LASER LINEAR COLLIDER WITH A TRAVELLING LASER FOCUS SUPPLY

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Abstract
Requirements considered for 2×1 *km* long linac, driven by a laser radiation distributed within open accelerating structure with special sweeping devices. These devices deflect the laser radiation to the open accelerating structure in accordance with instant position of accelerated particles The power reduction and shortening the time of illumination of every point of the structure is equal to the number of resolved spots, associated with the sweeping device. A 300 J, 100-ps laser flash could provide the energy 30 TeV for $\lambda\cong1\mu$ m and 3 TeV for $\lambda\cong10\mu$ m on 1 km with the method described. For repetition rate 160 Hz the luminosity associated with colliding beams could reach 10^{33} $cm^{-2}s^{-1}$ per bunch. Wall plug power required for operation of LLC is ~ 2 MW.

1 INTRODUCTION

The concept of a Linac, driven by a Traveling Laser Focus (TLF) method was originated in [1-3]. TLF deals with accelerating structure, what scaled down to a laser wavelength. The beam is going *inside* the structure similar to the existing practice. Tiny dimensions of the beam required could be achieved by proper preparation of the beam [4]. For excitation of accelerating cells, each of them has an opening from one side, what gives a possibility for parallel excitation. Laser radiation focused onto these openings. So the cells excited locally. Focusing in transverse direction is more radical, as the focusing lens could be positioned very close to the accelerating structure. Special sweeping (deflecting) device moves this focal spot in *longitudinal* direction in accordance with instant position of the particle. Due to this arrangement, all impulse laser power is acting for generation of accelerating field at the instant particle's location only. These arrangements reduce the power required from the source (laser) and reduce illuminating time. It was shown [2], that the power reduction and shortening of illuminating time of any point on the surface equal numerically to the number of resolved spots (pixels), associated with the sweeping device. One can see that the cells are working with zero phase shift per cell what yields the distance between the cells equal to the laser wavelength. The number of the particles required is about one million only, so the problems with wakes here are not more complicated, than in usual cm-wavelength structure.

2 TLF METHOD

Fig. 1 reminds the idea [1-3]. The laser bunch with longitudinal dimension much bigger, than transverse ones passing trough the sweeping device. This fast sweeping device is driven by electrical pulse synchronously with the particle's passage. It directs the beginning of the laser bunch to the entrance of accelerating structure and the end-to the exit of the structure. So closer to the structure laser bunch has an instant slope of 45 degrees to the direction of sweeping device. The local wave fronts still rectangular to the sweeping device, however. All deflecting elements are synchronized so that the electron bunch has continuous acceleration in all sections. One can see from Fig. 1, that the energy concentrated in the laser's bunch volume delivered here by the source by the time defined by the *length* of the laser bunch what is equal to the length of accelerating structure in Fig.1.

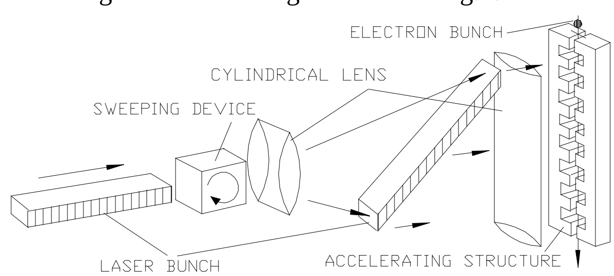

Figure 1: The principle. Lines across the laser bunch indicate the direction of wave fronts.

