All Magnets in the Beam Delivery System: Planning for the Engineering Design Phase

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General Goals of the ED Phase- those that pertain to Magnet Systems

- Taken from the ILC Project Management Plan for the Engineering Design Phase
- demonstrate through the ILC R&D program that all major accelerator components can be engineered to meet the required ILC performance specifications;
- provide an overall design such that *machine construction could start within two to three years* if the project is approved and funded;
- contain a detailed project execution plan including an achievable project schedule plan for competitive industrialization of high-volume components [13,000 magnets] across the regions;
- provide a complete value cost estimate for the machine [= more precise cost estimates for all magnets]

Organization of the GDE for the EDR phase

(chart as of 1st July- no names, but this is current structure)

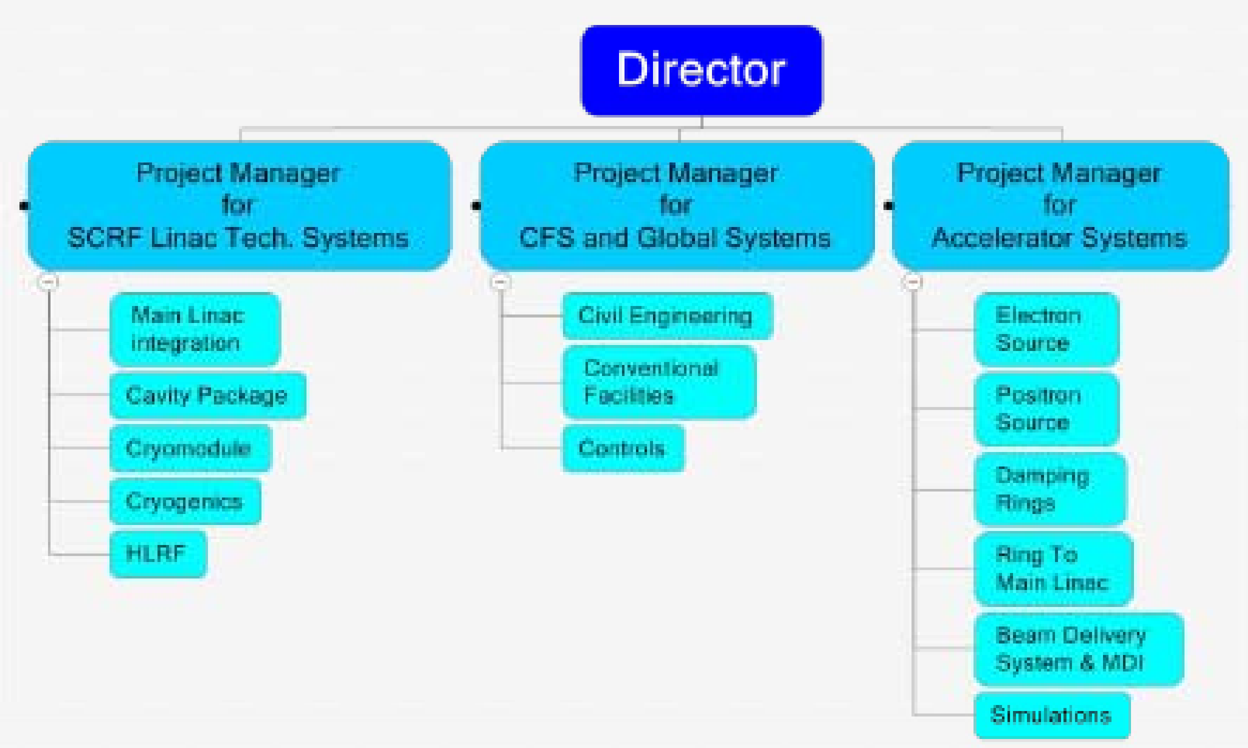


Figure 7.1: Basic proposed Project Management structure for the EDR phase. The org chart indicates the top three levels of management: level-1 Director; level-2 Project Managers; level-3 System Managers.

