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# PROPOSAL OF AN ACCELERATING RF-CAVITY COUPLED WITH AN ENERGY STORAGE CAVITY FOR HEAVY BEAM LOADING ACCELERATORS

TSUMORU SHINTAKE

*KEK: National Laboratory for High Energy Physics,*
*1–1 Oho, Tsukuba-shi, Ibaraki 305, Japan*

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An accelerating rf-cavity coupled with a large-volume high-Q energy-storage cavity is possible to eliminate the very serious longitudinal coupled-bunch instability due to the fundamental mode in high beam current storage rings, such as B-factories.

To eliminate the instability it is essential to reduce the detuning of the resonance frequency required for compensation of the reactive part of the beam loading current. Since the energy-storage cavity has a very large volume it can store a large amount of electromagnetic energy. Consequently, a small frequency detuning is sufficient for the compensation. By using a low-loss mode in the storage cavity we can reduce the required rf input power. At the same time, this coupled-cavity system shows a quite high Q-value. Consequently, the impedance tail of the fundamental mode becomes quite small. This is also an important factor for eliminating the instability.

An example application to the KEK B-factory was examined. It was shown that the frequency detuning can be reduced to as low as -15 kHz for a maximum beam current of 2.6 amperes. This detuning frequency is much smaller than the revolution frequency of 99 kHz in the KEK B-factory. The loaded Q-value becomes $7.2 \times 10^4$. The effective impedance for the coupled-bunch mode ($m = -1$) was reduced to as low as 18 kΩ/ring. Since the estimated growth time of the instability was 22 msec, which is comparable to the radiation damping time, this type of instability will not occur.

Brief discussions are given to an important problem of parasitic modes inherent to a coupled-cavity system, which must be solved in order to put this system into practical use.

KEY WORDS: rf-cavity, longitudinal instability, storage cavity, fundamental mode, storage rings, rf-devices

## 1. INTRODUCTION

In the next generation of high beam current electron and positron storage rings, such as B-factories,[1,2] the multi-bunch longitudinal instabilities due to the fundamental accelerating mode will become a very serious problem. Generally, in storage rings, for phase stability (Robinson damping) and to maintain a long beam lifetime, beams are accelerated at off the crest of the acceleration voltage. This generates a reactive power into the cavity. In order to compensate for the imaginary part of the beam loading current and to minimize the required generator power, the rf cavity is generally operated at off the resonance. In the high beam current machine, this detuning frequency becomes as high as the revolution frequency of the beam. In the extreme case of large rings it exceeds the revolution frequency. In this case, since the multi-bunch longitudinal instability is excited by the very high impedance of the fundamental mode of the cavity, the beam becomes quickly lost. Since the growth rate of this instability is quite high, it will be very hard to cure it by means of a negative feedback-loop in the rf system.

In order to eliminate this type of instability it is essential to reduce the detuning frequency of the cavity resonance. Because the required detuning frequency is inversely proportional to the stored energy in the cavity we need to increase the stored energy. One simple way to do this is to increase the cavity voltage. However, the wall dissipation power also increases in proportion to the square of the cavity voltage, and the required input rf-power becomes enormous. One possible way to overcome this difficulty is to use a super-conducting cavity. Because super-conductors show a quite low loss we can establish a high acceleration voltage with only moderate input rf-power level, and store a large amount of electromagnetic energy. Additionally, since the super-conducting cavity shows a very high Q-value, the impedance tail becomes quite small. This is also important to eliminate the instability. However, up to now, we have had no operational experience concerning a super-conducting cavity in a high beam current storage ring. Threrefore, many technical difficulties are expected and extensive R&D studies are required for the realization of a reliable super-conducting cavity system.

In this paper, a new method is proposed, which utilizes an accelerating rf-cavity coupled with a low-loss large-volume energy-storage cavity. Since they are normal conducting copper cavities this system will be safe against severe conditions experienced in high beam current rings. Because the storage cavity has a very large volume it can store a large amount of electromagnetic energy. For example, it is easy to store ten-times the energy compared to that of a conventional single-cell accelerating cavity. Consequently the frequency detuning becomes ten-times smaller. If we use a low-loss mode, such as the $TE_{01n}$ mode in a cylindrical cavity, the required input rf-power does not increase much. At the same time, the loaded Q-factors of the system can reach as high as $1\times10^5$, which is the same order as the super conducting cavity system. Therefore, we can eliminate the multi-bunch longitudinal instability without using a super-conducting cavity.

In this paper we first review the basic mechanism of the beam loading compensation by frequency detuning, and discuss the method to reduce it. In the next section, the storage cavity is introduced, and the basic performance is discussed. In section 4, the practical ability of this proposal is examined as an example application to the KEK B-factory case. In section 5 we discuss the important problems concerning parasitic mode inherent to a coupled-cavity system.

