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# STABILITY STUDY OF OFF CENTER BEAM IN THE SUPERCONDUCTING CAVITY FOR CESR IV

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## *Introduction*

The electrons and positrons in CESR IV design are guided through separate pipes and share the superconducting accelerating cavities. Their orbits inside the cavity are displaced by $\pm 4$ $cm$ from the axis of the cavity. Since this displacement is larger by 2 $cm$ than the present CESR III pretzeled orbit, and the beam current will be about 5 times larger, it is necessary to study the higher order mode characteristics and the beam stability at this displacement with the higher current.

## 1 *R/Q Calculations of the Higher Order Modes*

Calculations of $R/Q$ of the superconducting cavity [1] were done using the code URMEL [2]. In modeling the cavity only half the cell was simulated. In order to calculate all possible higher order modes, the program was run twice for each field mode $m = 0$, $m = 1$ using different boundary conditions at the symmetry line. The first one is when the tangential electric field is set to zero and the second is when the tangential magnetic field is set to zero. Figures 1-6 show the calculated $R/Q$ of the higher order modes for $m = 0, 1$ as function of the transverse displacement $r$. Note, the $R/Q$ of the longitudinal $m = 0$, Figures 1,2, and the transverse $m = 1$, Figure 4,5, higher order modes either stay constant or decrease as the beam is further displaced from the center. On the other hand, the longitudinal $R/Q$ of all modes with $m = 1$ increase with the transverse displacement up to $r = 6$ $cm$. See Figures 3,4.

## 2 *Stability Calculations*

If $k_b$ is the number of bunches in the storage ring, there will be $k_b$ coupled-bunch modes characterized by the longitudinal mode number $s = 0, 1, 2 ...(k_b - 1)$. In addition an individual bunch in the $s^{th}$ coupled-bunch mode requires an index $A = 1, 2, ...etc$ to describe its motion in the synchrotron phase space, *e.g.* the dipole mode $A = 1$, where the bunches move rigidly as they execute longitudinal synchrotron oscillation. The quadrupole mode $A = 2$ where the bunch head and tail oscillate longitudinally out of phase, etc.

For the transverse case, Two mode numbers $s$ and $A$ are again needed to described transverse coupled-bunch mode. One difference in the transverse case is that the index $A$ can assume the value $A = 0$, meaning that the bunch moves rigidly as it executes the transverse oscillations; This is called

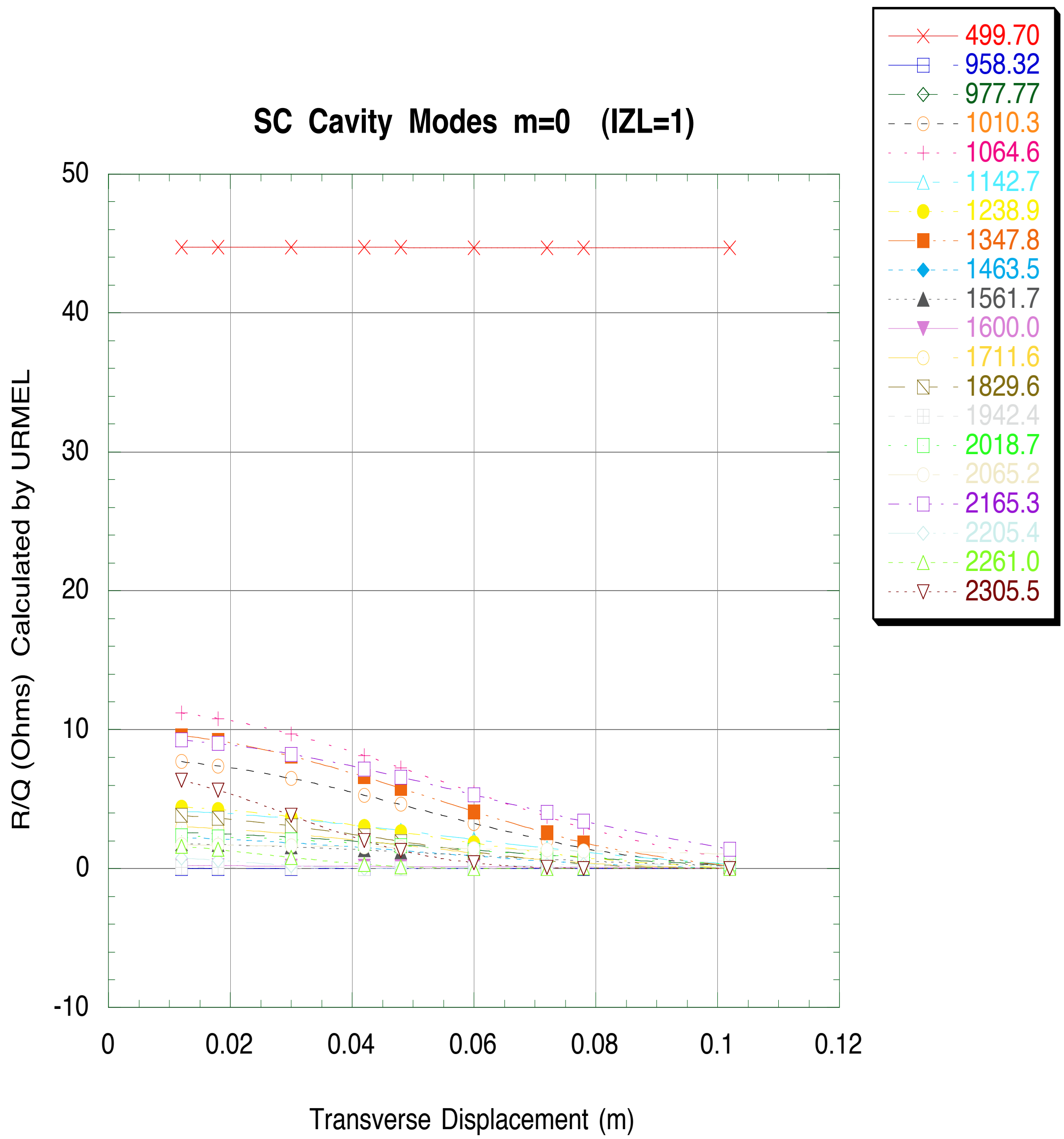


Figure 1: Longitudinal $m = 0$ $R/Q$ as function of transverse displacement for the modes with tangential ELECTRIC field zero at the leftmost boundary

