Cold Tests of L-band Accelerating Cavities

김 상훈, 문 성익, 조 무현, 남궁 원
포항공과대학교 물리학과

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강원도 평창군

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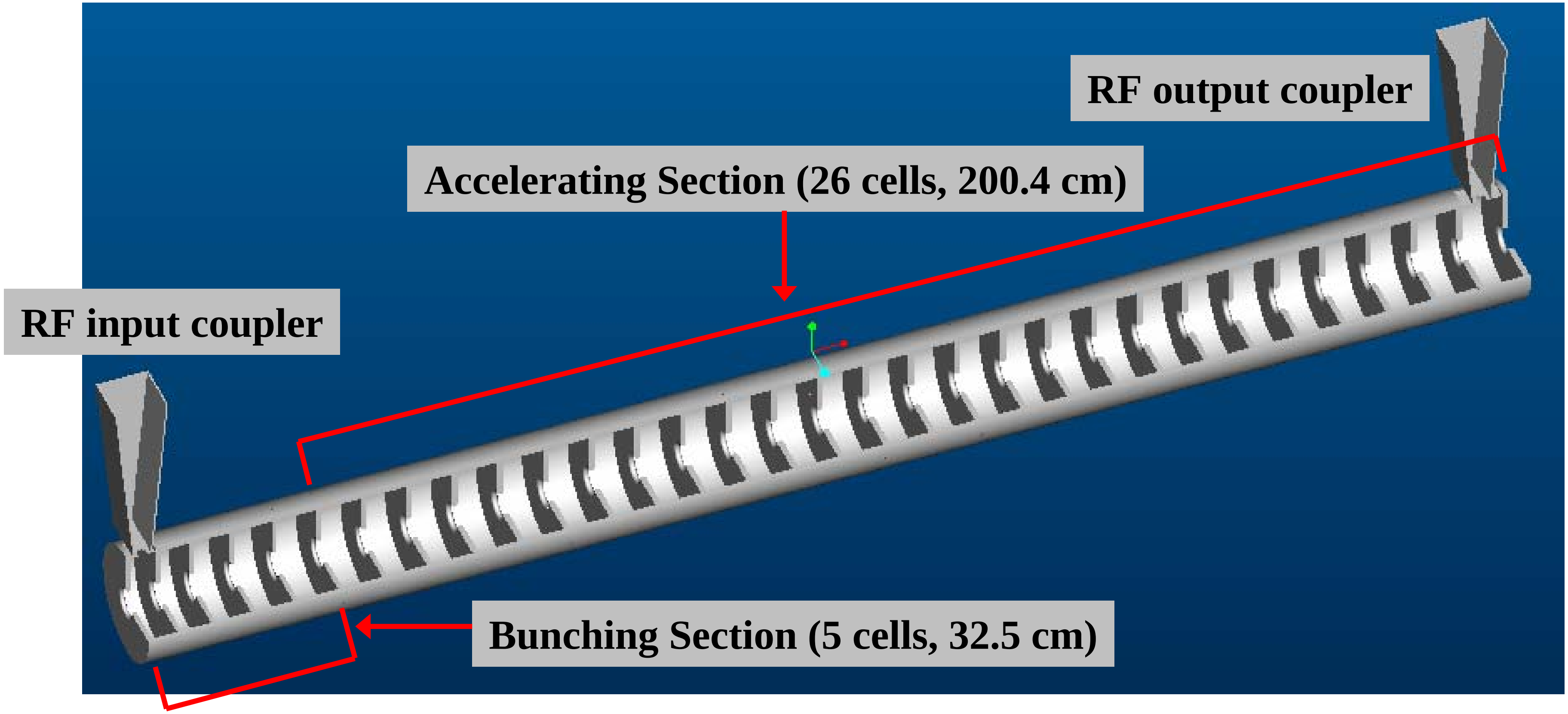
Abstract

- We present the results of cold tests on cavities of the L-band traveling-wave accelerator. We use SUPERFISH and ANSYS codes to design accelerating and bunching cavities. Fabricating test-cavities, we measure the actual resonant frequencies of them. We measure frequency shifts due to the thermal expansion. Based on this result, the operating temperature tolerance is determined as $\pm 0.5\ ^{o}C$ with consideration of beam properties change. We also design cooling jacket for the accelerating column by the ANSYS code. The RF input and output coupler cavities which have ellipse-like coupling apertures are designed by the analytical method.

Introduction to L-band Accelerating Column



- Operated with L-band (1.3GHz) traveling-wave as 2π/3-mode.
- Disk-loaded cavities with the constant impedance structure is used for accelerating section.
- $R_S = 43\ M\Omega / m,\ Q = 20000,\ \overline{E}_{acc} \cong 4.3 MV / m$ for accelerating section.

