Magnets

N.A.Morozov

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Magnets

Warm magnets with ferromagnetic core concept

Advantages:

- · simple and low cost design and
- manufacturing
- ·high reliability and preparation for
- operational condition
- · low cost operation
- · simple access to the magnets working
- space and equipment alignment
- · short time of realization

Magnets

Warm magnets with
ferromagnetic core concept

Problems:

- temperature stabilization
- adjustment of zero field
- hysteresis effects

Magnets

- Requirements

- resolution of $\Delta\int Bdl/\int Bdl < 2\times10^{-5}$
- reproducibility of $\Delta\int Bdl/\int Bdl < 2\times10^{-5}$
- electron beam energy E = (45 – 400) GeV
- deflection angle 1 mrad (0.5 mrad for ancillary magnets)
- distance between magnets 10 m

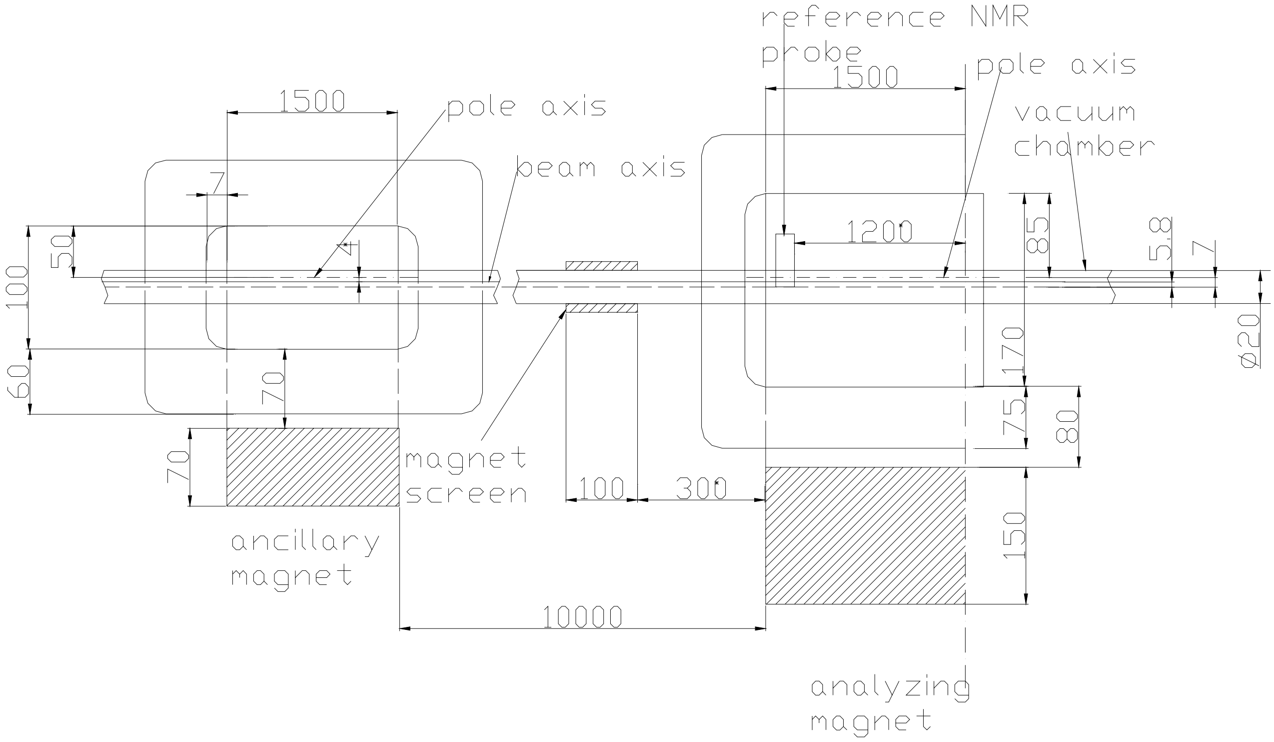
Magnets

- The basic objective of the project ($\Delta\int Bdl/\int Bdl \sim 2\times10^{-5}$)

  ▪

- experience of SLC, LEP and CEBAF
- corresponding design
- accurate manufacturing
- two independent magnetic field measurements technique at laboratory conditions
- two independent magnetic field measurements technique at working conditions
- magnet temperature and excitation current stabilization
- special demagnetization and ramp excitation current procedure

