

DOUBLE-FEED COUPLER FOR THE LINEAR COLLIDER

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Abstract

Symmetrical electric field in a coupling cavity was obtained with a double-feed type coupler in which two irises couple to symmetrical TM_{01} -mode. To simplify the structure, J-shaped waveguide was attached to the cavity for feeding the rf power through the two irises. Good field symmetry was verified by the perturbation method. The cavity was tested in maximum surface gradient up to 118 MV/m which was limited by a klystron performance and not breakdown limit. The field emission current was measured with Faraday cup and the microscopic field enhancement factor of 66 was obtained with Fowler-Nordheim plot and no critical discharge occurred. It was confirmed that the presented double-feed coupler is capable of handling high surface gradient more than 100 MV/m.

Introduction

In next generation linear colliders in the center of mass energy range of 300~500 GeV, high luminosity of 10^{33} ~ 10^{34} /cm²/s is required[1]. To obtain high luminosity, it is necessary to accelerate electron beams maintaining its low emittance. One of the main reason to cause beam deflection and emittance growth is the asymmetrical field around the axis because of its coupling iris. A magnetic field component associated with this asymmetrical field kicks electron beam in transverse direction. To solve this problem, different types of double-feed coupler have been proposed and developed by SLAC[2][3] and DESY[4]. They have good symmetrical field but the structures are rather complicated because they use power divider. To simplify the structure, we developed a new type of double-feed coupler of which J-shaped waveguide was attached to the cavity as shown in Fig. 1.

Structure

In the structure shown in Fig. 1, rf power is fed by J-shaped waveguide through two irises, which are located at opposite symmetrical positions around the axis of the cavity. Rf characteristics were measured as listed in Table 1.

Table 1. rf characteristics of the double-feed coupler .

Resonant frequency	2850.5 MHz
Coupling coefficient β	1.22
Unloaded Q	1.38×10^4

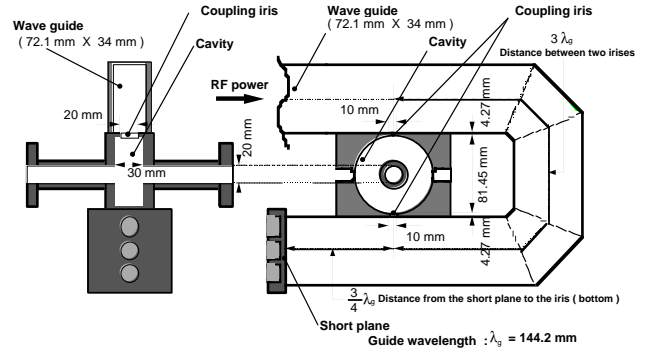


Fig. 1. Double-feed coupler. J-shaped waveguide was attached to the cavity .

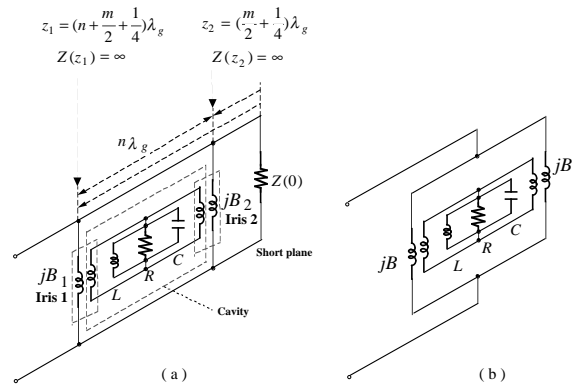


Fig. 2. (a) Equivalent circuit model of the double-feed coupler. (b) simplified model.

The principle of the double-feed coupler is explained with an equivalent circuit model as shown in 2 (a). The parallel LCR resonator represents coupling cavity and the susceptance jB_1 and jB_2 are associated with the irises. Here, we assume no loss in the transmission line. The impedance $Z(z)$ seen from an arbitrary position z to a short plane is given as:

$$Z(z) = jZ_0 \tan \frac{2\pi}{\lambda_g} z \quad (1)$$

where Z_0 is the characteristic impedance of the transmission line and λ_g is the guide wavelength. When the irises are

located at the position $z_1 = (n + \frac{m}{2} + \frac{1}{4})\lambda_g$ (n, m ; integer)

and $z_2 = (\frac{m}{2} + \frac{1}{4})\lambda_g$, the impedance $Z(z_1)$ and $Z(z_2)$ become infinite. The susceptance jB_1 and jB_2 looking from the rf source are equal because the distance between two irises is $n\lambda_g$. In this case, we can omit the impedance $Z(z)$ and simplify the equivalent circuit model from (a) to (b). Same power is fed in the cavity from each iris.

We chose the integers $m = 1$ and $n = 3$.

