

4. 研究現況

4.1 列車の運転整理

混合整数計画法を用いた方向別複々線の運転整理支援

森 拓哉

鉄道において、事故などによって一度運行計画が乱れると、司令員によって「運転整理」と呼ばれる列車運行計画の調整業務が行われる。運転整理案の作成には迅速性が求められるが、列車運行に関わる数多くの制約を満たしたうえで、定量的な評価が難しい「旅客の被る損失」を考慮した複雑な調整が同時に要求されるため非常に困難な作業である。したがって、計算機による運転整理支援システムの開発・導入が強く望まれている。

本研究では列車運行の乱れに対して、混合整数計画法によってすべての乗客を正しく評価し、自動で運転整理案を作成するシステムを提案する。また、同時に乗客の不効用に関する評価も行った。

Rescheduling of Railway Operation in Direction-Working Quadruple Track Line Based on Mixed-Integer Programming

Takuya Mori

In train operation, when disruption happens, train dispatchers conduct train rescheduling to recover the train operation. This task is quite difficult and a severe burden for the dispatchers due to a variety of recovery options, a necessity of swiftness and absence of a proper evaluation criterion. Consequently a computer-aided rescheduling support system is required.

We introduce a train rescheduling algorithm for disruption. This algorithm evaluates all passengers' travel time in correct way and produces the rescheduling diagram based on mixed-integer programming. We also evaluate the deviation of passengers' loss time.

4.2 永久磁石型同期電動機／リニアドライブ

*Proposal of double-sided transverse flux PMLSM and a simplified design approach
for maximum thrust in non-saturation region*

Shin Jung Seob

Large thrust is one of the performance requirements for the permanent magnet linear synchronous motor (PMLSM). The transverse-flux machinery (TFM) is suitable for a large-thrust design. However, the manufacturing process for conventional TFMs is difficult because of the complex structure resulting from the 3D magnetic circuit. In the conventional manufacturing process, a large number of segmented components are needed to make up the magnetic circuit, and the use of lamination is difficult.

On the other hand, the estimation of the design point at which maximum thrust is obtained is important in the preliminary design stage because it saves design time. If the design point is positioned in the saturation region where there is a non-linear characteristic between thrust and current, losses increase and control performance deteriorates, which degrades motor performance. Therefore, it is important to estimate the flux related to magnetic saturation and its position and develop a design for maximizing thrust in the range where magnetic saturation does not occur.

In this research, we propose a double-sided transverse flux linear synchronous motor to address the problem of the complex structure in TFM and a simplified design method for maximum thrust in non-saturation region in the preliminary design stage. The usefulness of the proposed model and method is analyzed and evaluated by 3D finite element method (FEM).

稠密な電機子構造を有する横方向磁束型主電動機の高トルク密度／高力率設計

山元 雄太

2013年1月より国際海事機関による新造船に対する環境規制 EEDI が始まり、昨今の燃料費高騰と相まって抜本的な省エネルギー、CO2 排出量削減を果たす方策が求められている。そういった状況で当研究室は船舶推進モータに注目し、船舶特有の低速高トルク特性を満たすべく狭極ピッチによる多極化が容易な横方向磁束型を採用して、設計／試作を進めてきた。先行研究では、ステータ空間密度の低さと小径丸線による多巻線構造から低トルク密度及び従来の横方向磁束型同様に力率が低いという問題があった。そこで、従来のアキシヤルギャップモータにて使われている稠密な構造を採用するとともに、導体面積が大きい平角線による少巻数構造とし、モータモデリングとパーミアンス法によるパラメータサーベイのための簡易設計と三次元数値解析による詳細設計の二つの工程で体系的に設計を実施し、従来比 70%程度の低電流密度設計ながらも現状の船舶推進モータと遜色ない 11.4Nm/l の高トルク密度化と 0.98 の高力率を達成できることを試作機により明らかにした。高トルク密度によるモータ単体の小型化に加え、高力率化により電力変換器も含めたモータドライブシステム全体の小型化を実現し、電気推進化のメリットを十分に生かせる主電動機を提案／実証した。