Optimal laser focus sweep is about 3cm for a practical reasons, so the accelerating device looks like a sequence of 3 cm- long accelerating structures. A short focusing *cylindrical* lens installed close to accelerating structure reduces *the transverse size* of the spot to a minimal one. Each part of the grating structure is illuminated by duration, which is defined by time $\tau\cong L/N_Rc\cong100\lambda$, where N_R–is the number of resolved spots, (see lower), L–is the length of the structure. For $\lambda=1\mu$ m, then $\tau\cong3\cdot10^{-13}$sec. This time is less than the time between electron-electron collisions, what is $\tau_{coll}\cong10^{-12}$ sec, still

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however longer, than the time, corresponding to reaction of electron plasma in a metal, what is $\tau_p \approx 3\cdot10^{-16}$ s. TLF method does not exclude the problems, associated with a breakdown limit of the structure, but *it allows drastically reduce the laser impulse power, required for excitation the structure* to this level. The latest measurements show a damage threshold increase while the illumination time is shortening. This breaks the $\tau^{1/2}$ low. This was explained by saturation of impact ionization rate per unit distance [5]. Measured threshold for 0.3 ps pulse was about 10 J/cm^2. For 1 ps the threshold measured was 6 J/cm^2. In our case we have 10mJ laser pulse distributed over area 3×10^{-3} cm^2 what gives 3 J/cm^2 and accelerating gradient 3 GeV/m. We believe that these figures could be improved after careful preparation the surface and optimizing the working temperature.

Main components of the scheme considered below.

3 DEFLECTING DEVICE

The ratio of deflection angle ϑ to diffraction angle $\vartheta_d \cong \lambda / a$, where a is an aperture of the deflecting device, defines the *number of resolved spots (pixels)*, $N_R = \vartheta / \vartheta_d$. The number of resolved spots N_R is *an invariant* under any optical transformations. As we mentioned above, N_R value gives the number for the lowering the laser power for gradient desired and, also, the number for the duty time reduction.

Electro-optical devices use controllable dependence of refractive index on electrical field strength and direction applied to some crystals (see Ref. To [2-3]). Short laser bunch could be swept with a travelling wave sweeping device [3], Fig. 2 below.

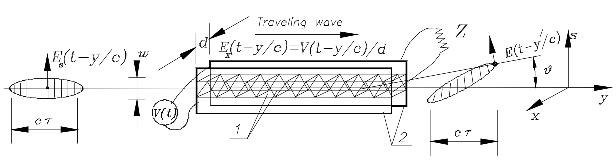

Figure 2: Deflecting device principle. Prisms 1 with *oppositely directed optical axes* installed in series between two parallel strip–line electrodes 2, *d*–is the distance between them. *Z*– is a matching impedance. Lines across the laser bunch schematically show the wave fronts. $E_x(t-y/c)$ –is a driving electrical field.

For the length of deflecting device *L*=50*cm*, one can expect $\Delta\vartheta \cong 10^{-2}$ rad. $N_R \cong 10$ for $\lambda \cong 10\mu$ m and $N_R \cong 100$ for $\lambda \cong 1\mu$ m. *Mechanical deflection system* and *Acousto-optical deflector* could be also used here [3]. Basically they give the same deflecting parameters.

4 ACCELERATING STRUCTURE

We took the foxhole-type structure described in [6] as a basis, Fig. 3. This structure has an advantage in pumping possibilities. The structure gives a good positioning for electrical field map [2,3].

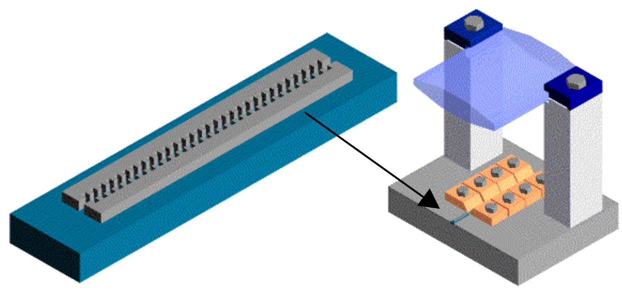

Figure 3: Accelerating structure and cylindrical lens. Structure on the left is scaled. Covers on accelerating structure are not shown.

Covers adjust the coupling between the groove and outer space. With these covers the height of a structure is about half of a laser wavelength and the cells have *inductive* coupling with outer space. The Q_{RF} factor of the order 5-10 could be expected here. Technological possibilities in lithography allow a structure fabrication for a laser with a wavelength $\lambda \cong 1\mu$ m. Each structure installed on a micro-table moved by a piezoelectric. Calculations for this type of structure done with GdfidL code [7]. There were investigated different shapes of cell and transit slit between the cells. Calculation shows that wakes are acceptable here. Despite dimensions are small, the bunch population about 10^6 only drastically rejects the wake problems.