Field Distribution

The field distribution was obtained by the perturbation method with a dielectric bead ($\phi 3.0$, spherical, made by macor) as a perturbation object. To verify improvement of the field symmetry, it was compared with that in a conventional single-iris coupler cavity.

When a dielectric bead is used, the deviation of the resonant frequency Δf is represented as:

$$\frac{\Delta f}{f_0} \sim -\frac{k\varepsilon_0\chi_e|\vec{E}|^2\Delta\tau}{4U} \quad (2)$$

where f_0 is the resonant frequency of the cavity, k the geometrical factor and equal to 3 in this case, ε_0 the dielectric constant in vacuum, χ_e the electric susceptibility, \vec{E} the electric field, $\Delta\tau$ the volume of a perturbation object and U the energy stored in the cavity. By moving the bead and measuring the frequency shift Δf , the field intensity is calculated from equation (2). The field distribution was measured by moving the bead from one iris to the other. The measured field distributions are shown in Fig. 3. The field symmetry in the cavity was better than that in the conventional single-iris coupler cavity.

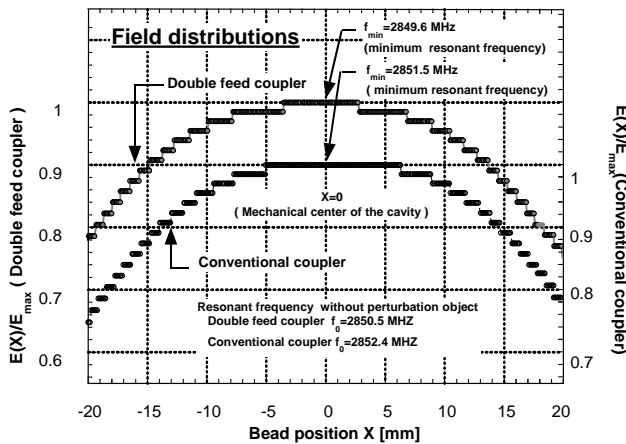


Fig. 3. Field distributions in cavities of the double-feed coupler and a conventional single-iris coupler.

High Gradient Experiment

In order to investigate the high power performance, high gradient experiment is performed. Maximum surface gradient, microscopic enhancement factor, momentum distribution of field emission current and vacuum level were measured. A layout of the experimental apparatus is shown in Fig. 4. A 5MW klystron is used as a power source which supplies rf power in the coupler cavity through a waveguide filled with SF₆ gas. An rf window separates this waveguide to the other vacuum type waveguide.

Incident and reflected power were measured with Bethe-hole type coupler and these waveforms are shown in Fig. 5. The maximum surface gradient $E_{s,max}$ is given as the function of the incident power P_{in} as:

$$E_{s,max} [\text{MV / m}] = 68\sqrt{P_{in} [\text{MW}]} \quad (3)$$

The incident power is limited by the klystron performance. In this case, the maximum power was limited up to 3.4 MW. The maximum surface gradient of 118 MV/m was obtained without any critical discharges. The break down limit seems considerably higher than this value.

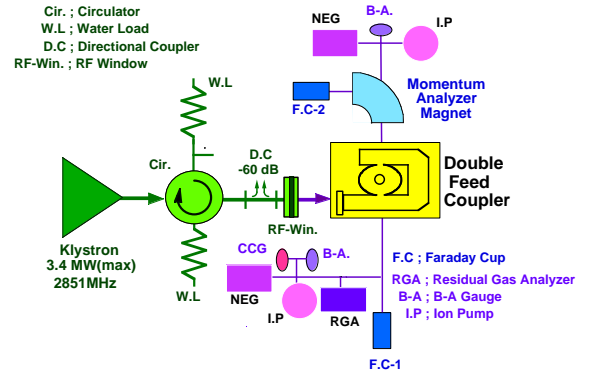


Fig. 4. Layout of the high gradient experiment.

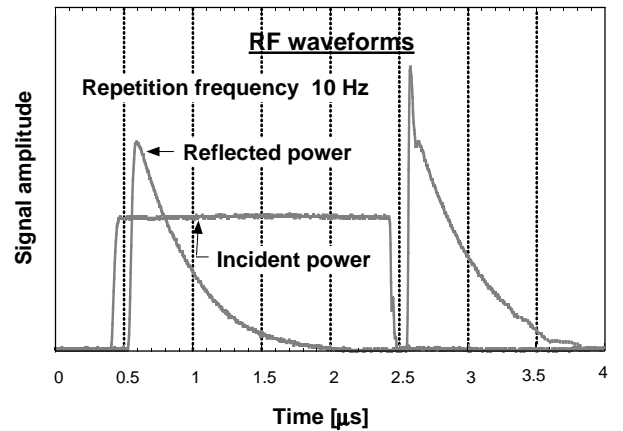


Fig. 5. The waveforms of incident rf power and reflected rf power.

