4.4　永久磁石型同期電動機／リニアドライブ

統計マップを用いた横方向磁束型リニア同期モータの求推力条件での体積設計点導出法

Practical Design Method of a Transverse Flux Linear Synchronous Motor for Compact Size, Small Mover Weight, High Efficiency, and Low Material Cost Using Graphical Mapping

Shin Jung Seob

The permanent magnet linear synchronous motor (PMLSM) has provided a good solution to many applications in industrial areas. Especially, PMLSMs with the transverse-flux-topology (TF-PMLSM) is suitable for applications in which large thrust at a low speed is required, such as 5-axis machining center, laser soldering, and wire electric discharge machine.

On the other hand, motor designers design PMLSMs in a certain designated volume according to user's (or application designers) requirement for thrust and have to provide users with PMLSMs with thrust in compact size, small mover weight, and high efficiency at a low cost as possible. Once volume is determined, the range of performance for which motor designers can design is also determined. For that reason, estimation of the appropriate volume to achieve compact size, small mover weight, high efficiency, and low material cost in the preliminary design stage is the important factor which motor designers have to consider as a start point of the design for the thrust requirement from users.

Typically, motor design are conducted with a large number of parameters, including material data, structure of the armature and field sides, and winding patterns etc. The finite element method (FEM) has been employed for the design of TF-PMLSM because it provides highly accurate design results. However, considered volume design as a start point of the design for the required thrust in the preliminary design stage, using FEM is computationally expensive and results in enormous amount of time for design. Using optimization theory is one of the good alternative to save design time in the TF-PMLSMs. However, theory itself is sometimes difficult to understand and a large multi-dimensional design parameter space inevitably increases the complexity of the optimization.

In this research, we propose the practical design method of TF-PMLSM using graphical mapping which is useful for estimation of the appropriate volume as a start point of the design for the thrust requirement to achieve compact size, small mover weight, high efficiency, and low material cost in the preliminary design stage.

リニア駆動都市鉄道の高性能化の研究
―リニア誘導モータの二次側構造の改良と ATO を積極的に活用する省エネ運転―

ニン バン クオン

リニア誘導モータ（LIM）はリニア地下鉄の駆動系交通機関の駆動装置として用いられ、今後も導入が続くと考えられます。一方、LIM には端効果・縁効果という特有の現象があり、その機械的速度の上昇に伴いモータ特性が劣化するという欠点があります。現在私の研究では三次元動機界計算に基づき、LIM のインピーダンス計算や実際の運用にてギャップ長の変化や LIM のリアクションプレート建設が生じた場合の特性の違いについて検討を行っております。また、リニア地下鉄が LIM による非接触直接駆動で、駆動及び制動の制御を電気で行えるため ATO 運転に適しており、運転曲線を積極的な省エネルギーの観点から再設計します。今後はこの結果をもとにリニア地下鉄システム全体のさらなる高性能化に関する研究へと発展させたいと考えております。

A Study on Enhancing the Performance of Linear Metro Driven Railway
-- Improve the Design of the Secondary part of Linear Induction Motor and
Energy-saving on Automatic Train Operation --

Ninh Van Cuong

Urban transportation systems are required to reduce construction, maintenance, and operating costs, and improve comfort and convenience, as well as to be environmentally friendly. Japanese companies have been working on the development of the linear metro since the 1970s to meet these requirements. Driven by a Linear Induction Motor (LIM) and employing a steel wheel/steel rail track system, the linear metro is an advanced urban transportation system offering a wide range of features that are not available in other train systems. On the other hand, in comparison with traditional driven system, LIM driven system has low efficiency and power factor, because LIM has special characteristics and inherent problems due to the non-continuity of the magnetic field. Longitudinal end effect and transverse edge effect are two major electromagnetic phenomena of LIM, which makes the analysis, design and control of this motor difficult. At this moment, based on the fundamental mathematics and formulation of the simplified field calculation, by using 3-D numerical analysis, the influence of the finite length of the primary part and the finite width of the secondary part will be considered in LIM performance. In order to reduce the influence of the non-continuity of electromagnetic field, based on the end-ring solution for rotary induction motor, the use of cap for secondary reaction plate has been considered in my research for designing new generation of LIM for linear metro system. In addition, saving energy in Automatic Train Operation (ATO) for linear metro will be positively thought by electric control of braking and driving mode.

