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Contribution to the T2K experiment at J-PARC, Tokai

Design, assembly and installation of the SMRD modules

(2008 – 2009)

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Praca wykonana w ramach projektu: T2K/57/2007, *Badania oscylacji neutrin - eksperyment drugiej generacji - budowa detektora i udział w pomiarach przeprowadzanych w eksperymencie T2K.*

Streszczenie

Pojedyncze liczniki scyntylacyjne detektora SMRD są łączone w większe jednostki zwane modułami. W Dziale Budowy Aparatury i Infrastruktury Naukowej (DAI) Instytutu Fizyki Jądrowej Polskiej Akademii Nauk im. H.Niewodniczańskiego (IFJ PAN) w Krakowie opracowano: konstrukcję modułów, sposób ich stabilizacji wewnątrz magnesu oraz metodę wkładania/wyjmowania modułów wraz z kablami sygnałowymi w szczeliny magnesu. Wszystkie elementy i narzędzia potrzebne do złożenia 440 modułów SMRD, ich stabilizacji oraz instalacji wykonano w Polsce w 2008 r. Moduły SMRD zostały złożone w J-PARC w Tokai a następnie zainstalowane w eksperymencie T2K w 2009 r.

Abstract

The SMRD detectors (counters) of the T2K experiment are assembled into bigger units called modules. The final design of the modules was elaborated in the Division of Scientific Equipment and Infrastructure Construction (DAI) of the H.Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN) in Krakow, Poland. The methods of the module assembly and stabilization inside the T2K magnet were also worked out. Installation procedures of the modules including cable handling were proposed as well. All elements and tools for the assembly, stabilization and installation of 440 SMRD modules had been produced in Poland in 2008. The SMRD modules had been assembled at J-PARC in Tokai and then installed in the T2K experiment in 2009.

1. Introduction

The ND280 off-axis near station had been constructed at J-PARC in Tokai, Japan. It consists of several sub-detectors shown in Fig.1. The Side Muon Range Detector (SMRD) is one of them. The SMRD scintillators are placed in the slits between steel plates of the UA1/NOMAD CERN magnet yoke. The magnet yoke comprising sixteen C-shaped elements is divided into two halves: the North (N) side and the South (S) side .

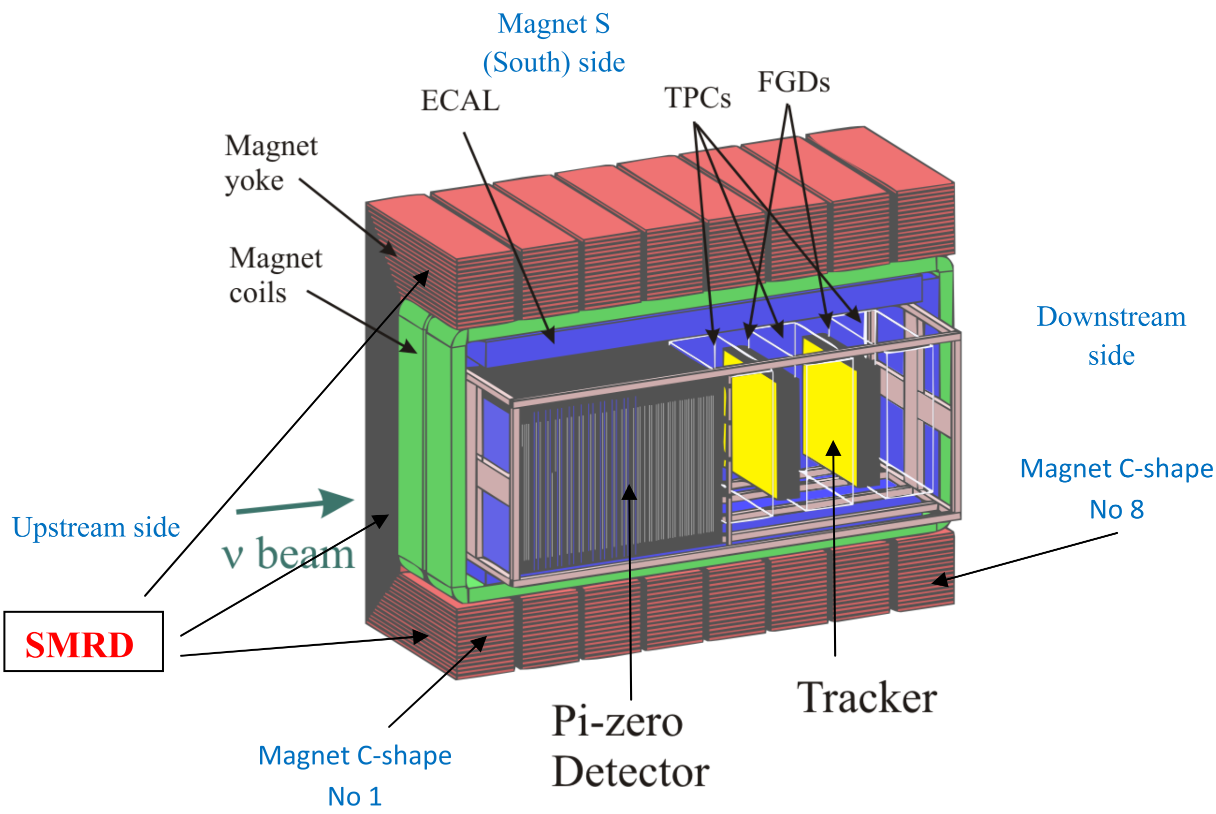


Fig.1 Arrangement of ND280 sub-detectors inside the UA1/NOMAD CERN magnet yoke
(8 C-shaped elements on the N side are not shown)

