NONDESTRUCTIVE DIAGNOSTICS OF PROTON BEAM HALO AND TRANSVERSE BUNCH POSITION BY CERENKOV SLOW WAVE STRUCTURES

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Abstract

An appearance of the halo around bunch of particles is very undesirable destructive phenomenon in high-intensity proton accelerators. We suggest using built-in short BWO section in form of the corrugated metallic waveguide, in order to control particle distribution in real time. In BWO low velocity proton bunch has synchronism with slow spatial harmonic of TM_{01} wave. Fields of slow harmonic sharply grow in direction from axis to walls and rf power, generated by flying bunch of the given charge, critically depends on transverse bunch size. Results of the simulation, carried out for 20 pC proton bunch of 10 ps duration, show that in 5 GHz BWO of 30 cm length the output rf pulse of several nanosecond duration is varied from mW- level (for 1 mm transverse bunch size) to several tens of mW (for bunch of 20 mm radius). This power level is high enough to control halo appearance in each single proton bunch. The producible rf power in a BWO is also dependent on bunch deflection from axis. This effect we plan to use, in order to provide transverse bunch position monitoring by means of two additional rectangular slow wave section which have corrugations on mutually perpendicular walls.

PROTON BEAM HALO MONITOR

High-intensity proton machines like Project-X in Fermilab [1] require accurate non-destructive on-line monitoring for bunch halo. Existing methods either do not provide non-destructive basis [2-3], or work well for electron bunches only [4]. New methods for diagnostics of heavy particles are necessary.

Short proton bunch, flying in an axial corrugated waveguide, can naturally cause BWO oscillations due to Cerenkov synchronism ($v_p \approx v_{ph}$) with slow backward eigen wave of the structure [5]. Because we consider protons with moderate energies ($v_p \leq 0.5c$), the mentioned Cerenkov synchronism is possible with -1st harmonic of the TM_{01} wave which has sharply growing fields in direction from axis to wall. That is why, power level of BWO excitation essentially depends on transverse bunch size. The bigger bunch size and the longer BWO section, the higher is rf signal (assuming full bunch charge to be constant). Therefore, one can measure in real time the magnitude of BWO oscillations and to recover bunch size.

Let us consider the BWO consisted of 15 periods (each period is 20 mm) in regular part and 6 periods in tapered part of the corrugation (full length is ~30 cm), average radius is 25 mm, corrugation depth is 10 mm. Bunch parameters of the bunch used in simulations are shown in Table 1.

Table 1: Bunch parameters.

Parameters	Value
Velocity, v_p	0.5c
Charge, Q	24 pC
Bunch length, l_b	12 ps
Radial space charge distribution	uniform

Dispersion of the TM_{01} mode in the chosen corrugated waveguide (Fig. 1) has intersection with bunch dispersion line near 5 GHz. At this point slow TM_{01} wave has distinctive surface character (Fig. 2).

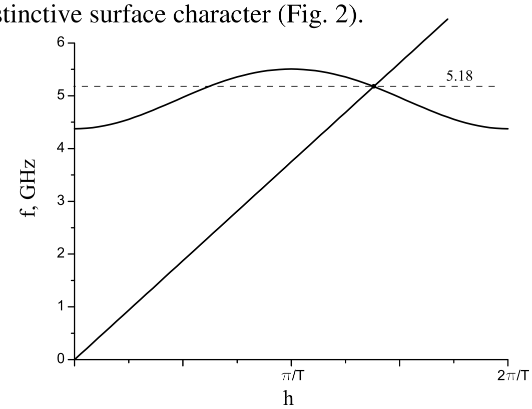

Figure 1: Dispersion curves of the operating TM_{01} eigen mode in BWO and proton bunch.

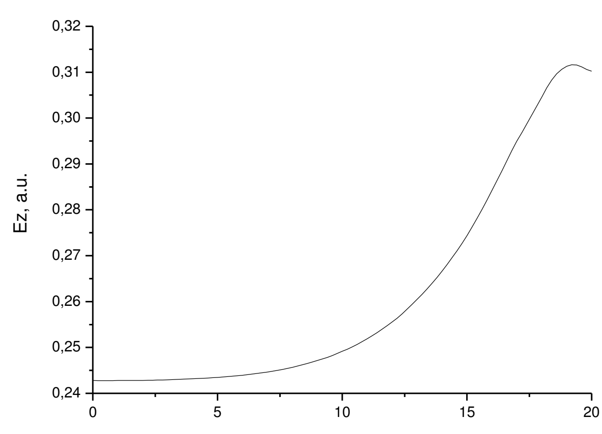

Figure 2: Longitudinal component of electric field for TM^{01} eigen mode in BWO vs. radial coordinate.

