Vacuum System

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Introduction

To achieve a beam life time of approximately 24 hours, the beam-on pressure was designed so as to maintain 1.3 x 10^{-7} Pa or less with a circulating current of 100 mA. The main pumping system is based on non-evaporable getter (NEG) strips which are used in the straight section and bending magnet chambers. In addition to the NEG strips, distributed ion pumps are installed in bending magnet chambers. Lumped NEG (LNP) and sputter ion pumps are used at the crotch and absorber locations.

Unnecessary synchrotron radiation (SR) from the bending magnets is almost intercepted by the crotches and absorbers placed just downstream and upstream of the bending magnets. An only photon emission of energies lower than 10 eV with a angular spread larger than 1.5 mrad in the vertical plane is intercepted by a slight part of 10 mm-photon beam slot walls of chambers. The important tasks for the vacuum system were 1) the design of crotches and absorbers *a)* in which photo-electrons, reflected photons and SR-induced out gasses are efficiently trapped and *b)* that can withstand the high photon beam power, and 2) the design of the chamber supports which can ensure the chamber displacement within the accuracy of 0.05 mm or less at the positions of a beam position monitors, even after repeated bake cycles at 150°C. To avoid the excessive production of ozone and corrosives in the air surrounding the vacuum chambers, synchrotron radiation shielding was considered in the crotch and absorber design.

To confirm the specifications of the vacuum system from various points of view, a full-size unit cell (29.92 m in length) was constructed prior to manufacturing the 48 cell full-scale vacuum system . The installation test of the one cell in the magnets assembling on the girders and the vacuum performance estimation before and after the bakeout at the temperature of 150°C were carried out. These experimental results will be briefly described in the individual reports of this volume by H.Ohkuma and H.Saeki, respectively.

System Constitution

Schematic of one unit cell including the magnet arrangement is shown Fig. 1, and the cross sectional views of the straight section and bending magnet chambers are shown in Figs. 2 and 3, respectively.

The one unit cell (or sector) consists of three straight section chambers, two bending magnet chambers, two crotches, four bellows chambers, two gate valves, one dummy chamber where the insertion device is installed, and one or two photon shutters for photon beams lines. The chambers are 6063-T5 aluminum extrusions and contain water channel for cooling and bakeout. One of the three straight chambers contains only a downstream end absorber, while the other two contain a downstream end absorber, upstream end bellows and photon beam extraction duct. The bending magnet chambers contain only downstream end bellows. The absorber, bellows and flanges are joined to the chamber extrusion with partial penetration welding, to prevent weldbeads from occurring on the inside surface of the beam chamber.

SR from Bending Magnets

The number of photons below 16 eV of SR from a bending magnet is about 8% of the total number of photons, but power contribution (about 3 x 10^{-3} %) is negligible. The fraction of the photons above 100 keV is less than 0.5%, but the power fraction is still 6%. Only SR corresponding ±0.75 mrad of 71.4 mrad from the bending magnet (BM1) and ±1.0 mrad from BM2 are extracted through holes in the photon absorber in the crotch, respectively. Almost all photons are intercepted by the crotches and absorbers, and photon energies are consumed for heating the absorbers and inducing gas desorption.

SR from Insertion Devices

For the SR from insertion devices, effective spreads in the horizontal and vertical direction are limited less than ±1.0 mrad and ± 0.3 mrad, respectively.

The chamber and crotch in which SR passes through were designed not to intercept the SR. To avoid the interception, the manufacturing accuracy of the photon absorber in the crotch including installation error must be less than

±0.3 mm, and that for the slots of a bending magnet chamber is required less than ± 2 mm.

Chamber Assembly

The worst example of flatnesses in the straight chambers assembled by welding the absorber, bellows and duct was 2.8 and 2.6 mm in the horizontal and vertical directions for a length of 5000 mm, respectively. Figures for the extruded chambers were 1.5 mm and 0.9 mm, respectively. After the 150°C pre-bakeout, the chambers were each installed in the magnets assembling on the girders. The flatnesses of the chambers were improved because of the pre-bakeout, and figures of 2.5 mm and 1.7 mm were obtained, respectively. To remove the chamber warps caused by the construction process and welding, all chambers will be pre-baked in advance of the installation in the magnets assembling in the actual ring.