The magnet C-shaped elements embed the inner sub-detectors of the ND280 near station. Eight from the North (N) side and the other eight from the South (S). The split enables installation of the

ND280 inner sub-detectors inside the magnet. Each pair of two C-shaped elements (one from N and one from S side) create so-called magnet ring. Each C-shaped element consisting of 12 azimuthal sections is built of steel plates 48 mm thick spaced by 17 mm air gaps called slits. The SMRD modules are placed in three slits of the horizontal sections (towers), two on top and two on bottom, and in three to six slits of the vertical ones, four on N side and four on S side, Fig.3. The horizontal and vertical gaps have different size. Thus, sizes and numbers of the scintillators matching the horizontal and vertical slits are also different. The vertical modules comprise five scintillator counters while the horizontal ones only four counters. Main requirements concerning the SMRD detector are described in the Technical Design Report [1]. In the same document are also presented technical details of the SMRD scintillator units.

The experimental area at J-PARC in Tokai, where the T2K near station was constructed, provided the following constraints affecting design of the SMRD modules and their installation procedures:

- insertion of SMRD detectors could be done from either the downstream or the upstream side;
- additional access to the inserted detectors was possible only from the magnet N and S sides through gaps 8 cm wide between neighboring magnet rings;
- detector insertion to the magnet rings No 1, 2, 3, 4 took place from the upstream side,
- detector insertion to the magnet rings No 5, 6, 7, 8 took place from the downstream side,
- available space at insertion sides was very limited (1.5 – 2 m).

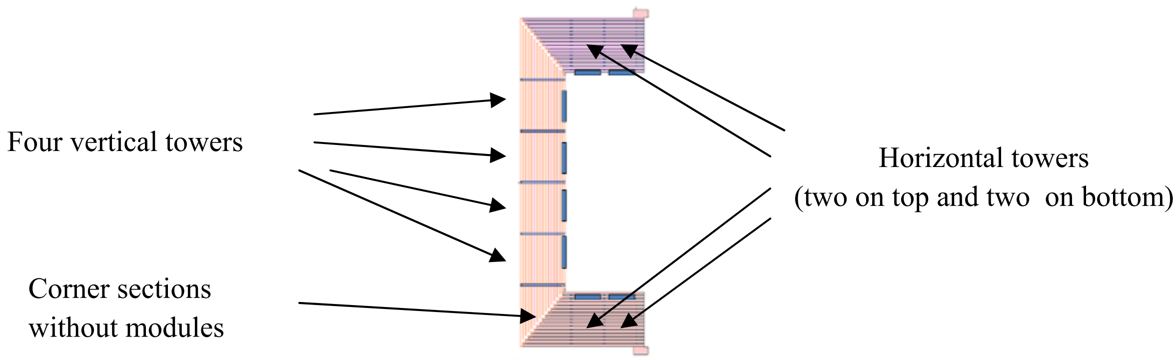


Fig.3 Distribution of vertical and horizontal towers in one C-shaped magnet element

2. Mockup of the T2K magnet

A simplified mockup of four magnet towers was built by the DAI team in Krakow to validate elaborated design and installation procedures of the SMRD modules. The towers are cubicle frames made of wooden members. Overall dimensions of the frames correspond to the vertical magnet towers i.e. 970mm x 880 mm x 870 mm (height x width x depth). There are two movable frames in each cubicle enabling various configurations of neighboring slits (size, relative position) . The wooden members are 48 mm thick to model steel plates of the magnet yoke. The uniform clearance of 8 cm between neighboring towers was set. Primarily, the mockup was used for the elaboration of the design and installation procedures of the vertical SMRD detectors. Then, the design and installation procedures of the horizontal detectors had been elaborated by using the mockup rotated by 90 º and modified accordingly, Fig.4.

Fig.4 Mockup of four magnet towers: AutoCAD drawing (left), set vertically (centre) and horizontally (right)

3. Design of the SMRD counters

The height of the vertical magnet slits is bigger than the width of the horizontal ones. Demands concerning performance of the SMRD detector resulted in different sizes of the horizontal and vertical scintillators. Moreover, number of scintillators placed in the horizontal slits is four while in the vertical ones – five. Detailed description of the SMRD detector design is presented in the SMRD TDR [1] and in [10]. Dimensions of the detectors relevant for the design of the horizontal and vertical modules are shown in Fig.5. A photo of one of the horizontal counters produced in Russia and delivered to J-PARC in 2008 is shown in Fig.6.

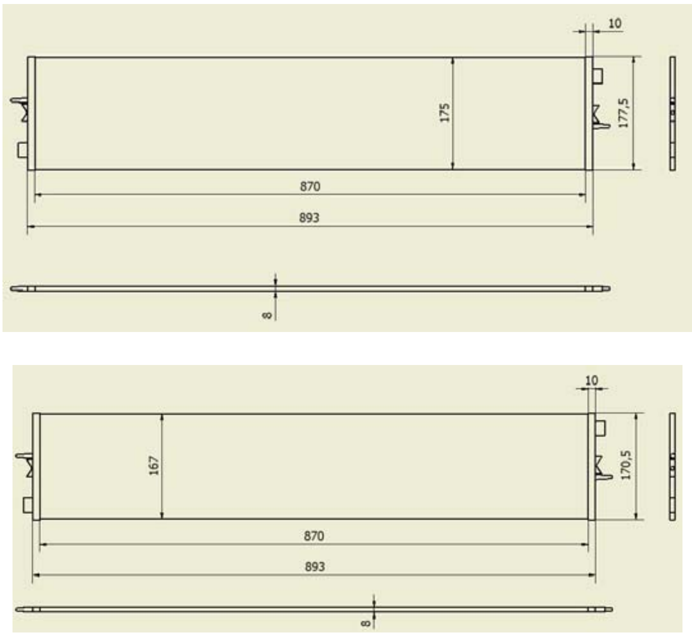


Fig.5 Dimensions of the vertical counter (top) and the horizontal one (bottom)

