# Generating Magnet Work Packages: Planning for the Engineering Design Phase

Cherrill Spencer, SLAC with input from other members of the ILC Magnet Systems Group

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# A Generic Magnet FULL Design Work Package would include:

- **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 many magnet styles are there & how long would it take to design/engineer them?

| 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** |

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*

| *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 |

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

12 FTE MAGNET ENGINEERS + 32 FTE DESIGNERS for e+ & e- MAGNETS

# Does ILC have the resources to pay 12 magnet engineers needed to engineer the e+ & e- magnets?

- NO!! What about the other ILC areas?
- 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…)
- Conclusion is that there will not be a significant no.of magnet styles in any area with detailed designs by FY2010. *Warning from non-existent Magnet Sys Grp:*
  - 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.

# 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

# What might be included in a Sources Magnet Work Package for EDR: at reduced level given in slide 6

- Work with beam physicists to completely specify their requirements for magnets and power supplies
- From physicist requirements: specify basic parameters (strength, length, aperture) of all styles of magnets and optimize (=minimize) number of magnet styles
- Do magnetic design of DC conventional magnets
- Share magnetic and pulser design of the one pulsed magnet style with RTML (e- only)
- Share magnetic design of the superconducting quads that sit on accelerator cryomodules with RTML (e+ only)
- Do magnetic design of one supercon solenoid (e+ only)
- Do documentation of all above magnets as described on previous slide
- Make detailed cost estimates of all magnet styles
- Specify families of DC PS needed for magnets
- Re-iterate on magnet designs to yield optimal PS and cables and total project cost
- Design stable supports for magnets

# Using official WP template nomenclature: Major Tasks and Objectives. Categories

**MAJOR TASKS AND OBJECTIVES**

1. **Generate magnet and PS detailed requirements**
2. **Generate magnet and PS conceptual design of all styles**
3. **Optimize Magnets with PS to reduce total cost**
4. **Integrate magnets with beampipe, LCW system, supports;**
   - **ensure fits in tunnel, enough space between magnets**
5. **Make detailed cost estimates of all magnet styles**
6. **Develop fabrication plan; measurement, installation & repair plans**
7. **Write the chapters of EDR on sources magnets and PS**

**CATEGORIES**

1. **Engineering design**
2. **Value engineering**
3. **Costing**

# Deliverables from e+ or e- sources WP

1. All Magnets’ and PS conceptual drawings, layout schemes
2. Conceptual drawings of magnets mounted in the tunnel
3. Detailed drawings of any prototype (none suggested)
4. Prototype test and magnetic measurement results (if any prototype)
5. Results of optimization of magnets-PS-cables
6. Detailed cost estimates
7. Plans for : procurement, measurement, installation, maintenance/repair
8. Sources Magnets and Power Supplies chapters of EDR

## *Minimum* times to do reduced level of tasks in work package (assuming workers are experts)

**Conventional, room temperature magnets**

1. Magnet specification – 1 week (Scientist, Engineer)
2. 2D Magnetic design – 2 weeks (Engineer)
3. Magnet engineering design – 2 weeks (Engineer)
4. Conceptual design drawings – 4 weeks (Designer)
5. Magnet support and installation in the tunnel - 2 week (Designer)
6. Magnet optimization & integration with other systems – 2 weeks (Engineer)
7. Magnet description including fabrication technology, test program, installation and repair info– 2 weeks (Technology Engineer)

Total time per conventional magnet style– 15 weeks or ~0.3 FTEs of various skill sets

Scale from conventional magnet to generate superconducting time:

Multiply by 1.5 -> 0.45 FTE for a superconducting magnet style

**Power Supplies & Cables**: see Paul Bellomo's presentation

# Estimate total FTEs for e- & e+ magnet EDR work packages

| Magnet style | e- #styles | e- # FTEs | e+ # styles | e+ # FTEs |
|---|---|---|---|---|
| Conventional Incl solenoids | 9 | 2.7 | 14 | 4.2 |
| Supercon Solenoid | 0.5 (share design w/ e+) | 0.23 | 0.5 (share design w/ e-) | 0.23 |
| Supercon Quads & Correctors | 0 | 0 | Borrow design from RTML | 0.07 |
| Pulsed | Borrow design from RTML | 0.07 | 0 | 0 |
| Totals | 9.5 | 3 | 14.5 | 4.5 |

# Suggested e- or e+ WP Major Milestones
## (preliminary version)

1. Magnet and PS requirements and specifications
   February 1, 2008

2. Conventional (room temp) magnets and DC PS conceptual designs
   October 1, 2008

3. Superconducting solenoid conceptual design December 1, 2009

4. Magnets – PS- cables optimization October 1, 2009

5. All magnets' integration details & beamline layout drawings
   February 1, 2009

6. Detailed costs of all magnet styles July 1, 2009

7. Overall fabrication, measurement, installation & repair plans
   February 1, 2010

8. Finish writing e- & e+ magnets and PS chapters of EDR
   May 1, 2010

# How to proceed with ~ zero magnet engineers for e+ & e- 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 e+ source would provide ~0.2 of an undulator engineer 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 – 20×10$^6$ 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**

# 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