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## Operation of the SKS magnet at the K1.8 beam line in the J-PARC hadron hall

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### Abstract

The Superconducting Kaon Spectrometer (SKS) magnet has been operated for 5 years in the hadron hall of the Japan Proton Accelerator Research Complex (J-PARC). The SKS had two long-term suspensions. One was due to damage by the 2011 off Pacific coast Tohoku Earthquake and the other was caused by the radioactive material leak accident at the hadron hall that occurred on May 23, 2013. The SKS was planned to be moved to another beam line to repair the damage caused by the earthquake. The planned move was postponed for processing after the accident.

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### 1. Introduction

The Superconducting Kaon Spectrometer (SKS) magnet is a large superconducting dipole magnet of the sector type employing a liquid He bath cooling method. Originally, it was constructed with a dedicated mid-sized refrigerator at the K6 beam line of the 12-GeV proton synchrotron at the KEK Tsukuba campus in 1991 and was operated for 15 years. After modification of the cryogenic system, it was installed at the K1.8 beam line of the

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hadron hall of the Japan Proton Accelerator Research Complex (J-PARC) in 2009 [1]. Three Gifford-McMahon/Joule-Thomson (GM/JT) cryocoolers to maintain the contained liquid He by re-condensation and three Gifford-McMahon (GM) cryocoolers to cool thermal shields were employed instead of the old mid-sized refrigerator.

These cryocoolers do not have the cooling power to cool from room temperature to the steady state of 4.3 K through liquefaction. It is therefore necessary to transfer liquid N<sub>2</sub> and liquid He manually for initial cooling, which takes two months. Consequently, the system was held at a low temperature as much as possible.

Since the first cooling down at J-PARC in 2009, improvements have been made in reducing cooling periods and in the safe operation of the SKS. During the five year operation period, the SKS has experienced many failures.

On March 11, 2011, the SKS magnet suffered damage by the 2011 off the Pacific coast Tohoku Earthquake [2]. After eight months efforts towards restoration, cooling from room temperature to 4.3 K and excitation tests succeeded, although there were still failures. The SKS magnet was planned to be transferred from the K1.8 beam line to the K1.1 in the autumn of 2013 to complete the repair.

On May 23, 2013, a radioactive material leak accident occurred in the hadron hall. The SKS operation was stopped on July 4. The transfer plan was postponed to investigate the cause of the accident and for improvement of the prevention mechanism of the radioactive material leak.

Fig. 1 shows the five year history of the SKS.

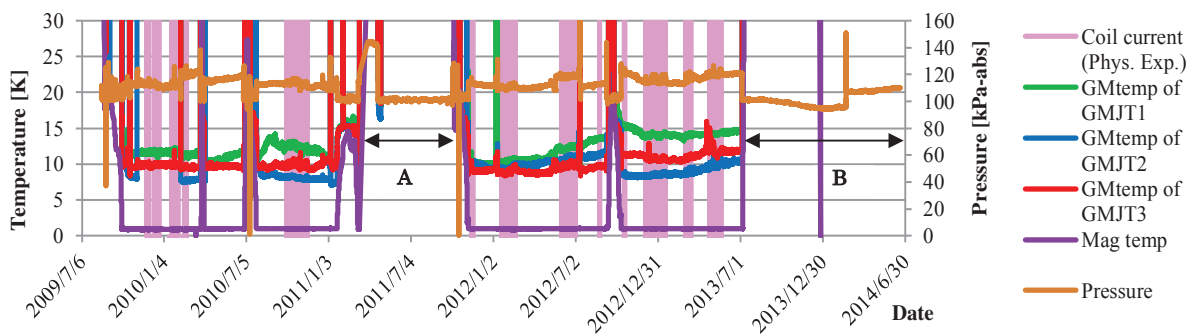


Fig. 1. GM temperature of the three GM/JTs and pressure of the system across five years.

A period: suspension by the earthquake; B period: suspension by the radioactive material leak accident.

## 2. Operation and maintenance before the 2011 off Pacific coast Tohoku Earthquake: 2009–2010

Cooling was started after installation in August 2009, and it achieved a steady state of 4.3 K in October. After excitation tests, it was used for several nuclear physics experiments.

### 2.1. Maintenance and preparation

It is recommended to conduct maintenance of cryocoolers after 10,000 operation hours. In the SKS, maintenance once a year has been performed as much as possible.

