Construction and Facilities Technologies for the K computer

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The facilities for housing the K computer and for cooling and supplying power have many features not found in other supercomputer sites. These include an expansive, pillar-free computer room, a power supply system that combines the functions of a cogeneration system (CGS) and a high-speed current-limiting circuit breaker without using an uninterruptible power supply (UPS), distribution boards installed under a raised floor instead of on computer-room walls, extremely quiet, high-efficiency air conditioning equipment, and a cooling-water system for CPUs featuring precise temperature control. These features are part of a policy that was adopted to ensure quick and easy installation and stable and safe operation of the K computer. The application of these unique features did not require the development or adoption of new technologies. It was accomplished by cleverly combining existing, proven, and mature technologies having a stable reputation, since a development project limited in time and budget should not adopt novel and unproven technologies. This paper describes the construction and facilities technologies supporting the operation of the K computer.

1. Introduction

The building housing the K computer[note 1)] was completed and delivered at the end of May 2010, and the cogeneration system (CGS) that provides power and heat to the K computer was completed and delivered at the end of January 2011. Installation of the K computer in this building got under way at the end of September 2010, and all computer racks had been installed by the end of August 2011. As rack installation progressed, power was applied and heat-source and cooling facilities were brought online. The CGS began continuous operation in April 2011.

Despite several initial problems such as kinks in the flexible pipes used to deliver CPU cooling water and the difficulty of transitional operations to gradually raise output power as more racks were installed, the various types of facilities have been operating continuously since their startup, and the installation of the K computer, holding of trial runs, and making of adjustments have gone unhindered.

This paper describes the construction and facilities technologies adopted for the K computer site to ensure stable and safe operation of this supercomputer.

2. Expansive, pillar-free computer room

The computer room housing the K computer is spacious, with a floor area of 3000 m^2 (60 m × 50 m) (**Figure 1**). A 600 m^2 anteroom (storeroom) is set up on the east side of the computer room,

note 1) “K computer” is the English name that RIKEN has been using for the supercomputer of this project since July 2010. “K” comes from the Japanese word “Kei,” which means ten peta or 10 to the 16th power.

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but since the walls of this anteroom can be dismantled and removed, the floor area of the computer room can actually be extended up to 3600 m^2 (60 m × 60 m). This is about twice the size of a public gymnasium.

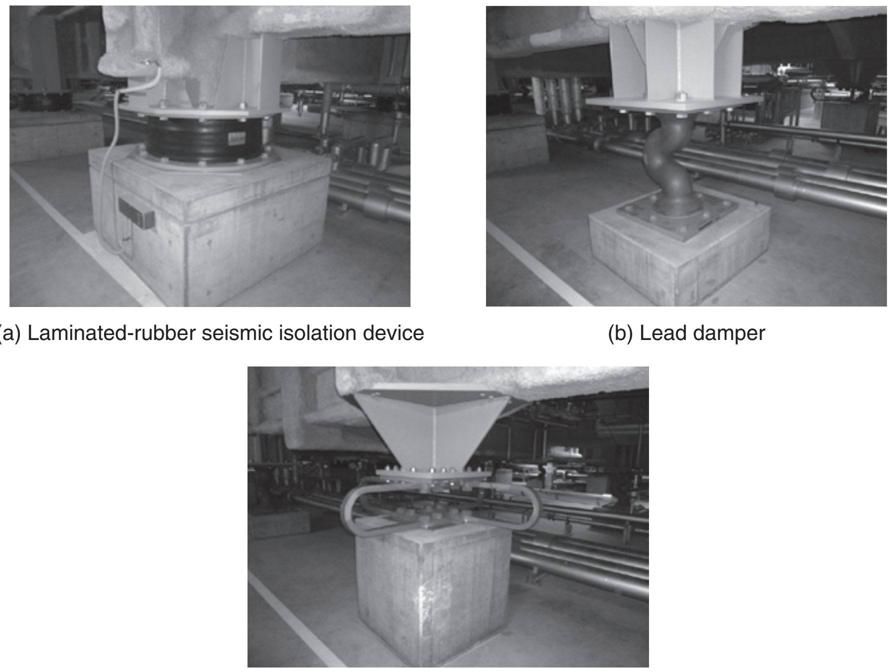
This expansive computer room was configured without pillars so that system racks could be arranged without restriction and the computer room could be laid out as desired. This pillar-free configuration was made possible by the following two technologies.