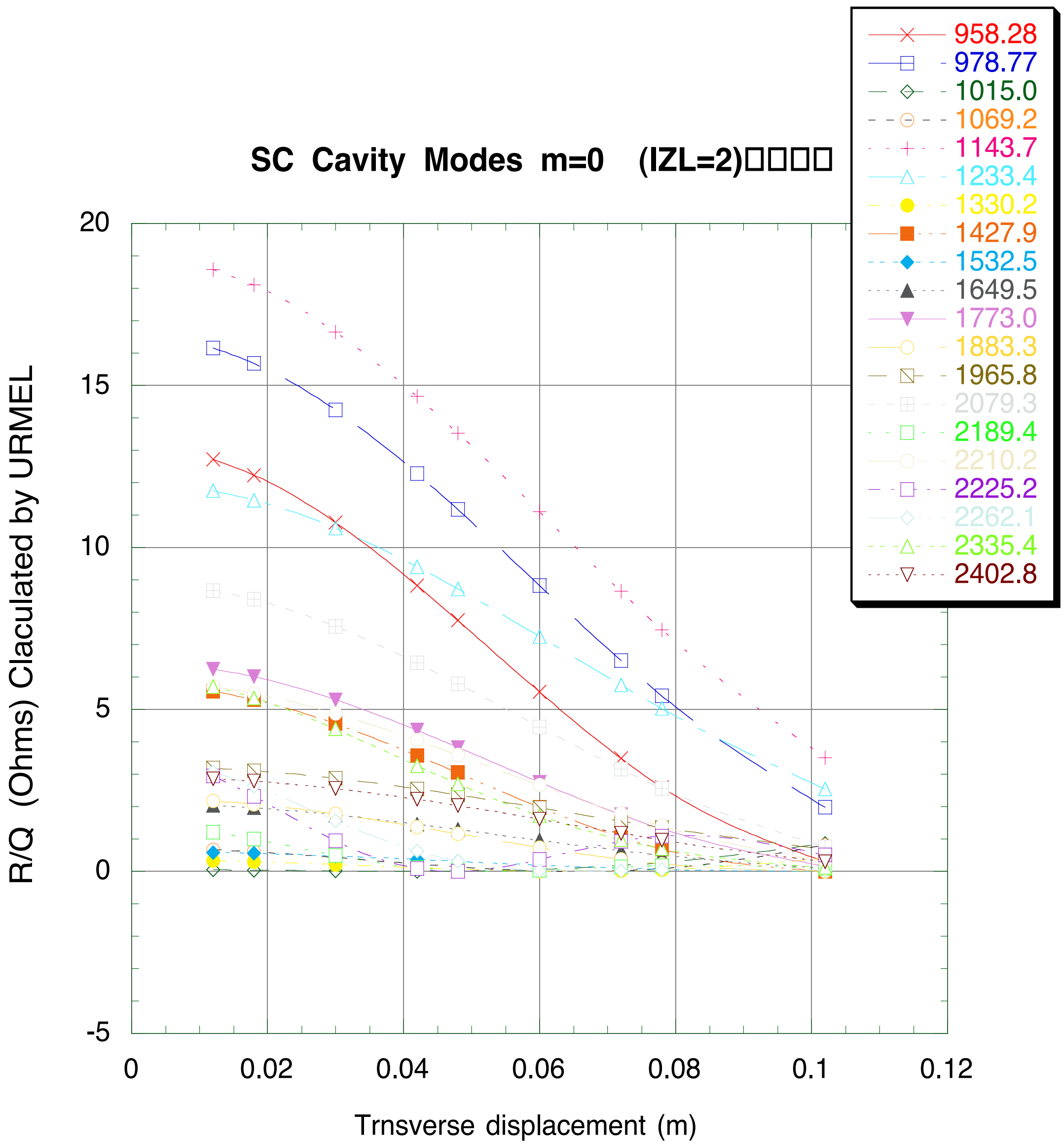


Figure 2: Longitudinal $m = 0$ $R/Q$ as function of transverse displacement for the modes with tangential MAGNETIC field zero at the leftmost boundary

