

MULTI-MODE, TWO-BEAM ACCELERATOR WITH FEEDBACK

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Abstract

A high-gradient accelerator consisted of the test and the drive beam structures is reported. The accelerating structure can be based on dielectric or corrugated cavities separated each other by irises. Each cavity is operated by several axisymmetric, TM-like eigen-modes with longitudinal indices to be related to frequencies. These modes are excited at Fourier harmonics of the drive current which consists of bunches spaced with the same period as test bunches. The superposition of the excited modes introduces a short RF pulse propagated in-phase with a moving test bunch and after reflection by iris (a feedback) this pulse accelerates next bunch. Such longitudinally-sweeping RF field promises reduction of the exposure time by high E- and H-fields and due to compact space shape can also help to obtain high shunt impedance.

INTRODUCTION

RF breakdown is a strong limiting factor towards increase of acceleration gradient, and one needs first of all to prevent the initiation of breakdown. Let us consider a particle beam to be accelerated as a periodic sequence of tight bunches that move along a straight path with a velocity close to the speed of the light. High accelerating fields at the axis of a structure need to exist only during the narrow time intervals when a bunch traverses this structure. During time intervals between bunches fields near the axis should preferably be as small as possible. This principle automatically requires that structure should contain equidistant spectrum of modes with harmonically related frequencies [1, 2]. Such multi-mode accelerating structures operating in several resonant, equidistantly-spaced, axisymmetric, TM-like eigenmodes allows reduction of the exposure time to surface fields. Experimental data obtained for many accelerating structures show that the breakdown probability is dependent on electric field threshold, but also dependent on exposure time. Thus, reducing exposure time one increases breakdown threshold and can obtain higher accelerating gradient.

Additionally, there are two complementary effects (that is reduction of high-field areas and reduction of those fields which are responsible for electron emission) which also help to increase accelerating gradient [2, 3]. The structures, which were studied in the cited papers, operate at TM modes with flat longitudinal E_z component (longitudinal mode indices are zero). Such modes can work effectively in rather short cavities, otherwise its have rather low shunt impedance, because transit time factor (TTF) for such modes rapidly drop with increasing of the transit time.

ACCELERATING CAVITY WITH HIGH-ORDER LONGITUDINAL MODES

The TTF for TM-modes without longitudinal variations ($n = 0$) and with $n = 1, 2$ variations are plotted in Fig. 1. One can see that maxima at $n > 0$ are comparable with maximum of the mode with $n = 0$. Unfortunately, eigenmode spectrum of a simple cylindrical cavity is essentially non-equidistant. In order to demonstrate that necessary quality of equidistance is achievable, we synthesized a cavity shown in Fig. 2 and simulated an excitation of this cavity by a beam consisted of bunches spaced with the frequency of the lowest eigenmode. As one can see in Figs. 3–6, the RF pulse makes periodic steering exactly following for a bunch motion.

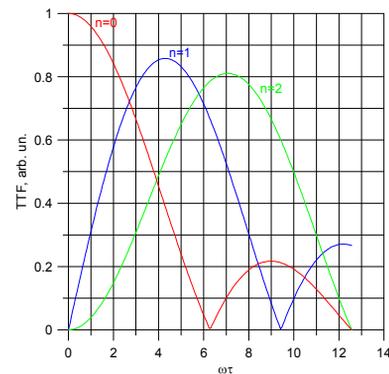


Figure 1: TTF as function of normalized transit time.

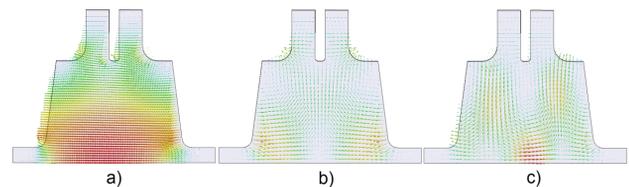


Figure 2: E-field structures of eigen modes with longitudinal indices: a) 0 (at 9.38 GHz, $Q = 4500$), b) 1 (at 18.76 GHz, $Q = 7150$), and c) 2 (at 28.14 GHz, $Q = 11800$).

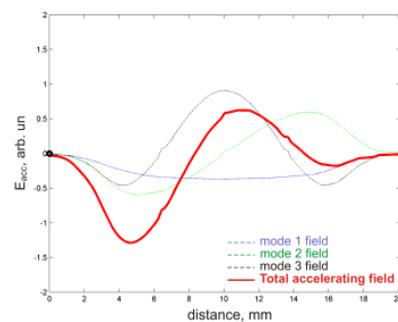


Figure 3: E_z -fields of modes and total field at cavity axis at $t = 0$.

