Suppression of coupled-bunch instabilities in the SPring-8 storage ring

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In the hybrid optics operation of the SPring-8 storage ring until July, 1999, coupled-bunch instabilities had been suppressed by our counter-measure and not been observed. The HHLV (High-beta Horizontal Low-beta Vertical) optics operation began in September, 1999 for upgrading brightness of synchrotron radiation by undulators and the horizontal betatron function in the cavity position became 25 times larger than that of the hybrid optics. Since the growth rate of a horizontal coupled-bunch instability arising from transverse coupling impedances of rf cavities depends on the betatron function, the horizontal coupled-bunch instability arose in the HHLV optics operation and was observed for the first time. The instability could not be suppressed by only chromaticity over-compensating but be easily and effectively suppressed by adjusting the resonant frequencies of higher-order modes (HOM's) in rf cavities with frequency tuners which were equipped to each rf cavity. The details of our technique on suppression of the coupled-bunch instabilities are described in the following references.

References

[1] H. Ego et al., Nucl. Instr. and Meth. A 383 (1996) 325-336.

[2] H. Ego et al., Nucl. Instr. and Meth. A 400 (1997) 195-212.

Our methods against the coupled-bunch instabilities.

1) Use of bell-shaped single-cell cavities with low HOM impedances.

a) The highest transverse coupling impedance in the bell-shaped single-cell cavity is 13.7 MΩ/m of TM111-like mode. The threshold beam current, I_{th} , limited by this impedance is 166 mA at a betatron function of 5 m.

$$I_{th} = \frac{2\,E}{\tau_b\, e\, \beta_x\, f_r\, \mathrm{Re}\,(Z_T)\, F'}$$

e : the electric charge of an electron, E: an electron energy,
τ_b : a transverse radiation damping time,
β_x : a betatron function in the cavity position, f_r : a beam revolution frequency,
Z_T : a transverse coupling impedance and F' : the Sacherer's form factor.

b) The highest longitudinal coupling impedance in the monopole HOM's is 2.8 MΩ of TM011-like mode. The threshold beam current limited by this longitudinal impedance is 208 mA.

2) Systematic modification of the inner structures of the cavities.

2 sets of 16 bell-shaped single-cell cavities with a different length of R_1 shown in Fig.2 were fabricated and one set of the cavities was rotated by 90˚ around the beam axis to reduce the overlaps of coupling impedances among the cavities.

3) Sophisticated adjustment of HOM frequencies.

Each cavity is provided with 2 frequency tuners as shown in Fig.2. The resonant frequencies of HOM's can be adjusted by one of the tuners while the accelerating TM010-like mode is kept resonating at 508.58 MHz by the other tuner. The temperature of cooling water for the rf cavities is also controlled with a precision of ± 0.01 ˚C.

4) Chromaticity over-compensating.

HHLV optics : $\xi x = +7$, $\xi y = +4$ Hybrid optics : $\xi x = +6$, $\xi y = +7$.