- Not all substitute cryocoolers were prepared at the beginning. Therefore, at the first maintenance in 2010, the magnet temperature rose to above 140 K, and it needed liquid N<sub>2</sub> pre-cooling. To reduce the temperature rise, it was required to shorten the maintenance time. Therefore, substitute cryocoolers were prepared one by one.
- Late in 2010, a dedicated water chiller was installed so that it could be used as an alternative with the hadron hall large-scale cooling-water system to cool the compressors of the cryocoolers.
- Late in 2010, to continue cryocooler operation during a scheduled power outage, the circuit for the external gasoline generator was installed.

## 2.2. Failures and measures

- When liquid N<sub>2</sub> pre-cooling was performed at the time of 2010 maintenance, liquid N<sub>2</sub> accumulated in the upper He reservoir. In response, a small current was loaded to the coil, which was in normal state, to heat it and purging with dry He gas was performed.
- In the low-pressure side of the Shield-GM cryocooler, which was being used from 1991, a small He leak occurred at the end of 2010. A bolt of the top flange of the Shield-GM broke, and a crack on the surface was found. Cryogenic operation was stopped, and the magnet temperature rose. Fortunately, the substitute for the Shield-GM was under manufacture. After installing the newly manufactured Shield-GM, cooling was performed again. The SKS achieved the steady state of 4.3 K on March 8, 2011.

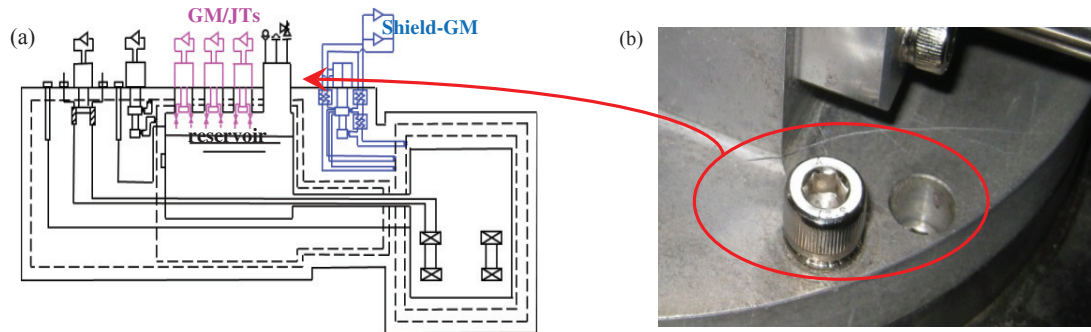


Fig. 2. (a) The SKS cryogenic system; (b) a broken bolt and a crack of the top flange of the Shield-GM.

## 3. Restoration from the disaster of the Off Pacific coast Tohoku Earthquake: 2011

Although the SKS suffered damage from the earthquake that occurred on March 11, 2011, it succeeded in cooling and excitation of the magnet in November [2].

### 3.1. Damages

The SKS was in steady state of 4.3 K and was not excited on the day of the earthquake. The SKS has a check valve and a pressure relief valve which are connected to a J-PARC He recovery system. The system is also equipped with a rupture disk. After power outage, the He gas evaporated from the SKS flowed into the J-PARC He recovery system through the check valve and pressure relief valve.

- (1) The entire magnet and yoke of 280 t moved by a maximum of 77 mm on the floor.
- (2) The yoke, which comprised numerous iron boards, moved (18 mm relatively) on the sector type stainless steel base board. There are relative sideslips between the stainless steel base board and the upper iron yoke.
- (3) All six M20 bolts of a bottom steel stand broke.

### 3.2. Cooling and excitation test

After repair works, cooling from room temperature was successfully performed from October 3 to November 7. It was the second cooling from room temperature after installation in 2009. An excitation test also succeeded.

- Although the hadron hall large-scale cooling-water system was not recovered yet, the prepared chiller was used to cool compressors and the magnet power supply for the first time.
- Repair of the above mentioned damages (2) and (3) was not completed because it needed decomposition and re-assembly of the magnet.

### 3.3. Failures and measures

The hadron hall is one of J-PARC's facilities closest to the ocean. Flexible hoses 40 m in length were connected between compressors in the K1.8 machine room and the SKS magnet on the hadron hall floor. The outside part between the hadron hall and the K1.8 machine room was covered with a pipe.

- A He leak occurred in the low-pressure hose of the Shield-GM in the summer before the cooling test. When the inside of the pipe containing hoses was looked at, rust had arisen on almost all hoses. In response, the leaked hose of the Shield-GM cryocooler was exchanged for a new one. Waterproofing and thermal insulation inside the pipe were also performed.