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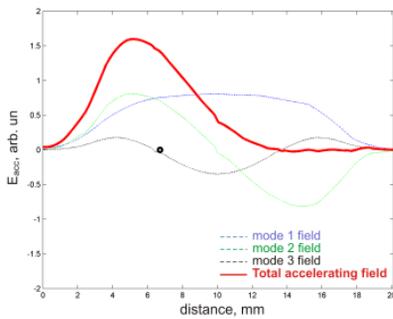


Figure 4: E_{acc} -fields of modes and total field at cavity axis at $t = T/2$.

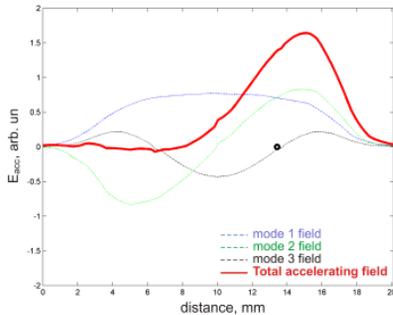


Figure 5: E_{acc} -fields of modes and total field at cavity axis at $t = 3/2T$.

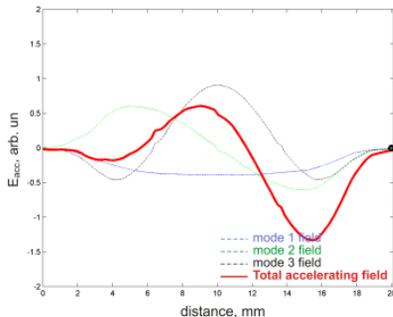


Figure 6: E_{acc} -fields of modes and total field at cavity axis at $t = T$.

MULTI-MODE, TWO-BEAM ACCELERATOR

In accordance with the previous example we have shown that there are axially symmetrical radial cavities which can be excited by several TM_{0n0} ($n \geq 2$) modes simultaneously. Unfortunately, cavity shape is rather complicated and does not allow involving very big number of modes. In order to solve the mentioned problem, it is attractive to use a simple cavity (Fig. 7) where short RF pulse also oscillates between two irises so that in path from left to right it moves in synchronism with a particle, then the pulse returns and begins to interact with next particle. The waveguide in-between the irises in Fig. 7 is actually a slow wave media in form of a section filled by some dielectric (or a metallic corrugated section). The mentioned RF pulse consists of several (three or more) TM_{01n} modes ($n \gg 1$). These modes with longitudinal

indices $n-1, n, n+1, \dots$ are excited by beam current harmonics $\omega_{s-1}, \omega_s, \omega_{s+1}, \dots$ correspondingly, because each mode (nearest to n -th mode) satisfies to a condition of the synchronism simultaneously. All these modes are able to have high enough transit time factors. In Fig. 8 the drive and the test beams have the separate channels coupled by means of transfer waveguide structure. Principles of the mode synchronization with bunches in both cases are illustrated in Fig. 9, where $h_n = \pi n/L$, where L – is a length of the cavity. In Figs. 10–12 field and bunch dynamics are shown at three sequent times. The parameters of the cavity in this example are: radius $R = 2.5$ mm, length of the cavity $L = 47.65$ mm, dielectric permittivity $\epsilon = 2.1$, $\text{tg}\delta = 10^{-3}$, radius of beam channel $R_b = 1.75$ mm, number of central mode $n = 8$, the corresponding beam harmonics $s = 17$. The parameter $s = 1$ would be correspondent in this example to frequency 1.82 GHz.

Note that high transformer ratios (TR) are achievable in the suggested structures by means of the use of a so-called detuning idea [1]. In order to provide high TR values the bunch repetition rate should be slightly detuned off the frequency of the central mode. In this case all other modes would be also automatically detuned so that drive bunches everytime see relatively low field, but the witness bunches are delayed so that they each time fly in the much higher field.

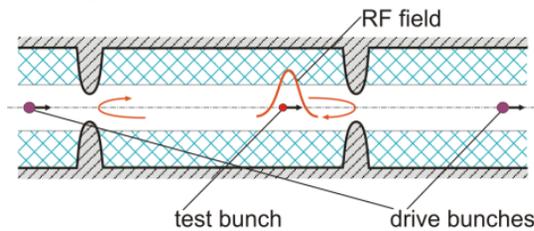


Figure 7: Conceptual sketch of two-beam accelerator based on metal-dielectric structure.

