ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
им. Г.И. Будкера СО РАН

E.A. Kushnirenko, A.A. Mikhailichenko, A.A. Sery

SUPERCONDUCTING FINAL FOCUSING QUAD FOR LINEAR COLLIDER

BUDKERINP 92-35

НОВОСИБИРСК

E.A.KUSHNIRENKO, A.A.MIKHAILICHENKO, A.A.SERY

SUPERCONDUCTING FINAL FOCUSING QUAD FOR LINEAR COLLIDER

G.I.Budker Institute of Nuclear Physics
630090, Novosibirsk, Russia
Branch of INP
142284, Protvino

ABSTRACTS

The possibility to fabricate and to use an ironless quad with superconducting winding in the final focusing system for next generation of the Linear Collider is reviewed in this paper.

The quad's total diameter (including thermoinsulation layer) will be as small as about 4 cm. Small transverse size of this lens will allow to increase significantly the solid angle covered by the detector and to decrease the background arisen because of interaction of he high energy particles with the lens and accelerator details.

Usual problems connected with presence of the quad with iron yoke in strong magnetic field of a detector - iron saturation and field distortion - partly excluded and partly become negligible.

The estimations have confirmed that creation of the ironless superconducting lens with gradient up to 300 kGs/cm is possible. This value of gradient is quite enough for focusing of the beam with energy up to 1 TeV.

Е.А.КУШНИРЕНКО, А.А.МИХАЙЛИЧЕНКО, А.А.СЕРЫЙ

СВЕРХПРОВОДЯЩАЯ ЛИНЗА ФИНАЛЬНОЙ ФОКУСИРОВКИ ЛИНЕЙНОГО КОЛЛАЙДЕРА

Институт Ядерной Физики им.Г.И.Будкера
630090, Новосибирск, Россия
Филиал ИЯФ
142284, Протвино, Московской обл.

АННОТАЦИЯ

В этой работе рассмотрена возможность применения безжелезной линзы со сверхпроводящими обмотками для системы финальной фокусировки следующего поколения Линейных Коллайдеров.

Полный диаметр квадруполя (включая термоизоляцию) оценивается в 4 см. Малый поперечный размер линзы позволяет значительно увеличить телесный угол, охватываемый детектором и понизить фон, возникающий от взаимодействия высокоэнергичных частиц с деталями линзы и ускорителя.

Проблемы, связанные с наличием магнитопровода в сильном магнитном поле детектора - насыщение железа и искажение поля - частично устраняются, а частично уменьшаются при использовании такой линзы.

Расчеты подтверждают, что возможно создание безжелезной линзы со сверхпроводящими обмотками и градиентом 300 кГс/см. Этого значения градиента достаточно для фокусировки пучка вплоть до энергии 1 ТэВ.

INTRODUCTION

The luminosity of Linear Collider is increasing when the sizes of colliding bunches are decreasing. Minimization of transverse size of the bunch can be done by focusing with help of quadrupole lenses. The last (final) quad plays major role in this focusing.

Consideration of a numerous different requirements yields the condition that this final quad should be placed close to the interaction point - within 1 or 2 m, i.e., inside the detector. This requirement is limiting, however, the solid angle covered by the detector: when the quad is closer to the interaction point and when it's transverse size is greater, then the solid angle of the detector is smaller. This final quad should also have short focal length, i.e., strong gradient.

The necessary value of focusing field gradient is about 200 ÷ 300 kGs/cm at energy of the Collider about 1 TeV. This value can be achieved in usual iron quad with inner aperture about 1 mm. One of possible schemes of such quad is described in [1]. Typical dimensions of the lens are about 10x10x100 cm^3. Presence of this iron lens near interaction point yields the following problems:

- the iron lens must be shielded to prevent it's saturation in the longitudinal magnetic field of the detector (10÷20 kGs); this will additionally increase transverse quad's size and, hence a) increase the solid angle missed by the detector and b) increase it's background;
- the solid angle missed by the detector increased due to finite size of the final quad;
- particles, created or scattered in the interaction point can hit the opposite lens surface and then backscattered or reemitted particles can increase background of the detector;
- strong distortions of the detector's magnetic field will appear. Thus the events treatment by the detector that is already complex, will be more complicated.

One possible configuration of Linear Collider interaction region was considered in publication [2]. This scheme used for final focusing the usual lens with iron yoke, placed in the magnetic field of the detector 20 kGs. The optimization of interaction region configuration performed by the author has been done with account of solenoid that shields the iron lens to prevent saturation and cone-like shielding that defenses the detector against particles backscattered from the lens's surface. The solid angle missed by the detector is two cone with the angle 400 mrad at the vertex.