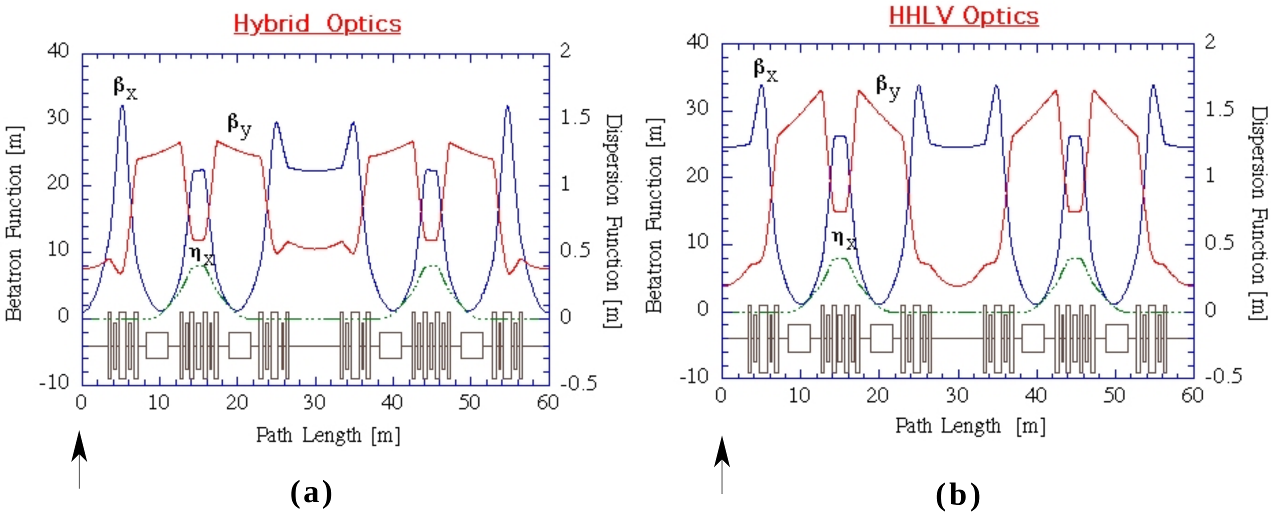

Fig.1 (a) Hybrid optics and (b) the HHLV optics of the SPring-8 storage ring. The arrows indicate the cavity position in the lattice.

