Design and Control for Linear Machines, Drives, and MAGLEVs—Part III

THIS is the Guest Editorial of the third issue of the Special Section on "Design and Control for Linear Machines, Drives, and MAGLEVs" of the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS. In this issue, 14 papers are presented. The subjects of these papers embrace the main subjects of interest of the scientific community related to linear ele (LEMs), ranging from innovative procedures for the optimal design of such machines, to their analysis with finite elements, to advanced control techniques, suitably devised for specific applications.

As for the analysis and design of LEMs, [Item 1) in the Appendix], from Mohammed *et al.*, proposes a detailed analysis of the behavior of eddy currents in a tubular permanent-magnet machine comprising an unconventional magnetic circuit, with particular reference to the field distribution and current directions. [Item 2) in the Appendix], from Zhao *et al.*, proposes the design of a novel transverse-flux tubular linear machine (TF-PMLM), comprising the evaluation of its electromagnetic performance by using a finite-element method and experiments. [Item 3) in the Appendix], from Huang *et al.*, proposes the electromagnetic analysis of a double-side permanent-magnet linear synchronous motor adopting the structure of staggering two primaries, with particular reference to the rearrangement of the windings for the thrust ripple reduction. [Item 4) in the Appendix], from Zhao *et al.*, proposes the design of a novel flux-switching transverse-flux permanent-magnet linear machine (TF-PMLM), presenting some advantages, such as higher force density and better controllable characteristic, due to the combined advantages of transverse-flux linear machines and flux-switching linear machines. [Item 5) in the Appendix], from Chen *et al.*, presents a hierarchical Markov model to assess the reliability of a double-sided linear switched reluctance generator system, capturing the effect of fault-tolerate capability on system reliability to improve assessment accuracy. [Item 6) in the Appendix], from Sui *et al.*, investigates a special tubular staggered-teeth transverse-flux permanent-magnet linear machine (TF-PMLM) for a free-piston Stirling power generation system and proposes new methods of for both efficiency and thrust density. [Item 7) in the Appendix], from Miric *et al.*, treats the adoption of tubular linear actuators in direct-drive systems, where linear reciprocal motion is needed, and compares their benefits with respect to systems where a rotational actuator is used together with a mechanical transmission. [Item 8) in the Appendix], from Flankl *et al.*, deals with a single-sided linear induction machine (SLIM) with solid secondary operating in generator mode and shows how it can harvest electric energy from the kinetic energy of a moving conductive body (secondary).

As for the control techniques, [Item 9) in the Appendix], from Huang *et al.*, shows a model predictive thrust force control based on the active voltage-vector (VV) selection and two-VV synthesis, developed to reduce the thrust force ripple of a complementary and modular linear flux-switching permanent-magnet machine. [Item 10) in the Appendix], from Zhu *et al.*, presents a methodology for the design and control of a high-stiffness fast tool servo (FTS) system for a practical application in diamond machining of freeform surfaces. The electromechanical model of the FTS system is established by combining the piezoelectric actuator and flexure hinge mechanism for the formulation of the control methodology. [Item 11) in the Appendix], from Chen *et al.*, proposes a novel 6-DOF magnetic levitation (Maglev) system to improve the robustness and upgrade positioning precision. [Item 12) in the Appendix], from Sun *et al.*, treats a thrust bias elimination method in the double sided linear induction motor (DSLIM) with segmented power supply. The mathematical model of the DSLIM module considering dynamic longitudinal end effect is established first and a new field orientation is presented as well. [Item 13) in the Appendix], from Cervera *et al.*, presents a design and implementation of a magnetic actuation system (MAS) with noninvasive displacement measurement by current sensing only. A platform-independent MAS modeling methodology is utilized, describing the cross-coupled system behavior by physical representation of mechanical and electromagnetic counterparts [Item 14) in the Appendix] from Trapanese *et al.*, proposes the design and testing of a linear generator for a highly reliable wave energy conversion system, where the system is able to produce hydrogen in order to store energy.

The guest editors hope that this special section will be of interest for people coming from both the academia and the industry who work in the area of LEMs. They are grateful to all the authors who have contributed to this special section, making it possible, and to all the reviewers who have spent their time studying and commenting on these contributions. The guest editors would also like to thank Prof. L. Franquelo, the past Editor-in-Chief of the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, for his support.