Fig.6 View of the horizontal counter delivered to J-PARC

4. Insertion of the SMRD counters into the magnet slits

Two concepts of insertion of the SMRD detectors were proposed to the collaboration by the DAI team. The first idea was to install single detectors, as produced in Russia, in the slits. Dummy detectors and other items required during insertion were manufactured at IFJ PAN. The method was verified on the magnet mockup arranged vertically, Fig.7. Technical details were described in [2] and reported to the SMRD group.

Fig.7 Single dummy counter with necessary accessories (H-rails, cables) inserted into the magnet mockup

The second approach was based on the assembly of scintillator counters into modules before their installation in the magnet slits. Due to different sizes of the vertical and horizontal slits two types of the modules were constructed. Vertical modules consisting of five scintillators, Fig.8, are bigger and heavier than the horizontal ones consisting of four scintillators, Fig.9, but their handling during the installation was easier.

The SMRD group finally decided to apply the second concept i.e. to build the modules. Total number of the SMRD modules to be assembled was 440 including 192 horizontal and 248 more complicated vertical ones.

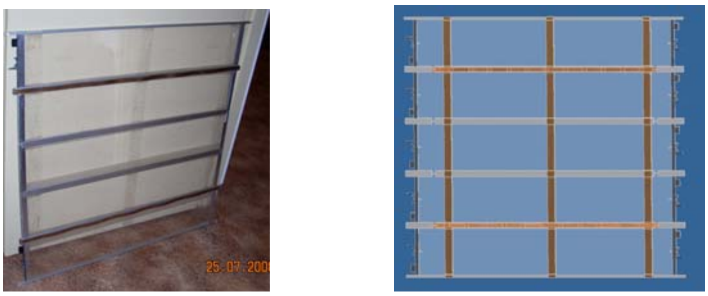


Fig.8 One of the module prototypes (left) and the final design (right) of the vertical SMRD module

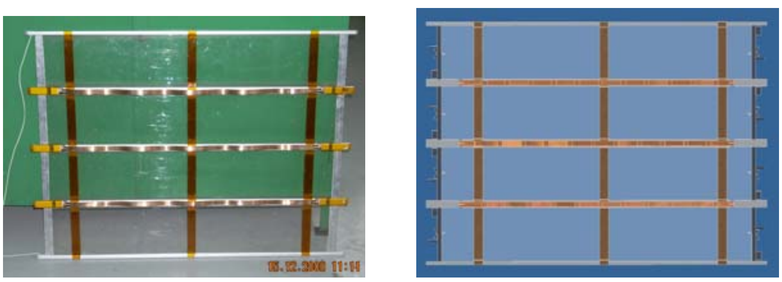


Fig.9 One of the module prototypes (left) and the final design (right) of the horizontal SMRD module

5. Design of the SMRD modules

Following the idea of Aoki-san and Suzuki-san from the SMRD group aluminum C – channels are on the bottom and on the top of each module. Depending on the module type four or three aluminum H – profiles are used to connect neighboring slabs. The slabs and the profiles are wrapped up with an adhesive tape in three places. The assembly prepared like that is relatively easy to handle.

Module supported along C – channels had a sag of 25 mm, while supported along the edges perpendicular to the C – channels only 1 mm. Evolution of the module design is recorded in [3], [4], [5], [6], [7], [8]. Dummy SMRD counters (vertical and horizontal) were made to validate both the final design of the modules and their installation procedures. Use of the magnet mockup was essential during the elaboration process. Concepts, technical details of the design and installation procedures were discussed and agreed with the SMRD group during numerous teleconferences. Dimensions of the vertical and horizontal modules are shown in Fig.10a and in Fig.10b respectively.

There was an open question whether each module will be inserted separately using special tooling or the modules will be connected together during installation forming a "module train". The module design enabled to make a choice at the last moment.