Plan view of the magnet system

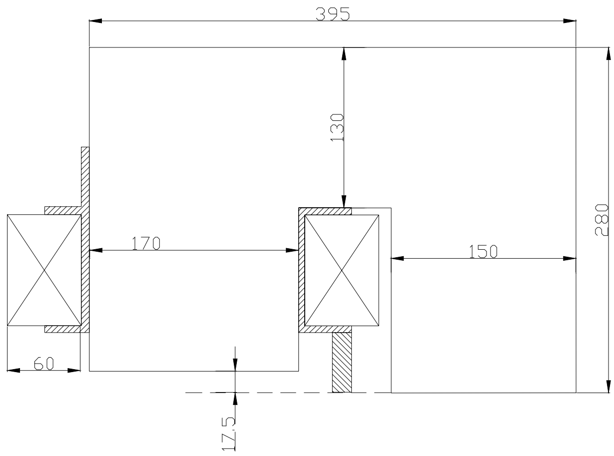


Basic spectrometers magnet parameters

	SLC	LEP	CEBAF	TESLA (Proposal)
Energy E (GeV)	42 - 50	40 - 100	0.5 – 7	45 - 400
Relative accuracy of energy measurement ΔE/E	5×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4} - 5×10^{-5}
Bending angle (mrad)	18.286	3.75		1
Magnetic field range (T)	0.88 – 1.1	0.086 – 0.216	0.04 – 0.6	0.05 – 0.44
Magnetic field integral (T•m)	2.56 – 3.05	0.5 – 1.242	0.12 – 1.8	0.15 – 1.33
Magnetic measurement error of the field integral (relative)	7×10^{-5}	3×10^{-5}	1×10^{-5}	$\sim 2\times10^{-5}$
Magnet iron length (m)	2.5	5.75	3	3
Effective magnet length (m)				3.045
Gap height (mm)	31.7	100	25.4	35
Magnet type	H	C	C	C
Laboratory ∫B•dl measurement technique	Moving wire, moving probe (NMR, Hall)	Moving probe (NMR, Hall), search coil	NMR probe, 2 search coils	Moving probe (NMR, Hall) , search coil
Operational ∫B•dl measurement technique	Flip coil, fixed probes (NMR)	Fixed probes (NMR)		Fixed probes (NMR), moving wire
Energy loss due to synchrotron radiation (max) (MeV)		3.55		0.02 - 120

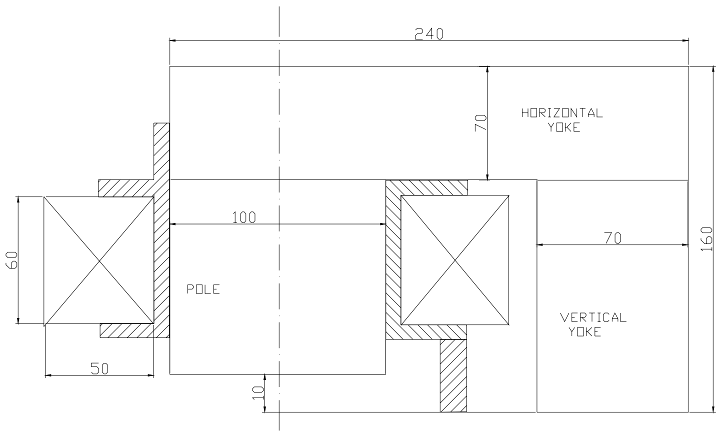
Analyzing magnet

- Iron length 3 m
- Pole gap 35 mm
- C-type
- Iron core from two parts
- Water cooled coil
- Common uniformity region (20 ppm) 11 mm



Ancillary magnet

- Iron length 1.5 m
- Pole gap 20 mm
- C-type
- Iron core from five parts
- Water cooled coil
- Common uniformity region (20 ppm) 8 mm

