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VACUUM SYSTEM FOR THE KEK PROTON SYNCHROTRON

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Summary

The construction and characteristic points of the vacuum system of KEK 12 GeV proton synchrotron are reported. The whole system is divided into three, i.e., for the injector and the beam transportation line to the booster, for the booster and transportation line to the main ring and for the main ring. Of these, only the last two vacuum systems will be reported in the following. In the design and construction, many new attempts have been made and some of them will be reported. The designed values of the average pressures in the booster and in the main ring are 4×10^{-4} Pa and 1×10^{-4} Pa respectively. These values correspond to the beam lives of 300 ms (in the booster) and 10 s (in the main ring), for a beam with injection energies of 20 MeV and 500 MeV respectively. Actually, the average pressures of 6×10^{-5} Pa in the booster and 3×10^{-5} Pa in the main ring are accomplished, which are much less than the designed value.

General

The designed values of maximum tolerable pressure, the expected life times of the beam for both cases of booster and main ring and relating parameters are summarized in Table I. For the realization of these,

	booster ring	main ring	unit
average pressure	4×10^{-4}	1×10^{-4}	(Pa)
beam life time	120	10,000	(ms)
energy (injected)	20	500	(MeV)
half aperture (vertical)	30	24	(mm)
ν	2.2	7.25	
$\lambda/(2\pi)$	2.7	7.45	(m)

Table I. Beam life times and relating parameters.

six ion pumps of 1000 ℓ/s in speed are installed around the booster ring. Two straight sections, S6 and S7, are devoted for RF acceleration cavities and it is impossible to install ion pump. For rough pumping, two turbo-molecular pump (TMP) units of 70 ℓ/s in speed and two rotary pumps of 950 ℓ/min are installed around the ring and evacuate the whole ring from 1 atomospheric pressure down to 10^{-2} Pa. After that, the ion pumps begin to operate. As to the main ring, the vacuum system is divided into 4 subsystems, each of which is composed of 14 to 16 ion pumps (two or three pumps of 1000 ℓ/s and 12 or more ion pumps of 160 ℓ/s) and a roughing unit of a TMP of 200 ℓ/s and a rotary pump of 950 ℓ/min. Each subsystem covers one quadrant of the ring and holds the pressure below 10^{-4} Pa.

Bellows type doughnuts tube

As the booster magnet is a fast cycling type with a repetition rate of 20 Hz, the eddy current induced in the doughnuts tube wall will have a harmful effect on the magnetic field. For that, we have developed a bellows type doughnuts tube. Thin sheet elements of 0.15 mm in thickness, are welded to form a bellows tube with an ellipse like corss section, and a doughnuts tube unit of 3 m in length is manufactured. The detailed structure of the tube is shown in Fig.1. As

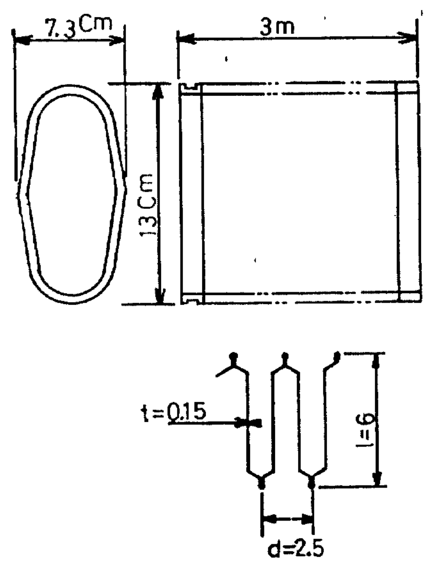


Fig. 1. Structure of bellows type doughnuts tube.

to the induction of eddy current, a tube of this structure is equivalent to a uniform tube with a thickness of the t_f, which is

$$t_f = \frac{dt}{2\ell}$$

where, ℓ and t are shown in Fig.1. In our case, d = 2.5 mm, ℓ = 6 mm and t = 0.15 mm, and we obtain

$$t_f \approx 0.03 \text{ mm}.$$

On the other hand, the strength against pressure difference of atomospheric pressure is large enough. By equating the second order moment of bellows structure (cf. Fig.1) to the one of a uniform plate of thickness t_f', we obtain a mechanical effective thickness t_f' as

$$t_f'^3 = \ell^3 \frac{2t}{d} \qquad (1)$$

By a substitution of actual values into Eq.(1), we obtain t_f' of the bellows type doughnuts tube as

$$t_f' = 3 \text{ mm}.$$

This value is thick enough for a stainless steel tube of the same size. Rough esitmations as to the magnetic field distortion ΔB and the temperature rise ΔT due to the eddy current have been made. ΔB is proportional to the time derivative of the main field, $\dot{B}$, and is estimated to be in the order of 1 G. The eddy current loss is about 30 W/m, which results in a temperature rise ΔT of about 30°C.