The chamber deformation at the location of beam position monitors (BPM) due to the evacuation of the straight chambers is required to be less than 0.03 mm. To suppress the effects of the chamber deformation at the location of the BPM, which are caused by the pressure difference between the atmospheric pressure and the vacuum, two reinforcing blocks (or ribs) are mounted just beside the BPM in the straight chamber as shown in Fig.4.

Depending on the welding place, three different methods are used for assembling the chamber.

Since the BPM is required to be mounted on the chamber with high accuracy and also has a brazed part and a transition joint by Hot Isostatic Pressing (HIP), the welding with less heat affection and less distortion is desired. For these reasons, we selected CO_2 laser welding. The CO_2 laser welding was carried out using high-weldability aluminum alloy A3003 without supplying the filler metal.

For 1.5 m length welding between the photon beam extraction duct and chamber, we adopted MIG welding that has advantages such as providing a larger leg length in one-pass welding and less heat affection because of a higher welding speed compared with TIG welding. To minimize further the chamber's deformation in welding, the MIG automatic welding was employed and carried out fixing the chamber with welding jig.

To mount the absorbers, bellows and flanges on the chamber, the TIG welding that allows fine adjustment was adopted because of the complex shape of the welding part.

Chamber Support

Depending on the position of the straight section, two or three supports are used. One support is rigid and does not allow the chamber to move in any direction. It is located near the end of the chamber. One of the other two supports is composed of a leaf spring and a support with a rotational bearing, making it possible to accommodate thermal expansion of the chamber in the direction of the electron beam during the chamber bake cycle. It is located near the another end of the chamber.

The axial force of approximately 700 kg by atmospheric pressure due to different cross section between the chamber and bellows, and the force of 100 kg generated by the offset of bellows and moment are applied to the supporting structure. Therefore, the structure was designed to withstand the moment and forces.

The chamber displacement at the BPM before and after the bakeout must be less than 0.05 mm required for the BPM.

Crotch

Isometric view of the CR are shown in Fig.5. The photon absorbers are made of Glid Cop (Al and Al_2O_3 dispersion strengthened copper) because of the high allowable thermal stress of 60 kg/mm^2, compared to 10 kg/mm^2 of OFHC. The thermal analysis results using 3-D finite element program ANSYS are as follows: **1**) The maximum calculated temperature at the heated wall is 417 °C less than the design criteria, namely, melting point (1083 °C for GlidCop Al-15)x0.5. **2**) The maximum temperature at the cooled wall is 151 °C in exceed slightly the boiling point of cooling water (143 °C) , but within the allowable limit. The 151 °C is much lower than 194 °C, at which a film boiling is expected to be started, and the maximum heat flux of the cooled surface is estimated at 193 W/cm^2. This value is only 9% of the critical heat flux of 2190 W/cm^2. **3**) The maximum thermal stress is decreased to 37 kg/cm^2 which is less than the design criteria, namely, two times of the yield point (25 kg/cm^2). **4**) As for fatigue strength, the allowable number of cycles is estimated at more than the design criteria of 10000.

The crotch and absorber have the structure in which particles such as reflected photons, photo-electrons and SR-induced outgasses are efficiently trapped, and were also designed to reduce their RF impedances. SR-induced outgasses are evacuated locally by the high capacity pumping system (see Fig. 6) before the outgasses have a chance to bounce into the beam chamber. Of the photon beam power from a bending magnet of 10.5 kW, about 5.6 kW (34k W/cm^2) is irradiated at the photon absorber of the CR and the remaining beam power deposited at the absorbers placed downstream of the CR.

To avoid the formation of ozone and nitrogen oxides in the air surrounding the vacuum chamber, the crotches and absorbers have been designed to be shielded against synchrotron radiation. The photon absorbers are of approximately 3 cm thickness. The photons of energies less than 80 keV are stopped at the photon absorbers, but those higher than about 100 keV penetrate the crotches and absorbers. Owing to the normal incidence of the synchrotron radiation on the photon absorber, the attenuation along the direct photon path traversing the 3 cm thickness is of the order of 10^{-3} at the photon energies of 200 keV.

To reduce further the radiation level outside the vacuum chamber, additional shielding is necessitated. The shielding for the crotches is provided with tungsten of a 2 mm thick-plate on the photon absorber as shown in Fig. 5, and the lead shielding with a 2 mm thick-plate for the absorber. The attenuation with the additional shielding becomes of the order of 10^{-6} for the same photon energies.

