FAST SWEEPING DEVICE FOR LASER BUNCH

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Abstract

An electro-optical laser sweeping device directs the head and the tail of a laser bunch into different frontal directions, so at some distance, the laser bunch becomes tilted with respect to forward direction. For sweeping of a laser bunch having 300 ps duration up to 10 mrad, the voltage drop along the laser bunch must be ~10kV. The repetition rate desirable for this type of device used in laser acceleration or generation secondary back-scattered electrons is up to 1 MHz. Details of this scheme are described here.

INTRODUCTION

The idea of a method of laser power density reduction on the surface is to excitation of accelerating structures by focused laser radiation *locally* through the side openings in these structures [1]. The radiation is focused onto that part of structure, where the accelerated bunch is currently located, so this focused spot follows the bunch while it is moving inside the structure. We proposed in [1] a method on how to arrange this local excitation by device, which makes sweeping focused laser radiation along the accelerating structure and called this procedure Travelling Laser Focus (TLF). For angular sweep the reduction associated with the number of resolved spots N_R ; so reduction is $\cong 1/N_R$. The number N_R is just a ratio of sweep angle to the diffraction angle associated with the sweeping device itself. Basically this number shows how many separated (resolved) focused spots this sweeping device can allocate along the accelerating structure. For laser radiation with the wavelengths $10\mu m \geq \lambda_{ac} \geq 1\mu m$ the number of resolved spots can be within 20-200. This shows that the laser power density distributed over accelerating surface can be up to two hundred times lower than when excitation is going for all structure at the time. One can see also, that lowering of illumination time two hundred times drastically reduces the probability of damaging the surface.

So we believe that TLF is the only way to reach electron-positron* collisions with multi-TeV energy.

In our previous publications [2], [3] we considered some aspects for TLF in general, including a sweeping device. Here we considered a sweeping device in more detail, including analyses for it's practical realization.

We concluded that a sweeping device based on an electro-optical effect (dependence of refractive index on electrical field applied) is mostly adequate to the problem. This device can work up to repetition rate up to few MHz (or even GHz) thereby decreasing requirements to the bunch population. The last part is very important, taking into account that the luminosity required is a growing function of energy.

* Also pion-pion, muon-muon, ion-ion and p-p collisions.

TRAVELING LASER FOCUS METHOD

According to this method, the laser power applied only to the places of the structure, where the accelerated bunch is located at the moment. As the bunch is moving with the speed of light, the laser radiation structure must appear as it is shown in Fig.1 below. Evidently that the slope angle for relativistic electrons or positrons becomes $\alpha \cong \pi/4$.

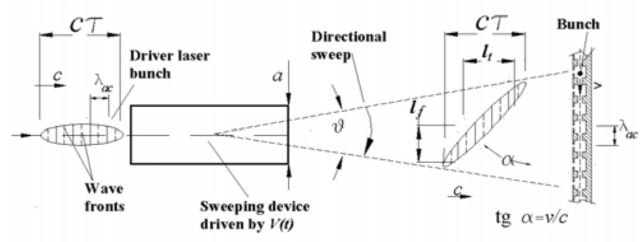

Figure 1: Arrangement of traveling laser focus with sweeping device. This device is driven by the time dependent voltage *V*(*t*).

Due to this arrangement, all laser pulsed power acts for generation of an accelerating field at the instant particle's location only. Power reduction and shortening of illuminating time is equal numerically to the *number of resolved spots* (*pixels*) N_R , associated with the sweeping device.

The electric field in each point of the laser bunch is perpendicular to the line, connecting this point with the center of the sweeping device. The height of the laser bunch in Fig. 2, which is $c\tau$ does not change, while transverse size is increasing with distance, calculated from the sweeping device.

ENGINEERING

Waveguide sweeping device

Calculations shows [3], that the slope of High Voltage must be ~10 KV at the distance $\sim c\tau \cong$ 3cm. Naturally UHF electromagnetic waves satisfy the requirements. These types of waves having period ~2-3 $c\tau$ what comes to ~5-10 cm. In this case the waveguide is mostly the natural element to use. Strip-line is also possible here and it becomes more desirable as it allows to make the sweeping device more compact, closer to integrated cirquit. Let us estimate the power requirements and possible design of waveguide-based sweeping device. Example of such a device is represented in Fig.2.

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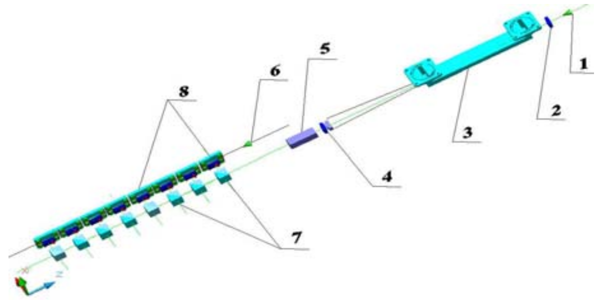

Figure 2: Example of engineering realization of scheme from Fig. 1. 1 –is the laser beam, 2–focusing lens, 3–waveguide sweeping device, 4–lens, 5–optical amplifier, 6–particle beam under acceleration, 7–laser power splitting devices, 8–accelerating structures with beam focusing elements.