A cascade starting scheme of ion pumps

As mentioned previously, the vacuum system of the main ring is divided into 4 subsystems. Each subsystems is composed of one roughing unit with a TMP of 200 ℓ/s in speed, a rotary pump of 950 ℓ/m and 14 to 16 ion pumps. The total length of the doughnuts tube in every subsystem amounts to 85 m. Therefore, the small cross sectional area of the doughnuts tube and the gas desorption from the inner surface of the tube make hard the rough pumping down to the range of 10^{-2} Pa, which is ncessary for the initial start of ion pump. By a simple analysis, the pressure distribution p(x) along a tube which is evacuated at one end and closed at the other end is

$$\bar{p}(x) = p_0 + \frac{q}{2C} x (2L - x) \qquad (2)$$

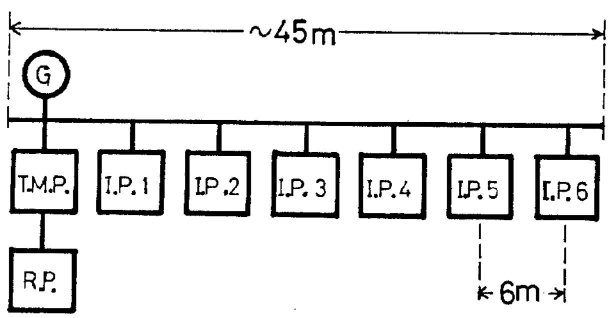
where, q, C, L and p_0 are the outgassing rate per unit length, the tube conductance reduced to unit length, total length of the tube and the pressure at the pump mouth (x = 0). p_0 is expressed by the pumping speed S as

$$p_0 = \frac{qL}{S} .$$

Therefore, the pressure at the end of the tube always exceeds $qL^2/(2C)$ even with the largest pump. In the case of the main ring, C = 80 ℓ/s m and L = 43 m. On the other hand, because the actual vacuum line of main ring is very complex and many devices are installed in it, the esitmation of q is difficult. After due consideration of these, we can roughly estimate q as

$$q = 3 \times 10^{-3} \text{ Pa } \ell \text{ s}^{-1}\text{m}^{-1},$$

which correspond to an outgassing rate per unit area, q_0, of 5.5×10^{-7} Pa ℓ $s^{-1}cm^{-2}$. This value is a reasonable value of a clean metal surface after several hours evacuation without baking. In practice, q_0 is a monotonic decreasing function of t, and we can expect that q_0 decreases down to 10^{-7} after tens of hours evacuation without baking. Using these values of C, L and q, we can obtain the pressure distribution along the vacuum line of main ring in a stage of rough pumping. From the above considertation, it can be said that for an ion pump near the roughing unit, the initial start is very easy but for a pump apart from the roughing unit the start is very difficult.



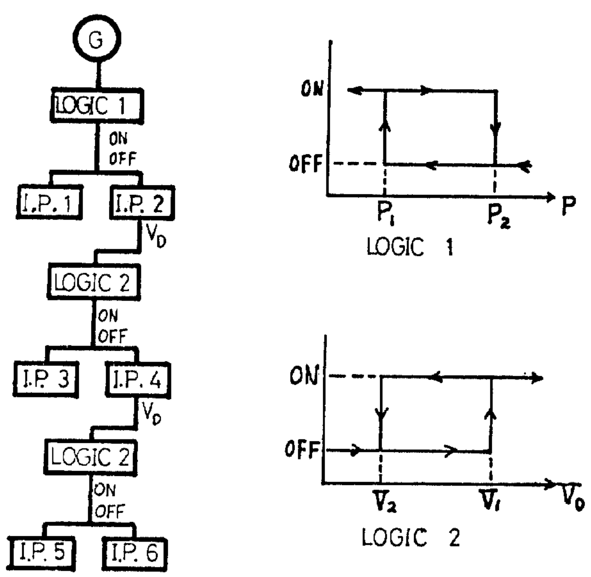


Fig. 2. A schematic diagram of cascade starting scheme.

