More about CESR's Sliding Joints*

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Abstract

In this paper, which compliments the former cylindrically symmetric simulation of sliding joints (CON-95-05), we study in details the trapped fields, the power lost by the bunches, the surface current which shows the hot areas on the beam pipe, and estimate the bunch lengthening due to the sliding joints.

1 THE STRUCTURE OF THE SLIDING JOINT

The 3D simulated structure of the sliding joint seen in Figure 1 with the cross sections in Figures 2,3 contains a small cavity inesrted in the beampipe. The depth of the cavity is determined by the original design, but the length is determined by the expension or compression of the beam pipe due to heating and temperature changes. Typicall values of this length is btween $0.9\ inch$ to $1.5\ inch$.

2 FIELD MODES

It is planed to operate the storage ring with bunches of $1.0\ cm$ long. These bunches have a frequency spectrum which extends up to $10\ GHz$ and thus will excite all the possible modes below $10\ GHz$. Modes with frequecy higher than the beam pipe cut off frequency ($4.1\ GHz$) will propagate out of the cavity and will not add substential heating. On the other hand, the modes below the beam pipe cut off frequency will be trapped and will resonate in the cavity for about 3τ where τ is the mode damping time $\tau = Q/(2\omega_r)$, Q the quality factor, and ω_r the mode resonance frequency. To calculate the possible modes in the sliding joints we used the eigenvalue solver of MAFIA.

2.1 Trapped Modes

We will look only at the trapped modes (below the beampipe cut off frequency). The field of these modes will be confined under the cavity. In order to identify the modes we look at the patteren of the electric and the magnetic fields as shown in Figures 4-11. The two observed trapped modes for $1.3\ inches$ opening are TM_{01} & TE_{11}. The oscillation frequency of the trapped modes depends on the opening of the sliding joint (The cavity length). The calculated resonance frequencies, quality factors and damping times of these modes for two sliding joints opening are shown in Table 1.

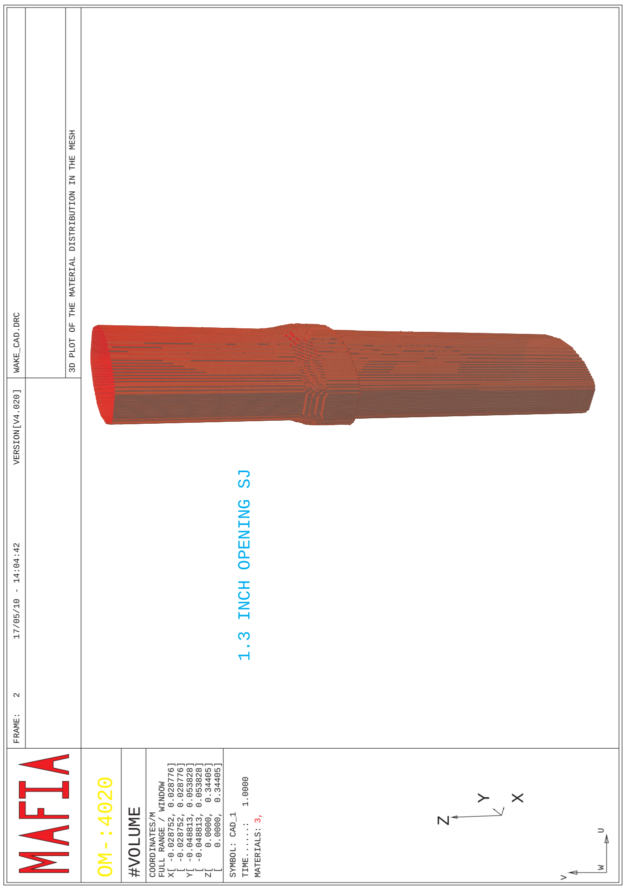

Figure 1: Longitudinal Trapped Mode.

Table 1: Margin specifications

S.J. Opening (inch)	Mode	Frequency (GHz)	Q	τ (sec)
1.06	TM_{01}	3.63		
1.3	TM_{01}	3.6	$1.3 \cdot 10^4$	

2.2 Measurement of the Tapped Mode Frequency

A direct measurement of the actual resonance frequency of the trapped mode in a sliding joint in the ring could have been done by using a prob through the wall into the sliding joint cavity. Unfortunately we do not have such probs, so the frequency was extracted from the temperature measurement as function of the bunch length. See Figure 12.

In general the measured temperature will depend on the bunch length in the following way:

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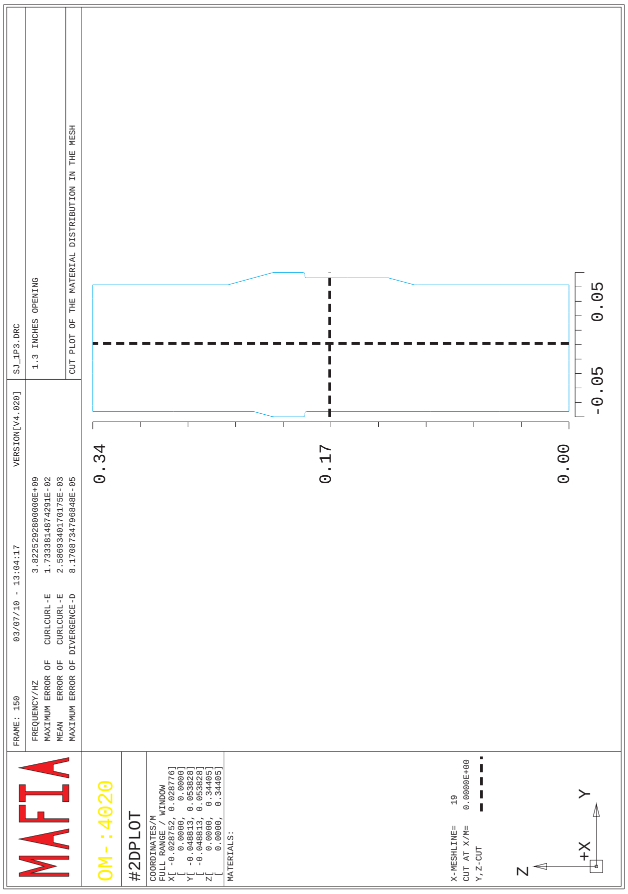

Figure 2: A cross-section of the sliding joint along the x-axis.

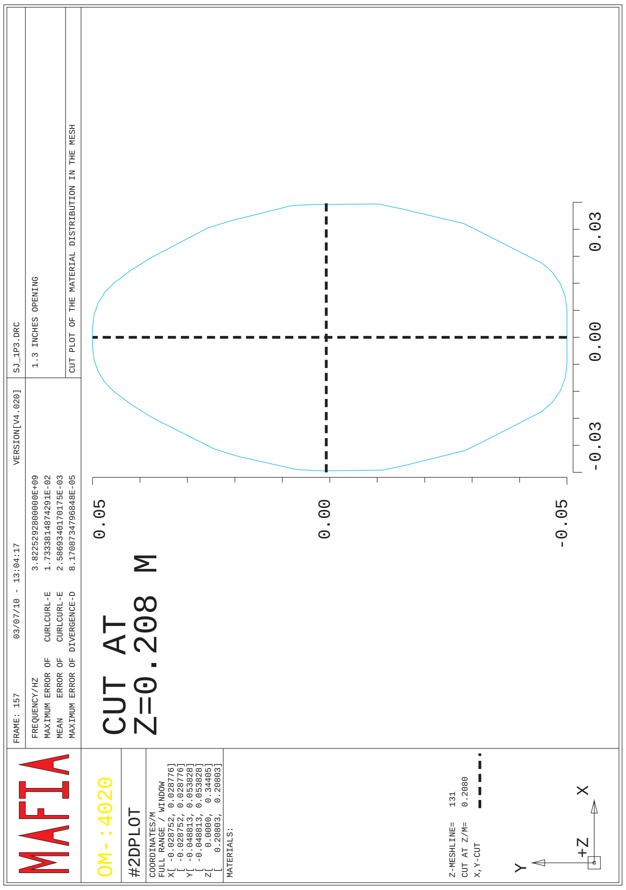

Figure 3: A cross-section of the sliding joint along the z-axis.

$$T = A_0 + A_1 I_b + A_2 I_b^2 \tag{1}$$

$A_0 \propto$ Ambient temperature.

$A_1 \propto$ Radiation.

$A_2 \propto$ Higher Order Mode (HOM) power, P_{HOM}.

Assuming that there is only one dominant longitudinal trapped mode, as found in the eigen value calculation discussed above:

$$A_2 \propto P_{HOM} \propto \frac{\omega_r}{4}\left(\frac{R}{Q}\right) exp(-\omega_r^2\sigma_t^2) \tag{2}$$

ω_r trapped mode's angular frequency
σ_t bunch length (sec)

If R/Q has negligbale dependence on σ_t (about 5% for $10\ mm$ compression of the sliding joint, see Figure 8,) the derivitive of the temperature (Equation 1) with respect to the bunch length, σ_t, is:

$$\frac{dT}{d\sigma_t} = \frac{1}{2}\frac{R}{Q}\omega_r^3\sigma_t exp(-\omega_r^2\sigma_t^2) \tag{3}$$

To find the curve $\frac{\Delta T}{\Delta \sigma_t}$ we fit a polynomial curve to the measured $T\ vs.\ \sigma_t$ points. See Figure 12 and calculate the derivative as function of σ_t as shown in Figure 13. Next we fit the $\frac{\Delta T}{\Delta \sigma_t}$ curve to the expression in Eqaution 3 and find the corresponding resonance frequency $f_r = \frac{\omega_r}{2\pi}$. The value of the frequencies falls within the expected frquencies for the range of sliding joint compressions measured in the ring $(0.9 - 1.5\ inch)$.

3 WAKE FIELD CALCULATIONS

The longitudinal wakefield along the center of the pipe created by $1\ cm$ long bunch is shown in Figure 14. The exited wake keeps oscillating in the sliding joint cavity long after the bunch passed. Its frequency is dominated by the $3.6\ GHz$ trapped mode with small interference of other modes. The csalculated frequency, loss parameter, and the energy, $E = k\frac{I_b^2}{f_{rev}^2}$, induced by a single $1\ cm$ bunch, for two sliding joints opening are shown in Table 2.

4 SURFACE CURRENT

The wall current calculated from $I = \nabla \times B$ is proportional to the heat distribution on the surface.

