YEREVAN PHYSICS INSTITUTE
(BEAM & ACCELERATOR PHYSICS)

YEREVAN - 2009

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1. ELECTRON SYNCHROTRON **Basic parameters** **2. 75 MEV S-BAND LINAC**

Putting into operation	1967		Putting into operation	1966
Energy	6 Gev		Energy	15 ÷ 75 MeV
Beam pulse current	(4÷7) ·10^{-3} A		Average current	~10 μA @ energy spread ± 5%; ~1μA @ energy spread ± 0.5%
Injector	75 MeV S-band linac		Repetition rate	50 Hz
Duty factor	10% at 50 Hz		Pulse duration	~ 1 μs
Number of beamlines	Gamma - 3, Electron - 1, SR -3		RF frequency	2797.2 MHz
Operation mode (1967-90) Experiments: Scheduled operation	 7 months per year 5 months per year		Operation mode	Injector Can be used independently of synchrotron
Status (conserved)	Putting into operation requires 3-4 months		Status	Putting into operation requires 1-2 weeks Increase of the repetition rate up to 150 Hz is being considered

Status of the synchrotron

<u>Syncrotron life's brief description (1967-2008)</u>

1967 – Putting into operation

1968 – 1978 - Experiments – 7 months per year, Scheduled operation – 5 months per year,

1979 – renewal after fire,

1980 – 1991 - Experiments - 7 months per year, Scheduled operation – 5 months per year,

1992 – conservation,

1993 – Scheduled operation, 1.5 months – experiment, conservation, 1994 – Scheduled operation, 2 GeV electron beam's test ejection, conservation

1995 – Scheduled operation, 2 GeV electron beam's ejection, conservation.

1996 – Scheduled operation, test acceleration up to 4 GeV, conservation.

1997 – Scheduled operation, test acceleration, conservation.

1998 – Scheduled operation, Experiment - 1.5 months, conservation.

1999 – 2004 – Scheduled operation, conservation.

2005 – Scheduled operation, Experiment – 1.5 months, conservation.

2006-2008 - Scheduled operation, conservation.

Annual damage inspection and preventive repairs allowed to keep the synchrotron in the satisfactory technical condition at rather small financial expenses

Injector (head of subdivision A.Matosyan, head of group V.Hayrapetyan)

Now injector has an efficient condition and allows to inject to synchrotron an average current ~1 μA at energy 50 (75) MeV. The basic problem is limitation of the S-band klystrons' and tyratrons' numbers . At the existing reserve the linear accelerator can operate:

- 25000 hours @ 75 MeV,
- 37000 hours @ 50 MeV,
- 75000 hours @ 25 MeV

Injection system (head of subdivision A.Matosyan)

The injection system is in operable state, is provided by necessary accessories and has the resources for 5-7 years in an operating mode about 5000 hours per year.

Ring magnet (RM) (chief ingineer E.Badalyan)

Condition of magnet blocks is normal. In a mode of 4.5 ГэВ RM can operate not less than 10-15 years for what it is necessary to perform the following routine maintenance:

- Repair of pole windings;
- Repair water-cooling tubes;
- Replacement of flexible tubing of water-cooling;
- Repair of jet relays.

RM powering system (head of laboratory H.Martirosyan)

According to the program of Yerevan Synchrotron prospective development a new system for flat-topping of the RM magnetic field have been put into operation on the Yerevan Synchrotron in 1995, which provided the duration of slow extraction plateau of the accelerated beam up to 10 ms.

Different approaches to the solving of the problem of plateau formation have been tested during sufficiently long period with the view of developing an Optimal Method for flat-topping of the magnetic field most suitable for the Yerevan Synchrotron.For increasing the duration of magnet field plateau and the extraction energy of particles it is most preferable to use the principle of "supplement" of flat section to the maximum of magnetic field sinusoid. To reduce and equalize the stray inductances of the circuits, a transposition of cables connecting the thyristor switches with capacitor banks of the resonant circuit has been made. As a result of experimental investigations of synchrotron operation at the energy of 2,5 GeV in the mode of magnetic field flat top, the following parameters were obtained:

- Duration of flat top – 9,9ms
- Duration of slow extraction of accelerated beam – 4ms
- Stability of the energy of extracted beam- $\Delta E/E = \pm 0,25\%$
- Duty factor- d.f.= 20%

The above mentioned works have been carried out in collaboration with the NIIEFA named after Efremov (St. Petersburg).

Stabilization's systems (head of subdivision K.Sadoyan)

Systems provide:

Stabilization of DC component of the RM;
Stabilization of AC component of the RM;
Stabilization of the magnetic field's rate of rise at the injection;
The stabilized feeding of the linear accelerator,
Stabilization of the magnet deflector's current;
Stabilization of experimental magnets' current .
To date all subsystems are in good fettle. The resource of stabilization systems can be estimated as 7-8 years.

RF system (head of laboratory A.Manukyan)

Now the 21 accelerating cavities are installed, ten of them fed by the first channel, and others 11 - by the second. All cavities have been tested. The tests have shown, that the RF-system is capable to provide acceleration up to 4.7 GeV. The RF-system has the necessary reserve of lamps. The estimated resource of RF-system is ~5 years.

Vacuum system (head of subdivision S.Zakharyan)

Results of maintenance have shown, that the existing vacuum system will be in the state of operability within several years. The vacuum serving group has organized the repair sites of : pumps , vacuum chamber's sections, elements of RF resonators, vaccum leak testers etc. At presence the minimal expenses allow to support a demanded technical condition of system

Beam lines (head of subdivision A.Markaryan)

Systems provide the beams' delivery with the following parameters:

Photon beams:

energy - 4.5 GeV,

number of photons - (2-3) $\times 10^{9}$ per sec,

extension - (2-3) msec,

efficiency ~75 %.

The mode of two channels' simultaneous operation is being provided;

Electron beam: (fast, bell-shaped ejection):

energy - 4.5 GeV,

number of ejected electrons - $\sim 1\times 10^{10}$ per sec,

extension - ~ 0.5 msec,

frequency of ejection - 25 Hz,

efficiency ~ 75 %;

Electron beam (Flat Top mode).

energy - 2 ГэВ,

number of ejected electrons - (5×10^{10} - 1×10^{11}) per sec

Beam monitors (head of laboratory A.Babayan, head of subdivision A.Matosyan)

Beam monitor system requires the upgrade and update fully

Control system (head of subdivision A.Matosyan)

Control system requires the upgrade and update fully

Water cooling, thermostating, power feeding, ventilation (head of subdivision G.Khachatryan)

The estimated resource of systems is not less than 5 years.

Buildings and electric power supplies (chief ingineer E.Badalyan, heads of subdivisions V.Martirosyan, B.Grigoryan,)

All buildingsr electric power supplies equire major repairs

3. Future's possible fulcrums (background)

Feasibility study and conceptual design of the Proton Therapy Regional Center (PTRC) on the base of Yerevan Synchrotron (V.Nikoghosyan, E.Laziev at al.)

Proton therapy is the most precise form of radiation treatment today. It primary radiates the tumor site, leaving surrounding healthy tissue and organs intact. Conventional radiation often radiates healthy tissue reaching and rounding the tumor site. Chemotherapy goes throughout in the body, unlike radiation and surgery which are considered “site specific” treatments. Similar to more conventional forms of radiation, however, much less severe; proton therapy has negligible side effects. Depending on the case, proton therapy may be used in conjunction with traditional radiation, chemotherapy and/or surgery. Most radiation oncologists know about proton therapy but have not experience working in the modality, making it difficult for them to advise patients on this for of treatment. Proton therapy cost is more than conventional radiation, but generally less than surfery.

Proton therapy had been limited to physics centers until now. More institutions have plans for proton therapy facilities in the near future including Harvard University at Massachusetts General Hospital. There are proton therapy facilities in USA, Canada, Japan, Germany, Russia, South Africa, Switzerland, France and UK. The cost of each of a center is being estimated in US $ 50-60 M. At the same time, in the densely populated region which covers Transcaucasia, Near East and Central Asia there is not a similar centre. In this connection the teams of Yerevan Physics Institute, Oncological Centre of Armenia, Moscow Radio Engineering Institute (MRTI, Russia) and Research Institute of the Electrophysical Equipment (NIIEFA, St-Petersburg, Russia) have offered to develop, design and create the PTRC in Armenia using the existing potentialities of YerPhI.

YerPhI is the largest accelerator centre in region which includes the Transcaucasia, Northern Caucasus, Central Asia and Near East. YerPhI has the set of accelerators with corresponding infrastructure and high qualified personnel. The using of the YerPhI’s existing potentialities will allow to reduce visibly the expenses of PTRC’s creation. Let’s note also, that in immediate proximity with YerPhI are being situated the largest Republican Hospital and Institute of Rontgenology

As shown in the Project the existing synchrotron allows to accelerate both electrons up to 4.5 - 5 GeV, which keeps the opportunity for conventional research programs with electron and photon beams, and protons up to 250 MeV. It was shown also, that for realization of proton acceleration mode in addition to electron acceleration was necessary to rebuilt cardinally synchrotron’s supply system and construct a new special RF accelerating system and others. Since the opportunity of acceleration and electron extraction must be retained then it will be reasonable to unite the injection and electron and proton output systems. Supply system of the ring magnet must allow a quick, during a few hours changing from electron to proton acceleration and vice versa.

It is suggested that protons will be accelerated from 12 MeV injection energy to 250 MeV. Six RF modules will be used to provide the proton's acceleration. For that 6 cavities with adjustable frequency and 1.6 kW in each of them will be added to the RF supply system.

The main parameters of the PTRC are

Proton's energy (MeV)	60 ÷ 250
Proton's intensity (protons/sec)	$\geq 10^{10}$
Proton's pulse spread (%)	(0.4-0.1)
Injection energy	12 MeV
Number of medical rooms	5 (3+2)
Number of patients/year	600
Preliminary cost of an user session ($)	10000
Preliminary cost of the PTRC creation including 5 medical rooms (млн $)	25 - 30
Preliminary duration of the PTRC creation (years)	3

The estimation shows that the creation of PTRC on Yerevan Electron Synchrotron base, with its developed infrastructure, determines the low construction expenses and their fast compensation. Under favorable conditions PTRC can operate in 3 years. The project has been developed at financial support of ISTC.

Some Features of superpower variable-phase asynchronous cyclotrons (VPAC) (A.Tumanyan et al)

The main results from improving the concept of an asynchronous cyclotron, the latest version of which has been dubbed a variable-phase asynchronous cyclotron. Its characteristics are considered using the example of a six-cavity scheme. Its advantages are shown for the multistage acceleration of ultrahigh-power proton beams with energies of 2–1000 MeV and continuous currents of up to hundreds of milliamperes over ordinary isochronous and superconducting versions of cyclotrons with separated orbits. The main relationships for the preliminary selection of its calculation parameters are presented.

Parameters VPAC	SOC 6-r
RF frequency in cavities, MHz	50
Maximum of the accelerating field, MV/m	3,3
Average beam current, mA	100
Number of beam turns	8
Injection energy, MeV	2
Extraction energy, MeV	17,5

Experimental study of wake wave excitation and electron acceleration in plasma (M.Petrosyan, head of laboratory).

The use of wake field acceleration in plasma basically is aimed to obtaining of high acceleration rate in comparison with traditional methods of acceleration. Meantime in the several last years in YerPhI it was offered to use wake field acceleration for acceleration of high-current electron bunches on energy about 100 MeV. Experimental installation for research of formation of high-current electron bunches of the needed configuration, necessary for wake field acceleration and acceleration of these bunches in plasma is created. The installation is intended for acceleration of electron bunches with a current of few tens amperes and up to energy 1-2 MeV. For excitation of wake waves in plasma the electron accelerator of direct action with use of high-voltage pulse transformer is used (see Fig. 1).

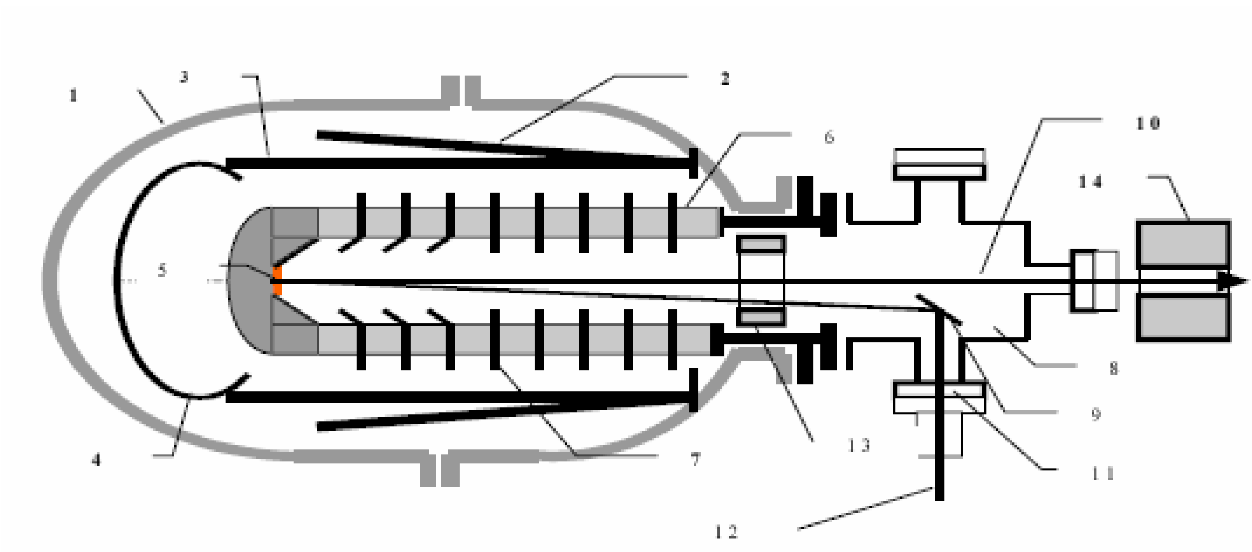

Figure 1: Schematic shape of the accelerator of electron bunchs with photocathode. 1 - tank for gas, 2 – primary winding of the pulse transformer, 3 - secondary winding of the pulse transformer, 4 - high-voltage electrode, 5 - photocathode, 6 - isolation rings of accelerating tube, 7 - electrodes of accelerating tube, 8 - vacuum chamber, 9 - mirror, 10 - electron beam, 11 - vacuum tube, 12- laser beam. 13- magnetic focusing lens, 14 - electromagnetic focusing lens.

Results of researches have revealed some properties of formation of high-current bunches, especially restrictions of a electron current because of space charge effects at sub-picoseconds duration of bunches. The basic parameters of the wake field acceleration project on energy about 100 MeV are given, taking into account the results of researches on experimental installation.

