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DIGITAL PHASE-DETECTOR ERROR UNDER BEAM-LOADED WAVESHAPES

The use of a digital phase detector is envisaged for the automatic tuning of the future PS-cavities (no trouble with limiters, no 90° phase shift necessary, simple circuit with standard components). A phase detector of this kind uses the zero-crossings of the voltages under test as input information; harmonics will change these zero-crossings, and the phase-reading of the fundamental will consequently be erroneous.

A FORTRAN program has been written to calculate this error for the expected shape of the beam-loaded accelerating voltage. Fig. 1 shows the equivalent cavity circuit and the triangular shaped bunch; the analysis has been performed by a Fourier-series under the following assumptions:

- the fundamental of the accelerating voltage is held constant by an AVC-circuit
- the circuit is tuned to zero phase between fundamental cavity voltage and fundamental generator current; the program calculates the time difference between zero passage of the distorted voltage and the fundamental cavity voltage (see Appendix II).

In order to test the program, 0.2 nsec-spaced values of the distorted cavity voltage around beam passage were printed and plotted for some beam durations (Fig. 2). It can bee seen that the dip in the cavity voltage approaches the value Q/C = 190 V for sufficiently short pulses as can be predicted by the initial-value-theorem of Laplace transforms; the Fourier-Routine seems therefore to be in order.

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Discussion of the results (Fig. 3)

a) For a given bunch length, the error is obviously inversely proportional to the peak accelerating voltage: the higher the cavity voltage, the more dominant the fundamental and the less the zero-crossing is influenced.

b) For a given accelerating voltage, but different bunch-length, there are two limiting cases:

- bunch length shorter than 10 nsec: the voltage around the zero-crossing is essentially the same as for a ϑ-impulse (see Fig. 2, where the shapes are all the same at small voltages). The tuning error tends to its maximum of $\sim 8^o$ (for 500 V cavity voltage)
- bunch length very long: the resulting waveshape tends towards the undistorted sinusoid with error $\rightarrow 0$.

c) The tuning error depends on the zero-crossing used: the crossing far from beam disturbation is much less influenced.

Conclusion: Even for $N = 1.25 \times 10^{13}$ protons in 20 bunches, the error is less than 8^o for all operating conditions. A digital phase detector is therefore useful for all cases, even where no filtering of the harmonics can be foreseen (accelerating without booster from $\beta = 0.3$, $N = 10^{12}$).

A low-pass filter with a cut-off of $\sim$ 12 MHz will however be provided in the final version: this will eliminate the effect of both higher modes of the cavity and of all the harmonics of a beam coming from the Booster ($N = 10^{13}$, f min $\sim$ 7 MHz).

Appendices

I. Program organisation: The program used consists of

- a main program ZCROSS which calculates the different fundamental currents and the tuning inductance
- function ZERO which runs into the zero-crossing by the aid of a Newton interpolation
- function EXCIT which delivers the spectral components of a triangular bunch form
- function FOURR which computes the voltage for a given time by a Fourier-series with 150 components.

For one parameter set, the time for the computation of the errors on both slopes of the cavity voltage is in the order of 1 sec on the 6400.

II. Theoretically, simultaneous zero-crossing of the generator current and the distorted accelerating voltage should be established first and then the tuning error be calculated (phase between generator and fundamental voltage). This requires an additional interpolation process for the tuning-L and results in a much slower program.

Since the zero-crossing of the resulting voltage compared to the zero-crossing of the fundamental voltage is practically independent of the cavity tuning, the first method can be used. In a test run for U = 500 V, $N = 1.25 \times 10^{13}$, the difference between the two methods was less than 0.1 degree.

