

4. 研究現況

4.1 列車の運転整理

数理的最適化手法に基づく運転整理の計算機支援

森 拓哉

鉄道が人身事故などでダイヤ乱れが生じた際、元のダイヤに戻す業務を運転整理と呼ぶ。平常時の運行管理に関しては自動化が進む一方、運転整理については指令員の経験と勘に頼って行われ、鉄道事業者にとって大きな負担となっており、計算機により運転整理案を自動で作成するシステムの開発が望まれている。今までも運転整理の研究は盛んに行われてきており、旅客損失に関する評価量に基づき、運転整理案を自動作成する手法の検討が行われてきた。しかし、これらの手法の多くは局所的判断の積み重ねに基づくメタヒューリスティクスなどの準最適化手法が用いられており、得られた解が本当に最適かどうかの保証がない。本研究では混合整数計画法の手法を用いて、旅客損失を主眼におきつつ、最適性の保証を持った運転整理案を導出することを目的としている。先行研究では現実時間内に解を導出するためにモデルが非常に単純なものとなっていた。そこで、より現実に即した評価を行うためにモデルの見直し、評価関数の選定などを行った。

Computer-aided Railway Rescheduling Based on Mathematical Optimization Technique

Takuya Mori

In train operation, when disruption occurs, train dispatchers operate trains to recover the schedule. This operation is called "rescheduling". While normal operation operated by computer, rescheduling is operated by human depending on dispatcher's experience and intuition. It has become a heavy burden for railway companies, so the system that creates rescheduled idea automatically is desired. The study of rescheduling problem based on evaluation of passenger loss has been considered even now, however, these techniques are based on metaheuristic techniques which do not guarantee optimality. The purpose of our research is the optimization of passenger loss with a guarantee of optimality by using Mixed Integer Programming (MIP) method. In previous research, the model was very simple due to the calculation time. Therefore, we review the model and the object function to evaluate more realistic scene.

乗車率に応じた旅客行動の変化を考慮した運転整理支援

大橋 和也

鉄道は専用軌道を持つため定時運行率が高いという特徴があるが、輸送障害は増加する傾向にある。輸送障害などによって列車ダイヤに乱れが生じた場合にはダイヤに変更を加えて復旧する業務が行われる。これを運転整理と呼ぶ。

平常時の運行管理は自動化が進んでいる一方、運転整理は自動化が進んでいない。これは、運転整理は指令員の経験による勘に頼る部分が大きいためである。したがって、指令員の負担を軽減するために運転整理案を自動で作成するシステムが望まれている。

先行研究において、旅客損失に主眼を置き混合整数計画法によって最適化を行う運転整理支援システムが提案されたが、実用化に向けていくつかの課題が残されている。

本研究では、それらの課題のうち、列車の混雑による旅客の行動の変化についてモデル化を行う。

Train rescheduling considering the change of passenger flow depending on train congestion

Kazuya Ohashi

In railway system, the rate of on-time service is high, but transport disorder tends to increase. When transport disorder occurs, train rescheduling is performed.

Since the train rescheduling in railway operation is a difficult task, the rescheduling system is expected to support the staff. Previous work suggested the train rescheduling system focusing on passenger delay, but it has problem that it doesn't consider the train congestion.

We introduce the mathematical model of the change of passenger flow depending on train congestion.

4.2 鉄道車両の電気駆動制御とエネルギー

直流電気鉄道の電力流を考慮した省エネルギー運転手法の研究

渡邊 翔一郎

いま鉄道は環境親和性の高い乗り物として注目を浴びているが、更なる省エネルギー化を実現する可能性を秘めている。本研究では都市交通で利用される直流電気鉄道に注目し、運行管理を見据えた省電力・省エネルギー化の実現に向けた研究を行った。

本研究ではまずこの回生失効を抑え、回生エネルギーを有効に活用するため、数値解析法を用いた異なる運転方法の電力および電力量の評価と試運転車両による営業路線での現車試験によるその理論の検証を行った。前者の数値解析では2つの省エネルギー運転方法を比較分析し、列車の加速に必要なエネルギーを減らすより回生ブレーキを性能いっぱい使うことが省エネルギーに有効との知見を得た。

現車試験ではその実証と問題点の抽出を行った。そして回生ブレーキを最大限活用するために運転士に運転方法をアシストする運転支援装置を開発し、実験的に明らかになった操作遅延の対策を行い、マニュアル運転の支援という形で提案する運転法が実現可能であるということを実証した。また、過去の運転最適化研究の成果として知られている最大力行・惰行・最大制動という結果に回生ブレーキを積極的に用いる考え方を適用し、回生電力の抑制を考慮した電力制限回生ブレーキの適用により従来よりも省エネルギー効果があることを明らかにした。

