PRESSURE-DISTRIBUTION ANALYSIS OF THE VACUUM SYSTEM FOR THE KEKB INJECTOR LINAC

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Abstract

An energy upgrade of the 2.5-GeV linac required for the KEKB project demands higher-power rf operation of the klystron and accelerator guides. In order to investigate a linac vacuum system having a better performance under such high-power operation, a pressure distribution analysis was carried out. We calculated the pressure distributions in several configurations of vacuum pumps using the characteristic matrix of the vacuum network geometry including the pumps. Pressure measurements were also performed for these configurations.

Introduction

The design of the KEKB project has been carried forward in order that electrons and positrons having energies of 8 and 3.5 GeV, respectively, can be injected to the collider rings. These beams will be obtained by realizing an energy upgrade of the 2.5-GeV linac. A klystron output power of 46 MW and an energy gain of 20 MeV/m [1] in the accelerator guides are required. Under such operational condition, it will take a longer time for rf conditioning; also, electrical breakdown phenomena at the accelerator guides and the rf window are among the serious problems expected.

The breakdown phenomena depend not on only the strength of the electric (accelerating) and magnetic (focusing) fields, but also on the surface and bulk conditions of the materials. Especially, such surface conditions as contamination and adsorbed water molecules are, in general, correlated to the vacuum pressure. In fact, klystron window breakdown is scarcely initiated from the inside of the klystron, where the pressure is lower than 1×10^{-6} Pa; ~ 10^{-5} Pa in the waveguide. It is thus expected that a pressure reduction would be one of the possible strategies for suppressing breakdown problems.

In this report, the optimization of the pump configuration in the KEKB vacuum system is discussed. By calculating the characteristic matrices for various configurations, we simulated the pressure distributions. The results are compared with the measured values.

Vacuum System of the Present 2.5-GeV Linac

The basic composition of an accelerator unit in the present 2.5-GeV linac, which has been operated since 1982, is shown in Fig. 1. The vacuum system of the accelerator unit is a multiply-connected network having waveguides, vacuum ducts and four 2-m accelerator guides. The rf pluses of 30 MW, 3.5 μs and 25 pps are fed to the unit from one 2856-MHz klystron. The unit is evacuated by a 50 ℓ/s pump and a 500 ℓ/s ion pump.

From the view point of the vacuum system, the unit has the following characteristics: (1) The pumps are installed in the klystron gallery so as to avoid radioactive contamination. Since a long vacuum duct is necessary, the effective pumping speed is low. (2) An rf window is inserted between a klystron and the first 3 dB-hybrid coupler in order to prevent accelerator guides from experiencing any atmospheric exposure during klystron replacement. However, the window has a problem concerning its own breakdown. (3) Baking has never been carried out. The rf conditioning required to reduce the outgassing rates of each component takes a longer period of about two weeks. The specifications of each component are listed in Table 1.

Formalism of the Pressure Distribution Calculation

The derivation of the characteristic [G] matrix [2] in a vacuum network having n nodes is briefly described here. Assuming that each conduit pipe has a uniform cross-section and a uniform outgassing rate, the pressure distribution (p(x)[Pa]) along a pipe in the steady-state is determined by

$$d^2 p(x) / dx^2 = -Q / CL^2, \qquad (1)$$

where Q [Pa m^3/s] is the total amount of outgassing in the pipe; C [m^3/s] and L [m] are the pipe conductance and length, respectively (Fig. 2). Thus, $p_{ij}(x)$ of the i-j pipe connecting

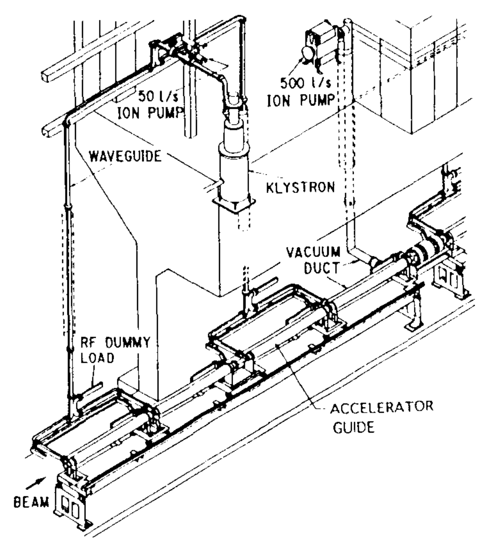

Fig. 1 Layout of an accelerator unit in the 2.5-GeV linac.

Table 1
Components in an Accelerator Unit

	Accelerator guide	Wave guide	Vacuum duct	
Material	OFC	OFC	SUS304	
Cross-sectional form	apertured disk	rectangle	circle /	ellipse
[Size (mm)]	[ID20, OD80]	[34×72]	[ϕ134.2] /	[21×45]
Total length (m)	8	26	14 /	1.2
Conductance ($\ell \cdot s^{-1} m^{-1}$)	1.2	20	290 /	9.4
Occupation [node-node]*	6-7, 7-8, 8-9, 9-10	7-12, 8-12, 9-11, 10-11, 11-15, 12-16, 13-14, 13-15,13-16	1-2, 2-3, 3-4, 4-5	/ 2-7, 3-8, 4-9, 5-10

* See Fig. 3.

