INDUCED RADIOACTIVITY AND REMOTE HANDLING METHODS FOR HIGH INTENSITY PROTON ACCELERATOR

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Abstract

As for the high intensity proton accelerator, the residual radio activity is a serious problem. The conceptual design of remote handling maintenance system and the actual development of vacuum equipment are described.

Introduction

Proposals of the JHP (Japan Hadron Project) include a development of a high intensity proton accelerator system. The expected maximum beam intensity is about 200 μA. The beam power is more than one hundred times stronger than KEK 500 MeV booster synchrotron. If the proposal should be implemented, the high intensity proton accelerator will imply a high rate of induced radioactivity.

Even after all precautions are taken to keep these activities at a minimum, it is expected the radiation levels in a substantial part of the machine will, for a considerable period after shut down, exceed the maximum permissible dose of radiation for a human by orders of magnitude.

The human access to perform maintenance and any desired machine modifications will be severely restricted or be entirely precluded. So a remote handling system must be developed for smooth operation of the JHP high intensity proton accelerators. As for the remote handling methods, the first thought is to use robots or manipulators. But it is very difficult and much expensive to replace the hole human handwork with manipulators or other elaborate machines.

To be able to use a remote handling system for the accelerator, we must design the structure of the accelerator equipment in the first place to be as simple as possible. In this paper we introduce a design concept of a whole machine and the actual development of vacuum equipment for remote handling using a simple mechanical contrivance.

Feasibility of conventional robots and master-slave manipulators

To date many types of robots have been developed for factory automation and for severe working conditions to replace human work. The motions of these robots are rather rigid and are adapted to repeat the same motion. Flexibility of motion to fit the situation is under development. To apply these robots to maintenance and modifications of an accelerator, many kinds of robots are necessary. As a result, the cost of remote handling would be very expensive.

On the other hand, master-slave manipulators which have been developed mainly for remote handling in nuclear industry have a certain dexterity. But the operation is a skilled job and it lacks sufficient accuracy of transmitted motion in spite of the history of 30 years and much fabrication experience.

Moreover, master-slave manipulators require a wide space around the working object, because of their limited joint motion. Usually a cyclic accelerator is designed as compact as possible to improve the efficiency of RF acceleration. So the components are packed into a rather narrow space.

Assembly and disassembly of flange, bolts and nuts connection of vacuum chambers are fundamental maintenance work of any machine. This type of work requires a great deal of skill to operate the manipulator. As for a conventional accelerator, it is very difficult to perform most of the maintenance work and modification using master-slave manipulators.

To perform maintenance and any desired modifications using the remote handling method, we must design the accelerator equipment to fit the remote handling method.

A modular system concept(1)

The entire machine can be divided into several superperiods, which,with the possible exception of the detail content of the straight section, are all identical. Each super period contains different types of guide magnets and straight section equipments. These machine components can be standardized into different types of modules, which are replaceable with spares.

If a failure occurs in any one of the modules, rather than trying to repair it remotely in the machine, the faulty module can be removed and replaced by a spare, thus reducing the necessary quantity of remote operation in the tunnel to a few standardized, well-engineered and rehearsed procedures. It would not be difficult to replace these standardized modules with the remote handling method because of its restricted kind of work.

The actual repair of the faulty module can then be performed at leisure after lengthy cool-off periods or, if urgent in conventional hot cells in spite of machine running time. The faulty module which is separated from the accelerator ring can be put in a wide working space and can be accessed from every possible directions. In the conventional hot cell, the master-slave manipulator can be used effectively for the actual repair.

Modular connections

Having arranged all remaining equipment into modules with standardized external connections, one comes to the main problem of module removal and replacement. The intermodular connections must be highly reliable and fail safe and must also be capable of sufficient separation so that their removal or replacement by means of a remotely operated crane is possible.

The problem of the detailed nature of intermodular connections is subject to a wide range of solutions. If one could decrease the varieties of module connections to two or three types, it might be possible that the all module connections could be automated completely,so that anyone of them would essentially be self-detaching or reattaching on command from the control room; otherwise one would use the best possible and most dexterous general purpose manipulator units, minimizing as much as possible complex modifications to machine connections and simplifying operational procedures.