## 2. RF CAVITY DETUNING

Here, we review the mechanism of beam loading compensation in an accelerating cavity in storage rings,[3] and discuss a way to minimize the detuning frequency.

Figure 1 shows an equivalent circuit diagram of an rf accelerating cavity connected to an rf generator of current $I_g$ and internal conductance of $\beta G_c$, where $\beta$ is the

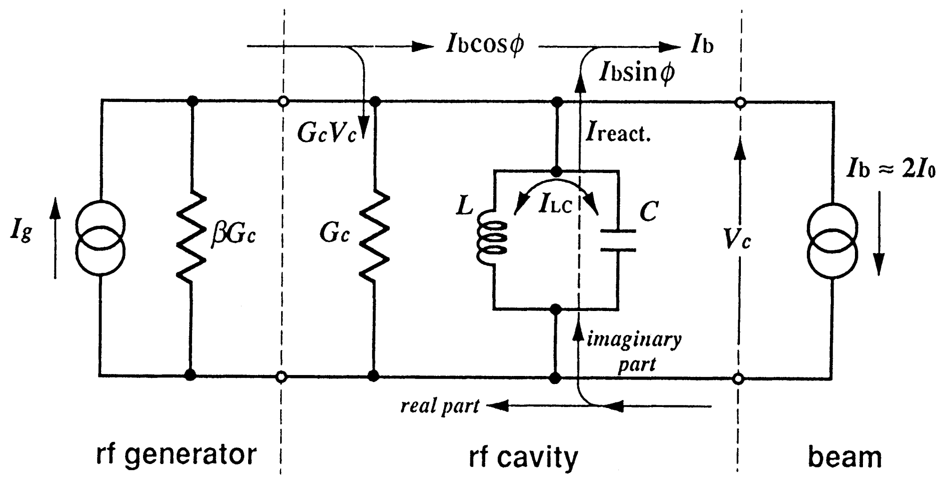


FIGURE 1: Equivalent circuit for a beam-loaded cavity coupled to an rf generator.

coupling coefficient between the rf cavity and the generator. The rf cavity is represented by an LC parallel resonator circuit, where $G_c$ represents the wall loss of the cavity. $V_c$ is the accelerating voltage, which includes the transit-time factor of the beam. $I_b$ is the Fourier component of the beam current at the accelerating frequency, which is approximately equal to twice of the DC beam current: $I_b \approx 2I_0$.

When the beam is accelerated by the cavity voltage it induces a beam loading current in the rf cavity circuit as a reaction. In electron or positron storage rings, in order to insure stability against phase oscillation the beam is accelerated at off the crest of the accelerating voltage. Therefore, the beam current $I_b$ is out of phase $\phi$ with the accelerating voltage, where $\phi$ is called the synchronous phase. The real part of the beam loading power, $\mathrm{Re}(\frac{1}{2}V_c I_b^*) = \frac{1}{2}V_c I_b \cos\phi$, is the time average of the net energy transfer utilized for beam acceleration. On the other hand, the imaginary part, $\frac{1}{2}V_c I_b \sin\phi$, is the reactive beam loading power, which can not be utilized for beam acceleration, and reflects back to the rf generator. Finally, it reduces the system power efficiency. In order to reduce this reflection power and to minimize the required generator power, the rf-cavity resonance is generally detuned from the generator frequency, and the imaginary part is compensated by bypassing through the LC circuit.

In an oscillating LC resonator electromagnetic energy is transferred alternatively between the electric potential energy stored in $C$ and the magnetic energy in $L$. Accompanying this energy exchange, the idler current $I_{LC}$ is always flowing between $L$ and $C$. At the resonance, the electric and magnetic energy become just equal to each other, and the total current flow along $C$ and $L$ are cancelled out. When the resonator is detuned from the generator frequency the balance is broken and the current begins to flow from the external circuit. This reactive current flow is given by

$$I_{\text{react.}} = j\omega C V_c + \frac{V_c}{j\omega L}$$

$$= j\omega_0 C V_c \left( \frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) \tag{1}$$

$$\cong j2I_{LC}\frac{\Delta\omega}{\omega_0},$$

where $\omega$ is the generator frequency, $\omega_0$ is the resonance frequency, and $\Delta\omega = \omega - \omega_0$. $I_{LC}$ is the idler cavity current ($= \omega_0 C V_c$).

We utilize this current to compensate the imaginary part of the beam loading current. This is the condition $I_{\text{react.}} = I_b \sin\phi$. From Eq. (1), the required detuning for this compensation becomes

$$\frac{\Delta\omega}{\omega_0} = \frac{I_b \sin\phi}{2I_{LC}}$$

$$= \frac{\operatorname{Im}\left(\frac{1}{2}V_c I_b^*\right)}{2\omega_0 W_0}, \tag{2}$$

where $W_0$ is the energy stored in the cavity. This equation implies that the required frequency detuning is equal to the ratio of the reactive part of the beam loading current to the idler cavity current, or the reactive energy flow per one cycle to the stored energy inside the cavity. Therefore, in order to minimize the frequency detuning we need to increase the idler cavity current, that is, increase the stored energy.