The broad band traveling wave deflector uses crystals located in the middle of a waveguide. Group velocity of electrical wave-pulse must be adjusted to the velocity of the laser radiation in the prisms. Widening of the waveguide helps to reach this goal. Additional dielectric, 6 in Fig 10, serves for this purpose.

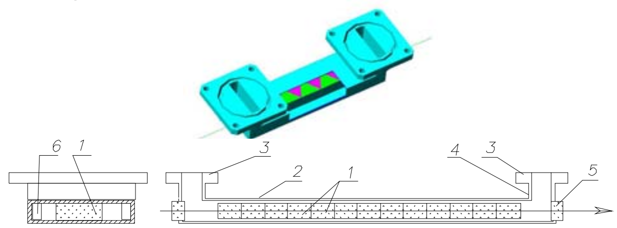

Figure 3: Enlarged multi-prism traveling wave sweeping device. 1–is electro-optical crystals, positioned in a waveguide 2, having bends 4 with flanges 3. 5–is an optical window. 6 –is a matching dielectric.

For waveguide deflector a klystron generator is mostly suitable power source. In a waveguide having cross-section $a\times b$ for the fundamental mode H_{10}, the electric field excited has a form $E = E_0 e^{i\beta z}$, where propagation constant defined as

$$\beta = \sqrt{\omega^2\varepsilon_{eff} - (2\pi/\lambda_{cr})^2}\,, \qquad (10)$$

and ε_{eff} stands for effective dielectric permittivity of the waveguide, ω is frequency and critical wavelength $\lambda_{cr} \cong 1/(2a\sqrt{\varepsilon_{eff}})$. For this type of wave the power transmitted and electrical field strength can be expressed as a relation

$$P \cong (E_0^2 ab/4Z_0)\sqrt{1-(\lambda/\lambda_{cr})^2}\,, \qquad (11)$$

where $Z_0 \cong 120\pi\sqrt{\varepsilon_{eff}}$. Substitute here $a \cong 5cm$, $b \cong 1cm$, $\lambda \cong 5cm$, $E_0 \cong 20$ *kV/cm* one can obtain the power, running through, as $P \cong 1.2\cdot 10^6$ or 1.2 MW, what is small enough.

For further power reduction required from the RF source, the resonant O-ring system can be used here. For this purposes "in" and "out" flanges connected, and directional coupler excites the traveling wave in this ring, see Fig. 4. If we suggest the quality factor for O-ring about modest value ~100, then power required for excitation goes to be ~1% of 1 MW. So RF generator can feed many devices in this way.

Time structure of the accelerated beam now can be seen as the train of bunches spaced with period ~wavelength of sweeping RF and these trains running with repetition rate ~few kHz, i.e. regime pretty typical for Radar operation. For the duty of RF ~1 μ s, the number of bunches in the train can be estimated as $n \cong 1\mu s/200\,ps = 5000$. As these bunches running with repetition rate ~1kHz, this brings the number of bunches per second to $n_b \cong 5\cdot 10^6$.

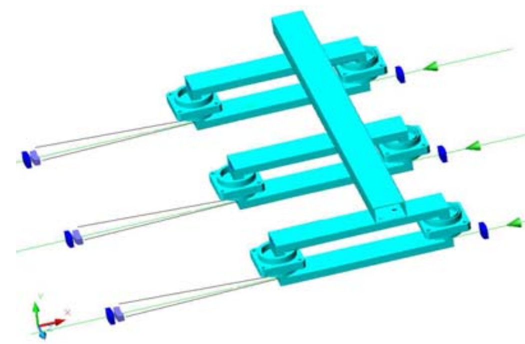

Figure 4: Feeding of sweeping devices in parallel. Upper waveguide running through full length of accelerator excites traveling wave in each O-ring resonators.

Once again, this scheme has a potential to be transformed into strip-line system. O-ring systems are well known in strip-line realization of transferring RF systems.

Sweeping device with pulsed voltage

Example of technical realization of this traveling wave deflector as a strip-line is represented in Fig. 5. Here, basically, strip-line electrodes 1 have triangle crystals 3 with opposite optical axes orientation in between. HV impulse applied to one end of strip-line trough connectors 4, propagates to the other end and further connected to the matching resistor 2. Slots in electrodes 1 made for proper current distribution across the line taking into account that wave front $\sim c\tau$ becomes comparable with the transverse size of the line.