Installation

The installation test and vacuum performance estimation before and after the 150 °C bakeout temperature for one unit cell were completed by early April 1994. The chambers were baked with mobile type water-heating units. The bending magnet and straight section vacuum chambers including the chamber components, CR and bellows were installed within the required accuracy. The chamber deformation at the location of beam position monitors (BPM) due to the evacuation of the straight chambers was less than 0.03 mm as specified in the design target. The chamber displacement at the location of the BPM before and after the bakeout was larger than 0.05 mm required for the BPM and at a few locations ranging from 0.1 mm to 0.15 mm because of the weakness of the rigid support and magnet girder. To ensure the chamber displacement within the accuracy of 0.05 mm or less, we are now investigating modifications of the support and girder.

Pumping System

The pumping system is based on: **1**) NEG (Non-Evaporable Getter) strips that are used in both straight and bending magnet chambers, **2**) LNP (Lumped NEG Pumps) which are concentrative pumps for SR-induced gas load and **3**) SIP (Sputter Ion Pumps) which assist the LNP are used at the crotch and absorber locations. The structure of the LNP and its pumping characteristics are shown in Figs. 6 and 7, respectively. During the NEG activation and chamber bakeout, the mobile roughing pump system, which consists of a turbo molecular pump and rotary pump, is used. The NEG strips and LNP are activated simultaneously for approximately 60 minutes during the bakeout. The total pressure gradient profiles over one cell after the 150 °C bakeout were in good agreement with calculated ones and the average pressure was of the order of 10^{-8} Pa.