The cascade starting scheme of ion pumps is one of the effective starting schemes (Fig.2). In the scheme, ion pumps near the roughing unit are operated firstly, and, after the pumps begin to operate properly, the next group of pumps is started and so on. For this starting scheme, some logics are required in the control. In general, when an ion pump is switched on after a long inactive period in atomospheric pressure, the pump will emit a large amount of gases. If the pump is continued to be in an on-state, the temperature of the pump will rise and finally, in the worst case, the pump will be damaged. For the protection against such a damage, a logic (logic 1) is inserted in the control for the power supply of the ion pump. In the first, the group of pumps nearest from the roughing unit (I.P.1 and I.P.2) is switched on when a monitor vacuum gauge mounted at the pump mouth indicates a pressure lower than a preset value P_1, and remains the on state until the pressure exceeds the second preset value P_2 ($>P_1$). So, in practice, the pumps will be repeatedly switched on and off, and finally operate properly with a steady pressure decrease. In the next stage of the cascade scheme, the next group (I.P.3 and I.P.4) is started by a signal from the first ion pump. In this stage, pumps in the first group act as a part of the roughing unit and, at the same time, as a monitor vacuum gauge (I.P.2). In the pressure range of $p < 2 \times 10^{-2}$ Pa, the discharge current decreases with the operating pressure. Therefore, the discharge current I or voltage V_D, which is a monotonic function of I, can take the place of pressure in the control. The V_D - p and I - p curves are shown in Fig.3. In this stage, the discharge voltage V_D of the ion pump in the first group controls the power supply for the second group, i.e., when the V_D rises up to a preset value V_1, the second pumps (I.P.3 and I.P.4) are switched on and remain in the on stage until V_D drops down to V_2($< V_1$). In the further stage, the scheme is just the same (Fig.2). In Fig.4, a set of typical curves of p(t) and V_D(t)'s of ion pumps in the cascade starting process of a quadrant is presented. In this scheme, a roughing unit is installed at the center of the vacuum line, and the cascade starting is carried

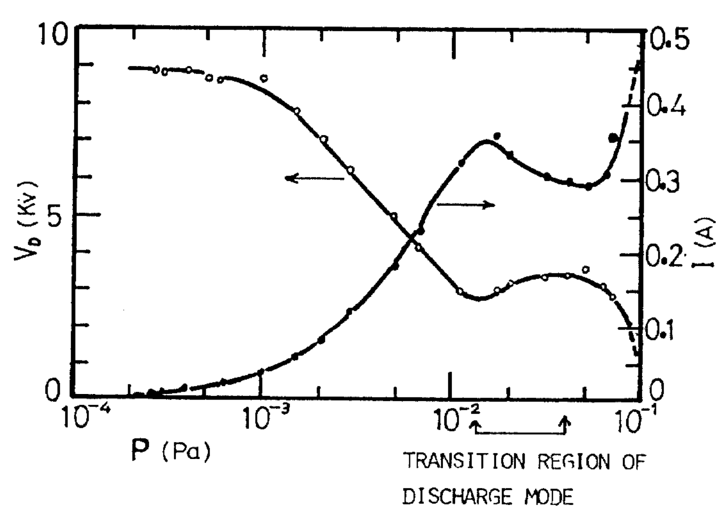


Fig. 3. V_D-p and I-p curves of ion pump of 160 ℓ/s.

