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論文内容の要旨

## Study of the unified control system of the magnets in the KEKB/PF-AR accelerators

KEKB is a double-ring, asymmetric-energy, electron-positron collider, which is pursuing luminosity frontier. In order to improve its luminosity, commissioning has been continued incessantly. Because various machine tunings are frequently necessary during the commissioning, the control system is required to be highly responsive and flexible. Especially for the magnets and magnet power supplies, which define optics of the accelerators, the efficiency and flexibility of the control system are essentially important.

To achieve these requirements the design and the construction of the control system of the magnet power supplies have been carried out with the following view points. The most important point is the unified treatment of the magnet power supplies. KEKB has wide variety of the magnet power supplies, from the large power supplies for the main bending magnets to the small power supplies for the steering magnets. The bending magnets, quadrupole magnets, sextupole magnets and steering magnets require different type of power supplies and are operated in the different manner. The magnet can be iron core or air core, superconducting or normal conducting, with or without auxiliary windings, and so on. There are many different types of the magnet power supplies, in the scale, in the regulation scheme, bipolar or unipolar, with or without pole changer, and so on. Although such differences exist, focusing on the common properties of the magnet power supplies, the hardware of the interface and the software of the control system have been designed not separately for each type but designed as universal for the all types as possible.

Another important point is reliability. Although resources of the budget and the man power to construct KEKB have been limited, it has been required to keep the control system reliable. Not only in the construction phase but also in the maintenance phase, reliability should be considered. In order to maintain reliability in such conditions, the design strategy adapted is simplification. Especially it is important how to simplify the interface to the magnet power supply with the control computer. It greatly influences the reliability of the control system. In the previous, TRISTAN, control system CAMAC was adopted as the standard interface. Between the CAMAC module and the magnet power supply there were wired signal lines for each signal one by one. If KEKB adopted the same scheme, the amount of wires could be huge because the number of magnet power supplies in KEKB is large, more than double. In KEKB, instead of the parallel wiring, one serial line has been introduced for a magnet power supply. All signals are exchanged through the single serial line.

Thus, considering unification and simplification as the important principles, the magnet power supply control system has been developed. There are two major tasks in the development. One is the development of the interface between the control computers and the magnet power supplies. The other is the development of the control software. KEKB control system has adopted EPICS (Experimental Physics and Industrial Control System) as the core software framework.

And two types of computers have been installed. One is IOC (Input/Output Controller), which directly controls the equipments through its own hardware connection to the equipments. The other is OPI (Operator Interface), which runs various high level applications like operator interface.

The synchronous operation of multiple magnet power supplies is required in order to change optics without loosing stored beams. For this purpose, the synchronous setting has been designed that the tracking data are calculated in the IOC and sent to the magnet power supply beforehand and then the synchronous start signal triggers the synchronous tacking. In this method the magnet power supply is required to store the array data for the tracking and to set them in sequence with the interval clock. Although it requires some intelligence in the magnet power supply, total system can be simplified and flexible operation is possible. ARCNET (Attached Resource Computer NETwork) has been adopted as the serial interface. It supports relatively long packet and communication speed is enough for our purpose. The twisted-pair cable with RS485 type differential driver has been chosen as the media of ARCNET. This configuration allows multi-drop wiring. The synchronous start signal is also delivered by the cable combined with ARCNET. Thus, the simplification of the wirings has been achieved. For the implementation of the ARCNET interface, the PSICM (Power Supply Interface Controller Module) has been developed. It is the plug-in module in the magnet power supply and has an ARCNET interface and a microcomputer with the control software (firmware). PSICM has been designed to be universal for any type of the power supplies. All of the magnet power supplies can be controlled in single manner using PSICM.

In the development of the control software, the magnet power supplies have been treated in unified manner. Among the different types of the magnets and the power supplies, the common features are abstracted. Major functions incorporated in the IOC are followings.

(1) parameter conversion from abstracted magnetic field strength to the current

(2) regular setting sequences to reduce the magnetic hysteresis problem

(3) synchronous and asynchronous operations for the current setting

Although the magnet power supply control system has been originally designed for the KEKB, because of its universal design, it has been also well applied to the PF-AR magnet control system. PF-AR has been upgraded in 2001. At that time its control system has been renewed using the same way as KEKB. PSICM can be used for PF-AR without any modifications. Most of the control software for KEKB can be also applied for PF-AR. In addition for PF-AR, the pattern operation of the acceleration has been developed based on the same mechanism of the synchronous operation. The tracking pattern of the acceleration can be flexibly configured.

As the unification has been implemented in the IOC layer, the magnet power supply can be treated as the abstracted object independent of the hardware in the OPI layer. Such abstraction has reduced the load of the development of the user application programs. Thus, during a decade of the commissioning of the KEKB accelerators, many application programs have been developed and have contributed to the tuning up and improvement of the accelerators continuously.

博士論文の審査結果の要旨

中村氏は KEKB 加速器の建設期から加速器の主要な装置の一つである電磁石および電磁石電源の制御システムを中心的な立場で担当し、その後も PF-AR の高度化における電磁石制御システム更新や Super KEKB の企画／建設においても電磁石システムの制御での中心メンバとして活躍されている。この論文はそれらの電源制御システムにおいて、加速器／ビーム制御の立場から統一的な取り扱いを進めることで効率の良い制御システムを構築できることを、これまでの経験をもとに論じている。これらの制御システムが最終的には先進的な加速器において設計性能を充分に発揮することにつながっている。

この論文では、中村氏はまず KEKB のような先進的な加速器において求められる電磁石／電源制御システムについて求められる性能について論じている。電磁石・電源は加速器においてその荷電粒子光学を決定し、その中での荷電粒子の安定性等を左右する重要なコンポーネントである。また加速器中のビームを操作するにも、この電磁石・電源制御システムを通じて行うことになる。制御システムには高信頼性／安定性とともに、運転状況の変更に対応するための柔軟性が必要となる。中村氏の論文は制御システムの設計の過程を KEKB を例に論じ、「統一性」と「簡素化」をキーワードにその設計を特徴づけた。

この「統一性」および「簡素化」の原則の適用範囲は、電磁石電源の配線方法、電磁石電源制御基盤の開発、電源制御システムへのソフトウェア的なアクセス方法など多方面にわたっている。論文ではさらに、氏が中心となって開発した KEKB 加速器の電磁石／電源制御システムの実現においてこれらの原則がどのように実現されたかを論じた。この電磁石電源制御システムによって、高度な加速器／ビーム制御が実現され、KEKB 加速器の目覚ましい発展に寄与したことは関係者のよく知る所である。

審査委員会は全員一致で、中村氏の仕事は、独創性に富み、加速器の電磁石電源制御システムの発展ひいては先進的な加速器性能の実現に貢献したものであり、また、今後建設される加速器およびその制御への大きな応用性を持つ価値ある研究であることから、中村氏の論文は学位論文に値するという結論に達した。