OVERVIEW OF INDUSTRIALIZATION STRATEGIES FOR ILC

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Abstract

ILC is by far the largest and most challenging application of superconducting RF accelerator technology. Starting from the experience with TESLA and XFEL I will describe the level of industrial competence in the three global regions (Asia, America and Europe). In particular I will refer to the state of the art of cavity fabrication, module assembly and auxiliary components as well as to the synergy with the XFEL project. I will use the fabrication experience with SC magnets for LHC at CERN as benchmark for industrialization strategies for ILC.

INTRODUCTION

Superconducting RF accelerating systems are in operation in a variety of accelerators, like storage rings, light sources and installations for nuclear and heavy ion physics. Presently XFEL [1] is the largest project based on sc accelerating systems (800 9-cell cavities). It was launched early June 2007 and should start its operation in 2013. It follows the pioneering and successful operation of FLASH [2], a 1 GeV superconducting FEL, installed at the TTF (TESLA Test Facility) area at DESY. It is worthwhile to note that one important result of the R&D effort for TESLA [3] resulted in a benefit factor (product of gradient increase (factor 5) divided by the factor of cost reduction (factor 0,25) of about 20.

In 2004 the R&D efforts on linear colliders based on normal (NLC) or superconducting (TESLA) technology were unified into the global enterprise of the superconducting version ILC [4]. A GDE (global design effort) [5] organization is installed. The main effort is to proceed from the CDR (Conceptional Design Report) to RDR (Reference Design Report) to the final EDR (Engineering design Report). Parallel to CDR the first costing of ILC has been completed with essential input from the industrialization effort for TESLA. Also new module test facilities are under construction at FNAL and KEK, similar to the installation already existing at DESY.

The industrialization process can be interpreted in several ways:

- Incorporation of industry in R&D efforts,
- building prototypes together with industry,
- Technology transfer of laboratory competence to industry,
- Optimization of design and flow of fabrication for cost reduction,
- Definition of appropriate QA methods, application of mass production technology to large scale manufacturing and
- Working out of the optimum cooperation between laboratories and industry.

At the end the industrialization process should prepare the boundary conditions for building the demanding accelerator for ILC within limits in cost and schedule. At the present time GDE has not yet presented a clear definition of the industrialization process. In this paper I will give a global picture of previous and ongoing activities of industrialization, comment on differences in competence and industrial culture and draw my conclusion.

GLOBAL INDUSTRIAL STUDIES

European Studies: TESLA Collaboration

In preparation for TESLA (and later also for XFEL) several “industrial studies” have been initiated by the TESLA collaboration under the leadership of DESY. The scope of these studies was to analyze large scale industrial production of major parts of the superconducting TESLA linac with respect to required resources and cost. According to the TESLA proposal about 20.000 9-cell cavities (see Fig. 1) should be fabricated within a period of 3 years, i.e. one cavity per hour. Until today (2007) no such fabrication facility exists.

Figure 1: Parts for Nb cavity production: hydroforming Nb sheets and electron beam welding of cavities. (Courtesy CERCA).

In the first part of these studies the present prototype production for TTF was analyzed:

- Describe present fabrication process
- Determine cost drivers, critical procedures
- Define core technology, outsourcing fabrication

In a second step large scale production methods were implemented

- Evaluate investment of machinery, tooling and roboting
- Optimize flow of fabrication
- Describe layout of the core factory

In a third step the core factory was described and evaluated

- Determine costs for buildings, investment, man power for ramp up, production and ramp down activities, overhead, consumables, QA effort, maintenance,...
- Get bids for fabrication of outsourced parts

Finally the total cost of in house and outsourced production is summed up. Please note that the strategy of these studies was to describe a new and dedicated fabrication facility rather than applying learning curve assumptions to prototype experience. The competence of industrial partners who were involved in the studies covers planning and building large scale fabrication facilities as well as world leading experience in sc RF technology. The following studies were completed:

- Fabrication of 500 tons of high purity Niobium (BNN& Heraeus)
- Fabrication of 20.000 9-cell Niobium cavities (BNN&Dornier)
- Preparation of 20.000 9-cell cavities (final cleaning steps and first cold measurements),(BNN&Dornier, ACCEL)
- Assembly of 2.500 modules. (BNN&Dornier; ACCEL; ZANON)

The amount of 500 tons of Niobium required for the superconducting linear collider is small compared to the yearly world production of about 45.000 tons. But in contrast to most other applications Niobium for sc cavities must have high thermal conductivity to allow operation at high electro-magnetic field. This requires a very low content of interstitial impurities. One major aspect of the industrial study for Niobium was to understand in detail the purification process and required cleanliness conditions so that QA technology can be developed in time. Furthermore possible cost savings of the fabrication process have been explored.

