DESIGN INTEGRATION AT THE INTERNATIONAL LINEAR COLLIDER

B. List#, L. Hagge, J. Kreutzkamp, N. J. Walker, DESY, Hamburg, Germany

Abstract

In preparation for the Technical Design Report of the International Linear Collider, a comprehensive design of the accelerator has been compiled. DESY has contributed a systematic design integration approach, which helps to achieve a complete, correct and consistent design. We use the lattice as the leading element for design integration. Geometry information including 3D visualisation models are derived from the lattice, and are used to ensure that the beamlines fit together and are suited for access and installation. The 3D models are also used as basis for tunnel and cavern layout. As detailed designs of components become available, the lattice is adjusted and the overall models are iterated. Lists of components are derived from the lattice and are used to generate a component bill of materials, which in turn serves as basis for cost estimation and installation planning. An integrated 3D model of the entire accelerator and all the civil construction elements helps to optimize the design for example with regard to space efficiency, ease of access for installation, and life safety. Setting up design integration in an early project stage results in a better design and thus helps to reduce costs.

INTRODUCTION

The complete design of the ILC encompasses a mechanical and geometric description of the planned facility, a description of its function suitable for simulations, a cost estimate and an implementation plan. The aim of Design Integration is to ensure that this overall design is complete, correct, and self-consistent. During the design-integration process, the separate design results from the various accelerator systems and the technical groups are brought together. The integration is performed horizontally, i.e., between different accelerator systems such as source and main linac, as well as vertical, i.e. between different technical groups, such as lattice design, magnet design, and civil engineering.

The main challenge for the design integration is to define an efficient process, in which the designs of all participants are collected, assembled, checked, and made available to all parties.

METHOD

Lattice Centric Design

During the Technical Design Phase II (TDP-II) of the International Linear Collider (ILC), which was recently concluded with the completion of the Technical Design Report (TDR) [1], the design integration focused on the lattice as a central description of the overall accelerator layout. First, the individual lattices of the accelerator systems were fit together with the help of treaty points that had been negotiated and agreed upon by the lattice designers and integration team. Then, using simple 3D visualisations of the lattices, the lattice geometry was optimised in order to avoid collisions between beamlines, to ensure there was sufficient space for installation of the components, and to assess whether or not it would be possible to reduce tunnel cross sections by a suitable alignment of the beamlines.

In addition to this horizontal integration work across accelerator systems, the design was integrated vertically between different technical areas. The geometrically integrated lattice was translated into coordinate sets that were communicated to the CFS group, who based the final tunnel layout on the lattice geometry. This ensures consistency between the accelerator and tunnel geometry as well as correctness and completeness (for instance with respect to space requirements of the various dump locations).

Use of 3D Models

Combining the 3D visualisation of the beamlines with a 3D tunnel design facilitates further planning and optimisation with regard to installation, accessibility and egress and life safety. Fig. 1 shows a particularly complex

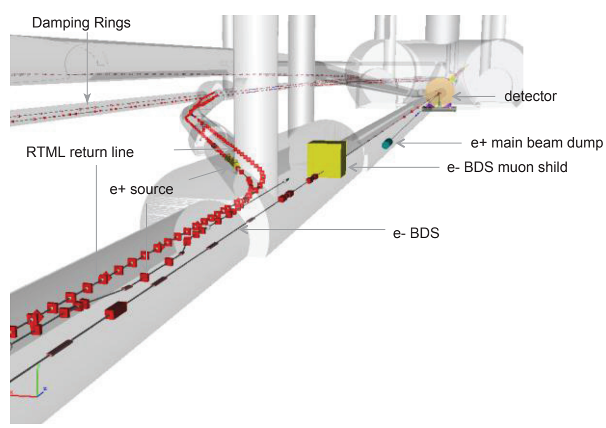

Figure 1: Example for design integration: the region where the transfer-tunnel branches off from the electron main tunnel towards the damping rings is shown. The European tunnel is shown together with a visualisation of the electron RTML and BDS and the positron-source beamlines. The transfer-tunnel geometry was changed in the central-region integration process in order to avoid the region around the positron main dump and the electron BDS muon shield.

