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A High Intensity Beam Handling System at the KEK-PS New Experimental Hall

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ABSTRACT

We would like to summarize newly developed technology for handling high-intensity beams. This was practically employed in the beam-handling system of primary protons at the KEK-PS new experimental hall.

I. INTRODUCTION

Beam intensity of primary protons extracted from the KEK-PS is gradually increasing because of strong requirements of physicists and endless efforts of accelerator people. Now it can be expected that 10^{13} pps (protons per second)

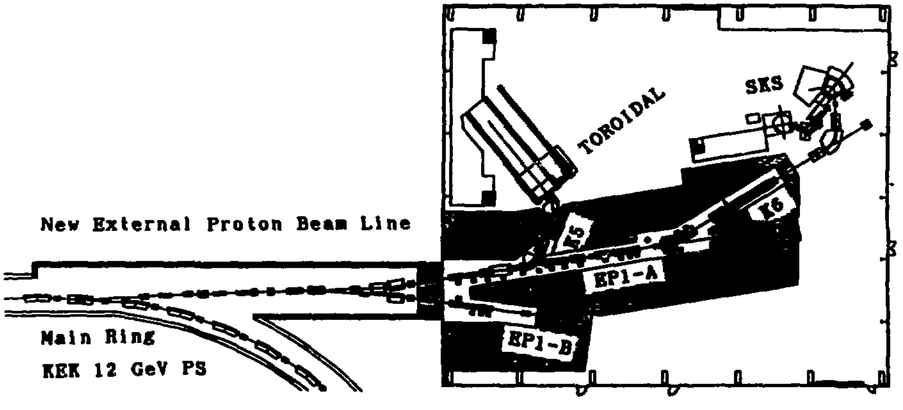

Fig. 1, Schematic illustration of the new counter experimental hall and beam lines of the KEK-PS.

will be realized in the near future by using the 1-GeV proton linac of the Japanese Hadron Facility (JHF)[1] as a new injector. This intensity is almost one order of magnitude greater than the present level of KEK-PS. The problem is that the present experimental hall was designed against 10^{12} pps and 10^{13} pps can not be extracted to the hall. We, therefore, decided to construct a new experimental hall[2] in which we can handle high-intensity beams. The construction work of the new hall started in 1987 and will be completed by the end of 1990. Tuning of the both primary and secondary beam lines will start in early 1991 at the latest. Schematic illustrations of both the new hall and the beam lines are shown in Fig. 1. The primary proton beam will be split in two directions (A and B). Two production targets will be irradiated in cascade at line A. Primary beam line B will supply protons to experiments which will require full and clean primaries.

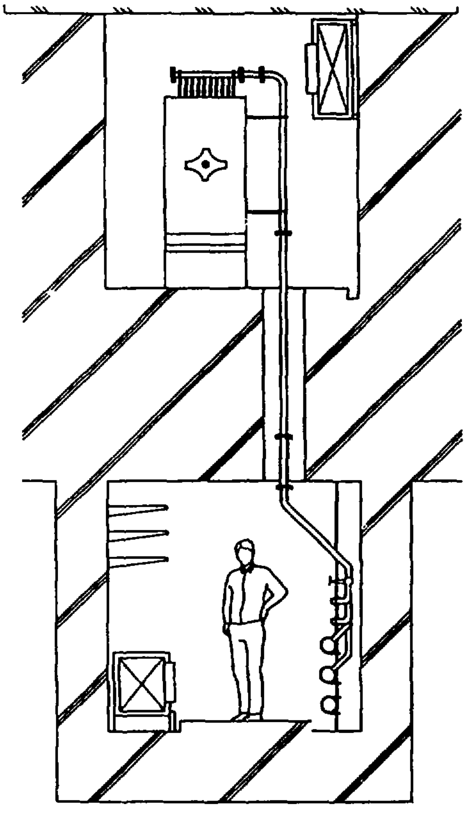

Fig. 2, Cross section of the beam line tunnel in the new experimental hall.

