SYSTEM ENGINEERING IN THE SSC LINAC*

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Abstract

The design and construction of the SSC Linac involves various departments within the SSCL and many outside vendors. The adaptive incorporation of system engineering principles into the SSC Linac is described. This involves the development of specification trees with the breakdown and flow of functional and physical requirements from the top level system specifications to the lower level component specifications. Interfaces are defined, which specify and control the interconnections between the various components. Review cycles are presented during which the requirements, evolution of the design, and test plans are reviewed, monitored, and finalized. The Linac specification tree, interface definition, and reviews of the Linac are presented, including typical examples.

Introduction

Within the SSCL, as described in the Project Management Plan [1], the Linac Group is responsible for the physics design of the Linac and for assuring that the Linac is designed, constructed, and brought into operation to achieve the required technical performance within the cost and schedule guidelines. The Accelerator Systems Division (ASD) is responsible for providing to the Linac Group all the technical components of the Linac according to the requirements. The engineering departments with ASD perform the design and fabrication of the components, or monitor the design and fabrication of those components that are provided by outside institutions.

As required by the Project Management Plan and defined in the Engineering Management Plan [2], a system engineering process has been incorporated into the SSCL to ensure that the SSC satisfies its performance, cost, and schedule requirements. It provides an orderly process for the documentation of requirements and the designs, considering all aspects, from the development of requirements, through the evolution of the design, to the final testing and ultimate operation. The process involves documentation of the requirements in specifications, monitoring of the designs through reviews, and bringing the technical equipment into operation according to accepted test plans and procedures. Often the design process is an iteration between the physics and engineering as technically realizable solutions to the physics requirements are developed within the cost and schedule constraints of the project. This process provides a formalized method for the reduction of risk associated with technical performance, cost, and schedule.

The following describes this process as it specifically relates to the Linac. The transmittal of and agreement on requirements will be discussed. The reviews that monitor the design of the components or subsystems of the Linac will be presented. The interface control process that helps to ensure that the various components properly interconnect and integrate into a working Linac is described.

Specifications

The SSC hardware, software, and facilities have been divided into manageable functional units, each with its technical specifications and design criteria. There are four major levels of specifications at the SSC.

The Level 1, or Project, specification sets the top level requirements for the SSC. The Level 2, or Systems, specifications divides the SSC into Accelerator System, Experimental System, SSC Buildings, and SSC Infrastructure and set the top-level requirements for each of these systems. Level 1 and Level 2 specifications require Department of Energy approval. The Linac is first specified in the Accelerator System specification.

Level 3 subdivides the Level 2 Accelerator System into the individual machines that make up the entire system and is divided into Level 3A and Level 3B. There are four level 3 specifications for the Linac. These are listed in Table 1. The Linac Level 3A, or Segment, specification contains the functional requirements, physics requirements, and the geometry or lattice definition for the Linac.

TABLE 1
Linac Level 3 Specifications

E10-000003	Linac 3A
E10-000025	Linear Accelerator 3B
E10-000026	Linac Transfer Line 3B
C12-00040	Linac Technical Facilities 3B

The two level 3B specifications for the Linear Accelerator and the Linac Transfer Line contain the engineering requirements of the RF cavities, RF power systems, magnets, controls, power supplies, beam instrumentation, etc. The Linac Technical Facilities specification contains the requirements of the tunnel and building that house the technical equipment of

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the Linac. This specification was transmitted to the architectural firm for the design of the building and the tunnel.

Level 4, or Subsystem and Component, specifications specify the component to be built at the SSCL or accompany a procurement package detailing the requirements to which the subject component is to be developed or built. These specify the performance, design, development, and test requirements for the particular subsystem or component. There are seventeen level 4 specifications for the Linear Accelerator. These are listed in Table 2. The RFQ, DTL, and CCL cavities, as well as the RF amplifiers for the RFQ, DTL Input Matching Section, DTL, CCL, and Energy Compressor, are all part of external procurement packages. The remainder specify components to be built or provided by the engineering departments of the Accelerator Systems Division of the SSCL.

TABLE 2
Linear Accelerator Level 4 Specifications

Document No.	Specification
E10-000081	Ion Source/LEBT & Support Systems
E10-000087	RFQ Cavity
ARA-2120099	RFQ Amplifier
AQA-1030001	RFQ Support Systems
E10-000053	DTL Input Matching Section
ARA-2120005	RFQ-DTL Buncher Amplifier
ARA-2120010	DTL Klystron Modulator System
ARA-2120011	CCL Klystron Modulator System
ARA-7120002	Energy Compressor RF Amplifier
AMA-2210001	DTL Cavities
E10-000072	DTL Support Systems
E10-000083	CCL Input Matching Section
AMA-2210002	CCL Cavities
E10-000079	CCL Support Systems
E10-000084	CCL Transport Line
E10-000090	Linac Utilities
E10-000089	Linac Systems

For the Linac Transfer Line there are eight Level 4 specifications. These specify magnets (dipole, quadrupole, and steering), magnet power supplies, mechanical hardware (including vacuum, beam pipe, and stands), instrumentation, abort, extraction and injection, safety, and controls.

Reviews

A series of four technical reviews are conducted to evaluate the adequacy of the technical requirements, to review the design as it progresses to the final detailed design, to verify that the cost and schedule meet projected values and dates, and to confirm proper interfaces. These are:

Preliminary Design Requirements Review (PDRR) verifies that the requirements of the associated specification are complete and understood and to evaluate the risks associated with the conceptual design.

Preliminary Design Review (PDR) evaluates the progress, technical adequacy, and risk (on technical, cost and schedule basis) of the selected design approach and checks the compatibility of its interfaces to other subsystems or components.