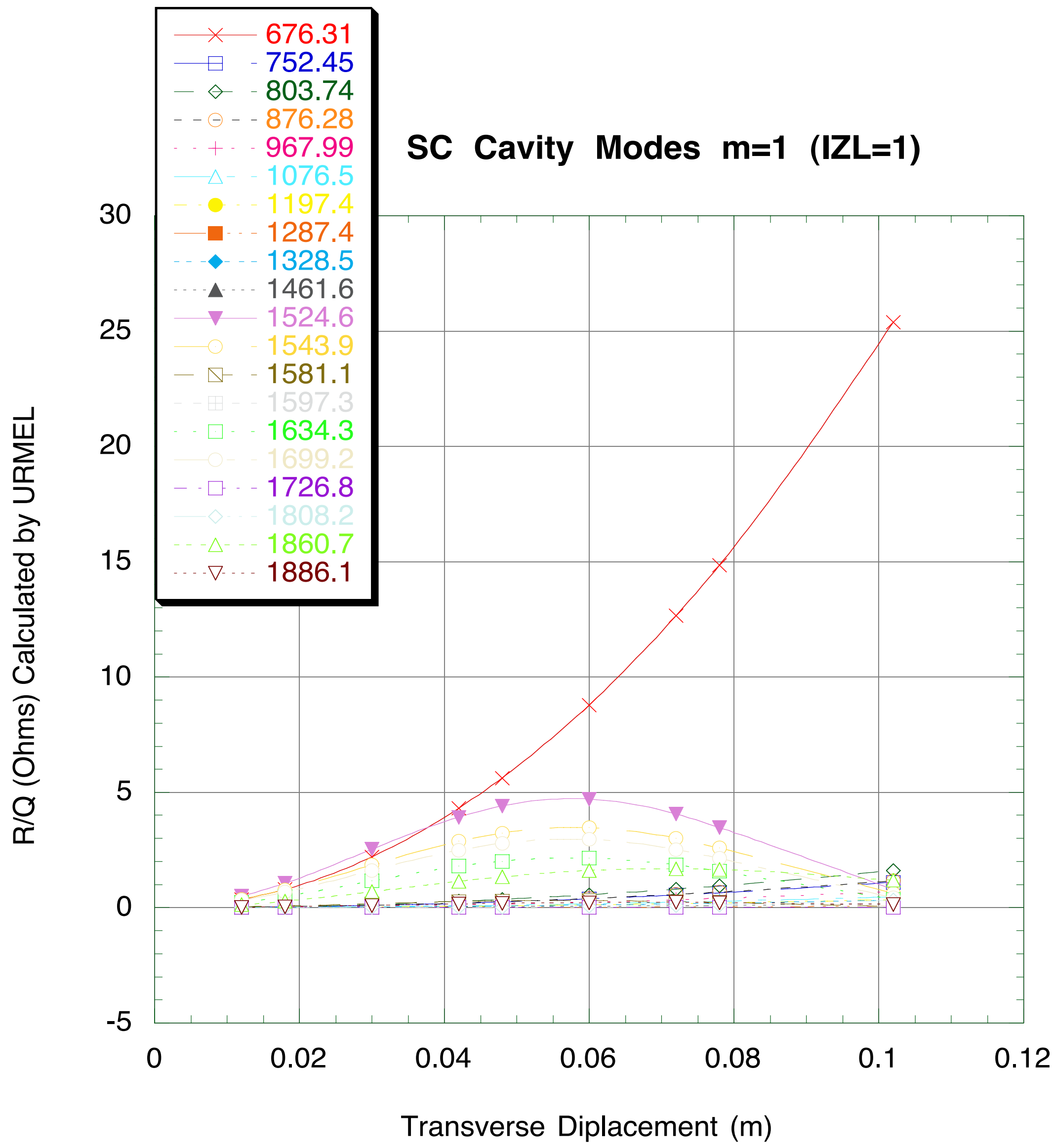


Figure 3: Longitudinal $m = 1$ $R/Q$ as function of transverse displacement for the modes with tangential ELECTRIC field zero at the leftmost boundary