Figure 1
Third-floor computer room (before computer installation).

1) Seismic isolated structure

Ordinary buildings tend to twist during an earthquake. To prevent a building from twisting and collapsing, pillars and beams must be made thicker, the number of pillars must be increased, and a large number of braces must be used. In contrast, a seismic isolated structure enables a building to sway mostly in the horizontal direction, which negates the need for an anti-twisting structure.

The computer building is supported by 49 laminated-rubber seismic isolation devices, as shown in **Figure 2 (a)**. This type of device can undergo a maximum displacement of 70 cm from its center position, making it difficult for seismic movement to be transferred to the building. Supporting the building with these devices keeps maximum acceleration of the building to 200 Gal, which prevents computer racks from toppling over. This level of earthquake



(a) Laminated-rubber seismic isolation device

(b) Lead damper

(c) Steel damper

Figure 2
Seismic isolation equipment.

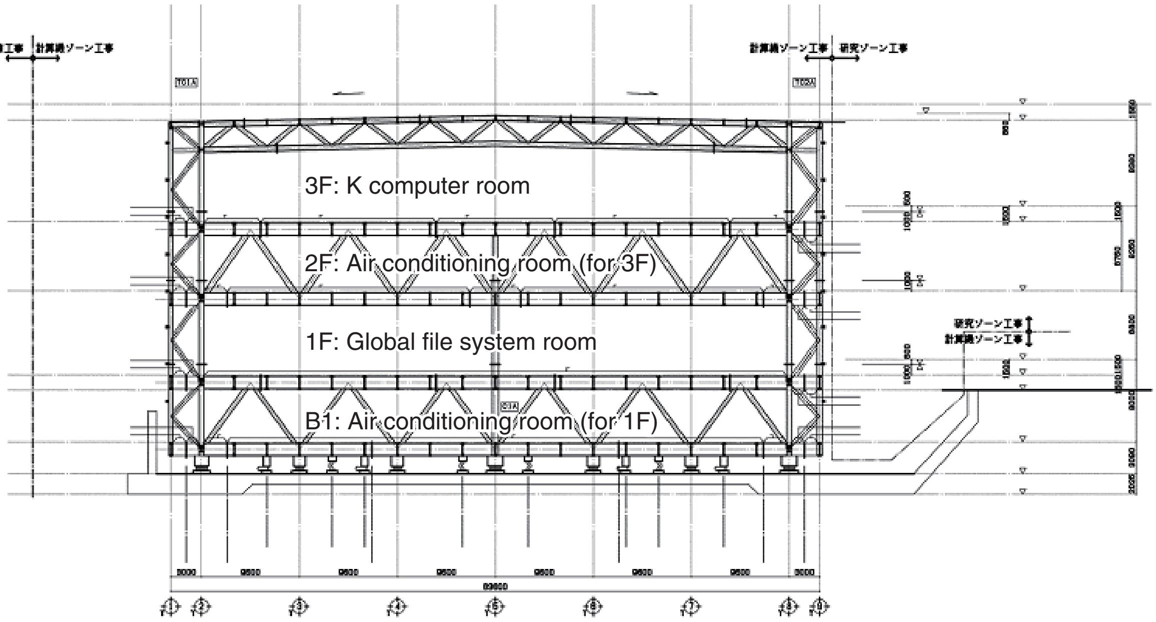


Figure 3
Cross-sectional diagram of computer building.

resistance is equivalent to that applied to critical buildings like disaster-response centers and hub hospitals that need to keep functioning after an earthquake. At this level, no damage occurs from a medium-scale earthquake of about 5 on the Japanese Meteorological Agency (JMA) seismic intensity scale and only slight damage from a large-scale earthquake of 6 upper, which means that main building functions can be maintained in either case. To ensure safety at the design stage, simulations were of course performed using the seismic wave model prescribed by Japan's Building Standards Law but also using actually measured waves and ones forecast to occur in a future earthquake in the Tonankai region[note 2)] of Japan where the K computer site is located.