The pilot model of a high current accelerator using wake field waves in plasma was developed. Pilot model consists of the accelerator - injector creating electron bunches of a necessary configuration; of the plasma chamber for acceleration of the second bunch and from the monitoring system and measurement. The accelerator - injector (photoelectron gun) is intended for production of double electron bunches with the following parameters:

• Energy of electrons up to 2 MeV

• Length of bunches 30-100 ps

• Distance between of bunches 5-20 cm

• Current in the first bunch up to 100 A

• Current in the second bunch up to 10 A

References

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Coherent interaction of relativistic electron beam and plasma . (G.Oksuzyan).

At present, plasma methods for the acceleration of charged particles are being actively developed. Theoretical and experimental papers aimed at investigating the mechanisms for the generation of strong wakefields show that one of the main directions in this area - the wakefield excitation by relativistic electron bunches - has many useful applications, in particular, in creating the conditions for the coherent interaction of a relativistic electron beam with a plasma. These conditions can be achieved, e.g., in the interaction of a modulated electron beam with a plasma driven by a microwave pulse at the frequency of the accelerating field in an accelerator. The experiments with a decaying plasma and a microwave-driven plasma have been carried out. The shift of the energy spectra of electron beam at passage through decaying plasma was measured, as well as the strong dependence of the electron current passing through microwave plasma vs RF phase was obtained (see figs below).

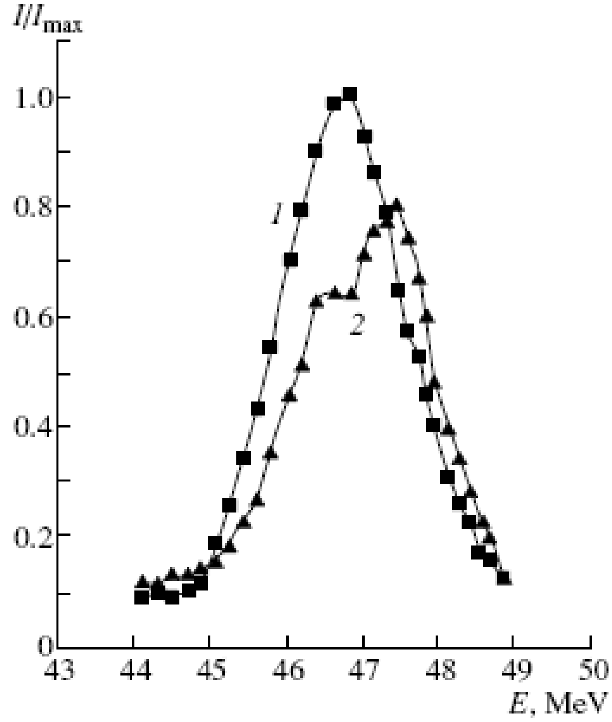

Fig. 1: Energy spectra of the beam electrons: (1) in the absence of a plasma and (2) in the presence of a plasma of density $n_p \sim 4 \cdot 10^{11} cm^{-3}$.

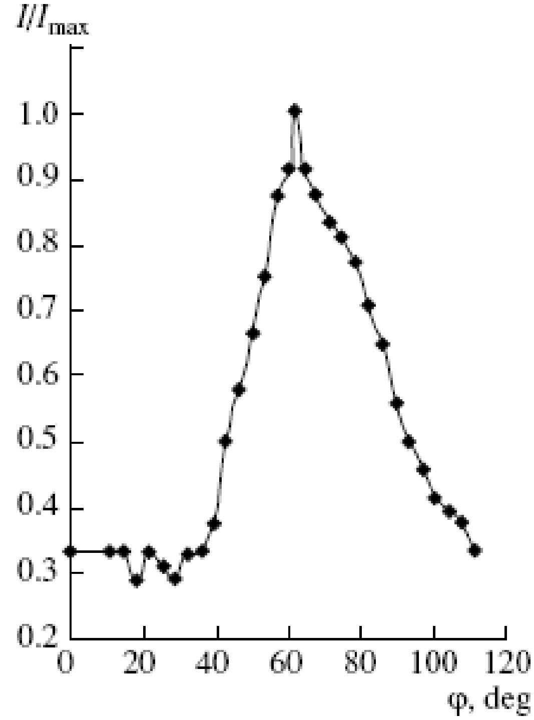

Fig. 2. Current of the 20 MeV electrons passing through the RF driven plasma vs the RF phase.

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Development, manufacturing and testing of original vibrating wire monitors (VWM) for measurement of charged-particle/photon beam transversal parameters (S.Arutunian).

Developed and created the original vibrating wire sensors and monitors for the measurement of beam transversal parameters of charged-particle and photon beams. By means of these devices, measurements of an electron beam in the Yerevan synchrotron, a proton beam at PETRA (DESY), and a hard X-ray undulator beam at the APS (ANL) have been performed.

The first scanning experiments on a charged beam were done on an electron beam at the Injector of Yerevan Synchrotron with an average current of about 10 nA (after collimation) and an electron energy of 20 MeV.

A series of experiments with the VWM were done on proton beam of the accelerator PETRA at DESY.

The vibrating wire scanner was also tested on an ion beam of energo-mass-analyzer EMAL-2. Approximately 16 pA of beam current interacted with the wire and a frequency decrement of about 0.15 Hz was measured.

Hard X-ray flux measurements with a vibrating wire monitor with two wires were conducted at APS. Vibrating wire sensor was used also for laser beam scan. This task is especially actual for infrared lasers.

Taking into account the extreme sensitivity of the vibrating wire sensors was suggested to place the VWM outside of vacuum to detect only very hard x-rays that penetrate the chamber at selected locations. The addition of convective cooling would reduce the response time substantially albeit with reduced sensitivity. The special 5 wire VWM was developed and manufactured. The sensor was mounted on the outboard side of a bending-magnet synchrotron radiation terminating flange in sector 37 at the APS storage ring.

The possibility of neutron beam measurements by VWM in Spallation Neutron Source (SNS) is discussed. SNS now provides the most intense pulsed neutron beams in the world for scientific research and industrial development.

Vibrating wire resonator was used also for original tension sensor development by which the critical parameters of superconductivity were investigated.

On the same principle a special device for magnetic fields gradient measurements was developed. Such device can be very useful for accelerator magnetic field components tests and calibrations.

References

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2. Arutunian S.G. Vibrating wire sensors for beam instrumentation. - Beam Instrumentation Workshop, BIW08, (May 4-8, 2008, Lake Tahoe, USA).

Modulation of electron bunches' charge density by laser beam (E. Gazazyan).

Electron beam slicing as implemented at third generation synchrotron radiation sources is a way to generate femtosecond electron bunches. The idea was proposed in 1996 by A. Zholents and M. Zolotorev, and the technique was first practically demonstrated several years later by Schoenlein, *et al.* At present, three synchrotrons have implemented this technique: the ALS in Berkeley, BESSY in Berlin, and the SLS.

The possibility to use the resonant energy exchange between a linearly polarized monochromatic electromagnetic field and electrons in an optical resonator for production of femtosecond electron bunches has been studied at YerPhI during the several last years. It is studied t the slicing effect of the comparably large dimension electron bunches (larger, than electromagnetic wave length) and scanning the ultra short (less than wave length) ones interaction effects with high intensity linear polarized electromagnetic wave (laser beam). The possibility of the bunch's charge distribution modulation (with high modulation rate) effect was demonstrated. It permits to divide the large bunches into very short sub-bunches (to get, for example, the femtosecond duration bunches) at the first case and scanning the ultra short bunches to investigate the charge distribution at the second one.

References

1. **E.D.Gazazyan, D.K.Kalantaryan, M.A.Khojoyan.** On the Possibility of Electron Bunch Charge Density Modulation in Laser Beam. Proc. of the 43rd Japan Workshop on Accelerator Sciences. KEK,Tsukuba, October 29-30, 2007, p.p. 93-104.
2. E.D.Gazazyan, A.K.Davtyan. **On the Electron Bunch Interaction with Monochromatic Electromagnetic Wave. Izvestia NAN Armenia, Fizika, v. 44, #2, p.p. 79-87 (2009).**

Bicylinndrical cavity as a TBA accelerating module (BAM) (E.Gazazyan)

Bicylindrical accelerating module as a unit of the Two Beam Acceleration (TBA) experiment have been developed at YerPhI [1]. The module's cross section has the form of two intersecting circles of different radii

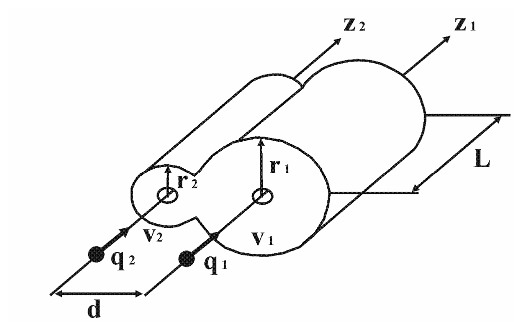


Fig.1. Bicylindrical accelerating module (BAM) A technique of calculation the properties of such cavities has been presented in [2]

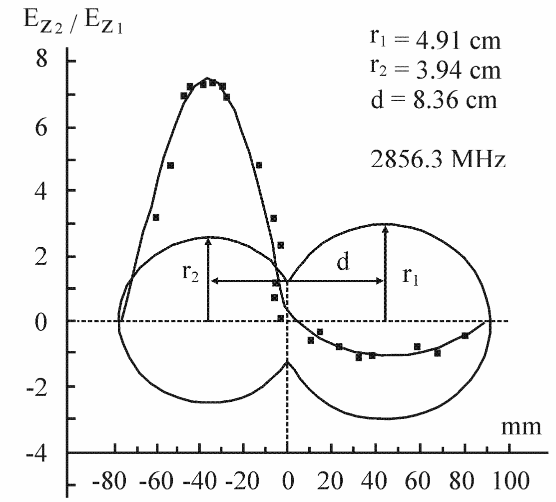


Fig. 2. Distribution of the longitudinal component of the electrical field in the cross section of a bicylindrical cavity. Solid line: theory, dots: experimentally measured data points.

We have shown that a similar device could be an effective transformer of an electrical field intensity and could be used as an accelerating module for TBA. Three modifications of the code that calculates the bicylindrical E-modes of such cavities have been written:

- A code using a trapeze method with numerical integration. The algorithm used contains three optimization parameters which allow to satisfy the boundary conditions with high accuracy;
- A code in which the numerical is done by a FFT algorithm which providing quick action;
- A code in which the numerical integration is replaced by the calculation of special functions. In this case the base integrals by which the longitudinal component of an electrical field is calculated, are reduced to Bessel functions. This code is intended to be used for the calculation of higher bicylindrical modes.

We have developed a rather complete theory for such cavities. Using this theory we can define those modes which determine the effectiveness of the such TBA module. A prototype cavity was constructed and tested at low level RF. The second symmetric mode is most suitable (see Fig. 2). For that mode it is typical that for a prescribed value of r_2/r_1 (>0.62) it is possible to get the high transformation ratio by choosing the right distance *d*.

References

1. E. Begloyan et al, Two beam acceleration at the Yerevan Physics Institute and a study of a prototype Cherenkov waveguide laser, Proc. Of the 21 FEL Conf., August 23-26, 1999, pp II-45
2. M. Ivanian, Modes of Bicylindrical Waveguide, Radiotekhnika i Elektronika, **44**, pp. 401-409 (in Russian), (1999)

<u>YerPhI-DESY collaboration</u>

<u>Power supplies laboratory (H. Martirosyan, head of laboratory).</u>

Collaboration program

1987-1992: Works on reconstruction of Yerevan synchrotron power supply system and development of magnetic field flat top [6].

1992- 2003: In the frame of YerPhI-DESY collaboration designed, manufactured and delivered to DESY a number of power supplies, including the Digital Controlled Power Supplies, as well as the cost effective remote controlled heating power supplies for super conducting magnets to be used in the accelerator power supply systems at DESY (TTF/VUV – FEL, X FEL).

Stages of works

1. **Agreement between DESY and YerPhI for period 1993 - 1995**

1.1. Development and building of direct current power supplies

MKK Technical Specification

- Nominal output current, A	500
- Nominal output voltage, V	100

- Ripple voltage, V	2,8
- Supply voltage, V	400
- Supply voltage frequency, Hz	50
- Cooling	natural
-Overall dimensions (L x B x H), mm	1180 x 850 x 1950
-Quantity	5

1.2. **Development and building of five DC power supplies for the TESLA Free Electron Laser (FEL) Project at DESY**

MKK Technical Specification 32/97 nov. 24, 1997. Je/Eck/st

- Nominal output current, A	500
- Nominal output voltage, V	100
- Ripple voltage, V	2,8
- Supply voltage, V	400, 3 phase
- Supply voltage frequency, Hz	50
- Cooling	water-cooling
-Quantity	5

1.3.**Development and building of five DC power supplies according to the Appendix 5**

MKK – Specification 15/2001, Sep. 21, 2001 Je/Re

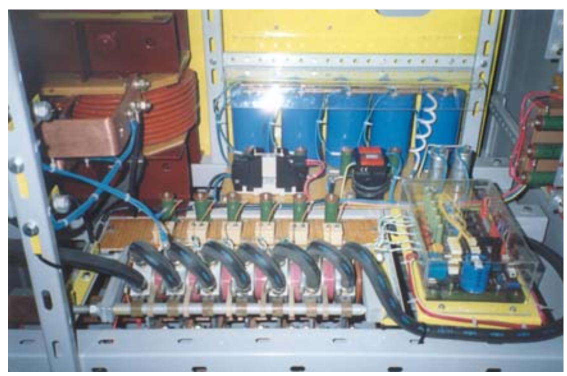
- Nominal output current, A	500
- Nominal output voltage, V	120
- Ripple voltage, V	2,8
- Supply voltage, V	690/400, 3 phase
- Supply voltage frequency, Hz	50
- Cooling	water-cooling
-Quantity	5

Thyristor – B6-bridge (6 pulse) with recovery diodes.

a) Front view

b) Interlock panel

c) Power transformer with watercooling system



d) Thyristor rectifier

Fig.1. Power supply 500A/100V

At present all above mentioned **15 units** of power supplies are under operations in the accelerator power supply systems at DESY [12].

2. Design of Digital Controlled Power Supplies at Yerevan Physics Institute (Agreement between DESY and YerPhI for years 2004-2005)

The objective of this Project is to design and the development of the new modern switch-mode power supplies at Yerevan Physics Institute to be used in the accelerator power supply systems at DESY (PETRA, X-FEL).

According to the Collaboration Agreement the following volume of the work has been carried out:

- Study of the new switch-mode power supplies and new technologies used in the design of power supplies and digital subsystems.
- Building of the test stand of a power-supply system to test a digital control board and software.
- Development of a digital control board using FPGA from Altera and test of the Chopper Interlock program.
- Integration of the FPGA based controller in the power supply system.
- Working-out of the technical documentation.

