"PAPER-LESS" CAD/CAM FOR ACCELERATOR COMPONENTS*

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Abstract

Computer-aided design and manufacture (CAD/CAM) have enabled advances in the design and manufacture of many accelerator components, though government procurement rules tend to inhibit its use. We developed and executed a method that provides adequate documentation for the procurement process, industrial vendor manufacturing processes, and laboratory installation activities. We detail our experiences in the design and manufacture of 60 separate and unique PEP-II Low Energy Ring Interaction Region vacuum chambers totaling ~ 140m in length as an example of how we used this technique, reducing design effort and manufacturing risk while streamlining the production process. We provide "lessons learned" to better implement and execute the process in subsequent iterations. We present our study to determine the estimated savings in the design and production of the Spallation Neutron Source room temperature linac if this process were utilized.

1 INTRODUCTION

Computer-aided design (CAD) is a tool that allows the design engineer to develop a computer model of the desired component. When coupled with computer-aided manufacturing (CAM), the production of the component is streamlined by avoiding duplication of effort by the manufacturer. Conventional practices often decouple CAD and CAM, generating formal paper drawings to document the design and provide the design information to the manufacturer. During a recent design, fabricate, and installation effort we found that, by grouping like parts into specific families, we were able to adopt a "paper-less" mindset, allowing us to use CAD/CAM as a system to mitigate budget and time pressures, and to avoid the risk associated with multiple entry of design information.

2 PEP-II EXPERIENCE

The PEP-II [1] machine at the Stanford Linear Accelerator Center (SLAC) consists primarily of two storage rings with counter-circulating beams located one above the other. The Low Energy Ring (LER) is elevated approximately 1 meter above the High Energy Ring. The LER vacuum chamber is designed to carry the beam down into a collision path with the High Energy Beam in the Interaction Region (IR) and back to the LER elevation afterwards. Sixty separate yet unique chambers are required to enable this beam transport scheme.

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2.1 Technical Requirements

Though in separate families, many of the chambers share similar features: synchrotron radiation masks, beam position monitors, vacuum pump ports, bend angles, and cooling bar attachments. Each chamber does not necessarily employ all features; the placement and size of the features can vary from chamber to chamber. We also required a pump plenum screen for each of the chambers. While unique, the screens also contained features similar to one another, making them candidates for the family of parts concept.

Figure 1: Several of the 60 IR2 Vacuum Chambers during assembly in the SLAC cleanroom.

2.2 Organizational Constraints

The 140-meter IR portion of the LER was the last segment of the ring planned to begin the design and fabrication process. This led to an extremely demanding critical path schedule, and a meager budget to accomplish the task. Procurement processes required documentation of each component. Given these constraints we needed to find a method that would reduce the design time and streamline the fabrication process.

2.3 Design Staff

Two designers were each assigned two families of parts. They created the electronic CAD file by working with the engineer to assure the physical requirements were met. A senior designer was assigned to a "master file keeper" role. His primary assignment was to check and integrate the current models into an electronic assembly file to assure successful interfaces between IR chambers and the chambers upstream and downstream of the IR. This provided a controlled layout of the entire system that was used during installation. Another function of the master

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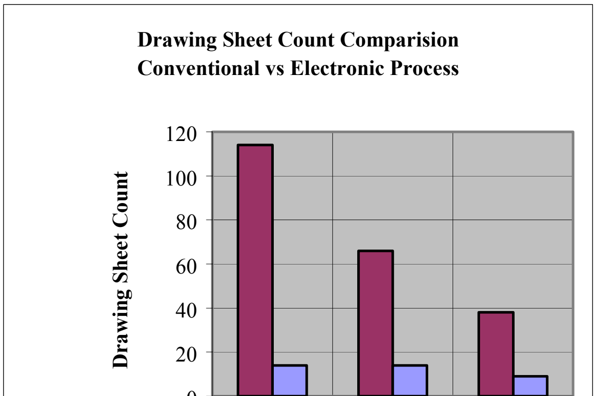
file was to assure that only the current revision of the working files was in circulation.

2.4 Drawing Count Reduction

Conventional design processes would generate 60 multi-sheet drawings with an estimated 218 E-size sheets. We realized we were able to divide the chambers into four distinct families based on the type magnet each passes through, and if bent or straight chamber geometry was required. We committed to provide a fully reviewed and released drawing of one representative chamber for each family of chamber and one set for each family of pump plenum screens, generating seven drawings with an



	38 Dipole Chambers	22 Quad Chambers	19 Pumping Screens
Conventional	114	66	38
Paper-Less	14	14	9

Figure 2: Graphic comparison showing drawing count reduction on IR vacuum chambers using "Paper-Less" CAD/CAM technique vs. conventional processes.

estimated 37 E-size sheets. These drawings serve as "Template Drawings" and identify datum surfaces, and tolerances; a general note explaining that the electronic files provide manufacturing details; and a tab block that identifies electronic file names with specific chambers. These details apply to all components within the family covered by the template drawing. The remaining components within each family were documented with sketches showing an isometric view, assuring that all relevant features were visible. Tabulated lists, consistent with the electronic model and the isometric sketch, were generated to delineate the features included on each chamber. This, coupled with the electronic files, provides complete definition of the components and satisfied the requirement for documentation.

2.5 Procurement and Fabrication

The vendor that we worked with was critical to our success. We found that, in making the "paper-less" CAD/CAM system work well, we valued a vendor with the following characteristics:

- technically qualified to participate.
- willing to participate.
- interested in our success.
- flexible throughout the execution phase.

