The TESLA Linear Collider

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for the TESLA Collaboration
Outline

• Project Overview
• Highlights 2000/2001
  – Publication of the TDR
  – Cavity R&D
  – TTF Operation
• A0 and PITZ
• TESLA Beam Dynamics
• Site Investigation (PFV)
• Summary
TESLA – A Quick Overview

• Superconducting 1.3 GHz cavities
  – small wakefields
  – high wall-plug power to beam power efficiency
  – long beam pulse with large inter-bunch spacing

• 500-800 GeV c.m.

• Luminosity $3.4-5.8 \times 10^{34}$ cm$^{-2}$s$^{-1}$

• Proposed by an international collaboration (42 institutes, 10 countries) on a site at DESY in Hamburg/Germany
• γ produced by high energy electron beam in undulator placed before the IP

• Thin target converts the γ to positrons
Electron Sources
• 17 km long to accommodate TESLA bunch train
• Looks unconventional, but major ‘new’ issue is space charge, cured by local coupling
• Needs a 20 ns rise/fall-time injection kicker system
• 1\textsuperscript{st} IP has no crossing angle

• FFTB style layout
# TESLA Parameters

<table>
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<th>Parameter</th>
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The TDR

- Colloquium March 2001
- 1134 authors from 36 countries
- Part 2: The Accelerator
  - 380 authors
  - 54 institutes
  - major activity in 2000
  - Includes:
    - System description
    - Technical description
    - Project costs and schedule

1: Executive Summary
2: The Accelerator
3: Physics at an e+e-Linear Collider
4: A Detector for TESLA
5: The X-Ray Free Electron Laser
6: Appendices

tesla.desy.de/new_pages/TDR_CD/start.html
• Standard 9-cell cavities >25 MV/m
• Gradient record >42 MV/m in **electro polished** **seamless** single-cell **NB** cavity
• Gradient > 40 MV/m in **seamless** single-cell **NBCu** cavity and in **electro polished** single-cell **NB** cavity
• Gradient 32 MV/m in **electro polished** 9-cell **NB** cavity
Standard Cavity Preparation

• Niobium sheets (RRR=300) are eddy-current scanned to avoid foreign material inclusions

• Industrial production of full nine-cell cavities:
  – Deep-drawing of subunits (half-cells, etc.) from niobium sheets
  – Electron-beam welding according to detailed specification

• 800 °C high temperature treatment stress anneals the Nb and removes hydrogen

• 1400 °C high temperature treatment with titanium getter layer to increase the thermal conductivity (RRR=500)

• Chemical etching to remove damage layer and titanium getter layer

• High pressure water rinsing as final treatment to avoid particle contamination
What do we get?

Excitation Curve Cavities Latest Production

Test temperature: 2K
Some Statistics

Mode analysis (single cell gradient of 9-cell cavity)

Improvements 1\textsuperscript{st}, 2\textsuperscript{nd} and 3\textsuperscript{rd} production

Known defects can explain tails
So – Where are we?

- 3 production series of 9-cell cavities with \( \approx 30 \) cavities each
- Improvements for series 2 and 3:
  - welding technique
  - eddy current scans of every Nb-sheet to detect imperfections
- 5 modules built so far, 3 tested with beam
- 4 (+1) more modules to be built
  - one with electropolished cavities
The Road to 35 MV/m

Quench limit

Improve surface quality of cavities through electropolishing

Lorentz forces / detuning

• Cavity stiffening
• Active tuning with piezoelectric tuner

Field emission

Cleaning, high power conditioning
Electropolishing (KEK, CERN/CEA/DESY)

Electropolishing of 1-cell cavities
(Scheme)

- EP electrolyte
- 90 % H₂SO₄
- 10 % HF
- 30 °C
- 0,5 μm/min removal of material

[Image of electropolishing scheme with diagram of acid flow and removal process]
Electropolishing Results – Single Cell

Sample of single cell NB cavities  
Same 6 cavities after BCP resp. EP

12 cavities > 40 MV/m worldwide, 10 EP, 2BCP
• Very promising result on 1st EP 9-cell cavity

• Goal:
  – Improve EP procedure
  – Built a module out of EP cavities only by 2003

• Infrastructure for 9-cell EP built at DESY, commissioning starts March

• Module 6 will be made of EP cavities only, test in 2003
TESLA Test Facility

- First SASE at 109 nm February 2000
- Saturation at 100 nm September 2001
Future Module Tests at TTF1 and 2

- Full beam-loading with high gradient  March/April 02
- **Superstructure without/with beam**  July-September 02
- **Reconstruction TTF1 to TTF2**  May 02 – June 03
- Module 1* (25 MV/m)  July-October 02
- Module 3, 4, 5 (all around 25 MV/m)
  - RF tests  Feb.-April 03
  - Beam operation  start July 03
- Module 6 (electro-polished)
  - On module test stand  End of 2003
  - In TTF2  2004
TESLA RF Distribution System

