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Report on the conclusions of the SuperB magnet costing working group

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Introductory considerations

The questions posed to the working group by SuperB management (see annex A) were triggered by the need to evaluate the proposal of the Budker Institute about the possibility to build some of the Main Rings magnets and the vacuum chamber. This proposal included a list of items that can be provided by BINP and the relative costs.

First of all we have to stress a series of preliminary considerations

- The basic document available to the Working Group is constituted by an excel file (*Magnets_V16.xlsx*) including the main characteristics of all dipoles, quadrupoles and sextupoles of the HER and LER lattices. Namely the field or gradient and the magnetic length are reported for any magnets.
- Some additional information about magnets was coming from PEPII TDR and from the CDR of SuperB.
- This basic information is indeed poor because important parameters such as magnet gap or bore, good field region and beam stay clear are not clearly specified.
- No magnet design exists also at very basic level.
- Under these conditions the mission of the working group appeared very difficult. The only way we could perform, at least partially, our work was to make ourselves assumptions about the magnet structures if not some simple design exercises on the basis of the existing information.

- An important parameter is the magnet gap or bore. For LER dipoles gaps from 63.3 mm to 100 mm were considered. For HER Dipoles gaps from 60 mm to 100 m were used for evaluation. For quadrupoles, and sextupoles bore radius of 30mm and 50 mm were considered. The reason why we analysed these gap/bore ranges is based on three main considerations:

  a) the lower limits directly were coming from indications given by SuperB responsible for the lattice;

  b) the upper value for the dipoles reflects a worry about the effects on beam pipe dimensions of the needed vacuum pumping rate;

  c) the upper value of the quadrupoles and sexupole bore is an assumption.

Methodologies

Two different methods were used oriented to have as final output a cost evaluation of thee ring magnets:

a) The first method is involving optimization formulae based on a long experience with these kinds of magnets (see annex B for the details), from which the basic geometry of each kind of magnet is calculated and then, using these data, some CERN's cost evaluation formulae are applied to each magnet and the cost is evaluated starting from the basic material cost.
b) The second method followed an analytical approach passing through magnetic computations of supposed magnet structures and then evaluating technically and economically the magnets (see annex C for a detailed report).

The vacuum line and ancillary were analysed after some considerations about synchrotron radiation power. A more detailed report about vacuum issues is under preparation and will follow soon the present document.

Findings

As first general remark we noted that the varieties of magnet appear to be quite large. As an example the HER include dipoles with 7 different lengths with field ranging from 0.067T to 0.319T and 22 different currents involved. For LER quadrupoles we have 3 main magnetic lengths, but more than 100 different currents (ranging from 5 A to 400 A). A reduction of the number of magnet types and especially of the number of different currents could be helpful later, in view of a better optimization of magnet designs with advantages for the costs of magnets and power supplies.

A second remark is related to the quadrupoles. The HER include many high gradient quadrupoles (20 T/m<G<32 T/m). These magnets are reasonable from the cost point of view if the bore is 60 mm. For larger bore (we looked up to 100 mm bore) the magnets are very massive and expensive. Some re-thinking about the needed gradients by the lattice designers looks necessary.

Costs

The result of the cost (in **k€**) analysis is summarised in the Table 1. The table includes the costs of the magnets as they would be bought new. Both the results of the *optimization* and the *analytical* approaches are shown. For both methods two different evaluations are reported: one for smaller gaps/bores and a second one for larger dimensions. The table can be used for composing the costs depending on the technical choices. However we can distinguish two main cases depending on the dimensions:

a) Dipole HER 60 mm/68 mm gap. Dipole LER 63.3 mm/64.8 mm gap. Quadrupole 60 mm bore. Sextupole 60 mm bore. The total cost of the rings magnets is ranging from **€ 57234** of *optimization* approach **to k€ 58373** of the analytical approach.

b) Dipole 100 mm/ gap. Quadrupole 100 mm bore. Sextupole 100 mm bore. The total cost of the rings magnets is **k€ 89437** according the optimization approach. The quadrupoles were not evaluated with the analytical approach due to the complexity of the design for these magnets. However scaling the costs of the quadrupoles with the radius the estimation gives an approximated cost of **k€ 81000**.