Design of Transverse Flux-Type Motor for High Torque Density and High Power Factor with Dense Armature Structure

Yuta Yamamoto

International Maritime Organization (IMO) has started mandatory of energy efficiency design index (EEDI) in January, 2013. The technical developments are essential to achieve energy saving and reduce CO2 emission. For that reason, we have focused on a direct-drive-type propulsion motor without gearbox. The motor is required for high torque at low speed, peculiar characteristics in marine application. Hence, we have designed and developed the motors taking advantage of transverse flux-type motor (TFM), suitable for short pole pitch and large pole numbers. In previous models, however, high torque density and high power factor (PF) are not achieved due to sparse armature structure and large number of turns with small diameter conductor. Therefore, dense structure in conventional axial-flux motor (AFM), trapezoidal stator teeth and field magnets, and flat-type wires with large area of conductor and high coil space factor are applied to a new motor. The design is systematically conducted through two processes, simple design for parameter search based on simple modeling of the motor and permeance method and detailed design by 3-D numerical computation. Torque density of 11.4 Nm/l with current density of 3.5 Arms/mm² and power factor of more than 0.98 are clarified and demonstrated by fabrication of the machine. Consequently, compactness of the motor by high torque density design and that of whole driven system including converters by high PF can be achieved simultaneously. The proposed motor contributes to further development of electric ship propulsion system thanks to high flexibility of ship layout by the compactness as well as high reliability and low maintenance requirements by the gearless configuration.

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上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~

Cuong Ninh Van

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.

波力発電応用に向けた横方向磁束型リニア発電機的设计

渡辺隆嗣

東日本大震災以降、再生可能エネルギー需要の高まりはますます活発になってきている。特に海に囲まれた日本では新技術として波力発電が注目を集めている。しかし、出力とメンテナンスの難しさから発電コストが高いという問題があり、商用に導入することが困難となっている。波力発電応用に向けた発電機の改良は実用化に向け必要とされている技術であり、その要求を達成するために横方向磁束型リニア発電機の提案を行った。

本研究では、波力発電に必要な大出力化と低コストを目指し、横方向磁束型リニア発電機的设计と共にリニア型発電機の簡易設計法の構築を行っている。

Design of Transverse Flux Linear Synchronous Generator for Wave Energy Conversion

Ryuji Watanabe

After the Great East Japan Earthquake, demand of renewable energy is increased. Especially, since Japan is surrounded by sea, the ocean wave has been expected as one of the useful renewable energy in Japan. However, there are a lot of problems such as high cost, low power conversion. Therefore, it is very hard to bring wave power generator into commercial use. Improvement of wave generator for wave energy conversion is one of the required items, and we proposed the transverse flux linear synchronous generator.

In our research, in order to achieve the large power and low cost, we design the transverse flux linear synchronous generator and construct the simple design method.

4.3 鉄道車両の電気駆動制御とエネルギー

電力負荷に応じた電車の回生ブレーキの有効利用**楊 哲**

電気鉄道車両が制動する時主電動機を用いて発電し、回収したエネルギーで付近の加速している電車、もしくは車両の冷房・暖房などの補機に提供する回生ブレーキは、省エネルギー対策の一つとして近年各鉄道会社に普及しつつある。しかし、このような機能の搭載する電車であっても、主電動機の仕様や架線電力負荷などの制限で回生ブレーキが使えない回生失効が起り、列車のブレーキ力を補足するために機械ブレーキを立ち上げざるを得なく、当初期待されるエネルギー回収と機械ブレーキの抑制を十分果たしていない状況にあった。

本研究では、回生ブレーキの有効活用を目的とし、ブレーキパワー上限の制限、及びそれに基づいた走行余裕時間を活かすブレーキ操作支援を提案する。そして実在路線での運転支援実験を通じ、省エネルギーと機械ブレーキの削減効果を実証する。

Regenerative brake based on load of the feeding network**Zhe Yang**

Regenerative brake, which is widely applied in electric railway, is expect to help reduce the wearing of mechanical brake and recycle running energy of the train. However in DC electric railway, regenerative brake will fails when the pantograph voltage is too high, resulting in limited energy recycling effect.