RF Unit: 1 klystron
3 cryomodules
36 cavities

286 RF Units per LINAC:
- 10,296 Cavities
- 858 Cryomodules
- 286 Klystrons
Multibeam Klystron

Acceptance test:
116 kV, 10 MW, 1.5 ms, 5 Hz, $\eta=65\%$

Typical operation at TTF in 2001:
95-100 kV, 3-4 MW, 1.5 ms, 1 Hz
Beam Loading Compensation

Full TESLA current

Performance of low level RF control
Lorentz Force Detuning

Piezo-Actuator:
1 = 39 mm
U_{max} = 150V
Δl = 4 to 5 μm at 2K
Δf_{max, static} = 500Hz
Two 9-cell resonators are fed by one input coupler

Higher filling factor 78.9% -- 84.8%  

ie gradient for 500 GeV  

23.4 -- 22 MV/m

Less input couplers and simpler waveguide-system  
Reduced cost

Resonators have independent tuners
all modes damped below $1 \times 10^5$, but …
Higher Order Mode Measurements with Beam

The Experiment:
- RF-Gun based photoinjector
- Laser pulse train and thus the charge is modulated with $f_{mod} = 90$ kHz to 27 MHz
- Dogleg Magnet
- Beam is injected into the module with a transverse offset of 19 mm
- Measure mode at HOM couplers with spectrum analyzer
- HOMs at a frequency $f_{hom}$ are excited if the modulation frequency $f_{mod}$ fulfills $f_{hom} = n \times 54$ MHz + $f_{mod}$

beam current 2 mA, modulation depth 20%, 1 V $\approx$ 2.2 mm

HOM Scan 9-Mar-2001

Step size 1 kHz
High-$Q$ HOM in the 3rd Passband

- Measured with intensity modulated beam with position offset
- Detected in HOM coupler and broadband BPM

HOM Pickup Signal

HOM at 2.585 GHz
Beam at 2.6 GHz
Decay time $\Rightarrow Q = 10^6$

35 $\mu$s beam

frequency domain
time domain
Damping the 2.585 GHz mode

DESY type HOM coupler

One coupler is "mirrored"

Coupling depends on frequency and polarization
Flat Beam Experiment at A0/FERMILAB

Extract flat beam from RF-gun through combination of non-zero solenoid field on cathode surface and skew quad beam transformer

Maximum measured emittance ratio: 50/1
Photo Injector Test Stand in Zeuthen

First photo electrons January 2002
‘Banana’ Effect – Beam-Beam Simulation

- Instability driven by vertical beam profile distortion
- Strong for high disruption
- Distortion caused by transverse wakefields and quad offset – only a few percent emittance growth
- Tuning can remove static part

Nominal TESLA Beam Parameters + y-z correlation (equivalent to few % projected emittance growth)

Beam centroids head on
‘Banana’ Effect

TDR Parameters

\[ \sigma_s = 300 \, \mu m \]
\[ \beta_x = 15 \, \text{mm} \]
\[ \beta_y = 0.4 \, \text{mm} \]

Bunch length shortened

\[ \sigma_s = 150 \, \mu m \]
\[ \beta_x = 20 \, \text{mm} \]
\[ \beta_y = 0.3 \, \text{mm} \]
DR to IP Simulations

Gaussian bunch from DR

Ideal machine

Change of bunch compressor phase by ± 2.5 deg (powerfull knob at the SLC)

This is just an example what one can (and will) do now
Planfeststellungsverfahren (PFV)

- Procedure to obtain legal approval to built TESLA on the specific site (not the political approval)
- Investigate:
  - Impact on Environment
  - Impact on Humans
  - Impact on Ecology
  - Safety issues
  - ...
Experimental Area
DESY Site and Cryo-Hall
Church of Rellingen
PFV

• Group of approximately 30 people (DESY and external contractors) works on:
  – Compiling the relevant information
  – Provide information to the public

• 3-D CAD heavily used for planning and communicating the concept

• Information publicly available on the WWW
  http://www.desy.de/tesla-planung/

• This is almost like pouring the concrete
Summary

• 9 years of R&D on TESLA culminated in the publication of the TDR March 2001
• The technology for a 500 GeV collider is at hand
• Cavity R&D program continues with the goal to reach the ultimate performance limit of SC cavities
• TESLA collaboration has initiated the formal approval procedure to built a linear collider in Hamburg
• Since Snowmass 2001 a very intense international discussion has started on how, who, where, what, when … and will continue during LC02

Thanks to all colleagues for providing me with information.