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Study of the Trapped Modes at the Vacuum Ports*

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Pumping ports in PEP-II vacuum chamber will be shielded with slots cut in the walls of the beam pipe. The number of slots n_s , their length l , and width w are defined by the required pumping conductance. The present design has 40 slots around the stainless steel round pipe in the straight sections, and, for the rectangular copper chamber of the arcs, there are 18 slots placed in upper and lower decks.

Here we want to address two potential problems related to the slots: radiation of the TE HOM-s through the slots, and generation of the trapped modes.

Radiation through the slots

Radiation through the slots is induced by the field of the beam and by the HOM propagating in the vacuum chamber. The excessive power radiated by the slots may be damaging to the pumps.

The energy radiated by a Gaussian bunch with number of particles N_B , and rms length σ_B through a longitudinal slot in a thin wall of a beam pipe with radius b is⁽¹⁾

$$\Delta U = \frac{N_B^2 c^2 (\alpha_c^2 + \alpha_m^2)}{3\pi(2\pi b)^2} \int_{-\infty}^{\infty} d\frac{\omega}{c} \left(\frac{\omega}{c}\right)^4 |\rho(\omega)|^2 \quad (1)$$

where $\alpha_{c,m}$ are polarizabilities of the slot, and $\rho(\omega) = \exp[-(\omega\sigma_B/c)^2]$.

Radiation induced by the field of a bunch or by TM HOM-s generated by a bunch somewhere upstream from the slot is given mostly by the transverse magnetic

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polarizability. For a long slot in a thick wall

$$\alpha_e = \alpha_m = lw^2/2\pi. \quad (2)$$

The radiation is exponentially small provided the slot is narrow compared with the wall thickness d , $2\pi d/w > 1$:

$$\Delta U = \frac{N_B^2 e^2}{2\sqrt{\pi}\sigma_B(2\pi b)^2} \left(\frac{lw^2}{2\pi\sigma_B^2}\right)^2 e^{-2\pi d/w}. \quad (3)$$

For $2dw < \pi\sigma^2$, the exponent is given by the attenuation in the slot rather than by the roll-off of the bunch spectrum.

However, the radiation from a slot induced by TE HOM-s is much larger because it is given by the longitudinal polarizability proportional to l^3 . The ratio of the radiated power to the power of the incident TE wave can be derived easily from Kurennoy's result^[1]:

$$\frac{\Delta P}{P_{in}} = \frac{2}{3\pi} \left(\frac{\omega}{c}\right)^3 \frac{k_c^2 \alpha_m^2}{qab} \quad (4)$$

where $k_c = \omega_c/c$ is given by the cutoff frequency ω_c , q is propagating constant, and

$$\alpha_m = \frac{\pi l^3}{24(\ln 4l/w - 1)}.$$

Note, that HOM can not propagate in the beam pipe with finite conductivity at the cutoff frequency. The worst case corresponds to high frequencies. At the maximum frequency of a bunch spectrum $\omega/c = 1/\sigma$, which is well above cutoff for short bunches, Eq. (4) can be simplified to

$$\frac{\Delta P}{P_{in}} = \frac{2\pi}{3} \left(\frac{\pi}{24}\right)^2 \frac{\sigma}{a \ln^2(4l/w)} \left(\frac{l^2}{\sigma_B b}\right)^3. \quad (5)$$

Eq. (5) is written for a rectangular beam pipe with dimensions $a \times b$, $b^2 \ll a^2$.

For the PEP-II arcs, $l = 10$ cm, $a = 10$ cm, $b = 5$ cm, $w = 0.3$ cm, and $\sigma_B = 1$ cm the ratio is close to one. This means that a slot is transparent for a TE mode. The power in the TE HOMs is unknown. Contrary to TM HOM-s, they are not coupled directly to the beam and may be generated by mode conversion due to the scattering of the TM modes in the beam pipe, or by broad-band losses to the hybrid modes mostly in the RF cavities. A TM $m = 0$ mode may mix with a TE mode only in a cavity without cylindrical symmetry. The TE component of the hybrid mode is proportional to the ratio of the surface areas of couplers, damping ports, etc to the total surface area of a cavity. We estimate this ratio as less than $S = 5\%$. A loss factor of TM modes above cutoff frequency of a RF cavities is 0.12 V/pC. Hence, 24 RF cavities of the HER can generate TE modes with power

$$P = Z_0 I_B^2 \frac{k_{TSh}}{4\pi} S = 4.5 \text{ kW} \quad (6)$$

at the beam current $I_b = 3$ A.