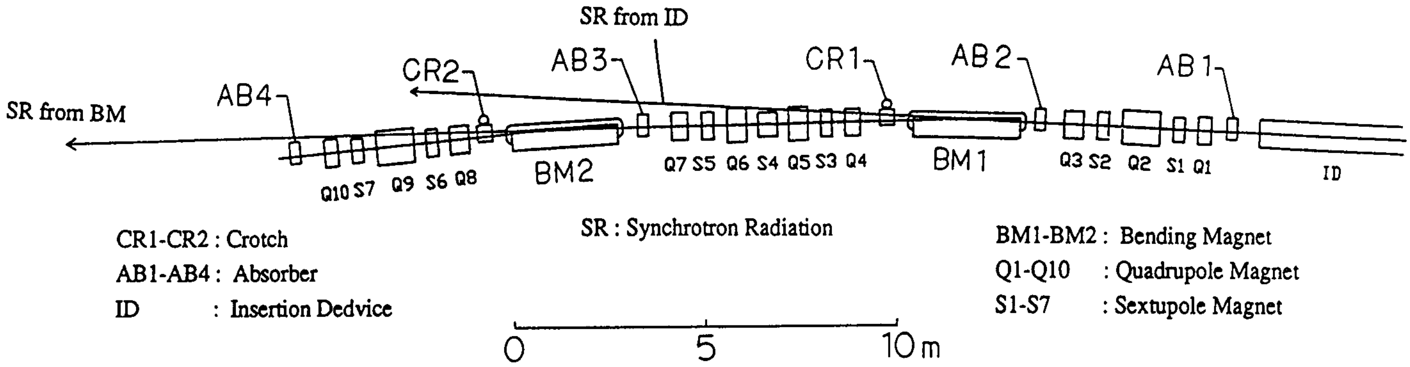


Fig.1 Layout of one cell

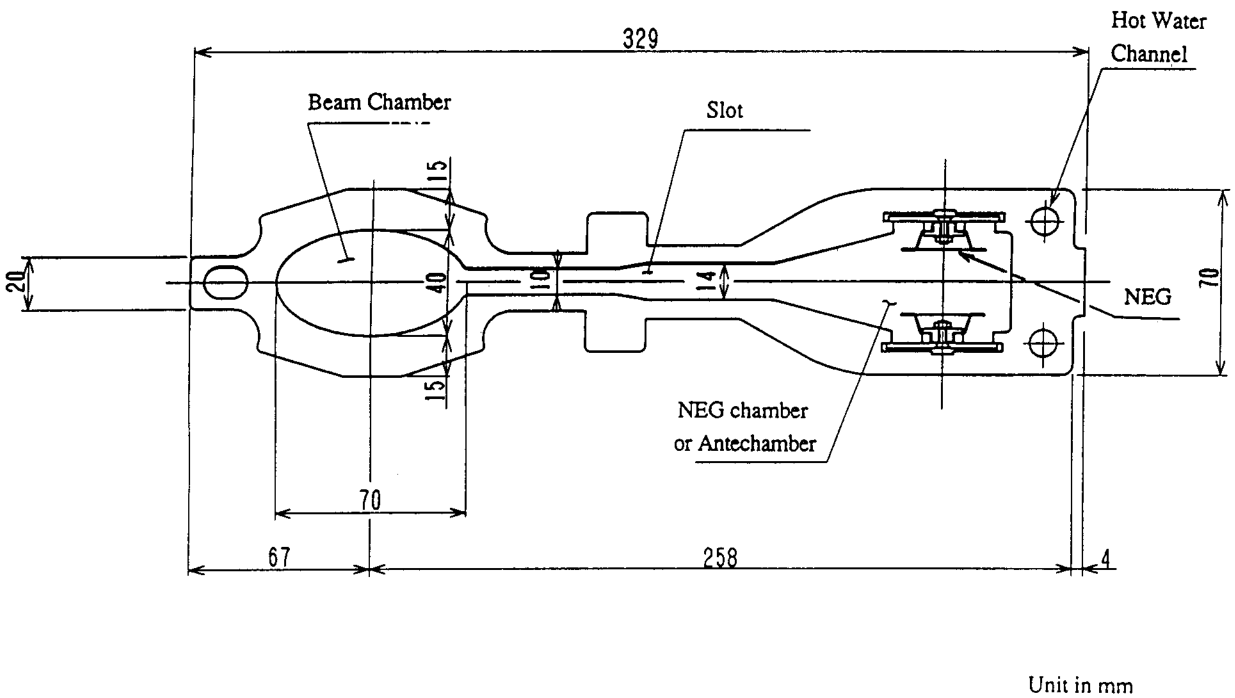
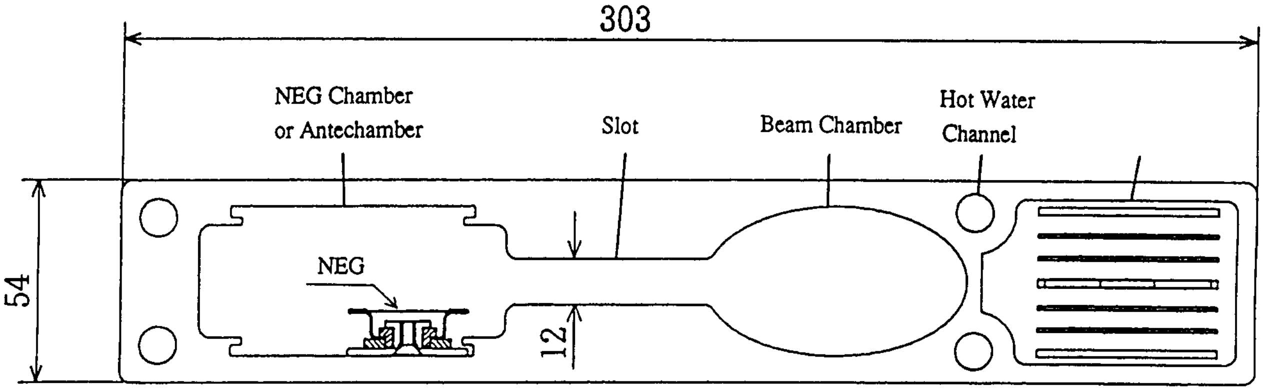


