HIGH GRADIENTS BY SIMULTANEOUS MULTIFREQUENCY OPERATION OF RF STRUCTURE

F. Caspers, H. Haseroth, J. Knott
CERN, CH-1211 Geneva 23, Switzerland

Abstract

In the context of new accelerating structures considered for single pass colliders (e.g. wake field transformer or switched power Linac) it is proposed to excite the cavity in a phase-locked multi-frequency mode of operation. The purpose is to obtain high accelerating gradients with smaller average losses than in the conventional single-frequency operation scheme. In general, the resonant frequencies are not harmonically related to each other. Assuming finite Q-values one can always find a frequency f_0 such that with a 3 dB bandwidth all resonances considered are at integer multiples of f_0. For the gap voltage one obtains in this case periodic pulses with a spcacing $\tau = 1/f_0$. Increasing the peak gap voltage by adding (exciting) further higher modes with equal CW power on each mode (equal shunt impedances assumed) results in power losses proportional to V_{peak} instead of $P_{loss} \sim V^2_{peak}$ for single-frequency operation.

Introduction

The switched power Linac[1]) is a very promising accelerator structure. Work is going on at several labs on different aspects of this proposal. Scaled-up model measurements have been performed at CERN[2]) to study different problems:
- enhancement as function of bandwidth
- radial field components in the accelerating gap
- influence of asymmetric feeding in space on time.

Measurements using synthesized pulse techniques with network analysers have been compared with those of real pulses and with real-time oscilloscopes. It was inevitable in this context that these measurements triggered some side-line ideas which, being judged as of sufficient interest, were also followed up.

Resonant Excitation

Pulses fed into the model cavity travel several times through the structure without too much attenuation or deformation. This observation suggested some form of resonant excitation with a pulse train. This pulse train could be Fourier-synthesized with the corresponding frequencies of CW transmitters.

The dispersive character of the cavity, however, will result in a successive deformation of the pulse. As we are not interested in the exact behaviour of the pulse but in a maximum field in the center, the use of the Eigen-frequencies may be an interesting alternative.

This will not yield a nice square pulse bouncing through the cavity, but, if at a certain moment all the maximum amplitudes of the individual Eigen-frequencies are in phase, the maximum field gradient will occur at the center of the cavity.

We are mainly interested in this very moment and it is not, a priori, important what happens before and after. In a way, we have then given up the picture of a pulse moving towards the center of the cavity and gaining in amplitude.

Multi-Mode Excitation

The orthogonal properties of the Eigen-frequencies guarantee the mutually undisturbed operation of the different RF generators (provided that they are isolated with frequency filters, corresponding to the appropriate mode) and permit a linear superposition in space and time of the corresponding individual field patterns in the cavity. In general, there is no rational ratio of the Eigen-frequencies. To obtain, nevertheless, a periodic excitation one can choose as operational frequencies integer multiples of a certain base frequency f_0 which are near enough (within the 3 dB bandwidth) to the corresponding Eigen-frequency. With a defined phase relation between the frequencies thus selected, electric field maxima will be obtained at equally spaced time intervals f_0^{-1} at the center.

Power Considerations

For most cavities the R/Q decreases for higher order modes but stays reasonably constant for a flat pillbox.

This means that we can easily add higher modes in order to achieve high gradients. Assuming constant Q and R/Q the maximum accelerating field will increase proportionally to the input power and not only with the square-root as for single frequency operation. However, the maximum field is limited to the very center and its duration is much shorter in the multi-frequency mode.

Assuming conventional cavities, the total power involved is still considerable. The advantage is nevertheless the high gradient which can be obtained this way, as compared to the single frequency operation at the same total power level. In particular higher gradients can be held when the pulses are shorter[1]). It should be noted that this method seems to offer some control of the pulse shape.

The total energy involved is comparable within about a factor 2 to the switched power Linac if we assume that the RF for the cavity is switched on according to its filling time. During the filling about an equal amount of energy would be lost in the cavity. After filling the stored energy should be equivalent to the switched power Linac, provided that an "equivalent" number of frequencies is being used.

Fig. 2 shows the electric field as a function of time at the center and Fig. 3 the same at r = 50 cm.

Computer Model Calculations

Using the dimensions of our model, the first 20 TM_{0n0} Eigen-frequencies have been determined and superimposed with the help of a computer program. The Eigen-frequencies were assumed to have equal amplitude and their maximum at t = 0. Fig. 1 shows the electric field amplitude as a function of the radius at different times. The field distribution is closely comparable to the one of the switched power Linac.

Preliminary measurements have been carried out on another cavity built for this purpose (Fig. 4). Eleven probes are located along one radius. In the center there is one probe coupling mainly to the longitudinal E-field. Eight positions on the circumference are used for coupling loops. Fig. 5 shows the initial experimental set-up, used to test the feasibility of simultaneous excitation of the cavity on several Eigen-frequencies. Due to lack of hardware we were limited to two frequencies. A network analyzer was used to demonstrate the radial enhancement in the frequency range of the first five Eigen-frequencies. Fig. 6 shows the resulting field levels as function of time at three radial positions.

