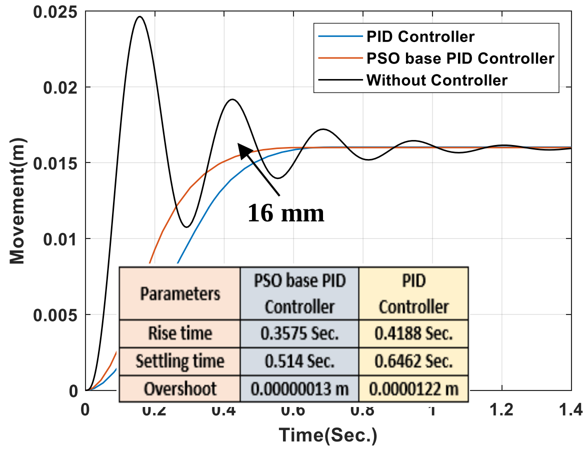

Fig.6 The movement of the LSRM at *ML*=5 Kg.

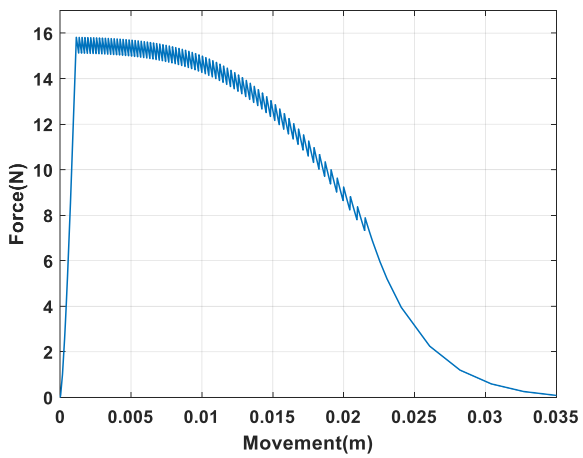

Fig.7 The force of the LSRM with PSO based on PID controller at *ML*=5 Kg.

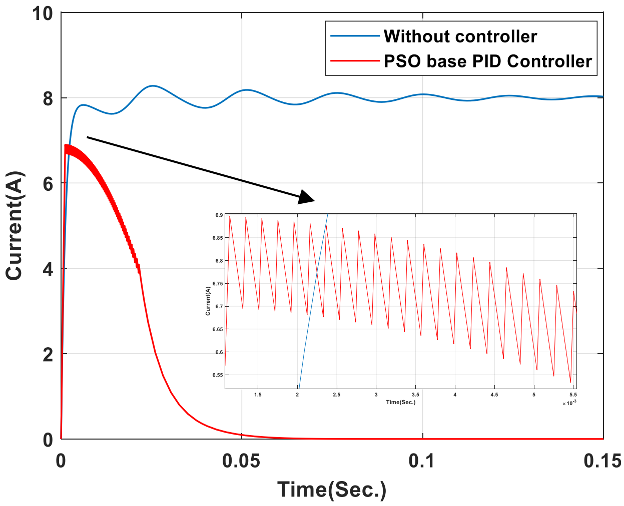

Fig.8 The phase current of the LSRM at *ML*=5 Kg.

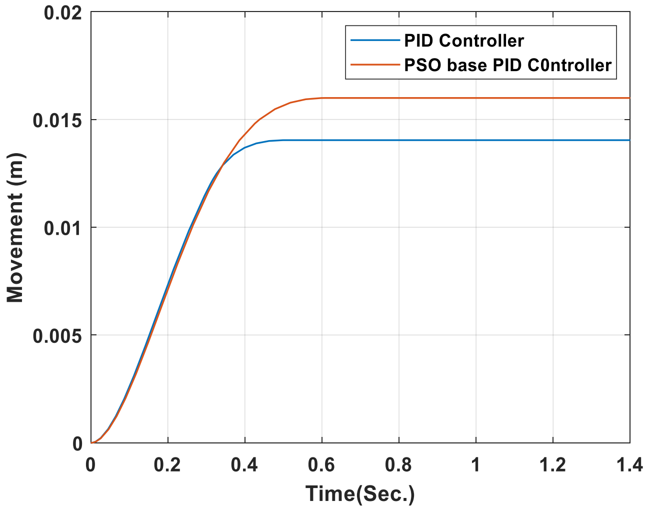

Fig.9 The movement of the LSRM at *ML*=6 Kg.

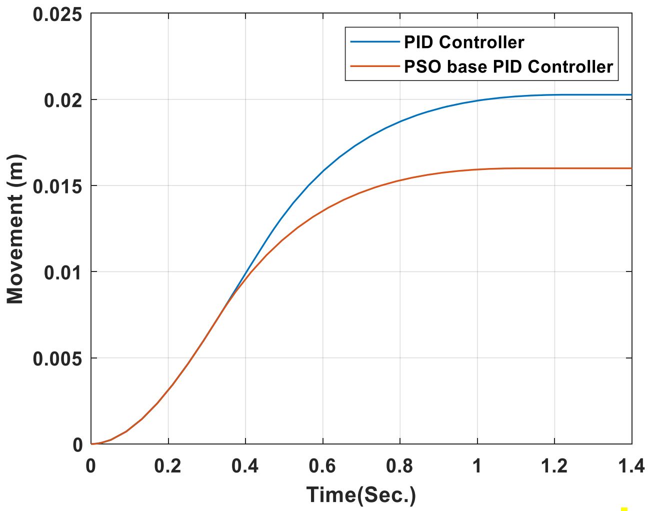

Fig.10 The movement of the LSRM at *ML*=10 Kg.