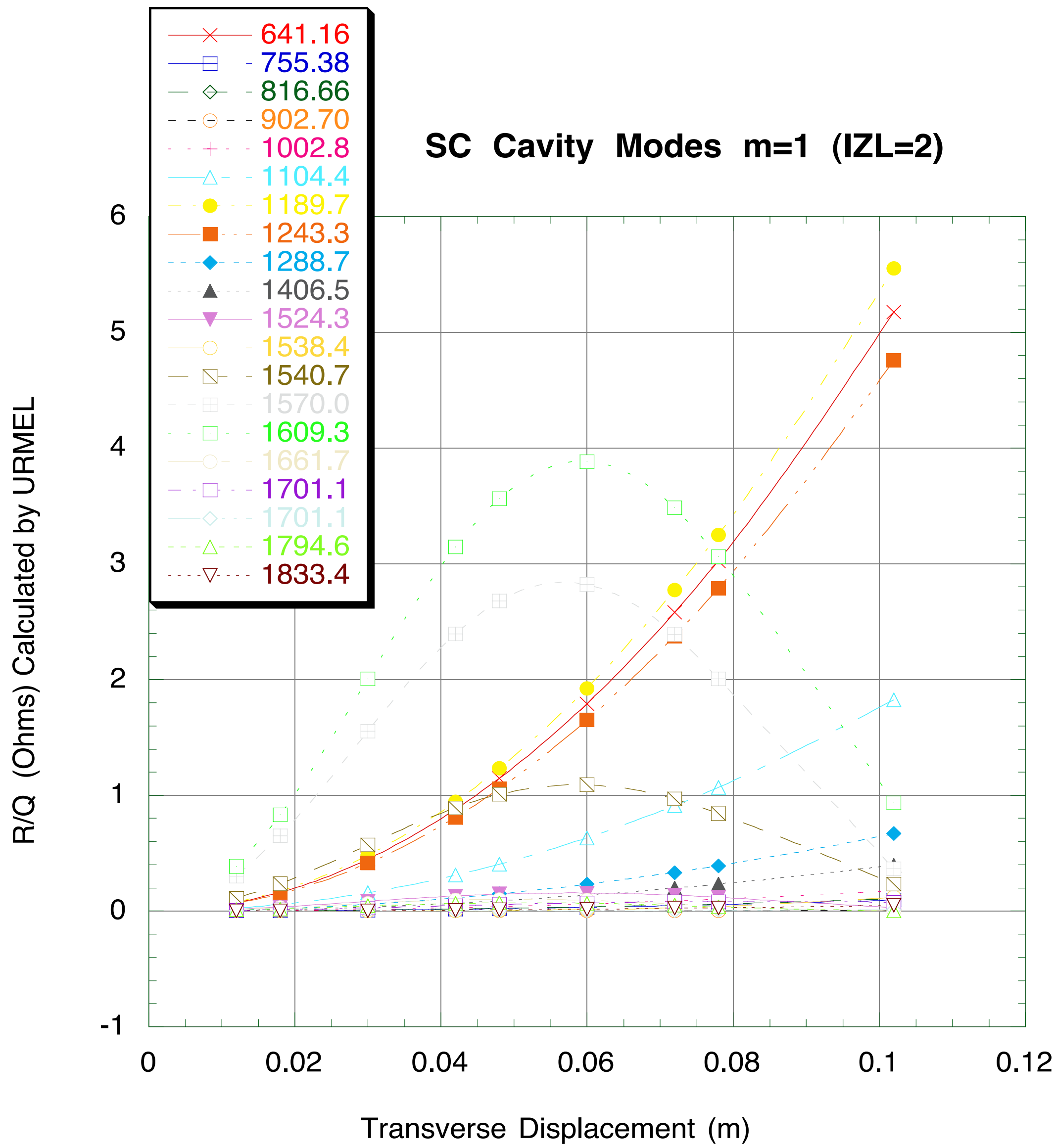


Figure 4: Longitudinal $m = 1$ $R/Q$ as function of transverse displacement for the modes with tangential MAGNETIC field zero at the leftmost boundary

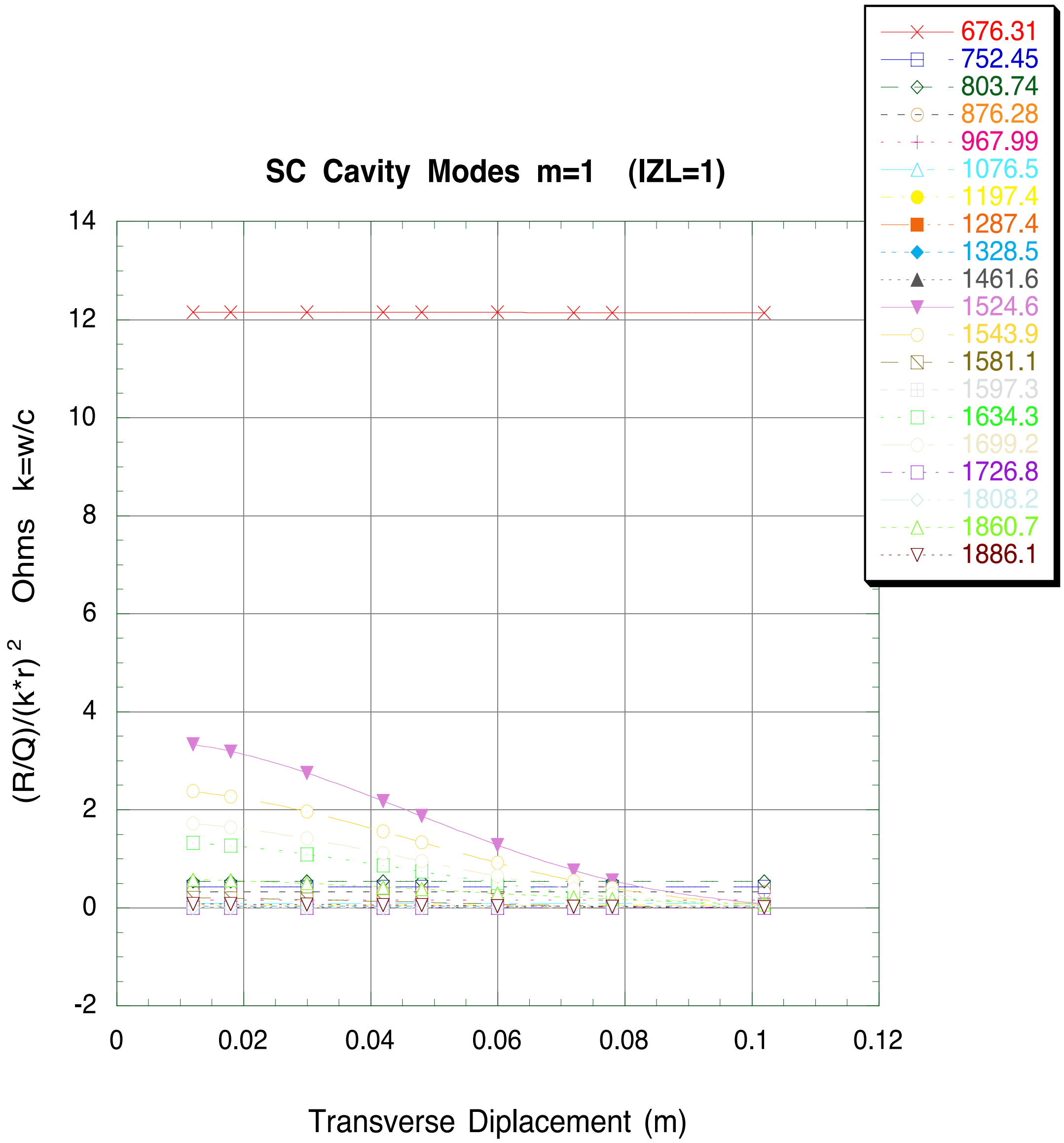


Figure 5: Transverse $m = 1$ $R/Q$ as function of transverse displacement for the modes with tangential ELECTRIC field zero at the leftmost boundary