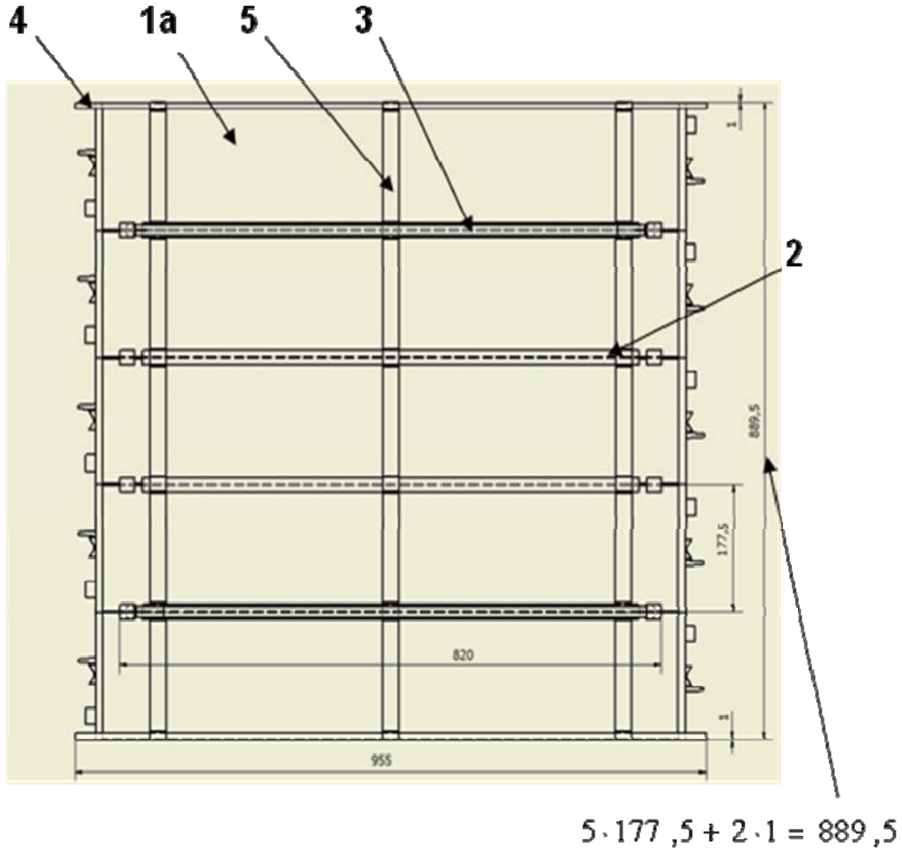


Fig.10a Dimensions of the vertical SMRD module:
1a – Vertical counter, **2 –** Al profiles (H), **3 –** Phosphor – bronze spring 0.4 mm thick, **4 –** Top/Bottom Al profiles (C), **5 –** Kapton tape (25 mm x 0,07 mm; two layers)

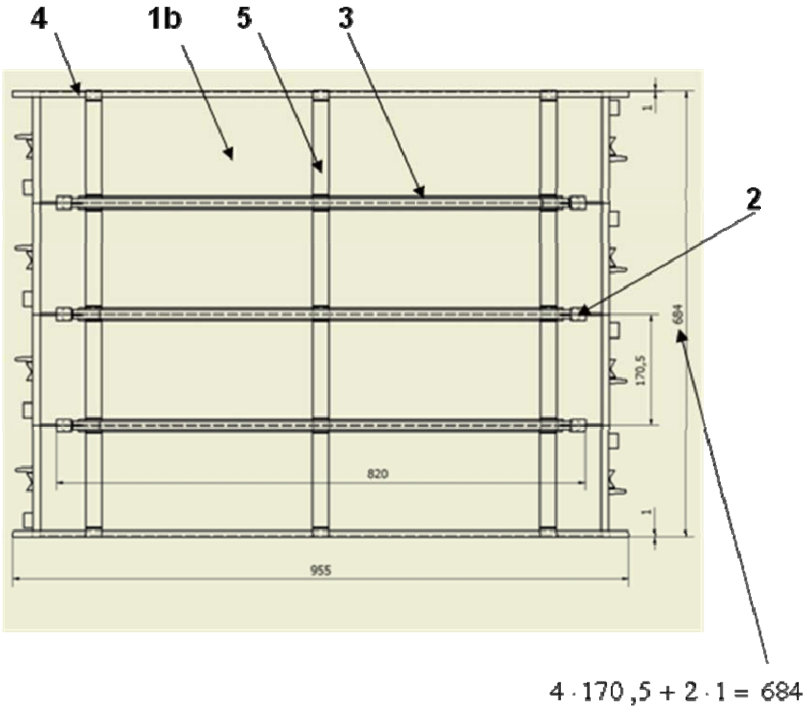


Fig.10b Dimensions of the horizontal SMRD module:
1b – Horizontal counter, **2 –** Al profiles (H), **3 –** Phosphor – bronze spring 0.4 mm thick,
4 –Top/Bottom Al profiles (C), **5 –** Kapton tape (25 mm x 0,07 mm; two layers)

6. Stabilization of the SMRD modules in the magnet slits

The main goal of the DAI team was to find a way of stabilization of the modules inside the magnet slits. Various concepts of stabilization were considered. Finally, it was decided to use tape springs made of phosphor – bronze and mounted on both sides of the modules. The springs are 900 mm long, 15 mm wide, 0.4 mm thick. Each spring has 5 waves. Shape of the springs is symmetric to ensure correct functioning during pushing in and pulling out the modules. Number of springs mounted on the modules is different for the vertical and the horizontal ones. Below two options of spring fixation to the modules are presented.

One option was to fix mechanically the springs on pins tightened in existing M6 holes in the end caps. Pins of 5 mm tightened in the holes keep the springs in a position enabling them longitudinal elongation, Fig.11. Lengths of pins were adjusted to the length of entirely flattened springs.

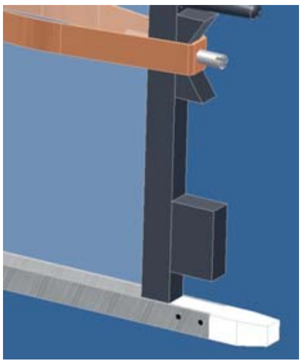


Fig.11 Springs fixed on pins tightened in the existing M6 holes

The SMRD group raised a problem of forces acting on the counters during installation of the modules in the magnet slits. Connections between the end caps and the counters were very fragile. Thus, the demand was to avoid any transmission of forces from the springs to the end caps.

The spring fixation was modified accordingly and tested. The springs were placed along H – profiles and fixed to them. As a consequence lateral and longitudinal forces from the springs act on the H profiles and not on the counters themselves, Fig.12.