Beam-line components such as electromagnets of high intensity beam lines are expected to work in very high radioactive environments and will have very strong residual radioactivity even during off-beam periods. Maintenance of these components, including a routine check up, must be carried out quickly from a distant location against very high radiation in order to minimize radiation exposure to maintenance personnel. The primary beam transport system that we employed in the new hall is a two-storied structure as schematically shown in Fig. 2. The beam line components are placed in the beam tunnel. Cooling water and electric power are supplied through a service tunnel constructed parallel to the beam tunnel. The interlock signals from the beam line components can be checked in the service tunnel. Some deteriorating components, such as beam monitors, can also be replaced from the service tunnel. The pumping down of the vacuum ducts in the beam tunnel is conducted from the service tunnel. The top shielding of the beam tunnel is made of movable blocks instead that the side shielding is constructed as an immovable permanent concrete wall. If some serious trouble occurs in a beam line component, the ceiling blocks can be removed and the component is lifted out using an overhead crane. Maintenance of the component can be carried out in a hot cell prepared in the experimental hall. Therefore, most components must be easily removed from the beam tunnel. For this purpose, a quick-disconnect system of water, electric power, and interlock signals has been developed. A quick-disconnect flange for the vacuum duct has also been developed. Details of this system are described in the next section.

It should be noticed that the most important and essential characteristic of the high-intensity beam-line equipment is its radiation hardness. In other words, those things must never break and should be maintenance free. In order to obtain the radiation hardness of the beam-handling system in the new hall, most components of the system are made of inorganic materials. The only organic material used is polyimide, which is known to be the most radiation-hard polymer[3]. The radiation lifetime of the polyimide was, however, tested by the existing proton beams from KEK-PS and no deterioration was found over 10^8Gy (10^{10}Rad). The seals employed for vacuum and water connections are metallic O-rings[4]. The insulator between the magnet coil and water manifold is made of ceramic[5]. Lubrication oil is replaced by MoS_2 or a special metal[6] which contains very fine carbon grains. The radiation-hard components, especially electromagnets, developed for making the beam line maintenance-free are described in the section III.

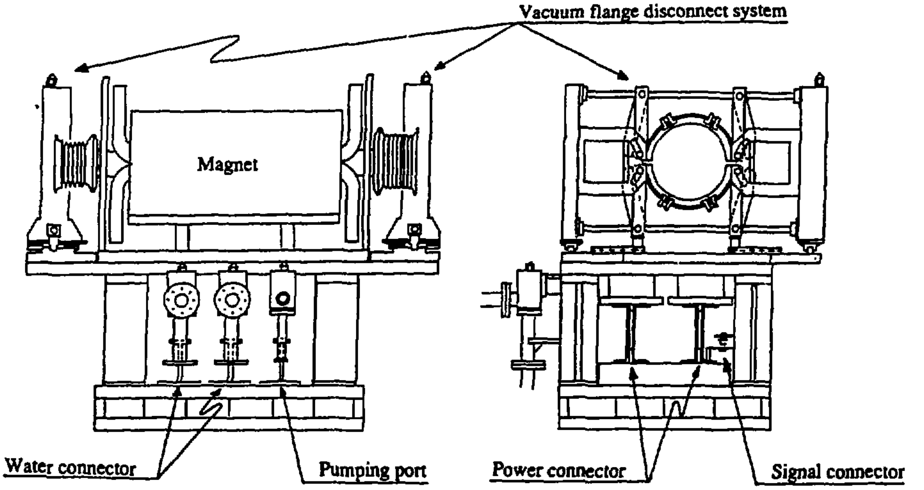

Fig.3. The magnet assembly with quick-disconnect devices.