Fig.2 Cross sectional view of the straight section chamber



Unit in mm

Fig.3 Cross sectional view of the bending magnet chamber

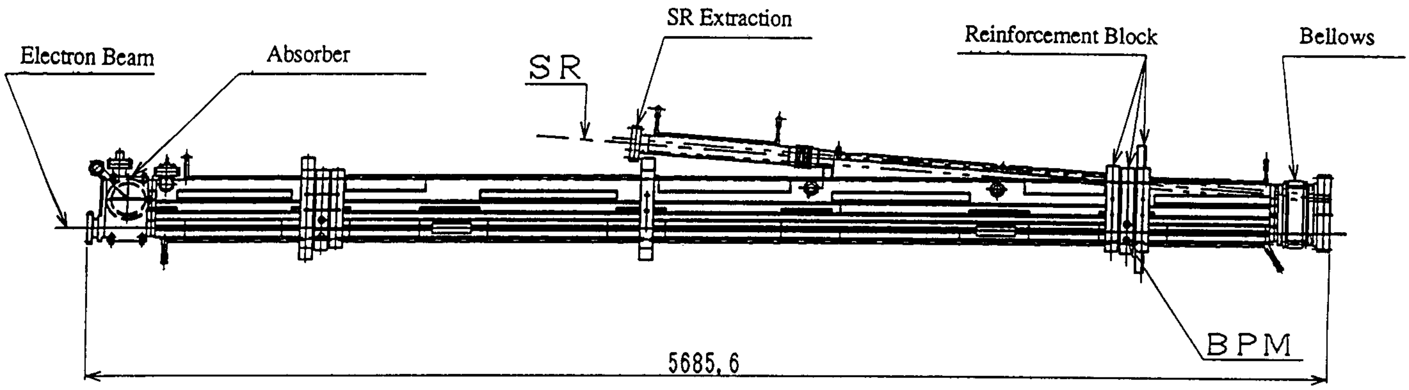
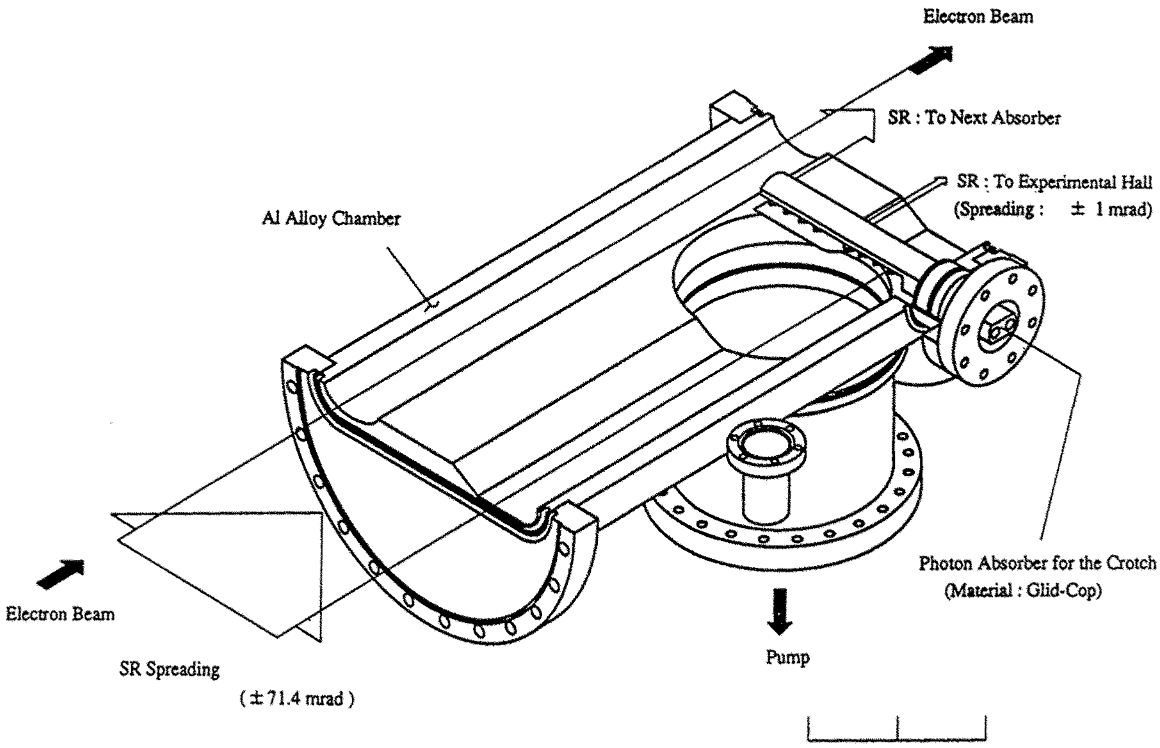
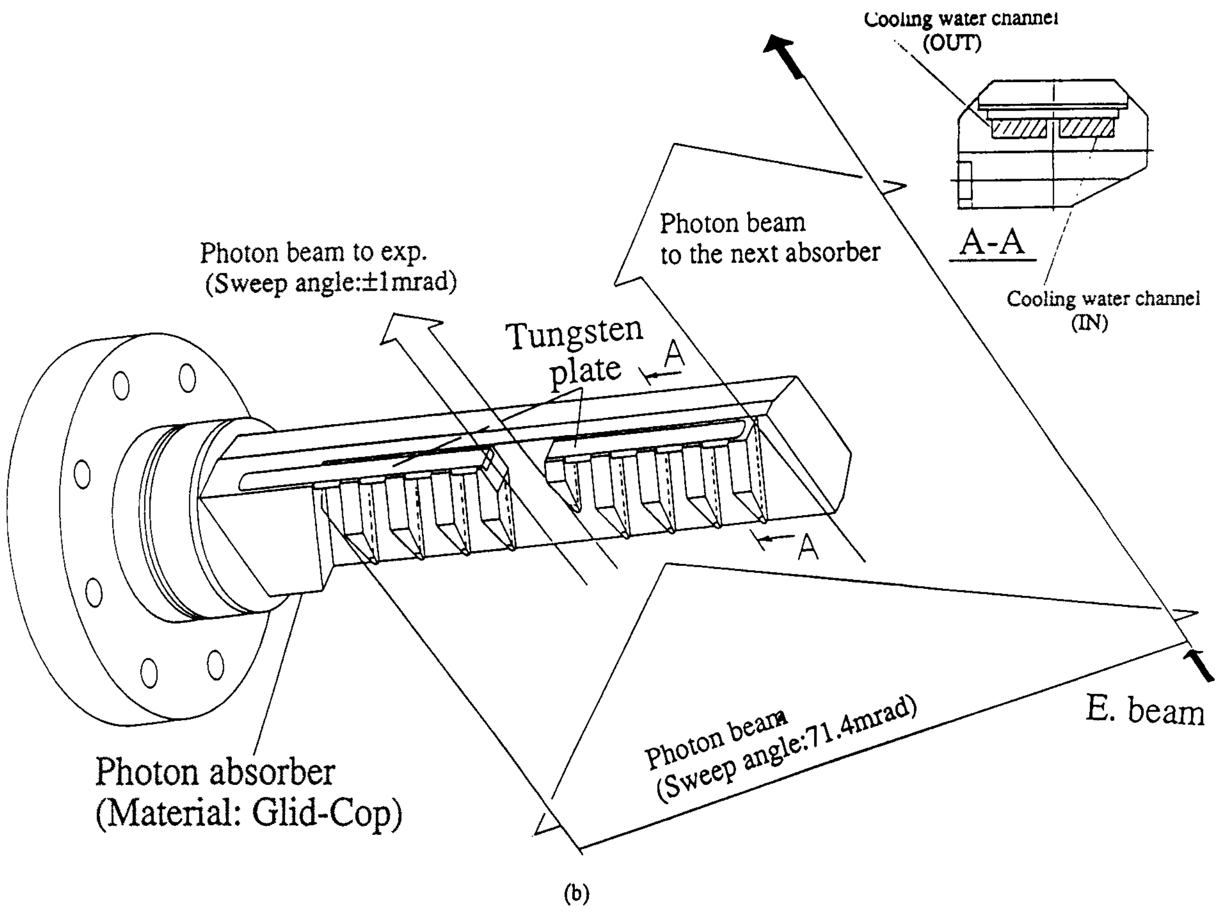