NOTE: No boxes for most technical systems such as Magnets, Vacuum, Installation. Tech Systems groups have already been formed, learnt how to work with each other & produced much technical info for the RDR, seems counter-productive to disband them at this stage.

EDR Magnet Design & Deliverables,
what level of detail would be best for project?

- Design for each magnet style:
  - Magnetic design 2D (and, if needed, 3D) magnetic field simulations to confirm specified field quality and magnet performance;
  - Pole profile and geometry optimization for better integrated field quality;
  - Mechanical and thermal analysis;
  - Magnet documentation**.**
- Magnet documentation package to include at least:
  - Magnet specifications with all necessary parameters;
  - Results of magnetic field analysis as well as mechanical and thermal calculations.
  - Magnet drawings - at a minimum cross-sections, transverse and longitudinal views, with all connections to power, water, and instrumentation and corresponding schematics;
  - Description of all materials: iron, copper, insulation, epoxies, cables, etc…
  - Description of magnet manufacturing technology: coil winding technique, epoxy impregnation, curing, stamping laminations, yoke and magnet assembly, etc…
  - General views of the magnet support structure with adjusting mechanisms
  - Drawing of the magnet support in the tunnel

A Generic Magnet Design Work Package

- **What a fully detailed magnet design work package might look like:**

1. Objective

1.1 Develop and design Area System conventional DC magnets, support stands, and interfaces to other systems.

2. Task Description

2.1 Work with Area System physicists, engineers, and designers to develop conventional magnet designs and specifications which meet the magnetic field requirements, alignment and stability requirements, aperture, length, and other dimensional requirements, availability requirements, electrical power requirements, heat generation requirement, and any other achievable system requirements.

2.2 Explore options to provide a cost-effective design meeting the above criteria and carry out the necessary engineering design work required by the Engineering Design Report.

2.3 The scope of work includes DC magnets, associated support stands, and definitions of interfaces with other systems; it does not include pulsed magnet systems.

3. Deliverables

3.1 Furnish, by **<**completion date> the following performance specifications, drawings and cost estimates:

3.1.1 Magnet specifications, including field strength, field uniformity, aperture, physical dimensions, total weight, electrical properties, including total resistance and inductance, required LCW flow rate (if applicable), operating temperature, conductor cross section, and other parameters necessary for design, fabrication, installation, and operation.

3.1.2 Magnet support stand specifications, including support points, adjustment range along and transverse to beam line, adjustment resolution,

3.1.2 Definition of interfaces with other systems: including vacuum systems, power systems, LCW, alignment, installation fixtures, etc.

3.1.3 Complete set of design and fabrication drawings suitable for procurement

3.1.7 Other information as necessary for the Engineering Design Report

How long would it take to design/engineer all the ILC magnet styles?

Magnet Type	Number of Styles	e- Source	e+ Source	Damping Rings	RTML	Main Linac	BDS
Dipole	24	3	5	2	6	0	8
Quadrupole	33	4	5	4	5	0	15
Sextupole	7	0	2	2	0	0	3
Octupole	2	0	0	0	0	0	2
Dipole Corrector	9	0	1	3	4	0	1
Solenoid	5	2	2	0	1	0	0
Pulsed Magnets	12	1	0	5	1	0	5
Muon Spoiler	1	0	0	0	0	0	1
SC Quads	5.5	0	3	0	0	2.5	0
SC Correctors	1	0	0	0	0	1	0
SC Solenoids	1	0	1	0	0	0	0
IR-SC Quads	10	0	0	0	0	0	10
IR-SC Correctors	12	0	0	0	0	0	12
IR-SC Sextupoles	4	0	0	0	0	0	4
IR-SC Octupoles	3	0	0	0	0	0	3
IR-SC Solenoids	2	0	0	0	0	0	2
SC Undulator	1	0	1	0	0	0	0
SC Wiggler	1	0	0	1	0	0	0

Total Styles: ***133.5***

The IR-SC magnets (BNL R&D), the e+ undulator (Daresbury /Rutherford), and the DR wigglers (Cornell) have not been included in the design staffing estimates.