Actually all of the various connections of accelerator equipments are divided broadly into five categories: 1. vacuum chamber beam pipes; 2. power supply lines to magnets and RF cavities; 3. signal lines for control and measuring equipments; 4. cooling water pipes; 5. adjusting and setting devices of modules.

If all of connections could be made with these five module connectors, it might be possible that all the module equipments can be removed or replaced by remotely operated crane and an auxiliary master-slave manipulator. The auxiliary manipulator need not have special dexterity. It can be a conventional one which is servocontroled and has a force feedback system.

Development of connecting devices

1. Vacuum beam pipe connectors

A vacuum chamber is the device nearest to the proton beam, as the result it is most often irradiated by lost beams. Usually the radiation level of vacuum chambers is the highest along with septum magnets for injection and extraction. Conventional vacuum chambers are connected with flanges and metal gasket fatened by screws, which is difficult to deal with remote handling methods. So we have developed the new connection system which is easy to connect and disconnect remotely.

For the remote handling system, the required working force is important to the difficulty of the operation. In the case of a high intensity accelerator, we can not use elastic rubber gaskets because of its deterioration with radiation damage. The soft metal gasket, for instance an indium gasket, is also inconvenient for its contamination and sticking fraction on the sealing surface of the flange. The con-flat type metal gasket needs high stress to fasten the flanges. So we have selected the elastic metal gasket "Helicoflex" which is composed of a coil spring and covered by an aluminum sheet, for its good elasticity and rather low compressive force.

To make the vacuum connection be easy to connect and disconnect quickly with the remote handling method, it is necessary to simplify the fundamental operation of setting and fastening. For this purpose, a special device, which performs connects with an one dimentional motion, has been developed.

The mechanical concept of the device is shown in Fig. 1. This concept is essentially a link mechanism and wedge structure to increase the fastening force. The link mechanism drives the compressing frame which compresses the wedged flanges. Through this process, at first, the compressing frame forces the wedged flanges to the center of the device, and then it presses the flanges to complete the connection. This compressive force is spplied by the link mechanism.

The actual procedure of fastening flange connection is shown in Fig. 2. When the modular vacuum chamber is brought by a remotely operated crane, the fastening device is shifted along the beam line to escape chamber setting. After the vacuum chamber is set in place, the fastening frame is shifted to the center of flange connection. As shown in Fig. 3, the driving unit tool is carried by remotely operated crance and is set on the link. Next the link is driven by this tool to the self-hold position. After this, the driving unit is removed to minimize the radiation damage caused by accelerator operation.

The characteristic curve of deformation and increasing rate of compressing force is shown in Fig. 4. The maximum deformation of this link is 1 mm and the increasing rate of force is infinitly large at the top of the link.

The characteristic curve of stress-deformation of the Helicoflex (continuous line) and necessary driving force of the link (dashed line) are shown in Fig. 5. As shown in Fig. 1, after the link arm move past the vertical the fastened flanges also slightly loosen, but the elasticity of Helicoflex compensates this looseness to keep the vacuum seal. At this state the position of link is self-hold, and keeps the compression force of the flange and gasket, although the outer working force is taken away. The self-holding point is designed as shown in Fig. 5. In this case, as for a gasket of total length 65 cm, the compressive force is 13,000 kgf and self-holding force is about 2,600 kgf.

2. Connecting devices for electric power supplies, signal transmission and cooling water

The design of the connecting device for electric power supplies signal transmission and cooling water uses the same concept. These joints are constructed with plugs and sockets. To operate remotely, an inserting clamp housing device is prepared and can fasten the any number of joints at one time.

This cramp housing methods for the remotely handled joint have already been developed for the space laboratories.[2] We will apply this technique to the remote handling system of the accelerator.

The actual procedure of operation is shown in Fig. 6. The device is operated mainly by a remotely operated crane and auxiliary servo controlled manipulator. After the plugs and sockets are set in the clamp housing using the crane and manipulator, the device is actuated by electrically powered wrench which is brought by crane.

As for the accelerator equipments side, electrically insulated cable must be made of ceramic for the sake of endurance against irradiated damage. In this case, the fastening device is fixed on the accelerator equipment. On the other hand, flexible lines are laid to the device from a feed station in the tunnel. These flexible lines, when deteriorated by irradiation, are always exchangeable.