The dipole modes in the RF cavities may be fully coupled with TE modes, but they are not excited by a beam with a zero offset r_b . Therefore, the loss to this modes is of the order of r_b/b compared to the losses to the $m = 0$ modes.

The power Eq. (6) will go through the slots of few closest to the RF cavities pumping ports and may damage them. That can be avoided by covering slots with a mesh of holes with small diameter from the outer side of the slots as it will be done for the dipole screens.

Mode trapping

Another issue is mode trapping. The leak of the magnetic field into a slot may shift the frequency of a mode close to the cutoff frequency ω_c below the cutoff producing a trapped mode which exponentially decays at the large distances from the slot,

$$E(z) \propto e^{-\eta|z|} \quad (7)$$

The effect of a slot is similar to the bulging of the beam pipe. The frequency shift is related to the localization length L of a mode, $L = 1/q$,

$$\frac{\Delta\omega}{\omega} = \frac{q^2}{2k_c^2} \quad (8)$$

where $k_c = \omega_c/c$. Theory^[2] predicts

$$q = \frac{k_c^2 V_b}{2 S} \quad (9)$$

where V_b is the volume of the bulging.

For an opening, the volume V_b should be replaced by the magnetic polarizability α_m of the opening. For a long slot in a thick wall, α_m is given by Eq. (2). If there are several slots within the localization length L , then α_m should be multiplied by the number of slots.

For a rectangular beam pipe with dimensions $a \times b$, $a > b$, and a slot in the upper or lower decks located at x_s , $0 < x_s < a$

$$q = \alpha_m \frac{(2\pi)^2}{2ab^3} \sin^2\left(\frac{\pi x_s}{a}\right). \quad (10)$$

For a large number of uniformly spaced slots $n_s \gg 1$, $\sin^2(\dots)$ can be replaced by $1/2$ and α_m by the $n_s \alpha_m$.

The shunt impedance of the trapped mode depends on the resistivity of the wall. For a round beam pipe with radius b , the shunt impedance of a trapped TM_{0n} mode is^[2]:

$$R_s = \frac{Z_0}{2\pi} \frac{\nu}{J_1^2(\nu)} \frac{b}{\delta} \left(\frac{\alpha_m}{\pi b^3}\right)^3 \quad (11)$$

where ν is the n -th root of the Bessel function $J_0(\nu) = 0$, and δ is the skin depth at the frequency ω_c .

The shunt impedance for a rectangular chamber with the full dimensions $a \times b$, $a > b$ with a slot in the upper or lower decks is

$$R_s = Z_0 \frac{a}{b} \left(\frac{1}{k_c a} \right)^5 \left(\frac{b_{eff}}{\delta} \right) \left[\frac{4\pi^2 \alpha_m}{b^3} \sin^2 \left(\frac{\pi x_s}{a} \right) \right]^3. \quad (12)$$

Here $k_c = \sqrt{(\pi/a)^2 + (\pi/b)^2}$, $b_{eff} = ab(a^2 + b^2)/(a^3 + b^3)$ is related to the half width of the resonance due to the finite conductivity of the wall

$$\left(\frac{\Delta\omega}{\omega} \right)_{RW} = \frac{\delta}{b_{eff}}. \quad (13)$$