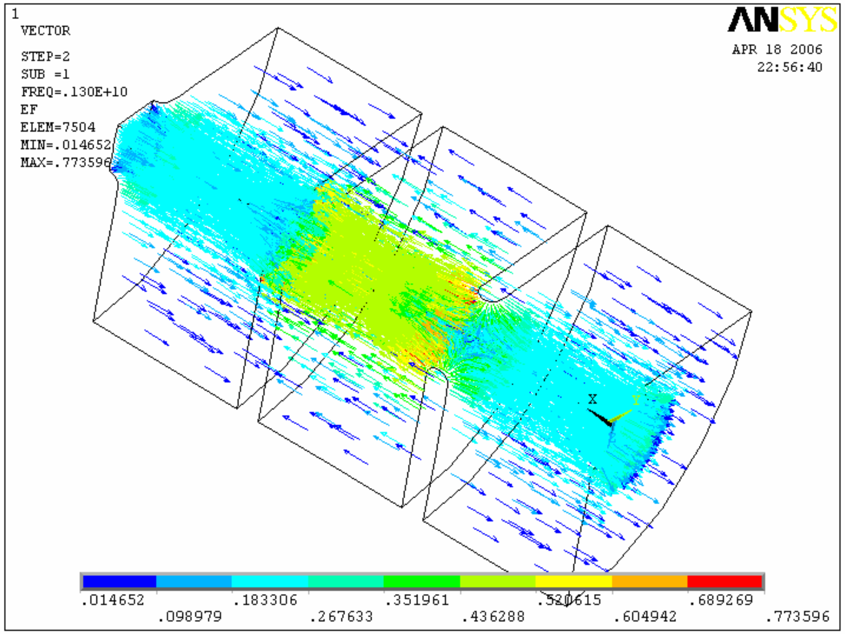
Simulational Design of L-band Accelerating Cavity

- Traveling-wave propagating through the accelerating cavities are represented as

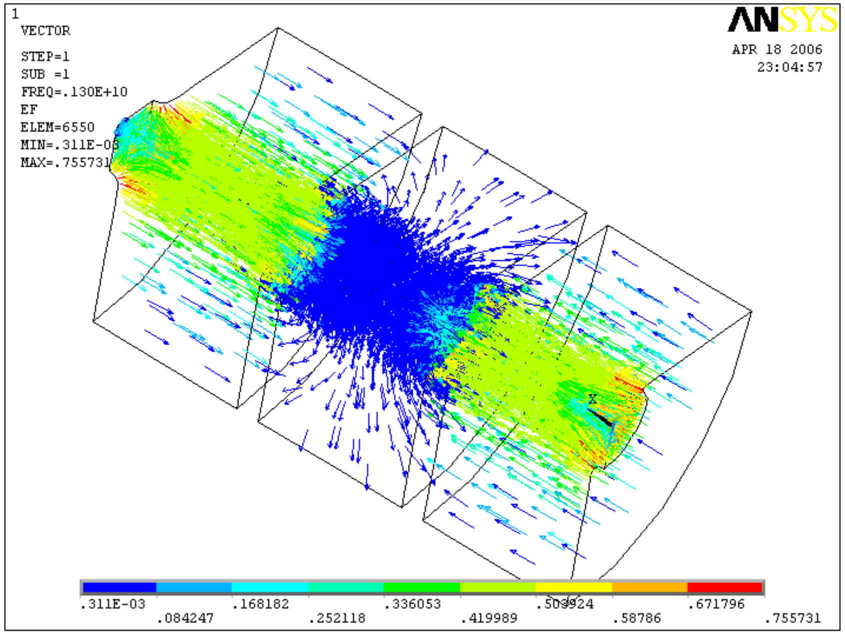
$$\vec{E}(r,z,t) = \vec{E}(r,z)\exp[i(wt - kz + \phi)]$$