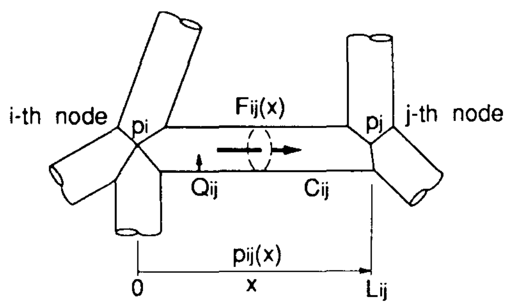

Fig. 2 Schematic drawing of outgassing (Q_{ij}) and gas flow ($F_{ij}(x)$) in the *i-j* pipe connected between the *i* - th and *j*- th nodes.

the i-th and j-th node is expressed as

$$p_{ij}(x) = p_i + \{(p_j - p_i) + Q_{ij}/2C_{ij}\}(x/L_{ij}) - (Q_{ij}/2C_{ij})(x/L_{ij})^2, \quad (2)$$

where p_i and p_j are the pressures at both ends (the i-th and j-th node) of the pipe.

By applying the *continuity law* of gas flow at every node, n sets of the following equations are obtained:

$$(p_i) = [G_{ij}](Q_j), \quad (3)$$

where $[G_{ij}]$ is an n × n matrix which comprises the pipe conductance and the pumping speeds; Q_j is the modified outgassing amount at the j-th node,

$$Q_j = \sum Q_{jh}/2 \quad \text{(h; around the j-th node).} \quad (4)$$

Calculations of the Pressure Distribution of the Linac

1) Pump installation in the klystron gallery

Some examples of the configurations to be calculated are shown in Fig. 3, including the present one (total of two pumps). Case (1) has one additional pump at the 13-th node (total of 3 pumps), and case (2) three additional pumps at the 13-, 15- and 16-th nodes (total of 5 pumps). The effective pumping speed of the ion pump at the 1-st node is considered to be about 250 ℓ/s (500 ℓ/s, nominal) on account of the pressure dependence of the pumping speed. It is supposed that the other pumps have an effective pumping speed of 10 ℓ/s at its mounted node.

By calculating the [G] matrix with the parameters given in Table 1 we can obtained the pressure distributions through

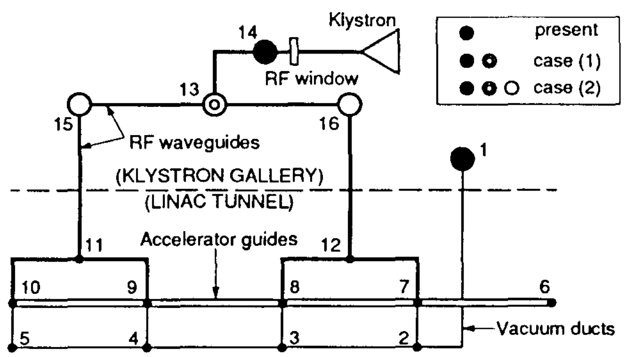

Fig. 3 Schematic diagram of the vacuum network in an accelerator unit.

the 1-, 2-, 7-, 8-, 12-, 16-, 13- and 14-th nodes (Fig. 4). In this calculation, Q_{ij} is evaluated by assuming that both stainless-steel 304 and OFC materials have an outgassing rate of 1×10^{-8} Pa m^3/m^2 s. For both cases of (1) and (2) the pressure at the window (14-th node) can be reduced by a factor of half, though it has little effect on the pressure at the accelerator guides (7- and 8-th nodes).

2) Pump installation in the linac tunnel

For a further reduction of the pressures at the accelerator

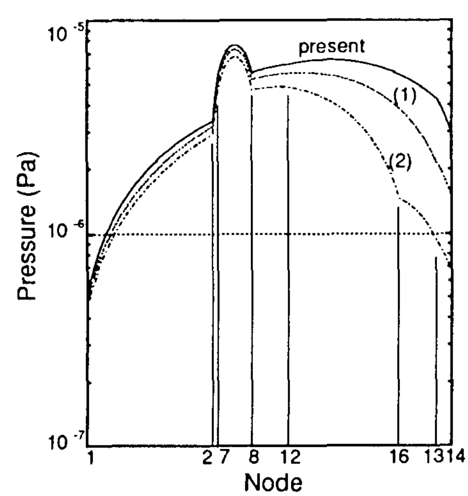

Fig. 4 Pressure distributions calculated for the present configuration and for cases (1) and (2).