Using the definition of the shunt impedance, $R/Q = V_c^2/\omega_0 W_0$, from Eq. (2) we obtain the following equation of the detuning in a well known form:

$$\frac{\Delta f}{f_0} = \frac{I_0 R/Q}{2V_c} \sin\phi\,. \tag{3}$$

This equation means that in order to reduce the detuning frequency we must determine the rf structure which possesses a low $R/Q$ value.

The wall dissipation power is given by $P_c = V_c^2/R$, where $R$ is the shunt impedance. Since $R = (R/Q)Q_0$, if the structure has a lower $R/Q$, at the same time the Q-value must be higher by the same factor. Otherwise, the required generator power becomes quite large.

## 3. EFFECT OF AN ENERGY STORAGE CAVITY

In the previous section it was shown that the frequency detuning required to compensate the reactive part of the beam loading current is inversely proportional to the stored energy in a cavity. Thus, in order to minimize frequency detuning it is necessary to maximize the stored energy.

Because the stored energy is the volume integral of the field energy density one straightforward way to increase the stored energy is to use a large-volume accelerating cavity. In this case, we use some higher order mode for the beam acceleration, such as $TM_{0n0}$ modes, instead of the $TM_{010}$ lowest dominant mode. Although the stored energy increases approximately proportional to the cavity radius, the wall loss on the end plates also increases by the same factor. Therefore, to achieve a ten-times larger stored energy, the required input power becomes ten-times higher.

In order to overcome this difficulty we introduce a storage cavity connected to a conventional rf cavity of the $TM_{010}$ mode, as shown in Fig. 2. If we use a large-volume storage cavity, the stored energy becomes very large and the required frequency detuning becomes very small. In order to minimize the wall dissipation power, we use a low-loss mode in the storage cavity. In this case, the required input rf-power does not increase so much. At the same time, the Q-value of this coupled cavity system becomes very high. As already mentioned, this is also important for eliminating the multi-bunch longitudinal instability, since the impedance tail of the fundamental mode at the instability resonance becomes quite small.

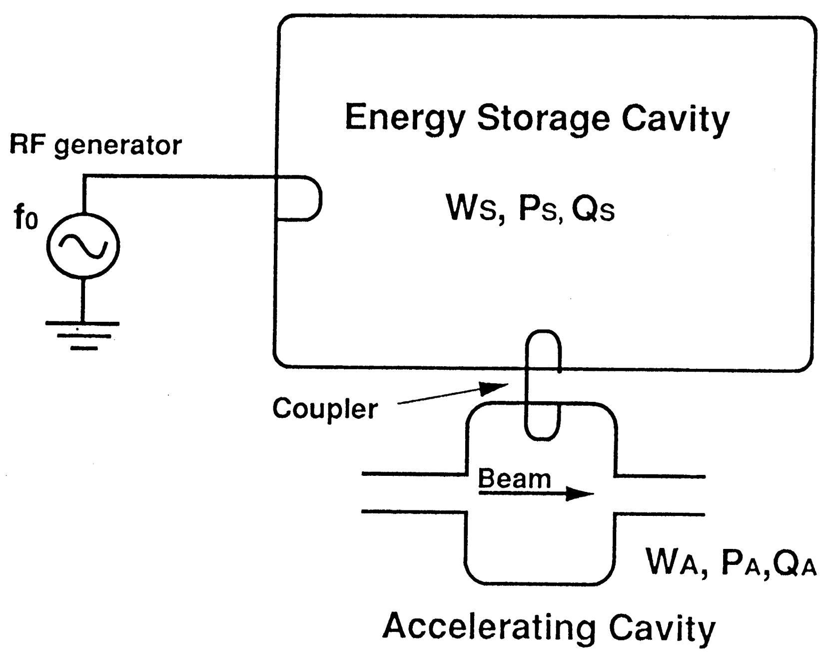


FIGURE 2: Accelerating cavity coupled to an energy storage cavity.

The total stored energy $W_{tot}$, and the wall-loss $P_{tot}$, $(R/Q)_{tot}$, the unloaded $Q_{tot}$ and shunt impedance $R_{tot}$ of this coupled cavity system are given by

$$W_{\rm tot} = W_A + W_S \,, \tag{4}$$

$$P_{\rm tot} = P_A + P_S \,, \tag{5}$$

$$(R/Q)_{\rm tot} = \frac{V_c^2}{\omega_0(W_A + W_S)} = \frac{(R/Q)_A}{1 + W_S/W_A} \,, \tag{6}$$

$$Q_{\rm tot} = \omega_0 \frac{W_A + W_S}{P_A + P_S} = Q_A \frac{1 + W_S/W_A}{1 + P_S/P_A} \,, \tag{7}$$

and

$$R_{\rm tot} = \frac{R_A}{1 + P_S/P_A} \,. \tag{8}$$

Here subscripts $A$ and $S$ denote the accelerating cavity and the storage cavity, respectively.