3. Development of cost effective remote Controlled heating power supplies at Yerevan Physics Institute (Agreement between DESY and YerPhI for years 2006-2007)

The objective of this Project is development of cost effective remote controlled heating power supplies at YerPhI for super conducting magnets to be used in the accelerator power supply systems at DESY (TTF/VUV – FEL, X FEL).

- Design of a digital remote survey system for existing TTF/VUV – FEL heating power supplies
- Create a prototype which includes the digital remote survey system and an existing TTF/VUV – FEL heating power supply
- Design a new low cost and highly reliable power part for X – FEL heating power supply and build a prototype which implements a digital remote control system.

The X-FEL heating power supply prototype and the documentation have been sent to DESY for implementation of joint work and detailed testing in the operation regime on electro physical equipments at DESY MKK group laboratory.

a) Front view　　　　　　　　　　b) Inside view

Fig.2. Remote controled power supply prototype

4. JAVA based remote data analysis of power supply for PETRA 3
(Agreement between DESY and YerPhI for years 2008-2009)

PETRA3 power supplies include a web controller which distributes a variety of data like temperatures, actual current, I/O voltage, status etc. The data is provided on a web page as integer values.

The first objective of this project is the conversion of the data to physically scaled values (i.e. temperature values) and their graphical presentation on a Java based web page.

PETRA3 power supplies will gain the following advantages from JAVA based web pages:

- The data is processed in the browser of comparably powerful remote computers. Advantage is taken of the increase of remote computing power over the next years while the power supply web controller stays the same.
- Computing power of the internal 16bit web controller is saved especially regarding the conversion of 20bit current values. Web communications are remarkably faster.
- Graphical presentation i.e. of temperatures, currents and voltages facilitate failure diagnostics. Time intensive measurements on live parts of the power supply are not required in most cases.

The second objective of this project is to establish direct communication between web controller and PETRA 3 control system (TINE) by means of web communication. The control system supports analysis, graphical presentation and archiving of all data.

These projects have been carried out by technical and financial support of DESY under the "Collaboration Agreement between DESY and YerPhI".

5. Plan of scientific –technical activities for the period of 2010-2014

1. Maintenance of the Synchrotron Power Supply System with forming of magnet field cycle in accordance with the program of physical experiments.
2. Reconstruction of Synchrotron Power Supply System on the basis of up-to-date implements, including the development of automatic digital controlled devices and synchronization systems with the purpose of optimizing of magnetic field parameters and increase of accelerator operation efficiency.
3. Design and development of digital remote controlled power supplies to be used in the accelerator power supply systems at DESY (PETRA, TTF/VUV-FEL, X-FEL) and YerPhI-within the frames of the collaboration agreements between DESY and YerPhI.
   Development and building of cost-effective remote controlled power supplies with commercial purpose, under working partnership with DESY.
4. Participation in working-out and realization of new projects on development and modernization of YerPhI accelerator complex.

<u>Competitive qualities</u>

The main competitive advantage of producing such power supplies in Armenia is their low cost as compared with those offered in foreign markets, due to the considerably low production costs in Armenia, particularly labor force cost. Power supplies have been produced in Armenia with high level of quality, no less of their analogs produced in European countries, which was proved by their operation in DESY [12].

YerPhI is the only institute in Armenia, which has received the order of producing such power supplies with the use of the modern technologies from abroad. Since high technologies development is one of the priorities for Armenian economy, the practical works done by YerPhI employees are worth of getting attention, and this indicates the existence of professionals with high qualification and potential for enhancement in the above mentioned area.

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A 20-75 MeV beam transport channels for applied researches experiment at YerPhI
(V.Nikoghosyan, A.Babayan)

In YerPhI in a ring hall of 6 GeV Yerevan synchrotron is developed and constructed 2 channels electron beamline on the basis of existing 75 MeV linac-injector for applied researches.

A 20 MeV electron beamline for radiation process experiment at YerPhI

Табл.1 The main parameters of the 20 MeV electron beam on a target

Parameter	Unit	Value
Electron energy	MeV	20
Pulse rep. rate	Hz	50
Frequency	GHz	2.7973
Pulse length	μs	0.5-1
Bunch length	ns	0.036
Energy spread	%	2
Horizontal beam size	mm	3
Vertical beam size	mm	2
Horizontal emittance	mm. mrad	1.0
Average current	nA	0.1-1000

In YerPhI is developed and constructed 20 MeV electron beamline obtained after double deflection parallel to the beam of the 75 MeV injector-linac of the 6 GeV Yerevan Synchrotron. The magnetic optics of the beamline, provides formation of a required beam parameters allow to carry out experimental investigation of various type of radiation processes- electron-crystal interaction with crystals of diamond and quartz, and also with a piezocrystal at presence of ultrasound.

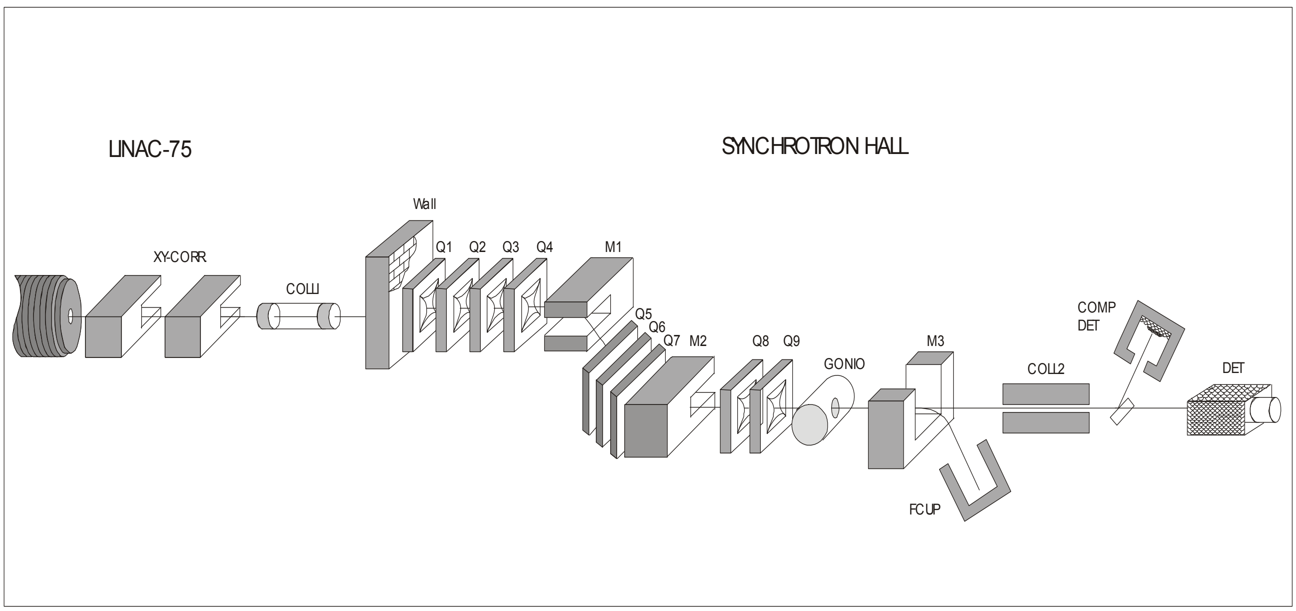

Fig. 1. Schematic view of the beamline

Three-millimeter collimator (coll1) is installed behind a radiationally-protective wall (indoors of linac) with the purpose of exception of photon background penetration in a synchrotron hall. After collimation we have a beam intensity 10^9 - 10^{10} electrons in an impulse.

In future we plan to reduce collimation up to 2 mm for reduction of a beam emittance.

Up to magnet M1 the beam is transported along the existing injection beamline to the synchrotron. The beam is bending on 26^0 from a synchrotron injection channel by magnet M1 and then goes through along new created beamline. The second magnet M2 (similar M1) is installed on distance ~4.5 m from the first magnet M1 is bending the beam back with the same angle 26^0.

Three qudrupole lenses are installed between bending magnets M1, M2. Thus is being provided the condition of nondispersive translating of a beam [1]. The doublet of lenses Q8, Q9 provides formation of ~3 mm beam spot at the target. After interaction with the target, the beam is bending downwards on 55^0 by magnet M3 and goes through a radiationally-protective floor to the Faraday cup. Beamline elements position allows to reduce photon background arising from interaction of electrons with collimator and Faraday cup.

It is necessary to note, that for beam formation four quadrupole lenses are installed up to the first bending magnet M1 on the beamline of injector.

Fig.2. View of beamline of 75 MeV injector-linac (right beamline) and 20 MeV deflected beamline (left bemline)

Calculation of magnetic optics of a beamline was carried out in 2 stages. At the first stage preliminary calculation of necessary quantity and parameters of magnetic elements of the beamline are performed based on beamline's geometry and also on requirements of a beam's final parameters.

Thus, distances between magnetic elements of a beamline, values of gradients of lenses and fields of bending magnets, quantity and place of putting correctors were defined.
Calculation of magnetic optics has been executed by code TRACE-3D [2].
The purpose of an optimum adjustment of magnetic optics is not only formation of the necessary beam sizes on a target, based on the requirement of performed experiments, but also achievement minimal transversal sizes of the beam along all beamline to reduce the photon background arising from interaction scattered electrons with the vacuum chamber.
The determining of the beam's ellipse parameters and emittances in two transverse phase planes is reached by measurements of the beam sizes at three locations [3].

Fig.3. View of a finite part of 20 MeV beamline

For that, screens covered with phosphor (ZnS) are installed on the site of a target and in two more locations of a beamline and with the help of 3 TV-cameras the projections of a beam pictures are controlled. The screens in first 2 locations are performed in the form of a grid with using a thin wire and with small step for having an opportunity of simultaneous measurement of the beam sizes in three locations. It allows to see beam spot on a target at simultaneous passage of a beam through the first 2 screens with small distortions.
These jobs are executed in frameworks of projects INTAS and ISTC [3-5].

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Production of medical isotopes on the basis of the 75 MeV injector-linac of the 6 GeV Yerevan Synchrotron

For researches on radionuclide production on existing injector-linac electron accelerator we need beam average current to increase up to 10-15 mkA for energy 20-40 MeV.
We use existing injector-linac beamline to the synchrotron. Researches are carried out on a straight-line portion of beamline up to the first bending magnet M1 (fig.1). Instead of a magnet M1 installed experimental setup with Faradey cup on the end. On a way of an electro beam is target consisting of a capsule with molybdenum 100. By electron beam interaction with target we have next reaction

$$\gamma + {}^{100}Mo \rightarrow {}^{99}Mo + n$$
$$\downarrow$$
$$T_{1/2} = 67 \text{ hours} \rightarrow {}^{99}Tc \ (T_{1/2} = 6 \text{ hour})$$

For beam formation we use four quadrupole lenses installed up to the experimental setup.

Developed of the wiggler model with hybrid structure allowing to optimize design and weight of wiggler magnet (A.Babayan).

The purpose of this work is to optimize the design of a permanent magnet wiggler, including optimization of the pole shape to improve a field quality for the ILC Dumping Ring according to requirement presented in ILC Damping Rings R&D Activities List.

The first proposal for a permanent magnet wiggler for the ILC damping rings is described in the EuroTeV report 2006-011, where has been considered wiggler magnet for TESLA DR and due to optimization of pole shape by means of multi-level shimming (3 shims) the field quality in the required good field-region ΔB/Bo is improved an order of magnitude (from 5.6 10^{-3} to 5.5 10^{-4}). The total thickness of the shims is 0.45 mm [1,2].

The second proposal for a permanent magnet wiggler for the ILC damping rings is described in the EuroTeV report 2007-004, where has been considered the design of the large aperture permanent magnet wiggler for the ILC Damping Rings (Fig.1). To further improve the field quality, has been proposed a new design,

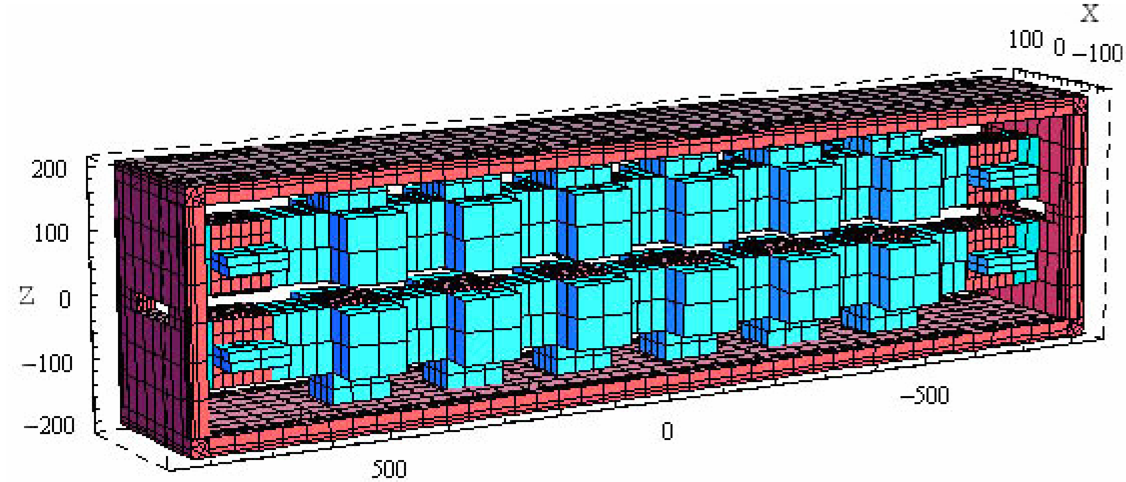

Fig.1: Wiggler magnet structure (three full periods + 2 end poles) shown without iron yoke sides

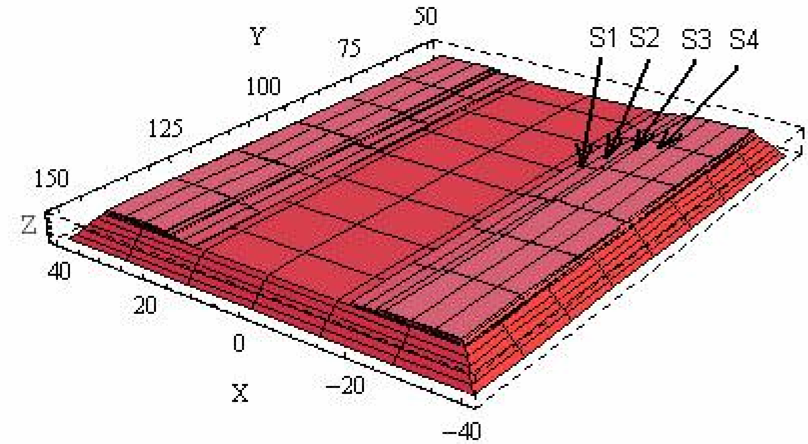

Fig. 2: Wiggler poles chamfer profile optimized with four shims: height of chamfer Z= 5 mm, S1-S4 – shims on pole surface