At the same time, a building supported only by laminated-rubber seismic isolation devices will continue to sway even after an earthquake has died down. Two types of passive vibration-suppression devices (dampers), as shown in **Figures 2 (b)** and **2 (c)**, are therefore used to bring this swaying to a stop in a relatively short time. Specifically, 28 lead dampers and 28 steel dampers are installed. The reason for using two types of dampers here is that they complement each other with respect to a variety of seismic waves and have good combined characteristics since the materials used in each have different breakdown points and initial-stiffness values. These two types of dampers are oriented in a variety of directions depending on where they are installed so that their combined characteristics remain unchanged regardless of the direction of seismic waves.

2) Bridge construction technology

The computer room that houses the K computer is on the third floor of the computer building. The same technology used to build bridges was used here to provide support for a large computer room without pillars on such a high floor. A cross-sectional diagram of the computer building is shown in **Figure 3**. The triangular truss structure of the second-floor air conditioning room provides support for the computer room above. It functions as a "truss

note 2) An earthquake-prone ocean area on the Pacific ocean side of Japan running from the Kii Peninsula to Enshu-nada Sea.

bridge," 60 m wide and 60 m long.

3. Countermeasures to power interruptions and voltage dips without using a UPS

3.1 Dealing with power interruptions using CGS and high-speed current-limiting circuit breaker

Data centers are generally required to provide services without any downtime and often use an uninterruptible power supply (UPS) or a redundant power supply for this reason. The K computer site, however, was planned under the condition that only certain critical loads (front-end facilities that exchange information with the outside via a network, data storage facilities, and portions of the research building where research must continue) would be targeted for protection from power interruptions. The demand power for such critical loads targeted for protection was estimated during the design stage to be at least 5000 kW, which makes the adoption of a standard storage-battery-type UPS difficult since it would increase initial costs and drive up running costs associated with maintaining the installation site, replacing batteries, etc. In addition, the time required for shutting down computers after a power interruption in a large-scale computer facility would be longer than the UPS protection time (5–10 minutes). In other words, the battery capacity of a UPS system is simply insufficient.

In light of the above, we combine a CGS and high-speed current-limiting circuit breaker as a power supply for a critical load system and take countermeasures to power interruptions and voltage dips by using this combined power supply as a UPS.[1] As shown in **Figure 4**, the CGS runs continuously, supplying power to all