If the wall dissipation power in the storage cavity is much smaller than the accelerating cavity ($P_S \ll P_A$), and the stored energy in the storage cavity is much larger than the accelerating cavity ($W_S \gg W_A$),

$$(R/Q)_{\rm tot} = \frac{W_A}{W_S}(R/Q)_A \ll (R/Q)_A, \tag{9}$$

$$Q_{\rm tot} = \frac{W_S}{W_A} Q_A \gg Q_A \,, \tag{10}$$

and

$$R_{\rm tot} = R_A \,. \tag{11}$$

As shown in these equations, by means of the low-loss storage cavity, we can reduce the $R/Q$ value in inverse proportion to the stored energy ratio. The frequency detuning

TABLE 1: Principal Machine Parameter of KEK B-factory (low energy ring)

| | | |
|---|---|---|
| Beam Energy | $E$ | 3.5 GeV |
| Beam Current | $I_0$ | 2.6 A |
| Revolution Frequency | $f_{\mathrm{rev}}$ | 99.3 kHz |
| RF frequency | $f_0$ | 508.6 MHz |
| Total Cavity Voltage | | 22 MV |
| Energy Loss per Turn | | 0.95 MV |
| Synchronous Phase | $\phi$ | 87.5 deg. |
| Synchrotron Frequency | $f_s$ | 6.9 kHz |
| Cavity Voltage | $V_c$ | 0.6 MV/cell |
| Number of Cells | | 37 |

for the beam loading compensation therefore becomes smaller by the same factor. Since the Q-value increases in proportion to the stored energy ratio, and the shunt impedance is kept constant in this ideal case, the required rf input power does not increase. Both small frequency detuning and a high Q-value are very important to reduce and cancel out the impedance tails at the instability resonances. Therefore, the present proposal of the storage cavity method can be one of the best solutions to cure the multi-bunch longitudinal instability in high beam current storage rings.

## 4. EXAMPLE APPLICATION TO KEK B-FACTORY

In the KEK B-factory project[1] we need to store a beam current of 2.6 A in low-energy ring, and 1.1 A in the high-energy ring in order to achieve the maximum design luminosity of $1\times10^{34}$ cm$^{-2}$sec$^{-1}$. Since the multi-bunch longitudinal instability problem is more severe in the low-energy ring than in the high-energy ring, we discuss here only the low-energy ring case. The principal machine parameters are listed in Table 1. We assumed the maximum wall-dissipation power per one-cell of the accelerating cavity to be 60 kW. From this limit the cavity voltage was determined to be 0.6 MV. In this case, we need 37 cells in the low-energy ring.

If we use a conventional normal-conducing rf cavity the required frequency detuning becomes 180 kH. This is approximately twice as high as the beam revolution frequency. Therefore, during beam accumulation the cavity tuning crosses the frequency of the coupled-bunch longitudinal instability, and the beam is lost.

We now examine the storage cavity system. It is well known that the modes of the TE0n mode family in a circular waveguide have quite low loss. Especially, for oversize waveguide the loss is extremely low, the attenuation constant of which decreases as a function of the frequency, $f^{-3/2}$. Such a mode has been successfully used as a high-power storage cavity in an rf-pulse compressor system of SLED[4] at S-band frequency,