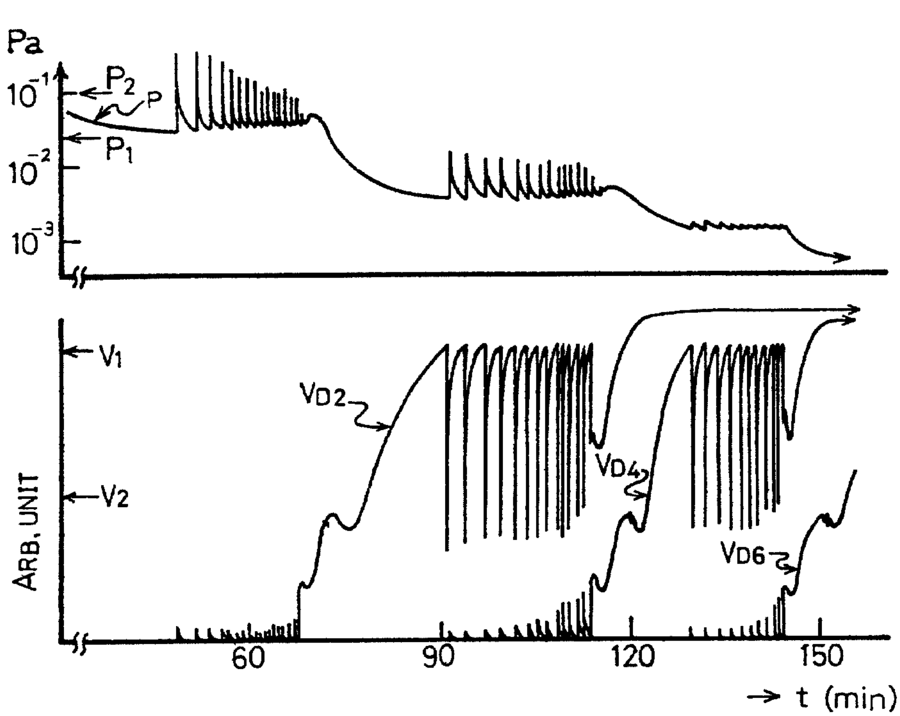


Fig. 4. Curves of p(t) and $V_D(t)$ in a cascade starting process.

out on both side. At the same time, two adjacent pumps are unified and considered as one pumping unit in the control. These curves show us that each pump begins to operate after many repetitions of on and off state and it takes 3 hours to make operate all the pumps. Actually, it takes 4 to 6 hours to finish the whole cascade starting process and evacuate the system down to the pressure of 1×10^{-4} Pa.

The time required for the evacuation down to 1×10^{-4} Pa depends largely on the decreasing characteristics of q_0 and less on the starting scheme. It will take nearly the same time to make all the pumps start and evacuate the system down to a pressure of 1×10^{-4} Pa even with a more strong roughing system. The cascade starting scheme saves the size and number of roughing unit in return of the initial heavy operation of ion pumps. But the time of heavy operation is short, and will be negligibly small compared with the total operation time.

H-gasket and flange

The H-gasket is a copper or aluminum gasket with a long parallelogramic cross section and is used between two identical flanges (Fig.5). The flange for the H-gasket, "H-flange", is of a sexless type and has a rectangular groove. The two knife edges of H-gasket contact with the flanges on the surface near the corner of the groove, and accomplish a complete vacuum tightness. This type of sealing has many advantages. One of them is a self-aligning action of the gasket. When the flanges are brought to close each other having a gasket between them, the centers of the flanges coincide automatically. This is the self-aligning action. In the second, the H-flange is very safe against a damage of the sealing surface. As the sealing point of the flange is near the groove corner, it is very seldom to be mechanically damaged. Thus, the best surface finish around the sealing point can easily be conserved. This reduces the minimum sealing forces per unit length as low as 7 kg/mm. In the third, a large width of the gasket (ℓ in Fig.5) acts as a spring, and holds the sealing force within a safety limit. More than 1000 sets of H-gasket and flanges are used in the vacuum system and operate properly as expected.

Recently, we have developed a new type H-gasket. The new type gasket is made of soft steel with knife edges of copper (Fig.5(b)). As the soft steel is good in spring action, the new type H-gasket can operate many times repeatedly. The gasket has been applied to a metal gate valve with a good result.

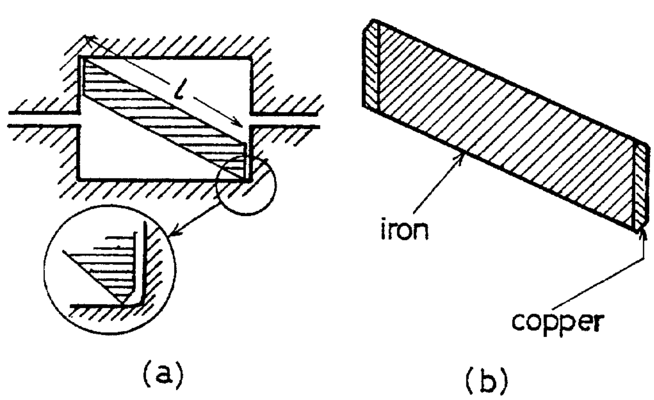


Fig. 5. (a) H-gasket and its detail.
(b) New type H-gasket for a gate valve.

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