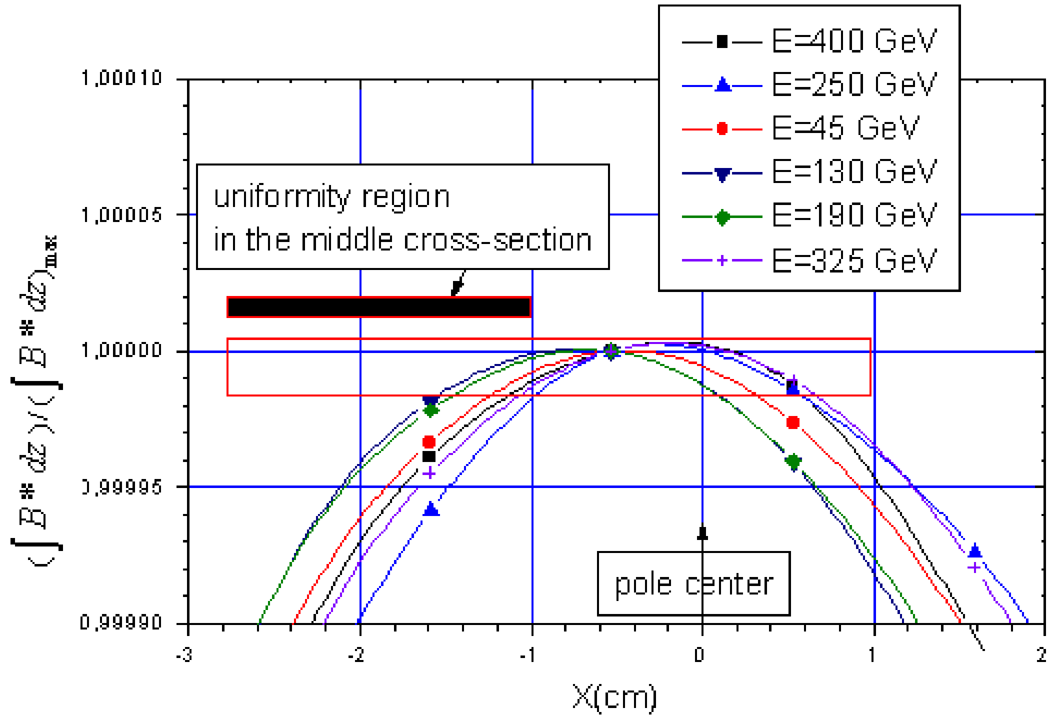


Basic technical parameters of the analyzing magnet

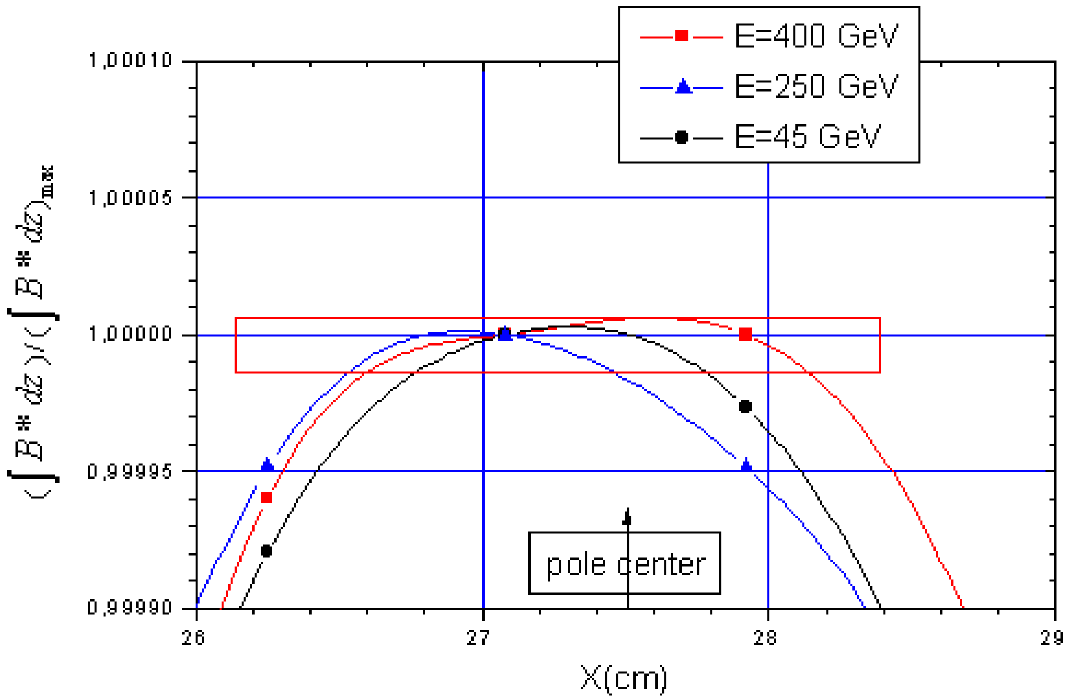
	Analyzing magnet
Magnetic field (min/max) (T)	0.05/0.44
Pole gap (mm)	35
Yoke type	C
Yoke dimensions (mm)	395×560×3000
Yoke weight (t)	4.51
A*turns (1 coil) (max)	6335
Number of turns (1 coil)	6*4=24
Conductor type	Cu, 12.5×12.5, ∅7.5
Conductor weight (t)	0.36
Coil current (max) (A)	264
Current density (max) (A/mm^2)	2.4
Coil voltage (max) (V)	13.3
Coils power dissipation (max) (kW)	3.5
Number of water cooling loops	6
Length of cooling loop (m)	56
Water input pressure (Bar)	6
Water input temperature (deg C)	30
Maximal temperature rise of the cooling water (deg C)	1.4