## 4. Operation and maintenance before the radioactive material leak accident: 2012– 2013

Although repair of the SKS was insufficient after the earthquake, it was used for nuclear physics experiments.

### 4.1. Operation

At the time of scheduled power outage, the external gasoline generator was used for the first time. The liquid He in the SKS did not decrease.

### 4.2. Failures and measures

It was the longest operational period for the SKS cryogenic system.

- May 6, 2012 experienced very severe weather. Two of the four fans on the top of the SKS chiller, placed outdoors, were broken because of a large hailstorm. Chiller operation could be continued because operating it in weak operation mode decreased vibration and noise. On the next day, the large-scale cooling water system started operation and the SKS compressors' cooling water was switched from the chiller to the large-scale cooling-water system. Compressor operation was not stopped. Subsequently, all plastic fans and covers of the chiller were exchanged to metal fans and covers.
- A butterfly valve at the vacuum vessel of the SKS was moved by vibration of the moving work of a vacuum pump; the vacuum worsened slightly. Gradually, the liquid He had evaporated and the coil temperature rose. This was because the butterfly valve could not be fixed in a closed position. The stop flange should have been used to close the butterfly valve below the  $N_2$  boiling temperature. The coil temperature was compulsorily increased to 100 K to evacuate the  $N_2$  gas from the vacuum vessel, and then cooling again.
- A JT valve of a GM/JT cryocooler had fallen out when the JT valve was adjusted during the above-mentioned cooling work. Although the valve was reinserted immediately, its temperature decreased to only 5 K. Cooling to 4.3 K (the re-condensation temperature) was not possible. Fortunately, two other GM/JTs could maintain the steady state and operation could be performed.

## 5. Plan and preparation of the move for repair

A new plan to dismantle the SKS, to move it to another K1.1 beam line, and to re-assemble it there for the purpose of completing repair of the damage caused by the earthquake was proposed.

### 5.1. Background of the move for repair

- To repair the horizontal sideslip between the yoke and the stainless steel base board and to remove a bottom steel stand where all bolts broke, the SKS was required to be dismantled.
- To improve the earthquake resistance over the sideslip between the yoke and the stainless steel base board, manufacture of a new stainless steel base board was required. A method using 23 bolts (M24), which are highly reinforced, was adopted as stoppers to fix the stainless steel base board and the yoke.

- The SKS was required to be moved to the K1.1 experimental area from K1.8 because a large space is required for dismantling and reassembling.
- Originally, the SKS had a pneumatic transpositioner system to move it over the floor. This system was required to be changed to a rail system with wheels because of the space at the K1.1 experimental area.

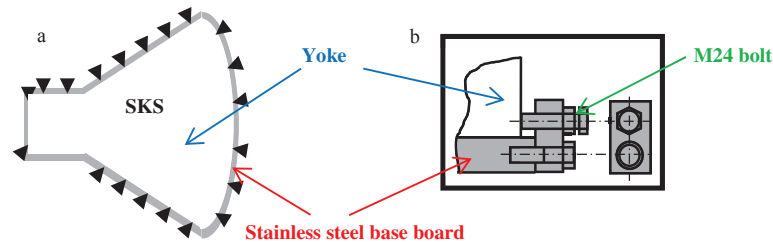


Fig.3. (a) Position of stopper Bolts; (b) A stopper bolt (M24) to fix the stainless steel base board to the yoke.

### 5.2. The original plan and situation

When the plan of moving for repair was formed and was partially underway, the radioactive material leak accident occurred.

- The rail system for the SKS for movement at the K1.1 experimental area was constructed from April to May 2013.
- In the original schedule, a new stainless steel base board should have been manufactured by October 2013.
- In the original plan, the dismantling, move, and reassembling of the SKS were scheduled from October to November 2013.

## 6. Impact of the radioactive material leak accident: 2013–

The outline of the radioactive material leak accident in the hadron hall is as follows:

The accident was triggered by a malfunction of the Extraction Quadrupole (EQ) magnets for the slow extraction system of the 50-GeV synchrotron to the hadron hall. As a result, a large number of proton beams, which have 400 times higher intensity than beams in normal operation, irradiated a gold target for 5 ms on May 23, 2013. The radioactive material evaporated and diffused into the hadron hall and the surrounding atmosphere outside the hall. Thirty-four people, who stayed in the hadron hall at that time, were subjected to internal exposure. The hadron hall was closed for a while to wait for decrease in the radiation level.

Because the SKS experiment had a low priority of beam use on May 23, 2013, the SKS magnet was in steady state, but not excited.