$$\vec{E}(r,z,t) = \{\vec{E}(r,z)\cos(kz) - i\vec{E}(r,z)\sin(kz)\}\exp(iwt)$$

Cosine solution

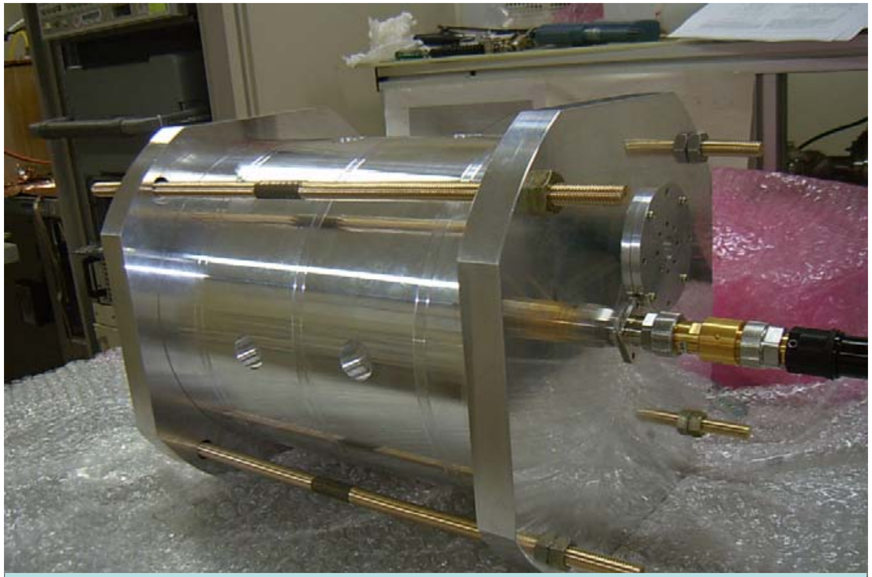


Sine solution

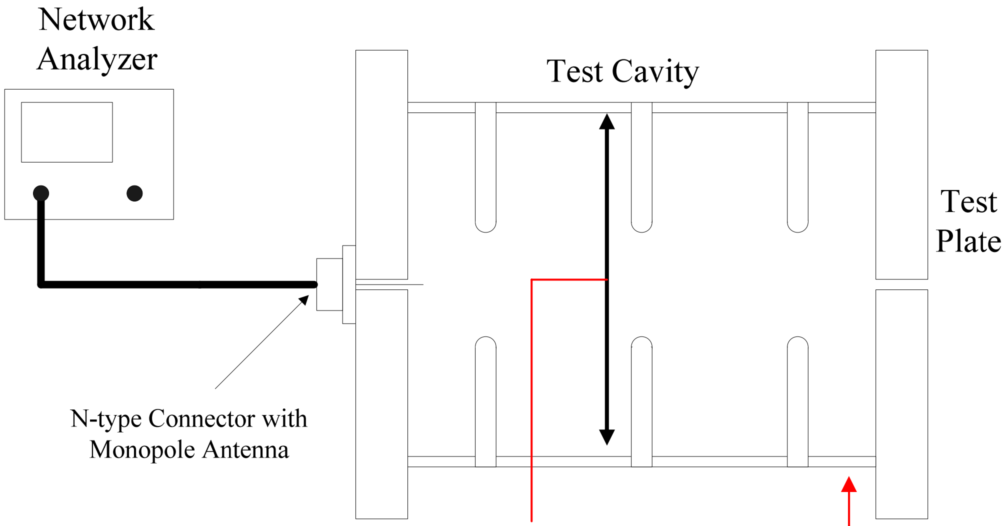


Normalized electric field profiles

Prototype Test - Resonant Frequency Measurement

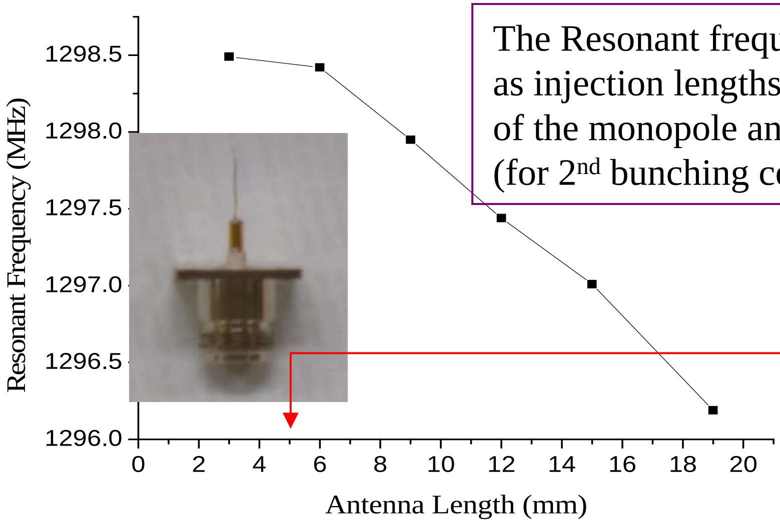


Material of the test cavity: Aluminum



The fabricated inner diameter of the cavity is 20μm larger than the designed value.