The accelerator tunnel structure

The sectional view and the side elevation of the accelerator tunnel are shown in Fig. 7 and Fig. 8 respectively. The 0.5 m thick concrete shield decreases γ rays from the steel irradiated by a high energy proton beam, most of which is Co60, to the rate of 1/500.

When repair is needed to accelerator equipment because of fault or modification, the modular unit is separated and carried by a remotely operated crane to the hot assembly area. The cables and pipes are set in the clamp jig outside of the shield wall with human hands. The champ jig is guided by rails through a hole in the shield to the connector near the equipment and clamped remotely.

The vacuum clamber connections are also disassembled and assembled remotely.

The structure is a semi-remote handling system which is operated remotely as much as possible. In some cases, as for a dexterous works or complex operations, the shielding concrete wall, which can be shifted it's position, enable us to support the remotely operated crane or other devices.

The exact position of modular equipment is decided with a reference plate which has been previously mounted on the equipment stand. Guide rails are used to pull the module into place.

Future plans

We are now testing the bakability of vacuum connector and setting system of gasket. The system is made of all metal and is free of oil, so it has a potential for the application of ultra high vacuum system. The prototype of connecting device for electric power supplies or cooling water is under developing. The checking system for misalignment of the modular equipments from the outside of shielding wall using laser technique is also proposed.

Acknowledgement

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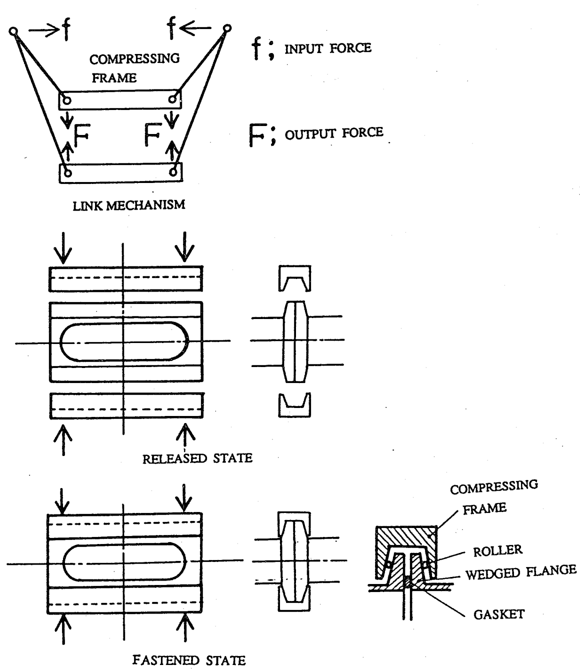

Fig. 1 The mechanical concept of the device.

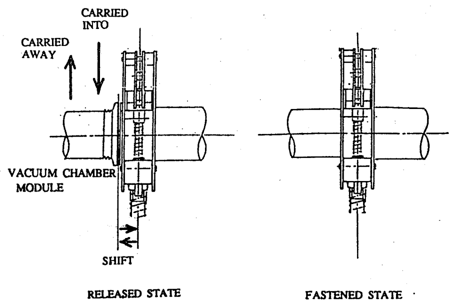

Fig. 2 The actual procedure of fastening flange connection and fastening device.

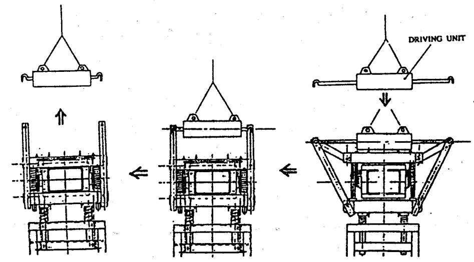

Fig. 3 The procedure of driving unit tool.