これらの検証により1列車で得られる省エネルギー効果の限界が把握できたため、さらに省エネルギー化を進めるため列車群の知的管理による省エネルギー手法の検討を行うこととした。現車試験データの分析により列車群の電力流に注目すれば回生負荷を予測できる成果を得たことから、列車群の電力制御に向けてATO制御路線を対象としたダイヤ改正を含めた検証試験を計画している。現在、ピーク電力をダイヤから数値解析し、補機電力を考慮した省エネルギー運転を評価することで駅間走行時分配分最適化をダイヤ改正の主力とする結論を得ている。

Research on Energy-Saving Operation Method Considering Power Flow in DC-Electric Railway

Shoichiro Watanabe

Effective use of regenerative brake is important to manage energy-saving. This paper presents the running method for energy-saving on DC-electric railways considering restriction of keeping running time. First, two methods are employed for an energy-saving operation. Second, we take an on-track test in order to verify the effectiveness of energy-saving operation. Third, we use rescheduled train diagram considered passenger flow by mixes-integer programming method and make power visualization diagram and calculate consumption power and regenerative power in order to reduce energy consumption and peak power. Finally, we propose the research schedule for doctoral course and future work in this area is on the way to consider train group control.

4.3 非接触給電

(非接触給電車両用の) 蓄電装置容量を最小化する電気鉄道の運転曲線設計法

A Design Method of Running Profiles of Electric Train Minimizing Required Capacity of Energy Storage Devices

(--For a Train fed by Intermittent Contactless Power Transmission--)

Doan Van Duc

In recent times, CPT-powered Train has attracted much attention because it avoids the disadvantages of ordinary trains fed by catenary wires, such as: high maintenance cost, noise and sparking effects due to contact problem, and adverse effects on the city's landscape and also environment [1]. There are two configurations of CPT-powered train. In the first configuration, the train is supplied on road during its running (dynamic charging). This configuration ensures continuous energy supply, but it requires long power lines along with the rail; therefore, its construction cost is quite high. In this research, we want to focus on the second configuration of CPT-powered train, the train is frequently charged only during the stopping time at every station (static charging).

While there are many researches about designing CPT modules for train to improve efficiency and capacity of CPT module as well as reduce its size and weight, only few researches concern about the operation of CPT-powered train such as: (1) How to realize Energy-saving operation; (2) How to realize the operation to minimize Required Capacity of ESDs. To CPT-powered train, ESDs supply the main energy for the train, so their weight and size are quite large, even their cost is also high, which is currently a problem of CPT-powered Train. Therefore, the operation of CPT-powered Train to minimize Required Capacity of ESDs, leading to reduce the weight and size of ESDs, is especially desired. This research will find a solution for this problem by finding appropriate Running Profiles with the aim at minimizing Required Capacity of ESDs. In addition, the optimal Running Profile that ensures the Energy-saving operation of CPT-powered train also will be considered.

鉄道用電磁誘導式非接触装置の研究

松岡 秀樹

電気鉄道は省エネルギーで二酸化炭素排出も少ない、環境負荷の小さい交通手段であるが、架線等の饋電設備の導入コストが大きいという問題がある。これを解決する一つの方法として、駅停車中の充電を想定した非接触給電システムが挙げられる。

本研究では大容量の電力伝送に適している電磁誘導方式の非接触装置を採用し、電磁誘導方式の弱点である位置ずれ時の効率低下に着目して研究を行なった。複数のコア形状と補償回路方式に比較検討し、位置ずれ時においても高効率なシステムについて提案した。

A Study on Inductive Contactless Transfer for Railways

Hideki Matsuoka

Although electric railways require low energy and emit fewer CO₂, it is a problem that initial costs for feeder facilities such as catenary lines are high. One of the solutions for this problem is a contactless power transfer system which feeds stopping trains in stations.

In this research, an inductive power transfer, which suits high power transfer, is adopted and the decline of efficiency under misalignment, which is a disadvantage of inductive power transfer, is focused. Comparing several shapes of cores and compensate circuits, high effective system even under misalignment is proposed.

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.

4.5 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 and a higher performance in intrinsic stiffness modulation.

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

Redundancy is a useful criteria, endowing systems with fault tolerance and dexterity while operating in dynamic and unpredictable environments. However, when these redundant degrees of freedom are not being employed in solving a particular problem, how best to distribute input contributions is ambiguous. This problem of redundancy resolution has been the subject of a great deal of deliberation, however the vast majority of implementations have chosen to make use of the 2-norm in resolving systems due to its simple implementation in general systems. To address the shortcomings of 2-norm resolution, while retaining the benefits of its simple implementation, we have introduced three resolution methods. Two methods have been introduced improving upon the concern of the limited resolvable output space of the 2-norm. The Extended Cascaded Generalized Inverse (eCGI) comprises the largest present extension of 2-norm resolution for general systems, though bares the possibility of discontinuity, like other existing methods. The Continuous Cascaded Generalized Inverse (cCGI) then represents the largest extension of 2-norm for general systems which ensures continuity. In a more specific implementation, the 2-norm and the infinity-norm were successfully combined in a continuous switching system for the resolution of biarticular actuation redundancy. This switching system allows for the benefit of both systems' physical advantage in all corresponding regions of interest.

4.6 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.

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