5 DESCRIPTION OF LLC

Parameters of this LLC are represented in Table 1. The beams of electrons and positrons can be polarized what gives the effective gain in luminosity and reduces the background. Details one can find in [2,3].

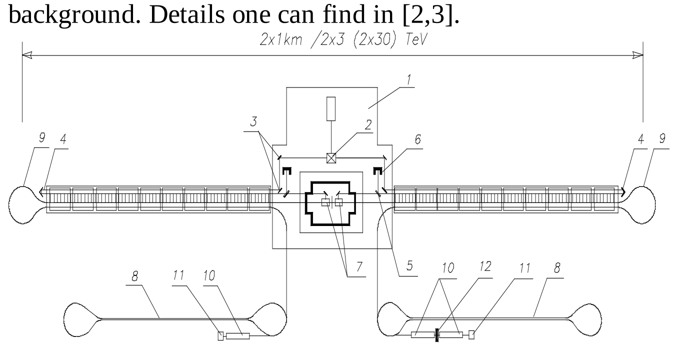

Figure 4: Linear Laser Collider (LLC) complex. 1–is a laser master oscillator platform, 2 –is an optical splitter, 3,4–are the mirrors, 5–is a semi-transparent mirror, 6—is a light absorber. 7–are the Final Focus Systems. 8–are the damping systems for preparing particle's beams with small emittances, 9—are the bends for particle's beam. 10–are

the accelerating X-band structures, 11–is electron gun (polarized), 12– is a positron converter.

TABLE 1. Parameters of Laser Linear Collider.

Parameter	$\lambda \cong 10\mu m$	$\lambda \cong 1\mu m$
Energy of $e^{\pm}$ beam	3×3 TeV	30×30 TeV
Length of section	3cm	3cm
Total length	2×1 km	2×1 km
Main linac gradient	3 GeV/m	30 GeV/m
Luminosity/bunch	$\leq1\cdot10^{33}$cm^{-2}s^{-1}	$\leq1\cdot10^{33}$cm^{-2}s^{-1}
Bunches/pulse	3 (≤100)*	10 (≤300)*
Laser flash J/Linac	300	300
Repetition rate	160 Hz	160 Hz
Beam power/Linac	2.3 kW	760W
Bunch population	$3\cdot10^7$	10^6
Bunch length	1μ m	0.1μ m
$\gamma\,\varepsilon_x\,/\,\gamma\,\varepsilon_y$ cm·rad	$10^{-8}/4\cdot10^{-10}$	$5\cdot10^{-9}/1\cdot10^{-10}$
Damping ring energy	0.7 GeV	0.7 GeV
Wall plug power**	2×0.5 MW	2×0.5 MW

*–Maximal possible number.

**–Laser efficiency$\approx$ 10%

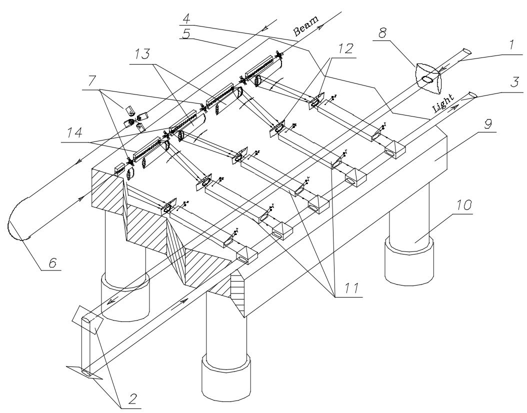

Figure 5: Table with a regular section of accelerator. 1,3– is a laser beam. 4,5–the beam of particles. 7 and 8–are the focusing elements for the particle's and laser beam correspondingly. 9 –is an optical platform. Legs 10 have active damping system to minimize vibrations. 11–are the sweeping devices 12–are the lenses for focusing the laser radiation in longitudinal direction. 13–are short focusing cylindrical lenses. 14–are accelerating structures

After the bend in systems 2,6 on the *back way to IP* necessary voltages applied to correcting elements, distributed along the linac.