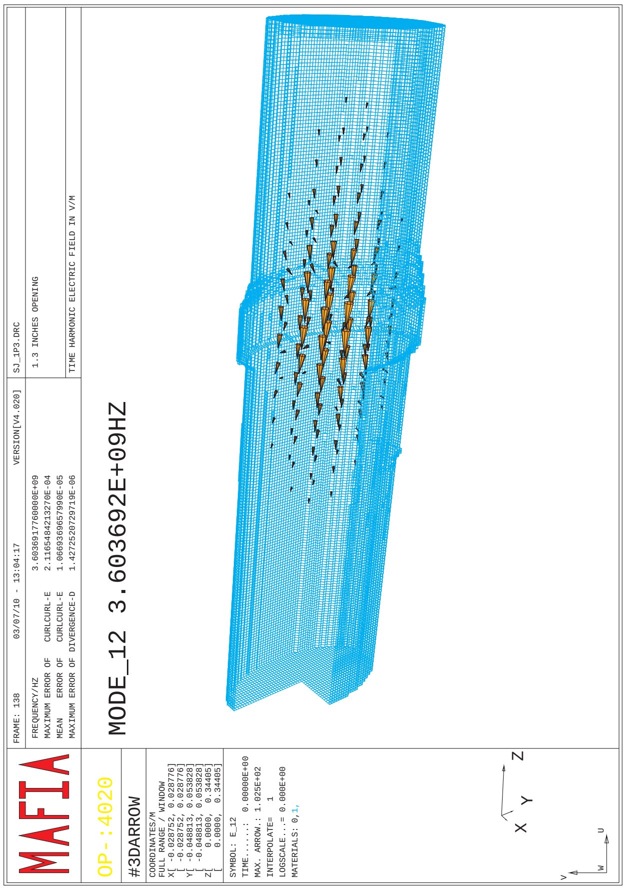

Figure 4: Electric Field of the Longitudinal Trapped Mode.

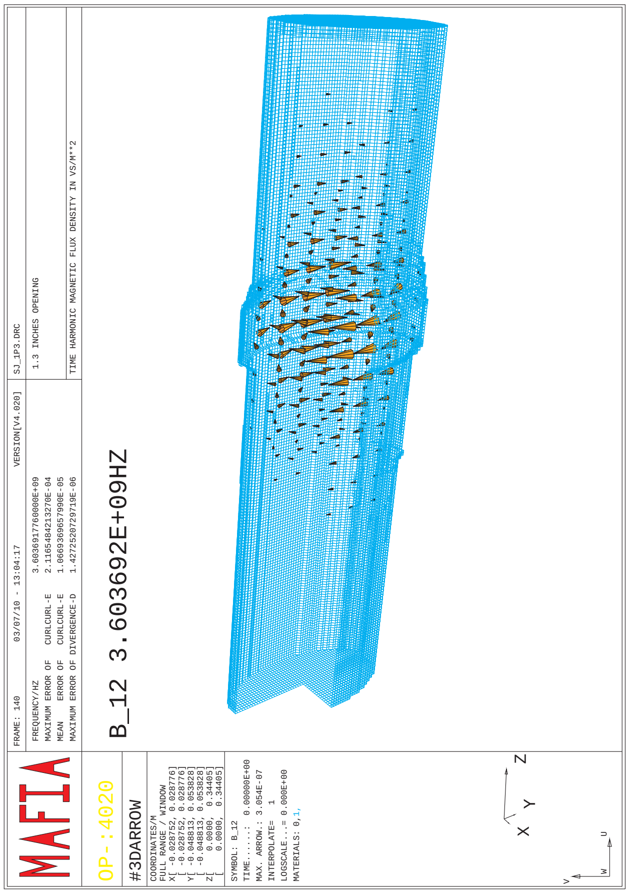

Figure 5: Magnetic Field of the Longitudinal Trapped Mode.

Table 2: Loss parameter and energy loss by 1 cm bunch for 1.06 inch and 1.3 inch opening

	LONGITUDINAD MODES	
	1.06 inch opening	1.3 inch opening
Mode	TM_{01}	TM_{01}
Frequency GHz	3.63	3.6
Loss Parameter $\frac{V}{pC}$	-0.01748	-0.01810
Energy lost by one bunch		

4.1 *Longitudinal Mode TM_{01}*

For The TM_{01} mode the surface current flows along the z-direction, see Figures 15,16. Most of the heating is on top and bottom of the pipe as shown in Figure 13.

4.2 *Transverse Mode TE_{11}*

The surface current in the transverse mode flows azimuthaly along th Θ-direction as shown in Figures 17,18. The heating due to this mode concentrates along the sliding fingers.

5 POWER DISSIPATED ON THE WALLS

The power, P_w, dissipated on the walls can be calculated using the stored energy, E, and the quality factor,Q, calculated in Section 3. For the longitudinal TM_{01} with $f_r =$

$$P_w(one\ bunch) = \frac{\omega_r E}{Q} = 16.22\,Watts \qquad (4)$$

Since the decay time of the field $\tau = \frac{2Q}{\omega_r} = 1.15 \cdot 10^{-6}\ sec$ is much larger than the time between bunches ($14\ nsec$), the total power dissipated by two beams of 9×6 ($108\ bunches$) may add up to be $1.75\ KWatt$. Note, the thermocouple which measures the sliding joint temperature is attached to the bellow surrounding the sliding joint and thus measures much lower temperature than the pipe itself. The conversion between the power directly on the sliding joint wall to the measured temperature is not known at this time. A bench test should be done to find it.