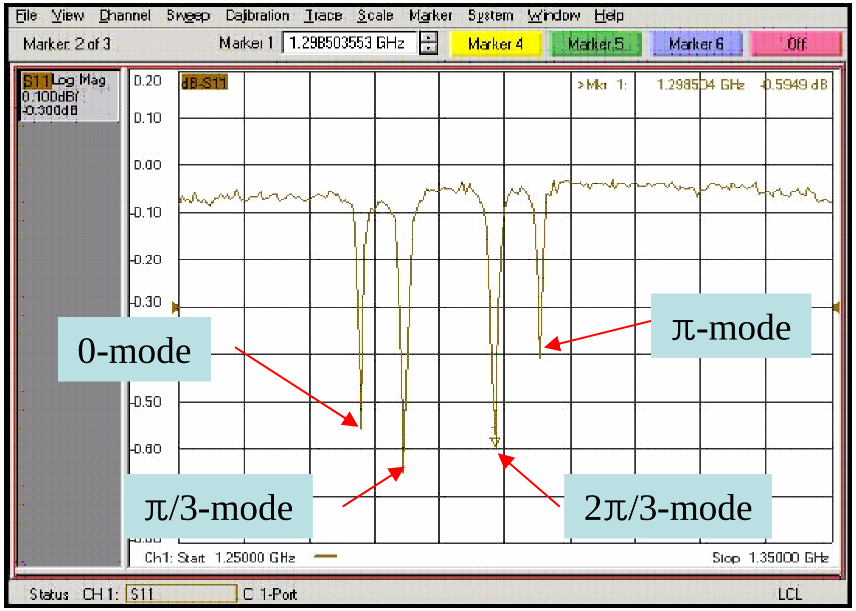
- 2 and 2 half cells
  - For accelerating cell, 2nd bunching cell
- 1 and 1 half cells
  - For 3rd, 4th, 5th bunching cell



The Resonant frequency shift as injection lengths of the monopole antenna (for 2nd bunching cell)

A 6 mm injected antenna is used for determining the resonant frequency at the $2\pi/3$-mode.

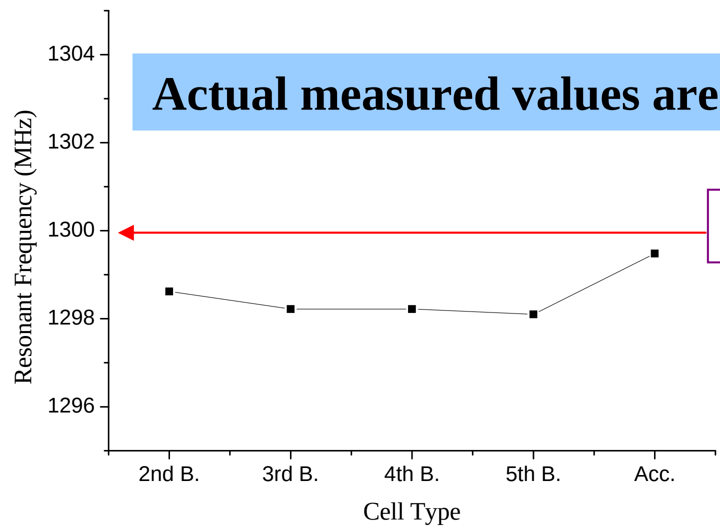
Measured Resonant Frequencies



Resonant frequency at each mode for the accelerating cell at 20 ºC

Mode	Measured (Aluminum)	SUPERFISH (Copper)	ANSYS (Copper)
0	1290.20	1290.80	1290.80
π/3	1293.20	1293.87	1293.89
2π/3	1299.44	1300.01	1300.07
π	1302.58	1303.07	1303.15

Measured Resonant frequency at 2π/3-mode for every cells at 20 ºC with materials of Al



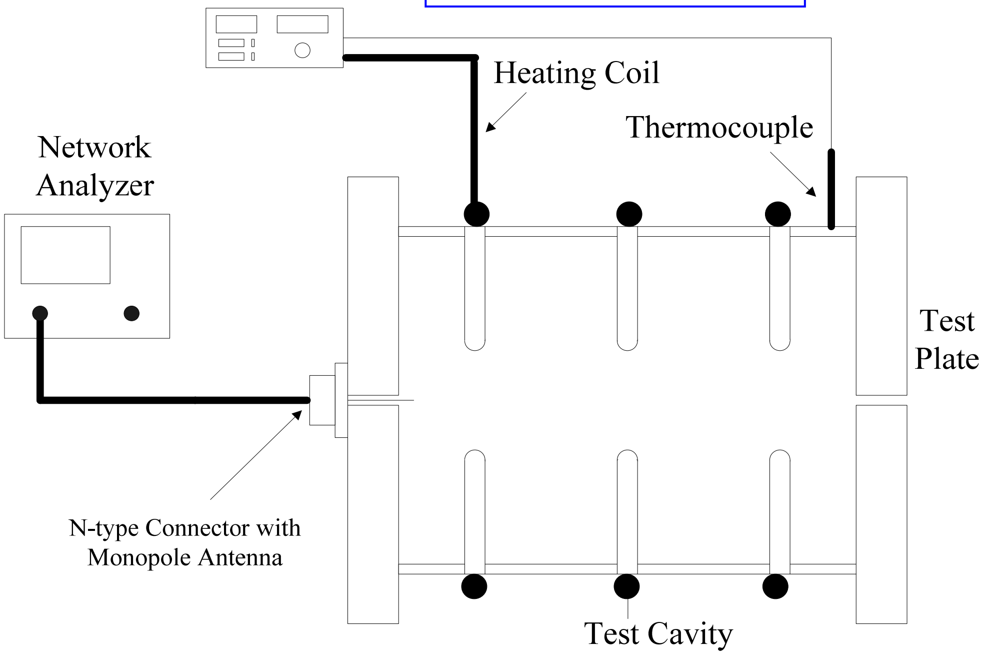
Actual measured values are in the tunable range.

