

Vacuum Pipe Heating in RHIC

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Vacuum Pipe Heating in RHIC

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Vacuum Pipe Heating

Assume M equally spaced bunches of the same shape and population with gaussian longitudinal distribution

let

N , number of particles per bunch

σ_z , rms bunch length

P , total power dissipated

$$P = \frac{1}{2} \sum_{n=1}^{\infty} R_{nM} I_{nM}^2$$

where

R_{nM} wall resistance at nM harmonic

I_{nM} beam current at nM harmonic

$$I_{RM} = 2 I_{ave} \exp\left(-\frac{1}{2} n^2 d^2\right)$$

$$d = M \sigma_L / R$$

R, average radius = 610.18 m

$$I_{ave} = Z N e \beta_c M / 2\pi R$$

Z charge state

Skin Depth

$$\delta = \frac{\delta_{\perp}}{\sqrt{n}}$$

$$\delta_{\perp} = \sqrt{\frac{2PR}{M Z_0}}$$

$$Z_0 = 377 \text{ ohm}$$

	<u>S.S.</u>	<u>Copper</u>
ρ @ 4.2 °K	50 $\mu\Omega \times \text{cm}$	0.055 $\mu\Omega \times \text{cm}$
δ_{\perp} , M=57	0.17 mm	0.0056 mm
M=114	0.12 mm	0.0040 mm
σ/l	$1.37 \times 10^{15} / \text{ohm} \cdot \text{m}^2$	$1.54 \times 10^{15} / \text{ohm} \cdot \text{m}^2$

l , free path length

$\sigma = 1/\rho$, conductivity

σ/l is an invariant which depends on the material density

① For those frequencies such that

$l/\delta < 1$ Normal Skin Depth

$$R_{NM} = R_1 n^{1/2}$$

$$R_1 = \sqrt{(Z_0 \rho R M) / 2 b^2}$$

② For those frequencies such that

$l/\delta > 1$ Abnormal Skin Depth

$$R_{NM} = R_1 n^{2/3}$$

$$R_1 = \left\{ \left(\frac{l}{\sigma} \right) \frac{\sqrt{3} Z_0^2 M^2 R}{4 \pi b^3} \right\}^{1/3}$$