Basic technical parameters of the ancillary magnet

Magnetic field (min/max) (T)	0.05/0.44
Pole gap (mm)	20
Pole length (mm)	1500
Magnetic field integral (T•m)	0.075/0.665
Magnetic measurement error of the field integral (relative)	$(2\text{-}5)\times10^{-4}$
Energy loss due to synchrotron radiation (max) (MeV)	0.01 - 60
Yoke type	C
Yoke dimensions (mm)	240×320×1500
Yoke weight (t)	0.73
A*turns (1 coil) (max)	3600
Number of turns (1 coil)	6*5=30
Conductor type	Cu, 8.5×8.5, ∅5.3
Conductor weight (t)	0.09
Coil current (max) (A)	120
Current density (max) (A/mm^2)	2.4
Coil voltage (max) (V)	8.5
Coils power dissipation (max) (kW)	1.0
Number of water cooling loops	6
Length of cooling loop (m)	33
Water input pressure (Bar)	6
Water input temperature (deg C)	30
Maximal temperature rise of the cooling water (deg C)	0.7



Longitudinal magnetic field integral (normalized) for the analyzing magnet



Longitudinal magnetic field integral (normalized) for the ancillary magnet

Magnets tolerances

Manufacturing

- **Critical issue – pole gap tolerance for the analyzing magnet**
- **Maximal variation 0.04 mm**
- **Decreases the uniformity region for the magnetic field integral from 11 to 7 mm**
- **Shifts on 20 mm the predicted transverse position of the uniformity region**
- **Final data for the unformity region will be estimated during the magnetic field mesurement procedure**

Basic magnets manufacturing tolerances

Type of magnet	Analyzing	Ancillary
Poles gap (mm)	0.02	0.1
Pole width (mm)	0.2	0.2
Pole length (mm)	0.5	0.5
Coils vertical position (mm)	1	1
Coils horizontal position (mm)	1	1

Magnets tolerances

Magnets material

- **Material tests on**
  - **the chemical composition**
  - **cavity defects**
- **longitudinal magnetic field variation ≤20 ppm**

<u>Basic magnets material requirements</u>

Type of magnet	Analyzing	Ancillary
Type of steel (Russia)	St-10	St-10
μ_{max}	~3000	~3000
Variation of the steel chemical composition (C, Si, Mn) (%)	<5	<10
Cavity defects (mm^3)	<20	<50

Magnets tolerances

Design elements

- **vacuum pipe material – magnetic field change 60 ppm**
- **magnetic field measurements inside vacuum pipe**
- **NMR probe requires 19 mm diameter**
- **end field screens are lowering the field integral error from 20 ppm to 0.1 ppm**
- **external field along BPM measurement arm 0.1 mT – integral error 600-5000 ppm**
- **BPM pipe screening decreases integral error to 3-25 ppm**

<u>Basic design magnets elements requirements</u>

Type of magnet	Analyzing	Ancillary
Joining elements for magnets parts	Stainless steel for two parts	Usual design
Girder material	Stainless steel	Usual steel
Vacuum pipe material	Stainless steel	Stainless steel
μ_r	<1.005	1.01
Wall thickness (mm)	<0.5	1 – 2
End field screen material	Permalloy	-
μ_{max}	~28000	-
Thickness (mm)	0.5	-

