A New Tool For Accelerator System Modeling And Analysis

George H. Gillespie and Barrey W. Hill

G. H. Gillespie Associates, Inc., P.O. Box 2961, Del Mar, CA 92014, U.S.A.

and

Robert A. Jameson

Los Alamos National Laboratory, P. O. Box 1663, Los Alamos, NM 87545, U.S.A.

Abstract

A novel computer code is being developed to generate system level designs of radiofrequency ion accelerators. The goal of the Accelerator System Model (ASM) code is to create a modeling and analysis tool that is easy to use, automates many of the initial design calculations, supports trade studies used in assessing alternate designs and yet is flexible enough to incorporate new technology concepts as they emerge. Hardware engineering parameters and beam dynamics are modeled at comparable levels of fidelity. Existing scaling models of accelerator subsystems were used to produce a prototype of ASM (version 1.0) working within the Shell for Particle Accelerator Related Codes (SPARC) graphical user interface. A small user group has been testing and evaluating the prototype for about a year. Several enhancements and improvements are now being developed. The current version (1.1) of ASM is briefly described and an example of the modeling and analysis capabilities is illustrated.

Introduction

The Accelerator System Model (ASM) is a computer program developed primarily to model proton and deuteron radiofrequency accelerators and to assist accelerator designers in carrying out system level trade studies. There are several programs that have been developed to model linear accelerator systems and ASM shares similarities with some of these other codes. The LIDOS code system [1] represents one of the most developed and integrated packages for ion linac beam dynamics design. LIDOS provides for different levels of accelerator modeling and utilizes an expert help system to assist scientists in developing designs. The LINACS program [2] also provides for different levels of modeling and incorporates engineering models. The ASM program described here focuses on one level of modeling, but includes both beam dynamics and engineering. In addition, ASM uses an advanced graphical user interface, with some expert system type features incorporated, that makes the program easy to use [3].
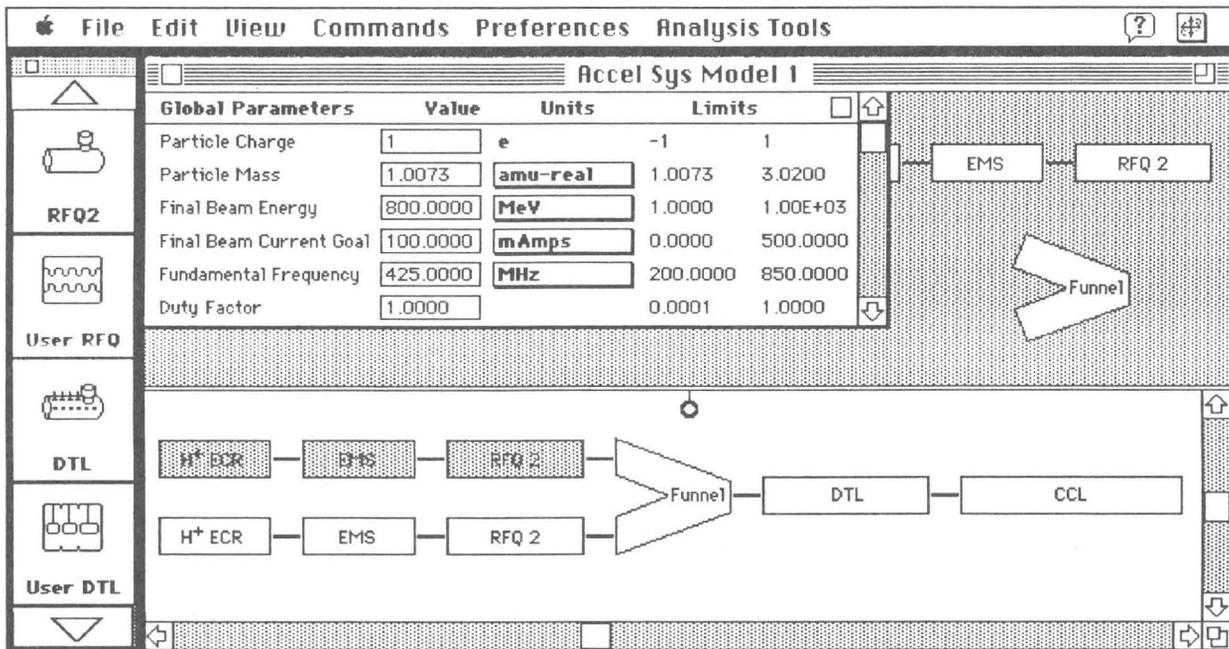
Fig. 1. Example of the ASM program's user interface.