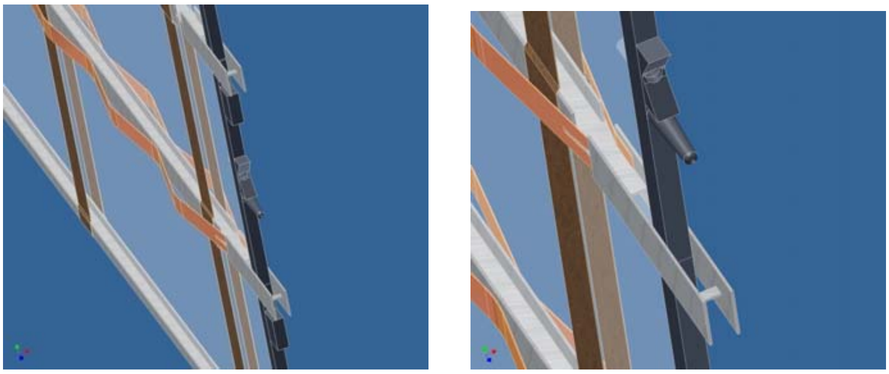


Fig.12 Springs mounted and fixed on H - profiles

7. Spring characteristics

Position of the modules inside the magnet is surveyed and should not change during data taking. Any significant change (± 10 mm) of modules position, e.g. due to an earthquake, will require re-surveying that is a complex and time consuming operation. The springs mounted on the modules are to stabilize positions of the modules after their installation inside the magnet slits.

Deformations of the spring in a function of the applied load had been measured. They appeared to be non-linear. Two types of the springs 0.4 mm thick had been investigated. Shapes and dimensions of the springs are shown in Fig.13. Type II spring is more rigid due to smaller radius of curvature (R=20 mm).

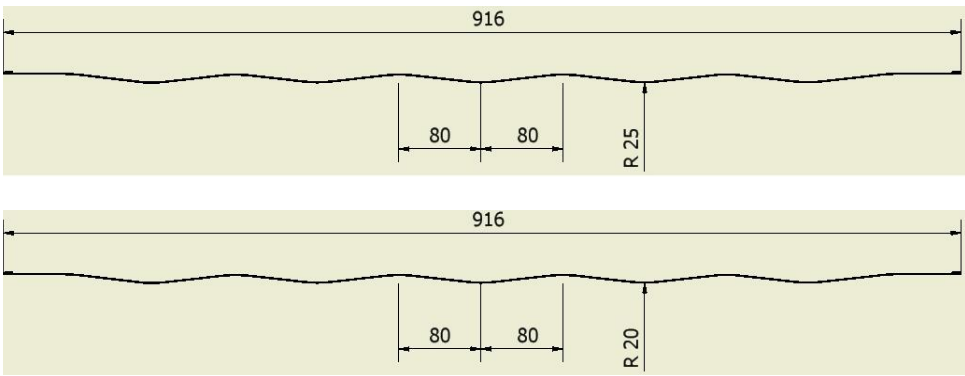
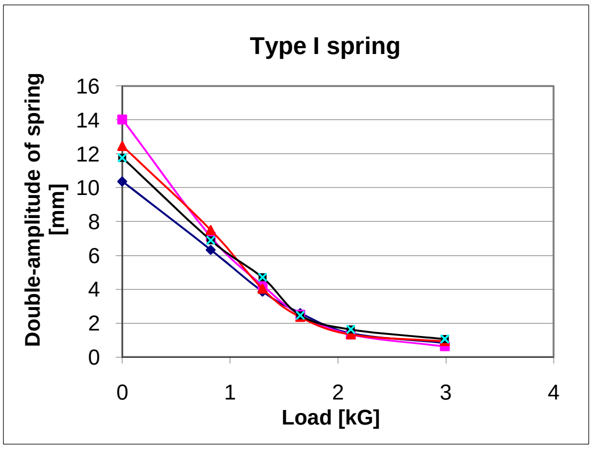


Fig.13 Type I spring (top) and type II spring (bottom)

The springs were hand made without any tooling, thus, their characteristics show certain distortions. The springs mounted on both sides of the H profiles are pre-stressed while the modules are placed inside the magnet slits. Width of the slits varies from 15 to 17 mm. Width of the H profile is 9 mm. There are 3-4 mm of space on both sides of each spring assuming a symmetrical position of the modules in the slits. Basing on the measured characteristics, Fig.14, each type I spring can absorb an additional load of 1.5 kG while type II spring – 3 kG.



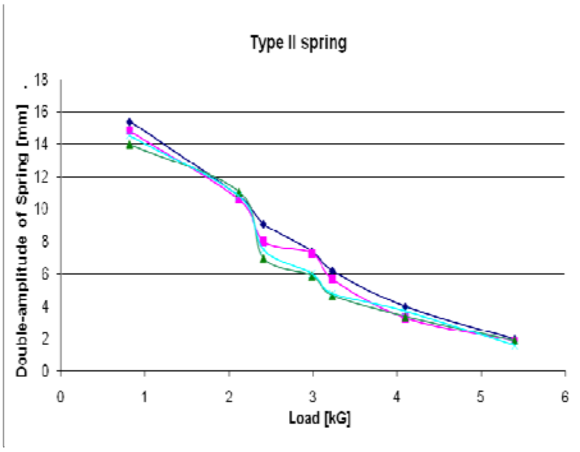


Fig.14 Measured characteristics of springs

Mass of the horizontal modules loads bottom springs while unloads the top ones. Estimated mass of the four - counter module is 6.5 kg. Five type I or three type II springs would be necessary to absorb that additional load. In case of earthquake, type I springs could absorb a vertical acceleration of 0.15g while type II springs - 0.35g. The realistic solution seems to be use of maximum three springs.