Magnets tolerances

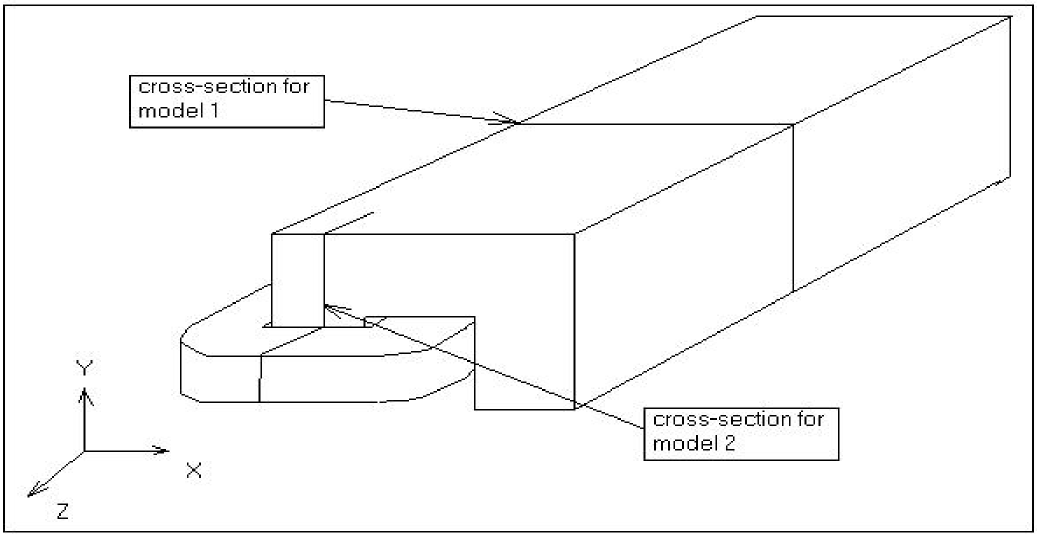
Magnets positioning

- **Easy to realize**

Tolerances for magnets positioning

Type of magnet	Analyzing	Ancillary
ΔX (mm)	0.5	0.5
ΔY (mm)	0.5	0.5
ΔZ (mm)	0.5	0.5
$\Delta\varphi_{xy}$ (mrad)	1	3
$\Delta\varphi_{xz}$ (mrad)	0.5	0.5
$\Delta\varphi_{yz}$ (mrad)	0.3	0.3

Magnets system of coordinates



Temperature stabilization

Temperature effects

- **variation of the magnet transverse geometry (particularly magnet gap)**
- **variation of the magnet longitudinal geometry (particularly magnet pole length)**
- **variation of the iron permeability**
- **summary magnet temperature factor (4.9-5.6) $*10^{-5}$ $1/^{o}C$**

Technical activity for the analyzing magnet temperature stabilization

- **stabilization of the inlet cooling water temperature with the accuracy 0.2 ^{o}C**
- **magnetic field point monitoring by the reference NMR probes (in 2 points)**
- **magnetic field integral monitoring by moving wire technique**
- **magnet iron core and current coils temperature monitoring by a set of temperature probes with accuracy 0.05 ^{o}C**

Magnets hysteresis and zero field effects

Hysteresis

LEP experience – field integral reproducibility 15 ppm by:

- **degausing cycles**
- **ramp**
- **bending modulation**
- **magnet temperature control**
- **magnetic field control by the reference NMR probes**

Zero field

Proposed to solve by:

- **degausing cycles**
- **zero control by mowing wire measurement technique**

Magnets power supplies

- **one for analyzing magnet**
- **one for two ancillary magnets connected in series**

Power supplies parameters

	Analyzing	Ancillary
Nominal current range (A)	30/265	13/120
Maximal current (A)	300	150
Nominal voltage range* (V)	1.4/13.3	2*(0.9/8.5)
Maximal voltage* (V)	15.1	2*10.6
Nominal power range* (kW)	0.04/3.5	2*(0.01/1)
Maximal power* (kW)	4.5	2*1.6
Long term current stability (ppm)	10	10

Cooling system

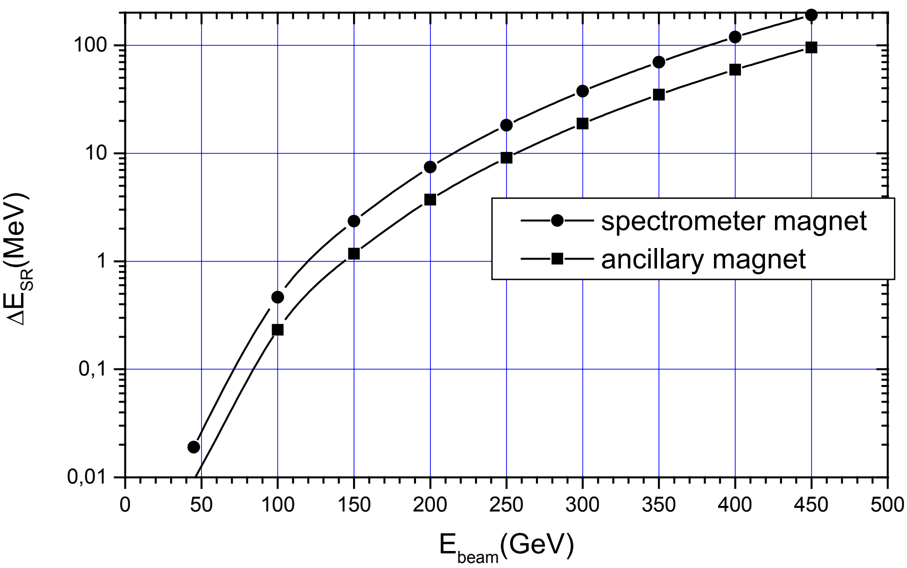
- **temperature stabilization of the inlet water with accuracy 0.2°C**
- **field integral variation no more 10 ppm**
- **such system realized in LEP**