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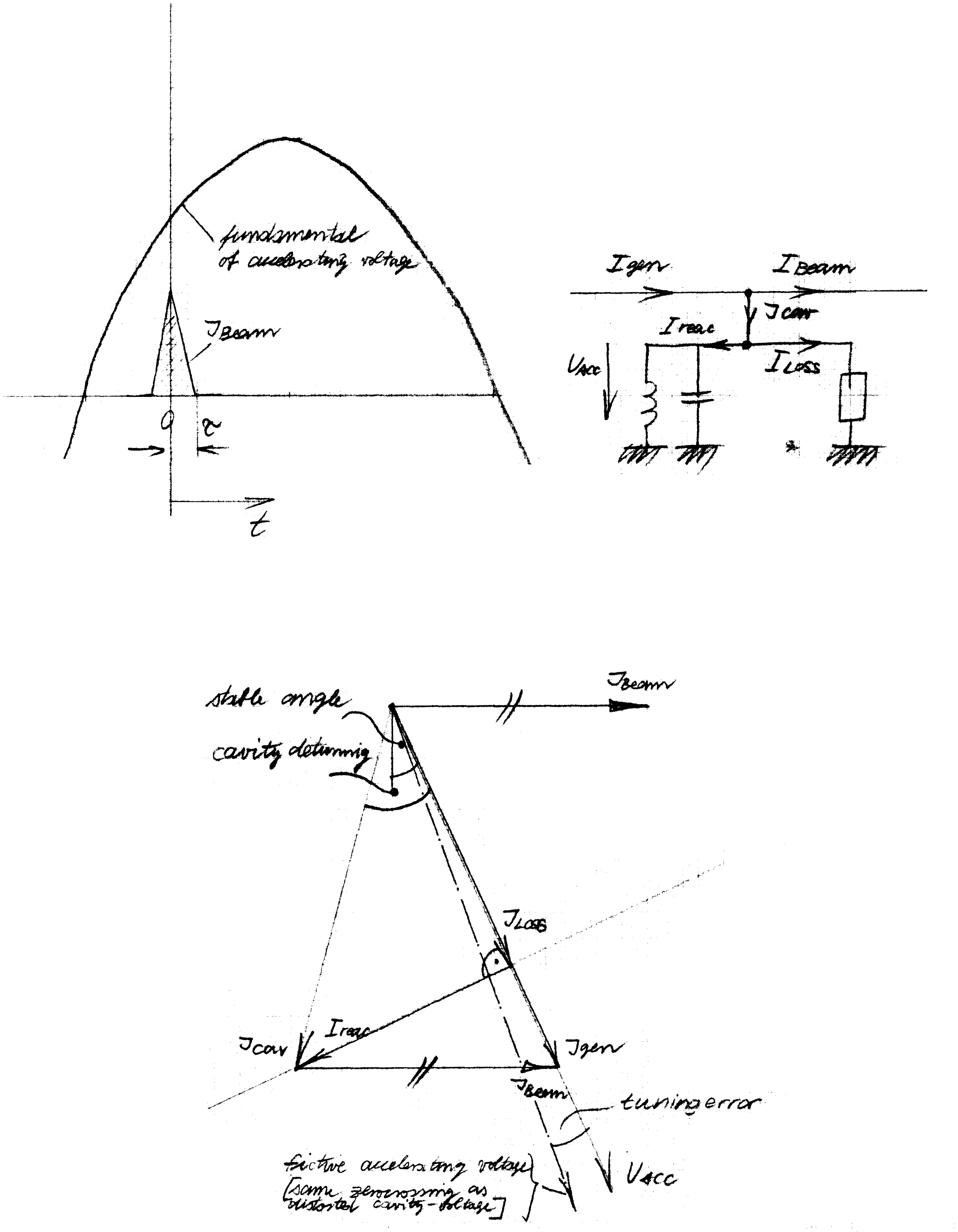
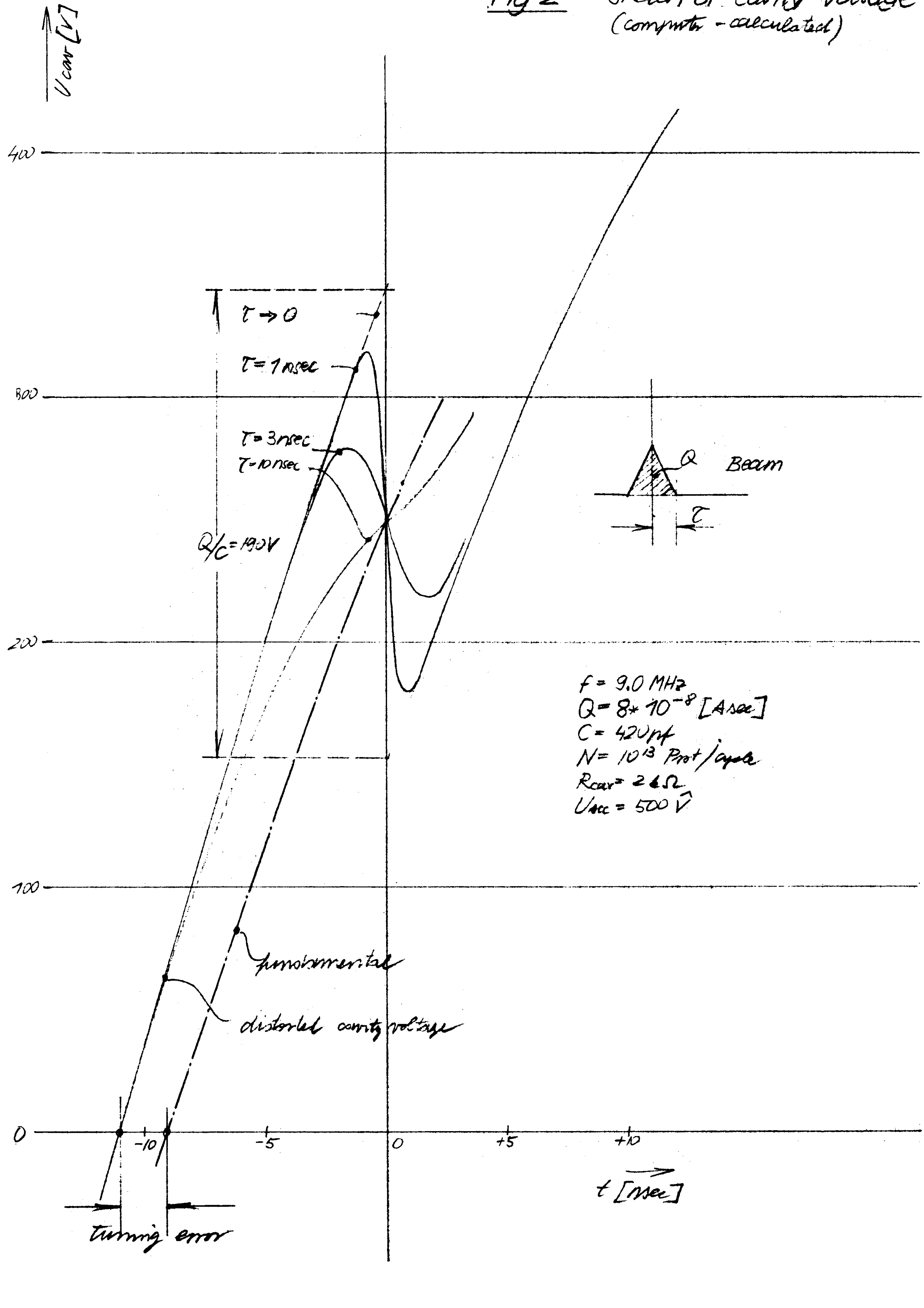