Mass of the vertical module does not load springs. Estimated mass of the five - counter module is 8.0 kg. Two type I springs could absorb a lateral acceleration of 0.35g in case of earthquake. Use of two type II springs increases their capability twice i.e. up to 0.7 g. The value 0.15g is the standard number used in earthquake calculations at CERN.

8. Installation procedure of the modules

The installation procedure had been developed by the DAI team after the modules design proposed by this group was approved by the SMRD collaboration. The horizontal set up of the magnet mock up was essential to validate this procedure. We measured forces necessary to pull out the following modules through 4 towers using a dynamometer:

1. One module (with four type I springs) – maximum force 4.5 kG,
2. Two modules connected together (each with four type I springs) – maximum force 9.0 kG,
3. One module (with four type II springs) – maximum 5.5 kG.

The bigger number of modules connected together the bigger force necessary for their insertion or pulling out. The more rigid spring the bigger force required. Basing on the measurements performed we focused on a method of inserting and pulling out a single module.

A segmented jig was proposed to push both the vertical and horizontal modules in the magnet slits. The jig consists of 3 detachable segments and two exchangeable heads matching either the vertical or the horizontal module, Fig.15. The jig had to be segmented because the access areas at upstream and downstream sides of the magnet were very limited.

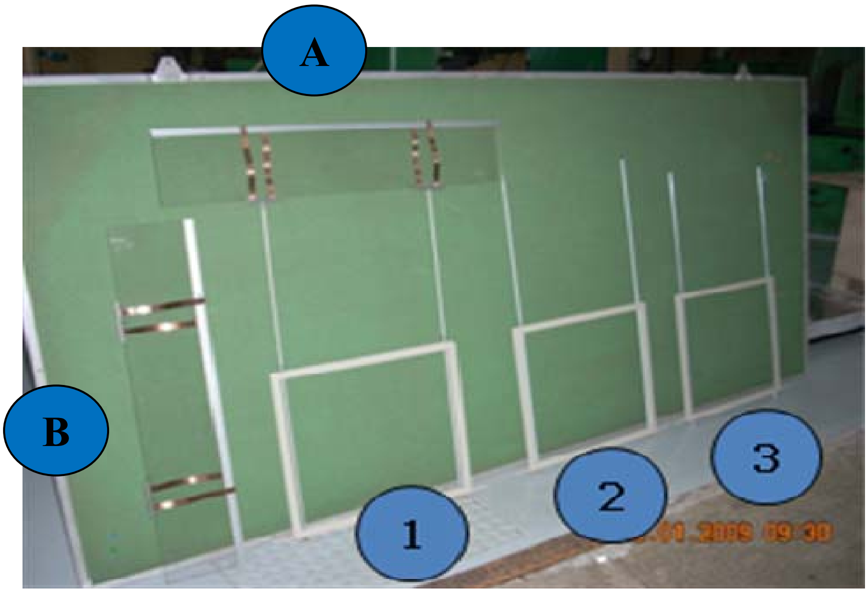


Fig.15 Three segments of the jig (1,2,3) and two heads matching vertical (A) and horizontal (B) modules

Fig.16 Dummy module inserted by hand to the outermost tower; two cables tightened to the top and bottom C-profiles to be used to pull the module out

Fig.17 Each segment of the jig enables a transition of the module through one tower

Fig. 18 Tapered ends of extended Al profiles facilitate transition of the modules from one tower to another (left); dummy module in the innermost tower (right)

Fully assembled jig (3 segments) enables insertion of the modules to the innermost positions e.i. the ring No 4 from the upstream side and to the ring No 5 from the downstream side. Pulling the cables attached to the modules is sufficient to get the modules out of the magnet, Fig.19. Tapered ends of the Al profiles make the operation smooth also in that case.

Fig.19 Extraction of the modules from the magnet slits using ropes

9. Fabrication of items

The Al profiles used during the assembly of the SMRD modules were designed by the DAI team. They had been manufactured at SAPA Aluminium, Trzcianka, Poland according to technical documentation approved by DAI. The company had manufactured 1250 of C-profiles and 2000 H-profiles, in total. They are shown in Fig.20 and 21.

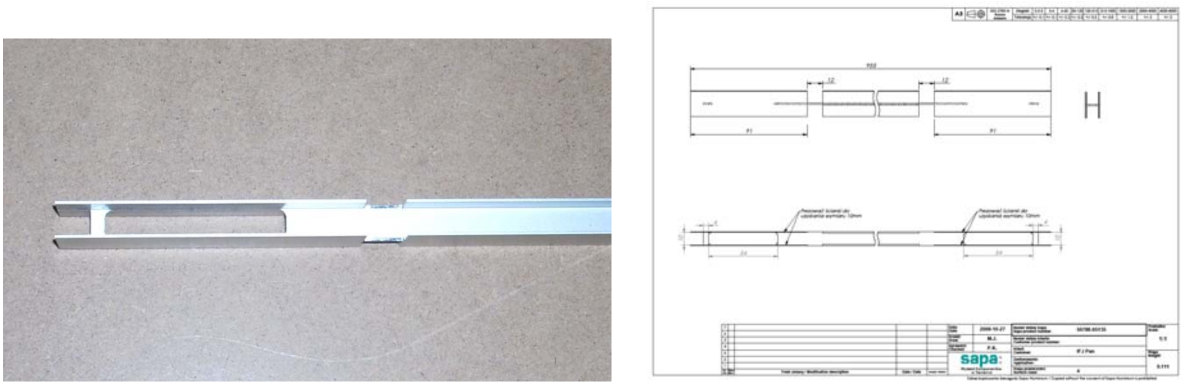


Fig.20 H-profile manufactured (left) according to the documentation (right)