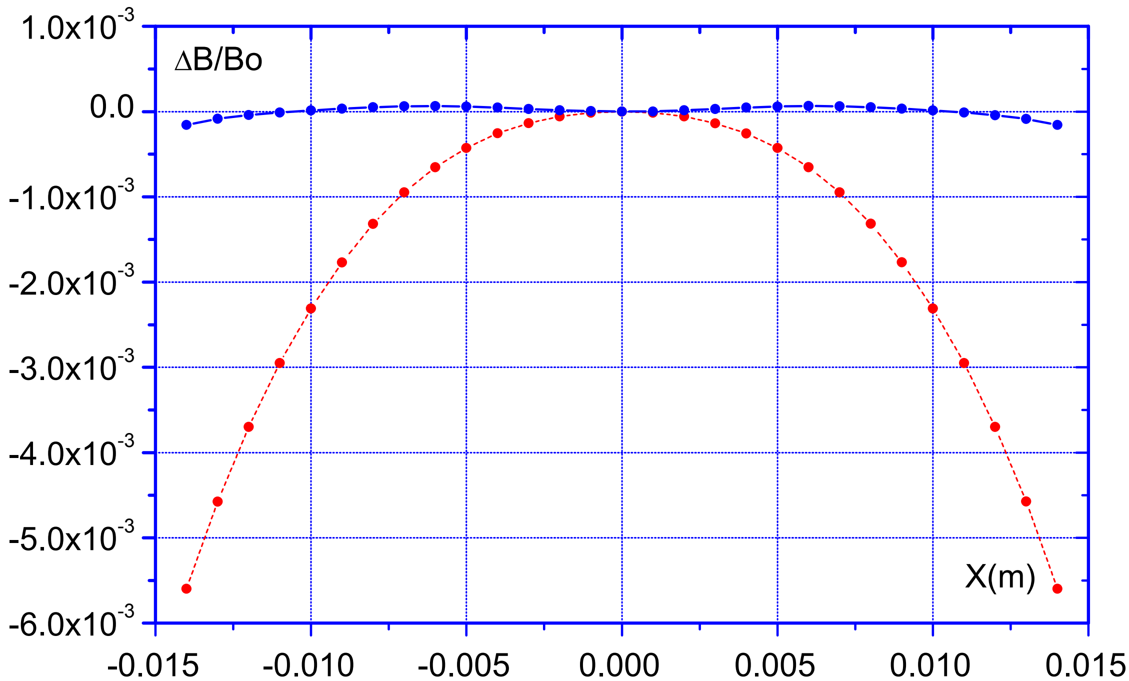

Fig.3: Relative change of magnetic field in transverse direction at the pole center: dotted line - without shims, full line - with shims.

with the gap height increased to 32 mm. and the good field region is enlarged from 20 to 28 mm. In fig.2 of 5 mm chamfer on the end of a pole with 4 shims is shown . With pole shape optimization by means of 4 shims, $\Delta B/B_0$ is improved more than an order of magnitude and does not exceed $1.6x10^{-4}$ (Fig.3) by relatively small overall dimensions of the wiggler[3] .

We consider the possibilities use of model of a wiggler for optimization of design of a undulator. Taking into account that total thickness of optimized shim is small (0.3-0.45 mm for gap up to 20 mm) that makes reasonable use for a hybrid undulator and wiggler used in DESY X-FEL project that will enlarge the good- field region and substantially improve a field quality. The placing of optimized shim on a pole surface fabricated or assembled of the undulator or wiggler not demands change of poles design.

Wiggler design optimization are executed in collaboration and financial support by DESY and also jointly with INFN-LNF (Frascati) in frameworks EUROTeV collaboration. Large aperture permanent magnet wiggler has been presented at the Frascati Workshop ILCDR07, March, 2007 [4]. By results of executed jobs YePhI is included on in ILC Damping Rings R&D Activities list by Institution[5].

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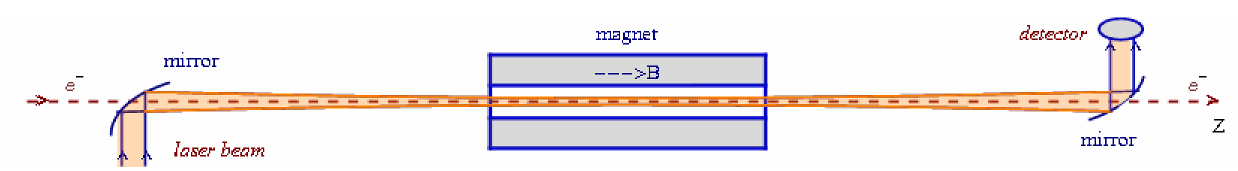
Precise measurement of the electron beam absolute energy using resonant absorption of photons in the magnetic field (R.A.Melikian)

The new method of precise measurement of electron beam absolute energy in a wide interval from 0.3 up to some hundreds GeV by means of the method" Resonant absorption of laser photons in a homogeneous static magnetic field " has been suggested and developed in YerPhI [1-4]. This method allows to measure absolute energy of electron beam with accuracy 10^{-4}.

For measurement of electron beam energy we consider the resonant absorption of circularly polarized photons by electrons in the static magnetic field $\vec{B}$, directed along movement of electrons. Laser photons are propagated in the same direction as the electrons.

The laser beam after interaction with electron beam in a magnetic field deviates to the detector of radiation which fixes the fact of resonant absorption of photons by means of measuring changes of the laser intensity.



Energy of the electrons is determined from the condition of resonant absorption of photons. The possibility of measurement of the electron beam absolute energy with accuracy 10^{-4} for Gaussian distribution over energy and for various distributions over angles of electrons is shown.

It is shown that the length of the magnet can be chosen in some admissible limits. It allows one to use homogeneous area of a magnetic field and exclude the influence of the edge effects.

Necessary intensity of the laser is determined.

Advantages of this method are the following aspects:

- for feasibility of this method it is important that the required detectors with the high spectral sensitivity and the high-speed answer are produced by the industry.
- lasers, necessary for the measurement of the energy of electrons by this method, are not unique and can be chosen from existing industrial samples.
- this method allows one to measure energy of both non-polarized and polarized electron beam without substantial loss of polarization degree.
- the parameters of the electron beam will not worsen during the measurement of the energy and this property of the method allows carrying out the continuous monitoring of the electron beam energy.

Opportunities of realization of experiment over precise measurement of electron beam energy (near to 300 MeV) by "Resonant Absorption" method on the Yerevan accelerator are supposed to be investigated. It is planned to make up the project of experiment.

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Proposal “Electron beam absolute energy measurement in the 50-500 MeV energy range by resonance absorption method at Yerevan synchrotron” (A.S.Ghalumyan, V.Ts.Nikoghosyan)

The measurement of electron beam absolute energy with accuracy of the order of 10^{-4} is important for some experimental programs. It must be used for real time and continuous electron energy monitoring during experiments.

Development of the theory of this method by stuff member of YerPhI Dr. R. Melikyan [1-3] shows the possibility of the electron beam absolute energy measurement using the superposition of the laser beam and magnetic field.

The method is based on the absorption of the laser beam energy by electrons in the magnetic field. The laser photons can be absorbed by electron beam being in resonance with electron energetic levels. Theoretically is shown [1] and detailed analyzed [2,3] the possibility of measurement of the electron absolute energy by means of the measurement of the electrons absorption intensity.

The history of the measurement of electron beam absolute energy with accuracy of the order of 10^{-4} by means of RA method started from 2000. During last years, supported by DESY, the theoretical base of the method and its experimental realization possibilities have been developed, detailed analyzed and reported on several ILC workshops [1-5].

During the period of 2009 have been analyzed the possibility of the experimental realization of the electron beam absolute energy measurement by RA method at levels of 50-500MeV by means of resonant absorption method, including:

- Analyze of the experimental conditions needed for the electron beam absolute energy measurement.
- Research and development of the setup technical requirements for the electron beam absolute energy measurement.
- Investigation of the state of the art equipment and components for the electron beam absolute energy measurements. Have been found real state of the art lasers and detectors which can be used for experimental realization of the method.
- Development of a setup for the Yerevan Synchrotron electron beam absolute energy measurement.
- Proposal "Electron Beam Average Absolute Energy Measurement In 50 - 500MeV Range By Resonant Absorption Method".

1. The Choice Of The Setup Technical Requirements For Electron Beam Average Absolute Energy Measurement

To reach the absorption of photons by electrons a magnetic field is needed to induce corresponding electron energetic levels. The levels of the electron energies to be measured dictate the solenoid magnetic field induction B value (Fig.1.).

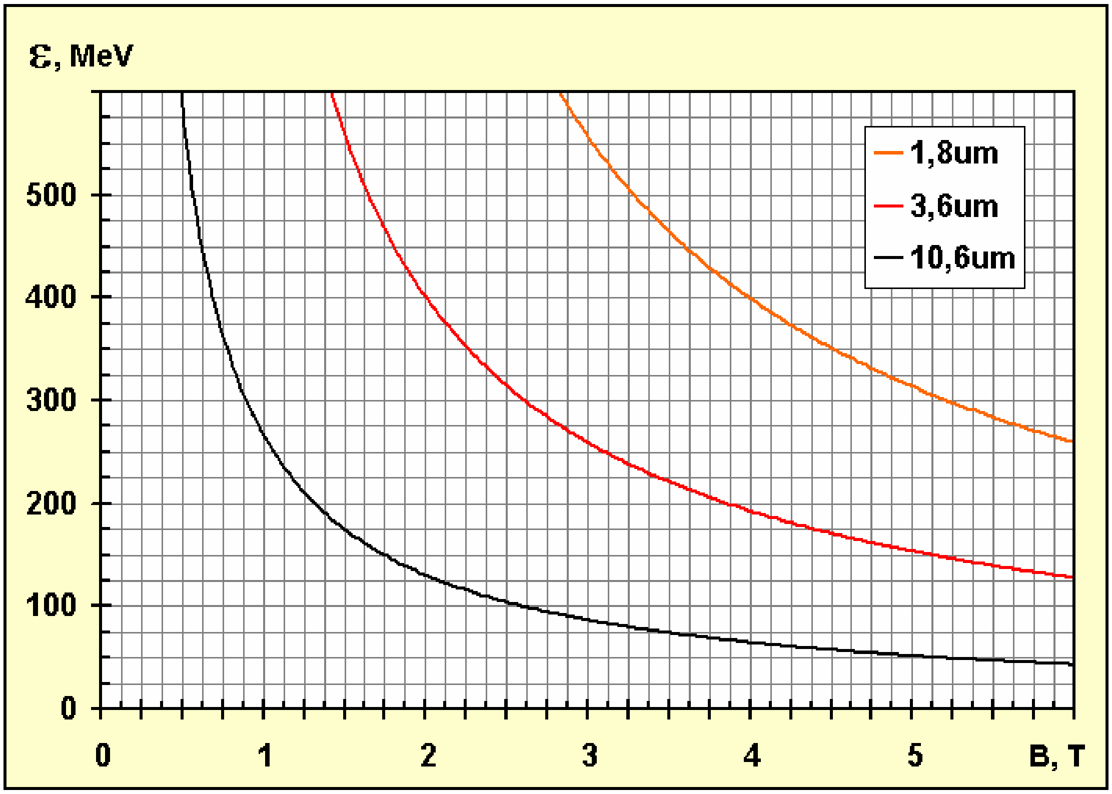

Fig.1. The dependence of the electron beam energy from the magnetic field induction for different laser wavelengths.

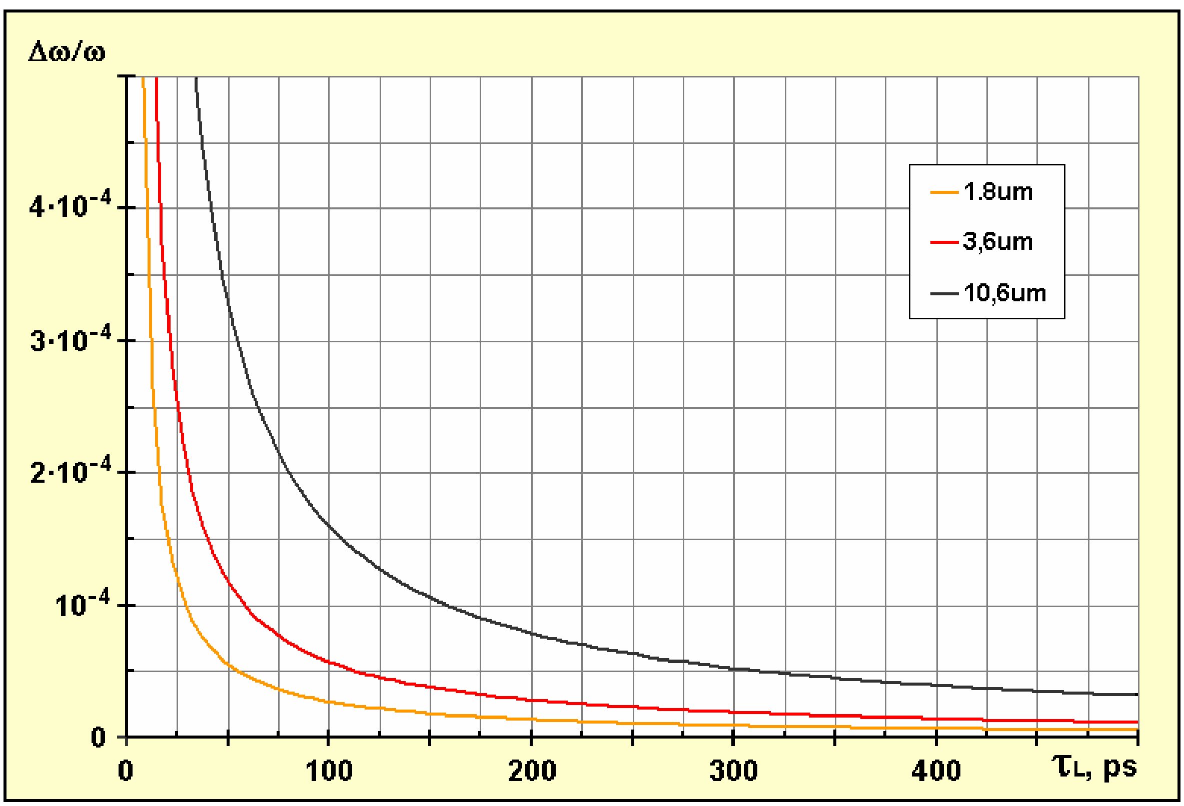

Fig.2. The dependence of the Δω/ω ratio from laser beam Pulse Duration for different laser wavelengths.