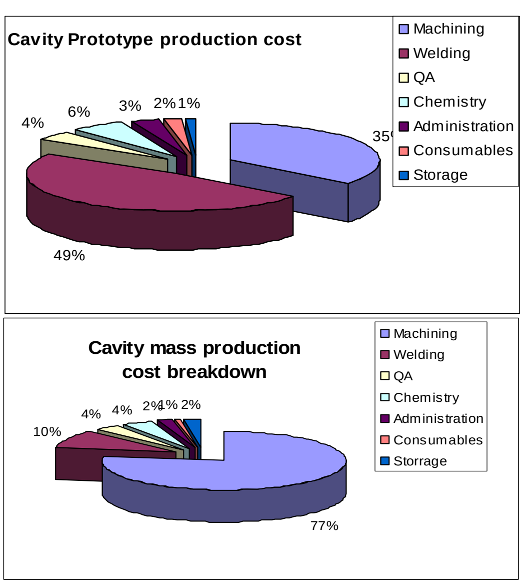

Figure 2: Comparison of cavity fabrication cost break down.

In the standard cavity fabrication process Nb sheets are formed by deep drawing and are welded to a cavity by electron beam technology (see Fig. 1). The industrial study identified the EB welding as major cost driver, mainly because of the time required for pump down and venting. Considerable cost reduction is expected by using a three vacuum chamber welding installation as well as using tools for multiple parts welding. Furthermore a consequent outsourcing of machining Nb parts to large metal working companies is recommended. A comparison of cost breakdown for prototype and mass production of Nb cavities is shown in Fig. 2.

European Studies: XFEL

Figure 3: Installation of a FLASH accelerator module.

The TESLA industrial study on module assembly concluded that manpower effort dominates the cost. It was decided in 2006 to launch a second study (now driven by the XFEL project) where industry (ACCEL; BNN) examines in detail the present assembly procedure and works out an optimized workflow (see Fig. 3, 4). At the time of this conference this study will nearly be completed. Part 1 of this study will describe the technical details of module assembly. This part will be published and be available for the bidding process of XFEL cryomodule assembly. Part 2 will contain a detailed cost figures but is confidential to assure competition in the bidding process.

Figure 4: Cavity string assembly for FLASH module.

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The RF input coupler (see Fig. 5) is a delicate component which has to fulfill requirements of high power RF, vacuum and cryogenics technology. The coupler was designed by the TESLA collaboration with major contributions from DESY and IN2P3. Orders for in total 70 TTF III couplers have been placed to industry (ACCEL, CPI); about 26 have already been installed in modules. A dedicated coupler test infrastructure is in operation at Orsay within an agreement between DESY, IN2P3 and XFEL.

The operating experience with these input couplers (so called TTF III version) prove that the basic design features meet the specified values. But for large scale production cost reductions are expected. Therefore a new industrial study was launched (ACCEL; E2V; Toshiba) by XFEL and IN2P3 for the XFEL coupler (a slightly modified version of the TTF III coupler). The major elements of this study are:

- Determine and explain the manufacturing processes, provide models for validation of each process. Finalize and justify the mechanical design with respect to lower cost in series and shorter time of assembly, evaluate risks
- Determine and comment the manufacturing logistics (in manpower, in building area) including conditioning, and evaluate difficulties and risks
- Deliver validation models and 2 prototypes
- Deliver a detailed report on price justification analysis.

The final result of these studies is expected early 2008.

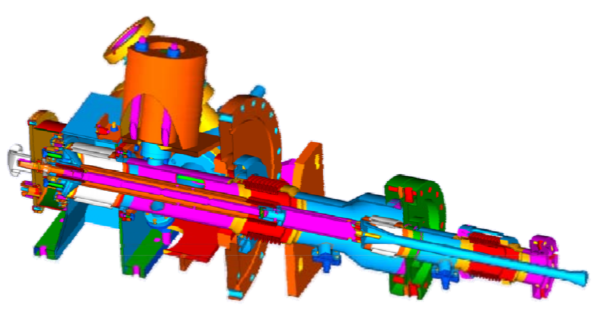

Figure 5: RF input coupler for XFEL.

Studies at USA

In spring 2007 a study on fabrication of main sc accelerator components for ILC (cavities, modules, high power RF) has been finished in USA by a consortium coordinated by AES (partner CPI, Meyer). The main task was to get a cost figure for the ILC linac construction. This study is different from the TESLA and XFEL investigations in several aspects. There is only very little experience in US companies in building sc prototypes. Therefore assumptions on learning curve benefit for large scale production are applied. An optimization of the fabrication process could not be finalized because of restrictions in time and resources. It is also assumed that the required infrastructure is built and paid by the US government. Details of this study are reported at this conference [6].