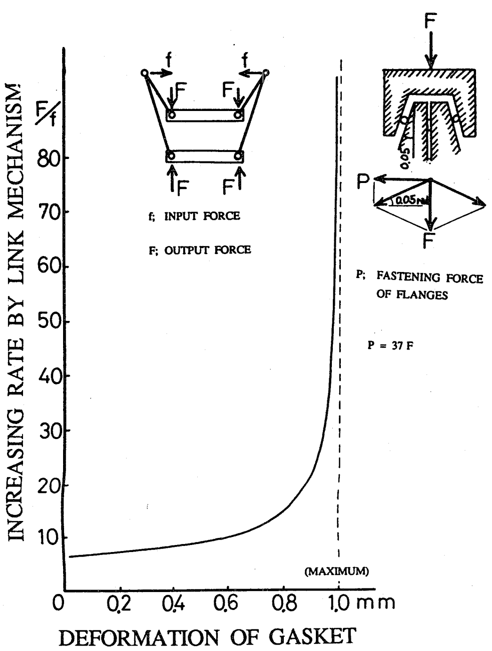

Fig. 4 The characteristic curve of deformation and increasing rate of force.

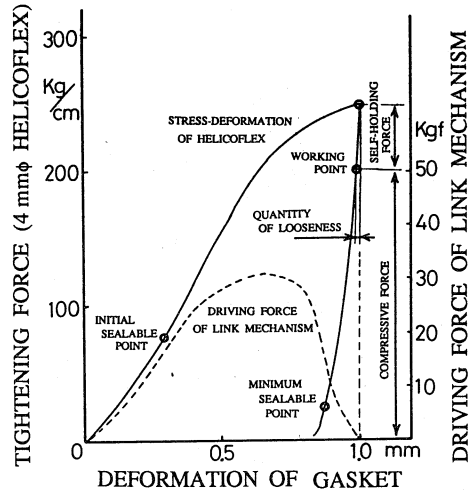

Fig. 5 The characteristic curve of stress-deformation of the Helicoflex

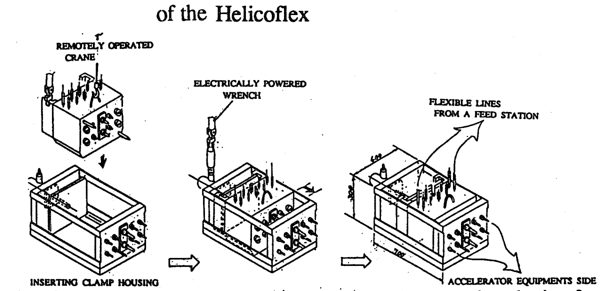

Fig. 6 The actual procedure of operation of connecting device for electric power supplies, signal transmission and cooling water.

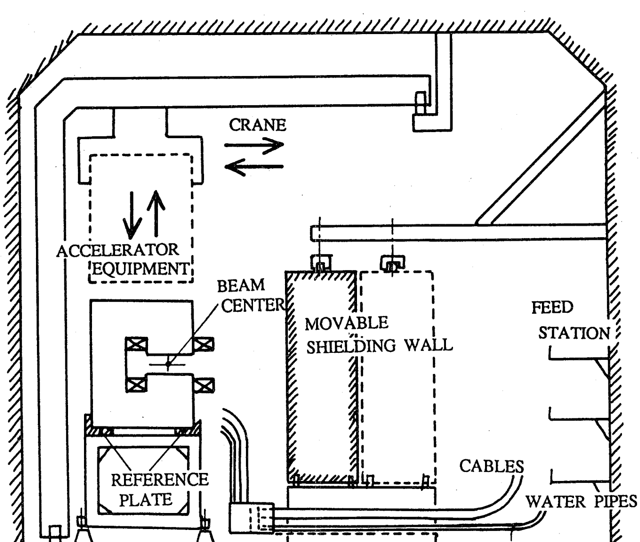

Fig. 7 The sectional view of accelerator tunnel.

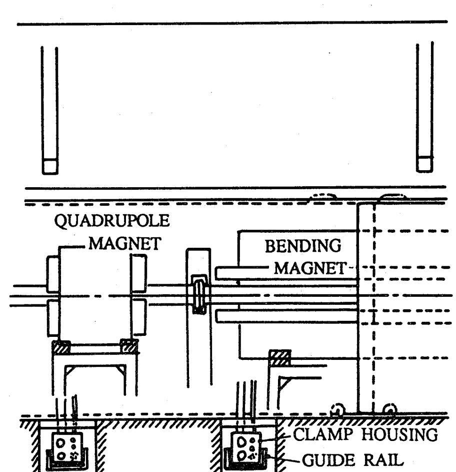

Fig. 8 The side elevation of the accelerator tunnel.