Introduction to the ILC's Conventional Magnets

For the LCFOA meeting at SLAC

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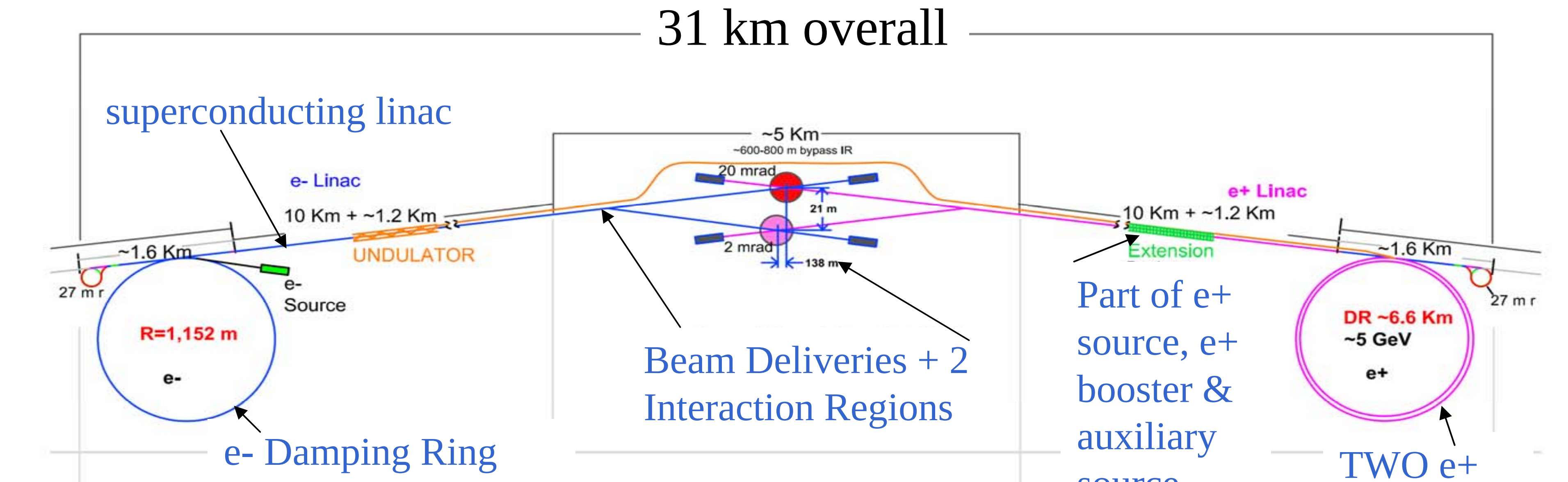
Topics I will cover

- Introduce the Magnet Systems Group
- Show the INAUGURAL table of ILC MAGNET QUANTITIES
- Indicate typical sizes of ILC conventional magnets
- Describe our ILC magnet design and manufacturing philosophies
- Describe our major technical challenges, in particular achieving high availabilities.
- Further details will be dealt with in break-out session.

Current General Layout of a 500Gev ILC



Electromagnets are utilized throughout the ILC beamlines to bend and focus the electron and positron beams.

ILC Magnet Systems Group: who we are & our responsibilities

- I am SLAC's Magnet Engineer. Have been designing and fabricating accelerator magnets at SLAC for nearly 18 years. In particular been designing & costing magnets for linear colliders for past 9 years.
- The ILC Technical Systems Groups will make engineering designs of the specified components, will provide information, design strategies and cost estimates to the Area groups and set engineering standards for the technical system.
- ILC Magnet Systems Group presently comprises about 15 magnet & power supply experts from about 9 HEP labs in Americas, Europe & Asia.
- **Magnet Systems:** Responsible for the design and costing of all magnet systems (including cold magnets), and associated power supplies, interlocks, cabling, cable trays, supports (including He vessel for cold magnets), and movers. Interface to control system at a serial digital interface. Responsibilities include specialty magnets such as the final focusing magnets, kicker systems, and undulator systems.