It is planned to increase the number of frequencies in the set-up shown in Fig. 5. In order to have periodic operation of the structure phase-locking of the different frequencies is necessary, as pointed out above. We intend to synchronize them with the spectral lines of a comb generator. For ease of operation it is not foreseen to have tuning for the individual frequencies in the cavity, as for conventional accelerators. Instead, electronic phase shifters will be installed in the individual feedback loops.

Looking at the problem in the frequency domain we can say that nevertheless, the operating frequency of each oscillator circuit belonging to a particular mode of the cavity may be slightly varied by means of its (electronic) phaseshifter in the feedback path. If it is ensured that within the possible tuning range of about a 3 dB bandwidth a spectral line of the comb generator can be found, phaselocking will be achieved using a PLL circuit and a harmonic mixer.

In the time domain approach the phase shifter will be used to correct for phase errors sampled at intervals given by the comb generator. Hence, the operating frequency can and must be allowed to jump from one comb line to the other, but must stay within the 3 dB bandwidth of the corresponding Eigenfrequency.

Superconducting Cavities

It is clear that high gradients will require high RF power. To keep the losses low and to recover the residual energy of the cavity that has not been taken out by the beam the use of superconductivity would be very interesting. For high fields superconductivity is limited by the RF losses and by the existance of certain maximum magnetic field levels. In the multi-mode excitation, however, the high gradients are very limited in space and time. Hence the RF losses are reduced as in the normal conducting case. There may also be the possibility to exceed certain superconducting field limits if the time of the applied pulse is sufficiently short (e.g. about 200 ps for an assumed upper frequency of 3 GHz). It is extremely interesting to explore these possibilities at least with type II superconductors[4]). The use of a superconducting cavity with normal copper surfaces at the center where the high gradients occur, may also be an alternative[5]). Even if superconductivity could not be used with high gradients, the multimode scheme could nevertheless be an interesting means to study the behaviour of superconductors at high fields with short pulses.

Acknowledgements

It is a pleasure for us to thank E. Tanke for extensive calculations and J.L. Vallet for help with the measurement set-up.

References

[1] W. Willis "The Switched Power Linac", Proceedings of the CAS-ECFA-INFN Workshop, Frascati, Sept. 1984.

[2] S. Aronson, F. Caspers, H. Haseroth, J. Knott, "Model Measurements for the Switched Power Linac", this conference.

[3] I.E. Campisi, Z.D. Farkas, "Superconductors for Pulsed RF Accelerators", IEEE Transaction Nucl. Science, vol. NS 32, No. 5, Oct. 1985

[4] H. Piel, Fachbereich Physik, Gesamthochschule Wuppertal, private communication.

[5] H. Lengeler, CERN, private communication.