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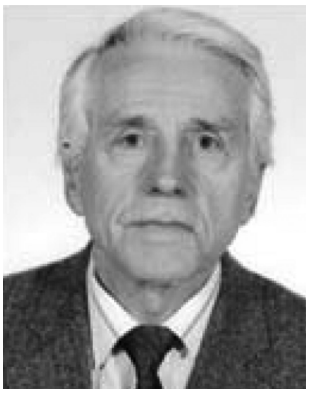
APPENDIX
RELATED WORK

1) A. Mohammed, M. Galea, T. Cox, and C. Gerada, "Consideration on eddy current reduction techniques for solid materials used in unconventional magnetic circuits," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4870–4879, Jun. 2019.
2) X. Zhao and S. Niu, "Development of a novel transverse flux tubular linear machine with parallel and complementary PM magnetic circuit for precision industrial processing," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4945–4955, Jun. 2019.
3) X. Z. Huang, J. Li, C. Zhang, Z. Y. Qian, L. Li, and D. Gerada, "Electromagnetic and thrust characteristics of double-side permanent magnet linear synchronous motor adopting staggering primaries structure," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4826–4836, Jun. 2019.
4) M. Zhao, Y. Wei, H. Yang, M. Xu, F. Han, G. Deng, D. Hou, and P. Zhang, "Development and analysis of novel flux-switching transverse-flux permanent magnet linear machine," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4923–4933, Jun. 2019.
5) H. Chen, S. Xu, W. Wei, J. Yang, and R. Nie, "Reliability assessment of double-sided linear switched reluctance generator system based on hierarchical Markov model," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4901–4911, Jun. 2019.
6) Y. Sui, Z. Yin, M. Wang, B. Yu, and P. Zheng, "A tubular staggered-teeth transverse-flux PMLM with circumferentially distributed three-phase windings," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4837–4848, Jun. 2019.
7) S. Miric, P. Küttel, A. Tuysuz, and J. W. Kolar, "Design and experimental analysis of a new magnetically levitated tubular linear actuator," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4816–4825, Jun. 2019.
8) M. Flankl, L. de Oliveira Baumann, A. Tuysuz, and J. W. Kolar, "Energy harvesting with single-sided linear induction machines featuring secondary conductive coating," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4880–4890, Jun. 2019.
9) W. Huang, W. Hua, F. Yin, F. Yu, and J. Qi, "Model predictive thrust force control of a linear flux-switching permanent magnet machine with voltage vectors selection and synthesis," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4956–4967, Jun. 2019.
10) W.-L. Zhu, X. Yang, F. Duan, Z. Zhu, and B.-F. Ju, "Design and adaptive terminal sliding mode control of a fast tool servo system for diamond machining of freeform surfaces," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4912–4922, Jun. 2019.
11) M.-Y. Chen, C.-F. Tsai, and L.-C. Fu, "A novel design and control to improve positioning precision and robustness for a planar maglev system," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4860–4869, Jun. 2019.
12) X. Sun, L. Shi, Z. Zhang, and H. Zhu, "Thrust control of a double-sided linear induction motor with segmented power supply," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4891–4900, Jun. 2019.
13) A. Cervera, O. Ezra, A. Kuperman, and M. M. Peretz, "Modeling and control of magnetic actuation systems based on sensorless displacement information," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4849–4859, Jun. 2019.
14) M. Trapanese, V. Boscaino, G. Cirpriani, D. Curto, V. Di Dio, and V. Franzitta, "A permanent magnet linear generator for the enhancement of the reliability of a wave energy conversion system," *IEEE Trans. Ind. Electron.*, vol. 66, no. 6, pp. 4934–4944, Jun. 2019.



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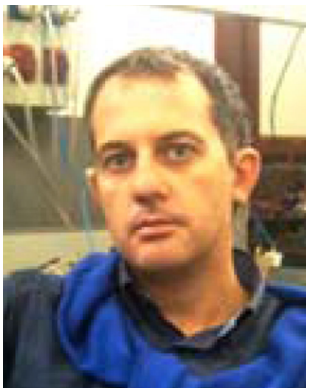

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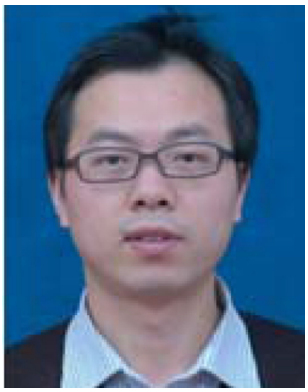

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