The table also includes the costs of the girders simply considered as a 10% of the total cost.

Finally the costs of four spin rotators and of the final focus quadrupoles (these are all superconducting magnets) were also evaluated with analytical approach.

Table 1: Cost evaluation

Item	Optimization approach		Analytical approach	
HER	Dipole Gap 60 mm Quad Bore 60 mm Sext. Bore 60 mm	Dipole Gap 100 mm Quad Bore 100 mm Sext. Bore 100 mm	Dipole Gap 68 mm Quad Bore 60 mm Sext. Bore 60 mm	Dipole Gap 100 mm Quad Bore 100 mm Sext. Bore 100 mm
Dipole	**16937**	**25893**	**17235**	**21434**
Quadrupole Low Gradient	**1349**	**2500**	**10845**	Not evaluated **(18000)**
Quadrupole High Gradient	**8576**	**16013**		
Sextupole	**2783**	**2783**	**2535**	**2535**
LER	Dipole Gap 63.3 mm Quad Bore 30 mm Sext. Bore 60 mm	Dipole Gap 100 mm Quad Bore 50 mm Sext. Bore 100 mm	Dipole Gap 64.8 mm Quad Bore 30 mm Sext. Bore 60 mm	Dipole Gap 100 mm Quad Bore 50 mm Sext. Bore 100 mm
Dipole Low field	**2641**	**3947**	**3153**	**3864**
Dipole High Field	**14034**	**20425**	**11181**	**14776**
Quadrupole Low Gradient	**5626**	**10430**	**10889**	Not evaluated **(18000)**
Quadrupole High Gradient	**2505**	**4663**		
Sextupole	**2783**	**2783**	**2535**	**2535**
Girders for magnets rings (~10% of magnets costs)	**5700**	**8900**	**5800**	**8100**
Spin rotators			**3550**	
Final focus			**3800**	

Reuse of PEPII magnets

In general it is noted that there are two possible modalities for reusing the PEPII magnets.

a) Some of the SuperB dipoles fit the length of existing PEPII magnets. In principle these magnets could be used "*as they are*". In facts the PEPII magnets have the windings in aluminum, while for electrical power consumption reasons all SuperB magnets shall involve a copper conductor. So these magnets shall be dismantled, new coils shall be constructed and then integrated into the yoke; finally magnetic test shall be performed.

b) For the magnet with different lengths only the iron yoke can be partially reused after a cutting for meeting the geometrical lengths of SuperB magnets.

Analysing the option *a)* for 40 dipoles of HER (the ones with length 5.4 m) with the analytical approach, one find that the costs to be paid are k€ 1525 for material and k€ 2353 for manpower. If new built, the costs for these 40 magnets is k€ 5047, giving a cost saving of k€ 1169.

Option *b)* for the remaining 154 dipoles of HER implies a cost of k€ 8923 with a cost saving of k€ 2012.

In total the costs saving for HER dipoles seems to be k€ 3190 over a total cost of about k€ 17000. The potential cost saving of 18% is too low to be seriously being considered, because the risks in re-using old equipments.

The same considerations apply to all magnets.

Comparison with proposal of Budker Institute

Comparing the costs reported in this document with the proposal made by Budker Institute, one can see that the costs envisaged by the Working Group are a factor about two higher than the BINP ones. From the analytical analysis it appeared that the manpower costs for the option with smaller gaps/bores is about 37000k€ (see Annex C). Considering that BINP could have these costs 50% lower, the BIMP costs are still 30% lower than the Working Group estimations. This point needs more deep discussions and it is presently post-poned to future developments.

Answer to the questions

On the basis of the studies and analyses done by the working group, the answers to the question posed by SuperB management are:

1. Are the magnet parameters adequate to the SuperB main rings?

The basic information is presently quite limited (important parameters such as magnet gap or bore, good field region and beam stay clear are not specified) and no magnet design exists also at very basic level. The answer to this question can be only partial. The working group thinks that some work is needed on the lattice optimization aimed to define the dipole gaps taking into account the problems coming from vacuum issues. A high pumping rate could require gaps as large as 100 mm with consequent high cost of the magnets. The quadrupoles of the HER and some quadrupole of LER have too high gradient (> 20T/m) requiring difficult and heavy magnet to be designed and built if the bore is 100 mm. For 60 mm bore no problems are envisaged.

