CONSTRUCTING THE ESS LINEAR ACCELERATOR: PRAGMATIC APPROACHES TO DESIGN AND SYSTEM INTEGRATION AT THE EUROPEAN SPALLATION SOURCE

G. Lanfranco, M. Conlon, E. Tanke, N. Gazis, E. Vaena, ESS, Lund, Sweden

Abstract

The European Spallation Source (ESS) is a neutron science facility, with planned start of construction in Lund in 2014, Sweden and it is one of the largest science and technology infrastructure projects being developed in the world today. It will include a 62.5 mA, 2 GeV proton linac, a tungsten target station, 22 state-of-the-art neutron instruments. ESS also includes a supercomputing data processing centre, which will be in Copenhagen, Denmark.

The Accelerator Systems project (ACCSYS) represents almost one third of the total ESS construction budget. Seventeen European countries are participating as in-kind contributing partners. Because of the project complexity and the important number of interacting parties, it is crucial to establish a pragmatic approach for design and systems integration. Guarantee of requirements consistency, clarity of interface definition and allocation of correct spaces are just some of the fundamental aspects that must be addressed for a successful integration. Potential functional or design inconsistencies must be promptly detected and actively resolved to bridge the project from conceptual design towards a smooth, timely, cost effective installation. Minimizing the administrative burden is also important given the intrinsic prototypical nature of this type of project.

This paper describes the pragmatic approaches to design and system integration as well as the system architecture and the tools deployed to integrate the design of the ESS Linear Accelerator and to prepare for its installation.

INTRODUCTION

The ESS accelerator high level requirements demand a 2.86 ms long proton pulse at 2.0 GeV and at a repetition rate of 14 Hz, with 5 MW of average beam power on target. In the first part of the ESS linac, the proton beam from the ion source is accelerated to 90 MeV by a Radio Frequency Quadrupole (RFQ) and five Drift Tube Linac (DTL) tanks. It is followed by a superconducting linac, comprised of spoke, medium and high beta cavities that accelerate the beam to the final energy of 2 GeV. Beam delivery of the 5 MW beam is achieved by the High Energy Beam Transport (HEBT). See Figure 1.

The design and construction of the ESS linear accelerator is a multinational, collaborative effort, and collaboration between different countries is taking place not only at beam line level but also within individual work packages. ESS staff in Lund remains responsible for overall integration and for the coordination of the work, services and hardware and software systems 'procured' through collaboration partnership agreements, in-kind contributions (IKC) and other suppliers. In summary, the major subsystems of the warm linac are being developed and delivered primarily through IKC from INFN Catania, CEA Saclay, ESS-Bilbao and INFN Legnaro. The superconducting cavities and associated cryomodules are designed, procured and assembled through IKC at IPN Orsay and CEA Saclay. The HEBT will be supplied by ISA, Aarhus, an ESS collaboration partner. Other major subsystems, such as the cryogenics plant, will be procured through commercial tendering. The complexity of handling multiple in-kind contributions to ultimately become one fully operational accelerator requires a pragmatic approach to integration.

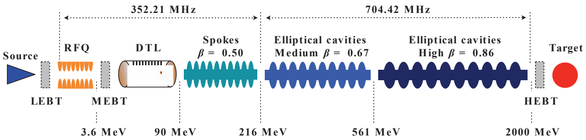

Figure 1: Basic layout of the sections within the ESS accelerator.

SYSTEMS ARCHITECTURE AND INTEGRATION

ESS applies a systematic approach to engineering development and management generally in accordance with the International Council on Systems Engineering (INCOSE) definition of Systems Engineering [1]. ESS also applies and adapts processes and terminology identified and explained in the International Organisation for Standardisation (ISO) [2].

The Systems Engineering approach used at ESS may also be represented in term of a 'V' model: the left side of the 'V' representing the decomposition of needs in iteration with the development of system descriptions of increasing detail, and the right side representing the synthesis of the system, in this case the ESS linear accelerator, including its physical, functional / operational integration and verification / validation.