b, vacuum chamber radius
assuming circular geometry = 3.6 cm

Thus

$$P = 2 I_{ave}^2 \sum_{n=1}^{\infty} R_{\perp n} n^{P_n} \exp(-n^2 d^2)$$

* For $n = 1$ to n_c

$$R_{\perp n} = R_{\perp normal}$$

$$P_n = 1/2$$

* For $n = (n_c + 1)$ to ∞

$$R_{\perp n} = R_{\perp abnormal}$$

$$P_n = 2/3$$

There is also a cut-off due to the finite bunch length

$$n_{cut-off} \sim \frac{1}{d} = \frac{R}{M \sigma_L}$$

$$n_c \sim \left(\frac{a}{l}\right)^2 (p \delta_1)^2$$

S.S. Copper

n_c 1.3×10^{10} 22

$n_{\text{cut-off}}$

<u>M</u>	<u>σ_L</u>	
57	0.4	26
114	0.4	13
57	0.2	52

We have summed up to \hat{n} given by

$$\hat{n} \alpha = 15$$

Assuming the Beam Parameters from CDR

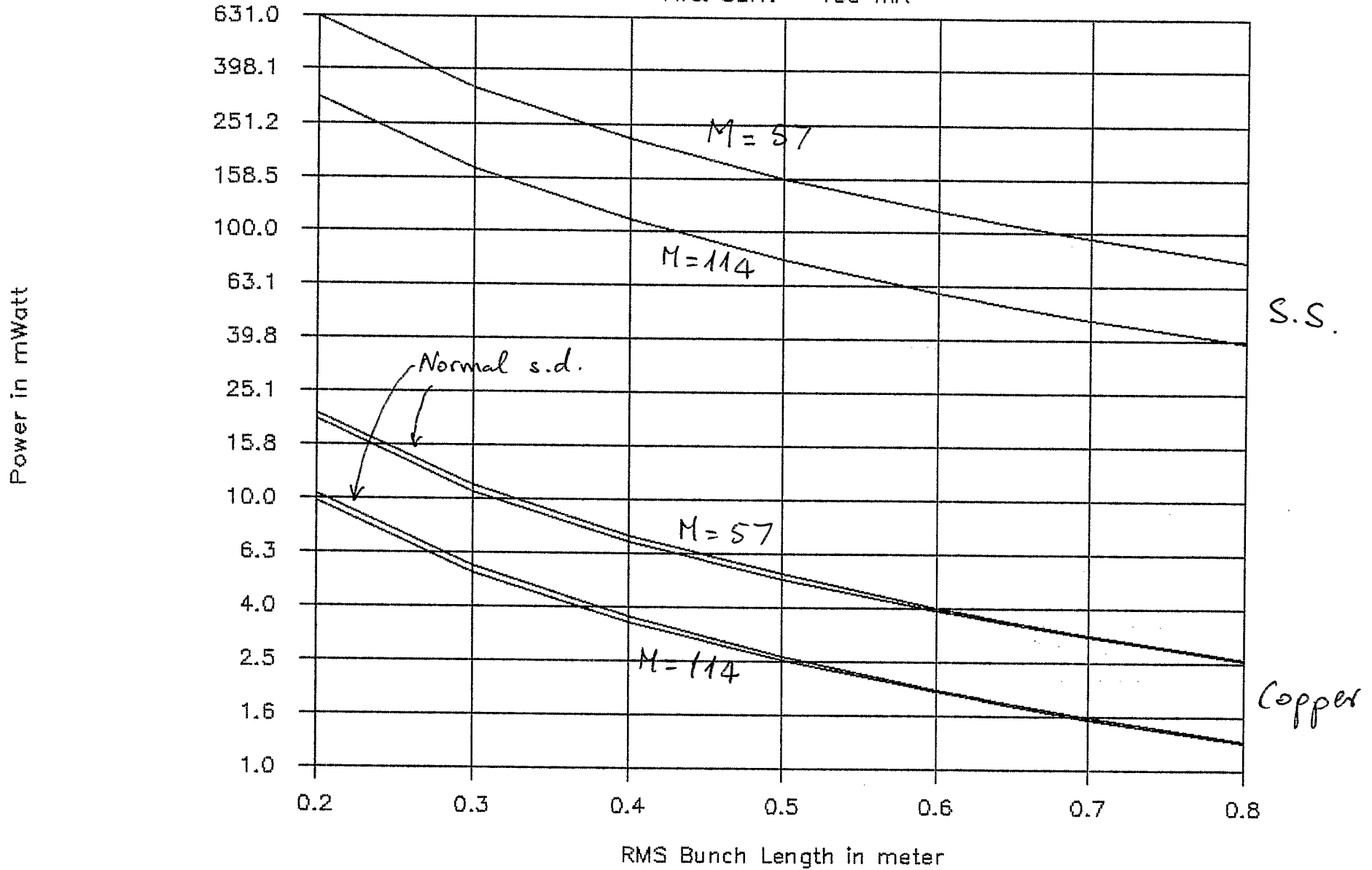
	Z	N	I _{ave}
proton	1	100×10^9	71 mA (electric)
Carbon	6	22	94
Sulfur	16	6.4	73
Copper	29	4.5	93
Iodine	53	2.6	98
Gold	79	1.1	62

with $M = 57$ bunches

As reference $\sigma_L = 40$ cm

Power dissipated per Dipole (10m)

Ave. Curr. = 100 mA



Power Dissipated per 10m Dipole in Watts
 Reference Case: Gold, Average Current = 62 mA
 Stainless Steel

M	N		sigma-L	
			0.40 m	0.20 m
57	1.1	$\times 10^9$	0.085	0.242
114	1.1		0.170	0.484
57	2.2		0.340	0.968
114	2.2		0.680	1.936
57	3.3		0.765	2.178
114	3.3		1.530	4.356

Power Dissipated per 10m Dipole in milli-Watts
 Reference Case: Gold, Average Current = 62 mA
 Copper, Normal + Abnormal Skin Depth

M	N		sigma-L	
			0.40 m	0.20 m
57	1.1	$\times 10^9$	2.7	7.6
114	1.1		5.4	15.2
57	2.2		10.8	30.4
114	2.2		21.5	60.7
57	3.3		24.2	68.3
114	3.3		48.4	136.6

Power Dissipated per 10m Dipole in Watts
 Reference Case: Protons, Average Current = 71 mA
 Stainless Steel

M	N	sigma-L		
		0.80 m	0.40 m	0.20 m
57	1 x 10 ¹¹	0.039	0.112	0.317
114	1	0.078	0.224	0.634
57	3	0.351	1.008	2.853
114	3	0.702	2.016	5.706
57	8	2.496	7.168	20.288
114	8	4.992	14.336	40.576

Power Dissipated per 10m Dipole in milli-Watts
 Reference Case: Protons, Average Current = 71 mA
 Copper, Normal + Abnormal Skin Depth

M	N	sigma-L		
		0.80 m	0.40 m	0.20 m
57	1 x 10 ¹¹	1.3	3.5	10.0
114	1	2.6	7.1	19.9
57	3	11.7	31.8	89.6
114	3	23.4	63.5	179.1
57	8	83.2	225.9	636.8
114	8	166.4	451.8	1273.6