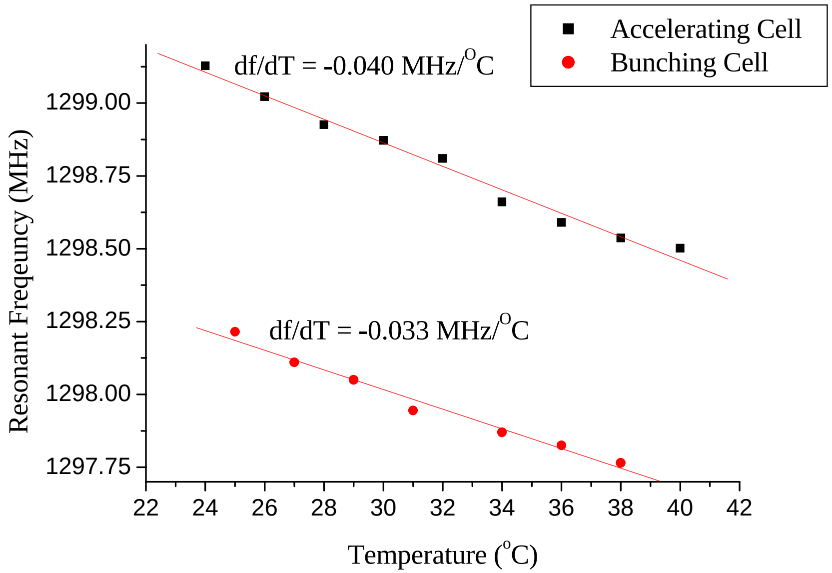
Desired value

Acronym
B.: Bunching cell
Acc.: Accelerating cell

Frequency Shift due to Thermal Expansion

Experimental Setup





The shift of resonant frequencies of $2\pi/3$ mode as cavity temperatures

Material: Al (Measured)

Cell Type	df/dT (MHz/oC)
Normal	-0.040
2nd Buncher	-0.033

Material: Cu (Calculated)

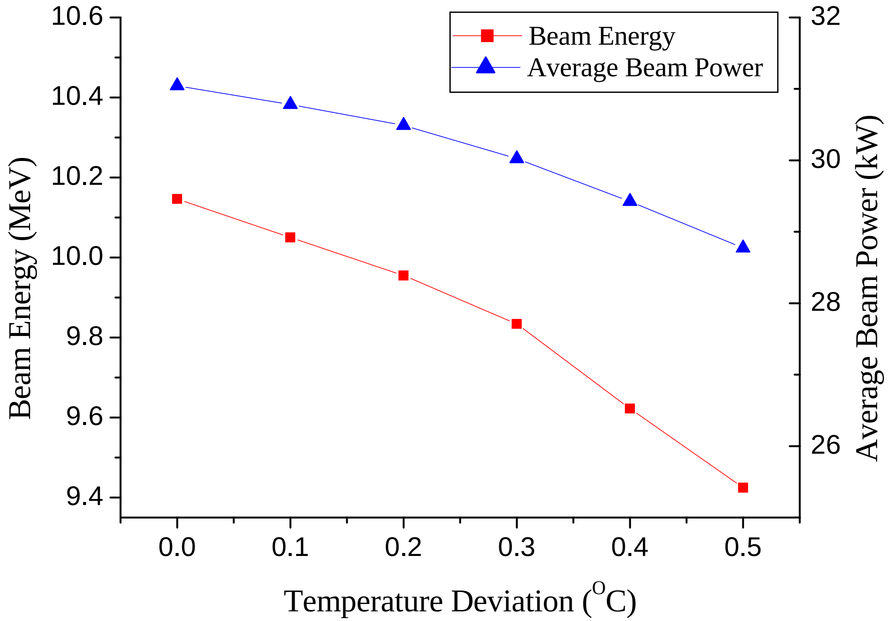
Cell Type	df/dT (MHz/oC)
Normal	-0.028
2nd Buncher	-0.023