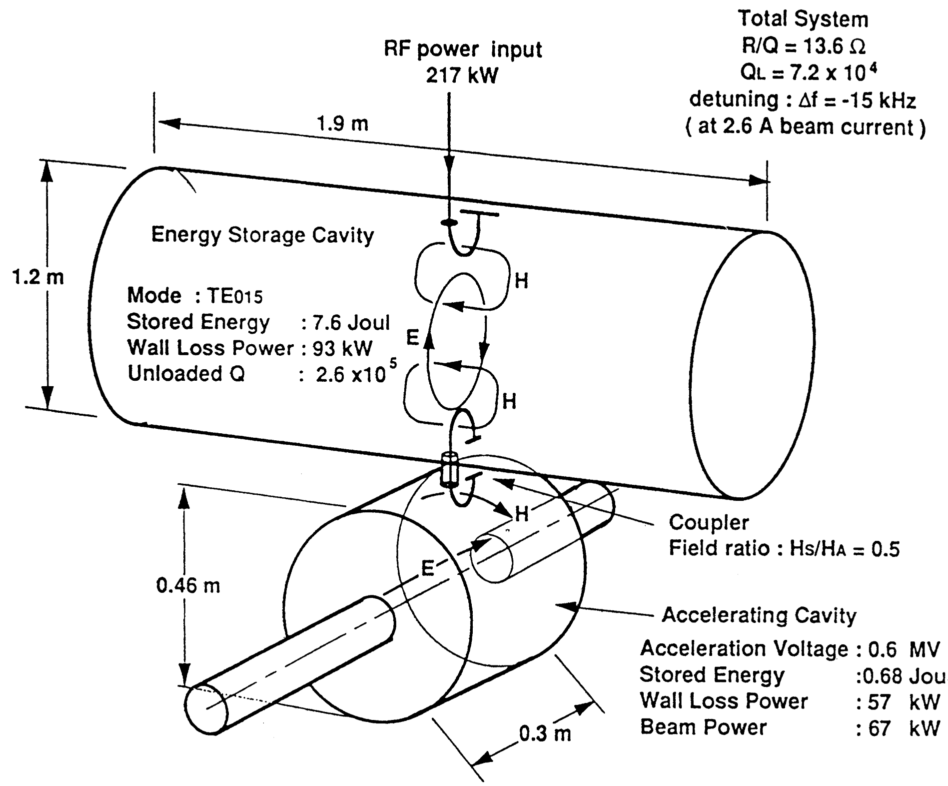


FIGURE 3: Proposed accelerating rf cavity system for the KEK B-factory.

where the $TE_{015}$ mode was used in a cylindrical cavity of length 33.59 cm and diameter 20.51 cm. An unloaded Q-value of $1\times10^5$ at 2856 MHz was obtained with a copper cavity. This Q-value is approximately seven times as high as that of the conventional accelerating cavity at the same frequency.

If we use the same cavity at 508 MHz, the cavity dimensions became a length of 1.89 m and a diameter of 1.15 m. The unloaded Q-value becomes $2.6\times10^5$. We connect this storage cavity to the conventional accelerating cavity as shown in Fig. 3. The parameters of both the accelerating cavity and the storage cavity are summarized in Table 2. The accelerating cavity is assumed to have a HOM-damper of the radial-line type with a choke[5] in oder to cure multi-bunch instabilities due to higher order modes. Due to this damper, the performance of the accelerating mode is lowered by some fraction. In Table 2, we assumed a degradation of 15% of the $Q$-value and 12% of $R/Q$.

Figure 4 shows the variation of the system parameters as a function of the field intensity ratio $H_S/H_A$: the magnetic field on the cylindrical wall in the storage cavity

TABLE 2: Cavity Parameters

| | | |
|---|---|---|
| Accelerating Cavity | | |
| Mode | TM010 | |
| Diameter | $2a_A$ | 0.46 m |
| Length | $l_A$ | 0.3 m |
| Unloaded Q | $Q_A$ | $3.8\times10^4$ |
| Shunt Impedance | $R_A$ | 6.3 MΩ/cell |
| | $(R/Q)_A$ | 165 Ω/cell |
| Storage Cavity | | |
| Mode | TE015 | |
| Diameter | $2a_s$ | 1.15 m |
| Length | $l_s$ | 1.89 m |
| Unloaded-Q | $Q_s$ | $2.6\times10^5$ |

versus that in the accelerating cavity (We can control the field intensity ratio, for example, by locating a coupling cell between two cavities and adjusting each coupling coefficients[6]). The plots are of the stored energy $W_{\text{tot}}$ and the wall dissipation power $P_{\text{tot}}$ of the total system, $R/Q$ and the Q-value, the shunt impedance $R_{\text{tot}}$ and the required input rf power $P_{\text{in}}$, the detuning frequency $\Delta f$ and the loaded Q-value. If we increase the field intensity in the storage cavity the stored energy becomes larger and $R/Q$ becomes lower inversely proportional to the stored energy, and the detuning frequency becomes smaller. However, as the wall dissipation power in the storage cavity becomes larger, the shunt impedance becomes lower. Hence, the required input rf-power becomes large. We must therefore compromise between these parameters. Here we choose a field intensity ratio of 0.5. The cavity parameters under this condition are summarized in Table 3. The total stored energy in this system becomes 8.3 Joules. This is twelve times as high as that in the accelerating cavity. Therefore, the detuning frequency becomes twelve-times smaller than in the case of not using the storage cavity. The detuning is only $-15$ kHz, which is much smaller than the beam revolution frequency in the KEK B-factory ring. The loaded Q-value is $7.2\times10^4$, which is much larger than that of the conventional accelerating cavity. Due to this high Q-value the impedance tail becomes very small. Additionally, due to the small frequency detuning the impedance cancellation works well between the growth and damp modes. Consequently, the effective impedance of the coupled-bunch mode is reduced to as low as 18.0 kΩ/ring. The estimated growth time of the multi-bunch longitudinal instability is 22 msec, which is comparable to the radiation damping time of the beam. This system is thus stable against this type of instability up to the maximum design beam current of 2.6 amperes