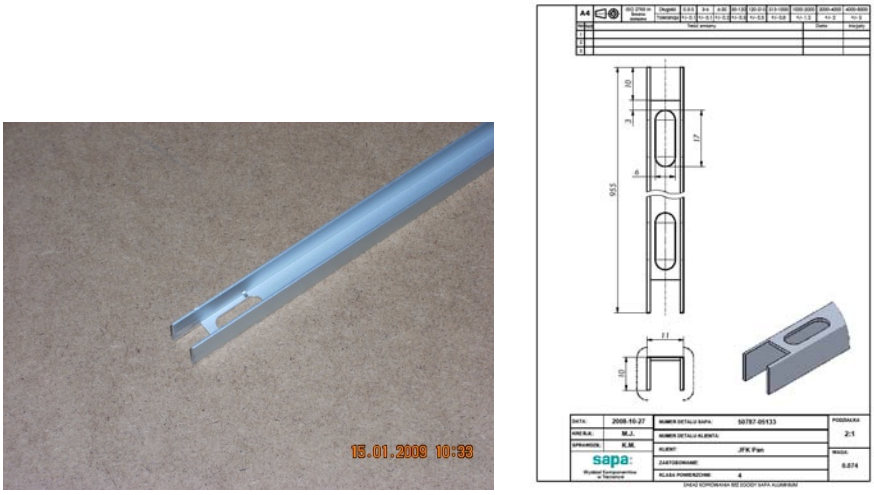


Fig.21 C-profile manufactured (left) according to the documentation (right)

Additional tools necessary for assembly of the modules were also designed and manufactured by the DAI team. One of those tools, used to taper the extended ends of the Al profiles, is shown in Fig.22. Another tool to widen H-profiles in case of unexpected distortion of the counter width is presented in Fig.23.

Fig.22 The tool to tapper ends (left) of C-profiles (centre) and H-profiles (right)

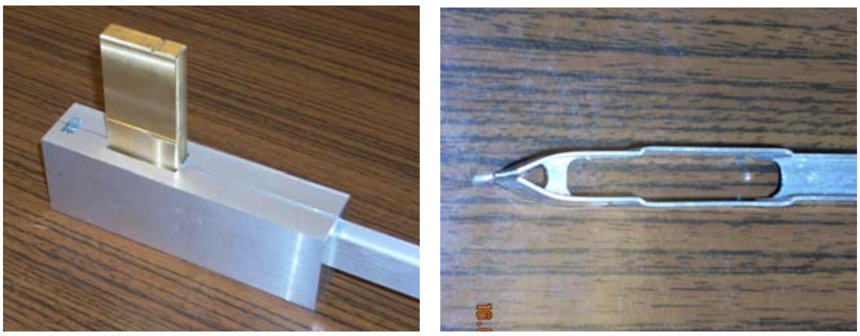


Fig.23 The tool to widen H-profiles (left); a widened H-profile (right)

Manufacturing of more than 2000 tape springs was completed in the DAI workshop within 3 months. The task required purchasing of phosphor-bronze sheets, cutting them into straps of certain length and width and corrugating of the straps, Fig.24. Manufacturing of the springs included also invention and fabrication of additional equipment facilitating spring production, Fig.25, 26.

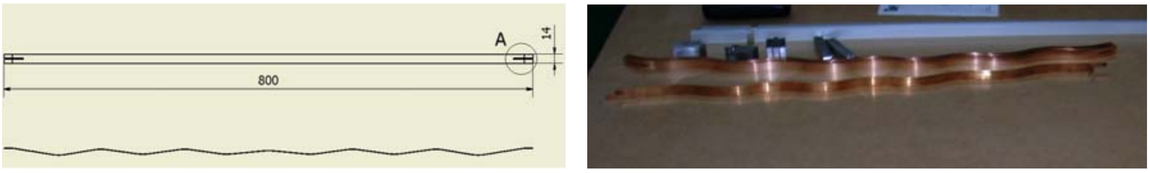


Fig.24 Spring design (left); spring manufactured (right)

Fig.25 Additional equipment mounted on the turning (left) and milling (right) machines

Fig.26 A tool used to bend ends of the springs

10. Modules assembly at J-PARC

All the scintillator counters produced in Russia, and all mechanical elements (aluminum profiles, tapes, tools, etc.), produced in Poland were delivered to Japan in January 2009. Two work stations for the module assembly and tests had been built, Fig.27.

Fig.27 Two work stations for the module assembly and testing

Four or five scintillator counters, Fig.28, had to be wrapped up by use of an adhesive tape and aluminum profiles as it is shown in Fig.29. To keep the correct dimensions of the modules small rubber spacers were inserted between counters. The next step was to adjust the length of phosphor-bronze springs, Fig. 30, and then to connect them with the module, Fig.31. Finally, the assembled and tested modules were stored in boxes, Fig.32.