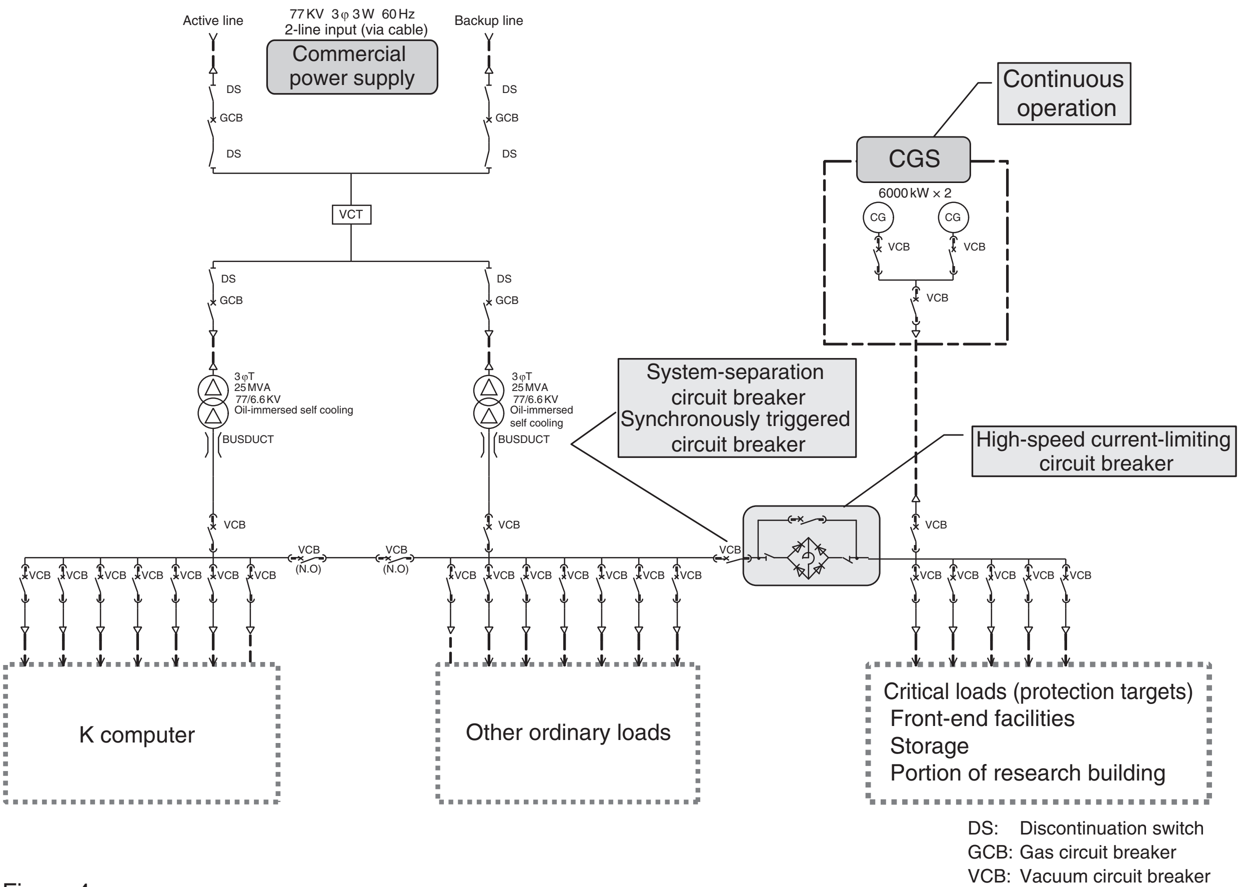


Figure 4
High-voltage facilities (single-line wiring diagram).

facilities with any shortfalls in power made up by the commercial power supply. At the time of a power interruption or voltage dip, the high-speed current-limiting circuit breaker kicks in to immediately insulate the commercial power supply from the CGS with the aim of diminishing the impact on critical loads and protecting the CGS. In this way, the system has been configured to protect the K computer and its cooling facilities from power interruptions and voltage dips.

3.2 Dealing with voltage dips using delayed-release electromagnetic switches

The maximum power consumed by the K computer is more than 10 000 kW, and, if we add the power consumed by the cooling system, it is unrealistic to expect a CGS to keep power supplied to the entire system, so there is no other choice but to operate under a commercial power supply. Nevertheless, appropriate measures must still be taken to prevent as much as possible interruptions to operations.

Voltage dips at the K computer site actually occur about three or four times per year. Such dips are usually small and short in duration. A supercomputer's circuits generally incorporate many capacitors, which prevents the computer from halting operations in the event of a voltage dip of short duration (about 0.1 s). It has been found, however, that electromagnetic switches used in power panels that drive chillers and air conditioning equipment are easily affected by slight voltage dips. In short, while the supercomputer itself can survive slight voltage dips, the cooling system can be halted due to the release of electromagnetic switches, which would have the inevitable effect of bringing the supercomputer down.

To therefore prevent the operation of the K computer from being halted due to slight voltage dips, it was decided to use a delayed-release type of electromagnetic switch in the power panels. This type of electromagnetic switch can maintain a closed-circuit state at a contact point for 1 s. Preventing chillers and air conditioning equipment from stopping operation due to slight voltage dips in this way helps to raise the availability factor of the K computer.