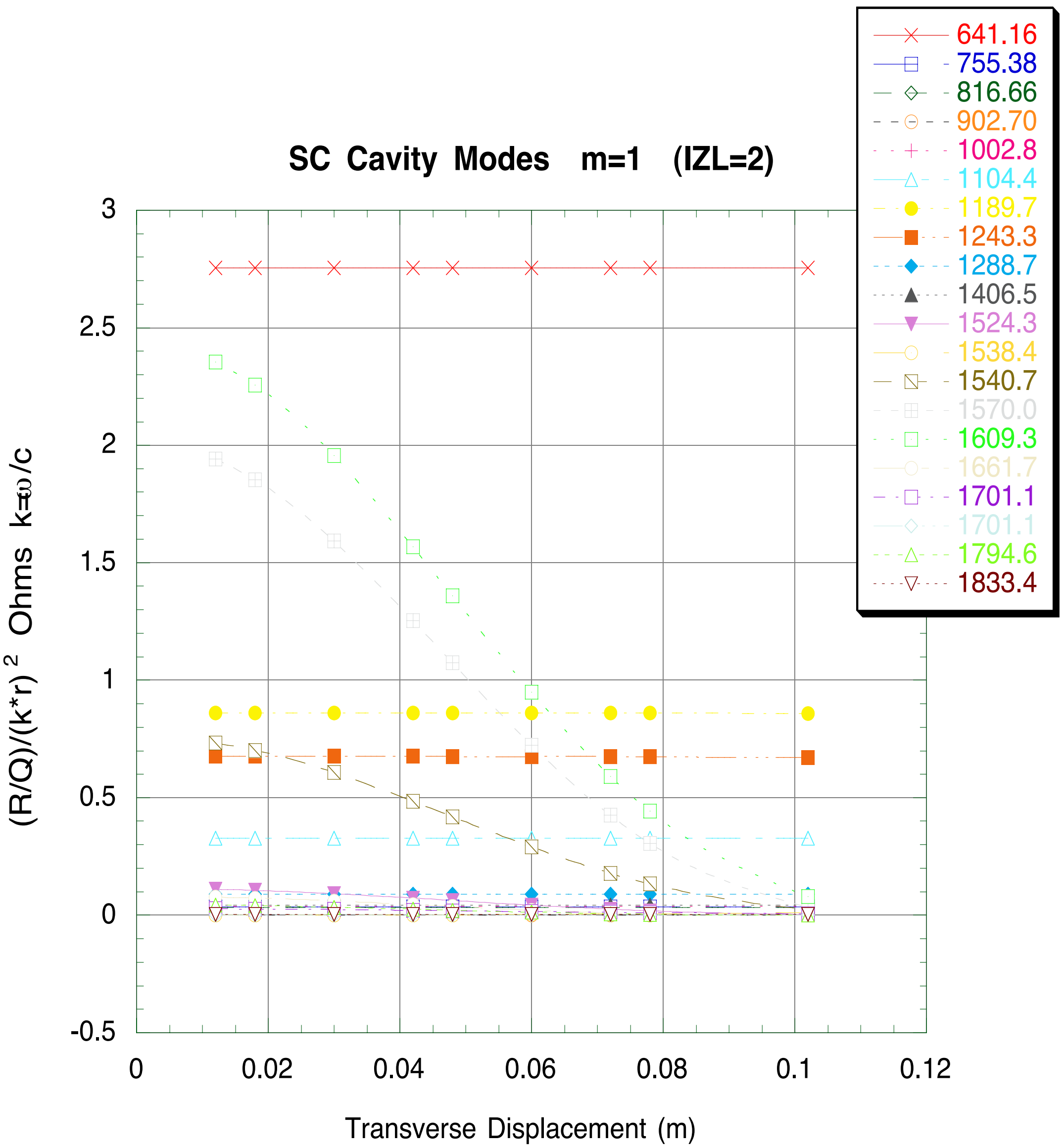


Figure 6: Transverse $m = 1$ $R/Q$ as function of transverse displacement for the modes with tangential MAGNETIC field zero at the leftmost boundary

| *CESR IV Parameters* | *units* |
|---|---|
| Ring Circumference | 756.106 $m$ |
| RF Frequency | 499.930 $MHz$ |
| No. of Cavities | 10 |
| No. of Bunches | 180 |
| Current per Bunch | 17 $ma$ |
| Beam Pipe Radius | 12 $cm$ |
| Beam Energy | 5289. $MeV$ |
| Horizontal Chromaticity | $-15.4$ |
| Horizontal Emittance | $1.96 \cdot 10^{-7}$ |
| Vertical Emittance | $2.38 \cdot 10^{-9}$ |
| Momentum compaction | 0.01086 |
| Horizontal Damping Time | 29 $msec$ |
| Energy Damping Time | 14 $msec$ |
| Harmonic No. | 1260 |
| Synchrotron Tune | 0.1125 |
| Bunch Length | 0.7 $cm$ |
| $\beta_H$ | 9.56 $m$ |
| $\beta_V$ | 13.942 $m$ |
| Horizontal Tune | 12.587 |
| Vertical Tune | 8.632 |

Table 1: Summary of CESR IV parameters used in ZAP

the transverse rigid dipole mode. The $A = 1$ implies the bunch head and tail oscillate transversely out of phase.

The growth time of the unstable coupled-bunch modes were calculated using the code ZAP [3] with the CESR IV parameters shown in *Table* 1. The simulation includes 10 cavities. For each cavity the values of the 20 highest $\left( \frac{R}{Q}\Big|_{r=4\ cm} \right) \cdot Q$ were used. While the $R/Q$ values were calculated by URMEL at $r = 4\ cm$ transverse displacement, the quality factor values $Q$ for each higher order mode were taken from measurements on the cavity including the ferrite. See Figure 7 [4].

Figures 8,9 show the growth time of the LONGITUDINAL instability for $m = 0$ and $m = 1$ field modes for various numbers of bunches. Figure 10 shows the TRANSVERSE instability $m = 1$ growth time versus the number of bunches. In each figure the growth time was calculated for the following two cases:

$a$. The bunch current is held constant at $(17.0\ ma/bunch)$.