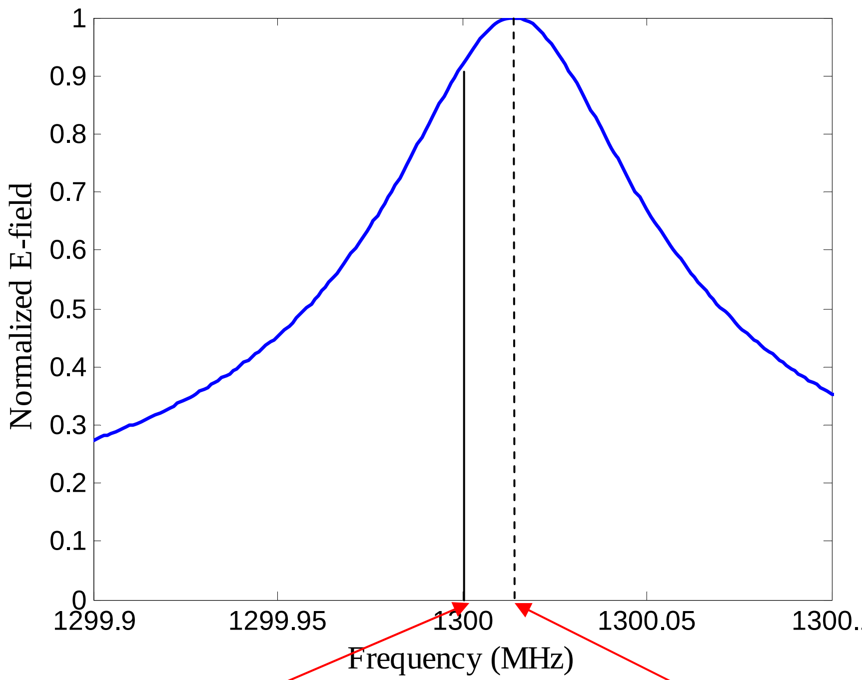
Beam Properties Change due to Temperature Deviation

Based on the relationship between the quality factor and the stored energy

$$|E(\omega)|^2 \propto \frac{1}{(\omega-\omega_0)^2+(\omega_0/2Q)^2}$$

Assume that every cavity has uniform temperature. So it is the worst case in the view of beam energy.





Frequency of RF source

Shifted resonant frequency of cavity

For accelerating cell with shifted resonant frequency of 0.014MHz (dT=0.5ºC)

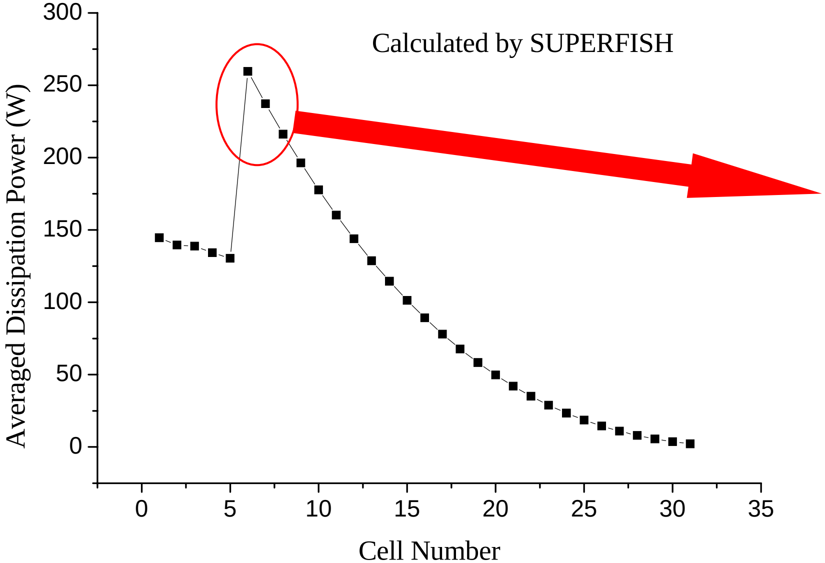
Within $\Delta T = \pm 0.5^\circ C$,
$\Delta E / E \leq 7\%$, $\Delta P / P \leq 7\%$