### 6.1. Managing the SKS after the accident

The SKS has a remote monitor surveillance system. In addition, it has three web cameras around the SKS magnet in the hadron hall and five web cameras around compressors in the K1.8 machine room.

- On May 24, it was discussed how the SKS was to be managed. The hadron hall was closed, and nobody could enter. To stop the SKS operation, it was required to enter the hadron hall and manually open a valve at the top of the upper He reservoir of the SKS so that the evaporated He gas is sent into the J-PARC He recovery system. It would take two days for the liquid He to be released from the He vessel of the SKS. After consideration of the situation, it was concluded that operations should continue until the radiation intensity in the hadron hall decreased to a safe level. The surveillance by the remote monitor and web cameras was continued.
- On July 3, a smear test around the SKS in the hadron hall was performed. As the result, it was found that the radiation level was safe and people could operate the valve. On July 4, all SKS cryocoolers were stopped and the valve was manually opened so that evaporated He gas was flown into the J-PARC He recovery system.

## 6.2. Influence of the accident for the SKS

The influence of the accident for the hadron hall is very serious. Physics experiments in the hadron hall were entirely cancelled after the accident, and have not been resumed for more than a year. The cause had been investigated immediately, and the system to control the area for radiation was changed. After it was confirmed that the radiation level was at a safe level, the hadron hall could be entered with some restriction. The system which prevents diffusion of radioactive material and equipment concerned with it have been changed. Continued efforts have been made to resume physics experiments in the hadron hall from the beginning of 2015.

The accident has had serious impact on the schedule of the SKS operation also.

- Manufacturing a new stainless steel base board, which originally should have been delivered by October 2013, was postponed temporarily, and it resumed after consideration of the situation. The newly manufactured base board was delivered at the end of March 2014.
- Evidence that it contained non-radioactive gas in the future operation of the SKS was required, because He gas flows into another building from the SKS in the hadron hall through the J-PARC He recovery system. The largest contribution to radio-activation of He is generation of tritium (T or  $^3\text{H}$ ), which is radioactive with a half-life time of 12.3 years. A neutron (n) reacts with  $^3\text{He}$  nucleus contained in liquid He and generates tritium. An evaluation was made based on the result of the neutron measurement at the K6 beam line of the KEK Tsukuba campus in 2002 and extrapolated. The result was that the generation of tritium of the SKS was 0.096 Bq per 1 L of He gas per half a year of physics experiment (0.096 Bq/L/0.5Y). This is smaller than 5 Bq/L, the detection limit of tritium. It became clear that radio-activation of He in the SKS was not serious.
- In the radiation survey after maintenance of the cryocoolers performed in June 2014, weak X-rays were detected from the removed Shield-GM. It was not allowed to bring it out of the hall. Details are under investigation.
- The dismantling, move, and reassembling of the SKS, which were originally scheduled from October to November 2013, were all postponed. The original contract was changed. Currently, it is being examined whether these plans can be carried out in 2015.

## 7. Summary

The SKS experienced suspensions caused by a natural disaster and an accident. On the other hand, performing physics experiments using the SKS was not suspended by the problem on the cryogenic system. It can be concluded that the worst situations were avoided by preparing substitutes.

The radioactive material leak accident, which occurred on May 23, 2013, had a large impact on the SKS operation schedule. The operation of the SKS was stopped for over one year. The dismantling, move, and reassembly of the SKS to repair the damage caused by the 2011 earthquake were postponed after the accident.

In the future, the SKS operation at the K1.8 beam line will resume from the autumn of 2014 to perform a physics experiment at the beginning of 2015. Dismantling, move to the K1.1 beam line and re-assembly for repair after the physics experiment, are now under consideration.

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## References

- [1] Aoki, K., et al. Construction of the SKS superconducting magnet using GM/JT cryocoolers. In: Chorowski M., et al., editors. *Proceedings of the Twenty-Third International Cryogenic Engineering Conference and International Cryogenic Materials Conference 2010*, Wroclaw: Oficyna Wydawnicza Politechniki Wroclawskiej; 2011, p. 965-970.
- [2] Aoki, K., et al. Restoration of the SKS superconducting magnet from the disaster of the 2011 off the Pacific coast of Tohoku Earthquake. In: Funaki K., et al., editors. *Proceedings of the Twenty-Fourth International Cryogenic Engineering Conference and International Cryogenic Materials Conference 2012*, Tokyo: Cryogenics and Superconductivity Society of Japan; 2013, p. 497-502.