The theory has been compared and is in good agreement with numerical codes^{[2][3]} for a pill-box bulging. We checked the theory using the code MAFIA for slots in a round pipe. Parameters we used were: $b = 4$ cm, $l = 10$ cm, $w = b\theta$, $\theta = 12^\circ$, number of slots uniformly placed around the beam pipe $n_s = 18$. The cutoff frequency in this case is $f_c = 2.8686$ GHz. The theory predicts $\delta\omega/\omega = 7.22 \times 10^{-3}$ or $f = 2.8479$ GHz, $\Delta f = 20.7$ MHz, $L = 13.8$ cm, and $R_s = 16.1$ k Ω . MAFIA finds a mode with $f = 2.8495$ GHz or the frequency shift $\Delta f = f_c - f = 19.1$ MHz in good agreement with the theory. The shunt impedance calculated for copper beam pipe and with the magnetic boundary conditions imposed at the distance $z = \pm 75$ cm from the center of the slots was somewhat smaller than in theory, $R_s = 2.52$ k Ω . The Q-factor of the mode is $Q = 16000$. The electric boundary conditions at $z = \pm 75$ cm give about the same frequency $f = 2.8496$ GHz, $Q = 16620$, and $R_s = 1.74$ k Ω . The field pattern in both cases agrees with exponentially decaying field. The field pattern confirms also that the magnetic field H_θ leaks into the slot by the length of the order of $w/2$.

Radiation from a slot may produce additional width of the resonance and, for a width larger than the frequency shift, would eliminate the trapped mode. Radiation outside from a slot in a thin wall can give quite noticeable width

$$\left(\frac{\Delta\omega}{\omega} \right)_{rad} = \frac{\nu^3 \alpha_m^2 q}{3b^5} \quad (14)$$

where α_m and q are defined by Eq. (2) and Eq. (8). However, such a radiation for a slot in a thick wall $\pi d/w \gg 1$ is suppressed by a factor $e^{-2\pi d/w} \simeq 2. \times 10^{-3}$ for PEP-II parameters and is negligibly small.

Radiation inside the beam pipe for the lowest TM_{01} mode is possible only into the TE_{11} mode, which frequency is below the cutoff frequency of the TM_{01} mode. The width due to such radiation for a round beam pipe is

$$\left(\frac{\Delta\omega}{\omega}\right)_{rad} = \left(\frac{\nu}{2\mu}\right)^2 \left(\frac{\alpha_m}{\pi b^3}\right)^3 \sqrt{\nu^2 - \mu^2} \left(\frac{\mu^2 - \nu^2}{\mu^2}\right) \frac{\sin^2(q_E l/2)}{(q_E l/2)^2}. \quad (15)$$

Here ν and μ are the roots of the Bessel functions $J_0(\nu) = 0$ and $dJ_1(\mu)/d\mu = 0$, and $q_E = (1/b)\sqrt{\nu^2 - \mu^2}$ is propagation constant of the TE mode at the frequency of the TM mode. For the lowest TM_{01} mode, $\nu = 2.405$ and $\mu = 1.88$. However, effect of this radiation is very small. For a symmetric placement of the slots, coupling of the TM mode to the dipole TE mode is suppressed additionally due to azimuthal symmetry.

Confidence in the theory allows us to analyze the situation in the PEP-II vacuum chamber.

In the straight sections with stainless-steel round beam pipe with radius $b = 4.445$ cm there will be 40 slots with length $l = 9$ cm and width $w = 3.26$ mm. The cutoff frequency $f_c = 2.5816$ GHz is well within the bunch spectrum. The frequency shift of the mode is $\Delta\omega/\omega = 3.5 \times 10^{-4}$, which is larger than the width $(\Delta\omega/\omega) = \delta/2b = 0.36 \times 10^{-4}$ given by the resistivity of the wall. Note, that $\Delta\omega/\omega$ is also larger than the spacing between coupled-mode resonances $\omega_{rev}/\omega = 5.4 \times 10^{-5}$. The shunt impedance is $R_s = 85 \Omega$ per pumping port.

In the arcs, there are 18 slots with length $l = 15.4$ cm and width $w = 2.54$ mm cut in the upper and lower decks of the copper 9×5 cm rectangular chamber. The cutoff frequency of the lowest TM mode is $f_c = 3.4296$ GHz, $\Delta\omega/\omega = 6. \times 10^{-4}$. The shunt impedance in the arcs is higher than in the straight sections, $R_s = 272 \Omega$ per pumping port.