$b$. $I_b = \frac{17.0\ ma \cdot 180\ bunches}{\#bunches}$ which maintains the designed total current of 3.06 $amp/beam$ at 180 $bunches$ per species.

The growth time values shown in Figures 5,6,7 correspond to the fastest growing coupled-bunch mode $s$. Because the $s^{th}$ coupled-bunch mode which has the fastest growth time, is different for the various numbers of bunches, there are some fluctuations in the calculated growth time versus $\#bunches$ $(=k_b)$. In general, in case $a$, the growth time decreases with increasing number of bunches. And, in case $b$ where the total current is held constant, the growth time decreased for $\#bunch < 180$ where the bunch current was increased above 17.0 $ma$ and increased for $\#bunch > 180$ where $I_b < 17.0\ ma$.

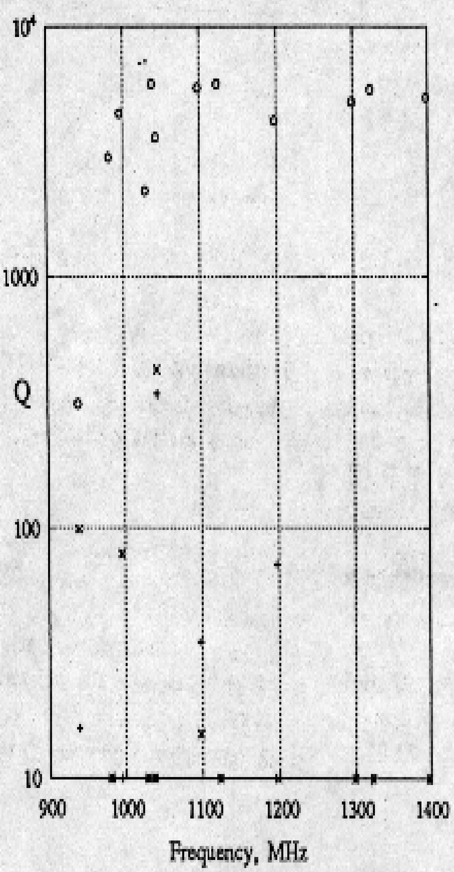


Fig. 4. Q values of monopole higher order modes:
o - without ferrites, + - with absorbers of Ferrite-50, x - with absorbers of ferrite TT2-111.

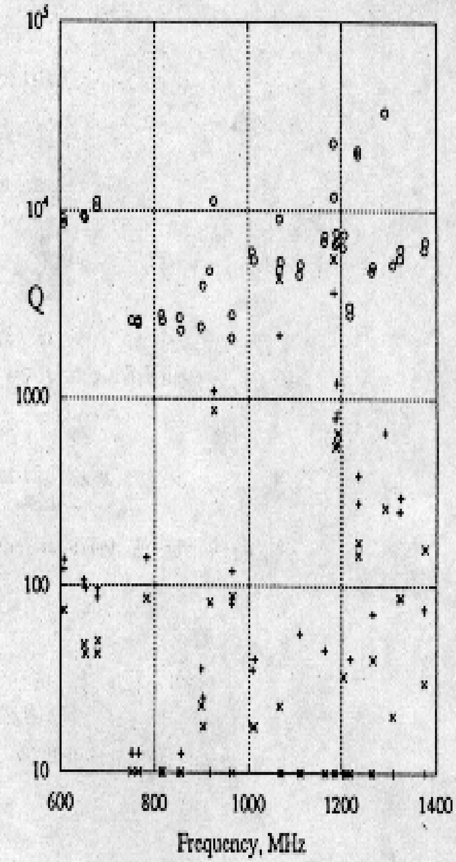


Fig. 5. Q values of dipole higher order modes:
o - without ferrites, + - with absorbers of Ferrite-50, x - with absorbers of ferrite TT2-111.