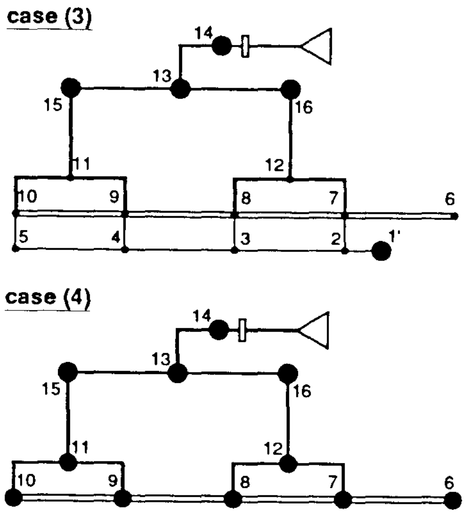

Fig. 5 Configurations of the additionally installed pumps in the linac tunnel.

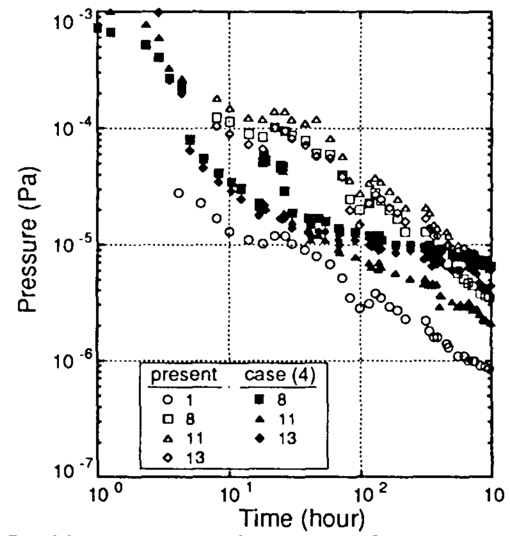

Fig. 7 Measured pressures for two cases of the present and other configuration at nodes.

guides, the other configurations were estimated (Fig. 5). The configuration of case (3) is slightly different from that of case (2). The 500 ℓ/s pump is shifted from the klystron gallery (1-st) to near the accelerator guides (1'-st) in the tunnel; the length of the penetrating vacuum duct (1-2) is shortened from 6 to 1-m. In case (4), eleven pumps having an effective pumping speed of 10 ℓ/s are mounted to every node.

The pressures of both ends of the accelerator guide are noticeably reduced in these configurations (Fig. 6). Especially, in case of a distributed configuration, such as case (4), although the sum of all the pumping speeds (110 ℓ/s) is less than those in any other cases, the pressures at the nodes in the tunnel (7-, 8- and 12-th) can be decreased approximately to one half of those in case (3). A significant reduction of the pressure at the accelerator-guide center is, however, difficult when using only distributing pumps, since an accelerator guide has a small conductance. When electrical breakdown phenomena occur in an accelerator guide, an additional pressure rise should take place.

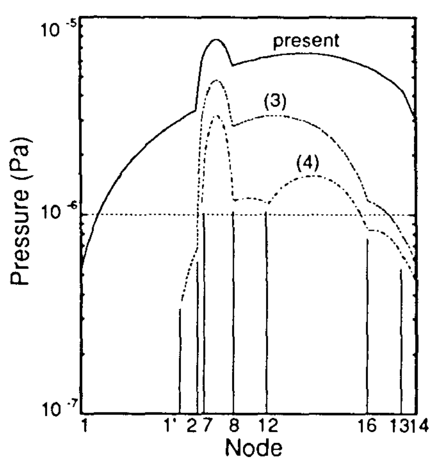

Fig. 6 Pressure distributions calculated for cases (3) and (4).

Pressure Measurement of the Linac

The actual pressure distributions in the accelerator units were measured for the above-described five cases using gauges mounted at the nodes of 1-, 6-, 7-, 8-, 9-, 11-, 12-, 13-, 14-, 15-, and 16-th. Some of the results have already been reported compared with the calculated distributions [3].

Figure 7 shows the time dependence of the pressures in the present and case (4) configurations during an evacuation followed by rf conditioning. For case (4), it can be confirmed that the pressures at the accelerator guides (8-th node) and near to the window (13-th node) are lower than those in the present case by about one half order. It is thus possible to shorten the time required for rf conditioning. Indeed, the pressures (8-, 11-, 13-th nodes) reached 2×10^{-5} Pa in about 50 hours, which is shorter by 100 hours than in the present configuration. No distinctive decrease of the pressures in case (4) was observed after ~ 50 hours; it must have been caused by a vacuum leak at the 12-th node, which was discovered by leak detecting after the measurements.

Conclusion

The calculations and measurements of pressure distributions were carried out with regard to the pump configurations. Based on the results, a distributed pump configuration has been found to be most effective for reducing the pressures in the accelerator unit, and, consequently, the rf conditioning time can be shortened.

References

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[2] Y. Saito et al., "Pressure distribution analysis of the KEK 2.5-GeV linac", Vacuum 43, 535 (1993).
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