Pulsed magnets are included for magnet design only; the pulser/power supply system is still in the realm of R&D.

Based on our experience as magnet engineers we estimate the hours to fully design, engineer & cost 3 generic types of magnets that exist in the ILC [does not include fabrication & mst.]

Conventional Conventional Magnets: hours for ONE style			
Design	**Engineer/ Physicist (hrs)**	**Procrmnt (hrs)**	**Designer (hrs)**
Magnetic Design/Specs	80		120
Mechanical Design	120		480
Tooling Design	40		160
Stand Design	40		120
Power Supply Specifications	12		
Controls Specifications	12		
Cost Estimation			
Magnet	12	16	
Tooling	8	8	
Stand	8	8	
Totals (hrs, task only)	**332**	**32**	**880**
Totals (FTE, task only)	**0.18**	**0.02**	**0.49**
Totals (FTE, realistic)	**0.29**	**0.03**	**0.77**

Ad hoc scale factor	1.6	*Reality - description*
'Overhead' for task sharing	**1.10**	People not full time on task: context switching - re-start/'re-learn' penalty
Changes in requirements	**1.15**	Specifications change due to system detail design changes, R&D input, configuration change, etc.
Programmatic shifts	**1.25**	Major system and requirements changes, etc. for programmatic reasons

Also compile hours for same tasks for *"unconventional conventional magnets"* and *superconducting magnets*. Sum all the hours per style and multiply by the number of styles to get total FTEs:

Total FTE's for engineering 100.5 styles			
Area	**Engineer/ Physicist (FTE)**	**Procuremnt (FTE)**	**Designer (FTE)**
e- Source	**3.65**	**0.34**	**10.00**
e+ Source	**8.13**	**0.77**	**21.54**
Damping Rings	**5.16**	**0.49**	**13.88**
RTML	**5.40**	**0.51**	**14.64**
Main Linac	**2.85**	**0.27**	**7.38**
BDS	**11.93**	**1.13**	**32.35**
Total FTE's	**37.13**	**3.52**	**99.78**

Note: these are total FTE's and will be spread over ~3 years ~3 years of EDR effort

Hours in work-year	**1800**
EDR time period (yrs)	**3**

12 FTE MAGNET ENGINEERS + 32 FTE DESIGNERS for BDS MAGNETS

Does ILC have the resources to pay 12 magnet engineers needed to engineer the BDS magnets?

- Consider the ED Report advertised timeline
- EDR – time scale FY07-FY09
  - FY2007 is over (funds are gone; magnet design not begun)
  - FY2008 has very limited resources for magnets…
  - FY2009 appears to have some additional resources for magnet detailed design (mostly rumor…)
- The conclusion is that there will not be a significant number of magnet styles in any area with detailed designs by FY2010
  - Without detailed designs, the EDR cost estimates will not be significantly more accurate or reliable than the RDR ones
  - Consequences of deferring design efforts will not go unnoticed…
- Even if we had the money not clear we could find professionals for magnet design and integration with the required experience.

How to proceed with ~0.8FTE magnet engineer for BDS tasks & evolve a magnet system group for ILC-wide tasks

- Are some magnet tasks that apply to all magnets so better dealt with across areas
- The present Magnet System Group is already working on some non-area-specific tasks that are necessary in our opinion
  - Developed common design & material standards
  - Improve magnet costing process: more detailed than the 2 fixed coefficients we used for RDR
  - Ensure that magnet & PS reliability will match the required MTBFs & magnets will be easily maintainable
  - Working with magnet vendors to get their advice
- Other tasks an ILC-wide magnet group ought to be doing during the EDR phase
  - Interface and integrate with other Tech. & Global Systems
    - Vacuum, alignment, AC power, LCW, controls, installation
  - Continue to design a magnetic measurement & test facility
  - Develop a realistic magnet production model, with attention to:
    - Funding profiles, resources, commercial risks
  - Oversight of magnet-related work packages in all areas