6 BUNCH LENGTHENING DUE TO SLIDING JOINTS

It is expected that the sliding joints will be the main source of bunch lengthening in the storage ring, since, other

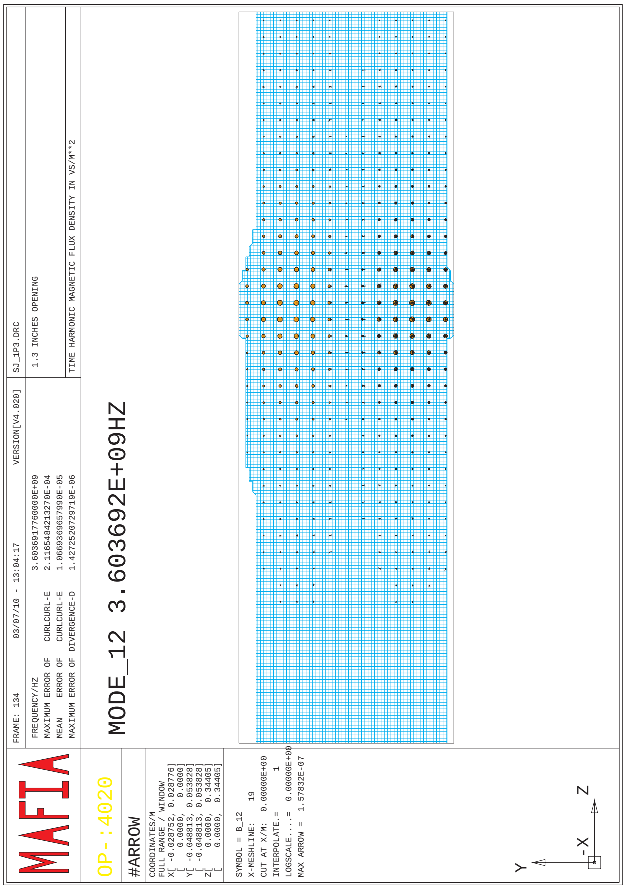

Figure 6: Longitudinal Trapped Mode.

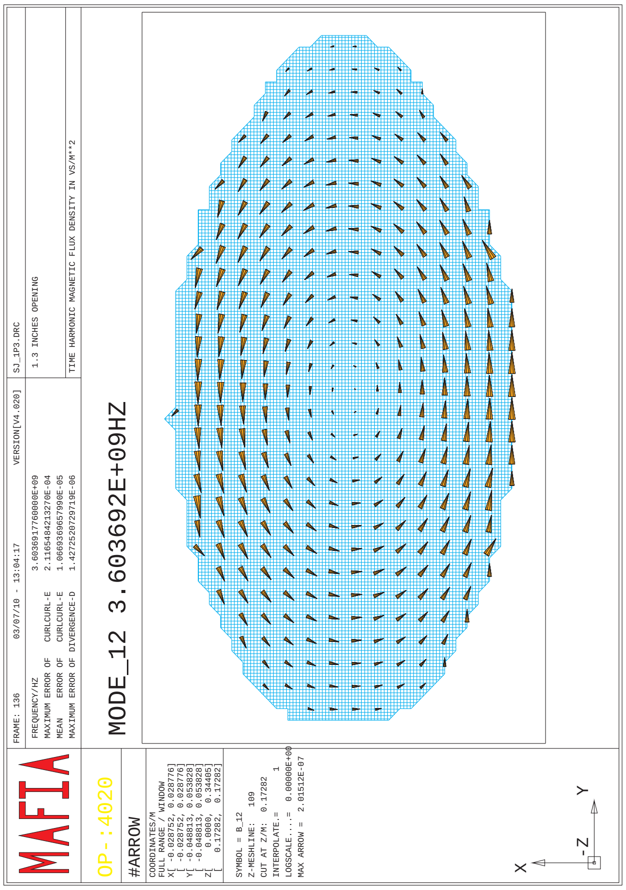

Figure 7: Longitudinal Trapped Mode.

impedances are mostly resistive (separators) or slightly capacitive (superconducting RF cavities). The bunch lengthening caused by the sliding joint impedance is calculated using the slope of the wake fields obtained in Section 3. In general, the bunch length, σ_s, can be estimated by:

$$\sigma_s = \sigma_o \left(1 - \frac{\dot{v}_b}{2\dot{V}_{RF}}\right) \tag{5}$$

σ_o is the bunch length at low current.

$\dot{v}_b$ is the time derivitive of the induced voltage by a single bunch at the center of the bunch.

$\dot{V}_{RF}$ is the slope of the RF source.

When $\frac{\dot{v}_b}{\dot{V}_{RF}} < 0$ the bunch will lengthens. This condition is met when the impedance has an inductive nature, like in the sliding joints.

