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Mechanical Parameter Influence on the TESLA Cavity Tune under Lorentz Forces

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Introduction

For different reasons today's super conducting cavities are made out of sheet metal with a typical wall thickness of a few millimetres. Once filled with RF fields the wall deforms under the influence of Lorentz forces. This is especially true at lower frequencies, where the cavity is large compared to the wall thickness. In case of CW operation the resulting frequency shift can be compensated with mechanical tuners. However for pulsed operation, like e.g. TESLA, tuners are not at all obvious.

In a very nice paper[1] A.Mosnier reports on measurements and simulations of a MACSE cavity detuning under pulsed operation. As unfortunately turned out, the mechanical time constant τ_m of the cavity is of the same order of magnitude as a typical RF pulse duration (τ=1-2 ms). The effect on the cavity tune was disastrous and is shown again in Fig.1.

We adopt here the procedure of Mosnier and use his system of differential equations to study cavity voltage, phase and tune:

$$\begin{aligned} \tau\frac{\partial A}{\partial t} &= A_g\cos(\phi-\phi_g)-A_b\cos(\phi-\phi_b)-A \\ \tau\frac{\partial \phi}{\partial t} &= -\frac{A_g}{A}\sin(\phi-\phi_g)+\frac{A_b}{A}\sin(\phi-\phi_b)-y_0+\tau\cdot\delta\omega_r \qquad (1) \\ \tau_m\frac{\partial \delta\omega_r}{\partial t} &= -\delta\omega_r-2\pi K A^2 \end{aligned}$$

with: Cavity, generator and beam voltages: $A\,e^{j\phi}$, $A_g\,e^{j\phi_g}$, $A_b\,e^{j\phi_b}$