To reach the measurement accuracy of 10^{-4} the ratio of $\Delta\omega/\omega$ had to be measured at the same order (Fig.2). The condition $\Delta\omega / \omega < 10^{-4}$ dictate the laser radiation line width and pulse duration. The limitations of the laser radiation line width and pulse duration depend on the laser beam wavelength (Fig.3. and Fig.4.).

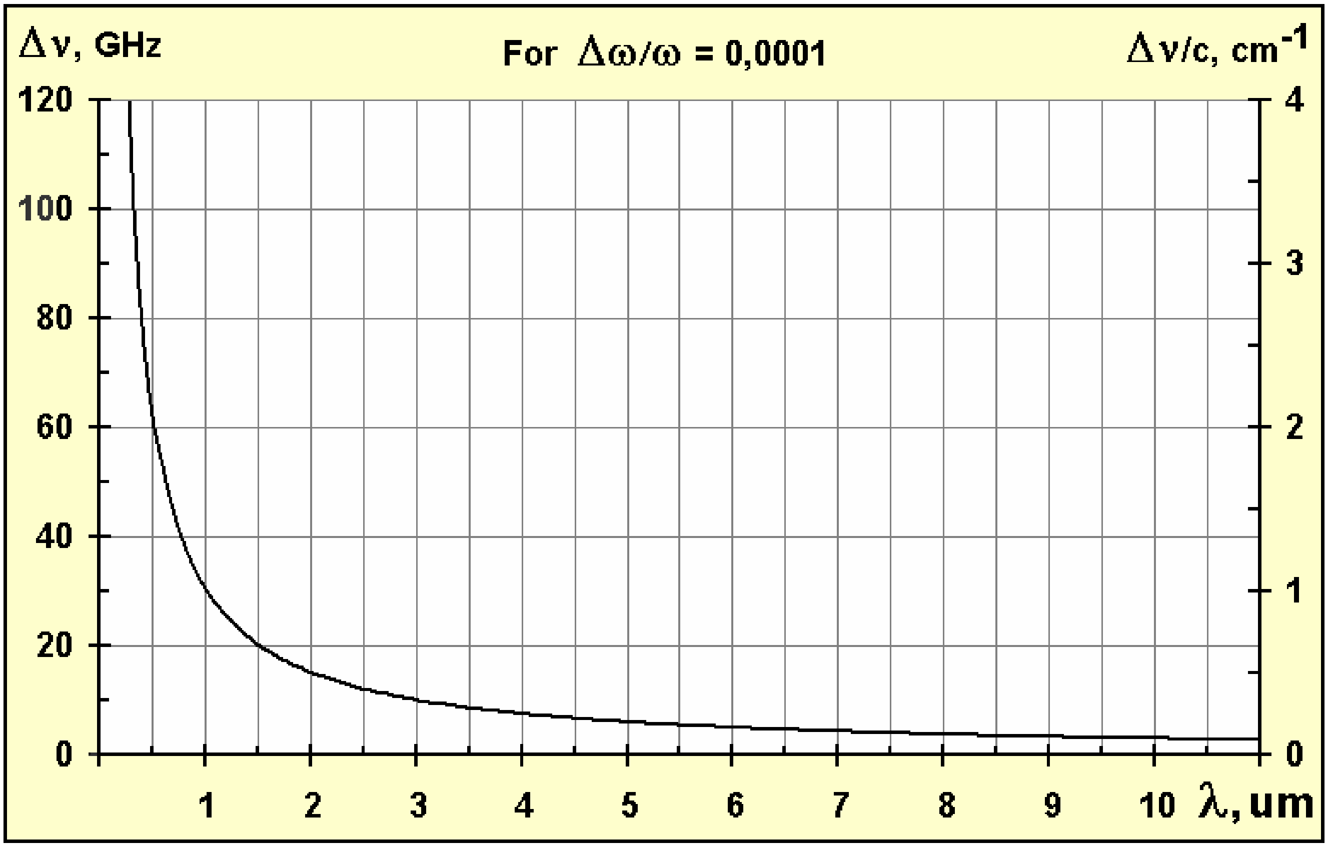

Fig.3. The dependence of the laser radiation line width from its wavelength.

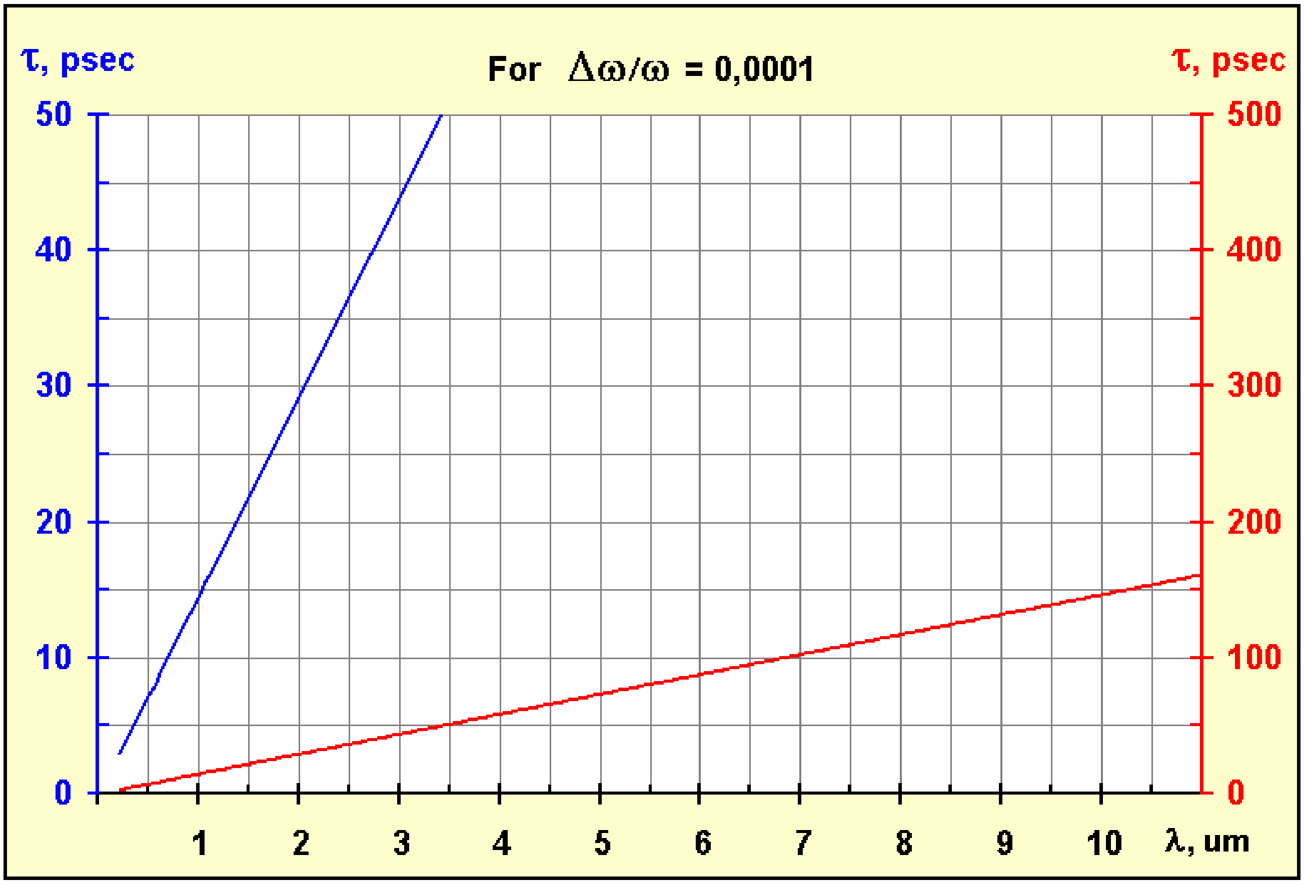

Fig.4. The dependence of the laser pulse duration from its wavelength.

The curve on the Fig.3. indicates the higher limit of the laser beam line width and the lines on the Fig.4. indicate the lower limits of the laser pulse duration.

The estimations for the laser beam output and solenoid parameters, needed for electron beam absolute energy measurements with accuracy of $< 10^{-4}$, shows (Tab.1) that they are among state of the art ones.

Tab. 1.

ELECTRON BEAM	
Electron energy, MeV	**50, 75, 300**
Repetition rate, Hz	**50**
Electron train length, μsec	**1**
No. of bunches per pulse	**2797**
Bunch spacing, psec	**357.5**
Charge per bunch	**$2x10^{11}$**
Beam size, mm	**10**
Bunch length, psec	**30**
Beam Divergence, rad	**$2x10^{-4}$**

Tab.1. Estimations for electron beam absolute energy measurement.

LASER BEAM	**CO_2**
Wavelength, um	**10.6**
Repetition rate, Hz	**50**
Energy per pulse, J	**$>1.2x10^{-4}$**
Beam diameter, mm	**6**
Pulse duration, μsec	**1**
Beam divergence, rad	**10^{-3}**
$\Delta\omega/\omega$	**10^{-4}**
$\Delta\nu/c$, cm^{-1} ($\Delta\nu$, GHz)	**0.09 (2.8)**
Overlap factor for Train	**0.084**
Energy to be Absorbed by Electron Train, J	**$1.0x10^{-5}$**
Optical System Focal length, m	**1.3**
Magnetic field induction, T	**5.2, 3.5, 0.9**

2. The Optical Setup For Electron Beam Absolute Energy Measurement

In the optical setup (Fig.5) is used a CO2 tunable laser MTL-3 (Edinburgh Instruments) as a laser emitter with radiation wavelengths of 9.2μm -10.8μm and of 1μs pulse duration. The laser has an radiation wavelength rapid tuning (pulse-to-pulse shifting) option between individual 20 lines. The laser can be operated in TEM_{00} mode with output pulse energy of 10-50mJ, radiation divergence of 1mrad and repetition rate of 50Hz.

The beam expander is used for collimation of the laser radiation and correspondence of its divergence with electron beam divergence in the interaction region.

The laser pulse energy, reflected from beam splitter, is controlled with the help of the Laser Energy-Power Meter Laserstar and photo detector PE50BB-S (OPHIR). Two positioning mirrors are used for alignment of laser radiation with electron beam.

The linear polarization of the laser beam can be converted to circular one by means of a Fresnel prism.

The attenuated laser radiation after collimation by beam expander by means of laser mirrors directed into the interaction region threw vacuum camera window. The electron beam reaches the interaction region and removes from it by means of dipole magnets.

After interaction with electron beam the laser radiation passes threw iris diaphragm and focuses on the photo detector. The diaphragm is used for cutting the laser photons not interacted with electrons. The focusing lenses are used to focus the laser beam on the photo detector as well as to filter the not precise angular overlap of electron and laser beams. Another photo detector is used for laser output pulse power instabilities measurements as well as for registration system triggering.

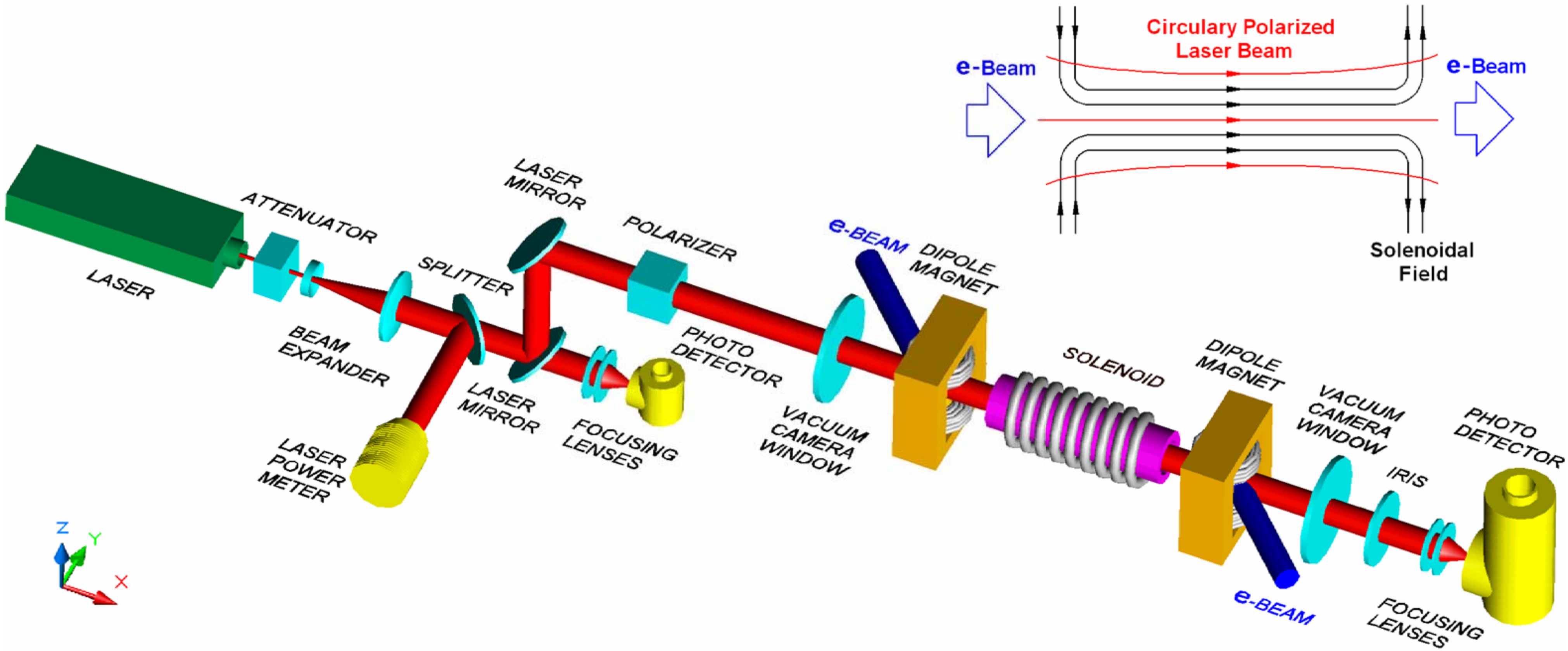

Fig.5. The optical setup for electron beam average absolute energy measurement by RA method.

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ELECTRON BEAM BUNCH-TO-BUNCH ABSOLUTE ENERGY MEASUREMENT BY RESONANT ABSORPTION METHOD

A.S. Ghalumyan, V.T. Nikoghosyan.

The measurement of electron beam bunch-to-bunch absolute energy with accuracy of the order of 10^{-4} is important for some experimental programs. It can be used for real time and continuous electron energy monitoring during experiments.

Development of the theory [1,2,3] shows the possibility of the electron beam absolute energy measurement using the superposition of the laser beam and magnetic field. It is important to analyze and develop the experimental conditions that will allow measuring the electron beam absolute energy by state of the art equipment.