The slope of the wake, $\dot{w}_b$, at the center of the bunch for 1.3 $inch$ opening is $1.2 \cdot 10^{21}\ \frac{V}{C \cdot sec}$. At bunch current $I_b = 9\ \frac{ma}{bunch}$ the bunch charge, Q_b, is:

$$Q_b = 9\,ma \times 2.5\,\mu sec = 2.25 \cdot 10^{-8}\ C \tag{6}$$

And the time-derivitive of the induced voltage, $\dot{v}_b$, will be:

$$\dot{v}_b(one\ s.j.,\ \sigma_o = 1.00\,cm,\ I_b = 9\,ma/bunch) = \ = \dot{w}_b \cdot Q_b = 2.7 \cdot 10^{13}\ \frac{V}{sec} \tag{7}$$

The RF voltage time-derivitive at $f_{RF} = 500\ MHz$ and peak volatage $V_{RF} = 6MV$ is:

$$\dot{V}_{RF} = \omega_{RF} \cdot V_{RF} = 1.885 \cdot 10^{16}\ \frac{V}{sec} \tag{8}$$

Thus the lengthening of 1.00 cm bunch length due to a hundred sliding joints is:

$$\Delta\sigma(100\ s.j.,\ \sigma_o = 1.00\ cm) = 0.07\ cm \tag{9}$$

Note, the decay time of the longitudinal traped mode is of the order of few μsec which is much larger than the spacing between the bunches (14 $nsec$). As a result, the combined wakefield of a train of bunches can have bigger slopes at the center of successive bunches, causing to an increase in the bunch length. This may be the reason we measure a bunch lengthening of 15% while the calculation predicted only 7%.

7 REFERENCES

[1] http://www.cern.ch/accelconf/

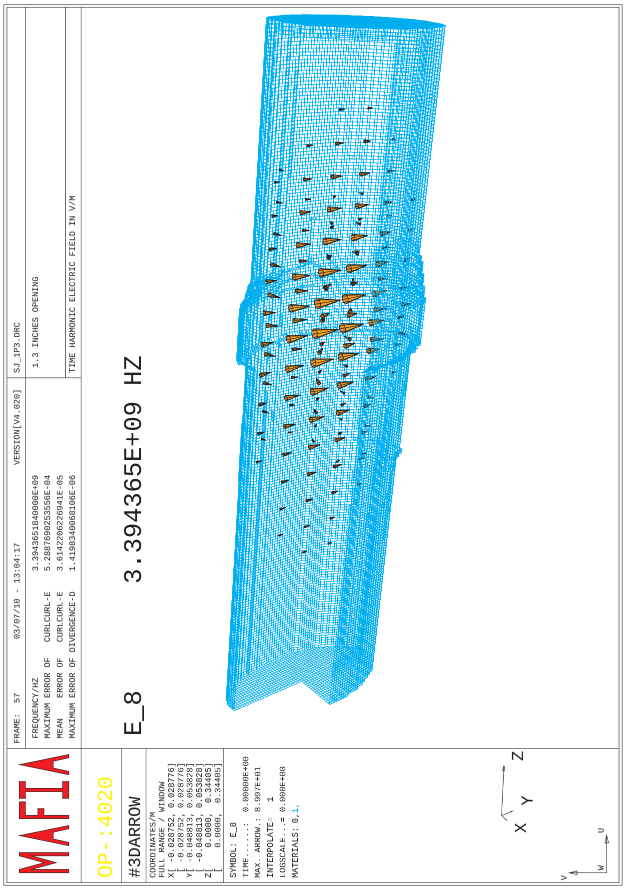

Figure 8: Transversed Trapped Mode.

[2] http://www.aps.anl.gov/conferences/mirrored/pac-epac

[3] http://pac99.bnl.gov/paper/instructions

[4] http://pac99.bnl.gov/editorial/help

[5] L. Liljeby, C. Petit-Jean-Genaz, and J. Poole, "Preparation of Papers for EPAC'98", Stockholm, (1998).

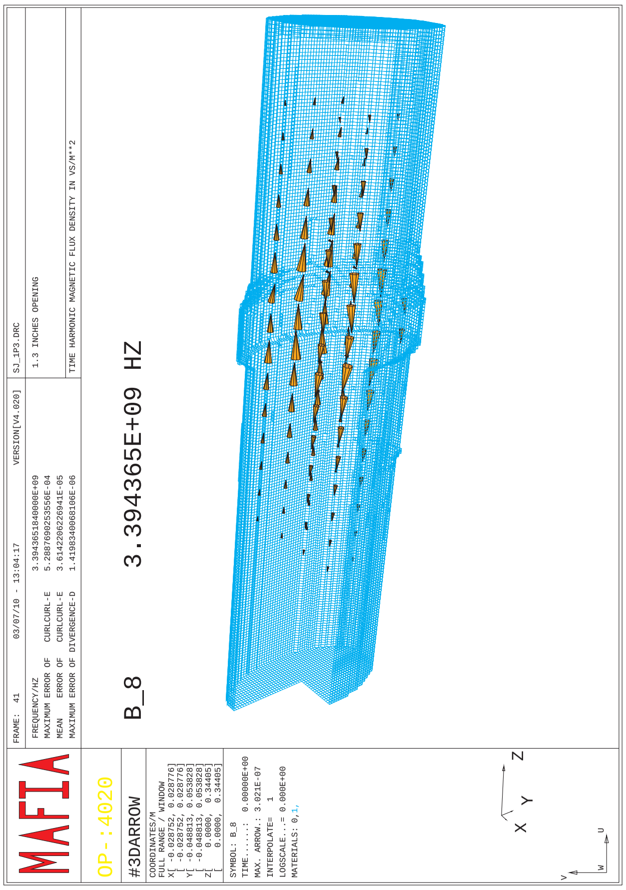

Figure 9: Transversed Trapped Mode.