II. Development of Quick Disconnect System

A quick-disconnect system we have presently developed is for cooling water, electric power and interlock signals for magnets, and the vacuum flange and pumping port for beam ducts. All devices are assembled on an iron base plate with the magnet as shown in Fig. 3. The base plate will be put on a floor table placed on the beam tunnel by an overhead crane. We employed a pivot fitting system between the base plate and the floor table for position reproducibility of the magnets. The floor table is well aligned and fixed on the beam tunnel. The magnet comes back from the hot cell after maintenance and is again placed on the floor table. The alignment clearance of the pivot fitting is better than 0.1mm.

The connectors of the electric power and interlock signals have a quick-disconnect structure without any external power, and are automatically joined by using the magnet weight when the magnet is brought down to the floor table. Therefore, these are set under the base plate of the magnet. The maximum current/voltage is DC 3000A/200V. In order to resist high-level radioactivity, all the insulation parts of the connectors are made of ceramics. The connector developed for the interlock signals is 49 pin contacts. All of the insulation parts of the connectors were also replaced by ceramics.

The water joint developed is the press-joint type using a toggle-link structure, as shown in Fig. 4. The applicable pipe size is 2 inches in diameter. The gasket is attached on the magnet side of the connector, so that the gasket is also brought to the hot cell and easily replaced. The pressure of the cooling water employed in the new experimental hall is 20kg/cm^2. The water connector was tested according to the JIS 20kg flange standard. No water leakage was found up to 50kg/cm^2. The pumping port has the same structure as the water connector. The inner diameter of the port is, however, 1 inch. A helium leak test was carried out and less than 10^{-8} Torr. l/s was found. Both devices are connected by using a simple rotation motion supplied from outside the tunnel.

The beam duct in the magnet should be disconnected at both ends of the magnet when the magnet is removed from the beam tunnel[7]. A disconnect device for the vacuum flange that we developed is shown in Fig. 5. After the flange-disconnect device is released, the beam duct becomes 80mm shorter at both ends with the flange and with the disconnect device, itself, in order to clear the facing flanges. A special inorganic lubrication material was employed in the flange-disconnect device. The flange collar was made of "Devametal[7]" which contains a fine carbon powder in a brass body, ensuring very low friction at the surface of the metal. Most parts which need lubrication were also made of Devametal. MoS_2 was not used because of its long-term instability. This beam-duct disconnect device is operated also by using a simple rotation motion supplied from outside the tunnel.

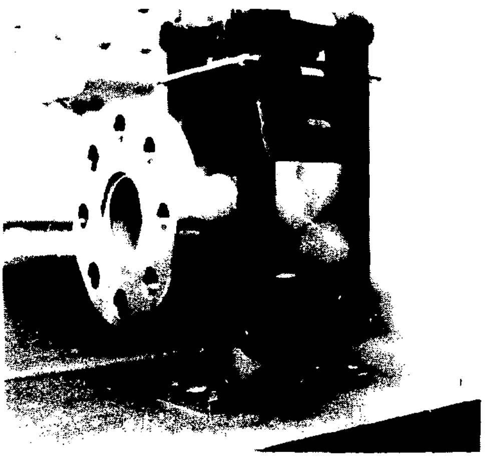

Fig.4, The press-joint type water connector using toggle-link structure.

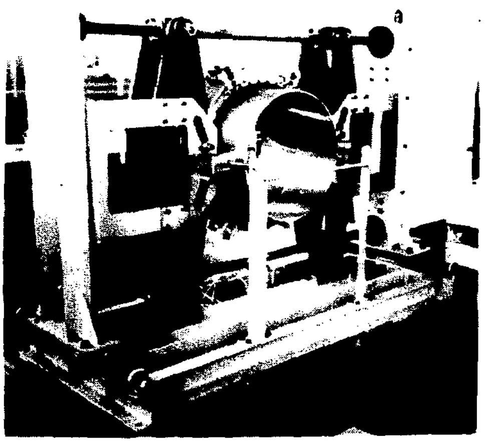

Fig. 5, Vacuum flange disconnect system.