4. Underfloor distribution boards for simplifying rack installation

The conventional approach to supplying power in a computer room is to mount the power distribution boards on the walls of the room and draw cables to the computer racks. The computer room housing the K computer, however, is expansive with a floor area of 3000 m^2, which calls for a relatively large number of distribution boards. But given that a wall is only about as long as the square root of the floor area, there is not enough wall space to accommodate such a large number of boards. One response to this problem of inadequate wall space is to set up a separate distribution board room, but this is also impractical since the wiring length (distance to a rack along the designated cable path) would be overly long. It was therefore decided to adopt a method that uses the space underneath the raised floor used for computer wiring to install one distribution (switching) board per computer rack as a way to supply power to computers (**Figure 5**).

The K computer development project competes with other supercomputer projects around the world, which makes it necessary to shorten the time taken to install computer racks. Placing a distribution board directly underneath each rack unit in the K computer enables power to be connected to a rack immediately after installing it. It also shortens wiring length for this connection, making for a more reliable power supply. The close proximity of each unit to an underfloor distribution board can also prevent erroneous operations when applying or cutting off power, thereby increasing operation safety.

Adopting an underfloor distribution board scheme negates the need to mount distribution boards on walls. This creates an atmosphere completely different from that of conventional computer rooms. Instead of an impersonal machine room, Fujitsu has succeeded in creating a streamlined and elegant atmosphere that sets the K computer apart in terms of supercomputer design.

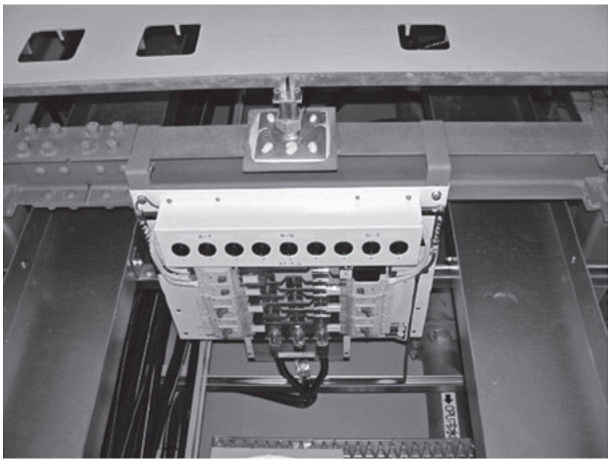


Figure 5
Distribution board under floor.

5. High-efficiency air/water cooling system

5.1 Effective use of full pressure

The height (depth) of the raised floor on which computer racks are installed is 1.5 m. The free-access space under this floor is used not just for wiring but also as space for CPU-cooling-water piping and as a supply chamber for cooling air. If the floor area of a computer room is not too large, as in a typical data center, air conditioning equipment can be installed along the periphery of the computers on the same floor. However, to distribute cold air uniformly through the large space housing the K computer (about 3000 m^2), there is no other alternative but to place the air conditioning equipment directly under the computers. This results in the placement of the computer room on an upper floor and of the air conditioning room on a lower floor, with the cooling air circulated between these two floors as if they were one floor in accordance with the Japanese Building Standards Law (**Figure 6**).