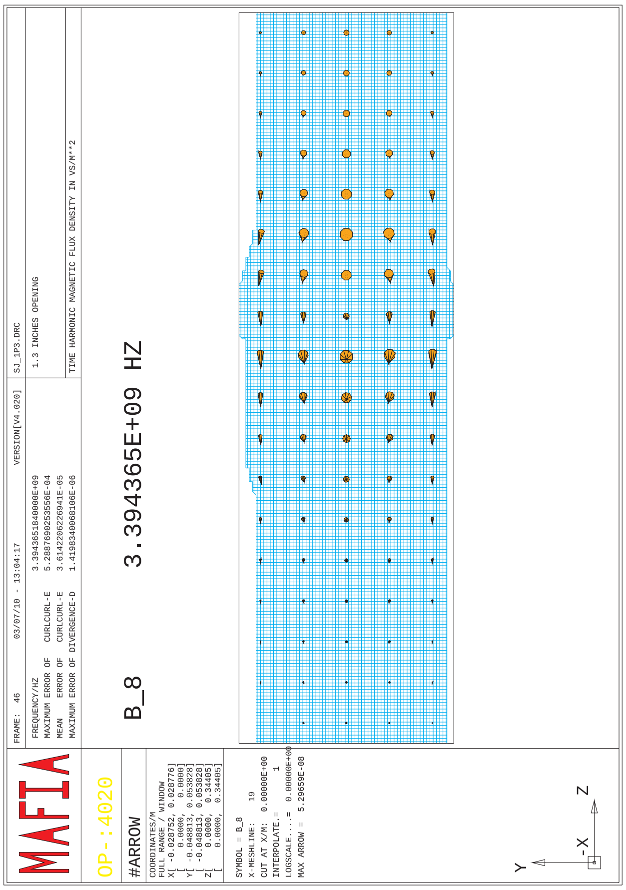

Figure 10: Transversed Trapped Mode.

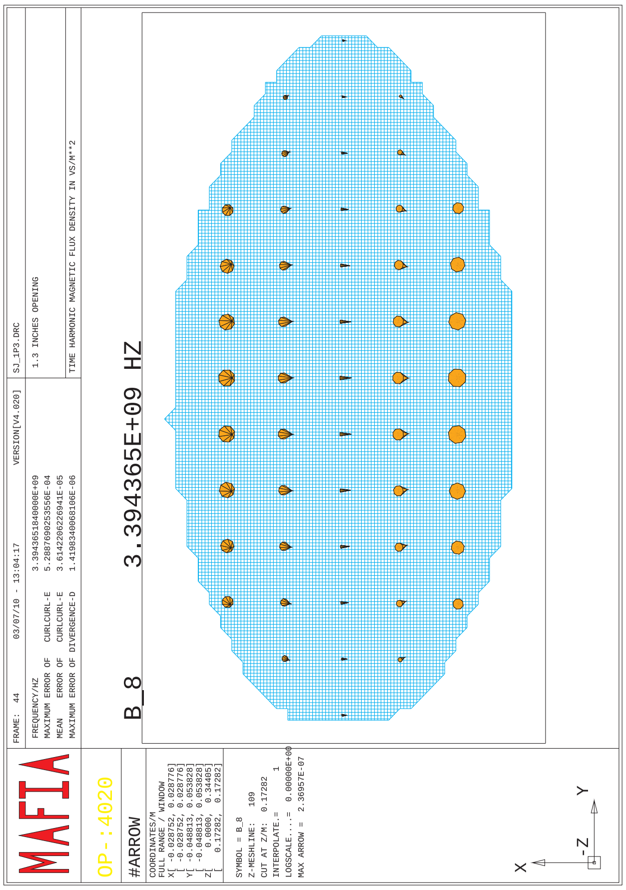

Figure 11: Transversed Trapped Mode.

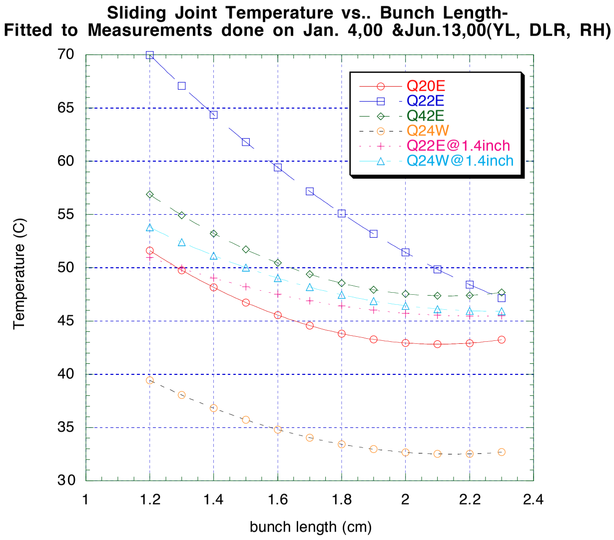

Figure 12: Transversed Trapped Mode.