横磁束形リニア波力発電機の応答曲面法を用いた高速最適設計とその評価

渡辺隆嗣

波力発電システムの市場導入には発電機自体に高出力、低コスト、容易なメンテナンス性の 3 つの要求があり、その要求を満たす発電機の設計が重要である。容易なメンテナンスの観点から、ギアと変換器をなくすことができるリニア発電機が適すると考えられ、高出力の観点から永久磁石を用いた同期発電機で横磁束形が適すると考えられた。よって本研究では波力発電用に横磁束形リニア発電機の設計を高出力と低コストを評価値として最適設計を行った。

横磁束形リニア機は磁束の作る面と進行方向が異なることから複雑な構造を形成し、最適設計が困難である問題が存在する。さらに横磁束形の有限要素法（FEM）を用いた解析には三次元解析が必須であり、従来は初期設計の段階から時間のかかる三次元過渡応答解析に比重をおいた設計を行っていた。これらの設計の問題点を解決するため、応答曲面法と三次元静磁界解析を用いた高速最適設計法の提案を行った。横磁束形リニア発電機のモデルはシンプルな磁気回路を構成することができ、容易な設計が達成される形状として円筒形 4 極機、円筒形 8 極機、円筒形 12 極機、正方形の 4 つのモデルにて提案手法を用いた最適設計を行い、その結果から高速最適設計法の評価をし、波力発電用の横磁束形リニア発電機の最適形状の提案を行った。

それらの結果から、誤差値が約 4%で 92.6%の時間短縮できる設計法が確立され、出力とコストの両面で優れたリニア発電機の設計に成功した。

Rapid design optimization using response surface methodology and its evaluation of transverse flux type linear wave generator

Ryuji Watanabe

Recently, ocean energy conversion has been of great interest in the industrial field. Generally, large power density, low cost, and easy maintenance are important technical requirements for wave power generation. The transverse flux type permanent magnet linear synchronous generator (TF-PMLSM) is an ideal alternative in which the flux is carried in the iron-back in a plane transverse (perpendicular) to the direction of motion and current flow.

However, the process for manufacturing conventional transverse-flux-type topologies is generally difficult because of the complex structure resulting from the presence of a 3D magnetic circuit, which limits its application for wave power generation. For solving these problems, the rapid optimal design method based on response surface methodology and three-dimensional (3D) static analysis is proposed. Four models, 4-poles model, 8-poles model, 12-poles and squared model, which have simple structure are designed by using proposed method. The validity of proposed design method is also confirmed.

As the results, the design error is about 4%, and design time is decreased to 7.4%. Moreover, linear generator which has advantage in output power and cost is designed.

リニア同期モータ長距離駆動のための位置・速度のハイブリッド制御

Hybrid Position and Speed Control of Long Stroke Linear Synchronous Motor

Qi Zhao

Advanced motion control like field oriented control required accurate position and velocity signals to realize better performance. In conventional linear control systems, linear optical-electrical encoders, linear induction synchronizer and laser interferometer is applied to get these signals. In addition,rotating motors require only one sensor in the shaft, but in linear motors, the sensors have to disperse along with roadway. These sensors increase the costs of the system and decrease the reliability. Therefore eliminating position sensors is more important in linear motors than in rotating motors.

Thus, for low cost and high reliability, we would like to implement sensorless control based on Back-EMF for long stroke linear synchronous motor. But Back-EMF based sensorless control showed bad performance at low-speed range. Therefore, several position detectors are used at two ends of motor to fulfill position control of linear synchronous motor, which needs transition from speed sensorless control.By combining position and sensorless speed control of long stroke linear synchronous motor together, it is hoped that low cost and high reliability could be achieved.