Conclusion

The modeling of the double-sided LSRM and the PID controller based on the PSO has been verified and designed using Matlab/Simulink software. Both controllers can drive the motor to the desired position. The results prove that the position response of the LSRM based on the PSO-PID controller is more accurate and has less position error than the PID controller. The LSRM show with PSO has a short rise time, no overshoot, smooth movement, and no oscillation. The results demonstrate that the suggested controller is effective for removing the oscillations during the movement of the LSRM and withstand the change in the load.

References

[1] D. Wang, X. Wang, and X.-F. Du, "Design and Comparison of a High Force Density Dual-Side Linear Switched Reluctance Motor for Long Rail Propulsion Application With Low Cost," *IEEE Transactions on Magnetics*, 53,. 6,. 1, June 2017.

[2] S. W. Zhao, N. C. Cheung, and W. C. Gan, "Trajectory Control of a Linear Switched Reluctance Motor using a Two-Degree-of-Freedom Controller," in *2006 IEEE International Power and Energy Conference*, Putra Jaya, Malaysia, April 2007.

[3] L. Qiu, Y. Shi, B. Zhang, J. Pan, and X. Lai, "Tracking Control of Networked Multiple Linear Switched Reluctance Machines Control System Based on Position Compensation Approach," *IEEE Transactions on Industrial Informatics*, 14,. 12,. 5368, December 2018.

[4] X. Xue, K. W. E. Cheng, Z. Zhang, J. Lin, and N. Cheung, " A Novel Method to Minimize Force Ripple of Multimodular Linear Switched Reluctance Actuators/Motors," *IEEE Transactions on Magnetics*,. 48, 11,. 3859, November 2012.

[5] D. Wang, D. Zhang, X. Du, and X. Wang, "Unitized Design Methodology of Linear Switched Reluctance Motor With Segmental Secondary for Long Rail Propulsion Application," *IEEE Transactions on Industrial Electronics*, 65, 12,. 9884, December 2018.

[6] W. Zaafrane, M. Dursun, and H. Rehaoulia, "Double sided linear switched reluctance motor analysis and modeling including end-effect," in *2018 5th International Conference on Electrical and Electronic Engineering (ICEEE)*, Istanbul, Turkey, June 2018.

[7] S. MasoudiI, M. R. Soltanpour, and H. Abdollahi, "A new adaptive fuzzy control method for a linear switched reluctance motor," *IET Electric Power Applications*,. 12,. 9,. 1328, August 2018.

[8] Maslan, M. Nazmin, H. Kokumai, and K. Sato, "Development and precise positioning control of a thin and compact linear switched reluctance motor," *Precision Engineering*, 48,. 265, April 2017.

[9] S. Zhou and H. Lin, "Modeling and Simulation of Switched Reluctance Motor Double Closed Loop Control System," *2006 6th World Congress on Intelligent Control and Automation*, Dalian, October 2006.

[10] F. Khan, A. Sunbul, M. Y. Ali, H. Abdei-Gawad, S. Rahnamayan, and V. K. Sood, "Maximum Power Point Tracking in Photovoltaic Farms Using DE and PSO Algorithms: A Comparative Study," in *2018 IEEE Congress on Evolutionary Computation (CEC)*, Rio de Janeiro, Brazil, October 2018.

[11] J. Wu, X. Sun, and J. Zhu, "Accurate torque modeling with PSO-based recursive robust LSSVR for a segmented-rotor switched reluctance motor," *CES Transactions on Electrical Machines and Systems*,. 4,. 2,. 2096, June 2020.

[12] M. Huang, H. Lin, H. Yunkai, P. Jin, and Y. Guo, "Fuzzy Control for Flux Weakening of Hybrid Exciting Synchronous Motor Based on Particle Swarm Optimization Algorithm," *IEEE Transactions on Magnetics* ,. 48, 11,. 2989, October 2012.

[13] G. A. Sultan, S. M. I. Amer F. Sheet, and Z. K. Fare, "Speed control of DC motor using fractional order PID controller based on particle swarm optimization," *Indonesian Journal of Electrical Engineering and Computer Science,* 22, 3,. 1345, June 2021.

[14] A. Polsena, Y. Kongjeen, and S. Watcharakhup, "Identifying Parameter and PI Tuning of DC Motor for Predict Behavior based on PSO," in *In 2021 9th International Electrical Engineering Congress (iEECON)*, Pattaya, Thailand, 31 May 2021.

[15] L. Zhen, L. Wang, X. Wang, and Z. Huang, "A Novel PSO-Inspired Probability-based Binary Optimization Algorithm," in *2008 International Symposium on Information Science and Engineering*, Shanghai, China, 30 December 2008.