Cavity filling time: $\tau=2Q/\omega_r$

Resonance frequency change: $\delta\omega_r$

Initial detuning: y_0

Detuning parameter $Hz/(MV/m)^2$: K

Mechanical time constant: τ_m

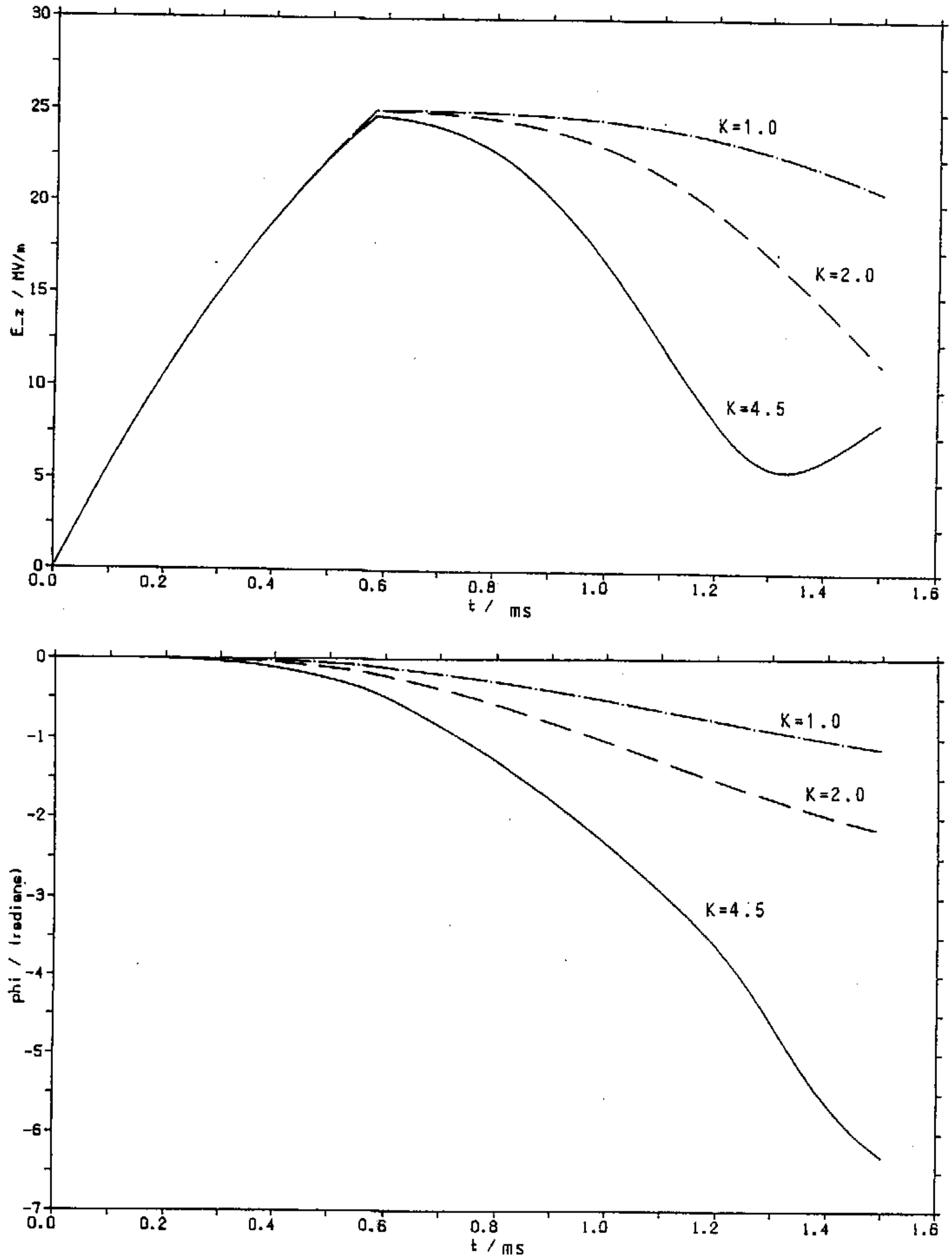

Fig.1 TESLA Cavity amplitude and phase under Lorentz forces with a generator current step at t=0 and a beam current step at t=0.58 ms (τ=0.83 ms, τ_m=1 ms).

Simulation Results

In view of the disastrous results of Mosnier, where even a feedback system could hardly offer relief, efforts were undertaken to stiffen the cavity and hence reduce its deformation under the Lorentz forces. Today it is believed[2], that the TESLA Cavity can reasonably be built with a K value in the range of K=0.2-0.8 Hz/(MV/m)^2. The mechanical time constant is expected to be between τ_m=0.2-1.0 ms. Even then, detuning is intolerably high, as can be seen in Fig.2.

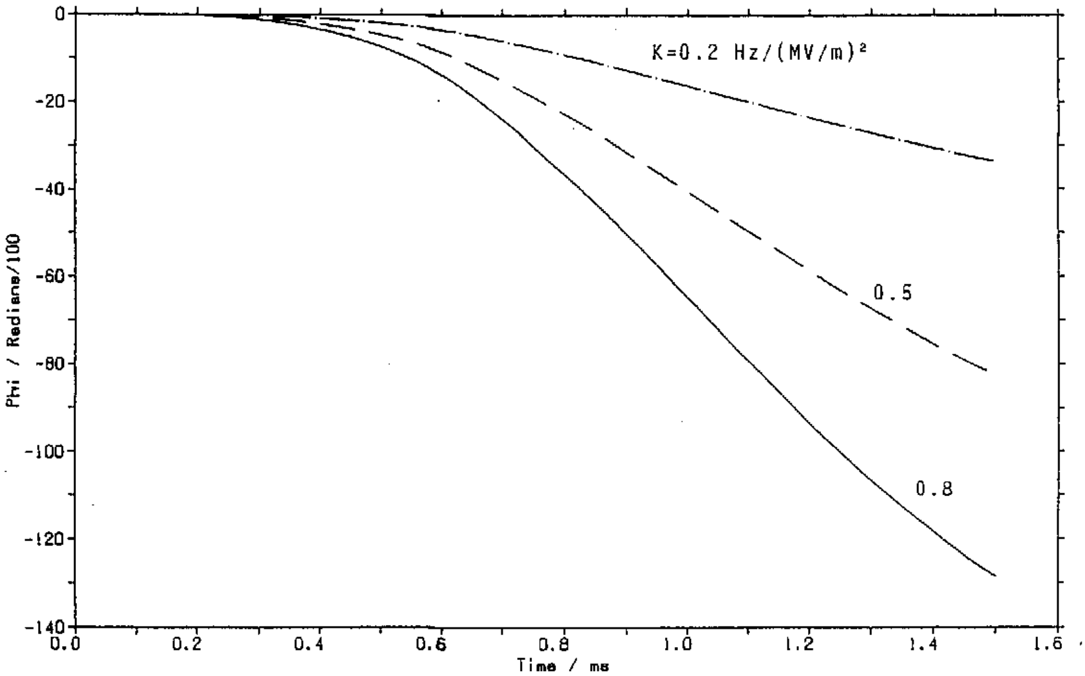

Fig.2 Cavity phase evolution during one pulse without feedback, τ_m=0.5 ms.