Another possible configuration of the interaction region can use an ironless superconducting focusing quadrupole lens with small transverse sizes. The ironless superconducting quad described in tutorials (see for example [8]) and in some way it was already mentioned in application for B-factory interaction region [3].

By this work the authors stress the advantages of application of such a lens to the focusing system of any Linear Collider.

PARAMETERS OF THE FINAL LENS

One of most important parameters of the final focusing system of a Linear Collider is the distance l^* between interaction point and nearest focusing quad. The distance play major role in design of a final focusing system and also it determines parameters of final quad because the focal length of the final quad should be approximately equal to l^*.

From one side, in order to obtain maximum value of solid angle covered by the detector and decrease it's background loading, the l^* should be greater than longitudinal size of the detector (about 10 m). But from another side in order to achieve maximal luminosity i.e. to focus the beam with nonzero energy spread to smallest size, the l^* must be small (less than 1 m).

The compromise value of l^* accepted in almost all projects of Linear Colliders lies between 1 and 2 meters. The focal length F of final quad is

$$F = BR/(Gl)$$

should be equal to the same value. Here $BR = pc/e$ - is magnetic rigidity of particles, G and l - quad's gradient and length, respectively.

Consideration of contradicting in some extend requirements

(including gradient minimization and optimization of focusing conditions for the beam with finite energy spread) leads to the condition, that the final quad length l should be also approximately equal to l^*.

Thus the final quad parameters are defined by the following conditions : $l \cong F \cong l^* \cong 1 \div 2$ m; gradient of the quad $G \cong BR/l^{*2}$. For example, at energy 1 TeV (magnetic rigidity $BR = 3.4 \cdot 10^6$ kGs cm) the necessary gradient of final lens is about 250 kGs/cm.

The gradient of usual lens with iron yoke is limited by the pole's saturation, so this lens can have this value of gradient only if it's aperture will be about 1 mm. The superconducting quad does not contain iron elements so it allows more flexible choosing of aperture value. Maximum gradient of the superconducting quad is limited (at fixed aperture) by the critical current density that depend on properties of used superconductors and by maximum value of magnetic field created by this current in the lens's winding.

For the following estimations we have chosen the typical value of total inner aperture of the superconducting quad equal to 1.6 mm. This is close to the values of all projects of Linear Colliders and also it takes into account possible resistive wall instability [4] of the bunch inside the lens.

ESTIMATION OF THE PARAMETERS OF THE SUPERCONDUCTING LENS

The main idea of superconducting final quad is described briefly in the work [5]. The simplest lens consist of four cylindrical rods with currents that provides quadrupole field (Fig.1). Length of

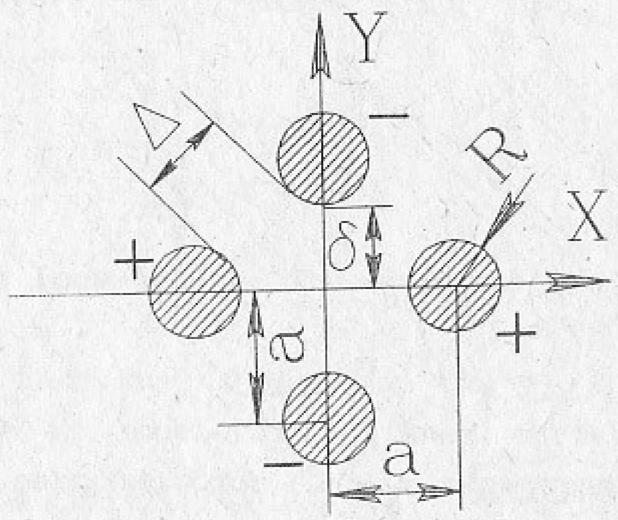

Fig.1. Cros-section of the lens.

the rods is about 1 meter. The rods are symmetrically placed relative to beam line (This rods also may be treated as multi-turn winding with *total* cros-section similar to the road's one).

In order to create maximal value of gradient G the rods should be placed on small distance d between them, so d « r, r- is the radius of the rod. The gradient G in this case is equal to

$$G = 0.4\ \pi\ j,$$

where j - is the current density in the rods in Ampere/cm^2, gradient G in Gauss/cm. For r = 2 mm and a = 2.8 mm (Fig.1) the lens aperture 2b will be 1.6 mm.

As it might be expected the value of magnetic field gradient G in these conditions depend only on the current density in the rods. The data, represented in [6] shows that the NbTi cable with diameter 2 mm at 4.2^0K and field strength 50 kGs allows to have current up to 9000 A, that correspond to the critical current density about 300 kA/cm^2. Supposing that filling factor of quad's winding is 0.7 we get that expected possible current density in the rods will be about 200 kA/cm^2. One should note that critical current density for Nb_3Sn is 2÷3 times greater than that for the NbTi [7]. Thus the value of gradient G (250-300) kGs/cm is quite possible that, as it was mentioned above, it is enough for final focusing of the beams with energy 1 TeV.