How to evolve a Magnet System Group : Spencer's idea

- Institutions are proposing to do work on certain magnet & power supply tasks for particular areas
- They will have funds to do these work packages and so they'll have paid-for magnet or PS experts
- Policy would be: if you are doing a magnet or PS work package you must provide a fraction (TBD) of your magnet expert's time to work on magnet system group ILC-wide tasks (described in previous slide)
- I reckon we would have at least 8 people generated by such a policy; equivalent to at least 2 FTEs
- Group would also help review proposals for work packages and enforce design & material standards

So BDS would provide ~0.2 of Spencer for e.g. to work with the ILC Magnet Group

- **Improving magnet reliability is an important 'up front' engineering task and cannot be left to the end. It must be a high priority task for the Magnet Group to continue working on.**
- **Achieving magnet reliability is a major concern**
  - **MTBF assigned for magnets in the range 10 – 20$\times$10^{6} hrs**
  - **Reliability must be 'built in' – part of the design process – and addressed early in the project**
- **FMEA – Failure Modes and Effect Analysis - is a structured, qualitative approach, carried out by a group of engineers, to understanding**
  - **which components in a system are most likely to fail**
  - **what the effects of the failure will be**
  - **the root causes of the failure**
  - **when in the component's lifetime it fails**

  (Note: FMEA was developed by the US military in 1960s - US MIL-STD-1629)
- **FMEA need to be carried out on specific magnet *detailed* designs, representative of the magnet spectrum**
  - **Conventional, H_20 cooled, medium complexity**
  - **Superconducting magnet, e.g. quad in cryomodule**
  - **Conventional, air-cooled, simple design**
  - **Specialty or critical magnets, e.g. kickers**

Magnet tasks specific to the BDS to be carried out during the Engineering Design phase

- GOAL: Improve the technical maturity of the BDS conventional magnet designs, using limited resources
- Recall: no BDS conventional magnets got to the drawing stage, only a few were modelled with POISSON
- Choose two magnets to work on, FIRST:
  - FF bends : for 500 GeV/ beam need 114 12m long weak dipoles
  - Turn one 12m into five 2.4m long, solid wire, steel core dipoles
  - For 250 GeV/ beam install one in 5 dipoles, run at higher field
  - Result: same design needs to run from ~50 to 450 gauss in gap
  - Worries about the repeatability of field values, equivalency amongst the dipoles that will be strung on one PS
  - Design & build prototype (2?) to investigate & deal with worries
  - Use this detailed design to carry out a FMEA for all solid wire mags
- EOI been received from Dubna HEP lab in Russia (Spencer also interested in doing this task)

Second BDS DC magnet to be worked on during ED phase

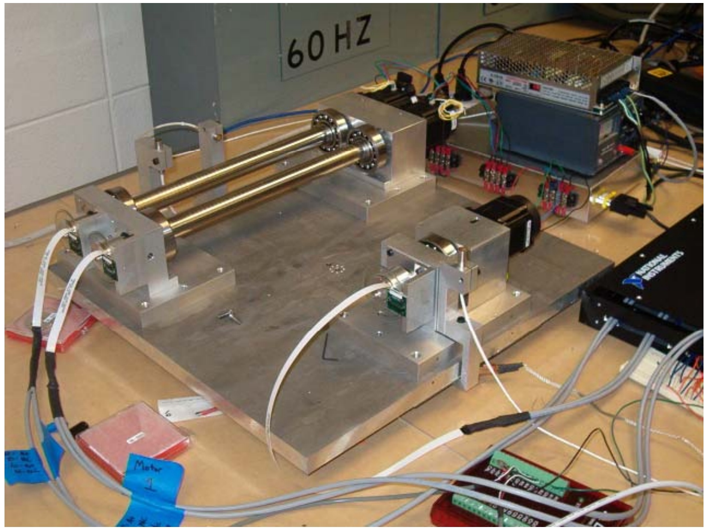
- PROBLEM being dealt with : the high power consumption extraction magnets, can their power and power in their cables be reduced?
- IDEA: use High Temperature Superconducting (HTS) coils in a warm steel standard shaped core [similar to what Gupta et al at BNL are doing]
- Spencer been corresponding with a commercial company who makes magnets with HTS coils; they produced a preliminary design of the 17.8 cm bore quad towards end of extraction line: is feasible.
- Approximate specs are:
  - 11.9T/m gradient as required, pole tip field 0.92 T
  - max field in iron ~1.78 T
  - Current density in coil pack 78 MA/m^2
  - Operating current 130 A
  - Operating temperature ~35 K
  - Length of HTS tape : 6 km
  - Power dissipated in coils ~15 W
  - Electric power required for cryocoolers ~4-8 kW
- They provided an extremely rough estimate - the construction cost of such a device (including cryo-refrigerators, cryostat, wire and power supply, but excluding the iron circuit) is approx the same as my water-cooled design (using 148 kW + 19kW in cables) plus its PS
- Encouraging them to submit an EOI (self-funded) for detailed design