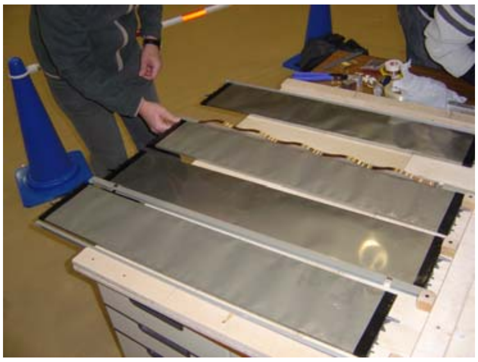


Fig.28 Four scintillator counters

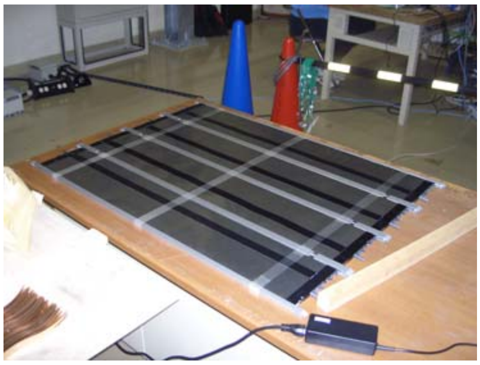


Fig.29 SMRD module composed of scintillators

Fig.30 Adjustment of the springs length

Fig.31 Installation of the springs

Fig.32 The modules stored in boxes

Each module has electrical read out cables which are two or three meters long. One end of each cable was connected to the module, Fig.33. The second end of each cable had to be routed through the magnet slits and between the magnet rings and finally connected to the electronic boxes which were on the side walls of the magnet. This is why all cables were wrapped together with a rope by use of an adhesive tape to increase their strength, Fig.34.

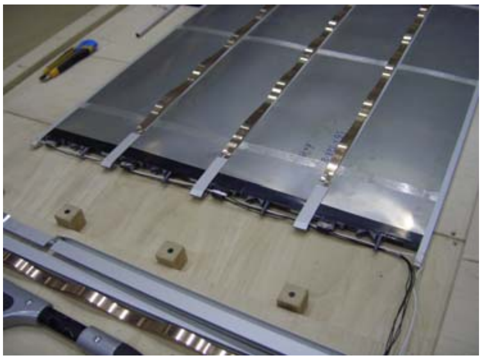


Fig.33 Electrical cables of the counters

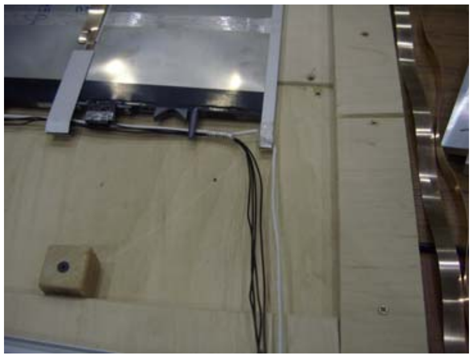


Fig.34 Cables with rope

11. Modules installation at J-PARC and cable handling

All the SMRD detectors had been installed in the magnet slits according to the procedure and using tools described in the Section 8. As can be seen in Fig.35 there was very limited space around the magnet so the insertion of the modules was rather difficult. At the beginning, dimensions of the magnet slits were tested with dummy modules, Fig.36.

Fig.35 The magnet in the pit

Fig.36 Testing slits of the magnet

After this operation the installation of the modules in the magnet slits started, Fig.37. The most difficult and delicate was the routing of the electrical read out cables. To perform this operation

Fig. 37 One horizontal module with read out cables before the installation in the magnet slit (left); the module in the magnet slit (right)

some additional tools have been prepared. First, a four meters long pipe with a rope inside and with a sinker allowed to route this rope in the slits, Fig.38. A stick with a hook, Fig.39, allowed routing the rope between the magnet rings. Then, using this rope the cable was routed appropriately. Using the procedure described 440 the SMRD modules had been installed in magnet slits.

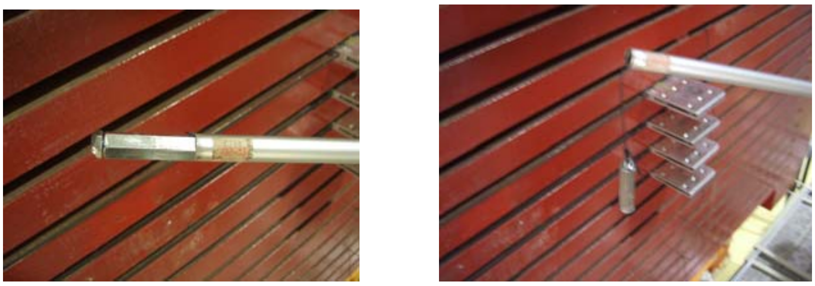


Fig.38 A four meters long pipe with a rope inside the pipe and with a sinker.

Fig.39 A stick with a hook.

12. Conclusions

The DAI team at IFJ PAN elaborated from scratch: the design of the SMRD modules, the assembly procedure of the modules, their installation method and the method of the read out cables handling during the installation. The assembly procedure and the installation method were verified and validated in Krakow using the mockup of a part of the T2K magnet.

All components necessary for the assembly and the installation of the SMRD modules were designed by the DAI engineers and manufactured either in the DAI workshop or in the Polish industry. The DAI engineers instructed other people and supervised the module assembly and installation processes at J-PARC.

All phases from the design till the installation of the last module lasted 1.5 year. The DAI effort summed up to 3 FTEs.

Starting from the Fall 2009 the SMRD detector has successfully taken data. The DAI engineers are co-authors of five scientific papers [10], [11], [12], [13], [14], so far. It is worth to mention that the modules passed successfully very severe exam i.e. the earthquake in 2011.

13. Acknowledgement

We would like to thank Prof. A.Zalewska for her professional support during the work and also during writing the report.

14. Literature

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