In Fig.5 is shown the lens, 5 giving longitudinal focus to the swept laser beam and the power splitter 6 which splits a fraction of laser radiation propagating along the accelerator. This engineering realization is very suitable for testing this principle. Powering of this device can be arranged with the power generator using for its operation Inversely Recovered Diodes technique [4], [5]. In these types of techniques, energy stored in an inductor while the current running through it. While fast-interrupted, this current flow raises voltage on the load. For interruption of the current the Drift-Step Recovery Diodes (DSRDs) used successfully. In more detail, the transition filled by the carriers during direct charge flow first. Then the second pulse with opposite polarity runs through the transition during the time determined by evacuation of carriers (electron-hole plasma) accumulated in transition region.

Typical PS of this class operates with repetition rate up to 1MHz providing rise time down to 50 ps and voltage up to 30 kV. Size of this device typically $350\times150\times300$ mm^3.

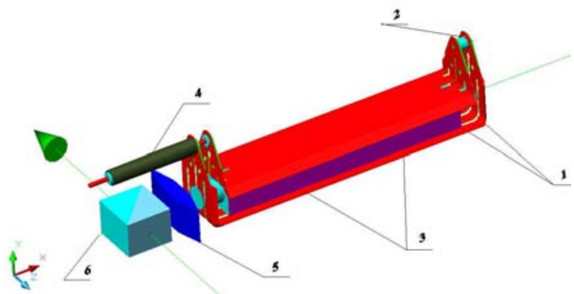

Figure 5: Example of technical realization of multi-prism sweeping device with traveling wave and pulsed feeding. Electro-optical crystals 3 are positioned between strip-lines 1, attached at the end to the matching resistors 2. Excitation is going with the help of cable 4. 5 and 6 are lens and splitting device respectively.

Optical triggering

A more advanced device is shown in Fig. 6. Here a Laser switched diode serves as the key element in triggering high voltage. First possibility might utilize the filling of diode transition by carriers with the help of laser pulse illuminating the diode. The second possibility lies in fast changing dielectric permeability of switching element by the laser radiation.

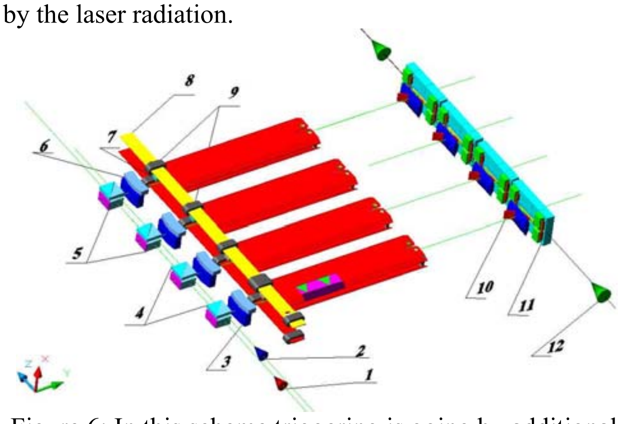

Figure 6: In this scheme triggering is going by additional laser bunch 2.

Here in Fig. 6, two laser pulses, marked by 1– for main accelerating pulse and by 2 – for the triggering one are propagating in the same direction. Lenses 3 focuses main laser pulse on accelerating structure plane (marked 11) and short focusing lenses 6 focus laser pulse onto triggering element 7. Splitters 4 and 5 serve for acquiring fraction of laser energy both from triggering and main (accelerating) laser pulses. Energy store in line 8 divided by inductors 9 into short pieces. Each of these pieces is associated with its own sweeping device. The strip-line, marked red (see also Fig.5) feed by this piece of line. While illuminated by triggering laser pulse the triggering element 7 transferees the energy stored in short piece of line to the sweeping strips. By 10, 11 and 12 the laser bunch configuration, accelerating structure module and accelerating bunch trajectory marked respectively. Synchronization required is now severe as the only phasing important for acceleration is the phase of main laser pulse, which is naturally the same over all accelerator. Despite of more advanced possibilities for integration of these elements into unite module, this scheme requires some development and mentioned here as a direction for future activities.

CONCLUSIONS

In spite of these unique properties, the device for the laser sweep requires, for its realization, well developed elements. A waveguide deflection device is looking absolutely guaranteed. Other possibility associated with usage of DSRD technique. Both RF generators for waveguide sweeping device and pulsed generators based on DSRD's for feeding the sweeping device widely available on the market.

A high repetition rate is achievable with waveguide sweeping device allowing ~10^6-10^7 bunches per second opens broad variety for optimization of luminosity with colliding beams.

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Extended version available at: http://www.lns.cornell.edu/public/CBN/2005/CBN05-6/cbn05-6.pdf.

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