#Benno.List@desy.de

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region around the branch off of the transfer tunnel, where the beamline geometry was substantially altered in the integration process after the inspection of the 3D model of an earlier design. By sharing a common vision of the machine through 3D modelling, the involved parties can evaluate the design at an early stage and agree on necessary modifications, which may affect the tunnel layout, the lattice geometry, or both.

Example: ILC Transfer Tunnel Design

An instructive example for the kind of problems that become apparent during design integration is depicted in Fig. 1, which shows the region where a transfer tunnel branches off which connects the damping rings to the main tunnel. In this region, beamlines from three different accelerator systems meet: the positron source beamline delivers 5 GeV positrons to the damping rings, the long transfer line of the RTML ("Ring To Main Linac") transports 5 GeV electrons from the damping ring upstream to the start of the main linac, and the beam delivery system (BDS) brings 250 GeV electrons to the interaction point. In addition, several small dump lines for commissioning purposes are located in that region. Fig. 1 shows also the muon stop directly downstream the branch-off, which protects the experiments from muons generated in the collimation section of the BDS, and the main positron dump. The muon stop consists of 5 m of magnetised iron that deflects the muons into the surrounding earth.

During the integration process the geometry of the transfer tunnel was modified in order to shift the branch-off point upstream, so that the muon stop and the (highly radioactive) main dump area are avoided by the RTML and source beamlines. The geometry of the branch-off bend is important for the positron source, because it rotates the positron spin from a longitudinal to a transverse orientation, which makes it necessary that the bending angle is an odd multiple of 7.93°, and at the same time provides the R_{56} needed for the energy compressor. When the bending angle was reduced from 5×7.93° to 3×7.93°, an additional chicane had to be designed to provide sufficient R_{56}. This chicane was later adapted in order to leave sufficient space for the BDS components.

Several designs of the beamline geometry were discussed at one of the Baseline Design Review (BDR) meetings that were conducted in during the TDP-II, with the help of early conceptual visualizations as 3D models. These visualisations helped to find problems such as overlaps between beamlines (e.g. in the case of the muon stop), but also to discuss issues such as installation space and access and egress for life safety with the experts of the Conventional Facilities and Siting group, to come up with a viable solution.

Lattice Integration

A first step of the design integration for the ILC was a horizontal integration of the lattices of the six accelerator systems: electron and positron sources, damping rings, RTML, main linac, and beam delivery system. Lattice files of all systems were collected in a common repository, and treaty points were agreed on and documented that define geometric start and end points of each beamline as well as the beam properties at these points. In addition, waypoint documents were set up that defined geometric layouts for beamlines that were agreed upon to ensure that beamlines sharing common tunnel spaces do neither intersect nor get apart so much that the tunnel cross section is unnecessarily increased.

All lattice sections were made available in the common xsif format that can be processed by MAD-8, even if the original lattice design was performed using other programs such as MAD-X or BMAD, in order to have one common lattice description available to all parties.

Components and the Lattice

Vertical integration between the lattice design and the component level was performed by adjusting the lattice such that it reflected realistic component dimensions. For instance, accelerating cavities in the booster sections of the electron and positron sources were grouped and rearranged such that they reflected realistic cryomodule designs. The extent of complex components such as cryomodules, which are represented by several lattice elements, is delineated with markers.

These markers serve as an important structuring aid that allows transforming the output of MAD's "SURVEY" command, which provides a list of all lattice elements with their position and orientation in space, into formats suitable for further processing, in particular Excel™ spreadsheets. These serve as basis for further analyses, for instance the generation of component counts for active elements such as magnets or cryomodules, and the derivation or cross-checking of specifications such as apertures or magnetic field strengths.

This data can then be made available to the various technical area groups, as basis for component design, installation planning, or cost estimation.

The availability of automated procedures for the extraction of this information makes it possible to track the effect of design changes efficiently and propagate their consequences. Thus, a process has been introduced that allows a real-time view on the various facets of the overall design to be kept while the design evolves.

Integration with Civil Engineering

An unusual aspect of the ILC design is the fact that the accelerator design has progressed quite far before a site decision has been made. Therefore the design of civil engineering infrastructure such as tunnels, caverns and shafts is necessarily rather generic and cannot take site-specific circumstances into account apart from rather general assumptions about the terrain (flat versus mountainous) and geology (sedimentary versus bedrock). Still, detailed civil engineering designs have been developed for all three major regions (America, Asia, and Europe) that partake in the ILC design, in order to arrive at a realistic cost estimate and judge the impact of the site on cost and schedule.