The electron beam absolute energy measurement methods using the superposition of the laser beam and magnetic field are based on the phenomena that energy of the electron beam in a magnetic field has a discrete spectrum. Two methods based on this phenomenon are mentioned in the literature.

The method is based on the absorption [1] of the laser beam energy by electrons in the magnetic field. The laser beam can be absorbed by electron beam being in resonance with electron energetic levels. Theoretically is shown [1] and detailed analyzed [2] the possibility of measurement of the electron absolute energy by means of the measurement of the electrons absorption spectrum in dependence from magnetic field induction.

During the period of 2008 have been analyzed the possibility of the experimental realization of the electron beam bunch-to-bunch absolute energy measurement by means of resonant absorption method including:

— Analyze of the experimental conditions needed for the electron beam bunch-to-bunch absolute energy measurement.

— Research and development of the setup technical requirements for the electron beam bunch-to-bunch absolute energy measurement.

— Investigation of the state of the art equipment and components for the electron beam bunch-to-bunch absolute energy measurements.

— Development of a setup for the electron beam bunch-to-bunch absolute energy measurement by means of the state of the art equipment.

— Proposal of the experimental realization of RA method for the electron beam bunch-to-bunch absolute energy measurement with accuracy of $<10^{-4}$.

— Is shown the reliability of the electron beam bunch-to-bunch absolute energy measurement by RA method by means of the state of the art equipment.

— Considered and indicated the main parameters of the equipment needed for elaboration and showed their definition ways.

— Report "Electron Beam Bunch-To-Bunch Energy Measurement By Differential Absorption Method" on the "Workshop on Energy and Polarization Measurement at the ILC" in Zeuthen DESY [4] (Appendix).

In the future it is planned to investigate and develop the estimations of experimental conditions for the experimental realization of the electron bunch-to-bunch energy measurement by resonant absorption method with accuracy of $<10^{-4}$. Develop the experimental conditions for realization of the method by means of existing in the world electron accelerators.

1. The Choice Of The Setup Technical Requirements For The Electron Beam Bunch-To-Bunch Absolute Energy Measurement

To reach the absorption of photons by electrons a magnetic field is needed to induce corresponding electron energetic levels. The levels of the electron energies to be measured dictate the solenoid magnetic field induction B value (Fig.1.).

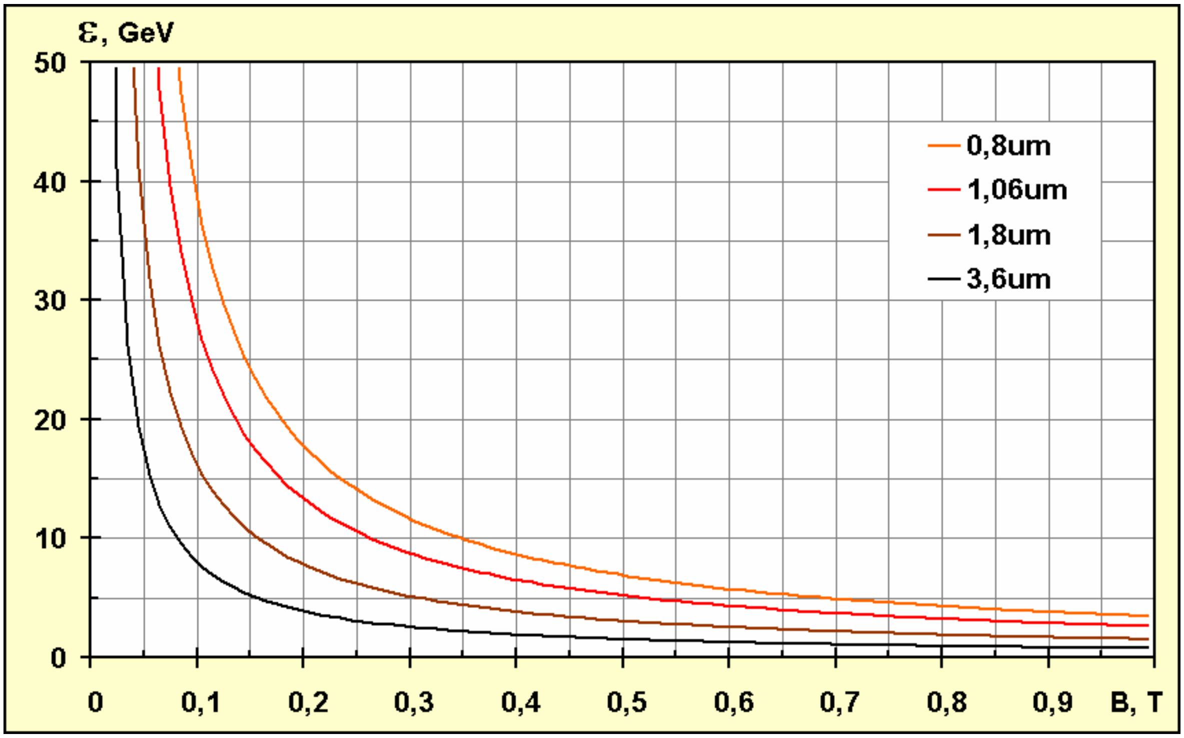


Fig.1. The dependence of the electron energy from the magnetic field induction for different laser wavelengths ($\theta = \varphi = 2$urad).

The estimations for the laser energy, its beam line width and the spectrometer resolution for measurement of the electron bunch energy with accuracy of 10^{-4} which have energy spread of 0.1% is presented in the Tab.1.

Tab.1.

Laser Type	**TiSa**	**Nd:YAG**	**Nd :YLF**	**OPO**
Wavelength, um	0.8	1.064	1.047	3.6
Bandwidth, nm	0.8	1.2	1.2	4
Repetition rate, Hz	5	5	5	5
Energy per pulse, J	10^{-3}	$1.3x10^{-3}$	$1.3x10^{-3}$	$4.3x10^{-3}$
Beam diameter, mm	1	1.3	1.3	4.4
Pulse duration, psec	20	20	20	20
Beam divergence, rad	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Spectrometer resolution, nm	0.04	0.05	0,05	0.2
Magnetic Field Induction, T	2,2	1.6	1.6	0.5
Focusing system focal length, m	1.3	1.3	1.3	1.3
Beams overlaps factor	$20x100^2$	$20x130^2$	$20x130^2$	$20x440^2$
Absorbed Energy , J	$4.97x10^{-9}$	$3.73x10^{-9}$	$3.79x10^{-9}$	$1.1x10^{-9}$
Electron Energy, GeV	1,5	1,5	1,5	1,5
Energy Resolution	$<9.2x10^{-5}$	$<9.5x10^{-5}$	$<9.5x10^{-5}$	$<9.1x10^{-5}$

2. The Optical Setup For The Electron Beam Bunch-To-Bunch Absolute Energy Measurement

Optical setup main components, units and equipment are shown on the Fig.2. The main difference from the optical setup for electron beam average energy measurement [4] is the existence of the spectrometer. Instead of a narrow line width laser here is used a broadband laser in accordance with the specifications indicated in the Tab.4.1. To measure the whole spectrum of one laser pulse is used a photo detector array or several photo detectors with parallel detection.

This optical setup (Fig.2.) will allow measuring the electron beam bunch-to-bunch absolute energy using the same laser beam several times.

Another version to measure the electron beam bunch-to-bunch absolute energy is the usage of a laser the repetition rate of which is equal to electron bunches repetition rate in the train. Here can be used not converted into second or forth harmonic part of the photo injector laser beam as shown on the Fig.3. With the help of dichroic mirrors not converted parts of the beam can be separated from the basic laser beam line. About 100uJ of the first harmonic and about 50uJ of the second harmonic of the laser beam is not used from PITZ photo injector laser. Can be noticed that the spatial and temporal characteristics of the photo injector laser are quite to electron beam characteristics as well as the synchronization of the laser pulses and electron bunches is solved. The main task here is the transportation of the laser beam to the electron beam energy measurement region.

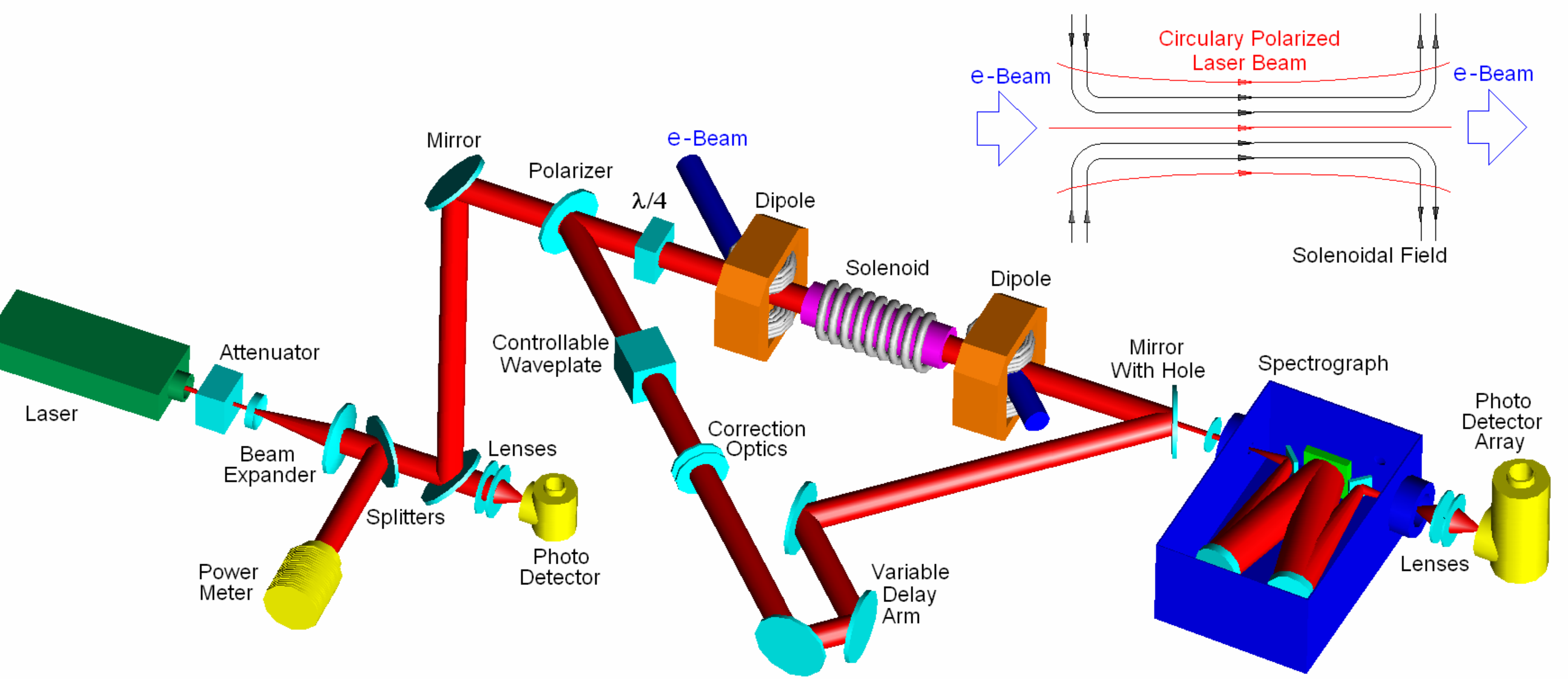


Fig.2. The optical setups for electron beam bunch-to-bunch absolute energy measurement by RA method.

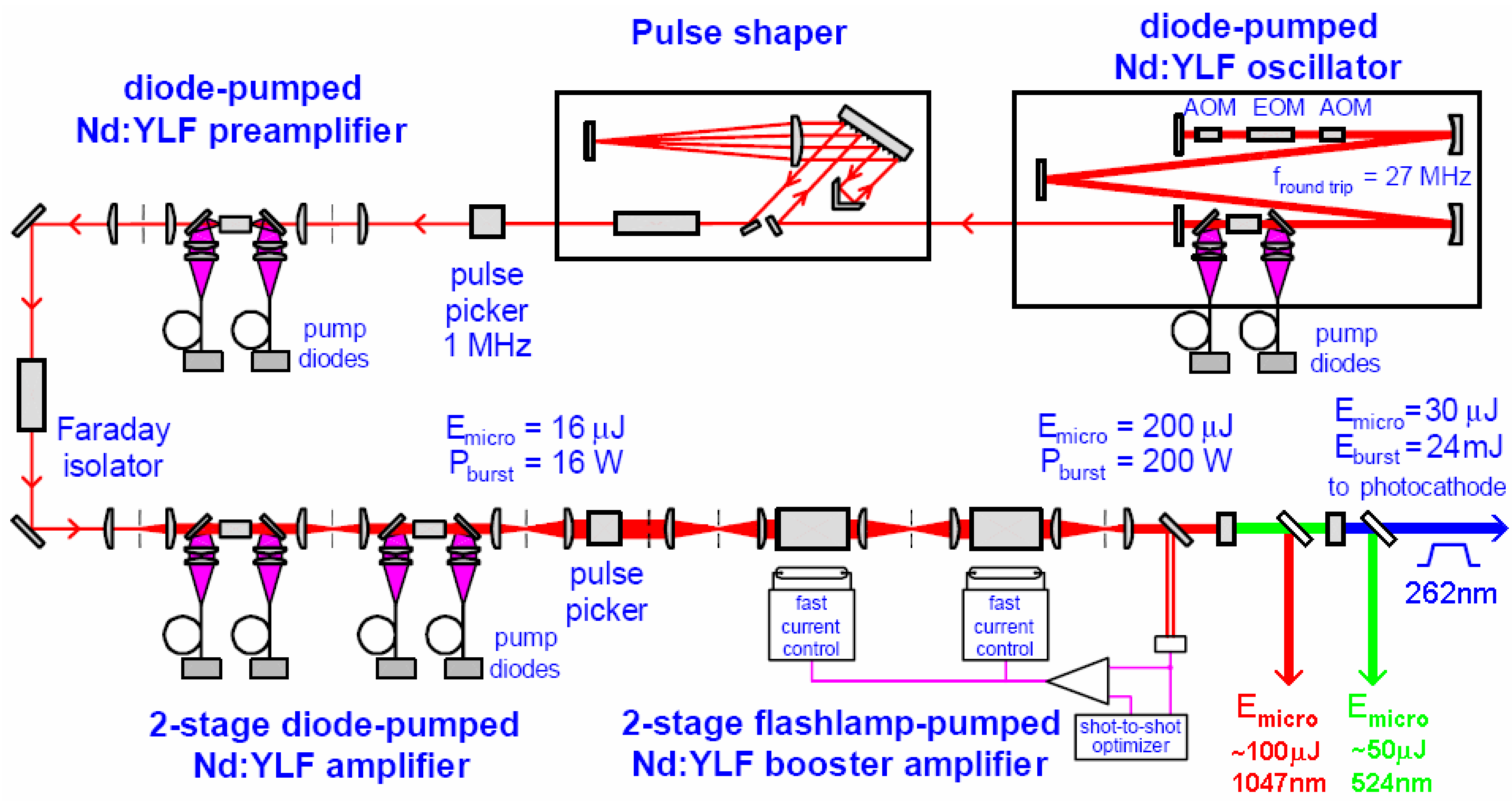


Fig.3. The optical setup of the PITZ photo injector laser.