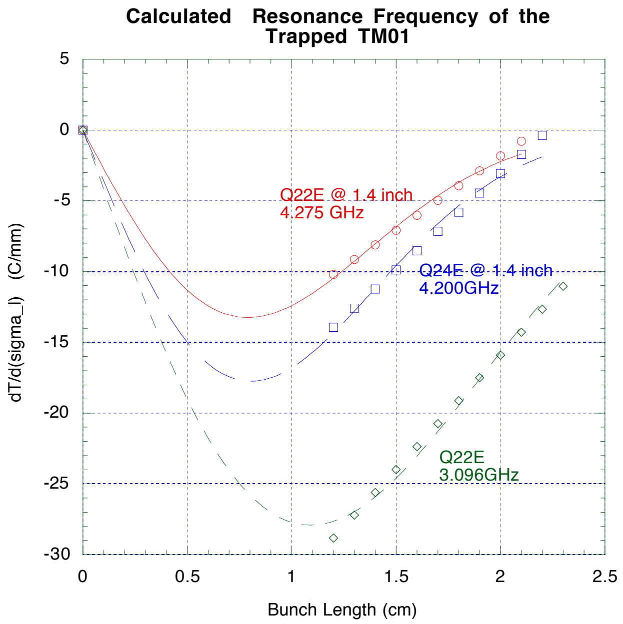

Figure 13: Transversed Trapped Mode.

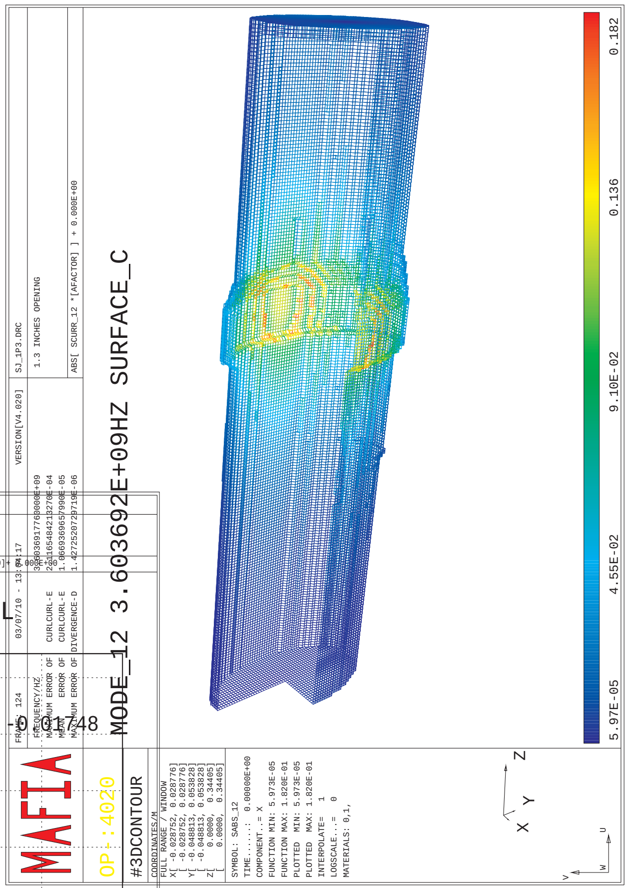

Figure 15: Surface Current of the Longitudinal Trapped Mode.

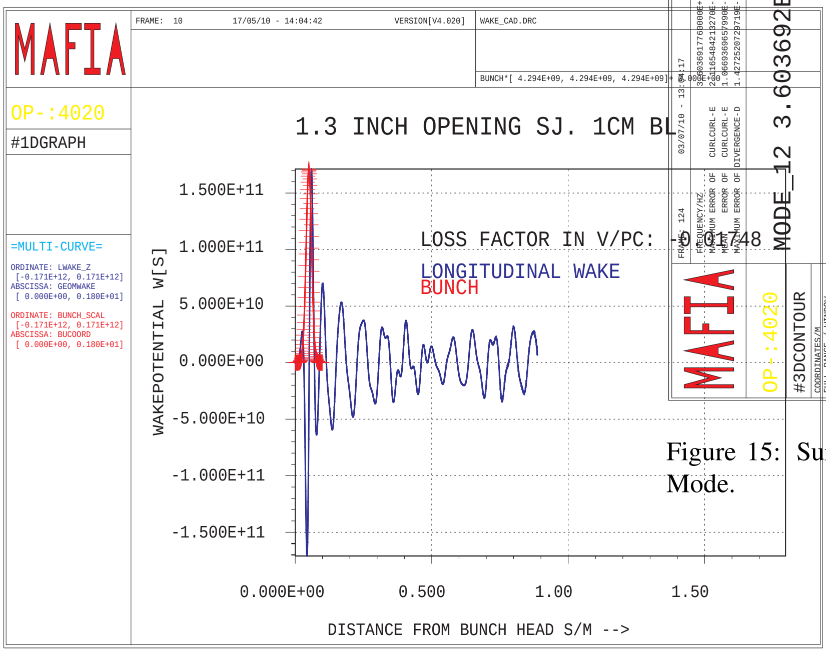

Figure 14: Longitudinal Wakefield due to 1 cm bunch length traveling along the center of the structure.