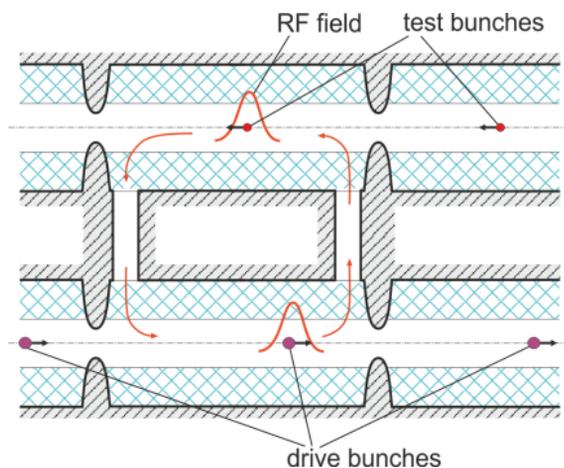


Figure 8: Conceptual sketch of two-beam accelerator module with transfer waveguides (PETs).

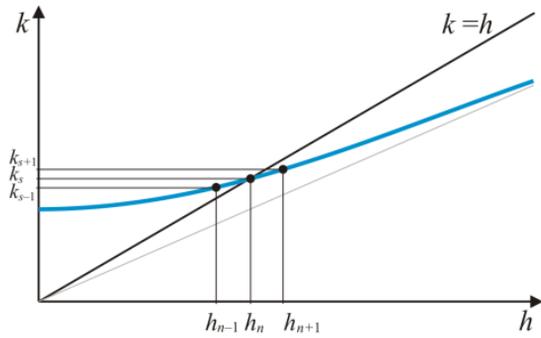


Figure 9: Equidistant eigenmodes of slow wave accelerating cavity.

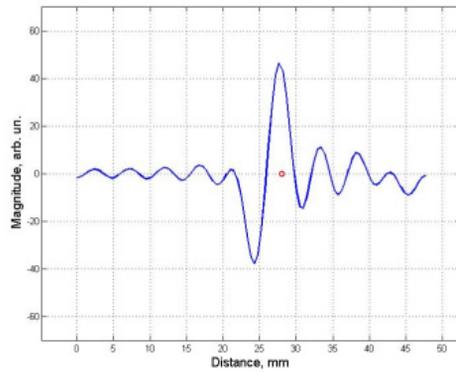


Figure 12: Accelerating field in cavity at $t = 9.4 \times 10^{-11}$ s.

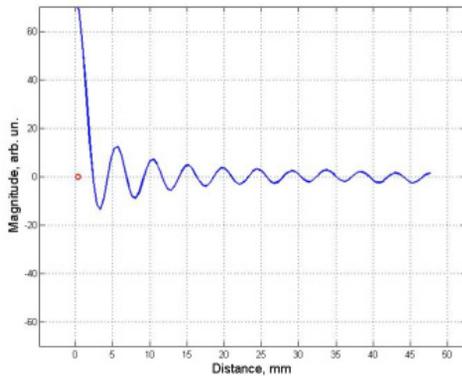


Figure 10: Accelerating field in cavity at time $t = 0$.

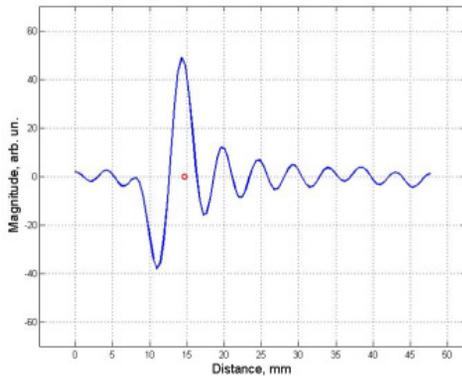


Figure 11: Accelerating field in cavity at $t = 4.7 \times 10^{-11}$ s.

CONCLUSION

The use of structures on high-order TM_{01n} modes ($n \gg 1$) with feedback allows making a two-beam accelerator where field in a form of periodically oscillating pulse is localized near moving bunches. In frames of such scheme one can obtain high breakdown thresholds, high gradient under repetition rate of gigahertz level, higher TTF and shunt impedance in comparison with structures on TM_{010} modes.

REFERENCES

- [1] S.V. Kuzikov, S.Yu. Kazakov, Y. Jiang, J.L. Hirshfield, "High-gradient two-beam accelerator structure", Phys. Rev. ST-AB 13(7), (2010) 071303.
- [2] S.V. Kuzikov et al., Advanced High Gradient RF Structure Development, Proc. of 14th Advanced Accelerator Concepts Workshop 1299(1), (2010) 307.
- [3] S.V. Kuzikov, S.Yu. Kazakov, Y. Jiang, J.L. Hirshfield, "Asymmetric bimodal accelerator cavity for raising RF breakdown thresholds", Phys. Rev. Lett. 104 (2010) 214801.