III. DEVELOPMENT OF THE RADIATION-RESISTANT MAGNETS

It is known from our beam-handling experience at the existing experimental hall of the KEK-PS that the radiation life of the beam line magnets should be over some 10^8Gy to realize ten years of stable operation with a beam of up to 10^{13} pps. This radiation hardness is, at least, a factor of ten more than the conventional magnets insulated by epoxy resin[8]. We therefore developed a new type of radiation-resistant magnets with use of a polyimide resin pre-impregnated (PRP) glass cloth as new insulating material of magnet coils[9]. The radiation life of PRP is expected to be several ten times longer than epoxy resin pre-impregnated and was tested at the existing external proton beam line of the KEK-PS.

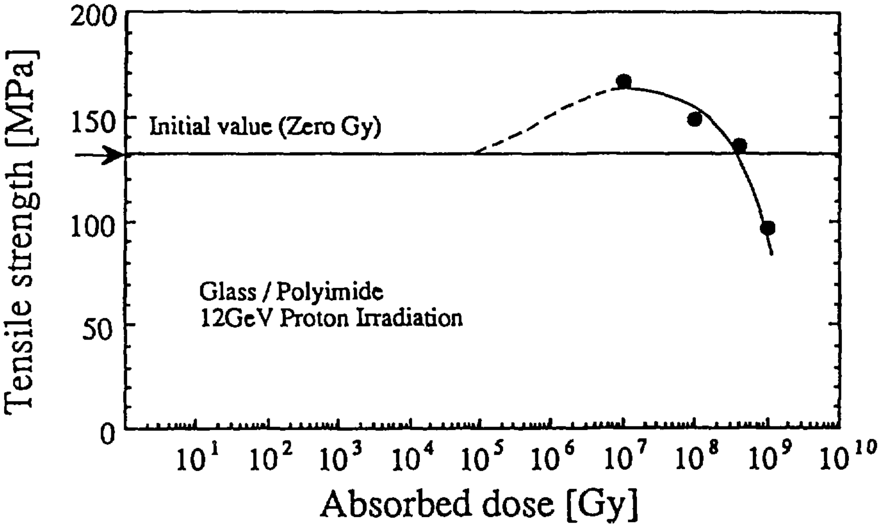

Fig. 6 Tensile strength of a cured PRP glass cloth plotted against the absorbed dose by 12GeV proton irradiation.

The polyimide we used was a BT (bismaleimide triazine) resin prepared by Mitubishi Gas Chemical Company Inc[10]. The test samples were strips 5mm wide, 50mm long and 0.25mm thick. 12-GeV protons were focused on the samples with a $1cm^2$ spot. Approximately 1.5 x 10^{12} protons were irradiated every 2.5 seconds, and 10^8Gy was achieved within 10 days (one experimental cycle). The tensile strength was measured at absorbed doses of 10^7, 10^8, 4 x 10^8 and 10^9Gy. No serious fall-off of the strength was observed up to 4 x 10^8Gy. However, at 10^9Gy the strength became approximately two thirds of the initial value. The results shown in Fig. 6 ensure a radiation life of the PRP insulated coil for over 10^8Gy. The breakdown voltage of the PRP insulator irradiated to 10^8Gy was also measured and was more than 4kV/mm. This fact also ensures the radiation resistivity of the PRP glass cloth for over 10^8Gy. Most magnets in the new hall were manufactured with a PRP glass cloth insulator. The glass cloth tape that we used was 0.25mm in thickness and was wrapped in a double layer on the conductor so that the insulation thickness between conductors was 1mm. No other organic material was used in the magnet, except for the PRP. Ceramic tubes were used for the electric insulation between the water manifold and the coil. Copper tubes were welded to both ends of the ceramic tube.