Fig.4 Structure of typical straight section chamber



(a)



(b)

Fig.5 (a) Isometric view of the crotch
(b) Isometric view of the photon absorber for the crotch

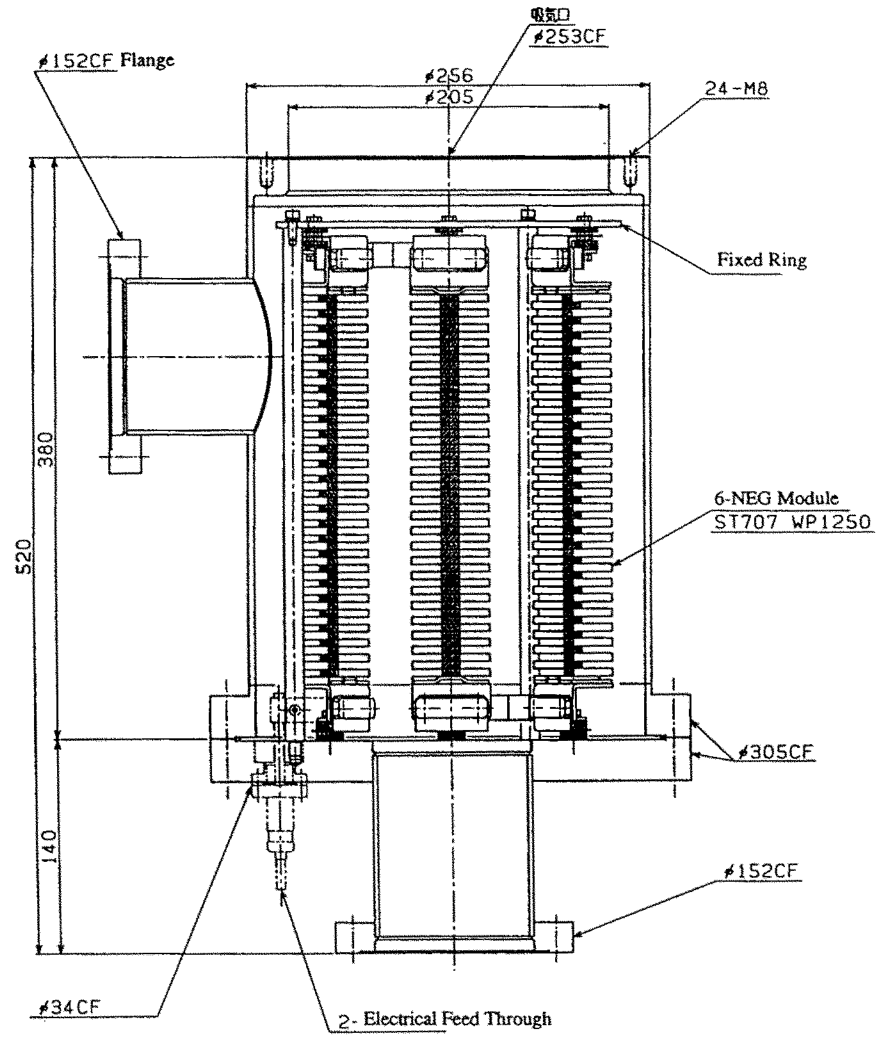


Fig.6 Structure of the lumped NEG pump consisting of NEG wafer modules

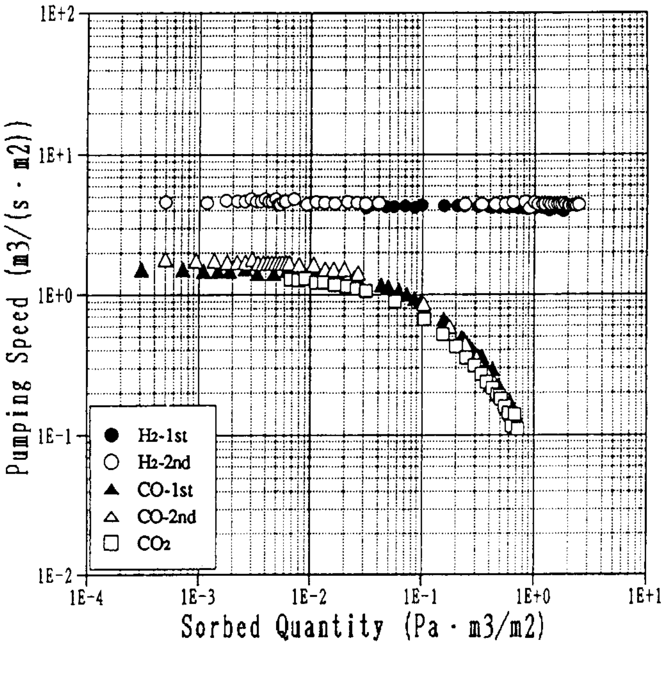


Fig.7 Pumping characteristics of the lumped NEG pump