To achieve an effective use of regenerative brake, I propose in this research that a power-limited braking pattern together with a driving assistance for the train driver. Comparing to other researches in this field, this proposal applies little alternation to current railway hardware system, and needs no modification of train diagram. Nevertheless, it brings in a significant lower ratio of regenerative cancellation, with little mechanical braking and with more recycle energy. All of these suggest it an efficient proposal to solve the regenerative cancellation problem in DC electric railway.

省エネルギー運行管理のための運転法の比較分析と列車群電力可視化

渡邊 翔一郎

電気鉄道の運行管理の議論に省エネルギーの視点を取り入れるための基礎検討として、2つの省エネルギー運転法について比較分析を行った。その運転法はノッチオフ速度を下げた走り手法と回生ブレーキを有効活用できるように走る手法で、それぞれにおいて複数の回生絞込条件を考慮した様々なケースでシミュレーションを行った。その結果、回生絞込の程度と走行時分に対しどの運転法が優位になるかがわかった。そして、エネルギーを考慮した運行管理支援するため、電力をダイヤ図に色分けして表示する電力の可視化法を提案している。

Comparison of Driving Patterns and Power Visualization for Energy-Saving Operational Control of a Group of Trains

Shoichiro Watanabe

For an energy-saving train operation, mainly we have two options. One is applying a low notch-off speed with a strong brake. The other one is applying a fully regenerative brake with an ordinary notch-off speed. We compare these two methods to find the evaluation indicators of energy consumption for the optimization of train scheduling.

*A Design of an Optimal Running Curve for Train Operation Based on a Novel Parameterization Method for Saving Energy***Doan Van Duc**

Railway transportation is facing increasing pressure to reduce the energy demand of its vehicle due to increasing concern for environment issues. Therefore, strategies in effectively using energy are becoming even more important, and studies on operation method of train to reduce the total energy consumption are necessary, also. Since the total energy consumption can be modeled as a function depending on the running curve, it is possible to optimize the total energy consumption by searching an optimal running curve, given constraints of running time and motor force. However, the solution for this energy optimization problem is not easily obtained because the cost function demonstrating the relationship between the total energy consumption and the running curve is very complicated due to the nonlinear model of train, and because there are also nonlinear constraints given such as running time and motor force, etc. Therefore, in this research, we focus on studying (1) Modelization Methods to obtain the cost function and the constraint function based on a novel parameterization method of the running curve, and (2) Effective Optimization Techniques to solve the optimization problem. If both of above problems would be solved, Driver Guidance systems or Automatic Train Operation (ATO) systems are able to take advantage of pre-calculated running curve.

4.4 生体機構を取り入れた運動制御

鉛直方向の負荷変動に対応する2足歩行の運動制御 –生体の筋構造の考慮の有無による相違の評価–

Bi-articular Actuation in Robot Arms: Resolving Actuator Redundancy Using Infinity Norm with Closed Form Expression

Salvucci Valerio

Bi-articular actuators - actuators spanning two joints - are gaining popularity for solving the known limitations of conventional robot arms. In contrast with kinematic redundancy, actuator redundancy resulting by the presence of bi-articular actuators increases stability, transfers mechanical energy from proximal to distal joints, and decreases the non-linearity of the end effector force as a function of force direction. From a control point of view, bi-articularly actuated robots often present more actuators than joints, resulting in actuator redundancy. The resolution of actuator redundancy represents a key point in the control design for such robots.

We propose a redundancy resolution approach based on infinity norm optimization criteria. The proposed approach is expressed in a closed form expression (no need for iterative algorithms) to be implemented in real time. The solution is expressed by piecewise linear functions continuous in all the domain.

The proposed solution has been compared with the widely used pseudoinverse matrix, and shown to lead to a greater maximum end effector force, a lower maximum joint actuator torque, and a faster response.