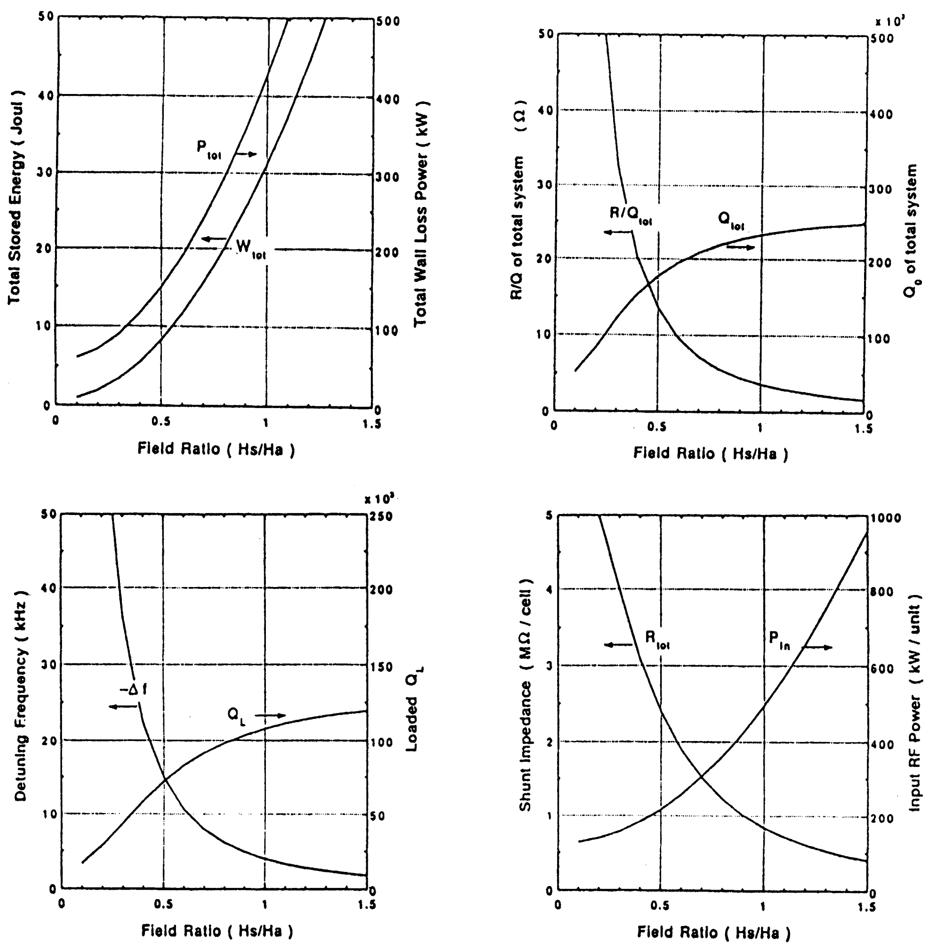


FIGURE 4: Variation of the system performances as a function of the field intensity ratio.

## 5. DISCUSSIONS

Although the use of the proposed system can solve the major problem of the multi-bunch longitudinal instability due to the fundamental mode, there are others that had to be solved for practical realization.

### *5.1 Parasitic Coupled Cavity Modes*

Generally, a coupled cavity system shows multiple resonances according to the number of cavities. A two-cavity-coupled system shows two different modes, (zero and $\pi$) according to the phase difference between the two cavities. If we use the $\pi$-mode for beam acceleration, another zero-mode will appear near to the accelerating frequency.

TABLE 3: Performance of the Storage Cavity Coupled System at a Field Intensity Ratio ($H_S/H_A$) of 0.5, and a Beam Current of 2.6 Amperes.

| | | |
|---|---|---|
| Stored Energy/unit | | |
| in accelerating cavity | $W_A$ | 0.68 Joul |
| in storage cavity | $W_S$ | 7.6 Joul |
| in total system | $W_{\mathrm{tot}}$ | 8.3 Joul |
| Wall Dissipation Power/unit | | |
| in accelerating cavity | $P_A$ | 57 kW |
| in storage cavity | $P_S$ | 93 kW |
| Beam acceleration power | $P_b$ | 67 kW |
| Input RF-power/unit | $P_{\mathrm{in}}$ | 217 kW |
| Shunt Impedance | $R_{\mathrm{tot}}$ | 2.40 MΩ/cell |
| | $(R/Q)_{\mathrm{tot}}$ | 13.6 Ω/cell |
| Unloaded-Q | $Q_{\mathrm{tot}}$ | $1.76\times10^5$ |
| Optimum Coupling | $\beta_0$ | 1.45 |
| Loaded-Q | $Q_L$ | $7.2\times10^4$ |
| Detuning Frequency | $\Delta f$ | $-15$ kHz |
| Effective Impedance | | |
| for the coupled-bunch mode (m = $-1$) | | |
| | $R^+ - R^-$ | 18.0 kΩ/ring |
| Growth Time of the Instability | | 22 msec |

Because the impedance of the zero-mode has the same order of magnitude as does the $\pi$-mode, and the frequency difference of this mode from the accelerating mode is much larger than the beam revolution frequency, it will cause the multi-bunch longitudinal instability. To cure this parasitic mode is therefore a key issue in using this type of coupled cavity system.