Figure 7: Measured quality factor for the superconducting cavity

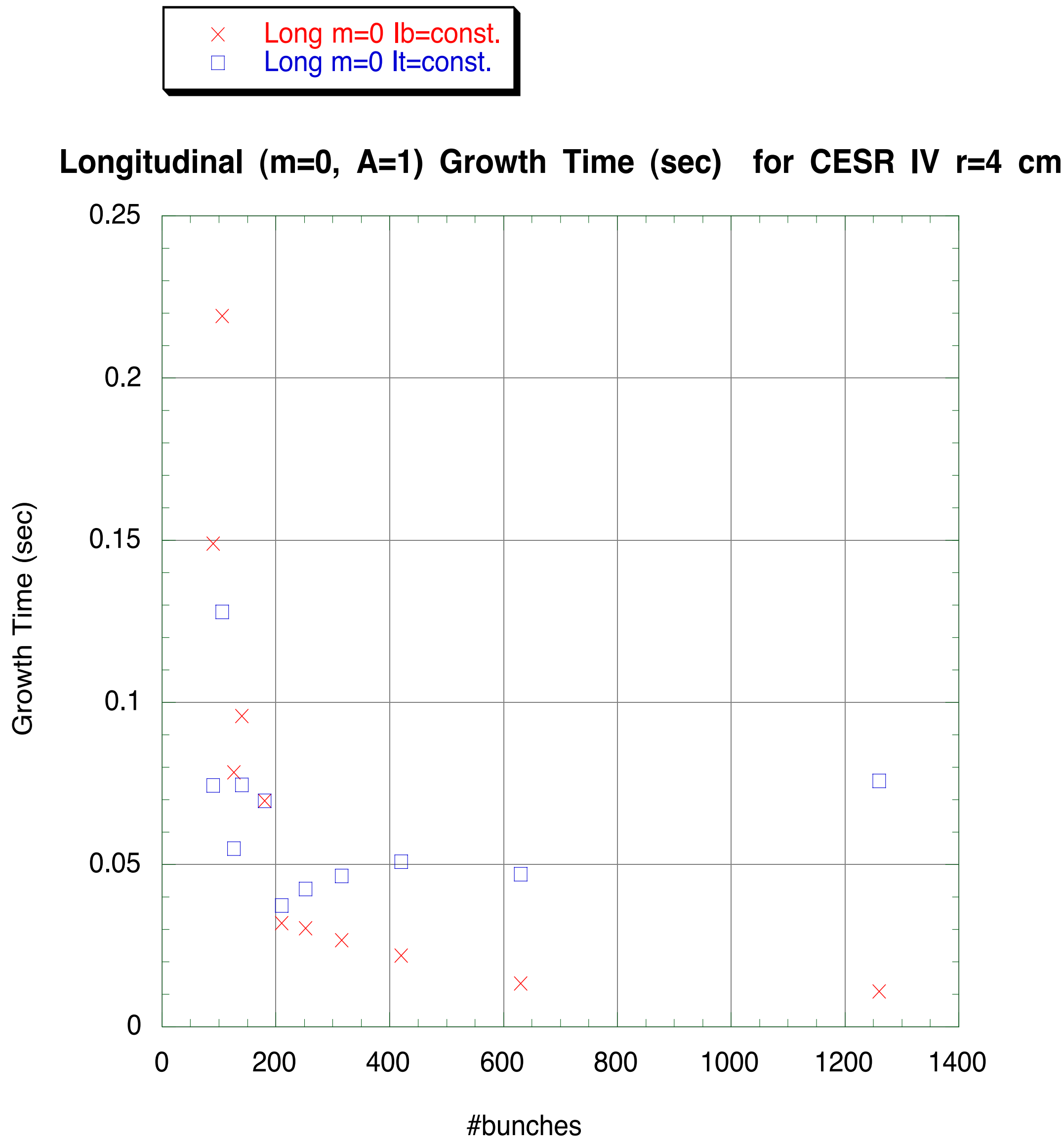


Figure 8: Growth Time of Longitudinal $m = 0$ modes with a. $I_b = 17.14\ ma/bunch$ b. $I_b = \frac{17.0\ ma \cdot 180\ bunches}{\#buches}$ $(It = 3.06\ amp = cons.)$ for various number of bunches

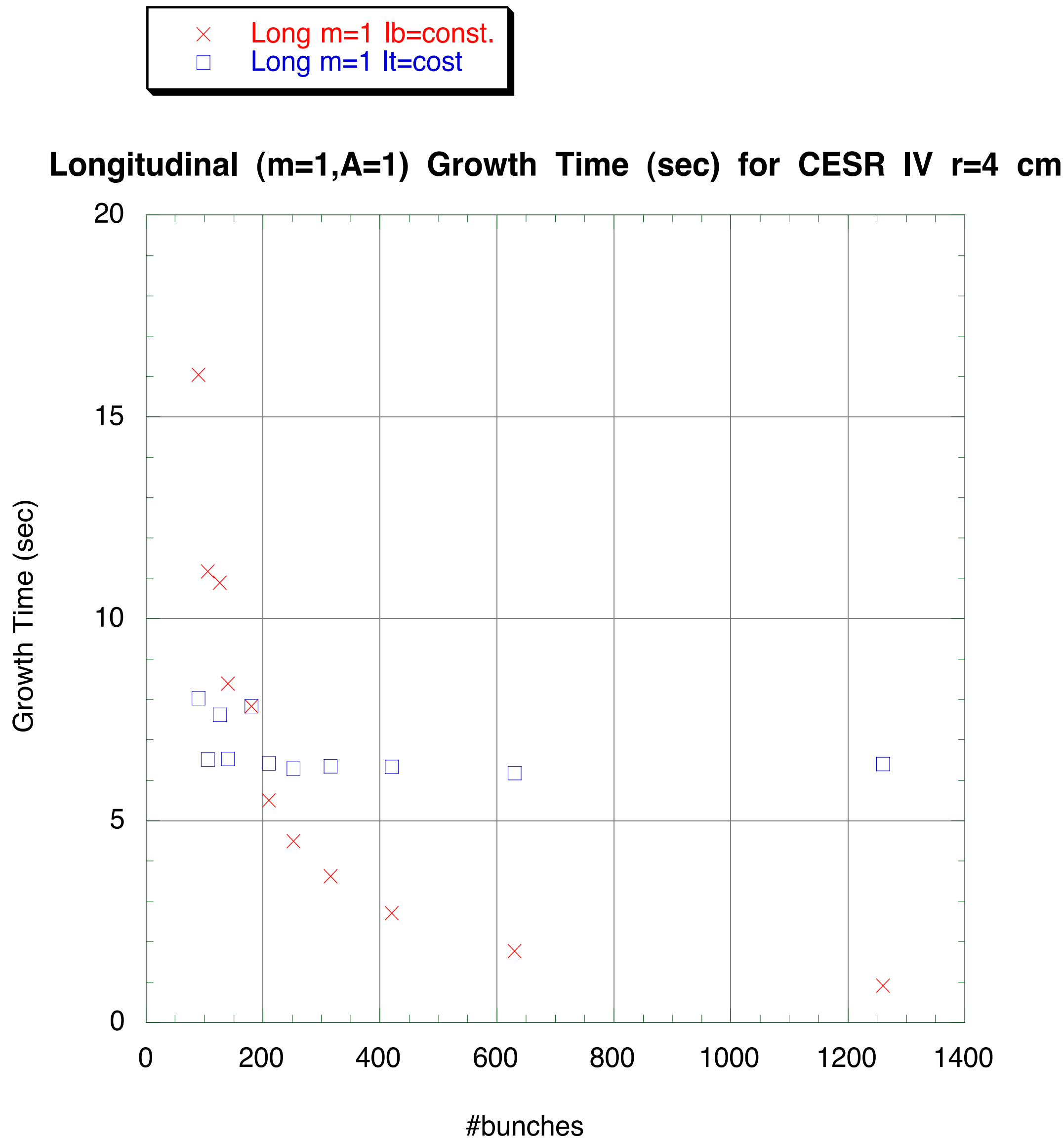


Figure 9: Growth Time of Longitudinal $m = 1$ modes with a. $I_b = 17.14\ ma/bunch$ b. $I_b = \frac{17.0\ ma \cdot 180\ bunches}{\#buches}$ $(It = 3.06\ amp = cons.)$ for various number of bunches