Understand & plan for the positional & field strength stability tolerances of BDS Magnets

- Main technical issues with BDS magnets are their positional and field strength stabilities
  - . Thermal and mechanical disturbances will be minimized by stabilizing the BDS tunnel air temperature [prefer to 0.5ºC], the cooling water to [prefer to 0.1ºC] , and limiting high frequency vibrations due to local equipment [prefer to the order of 10 nm]
  - ED tasks: (1) work with beam physicists to understand their requirements regarding stability tolerances, long & short term (2) translate beam requirements into LCW and air temperature stability requirements; (3) do value engineering to choose utility requirements & minimize cost

Further Development of Magnet Movers suitable for BDS magnets

- Imperative that the ILC beams go through the magnetic center (= where B is zero) of all the quads to maintain a very low emittance
- One method of ensuring this is to place every quad on a device that can move the magnet in at least 3 axes over a few mm range in tens of nm steps
- Linear Collider R&D money has been used by David Warner at Colorado State University from 2003-2006 on magnet mover development. Last status report-July 2006. Had asked for more funds to develop gears for moving weights up to 1200Kg; increase to 5 axes.



3 axis mover with top platform removed showing kinematic drive

To my knowledge the mover development is on hold at CSU and no-one else is doing any work on movers suitable for BDS.

RELATED TOPICS that should be addressed during ED phase: magnet stands; alignment procedures; height of beam above the tunnel floor- compatible magnet designs.

Pulsed Magnets for BDS

- How to proceed on BDS kickers and septa?
  - It's timely to do consistency checks to flesh out rough RDR designs
  - Note to be co-authored by optics, vacuum, magnets (Mattison)?
  - Kickers, septa, and sweepers are not "commodities"
    - Costs inherently less certain than most other systems
    - Won't be more certain until more engineering gets done
  - **There are significant cost tradeoffs between kickers and tunnel-length: "someone" should work on this**
- General comments about ILC pulsed magnets
  - Pulsed Magnet Systems R&D should not be constrained by Area System boundaries

    Is there a mechanism in the EDR approach to find a solution across Area System boundaries?
  - There should be one person coordinating / integrating the overall fast pulser R&D

GENERAL REMINDER: If we aim to be ready for an approval process in July 2010 without increasing personnel then:

- Limited EDR resources for magnet design compresses all of detailed design into the ‘pre-production’ and ‘early’ project phases
  - Cost estimate will not be significantly improved
    - Different people can apply different guesses but the ‘data’ will not have changed appreciably
  - Detailed design occurs later
    - In labs or in industry, it will require a greater number of engineers and designers in a shorter time period
    - The required technical oversight burden will be greater – more designs, less time – and will require more magnet engineers
  - Potential for ‘Pile-Up’ in schedule
    - Production facilities saturated
      - Alternative is more, less experienced, less qualified vendors
    - Costs will increase
      - More capital investment (tooling, production lines)
    - Risk of Installation Schedule issues
      - Late magnets will clog the system