Technical qualification includes the ability to read and query electronic files as the manufacturing details are contained in the file, and the manufacturing capability of producing the components. We found that our industrial partner had been working with other customers in this manner for many years and had mechanisms in place to read and query multiple file formats. Having an experienced partner involved placed us much higher on the learning curve at the outset of the effort. We found it advantageous to communicate with potential vendors during the early design phase so we could incorporate their experience and best practices into our process.

Conventional processes decouple CAD and CAM, communicating design intent on paper drawings. The typical manufacturer will re-enter the data into their CAD system by interpreting the paper drawing, enabling them to perform the CAM function necessary to generate machine tool code to manufacture the part. Risk is inherent in this re-entry of data, not only from misinterpretation but simple transposition errors lead to incorrect parts being produced. Utilizing CAD/CAM as a system mitigates this risk. The CAD model can be converted into a global file format, such as IGES, for use by vendors; therefore, direct processing of the IGES file provides machine tool code to cut the part as specified by the design organization, rather than the one specified by the vendor's programmer.

Fear of losing or changing data during the file translation and transfer was addressed. We verified several sets of data with our industrial partner after transferring files via File Transfer Protocol (FTP), e-mail, and hand carried disks. We did not encounter instances of incorrect information arriving at the manufacturing CAD system. Our industrial partner assured us that this is the general state of the process, and that considerable improvement in this area has come about in the past 10-20 years.

To expedite our schedule we transferred files to our vendor as they were completed, allowing fabrication to proceed on some chambers while others were still in design. This increased the risk of producing a part that might require changes at a later point. By identifying this risk, and generating a workable contingency plan should this event occur, we accepted this as a manageable risk scenario.

2.5 Assembly and Installation

A detailed assembly traveler was compiled and functioned as the build list to communicate to the assembly crew the correct components that needed to be mated with each chamber. As each chamber is unique, it needs a unique identifier to assure it is installed in the appropriate location in the ring. Electronic file names were not germane in the beamline tunnel so we chose to etch the chamber nomenclature and beam direction onto the top surface of the beam pipe to assist the installation crew in making correct location and orientation decisions. An installation drawing was generated from the master layout and used to communicate requirements to the installation crew.

2.6 Lessons Learned

Cost, schedule and technical risk were reduced. Producing 83% fewer paper drawings than our conventional processes would generate represented approximately one year of effort saved by eliminating 180 drawing pages. Data re-entry time at the manufacturer was eliminated, reducing risk of error, and generating a saving of schedule time.

This was a definite culture change for us and we felt the effects. We would involve more parties, procurement and inspection departments, vendors, the assembly crew, and installation crew, sooner in the process. We would also assure that the various entities were able to take advantage of the electronic nature of the information by providing means to view and understand the electronic file data. We expect this would reduce the resistance we felt from these entities.

Bookkeeping of the current file revision, and the transferred electronic files was difficult for one person. We recommend using a Product Data Manager (PDM) system to computerize this task. Effort is still needed to manage the PDM but we anticipate this to be much less than that of the master file keeper of our past experience. This reduces the risk of getting the incorrect file into the manufacturing operation and keeps all parties working on the currently approved version of the data.

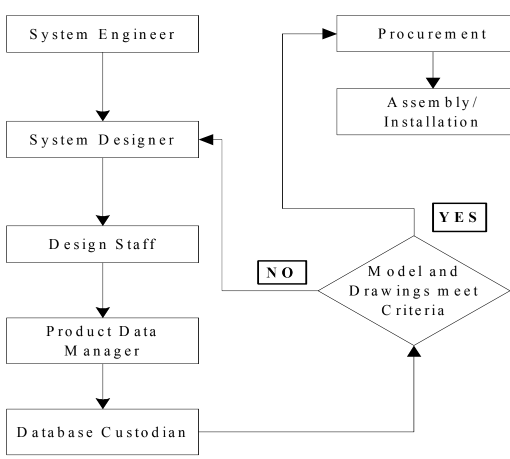


Figure 3: Conceptual flow diagram of the electronic design process.

3 SPALLATION NEUTRON SOURCE [3]

The Spallation Neutron Source (SNS) was initially designed to have approximately 450 meters of room-temperature copper linac structure. SNS has recently moved to use superconducting niobium cavities for the majority of the accelerating structure. We present our case for the initial configuration of room temperature components that are ideal candidates for CAD/CAM processes based on the following assumptions:

- Trained staff was available to design the accelerating structure components.
- Similar geometries are used in the structures.
- Suitable CAD/CAM software was available.
- Vendors were identified to participate in this manner.
- Electronic manufacturing methods are used throughout US industry.

3.1 CAD/CAM Applied to Accelerating Structure Components

The linac is divided into three major structures, Drift Tube Linac (DTL), Cavity Coupled DTL, and Cavity Coupled Linac. These components can be divided into families as was done with the PEP-II vacuum chambers. A Template Drawing for each family will identify datum surfaces, and tolerances; a general note explaining that the electronic files provide manufacturing details; and a tab block that identifies electronic file names for specific structure segments. In addition to this list of items we used for PEP-II, we proposed to include a tabulated list of dimension values for each structure segment. This can typically be generated as fully associative by the CAD program, meaning that, as modifications are made to components, the dimension table will automatically reflect the new values. Importing a manually developed spreadsheet can also generate the table, though this is more work and the associative nature will not be present, leading to potential problems with updating information.

3.2 Drawing Reduction

The project's initial estimate required more than 10,000 pages of paper drawings. An estimated 65 man-years are needed to design and oversee production of the components. In a recent study we applied CAD/CAM as a system to this effort and estimate that the number of drawings could be reduced to less than 1000 with the effort reduced to less than 36 man-years. We believe this provides sufficient documentation to fabricate and install the structures while providing cost and schedule savings.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

[1] http://www.slac.stanford.edu/accel/pepii/home.html
[2] http://www.sns.gov