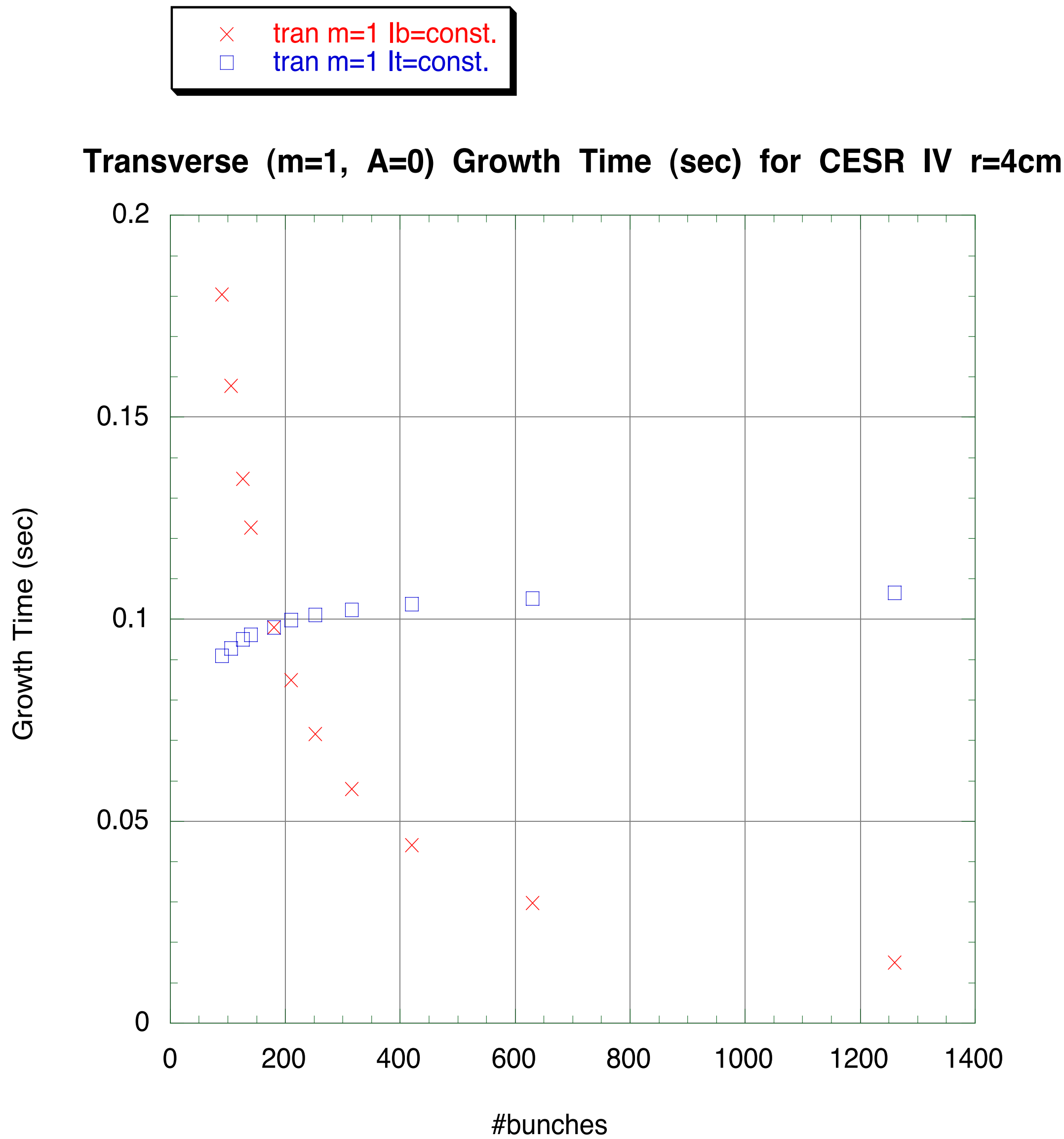


Figure 10: Growth Time of Transverse $m = 1$ $IZL = 1$ modes with a. $I_b = 17.14$ $ma/bunch$ b. $I_b = \frac{17.0\ ma \cdot 180\ bunches}{\#buches}$ $(It = 3.06\ amp = cons.)$ for various number of bunches

## 3 *Conclusion*

For CESR IV parameters (see Table 1) the growth time of the unstable modes in both planes, longitudinal and transverse, is larger than the radiation damping time. The instability growth time for LONGITUDINAL motion $m = 0$ and $m = 1$ are 70 $msec$ and 8 $sec$ respectively, compared to the radiation damping time of 14 $msec$. The TRANSVERSE mode instability growth time is 98 $msec$ while the radiation damping time is 29 $msec$. Thus both modes will be damped. Note, even though the LONGITUDINAL $R/Q$ of the $m = 1$ modes increase with displacement of the bunch from the center (Figures 3,4), their values are still about a quarter of the $R/Q$ of the $m = 0$ modes, making the longitudinal instabilty growth time of $m = 1$ very slow.

# References

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[2] C. Palm, U. van Rienen, T. Weiland, "URMEL User Guide", DESY M-85-11, 1985.

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