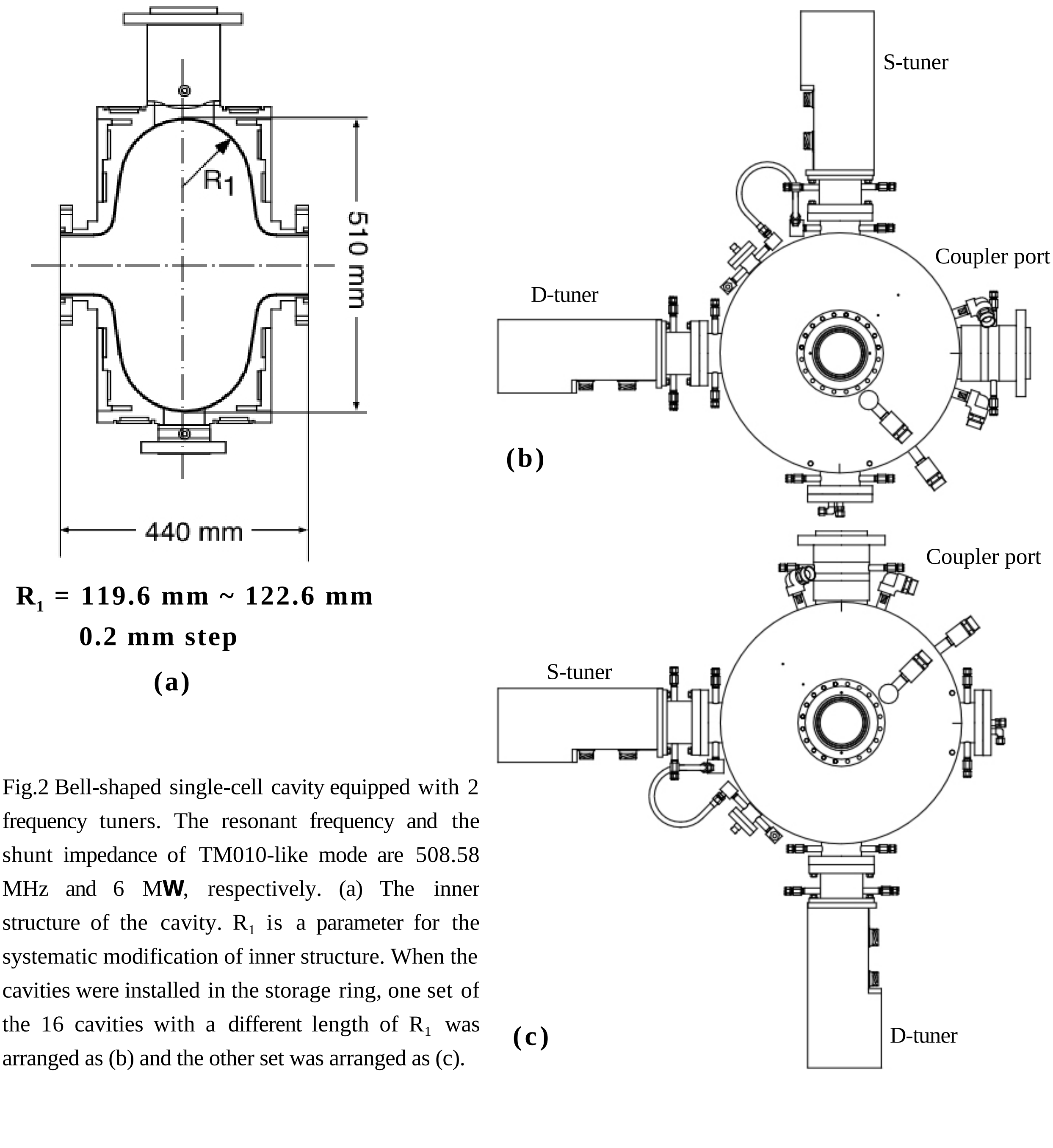

Fig.2 Bell-shaped single-cell cavity equipped with 2 frequency tuners. The resonant frequency and the shunt impedance of TM010-like mode are 508.58 MHz and 6 MΩ, respectively. (a) The inner structure of the cavity. R_1 is a parameter for the systematic modification of inner structure. When the cavities were installed in the storage ring, one set of the 16 cavities with a different length of R_1 was arranged as (b) and the other set was arranged as (c).