3. References

1. D.P. Barber, R.A. Melikian. “On The Possibility Of Precise Measuring Of Electron Beam Energy Using Resonance Absorption Of Laser Wave By Electrons In Static Magnetic Field”. Proc. 7th EPAC, Vienna, 2000.

2. R.A. Melikian. “The Possibility Of Precise Measurement Of Absolute Energy Of The Electron Beam By means Of Resonance Absorption Method”. ILC Beam Energy Meeting. June 6-8, 2007, Zeuthen.
http://www-zeuthen.desy.de/e_spec/june2007/robert_melikian.pdf

3. R.A. Melikian. “Development of the Theory of Measurement of Electron Beam absolute Energy by Resonance Absorption Method”. Workshop on Energy and Polarization Measurement at the ILC, April 9-11, 2008, Zeuthen, DESY.
https://indico.desy.de/

4. A.S.Ghalumyan, V.T. Nikoghosyan. “Electron Beam Absolute Energy Measurement Realization Possibility By Resonant Absorption Method”. ILC Beam Energy Meeting. June 6-8, 2007, Zeuthen, DESY.
http://www-zeuthen.desy.de/e_spec/june2007/arsen_ghalumyan.pdf

5. A.S.Ghalumyan, V.T. Nikoghosyan. “Electron Beam Bunch-To-Bunch Energy Measurement By Differential Absorption Method”. Workshop on Energy and Polarization Measurement at the ILC, April 9-11, 2008, Zeuthen, DESY.
https://indico.desy.de/

Proposal includes:

- Analysis of the experimental condition needed for the electron beam absolute energy measurement.
- R&D of the setup technical requirements.
- Study of the state of art equipment and components needed for experiment.
- Design of the setup.

In the near future we are planning to estimate of the experimental conditions needed for the experiment of bunch-to-bunch energy measurement.

4. Synchrotron operation modes in 2010-2014 by requests of experimental groups.

There are the following requests of synchrotron operation modes:

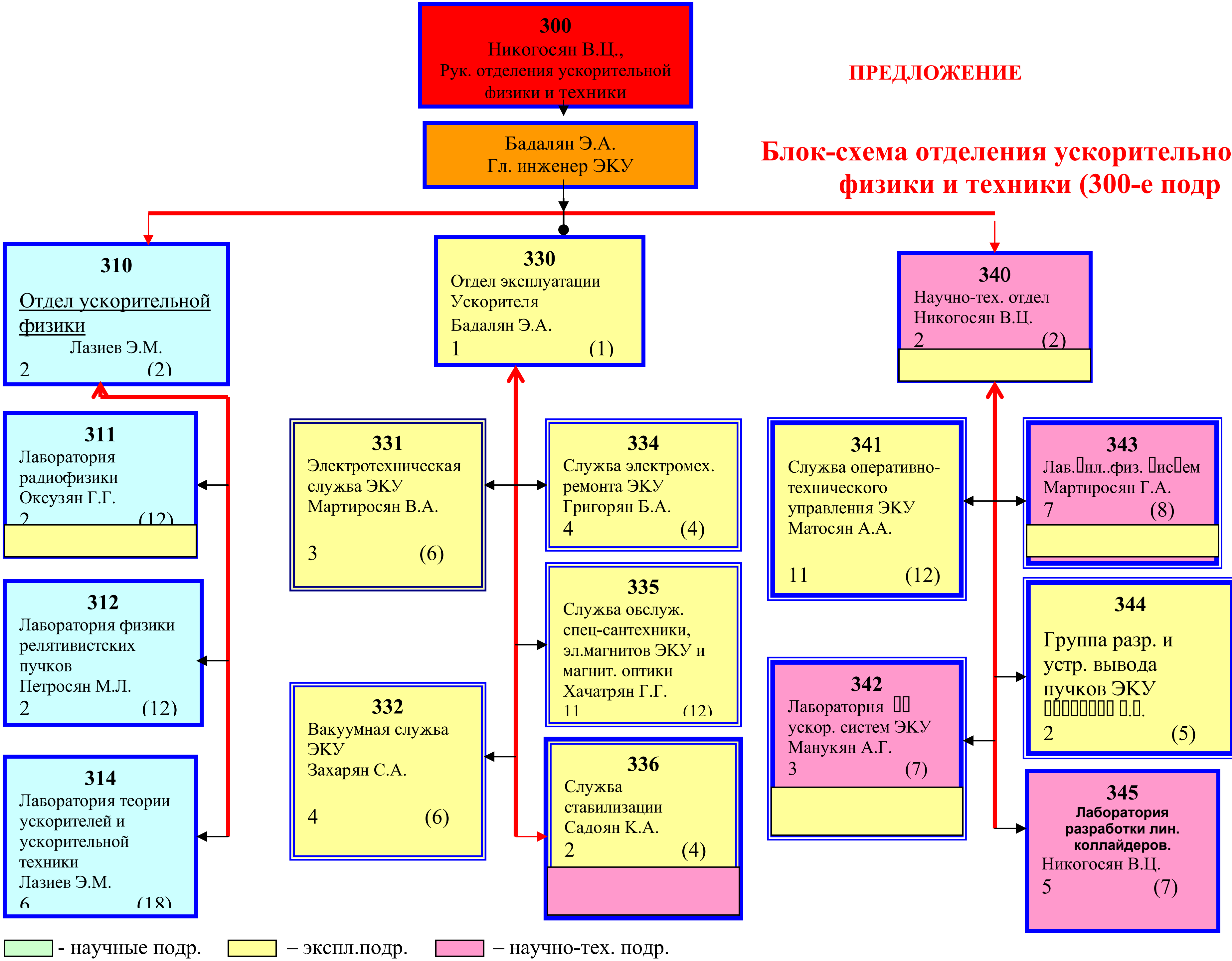
<u>Численность эксплуатационного персонала ЭКУ</u>

N подразделения	Численность имеющегося персонала	Необходимое кол-во при работе ЭКУ	Нехватка персонала при работе ЭКУ	Примечание
330	1	1	0	
331	3	6	3	
332	4	6	2	
334	4	4	0	
335	11	12	1	
336	2	4	2	
340	2	2	0	
341	11	12	1	
342	4	6	2	
343	7	8	1	
344	2	5	3	
ИТОГО:	53	77	15	

Суммарная зарплата на март 2009 г. =
Суммарная зарплата во время работы
ускорителя в режиме 1,5 ГеВ и выше = 4.620.000 драм

ПРЕДЛОЖЕНИЕ

Блок-схема отделения ускорительной физики и техники (300-е подр



Себестоимость работы ЭКУ в течение 1 месяца (в зависимости от энергии ускоряющего пучка)

Режим	**Эл. энергия**			**Вода питьевая**			**Вода аретезиан.**			**Материалы**		**Зарплата**		**Итого**		**Числ. э.п.**
работы	квтч	т.драм	$	M^3	т.драм	$	M^3	т.драм	$	т.драм	$	т.драм	$	т.драм	$	
0,05 кВт	**35000**	**595**	**1608**	**-**	**-**	**-**	**-**	**-**	**-**	**185**	**500**	**1628**	**4400**	**2408**	**6508**	22
0,3 ГэВ	**60000**	**1020**	**2733**	**-**	**-**	**-**	**-**	**-**	**-**	**60**	**160**	**2160**	**6000**	**3240**	**9000**	30
0,5 ГэВ	**158666**	**2697**	**7492**	**500**	**28**	**78**	**-**	**-**	**-**	**60**	**160**	**3600**	**10000**	**11882**	**17730**	50
1,5 ГэВ	**476000**	**8092**	**22477**	**500**	**28**	**78**	**-**	**-**	**-**	**180**	**500**	**5544**	**15400**	**13844**	**38455**	77
2,0 ГЭв	**634666**	**10789**	**29160**	**1000**	**56**	**156**	**-**	**-**	**-**	**360**	**1000**	**5544**	**15400**	**16749**	**45267**	77
2,5 ГэВ	**793332**	**13486**	**36450**	**1000**	**56**	**156**	**-**	**-**	**-**	**360**	**1000**	**5544**	**15400**	**19446**	**52556**	77
3,0 ГэВ	**885600**	**15055**	**41819**	**1000**	**56**	**156**	**6000**	**120**	**334**	**1375**	**3825**	**5544**	**15400**	**22150**	**61527**	77
3,5 ГэВ	**1029600**	**17503**	**48691**	**1000**	**56**	**156**	**6000**	**120**	**334**	**1375**	**3825**	**5544**	**15400**	**24598**	**66481**	77
4,0 ГэВ	**1209600**	**20563**	**57204**	**1000**	**56**	**156**	**6000**	**120**	**334**	**1375**	**3825**	**5544**	**15400**	**27658**	**74751**	77
4,5 ГэВ	**1353600**	**23011**	**64014**	**1000**	**56**	**156**	**6000**	**120**	**334**	**1375**	**3825**	**5544**	**15400**	**30106**	**81367**	77
Профи-лактика	**158666**	**2697**	**7492**	**500**	**28**	**78**	**-**	**-**	**-**	**60**	**160**	**3600**	**10000**	**11882**	**17730**	50
Консер-вация	**40000**	**680**	**1837**	**500**	**28**	**78**	**-**	**-**	**-**	**-**	**-**	**1800**	**5000**	**2508**	**6778**	25

Стоимости: 1 квтчас эл. энергии - 17 драм

1 м^3 питьевой воды - 56 драм

1 м^3 артезиан. воды - 20 драм

1$ = 360 ÷ 370 драм

Electron energy:

Модернизация синхротронного комплекса для работы в режиме 25, 50, 75, 500 MeV;

(V.Nikoghosyan, H.Martirpsyan, K.Sadoyan

Планируемая модернизация синхротронного комплекса направлена на создание интенсивных низкоэнергетических электронных и γ-пучков с высоким значением “duty” фактора. Генерируемые потоки пучков предназначены для проведения физических экспериментов в энергетическом диапазоне 50-500 MeV.

Модернизация охватывает основные узлы синхротронного комплекса:

1. **Линейный ускоритель электронов (инжектор).**

1.1. Замена катода электронной пушки катодом с повышенной эмиссией.

1.2. Увеличение длительности импульса электронной пушки до 2,0 μs.

1.3. Разработка и внедрение статического источника питания инжектора с высокой эффективностью и стабильностью:

мощность P=70 kVA; выходное напряжение U_n=380 V ±0,05% U_n.

Коэффициент полезного действия η = 96%.

2. **Тракт ввода.**

Установка второго инфлектора для осуществления двухоборотной инжекции электронного пучка линейного ускорителя, что приведет к увеличению тока циркулирующих электронов в синхротроне ~ в 2 раза.

3. **Система питания кольцевого электромагнита синхротрона.**

Создание прецизионных источников постоянного и переменного тока, посредством которых осуществляются режимы работы синхротрона:

- накопительный режим – в энергетическом диапазоне 50-70 MeV,
- ускорительный режим – в энергетическом диапазоне 70 – 500 MeV.

4. **Ускоряющая система синхротрона.**

Установка в прямолинейном промежутке между магнитными блоками N и N ускоряющей станции на 466,1 MHz, обеспечивающей высокую эффективность ускорения электронов до энергии 600 MeV в течение $7\cdot10^{-3}$ s (10^4 оборотов пучка в синхротроне).

5. **Вывод циркулирующего пучка.**

Разработана универсальная система вывода, которая формирует равномерные потоки γ-пучков при работе синхротрона в режимах накопления и ускорения электронов до энергии 500 MeV. Функционально система вывода состоит из:

- Системы «бим-бамп» , собранной на 4-х фокусирующих полублоках электромагнита;
- Системы формирования токов в обмотках выводных полублоков;
- Системы измерения и регистрации интенсивностей потоков γ-пучков;
- Синтезатора программ управления процессами вывода γ-пучков.

Модернизация системы вывода обеспечит равномерность выведенных пучков σ <12% при длительности вывода до 5 ms.

6. Система коррекции магнитного поля синхротрона.

Коррекция магнитного поля синхротрона на уровне инжекции осуществляется программно управляемыми источниками постоянного тока. Критериями оптимизации системы коррекции являются максимальное заполнение равновесной орбиты инжектируемым пучком и минимальная величина начальных амплитуд бетатронных колебаний.

Ожидаемые величины параметров пучка, захваченного в режим циркуляции:

- коэффициент заполнения орбиты - не менее 70 %
- начальные амплитуды бетатронных колебаний – не более 2 sm.

7. Система управления процессами синхротрона.

7.1. Накопительный режим.

Алгоритм управления процессами в этом режиме предусматривает следующую последовательность управления синхротронного комплекса:

- формирование инжекторного пучка,
- запуск системы ввода и захват частиц в накопительный режим,
- запуск систем вывода и коррекции.

7.2. Ускорительный режим.

Система управления запускается в момент достижения магнитным полем синхротрона величины, соответствующего энергии инжектируемого пучка. Дальнейшее управление процессами осуществляется аналогично накопительному режиму.

The supporting equipment will be developed and manufactured

1.5 GeV; 4.5 GeV - Для проведения физических экспериментов при этих энергиях ускоритель будет работать в обычных для синхротрона режимах:

For putting synchrotron into operation needs 3-4 months of preparatory services.

5. Proposed R&D in the field of accelerators during 2010-2014

R&D high average power (a few kW) THz FELs by using of the Yerevan synchrotron's existing systems (M.Petrosyan).

1. **R&D of terahertz FEL with the average power about KW on the base of the main system of Yerevan Synchrotron.**

The project realization permits one:

- To have a powerful FEL in the World.
- To save the Synchrotron for future investigations on high-energy physics, all the systems of which will be used in this FEL and won't be change and will be saved with previous parameters.
- To use the skilled personnel on the Synchrotron.

It is supposed to use the UH system of YerPhI Synchrotron as an accelerator device. The average power of UH generator is 40 KW. The bending magnets will be supplied with the current, which changes in accordance with the beam energy increasing.

The main parameters of FEL are the following:

electron energy (with 13 resonators)	5 MeV
electron beam pulse duration	4msec
beam current amplitude per bunch	5 mA
pulse repetition rate	50Hz
radiation wavelength	0.2 mm
electron beam power per bunch	up to 200 kW
average value of the power	up to 40 kW
terahertz radiation power per bunch	up to 1.6 kW
average value of the terahertz radiation	up to 0.5 kW
undulator magnet's length	2.5 m
periodic number of the undulator	62
amplification coefficientof the undulator	35%
coefficient of the losses in optical resonator	15%
beam diameter in the undulator	5 mm

Depending on the further planes of YerPhI it may be realized variant of straightforward installation of the resonators as well.