If added together, the shunt impedance of 300 trapped modes in 100 ports in the straight sections and 200 ports in the arcs give the total shunt impedance $R_s = 62.4$ k Ω . Variation of the beam pipe dimensions $\Delta b/b = \pm 12 \text{ mil} = 0.3$ mm spreads the frequencies of trapped modes around the ring. The frequency spread $\delta\omega/\omega =$

$\Delta b/b \simeq 6 \times 10^{-3}$ is large compared to the width of the trapped modes $\Delta\omega/\omega = 6 \times 10^{-4}$ in the arcs, which give the dominant contribution to the total shunt impedance. Therefore, the maximum total impedance of N pumps, averaged over the variations of the beam pipe dimensions,

$$Z_{max} = NR_s \frac{\Delta\omega/\omega}{\Delta\omega/\omega + \Delta\omega_b/b}$$

is reduced by a factor of 10 to the acceptable level $Z_{max} = 6.4 \text{ M}\Omega$.

The trapped modes may produce two effects. If the frequency of a trapped mode is close (within the width of the resonance $\Delta\omega/\omega = 2.4 \times 10^{-4}$) to a multiple of the frequency $f_b = c/s_B$ defined by the bunch spacing s_B , $f_b \simeq 230 \text{ MHz}$, then the resonance may produce additional heating of the beam pipe. These resonances are spaced by f_B and may be controlled by the proper dimension of the beam pipe. The cutoff frequency should be away from the multiples of f_b and dimensions should be controlled with the accuracy $\Delta b/b < f_b/f_c \simeq 0.06$ where f_b is the cutoff frequency. Variation of the dimensions of the beam pipe around the ring can bring some of the trapped modes to the resonance. For $I_b = 3 \text{ A}$ current, that would give power $P = I_b^2 R_s$ or $P = 560 \text{ W}$ per vacuum port in the arcs.

The second effect is the resonance with modes of coupled-bunch motion. These resonances are spaced by the revolution frequency $f_0 = 136 \text{ KHz}$, that is less than the width of a trapped mode and, hence, unavoidable. The total impedance of the trapped modes has a probability to give the growth rate larger than the radiation damping time and would require stabilization by the feedback system. That situation can be excluded if we can design the pumping ports to avoid trapping.

To destroy the trapped mode we should remember that the localization Eq. (9) and the frequency shift are defined by the total volume of the bulging. Hence, the trapping does not occur if the beam pipe has a dent with the volume

$$V_b > \alpha_m \quad (16)$$

where α_m and V_b is the polarizability of all slots and the total volume of a dent within the localization length of a mode.

We checked that with MAFIA modifying the model described above by an additional volume protruded inside of the beam pipe, see Fig. 3, with the volume larger than the total polarizability of the slots by 25%. MAFIA finds that the frequency of the mode, which was trapped without the dent, is shifted to the frequency $f = 2.8735$ well above the cutoff frequency.

If the beam pipe is recessed to make a smooth bow-like inward bend with the length equal to the length of a slot and with the maximum decrease of the radius Δ at the center of the slots, it would satisfy the condition Eq. (16) if $\Delta > 0.5$ mm in the straight pipes and $\Delta > 0.2$ mm in the arcs.

Another way to achieve the same goal is to put a small insertion in the plane transverse to the beam within the localization length of the trapped mode. In the arcs, the inserion may have a triangular geometry with 1 mm high at the center of the insertion and width 2.5 cm. To avoid heating by the synchrotron radiation, the insertion may have the C-shape. Such a double shallow taper produces, of course, some additional broad-band impedance. However, simulations with ABCI of the impedance of such an insertion in the beam pipe with radius $b = 2.5$ cm gives the loss factor $k_l = 3.7 \times 10^{-4}$ V/pC and inductance $L = 7.8 \times 10^{-3}$ nH. For 300 insertions this gives additional inductance 2.4 nH and increase the total machine inductance only by few percent. Two insertions of this kind put at the pumping ports separated by $L = 7$ m do not trap a mode between the insertions provided that

$$\frac{\nu w}{b} \sqrt{\frac{2\Delta}{b}} \ll 1 \quad (17).$$

For the parameters given above, the width of thew insertion $w = 2.5$ cm and the hight $\Delta = 1$ mm this condition is easily fulfilled both in the straight sections ($b = 4.5$ cm) and the arcs ($b = 2.5$ cm).