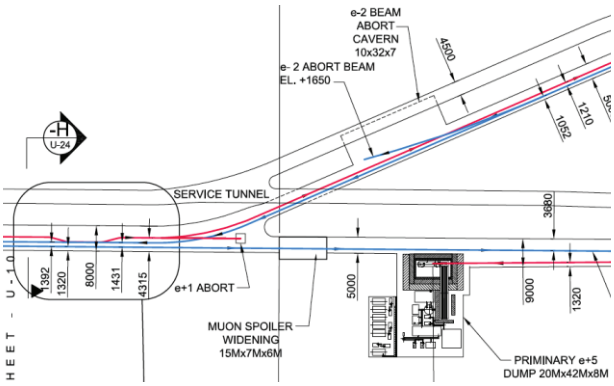

Figure 2: Detail of the Americas region tunnel design [2]; the same region as in Fig. 1 is depicted. The beamlines are drawn directly from imported lattice data.

The design of the underground buildings was based on the integrated lattice. Information about the location and nature of all beamline elements was made available in the form of Excel™ spreadsheets and VRML 3D models, and formed the basis for the detailed design of the tunnels and caverns, as shown in Figures 1 and 2.

Once a concrete site has been identified, this process will be iterated: the position of accelerator installations that require special infrastructure, such as target areas or cryogenic plants, will be adjusted, if possible, in order to match the site specific conditions. Keeping the lattice as leading design element ensures that lattice and civil structures remain in synchronization during such an iterative process. Figure 3 shows an example how detailed models of tunnel sections can be combined with a 3D model of the original lattice to verify the consistency of the design.

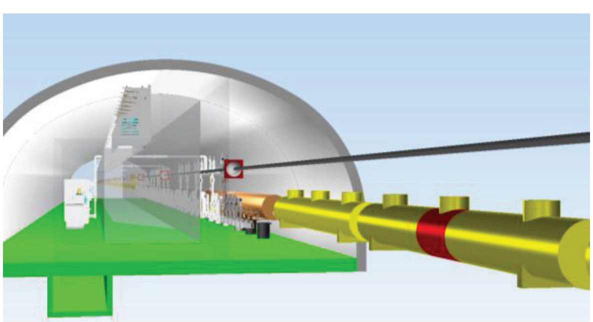

Figure 3: View of the conceptual lattice visualization (foreground) together with a detailed tunnel design for the sites with mountainous topography ("Kamaboko" shape, in the background).

Integration Office

The ILC is project that has been designed by a worldwide collaboration in an unprecedented way, without a central laboratory that leads, or dominates, the design process. Lattices, cavities, cryomodules, RF systems, magnets and civil infrastructure have been designed by groups scattered all over the world. Integration is just one more contribution to the overall design, albeit a crucial one. A core integration team, which collects and assembles design data, performs quality assurance, provides procedural guidance, and routes the design information to all concerned parties, has proven beneficial. The physical location and affiliation of the integration office is of secondary importance in a situation where the design teams are anyway distributed around the globe. More important is a design process that ensures that all relevant information is collected, maintained and made available to all parties, and that the completeness and correctness of the design documentation is ensured by proper techniques, in particular a formal change control protocol.

BENEFITS

In short, the goal of early design integration based on the lattice and augmented with ubiquitous three-dimensional visualization is a better design at an earlier project stage. This leads to less re-design at later stages, and thus provides a more reliable basis for all aspects of project planning such as cost estimation, scheduling, risk analysis.

The integrated design is "better" in the sense that it incorporates knowledge from different areas such as beam dynamics, magnet design, cryogenics, RF distribution, and civil engineering, and thus reveals tensions between different areas or opportunities for design optimization early on. For example, the lattice may be redesigned to allow a relocation of shafts or caverns, reduce tunnel cross sections, avoid critical areas of other beamlines, or improve access and egress paths. The lattice may also be adapted to ease the burden on component designers, e.g. reduce field gradients by providing more space for longer magnets.

In summary, design integration is an inherently important task that is essential for a coherent execution of the project. A central design office that collects and provides design information in a uniform manner under quality control and develops, establishes, and coordinates the integration process is instrumental for a successful and efficient implementation of design integration.

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