On the other hand, if the deformation under Lorentz forces is sufficiently reproducible and if this is also true for a group of cavities, a simple feedback system seems to be possible. First the specific detuned value of each group of cavities has to be measured. Then, prior to filling, each group of cavities and the power source is detuned by the determined amount. Once the generator pulse is turned on and the cavity deforms, the generator phase is locked onto the cavity resonance phase, thus permitting a proper cavity filling. At the very beginning of the beam pulse the generator phase is unlocked and driven with a small frequency jump δf. This frequency jump determines the final design frequency and must lie within the cavity bandwidth. Under these circumstances the remaining phase variations due to mechanical ringing of the cavity can be minimised. The initial detuning and the final frequency jump for each section of cavities was found experimentally.

The Figures 3 and 4 show the amplitude and phase variations if such a feedback system was adopted. The solid curve marks the optimised frequency jump for that set of parameters (K, τ_m). As can be seen the phase deviation stays within $\delta\phi = \pm 0.1$ radians or $\delta\phi = \pm 6°$ for the chosen set of parameters. The two other curves indicate the parameter sensitivity of the optimised case.

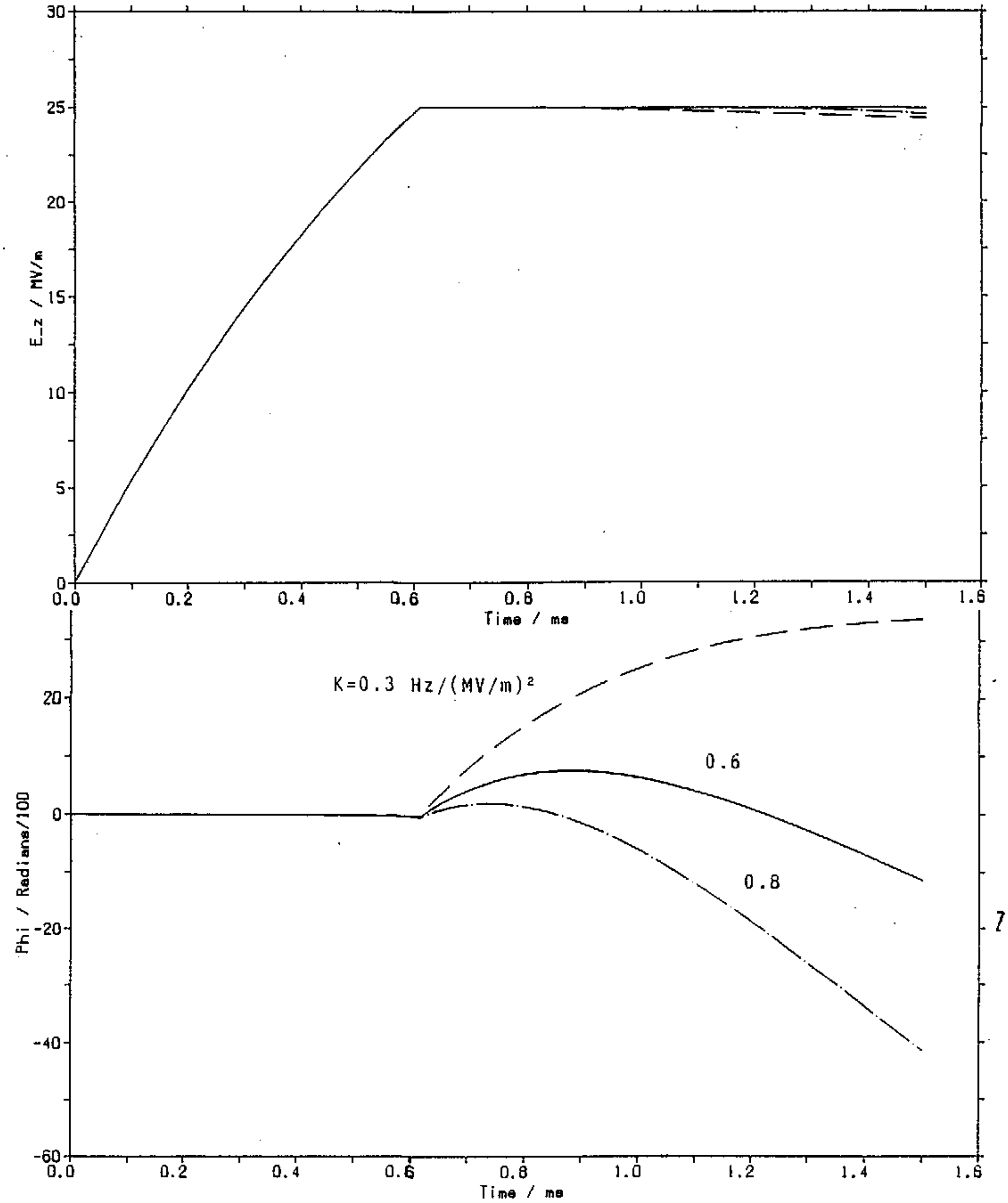

Fig.3 Amplitude and phase evolution during one pulse with feedback optimised for K=0.6 Hz/(MV/m)^2 and τ_m=0.6 ms. The frequency jump was set to δf=224 Hz.

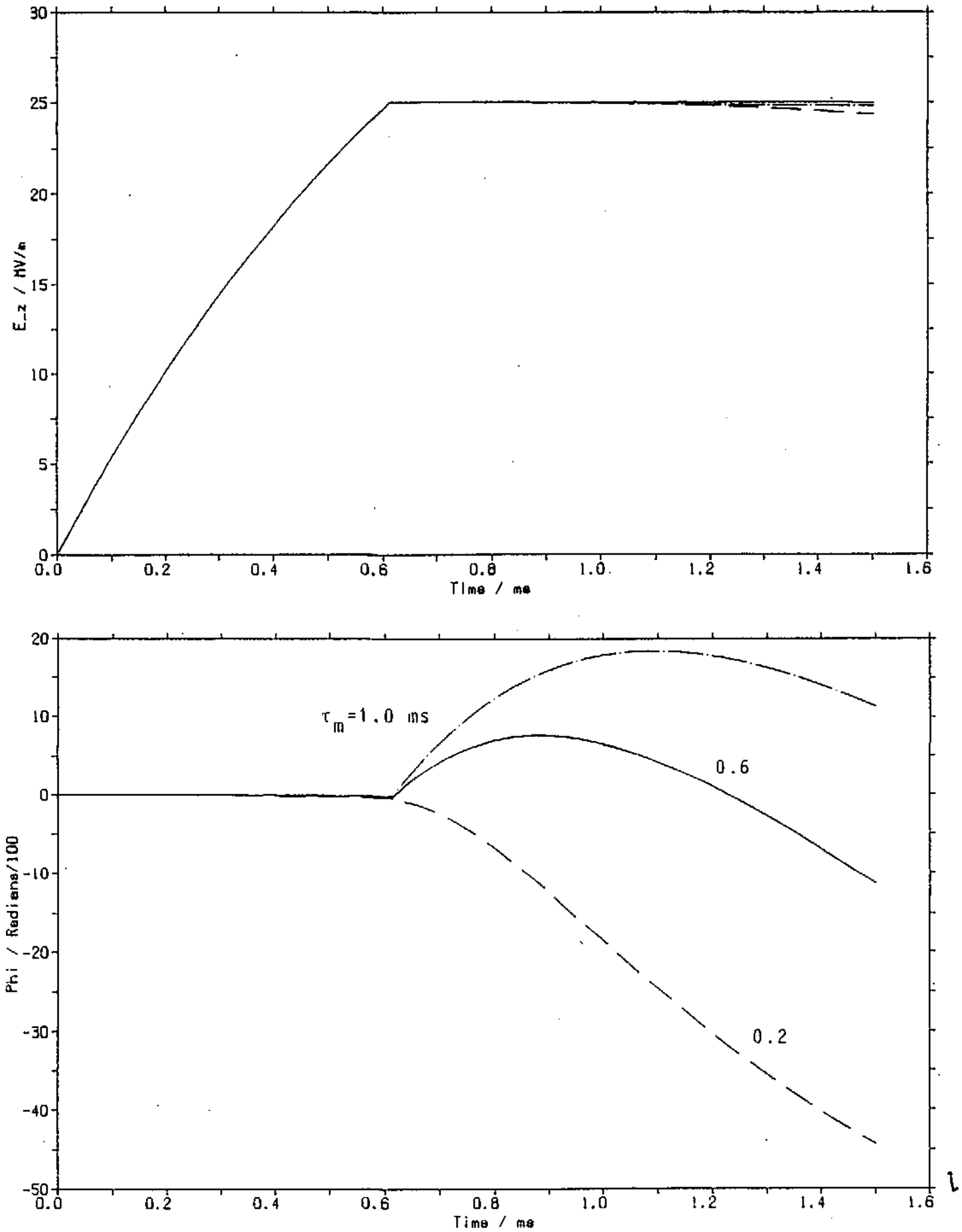

Fig.4 Amplitude and phase evolution during one pulse with feedback optimised for K=0.6 Hz/(MV/m)^2 and τ_m=0.6 ms. The frequency jump was set to δf=224 Hz.