Process the Magnet Systems Group is going through

- A beamline's magnetic components are defined by a beam physicist: quantity, order along the beamline, number of magnetic poles and integrated strength (this set of parameters called a lattice and each ILC area has several lattices)
- Magnet experts take the lattice description and transform it into a series of technical specs for real magnets. Do this for all ILC beamlines as lattices are released.
- Identify *styles* of magnets: same physical magnet will produce a range of magnetic specs; count the number of magnets and styles; design each style of magnet=>current & resistance; then power supplies can be specified; finally power cables and cable trays will be specified.
- When have understood the scope of the magnet systems then can develop appropriate ILC-wide design, manufacturing and QC philosophies for them.
- In last 2 weeks have received most of the areas' lattices: have made INAUGURAL COUNT OF ILC MAGNETS

ILC MAGNET COUNT: Inaugural Publication

Magnet Type	Grand Totals		Sources			Damping Rings			2 RTML		2 Linacs		2 BeamDel	
				e-	e+		e-DR	2e+DR						
	Styles	Quantity	Styl	Qty	Qty	Style	Qty	Qty	Style	Qty	Style	Qty	Styl	Qty
Dipole	35	2008	7	12	134	1	192	384	12	676	0	0	15	610
Quad	76	7326	11	47	3267	32	784	1566	7	670	3	560	23	432
Sextupole	14	1608	1	0	16	4	520	1040	0	0	0	0	9	32
Solenoid	7	55	6	8	39	0	0	0	1	8	0	0	0	0
Corrector	17	11000	1	0	6534	2	784	1566	8	1276	6	840	0	0
Pulsed/Kickers/Septa	12	278	2	0	21	4	3	6	3	20	0	0	3	228
Wiggler	1	234	0	0	0	1	78	156	0	0	0	0	0	0
Octupole/Undulator	1	35	1	[illegible]	1	0	0	0	0	0	0	0	0	34
Totals	163	22544	29	67	10012	44	2361	4718	31	2650	9	1400	50	1336
Totals w/o correctors	146	11544												

ILC Magnet count for 250Gev on 250Gev beams with baseline configuration

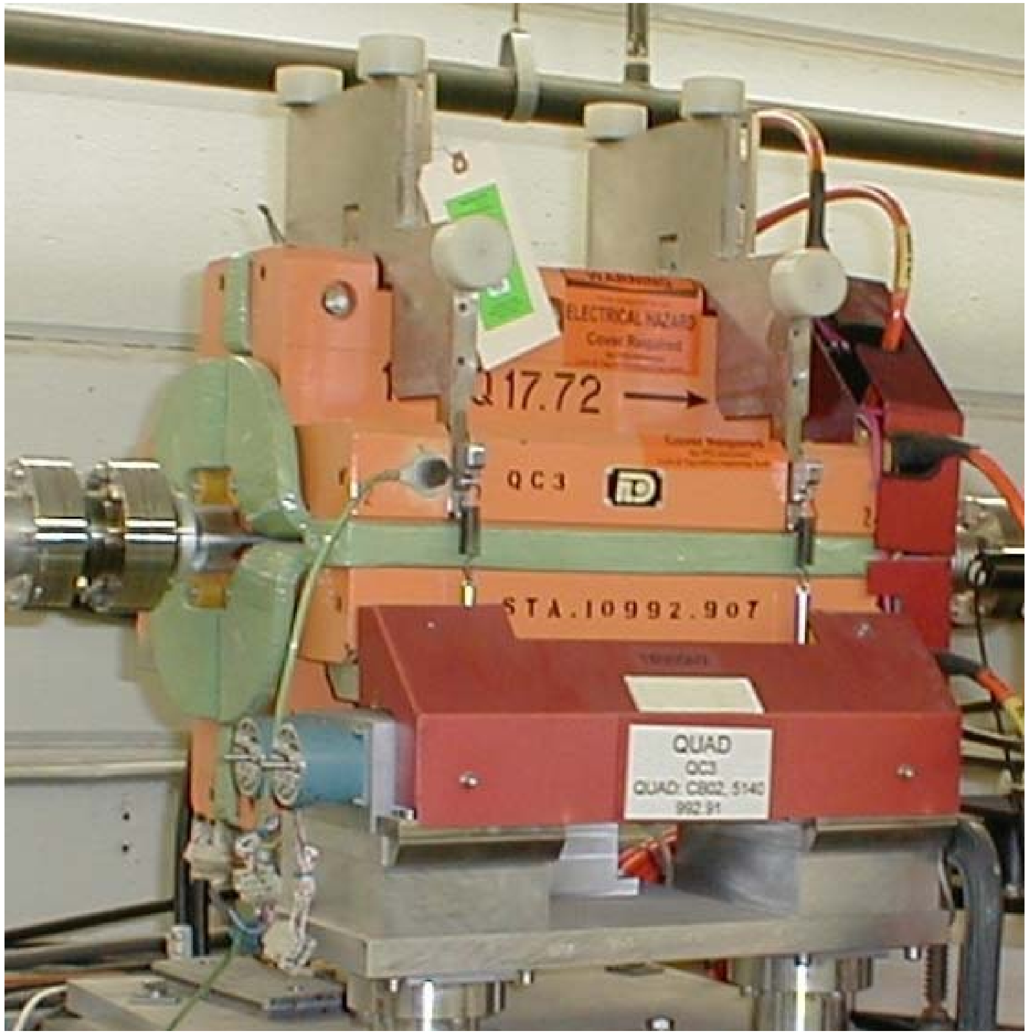
Compiled by Cherrill Spencer, ILC Magnet Systems Group, Inaugural Publication: 1May 2006