2. R&D of the source of quasi monochromatic γ-radiation in Yerevan synchrotron

(the Proposal is developed jointly with the division SD1)

R&D of quasy-monocromatic and polarized γ-radiation sources by using the inverse compton effect on the base of the existing facilities and equipment (the electron synchrotron, electron microtron, 400 J pulse CO_2 laser and the periodic pulse laser with average power of 1 kW PPL-1).

Such sources because of its monochromaticity and polarized γ quantum have an important value in many fields of nuclear physics, in elementary particles physics, particularly, in

- the investigations of photonuclear processes near the gigantic resonance and photo fission and for the research of photodisintegration and photo fission to mark out magnet and electrical modes of the perturbations, the reaction of the nucleus direct withdraw and investigations of the cluster structure of light nucleus
- .the investigations of the processes of meson photo production at the resonance energy;
- carry out the experiments to verify the predictions of non-linear quantum electrodynamics: non-linear Compton scattering the photon splitting and Delbruc's scattering in strong Coulomb field;
- working of the method to receive high-energy γ quantum and polarized positrons for the further linear colliders.

Channel's parameters

	Parameters of the devices	YerPhI	E-144
1.	Electron energy	4.5 GeV	45.6 GeV
2.	Energy of the γ quantum	36 MeV	
3.	Laser wave length	10.6 μm	1.06 μm
4.	Energy per bunch	400 J	1.2 J
5.	Laser pulse duration	0.1 nsec	1 pcsec
6.	Laser beam cross section	10^{-2} cm^2	$8 \cdot 10^{-7}$ cm^2
7.	Intensity of laser beam	$4 \cdot 10^{14}$ W/ cm^2	$8 \cdot 10^{18}$ W/ cm^2
8.	Intensity parameter of the wave ξ	0.13	0.6
9.	Radiation energy maximum shift	0.6 MeV	
10.	Intensity of the I harmonic	$4 \cdot 10^{7}$ γ/sec	
11.	Intensity of the II harmonic	$2 \cdot 10^{6}$ γ/sec	
12.	Intensity of the III harmonic	10^{5} γ/sec	

To optimize parameters of γ beam to carry out some experiments there are possible another regimes as well with the difference frequencies of laser and accelerator launching. These regimes will be considered more detailed in technical project of γ channel.

The Proposal for the Microtron

The status of the accelerators in lab.312

There are 4 microtrons and 1 high high-voltage pulse accelerators with energy 1 MeV.

- **Microtron M-7.5** – energy 7.5 MeV, the average current 2 μA (it is possible regime with the current 40 μA). It is under the exploitation. The some investigations of the interaction between the electromagnetic wave and electron beams of microtron have been carried out. It also has been used in radiation technology problems. 4 ISTC Projects have been completed using this device. At present the investigations on the FEL manufacturing using the Smith-Parcel effect on the microtron electron beam are carrying out.
- **Microtron M-7.5** – energy 7.5 MeV, the average current 2 μA. Has been launched in 1980. It was created for sale.
- **Microtron M-25** – energy 25 MeV, the average current 20 μA. Radiation safety isn't permit to launch Microtron.
- **Microtron M-25** – energy 25 MeV, the average current 20 μA. Is completed about 50%. It was created for sale.
- **Pulse accelerator**. Energy 1 MeV, current per pulse 100 A.Was created and used for the investigations to develope the new accelerating methods.

The following additional Proposals to the Microtron are suggested

1. Educational centre**. In 1974-1976 some practical training on accelerator physics has been carried out on the Microtron for the students of Yerevan State University. Now Microtron is supplied with the contemporary computer control system DOCS. 3 specialists are prepared already on DOCS for DESY.**
2. **Quasimonochromatic and polarized source of the radiation** based on Compton effect. For the last years takes on special significance the investigations of the dynamic processes by the short photon bunches in the solid medium and biology. It is supposed to use the powerful pulse CO_2 and NdYag lasers existing in laboratory. At energy of electrons 3-20 MeV one may receive photons with the energy 17-700 eV. Photons intensity per pulse will be $7 \cdot 10^{13}$ photon /second.
3. To create a source of THz radiation (100-300 μm) by using the undulator radiation on the base of microtron. These investigations have been begun in the frame of the ISTC project and the main devices were created.

R&D of quasy-monocromatic and polarized γ-radiation sources by using the inverse compton effect on the base of the existing facilities and equipment (the electron synchrotron, electron microtron, 400 J pulse CO_2 laser and the periodic pulse laser with average power of 1 kW PPL-1) (M.Petrosyan).

R&D of THz sources (M.Petrosyan).
Proposed to create a source of THz radiation (100-300 μm) by using the undulator radiation on the base of microtron. These investigations have been begun in the frame of the ISTC project and the main devices were created.

R&D of a high current (~1 MeV) technological electron source (E.Laziev, V.Nikoghosyan)
It is proposed to use the existing electron gun (150 keV, 10 A) and 466 MHz accelerating module.

Fig.1. electron gun with 150 keV, 10 A parameters

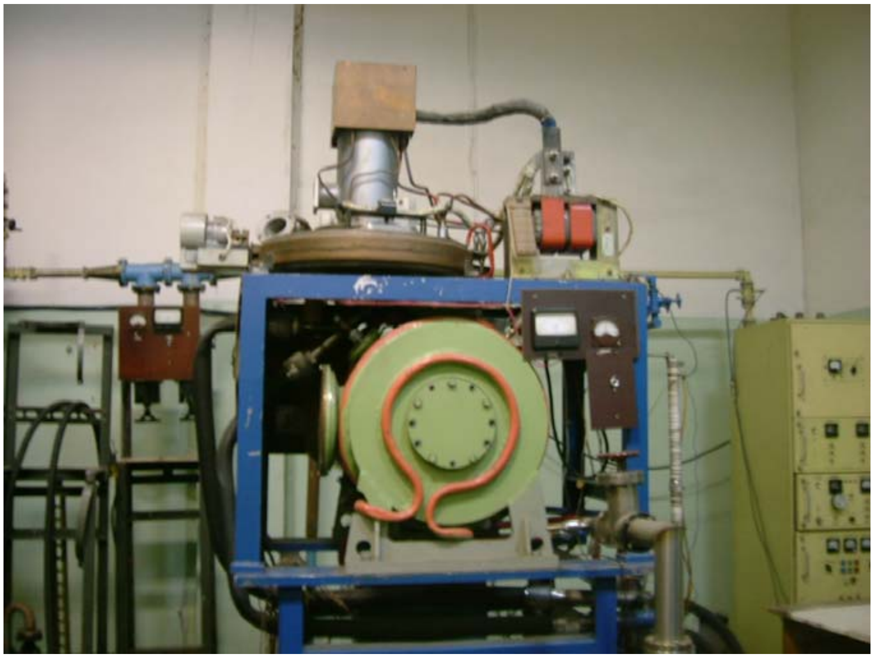


Fig.2. 466 MHz accelerating module

R&D of the electron bunch "Femtoslicing" Project (E.Gazazyan).
The Proposal of the "Femtoslising" experiment at YerPhI will be presented.
Upgrade and update of the synchrotron systems

R&D of the high current (~1 MeV) technological electron source

R&D of the electron bunch "Femtoslicing" Project.

R&D will begin from the consideration of the physical aspects of the electron bunch density modulation phenomenon caused by the bunch interaction with linear polarized electromagnetic wave which propagates along or opposite (the two cases will be considered as well) to the direction of electron bunch's motion. This problem is valuable from the viewpoint of examining the possibility a) of bunch slicing (at very high depth of modulation) into shorter bunches (sub-bunches) as well as the bunches density condensing with high charge density to receive a sequence of ultrashort bunches and b) the single condensed electron bunch forming.

The problems noticed above confirm that to observe efficiency slicing one will use the fields with the strengths $10^9 - 10^{10}$ V/m. Such values may be achieved by femtosecond lasers. One will hope that after the interaction between such lasers with the short electron bunches will be received the periodical train of coherent ultrashort bunches as a result of the slicing effect.

The second direction of the investigations concerns with the particle-wave opposite motion. The investigations noticed above predict that at this case may be received the condensed bunches with high charge density in them.

Thus, we propose:

- To develop the measurement schemes with the femtosecond lasers to study the bunch slicing or condensing effects with detailed analysis of the components of these devices and expected results as well.
- To study of the energy spread of the subbunches which are got after the slicing effect as well as the condensed bunch at opposite particle-wave motion.
- Development of the experiment's Proposal by using of the finding results. Initially we are planning to use of the existing 7 MeV microtron.

<u>R&D of the beam's diagnostic tools</u>

<u>Study of the electrodynamical properties of a toroidal resonator and its possible applications</u>

The toroidal resonator's own modes calculation is a hard theoretical problem, which is connected with the separation problems of the variables in toroidal system of coordinates to have a possibility to represent the electromagnetic oscillations as E- and H-type of the waves in toroid to receive the expressions for the fields. Two approaches have been applied to solve this problem: an approximate method (the uniform asymptotical expansion [2.3]) and the strict method [4]. Both of these methods are based on the assumption that the toroid will be filled with the dielectric medium having the toroidal inhomogeneity, which permits one to o separate the variables in Maxwell's equations. It will be noticed very important feature of this dielectric: for enough large toroid it transforms into the homogeneity medium and approximate well the empty toroid (dielectric constant becomes equal to 1).

We will consider the strict solution of the problem. One has shown that the received own functions may be represented in the orthogonality form (the orthogonality with some weight), which permits to consider, for example, the Magnet Bremsstrahlung effect of an electron (of an electron bunch), which is moving along the toroidal cavity axis under the influence of an external uniform magnetic field. It is supposed that the charged particle is moving in the toroid for finite time and then is vanished having made the finite number of the circulations in it. We suppose to receive self-consistent solutions of this problem.

The next problems are in prospect during discussing the demanded subject of the investigations:

- R&D of the algorithms and programs to calculate the own values (the own frequencies of the radiated field in the cavity) using code MATLAB;
- R&D to construct the own functions for both of types (E- and H) in the cavity using also the code MATLAB;
- The investigations of the influence of the radiated Magnet Bremsstrahlung fields on the radiated particle motion to construct the self consistent solutions;
- To consider a possibility to change the value of the external magnet field keeping the radiated particle into the cavity as long as it may be possible.

Preparation of the experiment "Electron beam absolute energy measurement in the 50-500 MeV energy range by resonance absorption method at Yerevan synchrotron"

Prolongation of the YerPhI-DESY collaboration according to "2009-2011 Agreement of Cooperation" including:

- Investigation of beam dynamics problems;
- R&D of power supplies for magnets;
- Improvement and test of the control system DOOCS for its further usage in accelerators storage rings and colliders;
- Pre-feasibility of the THz FELs driven by the low energy electron beam;
- Testing and examination of equipment in different location, including radioactive zones;
- Assembling and commissioning of accelerator equipment such as vacuum systems, magnet and control systems at DESY

International collaboration

The International scientific and technical collaboration is an integral part of YerPhI accelerator department activity. At present the department collaborates mainly with German acceleration centre DESY, as well as with Russian Federation Institutes – SRIERA (St.Petersburg), JINR (Dubna), MRTI, ANSALOO-VEI (Moscow), etc.

We would like to emphasize the multilateral co-operation with DESY, which was started since 1987, and rather effectively continues up to now. During the period of 1987-92 (Soviet Union time) the main efforts in our joint works have been directed to implementation of the programs of modernization of synchrotron systems, including:

- power supply system development of the methods for the magnet field flat-top formation;
- vacuum system – improvement of the methods of diagnostics and maintenance;

- RF-system – working out of the program for the improvement and raising of operation efficiency;
- Development and design of the stretcher-storage ring.

Since 1992, after SU collapse, management of DESY has greatly supported and provided regular financial assistance to Yerevan Physics Institute. During the last 20 years the young specialists from YerPhI have passed training on the modern accelerator systems at DESY. They are participated in the works on HERA, in the design of new equipment and software for accelerators, in particular for the TTF/VUV-FEL, as well as for the control system, made beam dynamics calculations for XFEL/ILC. Since 1987 the leading scientists and engineers have been receiving grants from DESY, which allow them to work in the sphere of advanced accelerator science and technic. Beside that accelerator department has received orders from DESY on development and building of the power supplies. In the period from 1993 to 2003 the 15 units of DC power supplies on 500A/100V have been built and shipped to DESY for use in DESY accelerator systems. At present the works on development and building of the new, digital remote controlled power supplies in Yerevan synchrotron PS laboratory are progressing.

The works on other programs are successful as well.

As a result of collaboration with DESY the new method of precise measurement of electron beam energy in range of several hundreds GeV for prospective experiments on ILC has been proposed. These offers have been published at the International Conferences (SPIN-1998, Protvino and 2000, EPAC-2000, Vienna).

In connection with existing interest to this problem this method has been developed by us during 2004-2008 within the framework of International Collaboration (DESY, Zeuthen; Dubna, Novosibirsk, Russia; SLAC, USA; London, UK; YerPhI, Armenia). The results of these researches have been reported and discussed in the «Meetings on Measurement of Electron Beam Energy», which were periodically organized in DESY (Zeuthen), in Dubna and in YerPhI, and are published in proceedings of these meetings and "Workshop" (9 reports).

In the framework of the Cooperation between DESY and YerPhI the model of permanent magnet wiggler is developed, allowing to optimize the design of wiggler, including optimization of the pole shape to improve a field quality [1,2]. In framework of EuroTev collaboration jointly with INFN-LNF (Frascati) the new design large aperture wiggler has been developed to reduce of nonlinearity $\Delta B/B_0$ more than an order of magnitude by relatively small overall dimensions of the wiggler[3,4]. By results of executed works the YerPhI is included in ILC Damping Rings R&D Activities list by

Institution. Improvements of model of a wiggler for optimization of wiggler design and poles shape will be continued to improve a field quality and also will be considered use of model of a wiggler for optimization of design of the undulator.

Let's note in addition we are planning to consider also a possibility to accelerate heavy ions (in particular, carbon) by Yerevan synchrotron taking into account a number of realistic prerequisites available in YerPhI:

- ***Possible production of the isotopes for medical purposes.***
- ***Possibility to purchase the tomography (PET).***

Yerevan Physics Institute is a unique scientific centre in the region, representing accelerator complex with the corresponding infrastructure and highly qualified staff members.

The indispensable condition of synchrotron reconstruction is preservation of the possibility of acceleration of electrons, which is necessary to continue conducting the adopted in YerPhI fundamental researches on the accelerated electron beams at the energy up to the 5 GeV.

As a result of realization of the proposed Project the regional centre of radiation therapy would be founded in Armenia.