Finally in the Figures 5 and 6 the optimum frequency jump δf for the parameter range of interest K=0.3-0.8 Hz/(MV/m)^2 and τ_m=0.2-1.0 ms is plotted.

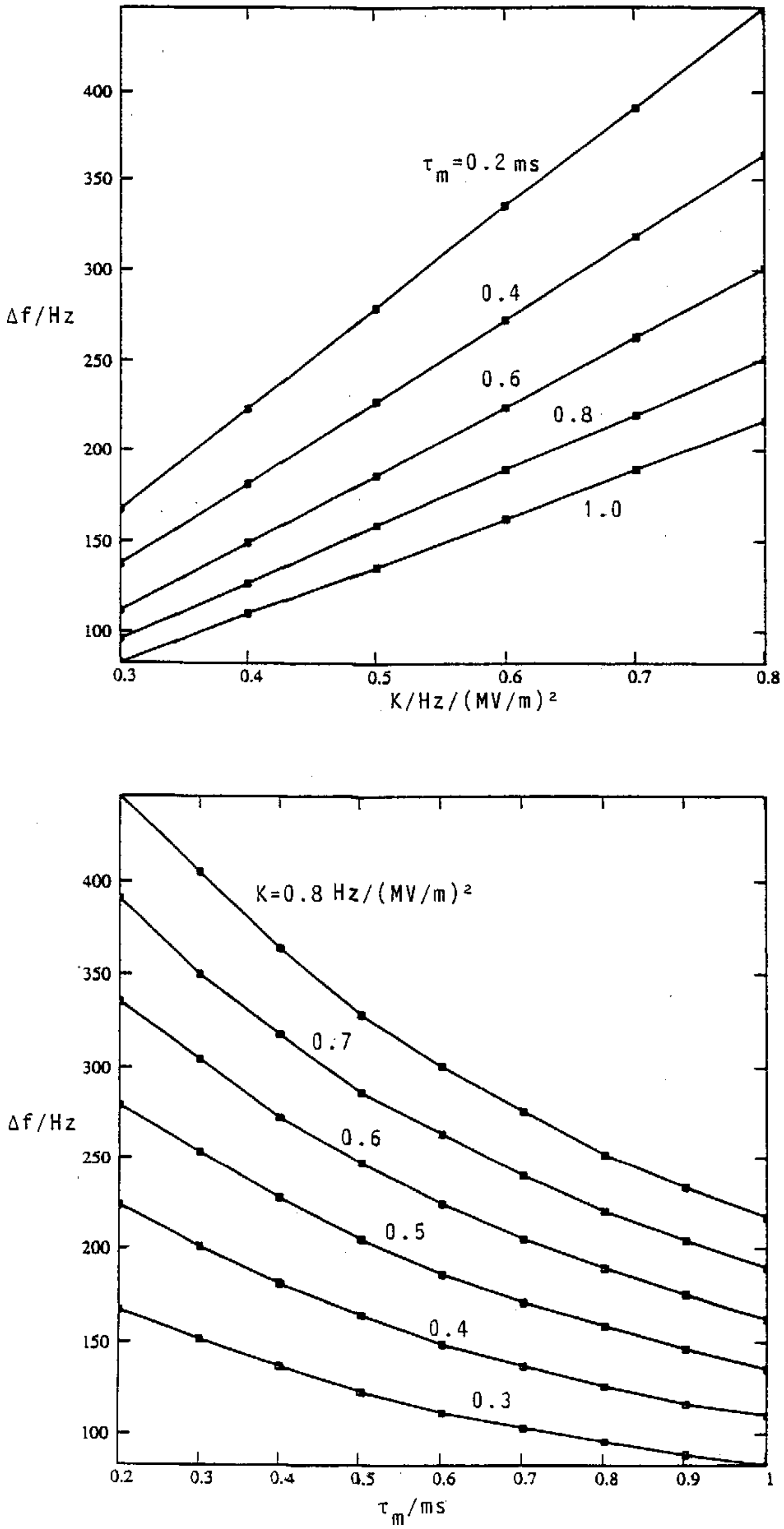

Fig. 5 Optimised frequency jumps δf for the feedback system.