Control system

- **power supplies**
- **analyzing magnet reference NMR probe**
- **analyzing magnet mowing wire measurement system**
- **analyzing magnet iron core and coil temperature monitoring control (~30 temperature sensors)**
- **system of the magnet cooling water stabilization**

Synchrotron radiation

- **electron beam energy loss → to be account at the energy calculation**
- **heat and radiation load for surrounding equipment**
- **shielding**



Energy loss due to synchrotron radiation

Magnets cost

The estimation conditions

- **the magnetic system design will be carried out in LNP JINR;**
- **the magnets manufacturing will be realized in JINR experimental shops;**
- **the magnetometer equipments manufacturing will be done in LNP JINR;**
- **as the mechanical basis of the magnetic field measurements stand, the measuring table installed in LNP JINR will be used (with its some modification);**
- **the laboratory measurements of the spectrometer magnets magnetic field will be carried out in LNP JINR.**

Preliminary cost for the spectrometer magnetic system (k€)

		Analyzing magnet	Ancillary magnet
1.	Design of manufacturing drawings	3	2
2.	Tooling	4	2*2.5=5
3.	Materials:		
3.1	Steel for magnet yoke	4	2*0.4=0.8
3.2	Copper conductor	2	2*0.5=1
3.3	Insulation	1	2*0.3=0.6
	Total as per point 3:	**7**	**2.4**
4.	Production		
4.1	Coils	3	2*2=4
4.2	Yoke	2	2*1=2
4.3	Other details including materials	1.2	2*1=2
4.4	Magnet assembly	2	2*1.2=2.4
	Total as per point 4:	**8.2**	**10.4**
	Total manufacturing cost:	**22.2**	**19.8**

5.	NMR Teslameter + probe multiplexer + 4 probes	7	
6.	Hall digital teslameter	2.5	
7.	Digital integrator + probe coils + moving wire probe	12	
8.	Digital multimeter	2	
9.	PC	1.5	
10.	Temperature probes interface + 50 sensors	6.5	
11.	Laser interferometer	7	
12.	Mechanical equipment for moving wire probe	8	
	Total magnetic measurement devices cost:	**46.5**	
13. 13.1 13.2 13.3 13.4 13.5	Magnets test and commissioning Stand modernization: • mechanical parts • control Measurement system computer software Stand assembly, testing and commissioning Magnets test, magnetic field measurements Technical documentation and manuals	 7 3 4 15 4	 2*4=8 2
	Total magnets test and commissioning cost:	**43**	
14.	Power supplies	15	11
15.	Water cooling system stabilization	10	
16.	Commissioning with no beam	4	

<u>Total cost: 171.5</u>

Magnetic field measurement stand

At SLC, LEP, CEBAF the field integral was measured by:

- **moving probe (NMR + Hall)**
- **moving wire**
- **search coils (one and two)**
- **flip coil**

Declared and realized tolerance (10-100) ppm

TESLA spectrometer

Laboratory measurements:

- moving probes (NMR probes in the main region, Hall probe in the edge field)
  - planned accuracy 20 ppm
  - using for the longitudinal distance determination of the high accuracy laser system
  - systematic Hall probe recalibration during the magnet mapping procedure
- two search coils (as in CEBAF)
  - planned accuracy 14 ppm
  - using for the longitudinal distance determination of the high accuracy laser system
  - NMR probe for the central field measurement

Operational measurements:

- reference NMR probes in two fixed points
  - planned accuracy 15 ppm
- moving wire
  - planned accuracy 19 ppm

Test measurements at the working magnet position:

- moving probes inside vacuum chamber (NMR probes in the main region, Hall probe in the edge field)
- reference NMR probes in two fixed points
- moving wire

The probes arrangement for the test and operational measurement technique