Mode trapping due to imperfections of the beam pipe.

The small recess required to avoid trapping brings in a question about the tolerances on the dimension of the beam pipe. Consider a round beam pipe. A periodic

variation of the beam pipe radius

$$b(z) = b_0 - \Delta \cos(2\pi z/\lambda) \quad (18)$$

may result in trapping of a TM HOM with frequency close to the cutoff. A trapped mode has to have a localization length L small compared to the wave length of the perturbation, $L \ll \lambda$, otherwise the average bulging volume would be averaged to zero. The TM mode close to the cutoff frequency generates a mode trapped in each wave length convolution of the boundary. Each wave length of the perturbation may be considered independently. More accurate consideration would show, of course, that the cross-talk of the trapped modes leads to formation of a narrow pass-band but the width of the pass-band, defined by the overlapping of the exponential tails of the individual trapped modes, is small and we can neglect this effect.

Exact solution of the problem requires consideration of the wave equation with the boundary condition $E_t(r = b(z)) = 0$ or

$$[E_z + \frac{db}{dz} E_r]_{r=b(z)} = 0. \quad (19)$$

This is a difficult problem. It can be simplified if we consider only long wave perturbations. In this case, $db/dz \simeq 2\pi\Delta/\lambda \ll 1$. Estimating E_z from the magnetic flux through the bulging with height Δ ,

$$E_z \simeq i(\omega_c/c)\Delta H_\phi, \quad H_\phi \simeq E_r,$$

we see that $E_z \gg b' E_r$ provided that $\lambda \gg b$. For a trapped mode localized at the maximum of the perturbation, $z = 0$, with the localization length $L \ll \lambda$ the second term in Eq. (18) additionally suppressed by a small factor $2\pi L/\lambda$ because in this case $db/dz \simeq (\Delta(2\pi/\lambda)^2 L$. Hence, we can simplify the boundary condition to $E_z(r = b(z)) = 0$. Then, the solution of the wave equation is $E_z(r, z) = J_0(\nu r/b(z))Z(z)$, where $J_0(\nu) = 0$ and $Z(z)$ satisfies the 1-D wave equation

$$[\frac{d^2}{dz^2} + \frac{\omega^2}{c^2} - (\frac{\nu}{b(z)})^2]Z(z) = 0. \quad (20)$$

Thus, $(\nu/b(z))^2$ plays a role of the potential barrier.

This equation can be simplified for small $\Delta \ll b_0$ expanding $b(z)$ over Δ and can be simplified even further expanding $\cos(2\pi z/\lambda)$ in z around the minimum $z = 0$ for $L \ll \lambda$. That gives

$$\left[\frac{d^2}{dz^2} + \epsilon - q^4 z^2\right]Z(z) = 0 \quad (21)$$

where $\epsilon = \frac{\omega^2}{c^2} - (\frac{\nu}{b_0 + \Delta})^2$, and

$$q^2 = \frac{2\pi\nu}{\lambda b_0} \sqrt{\frac{\Delta}{b_0}}. \quad (22)$$

The solution of Eq. (20) is well known. It gives the spectrum of the trapped modes $\epsilon_n = q^2(2n + 1)$. For the lowest mode $n = 1$ the solution is Gaussian in z : $Z(z) = Z(0)e^{-q^2 z^2/2}$. Hence, localization $L = 1/q$, and the assumption we made $L \ll \lambda$ is valid if

$$\frac{\pi\nu\lambda}{2b_0} \sqrt{\frac{\Delta}{b_0}} \gg 1. \quad (23)$$

Under this condition, there is at least one trapped mode. The maximum number of modes n_{max} defined by the condition $(\omega/c)^2 < (\nu/(b_0 - \Delta))^2$ is

$$n_{max} = \frac{2\lambda\nu}{\pi b_0} \sqrt{\frac{\Delta}{b_0}}. \quad (24)$$

Condition (22) means that $n_{max} \gg 1$.