Overview of ASM

The ASM computer program consists of two basic parts: (1) a set of accelerator physics and engineering models and (2) a graphical user interface. The physics and engineering models are written in FORTRAN. The interface is provide by the Shell for Particle Accelerator Related Codes (SPARC) which is written in C [3]. Both parts of the program are modular. The modules on the FORTRAN side of ASM correspond to accelerator "subsystems." Subsystems include ion sources, LEBTs, RFQs, DTLs, funnels, etc. The SPARC interface incorporates object-oriented structures that correspond to the same subsystems. Figure 1 illustrates the ASM interface.

The beam physics parameters and engineering parameters in ASM are represented by two vectors for each linac component. These vectors are referred to as the Beam Vector (BV) and Engineering Vector (EV). A given module in ASM generates a BV and EV as the primary output. The BV represents the state of the beam at each point in the accelerator and the vector's elements are physical properties of the beam at that point. ASM use an eight-dimensional BV:

$$BV = [E, I, \langle x^2 \rangle, \varepsilon_{t,rms}^2, \langle \Delta p^2 \rangle, \varepsilon_{l,rms}^2, \alpha_t, \alpha_l] . \quad (1)$$

Here, E is the beam energy, I the current, $\langle x^2 \rangle$ the mean-square extent of the beam (envelope), $\varepsilon_{t,rms}$ and $\varepsilon_{l,rms}$ the normalized (rms) transverse and longitudinal emittances, Δp the momentum dispersion and α_t and α_l are the transverse (magnitude) and longitudinal Twiss parameters.

The EV is used to describe the requirements of the accelerator component that produces the beam defined by Equation (1). The EV also has eight dimensions:

$$EV = [L, V, M, P, x, y, Conf, Cost] . \quad (2)$$

The EV elements shown in Equation (2) are: L device length, V device volume, M device mass, P device power requirement, x the maximum horizontal and y vertical dimensions of the component, as measured from the beam axis, $Conf$ a confidence factor for the device as modeled, and $Cost$ a cost estimate for the device.

Calculations in ASM proceed by advancing the BV from one subsystem module to the next, generating a BV and EV at each step. A given ASM beamline module maps the input BV to an output BV, and creates an EV that defines the requirements of that subsystem module necessary to accomplish this propagation of the beam.

ASM represents a new approach to the modeling of linac systems [4]. A baseline set of modules has been developed and a large number of user definable modules are also available. The physics/engineering models and interface parts of the

program are closely coupled together. This coupling requires users to adhere to guidelines when developing their own individual modules. However, the guidelines are flexible and allow for relatively sophisticated models of accelerator components to be incorporated into the application [5].

Trade Study Example

ASM was developed to support system level analyses, and trade studies are an important part of such analyses. Parametric trade studies are accomplished with ASM by using the Parameter Variation tool, which may be selected from the Analysis Tools menu shown in Figure 1. Figure 2 illustrates the two windows used to set up parametric trade studies using this tool.
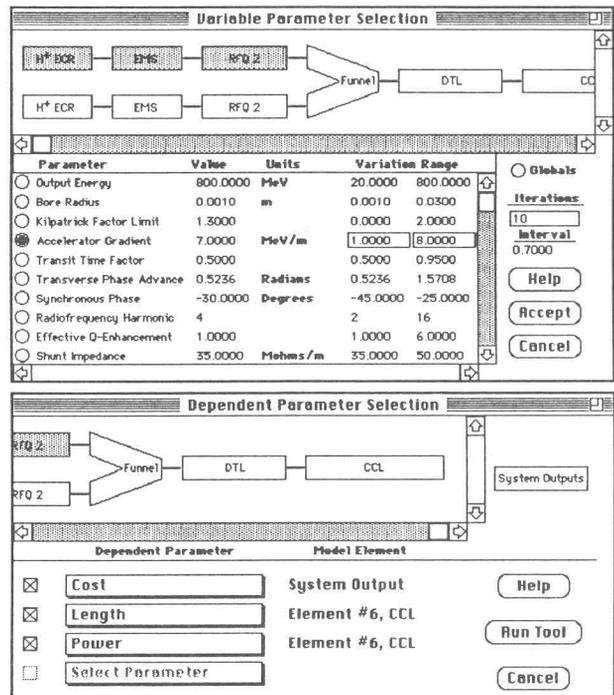
Fig. 2. Setting up an ASM parametric trade study. The upper window is used to select the parameter to be varied and the lower window is used to select the output parameters to be plotted as a function of the variable parameter.