The LCFOA is the first entity, worldwide, to see the inaugural ILC Magnet Count : quantities are **PRELIMINARY** and **WILL change**!

Further Details on the ILC Magnet Count

- Of the 22,544 magnets, 1559 of them will be superconducting. i.e. ~21,000 will be conventional
- 10,160 of the magnets are conventional “correctors”. They are mostly stand-alone weak dipoles that will likely be solid wire, sheet-metal core dipoles. The ILC is a one-shot accelerator and experience with SLAC’s linear collider informs us that many of the quads throughout the ILC need to have nearby steering dipoles in order to maintain the beam collisions at the interaction point.
- Putting aside the 10,160 correctors leaves 10,840 conventional magnets of 146 different styles to be designed and fabricated in 5-7 years
- 9504 magnets bend or focus beams with energy <5.1Gev, so they are quite modest in physical size. E.g. 0.5-2 m long

Typical Size of an ILC conventional quadrupole

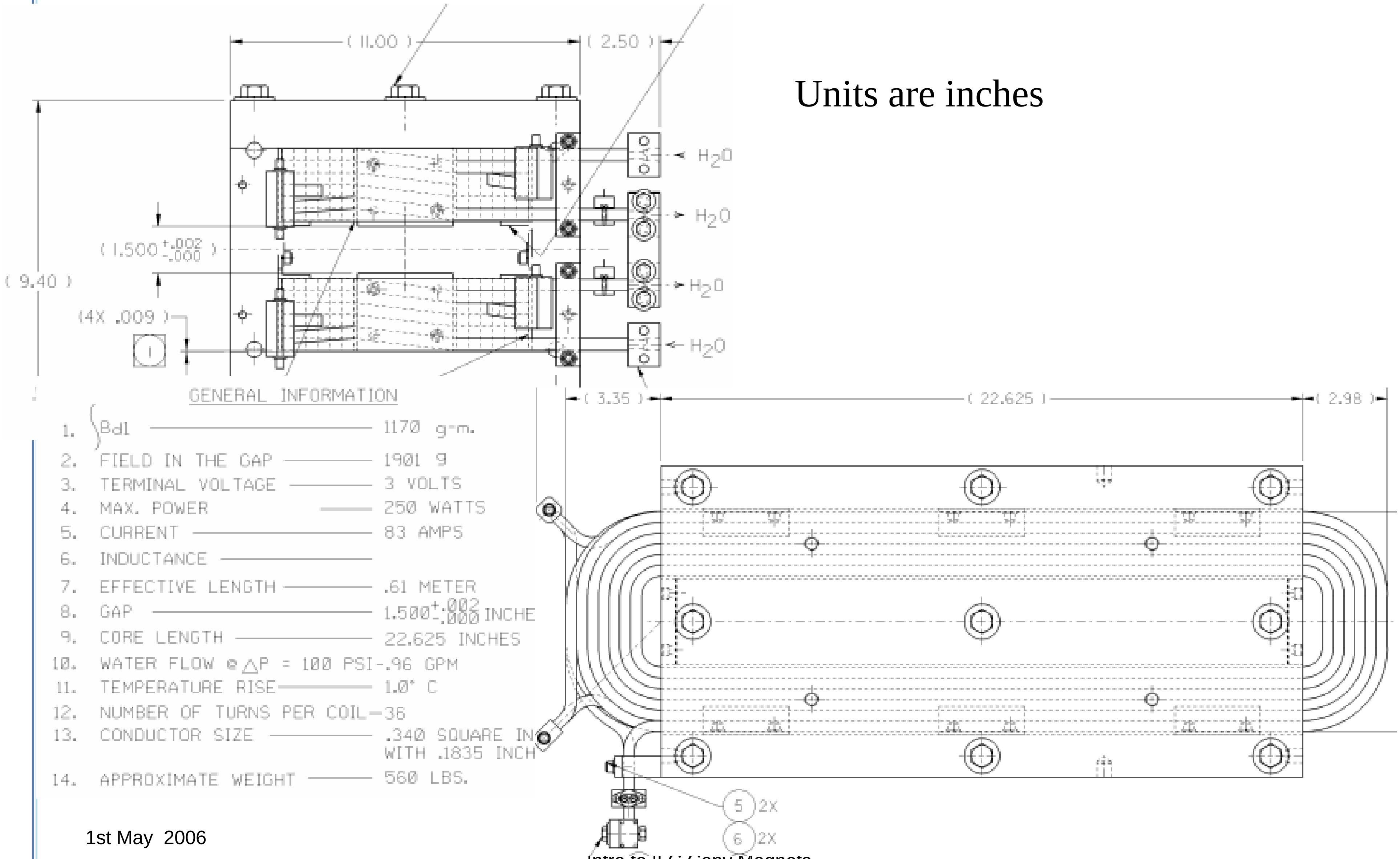


Overall length about 60 cm, overall height about 40 cm.

Copper conductor is 0.255” square with 0.125” hole.

Typical Size of an ILC conventional dipole, some will be larger

Units are inches



International Linear Collider at Stanford Linear Accelerator Center

Quantities associated with various styles

- Presently there are 163 different styles of magnets. The magnet engineers will strenuously be working with the beam physicists to reduce the number of styles.
- About 10 corrector styles will have several 100 each

Considering non-corrector magnets:

- Only 1 style has over 1000 magnets (-> 3000 e+ quads)
- About 6 styles have over 500 magnets
- About 60 styles have 100 to 200 magnets
- About 80 styles have 2-99 magnets

ILC-wide Magnet Design Philosophy (in formation)

ILC magnets are approx 93% water or air cooled conventional electromagnets; and approx 7% superconducting magnets

All preliminary design done by ILC; detailed engineering and drafting: some magnets by ILC, other magnets by industry

Our major production challenges:

- Produce ~22544 magnets over 5-7 years
- Make them extremely reliable
- Minimize cost while maintaining performance

To meet these challenges we will:

- Identify failure modes using FMEA, design in reliability
- Have uniform standards for common materials such as ferrite, steel, conductor, cooling hoses- MUST BE FOLLOWED WHEREVER MAGNET BEING MADE
- Have standard designs for common parts such as terminal blocks, coil retainers, LCW manifolds
- Have a restricted list of approved off-the-shelf parts: water fittings, insulation, epoxies

ILC-wide Magnet Manufacturing Philosophy (in formation)

- *Most* electromagnets will be fabricated by commercial companies situated all over the world. Some technically difficult magnets will be fabricated at HEP labs.
- There are so any magnets it will saturate the worldwide capacity for accelerator magnets and USA companies should be able to submit successful bids (in my opinion).
- Will have on-site high capacity + comprehensive incoming magnet inspection and measurement facility (still under discussion)