For the waves of few meters long, Eq. (23) gives very small Δ . Consider, for example, the modulation with $\lambda = 3\text{m}$ in the beam pipe $b_0 = 3\text{ cm}$. The trapped mode exist if $\Delta > 0.2\ \mu\text{m}$.

The width of the mode $\delta\omega/\omega$ is smaller than the width due to resistive wall if

$$\frac{\pi\nu\lambda}{b_0} \sqrt{\frac{\Delta}{b_0}} > \frac{\delta}{b_0} \left(\frac{\nu\lambda}{2b}\right)^2. \quad (25)$$

This condition is stronger than Eq. (23) for $\lambda > (2b/\nu)\sqrt{b/\delta}$. For the arcs that means $\lambda > 8\text{ m}$.

The shunt impedance of a trapped mode is given by Eq. (11) where α_m has to be replaced by the volume $V_b = 2\pi b_0 \Delta / q$ with q defined in Eq.(21):

$$R_s = \frac{Z_0}{2\pi} \frac{\nu}{J_1^2(\nu)} \frac{b}{\delta} \left(\frac{2\lambda}{\pi \nu b} \right)^{3/2} \left(\frac{\Delta}{b} \right)^{9/4} \quad (26)$$

or

$$R_s = 78.7 \frac{b}{\delta} \left(\frac{\lambda}{b} \right)^{3/2} \left(\frac{\Delta}{b} \right)^{9/4} \Omega. \quad (27)$$

The shunt impedance decreases rapidly with the amplitude Δ . However, it is quite noticable even for small amplitudes for long wave length. Take $\Delta = 10 \mu m$, $\lambda = 3 m$, $b = 3 cm$. Then $R_s \simeq 400 \Omega$.

The question remains if there is a limit on small Δ -s which still can trapped mode. One of such a mechanism is the random variations of the radius $b(z) = b_0 + \delta_r(z)$. Let $\delta(z)$ be a random noise, $\langle \delta_r \rangle = 0$, $\langle \delta_r^2 \rangle = \delta_0^2$, with the correaltion length ζ .

Effect of the noise can be explained considering probability of the trapped mode to leak under the barrier of Eq. (19) to the neighbouring potential well. Large probability of the leak means low external Q -factor and damping of the mode. Normally, probability of the tunneling is exponentially small, $P \propto e^{-q\lambda}$ because $q\lambda = \lambda/L \gg 1$. Replace, however, the potential barrier with the length λ by n small barriers each with the same hight but with the length λ/n separated by small gaps of the same width. Penetration through a single small barrier can be described by the matrix relation

$$\begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix} = S \begin{pmatrix} \psi_3 \\ \psi_4 \end{pmatrix}; \quad S = \begin{pmatrix} 1 - \epsilon & \epsilon \\ -\epsilon & 1 + \epsilon \end{pmatrix}$$

where $\epsilon = e^{2q\lambda/n} - 1$, and ψ_1, ψ_2 are amplitudes of the waves incoming and reflected from the barrier from the left, and ψ_4, ψ_3 are the amplitudes of the waves incoming and reflected from the barrier respectively. We assume, that the gaps are narrow and phase advance per barrier is very small. In this approximation, all ψ -s are real.

Multiplying the matrices, we get

$$S = \begin{pmatrix} 1 - n\epsilon & n\epsilon \\ -n\epsilon & 1 + n\epsilon \end{pmatrix}$$

The probability to penetrate through n small barriers can be obtained from that imposing condition $\psi_4 = 0$. That gives

$$\psi_3 = \frac{1}{1 + n\epsilon} \psi_1.$$

For $n = 1$, and $q\lambda > 1$ that gives exponentially small probability. In the limit $n \rightarrow \infty$, $q\lambda \gg 1$, the probability to penetrate through the total barrier is $P = (1 + 2q\lambda)^{-2}$ rather than being exponentially small.