The upper window in Figure 2 is used to select the parameter to be varied and contains three window "panes." The top pane shows a duplicate image of the accelerator model under study (Figure 1) and the user selects ("clicks on") the component that contains the desired parameter. The bottom left pane displays a data table for all the input parameters of the selected component, in this example the CCL. The variable parameter is selected ("pushing the button") and then

the range to be covered in the variation may be set. In this example the Acceleration Gradient of the CCL will be varied between 1 and 7 MeV/meter. The lower right pane is used to set the number of iterations (10 in the example) and then accept the settings.

Once the setup for the variable parameter is accepted, the window shown in the lower part of Figure 2 comes up and is used to selected the ASM model outputs to be graphed as a function of the variable parameter. This is also a multi-pane window and the procedure for choosing the dependent parameters is similar to that used for the variable parameter. Up to four dependent parameters may be selected for each plot and an unlimited number of plot windows may be open at once. In this example, the total system cost, together with the length and power requirement for the CCL, have been selected for plotting.

The parameter variation is executed when the Run Tool button in the bottom pane of the Dependent Parameter Selection Window is pushed. The outputs are then plotted using a color coded graph. The plot window contains unlimited zooms, display options for calculated points and curves, plotted point coordinate displays, and other features to aid the user in analyzing the results. The user may also "copy and paste" the graphs into other documents. Figure 3 shows the graph generated for the example trade study.
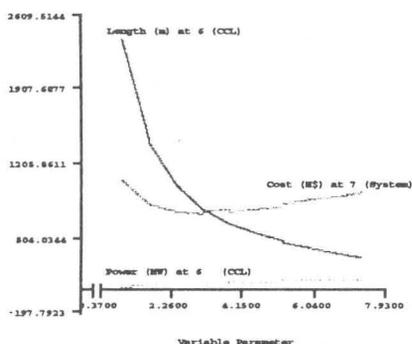
Fig. 3. Sample results for the ASM parametric trade study.

The cost model used for this trade study example is relatively simple and assumes that the primary (capital) costs scale with the length of the CCL and the total radiofrequency power required, which is dominated by the CCL power. This cost model has been developed by Lawrence and others [2,6], and is one of three incorporated into the baseline ASM modeling. The example used here is intended to illustrate the capabilities of ASM and the specific numbers should not be taken to represent a realistic accelerator design. In addition, the current baseline CCL module in ASM is lacking some important features. Nevertheless, the results shown in Figure

3 display the expected cost minimum as a function of the CCL accelerating gradient. This type of analysis can be used to generate an optimized set of linac parameters.

Summary

ASM is a new tool for modeling radiofrequency linear accelerator systems. Both beam dynamics and engineering parameters are incorporated. An advanced graphical user interface makes ASM easy to use and provides interactive tools for supporting trade studies and other analyses important in system design. The approach used is sufficiently flexible that relatively sophisticated models of linac technology can be incorporated. On-going work should bring ASM up to the standards needed by accelerator scientists to be the basis of a comprehensive design tool for a variety of applications.

Acknowledgements

References

[1] B. P. Murin, B. I. Bondarev, A. P. Durkin, G. T. Nikolaishvili, T. N. Tsygankova and O. Yu. Shlygin, "A Computing Optimization System for Ion Linac Accelerating/Focusing Channels," 1992 Linear Accelerator Conference Proceedings (Ottawa) AECL-10728, 734-736 (1992).

[2] R. A. Jameson, et al, "Scaling and Optimization in High-Intensity Linear Accelerator," Los Alamos National Laboratory Report No. LA-CP-91-272 (1991).

[3] G. H. Gillespie, "The Shell for Particle Accelerated Related Codes (SPARC) - A Unique Graphical User Interface," AIP Conference Proceedings 297, 576-583 (1993).

[4] G. H. Gillespie, B. W. Hill and R. A. Jameson, "A New Approach to Modeling Linear Accelerator Systems," to be published in the Proceedings of the International Conference on Accelerator-Driven Transmutation Technologies and Applications, held in Las Vegas, NV, 25-29 July (1994).

[5] A. A. M. Todd, C. C. Paulson, M. A. Peacock and M. F. Reusch, "A Systems Model for an Accelerator-Driven Transmutation Facility," to be published in the Proceedings of the International Conference on Accelerator-Driven Transmutation Technologies and Applications, held in Las Vegas, NV, 25-29 July (1994).

[6] G. A. Lawrence, private communications (1993).