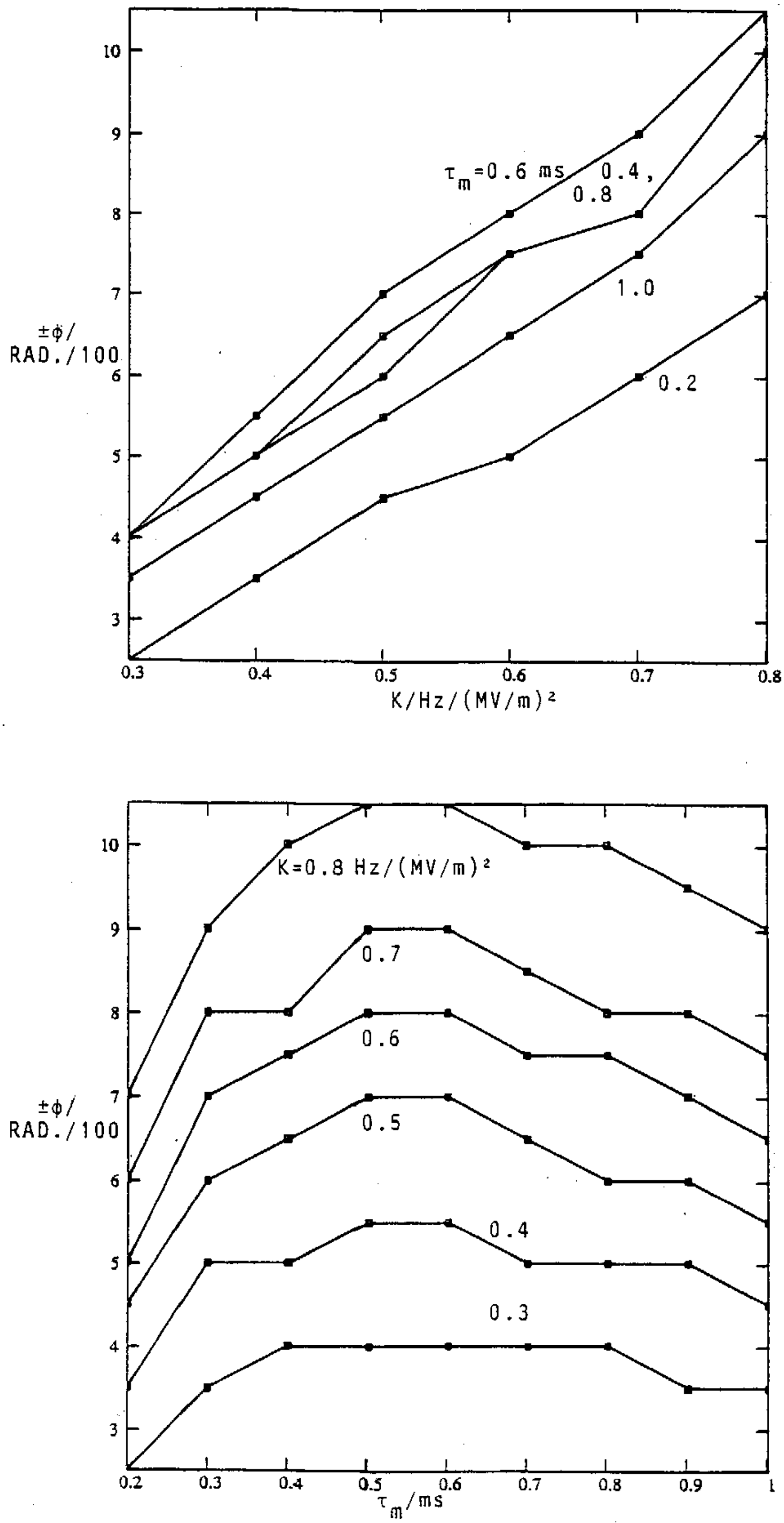

Fig. 6 Resulting phase deviations $\delta\phi$ with an optimised feedback system as given in Fig.5.

References

1. A.Mosnier, Dynamic Measurement of the Lorentz Forces on a MACSE Cavity, report DAPNIA/SEA 92-05, CEA Saclay, 1992
2. D.Proch, Private Communications, 1992