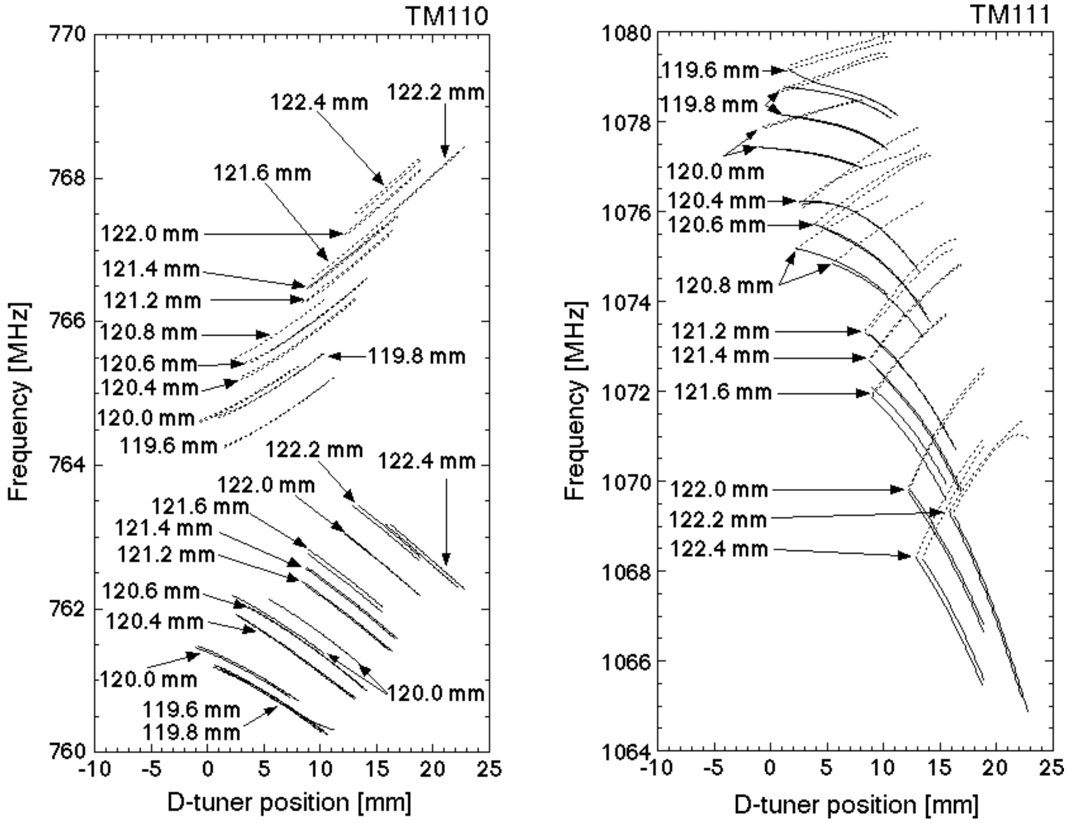

Fig.3 Frequency diagrams of TM110-like and TM111-like modes in the bell-shaped single-cell cavities with a different length of R_1. The frequencies of the modes can be changed by the D-tuner in Fig.2 while TM010-like mode is always kept resonating at 508.58 MHz by the S-tuner. The transverse shunt impedance of TM110-like mode is 10.7 M**W**/m.

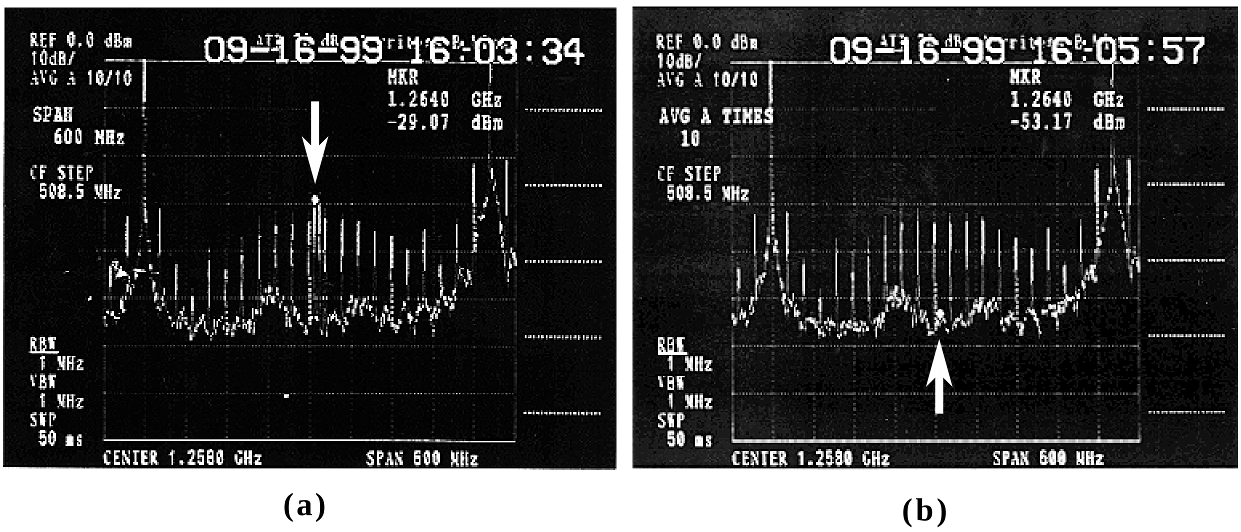

Fig.4 Frequency spectra detected with a beam position monitor in the HHLV optics operation (a) before and (b) after adjusting the frequency of TM110-like mode in one rf cavity by its frequency tuners. (a) The marker shows a frequency peak of the coherent horizontal beam oscillation by the TM110-like mode resonance. (b) The peak disappeared and the oscillation stopped after the adjustment by the tuners.