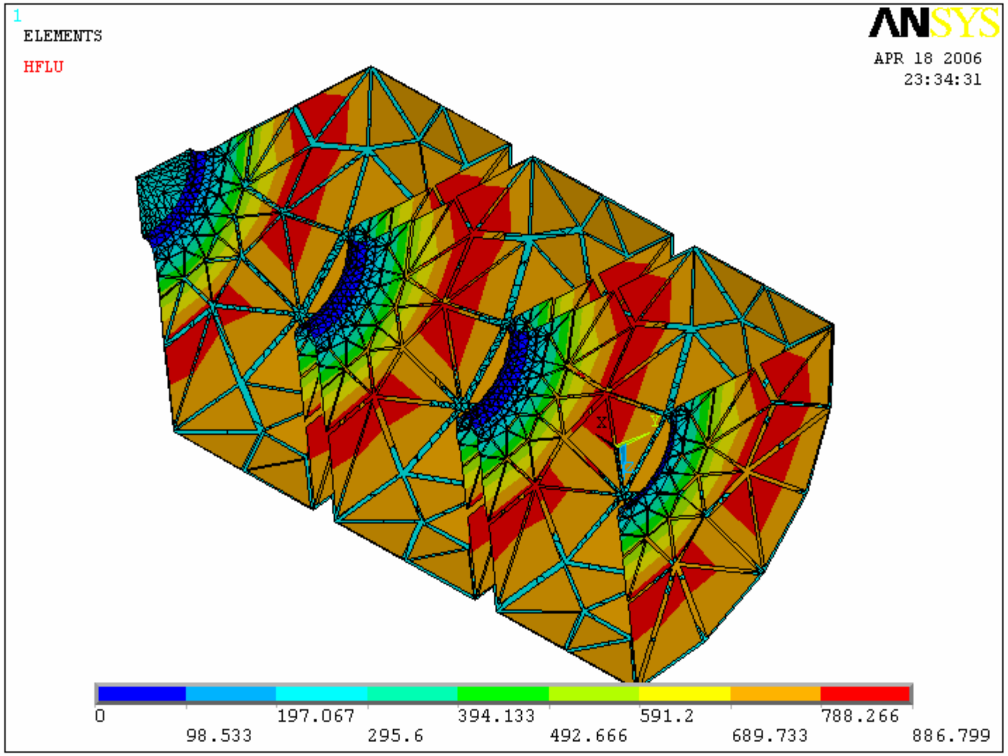
Evaluation of Heat Flux due to Surface Power Dissipation

$$P = \frac{1}{2}\iint_S R_s \left|\vec{H}(r,z)\right|^2 da$$
$$= \frac{1}{2}\iint_S R_s \left\{\left|\vec{H}_{\cos}(r,z)\right|^2 + \left|\vec{H}_{\sin}(r,z)\right|^2\right\} da$$

Time-averaged power dissipation
= power dissipation of cosine solution
+ power dissipation of sine solution

Averaged dissipation power per cell
(including bunching cells)





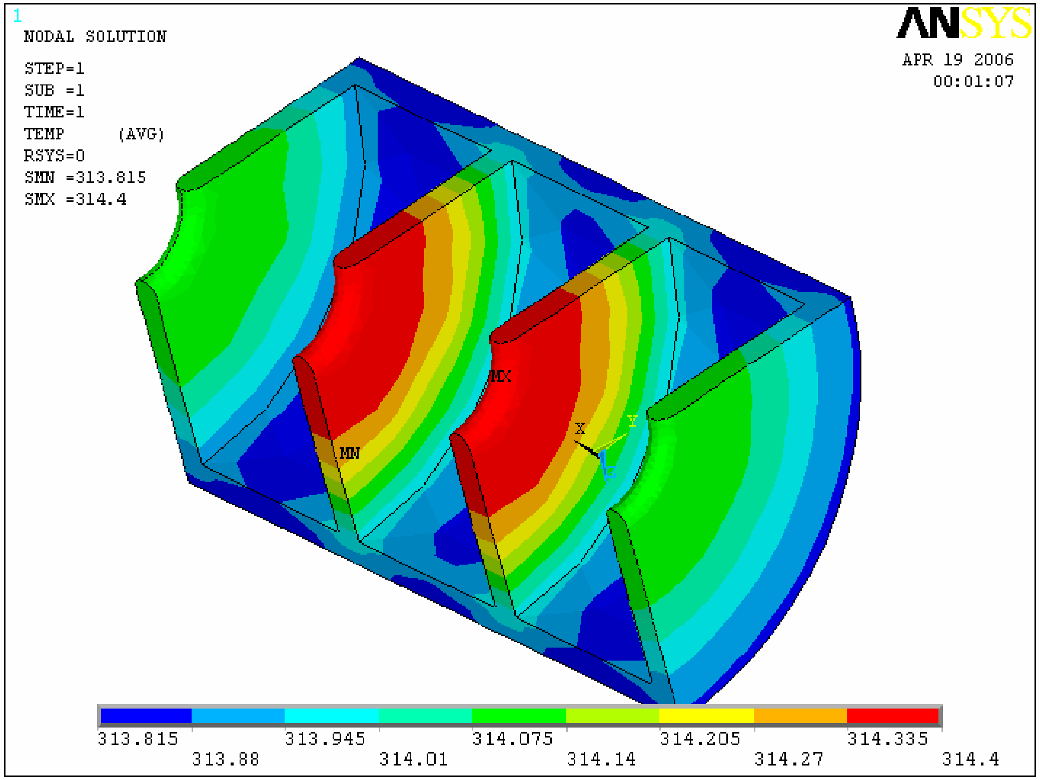
Heat fluxes on the quarter part of the accelerating cells