- *Are there clear economic advantages in using the PEP---II rings magnets?*

  The SuperB ring magnets are quite different from PEPII magnets. In facts a lot of SuperB magnets have lengths not matching the PEP magnet lengths. In case gaps of 60 mm are acceptable, PEPII dipole could be reused with a potential cost save of 18%. For the quadrupoles (if bore is 100mm) same considerations apply; in this case cost saving can be even lower because the replacement of all the coils is a driving factor of the costs and the higher gradient quadrupoles shall be procured new. Considering the errors related to the present evaluation and the risks related to involve old components, the reuse of PEPII ring magnets is discouraged.

- *Are there some construction risks and what can be done to mitigate them? (for example: spare parts, maintenance strategy,…)*

  If the magnets are procured as new, there is non particular technical risk, but the high gradient quadrupoles. In general it is found that too many magnets types are presently included in the HER and LER lattices. As remarked above, a reduction of the number of magnet types and especially of the number of different currents could be helpful later for a better optimization of magnet designs with advantages for the costs of magnets and power supplies. Presently there are not the conditions for defining a spare part or maintenance strategy.

- *When and how we can define the main rings layout to evaluate its impact on civil engineering and environmental conditions?*

The magnets of the lattice have a fundamental impact on the civil engineering not only for the dimensions and the weights, but essentially for a series of ancillary equipments (the required cooling plants, the power supply dimensioning and distribution lay-out) and for the space requirements in view of the assembly of the ring components. A better definition of the magnets is required before the civil engineering can be frozen.

2. *What is needed to assess how the solution proposed compares with the one reusing PEPII magnets.*

The suggestion of this working group is not to reuse PEPII magnets. This conclusion is based on a preliminary analysis done on the information available now. It is clear that an assessment how the option of procure new magnets compares with the reuse of PEPII magnets can be done only after a design of the magnet exists. However this Working Group is not expecting a different conclusion.

APPENDIX A

Charge to the working group

Frascati, February 14th 2012

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A. Clozza, INFN-LNF, Frascati, Italy

P. Fabbricatore, INFN-Genova, Italy (*chair*)

E. Levichev, BINP, Russia

C. Sanelli, INFN-LNF, Frascati, Italy

D. Tommasini, CERN, Switzerland

U. Wienands, SLAC, USA

Dear Colleague,

The Nicola Cabibbo Laboratory, in charge of the construction of the SuperB project at the Roma Tor Vergata University campus, is planning to collaborate with other international laboratories for the provision of parts of the accelerator.

The Budker Institute in Novosibirsk (Russia) has evaluated the possibility to build some of the Main Rings magnets and the vacuum chamber. A list of items that can be provided by BINP, and relative costs, has been presented by Prof. E. Levichev.

In order to be able to correctly evaluate the proposal of BINP we would like to invite you, as an expert in the field, to participate to an evaluation group.

Examples of key points to be addressed are reported below.

1. Are the magnet parameters adequate to the SuperB main rings?
   Are there clear economic advantages in using the PEP-II rings magnets?
   Are there some construction risks and what can be done to mitigate them? (for example: spare parts, maintenance strategy, ...)
   When and how we can define the main rings layout to evaluate its impact on civil engineering and environmental conditions?
2. What is needed to assess how the solution proposed compares with the one reusing PEPII magnets

We hope that you will accept this charge. Looking forward to a fruitful collaboration, please accept our best regards.

Roberto Petronzio
Director General, Cabibbo Laboratory

Walter Scandale
Director of lab infrastructures, Cabibbo Laboratory

RP-WS/MRF

APPENDIX B

RINGS MAGNETS COST EVALUATION USING A SCALING APPROACH

C.Sanelli

Presentation given

At 3rd SuperB meeting LNF March 19-23

APPENDIX C

RINGS MAGNETS COST EVALUATION USING AN ANALYTICAL APPROACH

P.Fabbricatore

Presentation given

At 3rd SuperB meeting LNF March 19-23