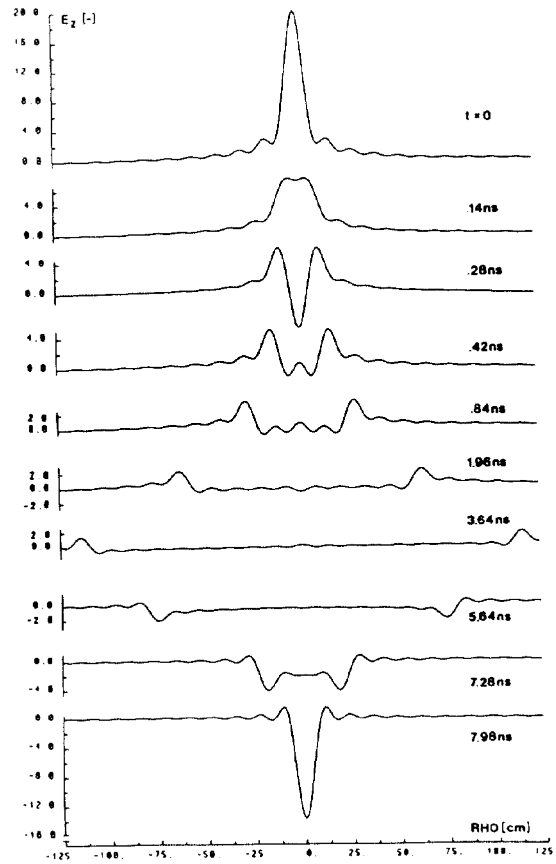

Fig. 1 Electric field in the cavity at different times

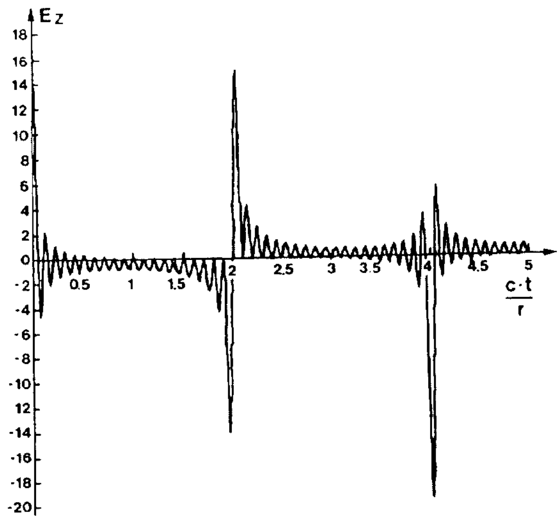

Fig. 2 Electric field at center as function of time

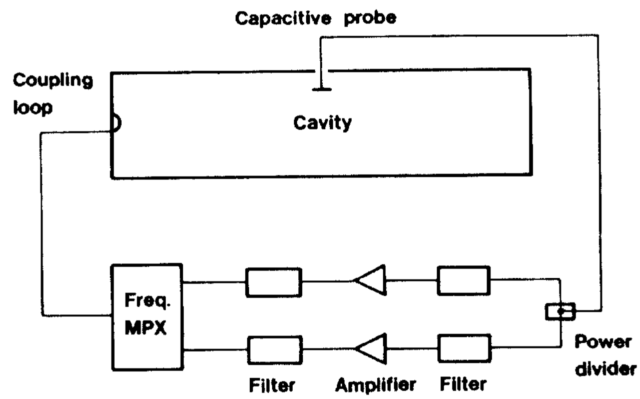

Fig. 5 Initial test set-up

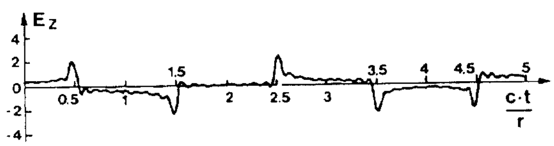

Fig. 3 Electric field at r = 50 cm as function of time

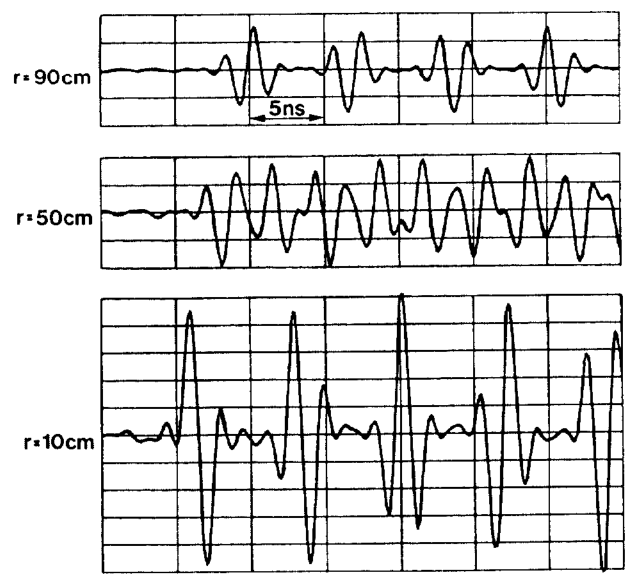

Fig. 6 Radial enhancement for different radii

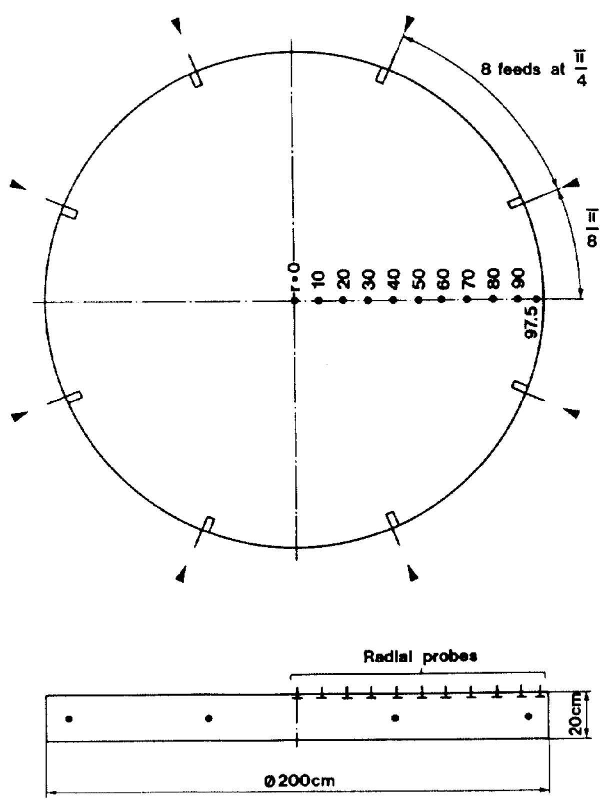

Fig. 4 Test cavity for multimode excitation