Air conditioning power must be high enough

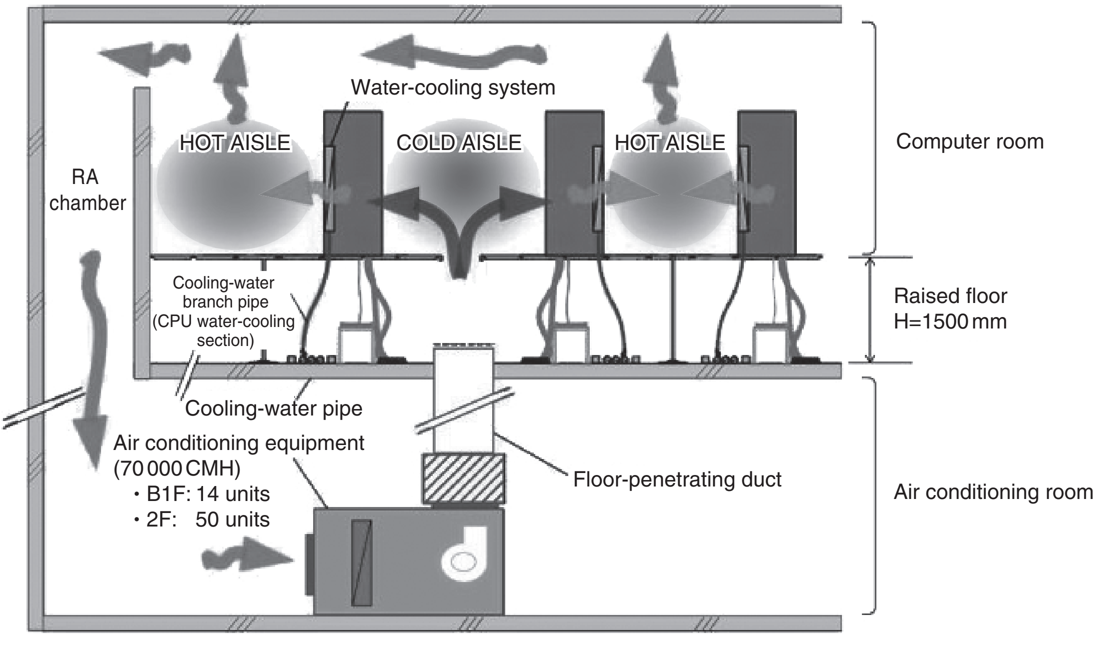


Figure 6
Air conditioning system for the K computer room.

to produce fast air flow and large pressure loss. The structure of the computer building is such that air conditioning equipment is placed on the floor directly under the K computer room so that cold air can be blown directly into the free-access space under the raised floor directly under the computer racks. As a result, cold air is blown at high speed from the free-access space into a cold isle and then returned slowly to the air conditioning room on the lower floor via a return-air (RA) chamber after cooling the computers. This arrangement minimizes duct length and decreases duct loss and other types of energy loss. This system makes effective use of both static pressure and dynamic pressure to blow cold air directly into the free-access space; that is, it uses the total efficiency of the air conditioning equipment.

5.2 Adoption of high-efficiency plug fans

The efficiency of belt-driven sirocco fans used in ordinary air conditioning equipment is no more than 30% while the total efficiency of direct-drive plug fans as adopted here can be as high as 70%. As a result, fan-motor capacity (= consumed power) can be reduced by more than half compared to that of a sirocco-fan system.

The use of high-efficiency fans here results in a noise value of about 75 dB in the air conditioning room, even with all equipment running, which is a level at which people can carry on conversations. A high noise value essentially means poor energy-conversion efficiency since energy that should be used to transport air is being converted to noise energy. The high-efficiency fans also help to reduce noise in the computer room given that the cooling air establishes a continuous connection between the two rooms.

5.3 CPU cooling-water facility

A direct-cooling system using water was adopted for the CPUs and InterConnect Controllers (ICCs) in the K computer. Water has a heat capacity four times that of air while being an incompressible fluid, which means that the power for transporting water as a cooling medium can be made less than one-fourth that of cold air. At this site, primary cold water is shared with air conditioning equipment and is conveyed to each rack after passing through heat exchangers installed in the second-floor air conditioning room. The temperature of this conveyed water is kept to 15 ± 1°C. RIKEN has experience in using a cooling-water facility at its accelerator site and was able to apply that technology to the K computer site, resulting in a stable CPU cooling-water facility.

6. Conclusion

The K computer is housed in a safe and stable site using construction and facilities technologies that take energy efficiency and environmental preservation into account. The energy-saving performance of an entire site such as a data center is commonly evaluated on the basis of power usage effectiveness (PUE). The K computer site recorded a PUE of 1.34 during the LINPACK benchmark test conducted in October 2011, which confirmed the energy-saving and environment-friendly characteristics of the K computer. (The method used here to calculate PUE followed the "Guidelines for PUE/DCiE Calculation (Ver. 2.1)" issued by the Environmental Standard WG of the Japan Data Center Council.) Looking forward, the plan is to operate the K computer site using PUE = 1.3 as a target.

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