The lens winding should consist of main coil and two trim coils. The letter will allow to change position of quad axis. Possible scheme of winding is shown on Fig.2. This scheme

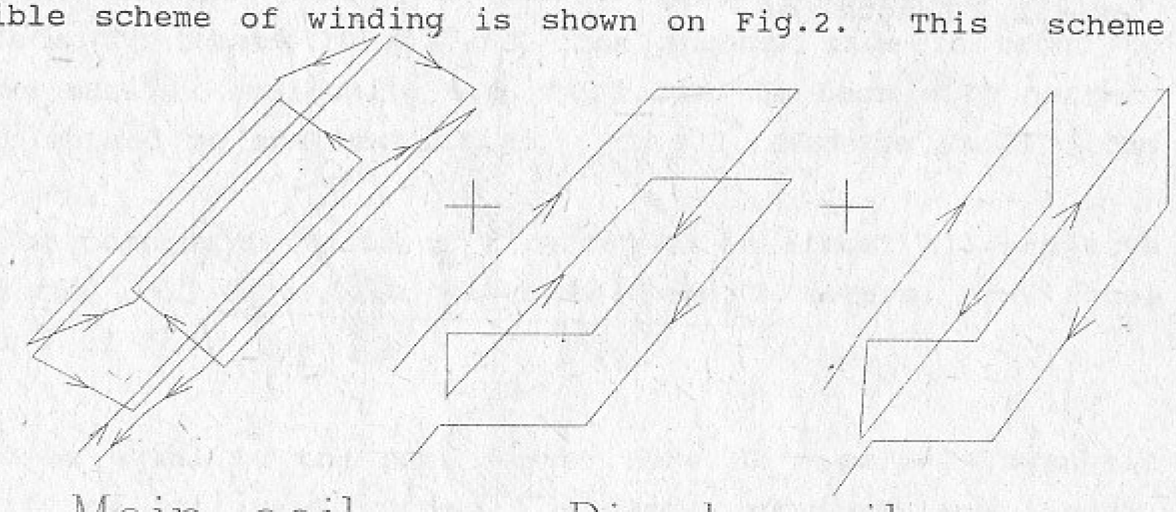

Fig.2. Principle of correction of the center of the lens with the pair of coils, providing the dipole field.

allows to achieve small influence of the lens's edge on the particles trajectories. Input current for the lens feeding can be made small enough. The main and trim coils (Fig.2) can be optimized at detailed studying of the lens design.

Let us consider the forces acting on the winding. Each rod itself is pressed under ponderomotor forces while different rods are deattracting each other with the force about 20 kG/cm at our parameters. This situation allows to solve easily the problem of coils maintaining by placing them between two coaxial tubes. Inner tube will be about unloaded while the outer tube will act against stretching. It is obvious that the forces acting on the main coil will assist to the correct alignment of rods relative to each other.

The forces, created by trim coils is much smaller and their influence is negligible.