Critical Design Review (CDR) evaluates the detailed design's capability to satisfy the requirements on a technical, cost, and schedule basis.

Acceptance Test Plan Review (ATPR) reviews the plan that will demonstrate whether the requirements have been met.

The Level 3 PDRR reviews the 3A and 3B specifications and provides the physics and engineering assessment of conceptual design with at least one practical design. At Level 3, the PDR and CDR nominally occur after a majority of the Level 4 PDR's or CDR's to verify that the Linac has an integrated design which will meet its performance and engineering requirements as defined in the Level 3 specifications. The Level 3 ATPR reviews the installation and commissioning plan of the Linac. At Level 3, these reviews can and often do have committee members from outside the SSC. In the case of the Linac, the PDR committee was composed entirely by non-SSCL scientists.

The Level 4 reviews are divided into two types. One type is for an item that is to be provided by a Vendor. The cavities and RF amplifiers of the RFQ, DTL, and CCL are of this type. The PDRR reviews the specification to which the vendor will design, and that, when approved, allows procurement to proceed. The Vendor presents the PDR and CDR as the SSCL monitors the design progress of the Vendor and authorizes fabrication after the CDR, or long-lead procurements after the PDR, if necessary. The ATPR is also presented by the Vendor for review of the plan to test the item to demonstrate that requirements are met prior to shipment to the SSCL.

The second type is for build-to-print or built-by-SSCL, where the design progress of the engineers is monitored by the Linac Group and other engineers within the SSCL, or outside the SSCL, as demeaned appropriate. In this case, the reviews are presented by the SSCL engineering departments.

For the Linear Accelerator, there are 47 Level 4 reviews, as shown in Table 3, approximately a quarter of which are provided by Vendors. To minimize the number of reviews, several sections or subsystems of a section of the Linear Accelerator have been combined. For example, the set of reviews for the CCL Systems includes the CCL Input Matching Section, CCL Support Systems, and the CCL Transport Line. This encompasses everything in these sections except the CCL modules and the RF amplifiers of these sections.

TABLE 3
Linac Level 4 Reviews

Item	Review	Responsibility
Ion Source/LEBT	PDRR	SSCL
	PDR	SSCL
	CDR	SSCL
	ATPR	SSCL
RFQ	CDR	Vendor
	ATPR	SSCL
RFQ RF Amp	PDRR/PDR	Vendor
	CDR/ATPR	Vendor
RFQ Support Systems	PDRR	SSCL
	PDR	SSCL
	CDR	SSCL
	ATPR	SSCL
DTL Input Match	PDRR/PDR	SSCL
	CDR	SSCL
	ATPR	SSCL
DTL Input Match RF Amplifiers	PDRR	SSCL
	PDR	Vendor
	CDR	Vendor
	ATPR	Vendor
DTL & CCL RF Amplifiers	PDRR	SSCL
	PDR	Vendor
	CDR	Vendor
	ATPR	Vendor
DTL Cavities	PDRR	SSCL
	PDR	Vendor
	CDR	Vendor
	ATPR	Vendor
DTL Support Systems	PDRR	SSCL
	PDR	SSCL
	CDR	SSCL
	ATPR	SSCL
CCL Cavities	PDRR/PDR	SSCL
	CDR/ATPR	SSCL
CCL Systems	PDRR	SSCL
	PDR	SSCL
	CDR	SSCL
	ATPR	SSCL
Energy Comp. RF Amplifier	PDRR	SSCL
	PDR	Vendor
	CDR	Vendor
	ATPR	Vendor
Linac Utilities	PDRR	SSCL
	PDR	SSCL
	CDR	SSCL
	ATPR	SSCL
Linac Systems	PDRR	SSCL
	PDR	SSCL
	CDR	SSCL
	ATPR	SSCL

Interface Control

Just as the specifications define the performance and physical requirements of the item, the Interface Control Documents define the requirements as to how the various items interconnect. These can be in hardware (for example, a cable connector, a vacuum flange, or a pipe fitting) or software (for example, information on data inputs, outputs, rates, and formats). They are essentially an agreement between the two groups, whether a Vendor and the SSC or two SSC engineering departments, who are providing the two items, that the two items will connect in the agreed upon manner. For example, the Interface Control Document for the DTL Cavities, which is provided by the Vendor, is an agreement between SSCL and the Vendor on the interfaces of the waveguides and RF probes, cavity input and output flanges, vacuum system instrumentation and control, and the control, monitor, and water connections to the temperature control unit.

Since the interfaces cannot be specified until the design of the item is chosen from the various alternatives and detailed, an Interface Control Document is presented in a draft form at the PDR and in its final form at the CDR. They are approved by the Linac or Transfer Line Group and the involved engineering departments. For the Linear Accelerator, there are nine Interface Control Documents:

- Ion Source/LEBT
- RFQ
- DTL Input Matching Section
- DTL
- CCL Input Matching Section
- CCL
- CCL Transport Line
- Linac Utilities
- Linac Systems

For the Linac Transfer Line, there are four Interface Control Documents:

- Main Magnets and Power Supplies
- Injection Girder
- Vacuum and Utilities
- Safety, Beam Instrumentation, and Controls

Conclusion

A System Engineering process has been incorporated into the SSCL that provides an orderly method for documenting and monitoring changes to the performance and physical requirements that must be satisfied by the technical equipment and facilities. As summarized in this paper, the process provides a means to review and agree on the requirements, to monitor the design of the components or subsystems, to ensure that the various components or subsystems join together to form a functioning Linac, and to review the test plans to verify that the requirements are satisfied. This process is applied to all the other accelerators of the SSC as well.

References

[1] SSCL Document No. P40-000021
[2] SSCL Document No. E10-000029