生体機構の特徴を取り入れた仮想伸縮脚モデルによる効率的二足歩行制御**河邊 貴之**

本研究では、ヒトの特徴を取り入れたヒューマノイドロボットの二足歩行制御を提案した。特にエネルギー効率の良い準受動的歩行に基づき、ヒトの筋骨格構造と制御的な効率に着目することで、歩行と筋骨格構造の本質的特徴を見出し定式化することにより、仮想伸縮脚コンパスモデルに基づく直感的な歩行制御が可能とした。

歩行立脚期・遊脚期において、支点と先端を結ぶ方向への制御において大きなメリットを持つことを明らかにし、提案歩行制御手法により、エネルギー効率に優れた準受動的歩行を、支点と先端を結んだ方向への運動に基づく運動制御によって簡単に実現することができる。

さらに、提案する歩行制御の実機への適用を行なう際に問題となるバックドライバビリティを解決する、関節受動化制御を導入し検討を行った。

Efficient life-inspired motion control for biped walking based on virtual stretching leg model**Takayuki Kawabe**

We presents a energy efficient biped walking control based on biological structures. We focused on biological structures and efficiency of human's motion control. The proposed method enables robots to walk very intuitively with virtual compasses model. Advantages of proposed straight motion control is clarified and proposed method is verified with energy efficient walking. In addition, we examined backdrivable joint control for experiments.

*A Constrained Cascaded Generalized Inverse Ensuring Continuity in Redundancy Resolution***Baratcart Travis**

It often occurs in the resolution of redundant systems that for a desired realizable output, the resolved inputs exceed input limits, rendering the solution unfeasible. The Cascaded Generalized Inverse (CGI) was introduced to take these input limits into accounts and extend the resolvable range of the popular pseudo-inverse method of resolution, by iteratively reallocating to under-utilized inputs. However in extending the range of the pseudo-inverse, it also loses one of its main benefits in resolution – continuity. These discontinuities observed in CGI resolution can introduce tracking error, instability, and other negative effects (e.g. joint knocking in robotic manipulators) in physical systems. To overcome this issue of discontinuity, we have proposed a constrained CGI which restricts the domain of CGI – sacrificing some extended output range while ensuring continuity. Implementation of constrained CGI has been demonstrated resolving kinematic redundancy and avoiding the discontinuities observed in CGI resolution.

省エネルギー歩行における速度・歩容の探索

本田 拓馬

二足歩行ロボットは、危険地帯での作業など、人間に代わり人間の作業空間において活動することを求められている。しかし、エネルギー効率の悪さなどの点により、要求されている活動を行うことは難しい。

本研究では、人間の二足歩行の特徴に注目し、また人間の生体機構である二関節筋を用いることで、二足歩行ロボットの基本動作である二足歩行におけるエネルギー効率を向上することができた。

Searching optimized velocity and a gait of a biped robot for energy saving walking

Takuma Honda

A biped robot is demanded to work as a substitute for human in human's workspace, for example, working in a danger zone. However, today, it is difficult to do such things because of its low energy efficiency.

In this study, we tried to improve energy efficiency of robot's biped walking by using bi-articular muscle.

4.5 ロボットの自律制御

個人対応の移動ロボットとモバイル情報機器を用いた生活支援のための人間活動の仮想化技術の研究

Human activity virtualization for daily life support using a personal mobile robot and digital devices

Wee Hong Ong

In the modern society, human activity support or assisted living technologies are useful to address various social needs such as personal assistant and elderly care. However, such technologies have not been accessible to average people in real home setting due to the expensive infrastructure requirement. This research study the solution with a system composed from affordable consumer devices-personal digital devices and low-cost mobile robot. Currently, we are working on the core functionality of such system: human activity recognition. We are taking the approach of unsupervised learning to detect human actions with features constrained by human range of movements. Unsupervised human activity recognition will be an enabling technology for self-learning human activity support intelligent systems, be smart space or personal assistant robot.