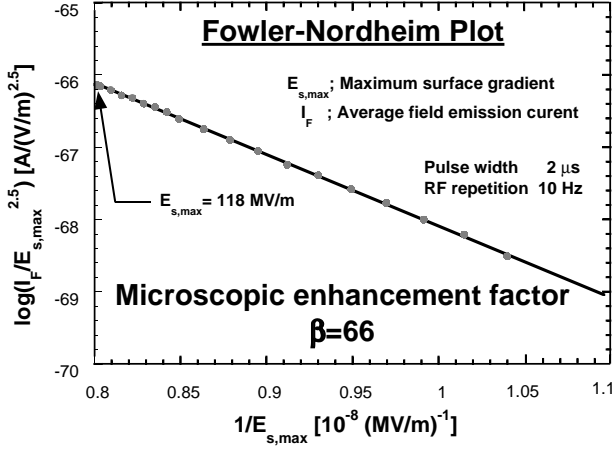


Fig. 6. Fowler-Nordheim plot from which the microscopic enhancement factor of 66 is obtained.

Microscopic enhancement factor β is obtained from Fowler-Nordheim plot which is given as:

$$\log\left(\frac{\bar{j}_F}{E_{s,max}^{2.5}}\right) = -\frac{6.53 \times 10^9 \cdot \phi^{1.5}}{\beta E_{s,max}} + \log\left(\frac{5.7 \times 10^{-12} \times 10^{4.52\phi^{0.5}} \cdot \beta^{2.5}}{\phi^{1.75}}\right) \quad (4)$$

where \bar{j}_F is the field emission current, ϕ the work function. The field emission current was measured with Faraday cup FC-1 and the maximum surface gradient was given by equation (3). The microscopic enhancement factor of $\beta = 66$ was obtained from the Fowler-Nordheim plot as shown in Fig. 6.

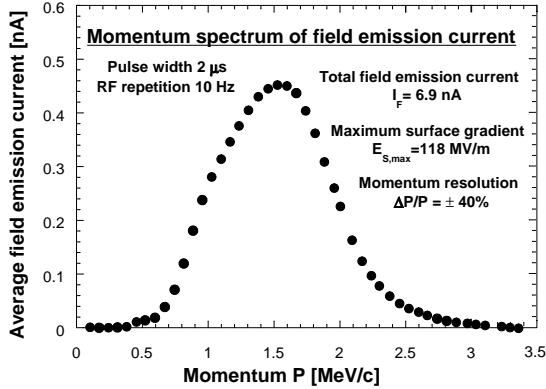


Fig. 7. Momentum distribution of the field emission current in the coupler cavity.

The momentum distribution of the field emission current is shown in Fig. 7. The momentum was measured with the momentum analyzer magnet and the current value was measured with Faraday cup FC-2 in Fig. 4. As the momentum acceptance $\Delta P/P$ of the system was about 40 %, the

maximum momentum of the field emission current was estimated to be about 2.0 MeV/c. Then the calculated accelerating field in the cavity was above 60 MV/m.

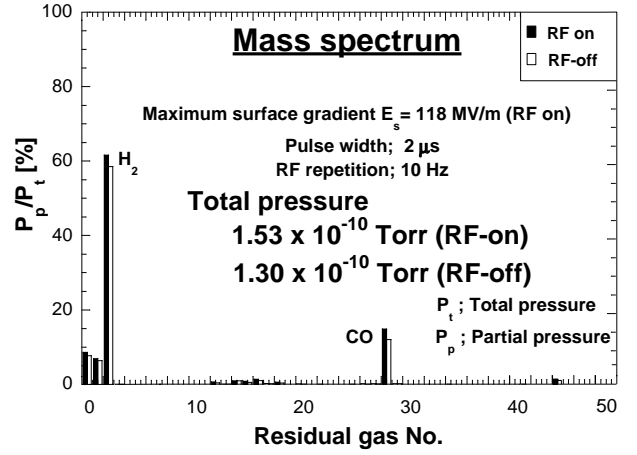


Fig. 8. Mass spectrum of the residual gases. There was no critical difference between rf-on case and rf-off case. No critical discharge occurred.

The vacuum level of 1.53×10^{-10} Torr was measured with B-A gauge. Mass spectrum of the residual gas was obtained by a residual gas analyzer as shown in Fig. 8. There was no critical difference between rf-on case and rf-off case. It shows that no critical discharge occurred.

Summary

Field symmetry was improved by adopting the double-feed type coupler. The high gradient experiment showed that it is capable of handling high surface gradient more than 100 MV/m. This type double-feed couplers have already been used for some accelerating structures at KEK.

Acknowledgment

The authors wish to acknowledge Prof. M. Yoshioka, Dr. T. Shintake and Dr. Y. Takeuchi for their continuous encouragement.

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