In principle, there are two methods to reduce this parasitic mode impedance. The first method is to damp the mode by extracting energy through a coupler into a matched load. In our system we will implement a higher order mode damper using a radial-line with a choke[5] in the accelerating cavity. Because the choke is a kind of narrow notch-filter (tuned to the accelerating rf frequency), the accelerating rf power does not leak into the damper. On the other hand, all of the higher order modes are effectively absorbed and damped. This damper also damps the unwanted coupled cavity modes. In order to achieve a good damping effect, a larger mode separation frequency is desired. However, because the stored energy in this system is quite large the mode separation becomes narrower than that in a coupled cavity system consisting of two conventional accelerating cavities with low stored energy. Therefore, since the use of only this damper in the accelerating cavity will not be sufficient, we need to add an additional damper in either the coupling structure or the storage cavity.

It is also possible[6] to locate a coupling cell between the accelerating cavity and the storage cavity in analogy with the alternating periodic structure (or sometimes referred to as the bi-periodic structure). The $\pi/2$ mode is used for the beam acceleration taking full use of the field stabilizing ability of the $\pi/2$ mode against the beam loading. Since the field in the coupling cell vanished for the $\pi/2$ mode, a damping mechanism for the zero and $\pi$ modes can be installed to the coupling cell, without any influence on the $\pi/2$ mode.

The second method is mode cancellation. In the case of a $\pi$-mode two-cell accelerating structure it has an unwanted zero-mode. Because the distance between the two cavities is adjusted to the half wavelength ($\lambda/2$) of the operating rf frequency, the excitation voltages of the zero-mode in the two cavities are cancelled out. Therefore, the impedance of the zero-mode, looking from a beam, becomes very small. We can utilize this phenomena in the storage cavity system, as shown in Fig. 5(a). This is a kind of three-cell coupled-cavity system, which shows three different modes: zero $\pi/2$ and $\pi$. If we adjust the distance between two accelerating cavities as the half-wavelength we can cancel out the zero and $\pi$-modes. We use the $\pi/2$ mode for beam acceleration. However, in the case of the $\pi/2$ mode the voltage of the storage cavity becomes zero. Consequently, the energy in the storage cavity also becomes zero, and the detuning frequency for the beam loading compensation again becomes large.

One possible way to overcome this difficulty is to use a hybrid coupler between the cavities, as shown in Fig. 5(b), where the two-accelerating cavities and the two storage cavities are coupled through a 3 dB hybrid coupler. Since the hybrid-coupler splits a wave into two waves of in-phase (0°) and quadrature (90°) components, the wave traveling from cavity-1 to cavity-2 does not cancel the wave oppositely traveling from cavity-2 to cavity-1. Therefore, we can store electromagnetic energy in the storage cavity. The unwanted zero-mode and $\pi$-mode are canceled out, since the beam excitation voltages in each acceleration cavity are the same amplitude, but of opposite polarity.

### 5.2 *Coupling*

The coupling coefficient between the accelerating cavity and the storage cavity must be sufficiently high to ensure that the impedance looking from a beam acts as if the system is a single cell cavity. This condition is equivalent to the compensation current for the imaginary part of the beam loading current being smoothly fed from the storage cavity through the coupler. The reactive power flow between two cavities is

$$\mathrm{Im}\left(\frac{1}{2}V_c I_{AS}^*\right) = \frac{1}{2}V_c I_b \sin\phi \frac{W_S}{W_A + W_S} \approx V_c I_0 \sin\phi\,. \tag{12}$$

Here $I_{AS}$ is reactive current flow between the accelerating cavity and the storage cavity. In the example case discussed in section 4 this power becomes 1.6 MW. Note that this is a reactive power and the net energy flow is zero. Therefore, the requirement for this condition is only to keep the coupling coefficient between the two cavities