A *kayak-paddle cooler* pos. 8, Fig.4 serves as injector [4]. This is basically a racetrack, which has a sequence of wigglers and RF cavities in a straight section. This injector yields the equilibrium emittances

$$(\gamma\varepsilon_x)\cong1\cdot10^{-8}\ cm\cdot rad\ ,(\gamma\varepsilon_y)\cong4\cdot10^{-10}\ cm\cdot rad\,.$$

Scrapping extra particles remains a valid procedure for the emittance lowering. Intra-Beam Scattering is reduced for diluted beam. *The focusing system* includes the quadrupole lenses of appropriate dimensions and a RF focusing. *Accelerating gradient* defined by the laser flash energy *Q*. A laser flash with $Q\cong10$ mJ, $\tau\cong0.1$ ns at $\lambda\cong1\mu$ m is able to feed the accelerating structure with the length about $c\tau\approx3$ cm with $\geq$ 30 GeV/m. Nd-Glass laser can be used here. CO_2 laser based system gives lower final energy. The power required $P_i\cong Q/\tau\approx10^8\,W$ is within routinely obtained. The laser amplifier could be sectioned with few structures or even each 3*cm* section could has it's own amplifier. For pumping the driving lasers the *diode laser arrays* could be used for the wavelengths indicated.

Bunch population defined by a loading of structure and by wakes. With 5% loading $N\cong1\cdot10^6$ for $\lambda\cong1\mu m$. For $\lambda\cong10\mu m$ this will be $N\cong3\cdot10^7$. *Final focus* made with *a multiplet* of FODO structures having the number of the RF lenses in it of the order of few hundreds.

Luminosity could reach $L\approx1\cdot10^{33}$ cm-^{2}s^{-1} for $\lambda\cong10\mu$ $\gamma=2\cdot10^6$ (*pc*=1TeV), $N\cong2\cdot10^7$, $f\cong$160Hz . For $\lambda\cong1\mu$ m result will be about the same.

6 CONCLUSION

Reduction of illuminating time and total laser power (or the flash energy) both defined by the number of resolved spots (pixels) associated with a deflecting device. Number of resolved spots $\approx20-100$ achievable. Lasers for the TLF method need to have more power in intermediate time duration $\tau\approx100ps$ rather than in a shorter time interval. Equivalent time of illumination of accelerating structure with this pulse is $0.1\div1ps$, however. For a 0.5×0.5 TeV Collider the length becomes 2×170 *m* for $\lambda\cong10\mu$ m and 2×17 m for $\lambda\cong1\mu$ m, respectively.

7 REFERENCES

[1] A.A. Mikhailichenko, *The method of acceleration of charged particles*, Author's certificate USSR N^o 1609423, Priority May 1989, Bulletin of Inventions (in Russian), N6, p.220, 1994.

[2] A.A. Mikhailichenko, *A concept of a Linac Driven by a Traveling Laser Focus*, 7th Advanced Accelerator oncepts Workshop, AIP 398 Proceedings, p.547.

[3]A.A. Mikhailichenko, *Laser Acceleration: a Practical Approach*, CLNS 97/1529, Cornell, 1997; also a Talk on LASERS'97, Fairmont Hotel, New Orleans LA, December 15-19, 1997.

[4] A.A. Mikhailichenko, *Injector for a Laser Linear Collider*, CLNS 98/1668.

[5] D. Du, X. Lu, G. Korn, J Squuier, G. Mourou, *Optical Breackdown with Femtosecond Laser Pulses*, CLEO94, May 8-13, 1994, Anaheim, California, Vol.8, p.407.

[6] R.C.Fernow, J.Claus, AIP Conference Proceedings, 279, 1992, p.212.
[7] W. Bruns, **GdfidL,** TU Berlin, 1997.