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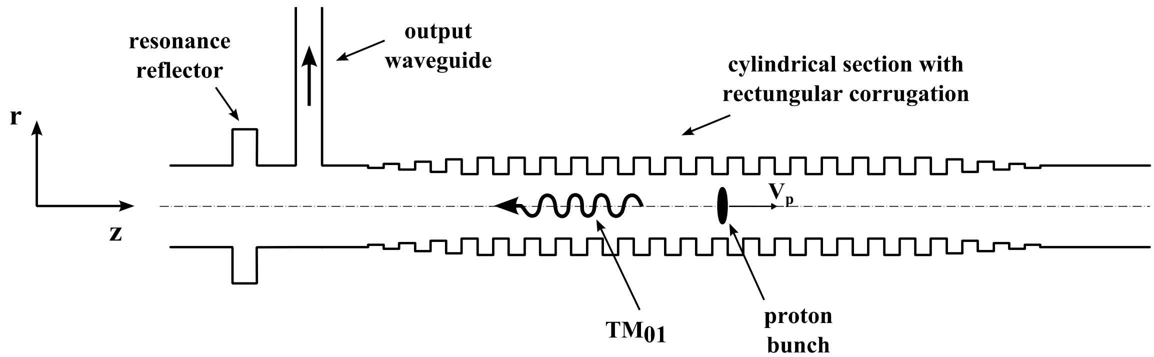

Figure 3: Scheme of bunch halo monitor.

For measurements of BWO output the scheme, shown in Fig. 3, can be used. This scheme includes axial TM_{01} reflector and the TM_{01} (circular cross-section waveguide to standard TE_{10} rectangular waveguide transducer with built-in detector).

Results of simulations carried out by means of KARAT particle-in-cell code [6] for the suggested scheme of the measurements are presented in Figs. 4-6. Typical BWO signal (Fig. 4) has about 20 ns duration with single 5.17 GHz carrying frequency according to Fourier analysis (Fig. 5).

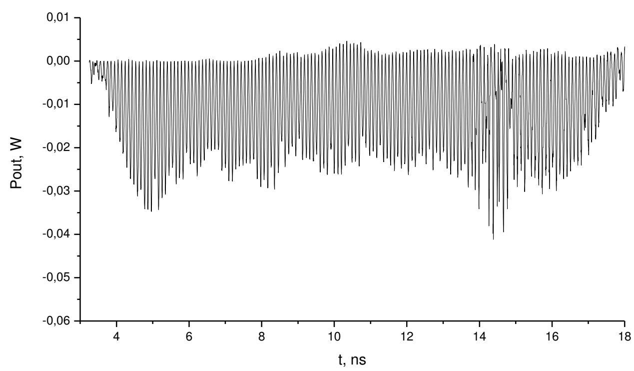

Figure 4: Output monitor signal (bunch radius *R*=15 mm).

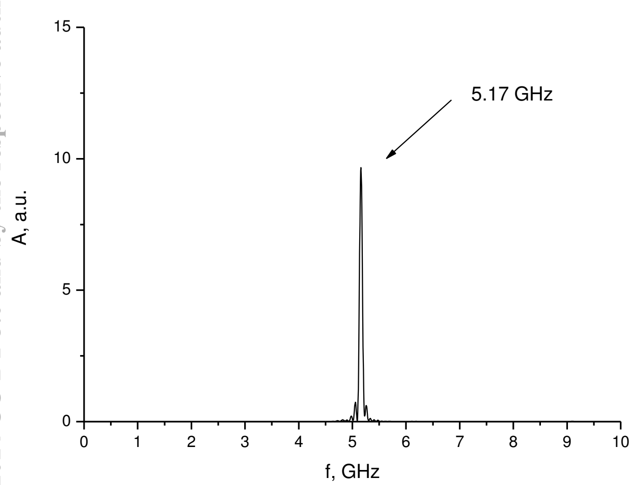

Figure 5: Fourier spectrum of output monitor signal (*R*=15 mm).

The key plot for the suggested idea is actually Figure 6, where one can see how the output received signal depends on transverse bunch size. In accordance with Fig. 6 the output signal reaches tens of milliwatts. The accuracy of bunch size measurements near the axis is not too high. This accuracy is the result of low frequency of the used BWO. Nevertheless, the achievable level seems high enough, in order to use halo monitor in accelerator protection system.

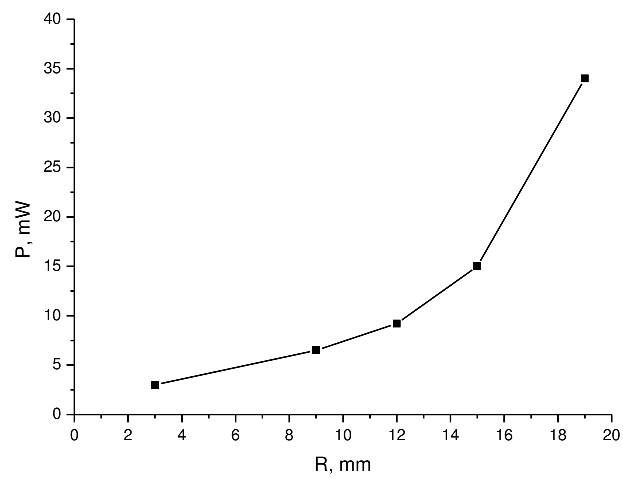

Figure 6: Output signal power vs. bunch radius.