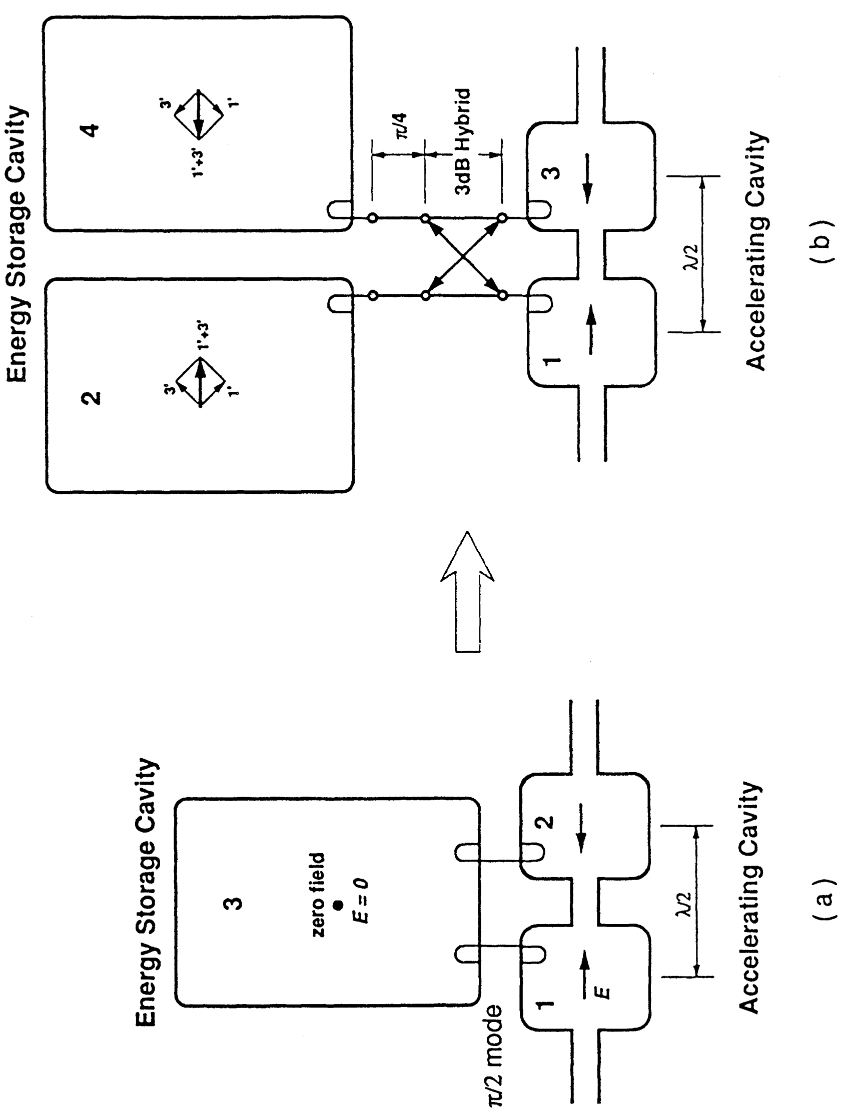


FIGURE 5: Possible cure for the parasitic coupled-cavity resonance via mode cancellation. (a) serially connected three-cavity system using $\pi/2$ mode, and (b) hybrid-coupled four-cavity system using split $\pi/2$ mode.

better than a limit value. In other words, the external $Q_{\text{ext}}$ looking from each cavity to the coupling structure must satisfy

$$Q_{\text{ext.i}} < \omega_0 \frac{W_i}{\text{Im}\left(\frac{1}{2} V_c I_{AS}^*\right)}, \tag{13}$$

where $i$ denotes the accelerating cavity or the storage cavity. In the example case of section 4, for the accelerating cavity this limit becomes $Q_{\text{ext}} < 1400$. This is a relatively easy value to realize via a waveguide coupler. If we design the coupling coefficient so as to be lower than this value, the storage cavity cannot effectively supply the compensation current into the acceleration cavity (the phase difference between two cavities becomes large due to the coupling series impedance), and the required detuning frequency becomes higher and the multi-bunch longitudinal instability can occur.

### 5.3 *Storage Cavity*

In section 4 we discussed the $TE_{015}$ mode in a cylindrical cavity. However, because of the large atmospheric pressure, high mechanical rigidity is required for the plain end-plates, thus necessitating thick and heavy plates. As already employed in the rf system for the LEP project at CERN,[7] the spherical cavity will be one possible solution to this problem.

## 6. CONCLUSIONS

An accelerating cavity coupled with an energy storage cavity has been proposed for a stable accelerating system in heavy beam loading accelerators. The practical ability of this proposal has been discussed by an example application to the KEK B-factory, where it has been shown that a cylindrical storage cavity of 1.2 m diameter and 1.9 m length using the $TE_{015}$ low-loss mode will suffice to eliminate the multi-bunch longitudinal instability due to the fundamental mode.

This system has another big advantage in application to electron and positron damping rings in $e^+e^-$ linear colliders. In order to maintain high beam-beam luminosity at the collision point, it is necessary to inject the beam into the main linac as stably as possible. Therefore, the circulating beams in the damping ring must be stable against any fluctuations, especially non-uniform beam loading due to the beam gap (vacant rf buckets between bunch train-to-train). Since $R/Q$ of the proposed system is quite small (= large electromagnetic energy is stored in the cavity), the phase and energy fluctuations induced by the beam gap can be made very small.

Although the proposed system can solve the major problem of the multi-bunch longitudinal instability due to the fundamental mode, extensive R/D studies will be required for practical realization, especially curing the parasitic coupled-cavity mode problem will be the most important key issue.

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