Methodology for Developing Requirements and Systems

The majority of ESS stakeholder needs can be met by systems, which are primarily mature in their technologies. Furthermore, analysis to date by the Accelerator project indicates that the technical risk in delivering the ESS linear accelerator is somewhat lower than for other more developmental systems and instruments being developed for the ESS facility. Consequently Accelerator's scope-driven budget and time schedule, has also been adjusted for this assessed risk profile.

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Comparatively lower technical risk has allowed the Accelerator project to apply a direct 'waterfall' methodology for conducting design and in managing construction. This approach sees a sequential progression from requirements, through analysis and design including prototyping, to implementation, the latter involving system synthesis, verification, integration and validation. However in the design and construction of the ESS linear accelerator there is less emphasis on the rigorous application of such a methodology or process, and more emphasis on achieving completeness, utility and overall value from the outputs. Thus, the Accelerator project develops its requirements in some cases starting from a first-principles functional decomposition of needs, and use-case analysis, and in other cases starting from brain-stormed or borrowed and reused concepts and models for systems.

Proposing concepts and models for systems sometimes in advance of documenting requirements for those systems is not however used to avoid or negate requirements-based design, and on the contrary, requirements are the essential language and vehicles for delivering the ESS linear accelerator. In this sense Accelerator's requirements range across a spectrum from requirements which capture needs, functions or performance aspirations more abstractly, to requirements which more tangibly specify hardware and software system solutions. The former category of requirements may provide guidance as well as latitude for further design, whereas the latter requirements are used to provide constraint and direction where design concepts are already well established and what is needed is (only) detailed design and/or build-to-print procurement. In every case, requirements also form the basis for verification. Accelerator's requirements are managed using a commercially available web-based database tool. See also [3].

Architectural Structures for Managing Requirements and Accelerator System Products

The ESS Linear Accelerator is defined and constructed through the interplay of two groupings within the Accelerator project organisation: the engineering and integration leads (ACCSYS Integration Group) and the project's 'support' or delivery grouping (ACCSYS work package teams). Note that Accelerator work packages are the first level of the work breakdown structure (WBS) of the project's scope, budget and time schedule.

The Integration Group has the internal 'customers' who lead the development of requirements, whereas the work package teams, are the 'suppliers' delivering or facilitating the delivery of detailed design services and linear accelerator hardware and software products through their own efforts, through collaboration with partner labs, through in-kind contributions, and through procurement contracting with commercial suppliers.

Accelerator project's 'system' is the ESS Linear Accelerator, and this system has been decomposed using a Product Breakdown Structure (PBS). The PBS is a hybrid structure, useful to define, map and allocate a hierarchy of requirements to a hierarchy of hardware and software solutions. See Figure 2. Note that the PBS' Level 4 (L4), is defined in terms of Accelerator 'disciplines', specifically to facilitate the exchange of requirements from the engineering and integration lead 'customers' to become technical specifications in the statements of work used by work package team 'suppliers' procuring detailed design services and linear accelerator product hardware and software. PBS L4 disciplines map to WBS level 2 work packages, given that WBS level 1 is the Accelerator project itself.

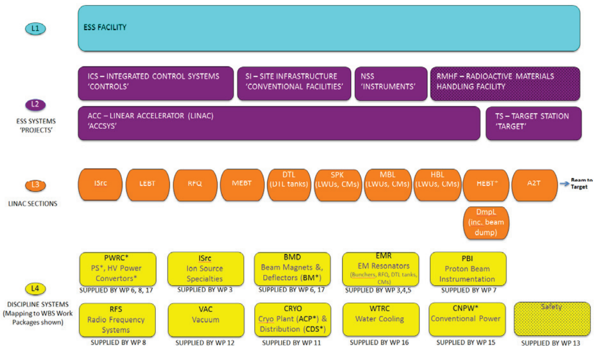

Figure 2: Product Breakdown Structure (PBS) for ESS Accelerator's levels of breakdown L1 to L4

Interface Management

Interfaces between PBS elements and levels, both internal to Accelerator and with external systems, are identified using simple interface matrices. Requirements are 'tagged' for the interfaces each has, and this and other information linked to specific requirements is also stored, managed and can be analysed within the web-based requirements tool. Requirements-based interface information is then used to guide design and organisational responsibilities. The web interface has been set up in such a way that approval signatures can be made by the system owners of the interfacing systems. One can then export relevant sets of requirements to provide, for example: the basis for technical specifications for procurement contracting and collaboration / IKC agreements or technical statements of work; or as core content for interface control descriptions.