Fig. 1 Waveshape & vector diagram (fundamental) beam before transition

Fig 2 Sketch of cavity voltage (computer-calculated)



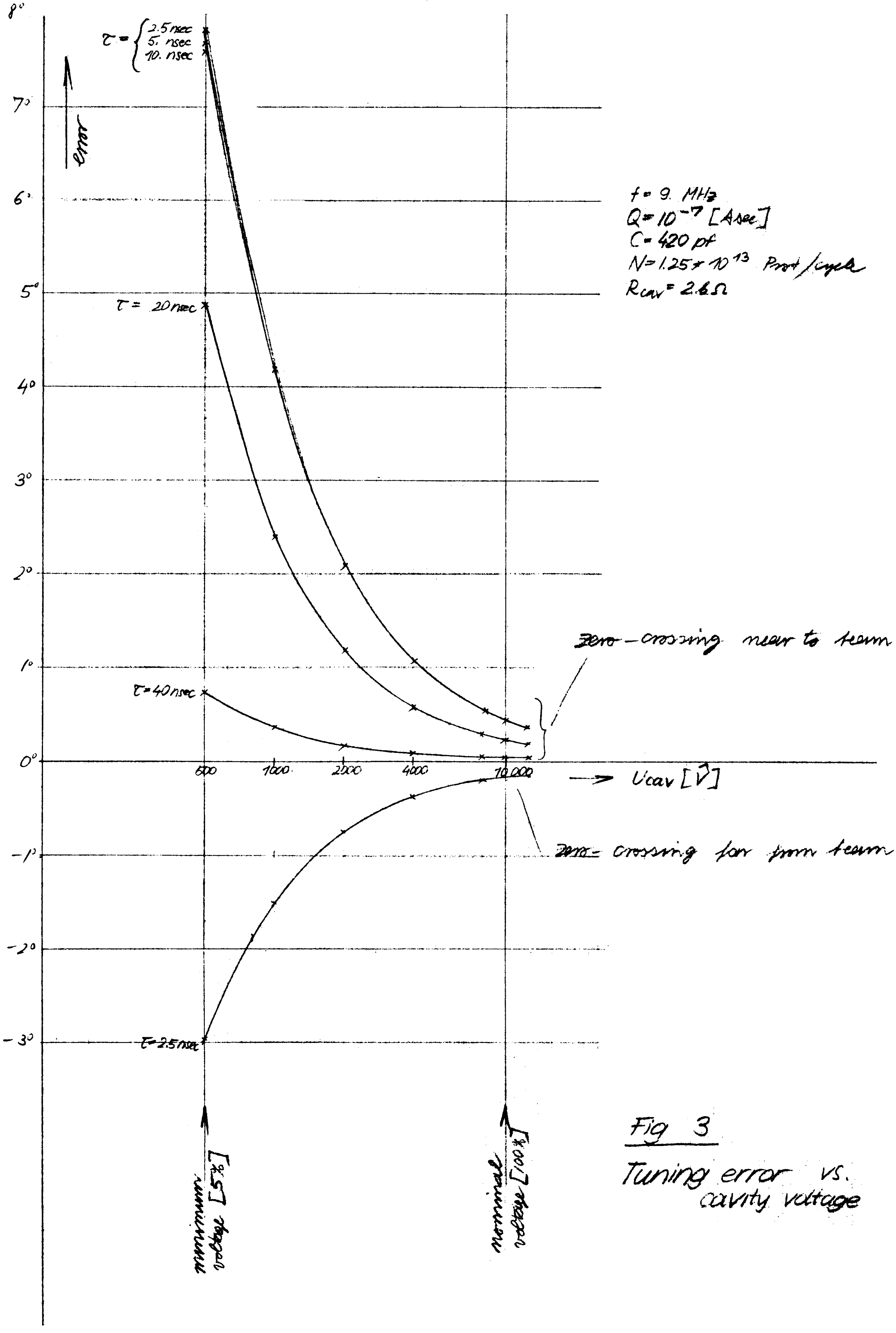


Fig 3

Tuning error vs. cavity voltage