Technical Challenges of ILC Magnets

- Alignment with respect to beam path
  - Focusing elements must preserve beam size: beam to pass down magnetic center
  - Offset of quadrupoles from beam axis must be adjusted by correction (steering) elements
  - Sub–µ level achieved with mechanical 'movers' in certain areas
- Stability
  - Geometry– if magnet core is not mechanically stable its magnetic center will wander
  - Field reproducibility
    - Over time
    - With respect to changes in current
- *Reliability*
  - Meeting all of the demanding beam physics requirements for magnet performance can be defeated by MTBF…
  - Magnet reliability requirements are very challenging – to be discussed in more detail in what follows.
- Cost
  - A critical technical requirement is a design which is cost efficient
  - Designs must be developed to meet lattice requirements, reliability, and cost optimization. INDUSTRIAL INPUT WILL BE VERY HELPFUL on last two.

Technical Challenges of ILC Magnets (cont)

- High radiation expected in several beamlines
- The most intense radiation environment is due to stray particles in the Damping Rings where the average radiation level two inches from the beam-pipe might be 2 Mega-Rads per hour, and the peak level at isolated locations might be as high as 60 Mega-Rads per hour. Therefore need rad-hard materials- prototypes could be useful for testing materials.
- Many dipoles in Beam Delivery have very low gap fields- concerns about remnant fields & reproducibility of the integrated strength. Must be low field to minimize synchrotron radiation emitted by e- or e+.
- Come to the magnet break-out session to see examples of technically difficult conventional magnets.

MOST CHALLENGING ASPECT OF ILC CONVENTIONAL MAGNETS: MAKING THEM RELIABLE ENOUGH

- Consider the availability requirements of the ILC as set out in the BaselineConfigDoc.
- A simulation of the whole ILC has been developed and the model's output tells you how long the ILC will be down if its components have certain mean time between failures (MTBF) and certain times to repair (Mean Time to Repair, MTTR).
- OVERALL ILC UPTIME GOAL IS 85% during the official runs of 9 months per year

Availability DEFINITIONS

Availability: Average ratio of the time that the system or component is usable to the total amount of time that is needed.

$$Availability\quad (A) = \frac{Uptime}{Uptime + Downtime} = \frac{MTBF}{MTBF + MTTR}$$

MTBF (Mean Time Between Failure): MTBF is a basic measure of reliability for repairable items. It can be described as the number of hours that pass before a component, assembly, or system fails.

Failure rate = $MTBF^{-1} = \lambda$

MTTR (Mean Time To Repair): MTTR is the average time required to perform corrective repair on the removable items in a product or system.

Availability of N magnets = (Availability of one magnet) ^{N}

Expected Downtime in hours = (1-Availability) x Operation hour/year

How to improve availability

$$Availability\quad (A) = \frac{Uptime}{Uptime + Downtime} = \frac{MTBF}{MTBF + MTTR}$$

Perfect A = 1–> reached by having a ZERO repair time

Have to increase MTBF AND reduce MTTR

Repair time is influenced by detailed design of the magnet– this must be paid attention to during design stage.

SLAC magnet failure data showed MTBFs of individual SLAC magnets varying between ~600,000 hours and 12,000,000 hours.

Availability model demands individual magnet MTBF of 20,000,000 hours, so that magnet system as a whole will be available 99.2% of the time. Our not-available “allowance” is 0.8%

Therefore is paramount that we learn how to design and fabricate more reliable magnets, else the ILC will never usefully run!!!!

When we really get to design the ILC magnets we will have to do FMEAs on basic magnet styles

- Failure Mode and Effects Analysis (FMEA) process considers each mode of failure of every component of the system, identifies their causes and ascertains the effects of each failure mode on system operation (ALL ILC components should have FMEA done on them).
- **The final designs will have best cost/performance trade-offs**
- Come to the magnet break-out session to learn more about availability, FMEA and a prototype HA magnet we already made and tested

CONCLUSIONS

- The ILC has a huge number of magnets and we are desirous of working closely with commercial magnet companies to ensure they are made in a timely fashion, work reliably, and do not cost us "an arm and a leg"!
- Please join me at the magnet breakout session for initial discussions