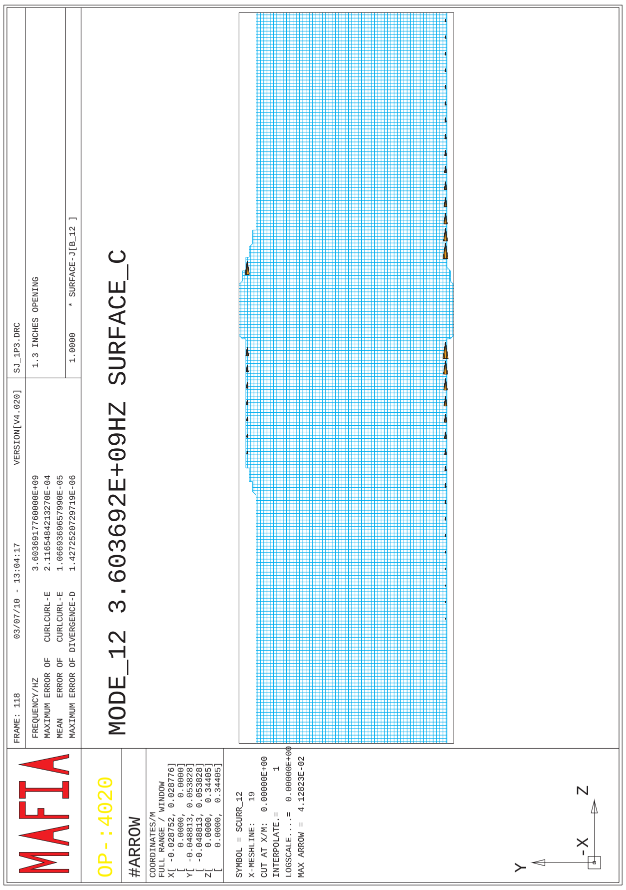

Figure 16: A Cross-Section along the x-axis of the Longitudinal Trapped Mode.

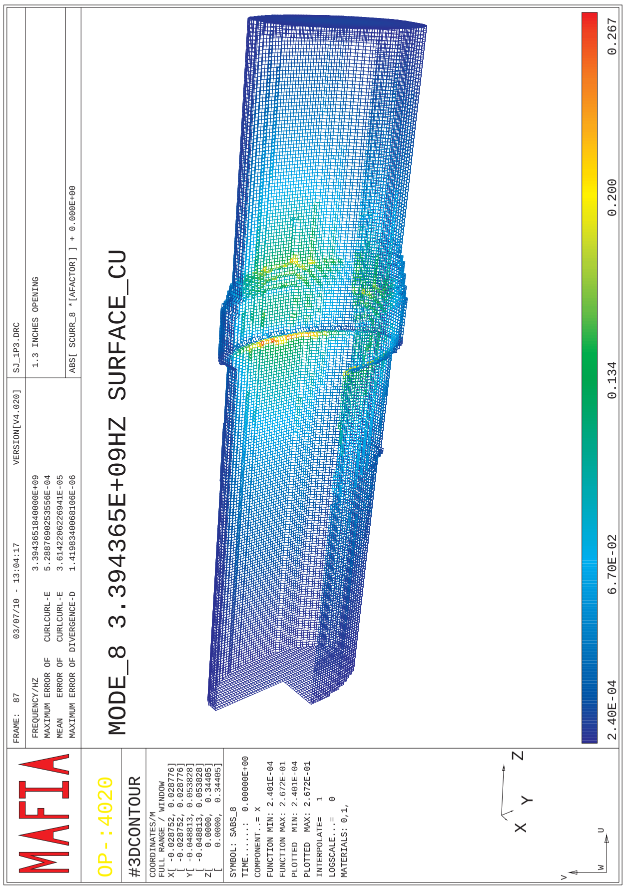

Figure 17: Surface Current of the Transversed Trapped Mode.

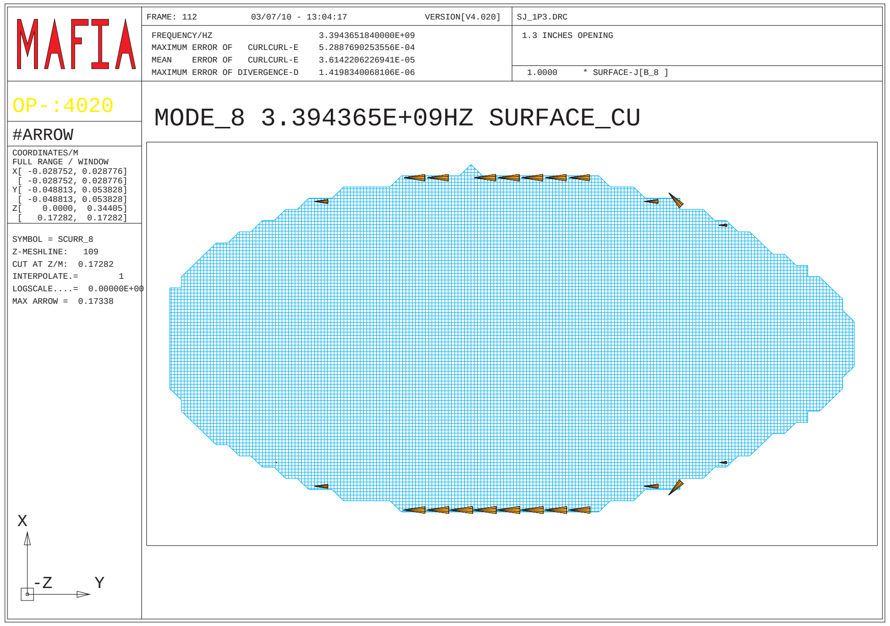

Figure 18: A Cross-Section along the z axis of the Transversed Trapped Mode.