The magnets placed just downstream of the target station require a higher radiation hardness of up to 10^{11}Gy. In such a case the magnet must be assembled without any organic materials. We assembled a small Q magnet (25cm in bore diameter and 40cm long) from completely inorganic materials. The magnet coil was insulated by high-alumina cement (HAC) and asbestos tape. First, a hollow conductor was wound into a final Q-magnet coil shape without any insulators. The distance between conductors was temporarily maintained by 2mm thick copper spacers. Second, the asbestos tape was wrapped by hand after the spacers were removed. An inorganic ceramic bond[11] was used to fix the asbestos tape on the conductor as needed. Figure 7 shows the coil just before being filled with cement (a mixture of 27% HAC, 55% natural Al_2O_3 and 18% water by weight).

Fig. 7, Coil just before cement filling.

Fig. 8, Coil cured by the cement.

The cement was poured into a wooden box in which the coil was placed and left 48 hours for curing. The drying stage was divided into two parts. The first stage was two days in a 120 °C oven; the second was also two days, but in a vacuum tank. The electric resistance between windings of the coil was measured during each stage and $10^3 M\Omega$ was finally achieved. The coil was then hermetically sealed in a stainless-steel casing. Figure 8 shows the coil before casing. The air in the casing was pumped down for an additional two days and replaced by dry nitrogen. The pumping hole was sealed by metallic gaskets. Metalized ceramic tubes were used as power and water lead-throughs to the coil. Since the completion of the cement insulated magnet there has been no electric breakdown during the last three years.

Just after the establishment of cement-insulation coil technology[12], a trial to produce mineral insulation cables (MIC) in Japan was started. Though we can use any size of copper conductor in cement-insulation coil, the assembly technique of the cement coil is somewhat complicated and may not be suited for mass production. MIC consist of compacted MgO insulation surrounding the copper conductor, and covered with a metal sheath. The hollow conductor can be used for direct water cooling in order to achieve a higher current density. The sizes of MIC available in the world are very much limited now; there are almost three kinds of MIC with a hollow conductor[13]. The technique to form MIC into a magnet coil may be, however, relatively easy compared to the cement coil. At present the largest MIC available is 1800A class, which is sometimes insufficient to assemble higher field magnet. We, then, started a project to produce MIC in Japan. Our final goal is to prepare a larger size MIC, such as 2500A/3000A class.

At present, 750A class and 1800A class MI cables have become available in Japan. The cable length is, however, up to 30m. The quality of Japanese MI cable was tested by using bending samples and no serious failure was found. MI cable longer than 60m will be available by the end of 1991 for both 1800A class and 2500A class.

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(4) The metallic O-ring used was "Helicoflex" prepared by Usui Kokusai Sangyo Co., Ltd., Nagasawa 131-1, Shimizu-machi, Shizuoka-ken, 411 Japan.

(5) Ceramic insulating terminals were prepared by Hitachi Haramachi Electronics Ltd., 3-10-2 Benten-cho, Hitachi-shi, Ibaraki-ken, 317 Japan.

(6) The material used was "Devametal" prepared by Daido Metal Co., Ltd., Kita-ku, Nagoya-shi, 462 Japan.

(7) M. Goujon and M. Mathieu, Raccord a vide telecommande, CERN, Note Technique SPS/SME/78-240 (1978).

(8) H. Schoenbacher and A. Stolarz-lzycka, Compilation of Radiation Damage Test Data Part II: Thermosetting and thermoplastic resins, CERN 79-08 (1989).

(9) The Coil was assembled by Electromagnet division of TOKIN Corporation, 6-7-1 Koriyama, Taihaku-ku, Sendai-shi, 982 Japan

(10) Mitubishi Gas Chemical Company Inc., 2-5-2 Marunouchi, Chiyoda-ku, Tokyo, 100 Japan.

(11) The bond used was "BOND X" of Nissan Chemical Industries Ltd., 3-7-1 Kanda-nishiki-cho, Chiyoda-ku, Tokyo, 101 Japan.

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Q(I.M.Thorson): How do you align elements in the beam line? Do you depend on pre-alignment only? Can you check alignment after installation?

A(K.H.Tanaka): *It will be almost impossible to check* alignment after beam irradiation on targets. We, therefore, prepared several steering magnets at every important points so that we can align beam with beamline.