GLOBAL INDUSTRIAL COMPETENZ

More than 1000 superconducting cavities have been built worldwide for the acceleration of electrons, protons and heavy ions. For electrons and protons the cavities are of elliptical shape (see Fig. 1), heavy ions (or low energy protons) are accelerated by a variety of small gap geometries to slow down the phase velocity. In most cases the final cavity treatment and assembly is done in the laboratories.

European Industry

European industry is involved in cavity production since more than 20 years. At present there are three companies with expertise in Niobium cavity fabrication: ACCEL, Zanon and CERCA (Dornier was pioneering this field but is no longer active). The dominant part of the global cavity production is handled by these European companies, e.g. 364 cavities for CEBAF [7], 109 cavities (CU-Nb sputter technology) for LEP [8] and LHC [9], 109 Nb cavities for SNS [10] and 130 cavities for TTF / FLASH (and another 30 under production). Already 38 complete modules for different sc RF accelerator systems have been fabricated by ACCEL Company, some of those under “turn key” conditions, i.e. with complete cavity preparation and module assembly.

Japanese Industry

It is Japanese tradition to involve industry already in an early stage of R&D and preparation for a new accelerator project. The design of the device, the specifications and the technical information are explained to industry. In the following discussion the realization of the specification is investigated with drawings and calculations made by industry. After approval of the project industry can set up the production facility very quickly. Examples of such projects are the construction of the superconducting RF system in TRISTAN [11] (52 cavities; Mitsubishi Heavy Industry) and recently the installation of the module test facility STF at KEK.

American Industry

American industry is in a very early stage of production of cavities (AES) and cryostats for superconducting RF systems (Meyer). At the Jlab laboratory expertise in cavity preparation and module design / assembly was accumulated during assembly of modules for the CEBAF linac as well as for the SNS superconducting RF system. In both cases the cavities were built by the European

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company ACCEL. Technology transfer from Jlab to American industry has not yet materialized.

PRESENT LARGE SC ACCELERATOR PROJECTS

LHC SC Dipole Magnet Fabrication

In total 1232 dipole magnets, each one about 15 m long and 28 tons heavy have been manufactured by European industry for the LHC (Ansaldo, BNN, and Alstom-Jeumont). Superconducting magnets and superconducting RF accelerating systems have some similarities:

- Magnets and cavities are imbedded in a 2K cryogenic system
- Both rely on intrinsic properties of the superconductor
- Magnets and cavities require a cold acceptance test
- Both components are at the edge of technology
- Fabrication technology is not available “off the shelf”

One major difference is that magnets require very precise alignment and very low magnetization of the metal collar whereas cavities need a final critical surface treatment under clean room conditions.
Following the prototype development at CERN each of the three companies mentioned above were asked to fabricate a pre-series of 30 magnets. Based on this experience the companies were in a position to prepare an offer for the main production (3 times 386) with small risk with respect to costs and schedule. For the

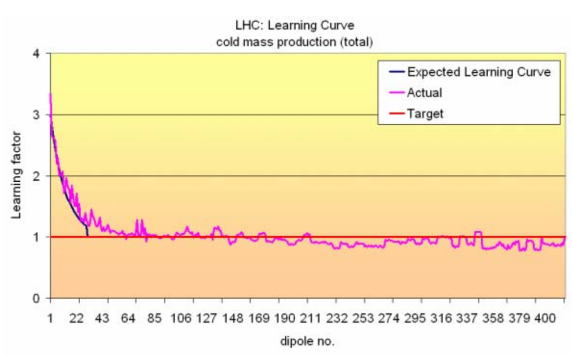

Figure 6: Learning effect of cold mass production for LHC (courtesy BNN) [12].

production, nearly all main components were directly procured by CERN. Heavy tooling was designed and procured by CERN; also essential quality control equipment was designed and supplied by CERN. In order to assure the strict application of manufacturing specifications resident inspectors under CERN contract stayed at the vendors’ premises. One important conclusion from the LHC magnet production is that the learning effect of cryostat assembly levels after about 45 units (see Fig. 6), which also should be valid for the cavity module assembly.