TRANSVERSE BUNCH POSITION MONITOR BASED ON TWT-BWO SECTION

The power, produced in slow wave Cerenkov structure, is naturally dependent on bunch off-axis shift. This phenomenon might also be involved in measurements of the transverse bunch position. For this purpose we suggest to employ the corrugated rectangular waveguide cross-section. The possible scheme of the monitor, consisted of the central rectangular waveguide with double corrugation and two receiving waveguides with detectors,

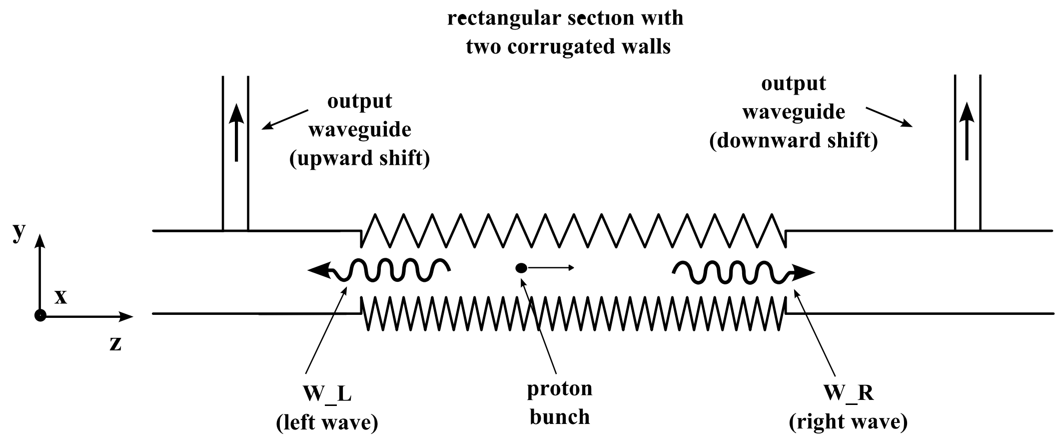

Figure 7: Scheme of bunch transverse position monitor based on TWT-BWO section.

is shown in Fig. 7. In this scheme central corrugated waveguide has two corrugations with different periods. The first corrugation is responsible for BWO mechanism of rf production, the second corrugation introduces the so-called TWT. The output signal of the BWO propagates on the left, the TWT forms signal propagating from the corrugated section on the right side. It is remarkable that if bunch gets shift and becomes closer to one of the corrugated walls, the corresponded signal (left or right) grows up. The signal, formed by the opposite wall, goes down. This signals behavior allows easily recovering the sign of the shift and value of this shift as well. Two sections of the described type with independent corrugations in two mutually perpendicular directions could be used to recognize bunch shift in X- as well as in Y-directions simultaneously.

In simulations we tested waveguide 72×34 mm^2 with corrugation parameters: depth of the corrugation – 22 mm, period – 10 mm (TWT); depth of the corrugation – 22 mm, period – 20 mm (BWO). Results of the simulations are shown in Fig. 8, where one can see the described behavior of signals arisen due to off-axis bunch shift.

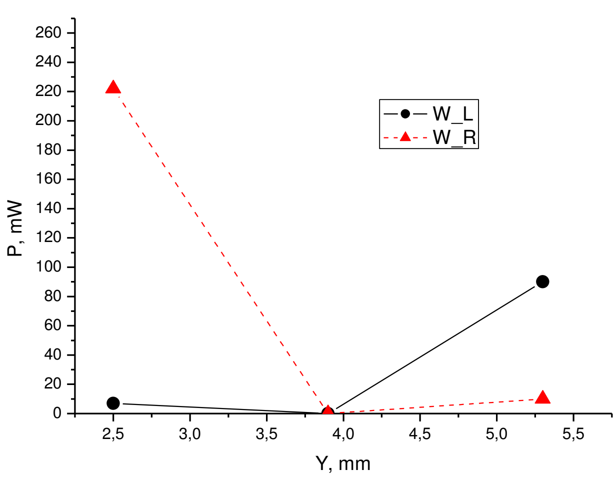

Figure 8: Output signals vs. bunch shift on y-axis. The red points correspond to TWT signal propagating on right side. The black points describe BWO signal on the left side.

CONCLUSION

The suggested method for on-line nondestructive diagnostics of proton beam halo, used the strong dependence of BWO excitation level on transverse bunch size, might provide simple monitoring of radial charge distribution in accordance with principle of the "alarm lamp" in order to switch off accelerator to protect it. The BWO section might be also used for transverse position monitoring. The use of two corrugations in one section allows providing better than ±0.5 mm accuracy for bunch off-axis shift measurements.

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