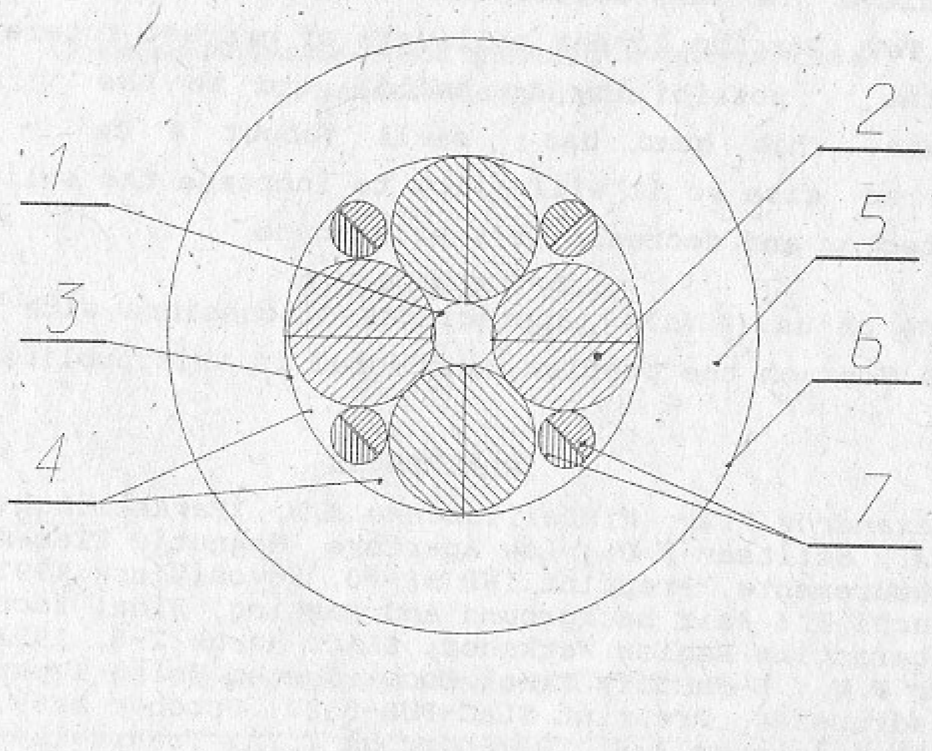

Fig.3. Possible lens design. The comments are in the text.

The scheme of the lens is shown on the Fig.3. Here 1-is the vacuum chamber of an accelerator (inner surface covered by thin layer of superconductor), 2 -is superconducting winding, 3-is outer tube, 4-is the channels for liquid helium, 5 -is the vacuumed space for superinsulation, 6 - is the outer wall of thermoinsulation. If its thickness is about 1 cm, then the total diameter of the lens will be about (3.5÷4) cm. 7 - is the trim coils.

At these parameters the value of magnetic field on the surface of neighboring lens's rods will be about 50 kGs. So the value of critical current density that we used for estimations is quite realistic.

In this work only simplest scheme of superconducting lens was considered. Windings of more complex shape can be found, for example in the [8]. The value of achievable gradient depends very slowly on the winding shape however. But nevertheless this optimization should be performed more carefully when the real quadrupole will be design and should include consideration of technology and other factors.

CONCLUSION

The superconducting ironless quad considered in this paper, can achieve gradient sufficient to focus beams with energy up to 1 TeV. For the linear colliders of nearest future (200-300) GeV the possibility to build and to use this lens is doubtless. This quad has small (about 4 cm in diameter) transverse size so it will allow to increase the solid angle of the detector and decrease it's background.

One of us (A.A.M.) appreciates discussions with P.M.Ivanov and G.A.Voss on the problem considered in this publication.

REFERENCES

[1] *Alexandrov V.A., Mikhailichenko A.A., Parkhomchuk V.V., Sery A.A., Shiltsev V.D.*: Low Aperture Magnetic Element Measurements, Preprint INP 91-70. Novosibirsk 1991.

[2] *Tauchi T.*: Pair background and masking, Final focus and Interaction Region Workshop, SLAC, March 2-6, 1992.

[3] *Ash W.W.*: B-Factory Final Focus System Using Superconducting Quadrupoles, Preprint SLAC-PUB-5127, October 1989.

[4] *Mikhailichenko A.A., Parkhomchuk V.V.*: Transverse resistive instability of a single bunch in Linear Collider, Preprint INP 91-55,Novosibirsk, 1991.

[5] *Kushnirenko E., Mikhailichenko A., Sery A.*: Superconducting final focus quadrupole, Final Focus and Interaction Region Workshop, SLAC, March 2-6, 1992.

[6] *Superconducting cables with insulation*, VNIIKP cable price list Moscow, 1991.

[7] Spravochnik po fiziko-texniceskim osnovam kryogeniki pod red. M.P.Malkova, Energoatomizdat, Moscow, 1985 (in Russian).

[8] *Brechna H.*: Superconducting Magnet System, Springer-Verlag, Berlin, 1973.

E.A. Kushnirenko, A.A. Mikhailichenko, A.A. Sery

G.I. Budker Institute of Nuclear Physics
630090, Novosibirsk-90, Russia
Branch of INP
142284, Protvino Moscow Region

Superconducting Final Focusing Quad for Linear Collider

Е.А. Кушниренко, А.А. Михайличенко, А.А. Серый

Институт ядерной физики им. Г.И. Будкера
630090, Новосибирск-90, Россия
Филиал ИЯФ
142284, Протвино, Московской области

Сверхпроводящая линза финальной фокусировки линейного коллайдера

BUDKERINP 92-35

Ответственный за выпуск С.Г. Попов

Работа поступила 25 мая 1992 г.
Подписано в печать 25 мая 1992 г.
Формат бумаги 60×90 1/16. Объем 0,7 печ.л., 0,6 уч.-изд.л.
Тираж 180 экз. Бесплатно. Заказ N 35.

Обработано на IBM PC и отпечатано на
ротапринте ИЯФ им. Г.И. Будкера СО РАН,
Новосибирск, 630090, пр. академика Лаврентьева, 11.