IMPLEMENTING SYSTEM DESIGN

The design becomes hardware and software deliverables in the implementation phase by adhering to the established system architecture and by satisfying the specified requirements and interfaces.

Design Data Flow

Achieving an effective data flow is paramount to guarantee robust information exchange. All project stakeholders must be constantly aware of the current design configurations, continually evolving in the first stages of the project, and must be able to promptly react to resolve undesired deviations from the project scope.

Established procedures and tools are required from the start which support proper data flow in a rapidly growing[*] environment.

Figure 3 describes the data exchange architecture currently under implementation for ACCSYS. A Back Office, established within the ACCSYS project team in Lund, is responsible to collect all data from the project collaborators (IKC, Conventional Facilities project, vendors, suppliers, etc.). The ACCSYS Integration Group guarantees the data quality, translates the data to the proper formats, if needed, and integrates the CAD data in the ACCSYS three dimensional virtual model. Ultimately, the data is exported to the ESS data repository to make it readily available. Figure 3 also shows the Conventional Facilities project data flow architecture, similar to ACCSYS's.

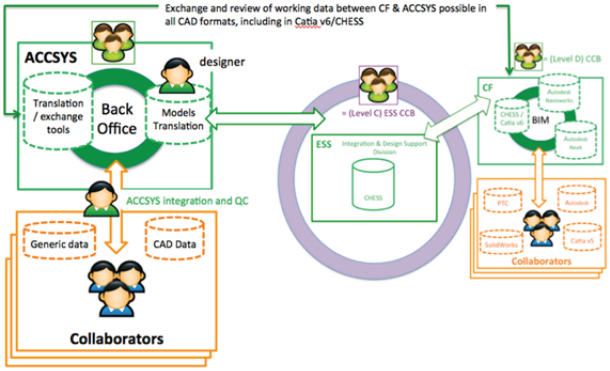

Figure 3: ACCSYS data exchange architecture.

Lattice Database and Virtual Model

The virtual model (ACCSYS Assembly) has a central part in the design implementation. Through it, integration of systems into the accelerator premises is achieved by means of correct space allocation and interface verification (clash detection). Moreover, 3D models are necessary to produce procurement drawings and to create graphical representations for installation procedures.

The main accelerator systems, such as accelerating structures, optics and instrumentation, received by the ACCSYS back office must be accurately positioned within the ACCSYS Assembly. Each beamline element is defined in the lattice database by six coordinates which locate its characteristic centre[†] according to the Machine Coordinate System (MCS)[‡]. The *skeleton* is the spline formed by these points to which virtual models are rigidly constrained, thus guaranteeing correct positioning.

Software Tools

A set of requirements has been initially produced to define the functionalities the data management software must satisfy to allow handling and integration of ACCSYS data and to gain better control over project outcomes before construction begins.

Criteria have been introduced to benchmark data handling robustness (single point of truth) and ease of use. Given the wide number of collaborating parties, the system that shall be adopted will need to offer platform-independent, web-based functionalities.

Selected software must deliver a plant design oriented solution and not, as is often done in similar projects, a purely mechanically oriented one, which often falls short when resolving integration issues with conventional utilities, routing cables and piping.

Several software solutions are being investigated to verify the required functionalities for data management and project review of the ACCSYS project.

CONCLUSION

The ESS Accelerator project has adapted and implemented a pragmatic systems engineering methodology, which is identifying and resolving issues arising in this large, complex and multi-party endeavor.

The application of a requirement-based approach and the establishment of agile architectural structures for managing interfaces and deliverables are fundamental for delivering the ESS linear accelerator.

Effective systems integration is achieved by implementing and managing a robust data design flow that facilitates interactions among stakeholders, minimizes data travel paths and uses plant design software tools which focus on simplicity and interoperability.

ACKNOWLEDGMENT

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REFERENCES

[1] International Council on Systems Engineering; http://www.incose.org
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[*] Either in terms of data produced or in terms of people producing it.

[†] Either geometric or magnetic.

[‡] MCS is conveniently established at the proton source.