This example shows, that if the amplitude of a noise of the boundary is comparable with the amplitude of the periodic wave the penetration through the barrier is much larger than for the exponentially small tunneling under the barrier. The result corresponds to diffusion of the wave through small barriers and, therefore, should be valid not only for equal but also for large number of small but otherwise arbitrary barriers including random noise. In particular, that means that random perturbation of the boundary can not produce trapped modes.

Summary

The vacuum ports will be screened with slots. It is shown that slots do not screen pumps from the TE HOM-s propagating in the beam pipe.

Mode trapping produced by the leak of the magnetic field in the slots may cause mode trapping. This effect, predicted theoretically, is confirmed by MAFIA and in a good agreement with theory. The width of these modes given by resistive wall and radiation is found to be small. We discuss the means to avoid these modes, which are potentially dangerous for heating of the beam pipe and the longitudinal coupled-bunch instability.

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Figure Captions

1. Fig. 1 Dependence of E_z of the trapped mode on the distance from the slot center ($z = 0$).
2. Fig. 2 Leak of the magnetic field of a trapped mode into the slot.
3. The same as in Fig. 2 but with insertions. The frequency of the lowest mode is pushed above cutoff.

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MAFIA

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*MEAN ERROR OF CURLCURL-E 2.1786121651530E-02
*MAXIMUM ERROR OF DIVERGENCE-D 7.1002176264301E-04

TIME HARMONIC ELECTRIC FIELD IN V/M

P--:3.20

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COORDINATES/M
FULL RANGE / WINDOW
R[.0000, .065000]
I[.0000, .0000]
F[.0000, 20.000]
I[3.0000, 3.0000]
Z[.0000, .75000]
I[.0000, .75000]

R-MESHLINE: 1

F-MESHLINE: 4

LINE AT R/M: .0000E+00

F/M: 3.000

KEY:

E 1 * [Z] —

MAFIA

FRAME: 4 30/01/95 - 11:04:17 VERSION(V320.01) SLV3.DRC

FREQUENCY/Hz 2.8734842880000E+09
 MAXIMUM ERROR OF CURLCURL-E 9.1577368994453E-02
 MEAN ERROR OF CURLCURL-E 2.4019556585699E-03
 MAXIMUM ERROR OF DIVERGENCE-D 2.9303017072380E-05

TIME HARMONIC MAGNETIC FLUX DENSITY IN VS/M**2

P--:3.20

#ARROW

COORDINATES/M

FULL RANGE / WINDOW

R| .0000 .065000|
 I| .0000 .065000|
 P| .0000 .20.000|
 Z| .0000 .20.000|
 Z| .0000 .75000|
 I| .010000 .010000|

SYMBOL = R.1

Z-MESHLINE: 2

CUT AT Z/M: 1.00000E-02

INTERPOLATE.= 1

LOGSCALE....= 0.00000E+0

MAX ARROW = 4.44122E-08

2.223E-02

1.112E-02

0.000E+00

0.000E+00

3.250E-02

6.500E-02

F

↑

+Z

→

R

MAFIA

FRAME: 5 25/01/95 - 10:56:14 VERSION[V320.0]

SLY3.DRC

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 *MAXIMUM ERROR OF CURL/CURL-E 4.8146015405655E-01
 *MEAN ERROR OF CURL/CURL-E 2.1786321651530E-02
 *MAXIMUM ERROR OF DIVERGENCE-D 7.1002176264301E-04

TIME HARMONIC MAGNETIC FLUX DENSITY IN VS/M**2

P--:3.20

#ARROW

COORDINATES/M

FULL RANGE / WINDOW
 R [.0000, .065000)
 F [.0000, .065000)
 Z [.0000, 20.000)
 Z [.0000, 20.000)
 Z [.0000, .75000)
 Z [.0100000, .0100000)

SYMBOL = B_1
 S-MESHLINE: 2
 CUT AT Z/M: 1.00000E-02
 INTERPOLATE = 1
 LOOK-ALike 0.00000E+00
 MAX XJROW = 5.64765E-07

2.22E-02

1.11E-02

0.000E+00

0.000E+00

3.250E-02

6.500E-02

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