XFEL Project

On 5th of June this year the official start of the XFEL project was celebrated. The XFEL superconducting linac consists of 101 accelerating modules each containing eight 9-cell cavities. The plan is to be ready for ordering all accelerating components at the end of 2008. The first cold mass and cavity string components should be delivered in Q3/2009.
There are at least two well established ‘sources’ for an industrial cavity production guaranteeing the required rate of 8 to 10 cavities per week over two years. At the companies, new infrastructure is required but the effort is well understood.
Cavity treatment will be done in industry. In order to prepare this, two companies (ACCEL, Henkel) will do the first electro-polishing of 12 9-cell cavities each in 2007. The quality check will be done in terms of a vertical test on the XFEL/DESY site.
The tested cavities will be given to industry for string/module assembly. The technology transfer to industry is nearly done for the XFEL (see industrial study on module assembly). The XFEL accelerator module is based on the 3rd cryomodule generation tested at the TESLA Test Facility and designed by INFN. Already 10 cryomodules have been built and commissioned for the TTF Linac. Module 6 and Module 7 were just recently installed at TTF/FLASH. Two additional cryostats will be available at the end of this year.
Minor differences in the module design have basically no impact. The XFEL foresees two parallel lines (companies) for string assembly. All modules will be tested at the AMTF (accelerator module test facility) at DESY between mid 2010 and mid 2012

The XFEL will use 800 RF input power couplers of type TTF III. Also here the technology transfer to industry is nearly done for the XFEL (see industrial study by IN2P3, Orsay). Several companies should be qualified to build a larger number of couplers. The XFEL foresees at least two parallel lines (companies) for coupler production. Coupler conditioning might still be done in the laboratories; the transfer to industry is preferred but requires setting-up complete RF stations.

DISCUSSION & CONCLUSION

ILC is planned as a global enterprise to serve the international high energy physics community. The necessary R&D effort is already organized on a worldwide scale. Superconducting accelerator technology is the key expertise for the ILC project. This industrial competence should be established in all three regions Asia, Europe and USA. It is advantageous to have competition between companies because of costing and

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schedule reasons. Furthermore it opens the possibility for in kind contributions by partners in the different regions. At present there is a remarkable difference in industrial experience between the various regions. This will even become more pronounced by the construction of XFEL. The efforts at the test facilities at KEK and FNAL could help in building up more industrial expertise in these regions. But additional large resources are required to reach this goal. For example the European efforts in particular the "industrial studies" for TESLA and XFEL covered a period of 5 years with costs of more than 3 M€ (excluding the manpower effort in the laboratories). Further industrial expertise, e.g. in Russia and the so called new countries such as China and India would enlarge the technical basis and be of great benefit for the whole project.

Both the fabrication of sc magnets for LHC and sc accelerator components for ILC rely on frontier technology which cannot be ordered off the shelf. For LHC costly tooling as well as quality assurance methods had to be developed by CERN. Also inspectors have been at the vendor's premises to assure strict application of manufacturing specification. In a sense this means to fabricate to blue print rather than to performance. A bonus system for early or exceeding performance delivery could be advantageous. This cooperative and trustful spirit between laboratories and industry has been developed early before start of the main construction. ILC should learn from this experience and proceed accordingly.

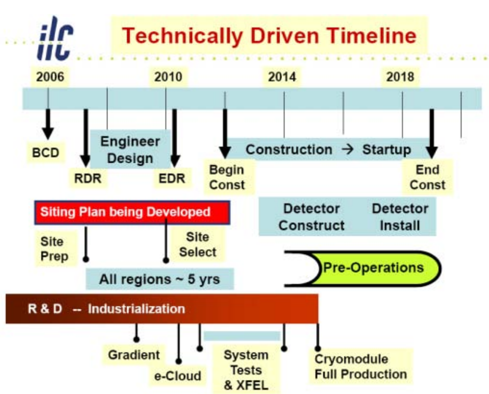

Figure 7: Timeline ILC [13].

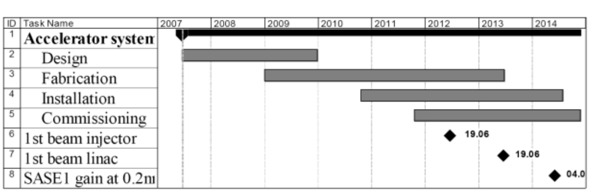

Figure 8: Timeline XFEL [14].

The technical layout of ILC and XFEL cryomodules are very similar and will require the same high competent industrial partners. The main difference is the higher operating gradient of 31.5 MV/m for ILC as compared to 23.5 MV/m for XFEL. The construction of XFEL actually was one of the main five bullet points in the decision of ITRP in favor of a superconducting linear collider. The present ILC and XFEL schedule (see Fig. 7, 8) would even allow ILC to use the industrial XFEL expertise without a time gap which has the danger of loosing industrial competence. As conclusion GDE should establish a solid link to XFEL or even take part in this project to gain a maximum benefit for ILC.

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