Design of Cooling Jacket by Thermal Analysis

The cooling jacket on the cavity outer surface

Inner diameter	20 cm
Outer diameter	22 cm
Flow rate	250 liter/min
Temperature	40 ºC
Pressure	3 atm

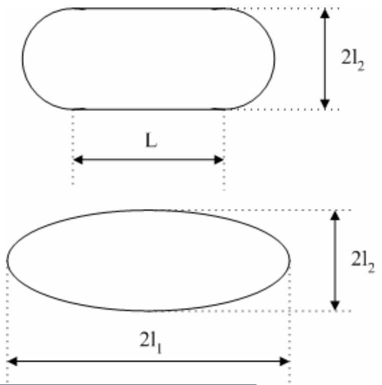
Heat transfer coefficient
$= 1372\ W / m^2 K$



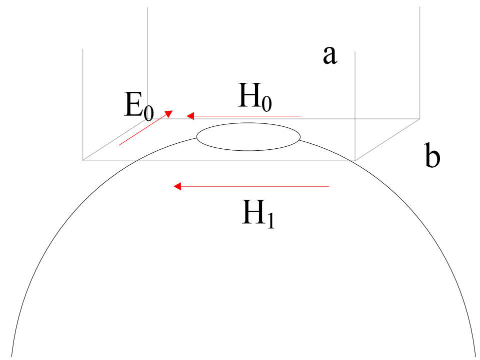
Temperature distribution of the accelerating cell (unit: K)

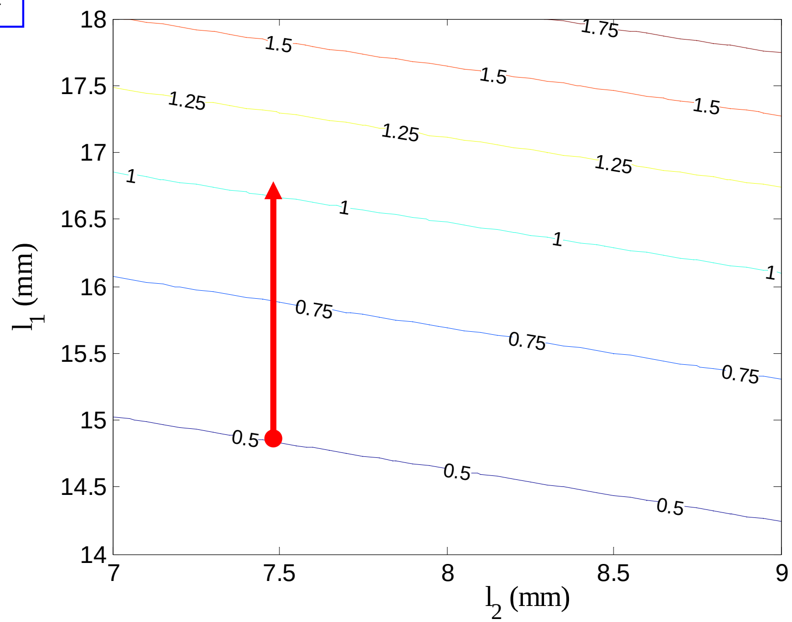
Design of Input/Output Coupler

Actual shape



Imaginary shape





Coupling ratio

$$\beta = \frac{16 Z_{0f} k_0 \Gamma_{10} l_1^6 \exp(-2\alpha d)}{9ab\left(1+\frac{1}{8}e_0^2+\frac{15}{64}e_0^4+\frac{315}{3072}e_0^6\right)^2}\frac{H_1^2}{P_c}$$

H_1 : magnetic field on the cavity surface

P_c : dissipation power on the cavity

$e_0 = (1 - l_2^2 / l_1^2)^{1/2}$ $\quad Z_{0f} = 120\pi\Omega$

$k_0 = 2\pi/\lambda$ $\quad \Gamma_{10} = k_0(1-(\lambda/2a)^2)^{1/2}$

a : longer side of the waveguide

b : shorter side of the waveguide

Coupler dimension starts from where β=0.5.

Summary

1. Designed dimensions of cavities in L-band accelerating column are checked by prototype tests. Every resonant frequency is in the tunable range.
2. Frequency shift due to thermal effect is measured. Since prototype cavities are made of aluminum actual frequency shift is estimated based on the difference of the thermal expansion coefficient between aluminum and copper.
3. Considering the change of beam properties due to non-uniform temperature of cavities, deviations of the operating temperature is determined as ± 0.5 ºC.
4. The jacket-shaped cooling system is designed by electromagnetic and thermal analysis of the cavity.
5. Couplers are designed analytically and tests will be done.