PARAMETRIC STUDY OF EMERGING HIGH POWER ACCELERATOR APPLICATIONS USING ACCELERATOR SYSTEMS MODEL (ASM)

D.H. Berwald, S. S. Mendelsohn, T.J. Myers, C.C. Paulson,
M.A. Peacock, C.M. Piaszczyk, and J.W. Rathke,
Advanced Technology & Development Center
Northrop Grumman Corporation
1111 Stewart Ave.
Bethpage, NY 11714

E.M. Piechowiak
Electronic Sensors & Systems Division
Northrop Grumman Corp.
Post Office Box 1897-Ms709
Baltimore MD 21203

Abstract

Emerging applications for high power rf linacs include fusion materials testing, generation of intense spallation neutrons for neutron physics and materials studies, production of nuclear materials and destruction of nuclear waste. Each requires the selection of an optimal configuration and operating parameters for its accelerator, rf power system and other supporting subsystems. Because of the high cost associated with these facilities, economic considerations become paramount, dictating a full evaluation of the electrical and rf performance, system reliability/ availability, and capital, operating, and life cycle costs.

The Accelerator Systems Model (ASM), expanded and modified by Northrop Grumman during 1993-96, provides a unique capability for detailed layout and evaluation of a wide variety of normal and superconducting accelerator and rf power configurations. This paper will discuss the current capabilities of ASM, including the available models and data base, and types of trade studies that can be performed for the above applications.

Introduction And Background

High power rf-driven ion linacs are currently being considered for a variety of applications including, but not limited to:

- Spallation neutron production for scientific and materials studies (e.g., European Spallation Source [ESS], US National Spallation Neutron Source [NSNS])
- ~14 MeV neutron production for fusion materials testing (e.g., International Fusion Materials Irradiation Facility [IFMIF])
- Production of nuclear materials (e.g., Accelerator Production Of Tritium [APT])
- Destruction of high-level nuclear waste (e.g., Accelerator Transmutation of Waste [ATW])

The Accelerator Systems Model (ASM), expanded and modified by Northrop Grumman since 1993, provides a unique capability for detailed layout and evaluation of the wide variety of rf linac and rf power configurations. This capability, recently used to support the IFMIF accelerator design effort (as well as internally funded efforts involving higher energy linacs), provides the following features:

- Ability to model ion linac configurations based upon a large number of existing and recently proposed normal and superconducting linac structures, operating over a wide range of rf frequencies
- Detailed tracking of the linac's cell-by-cell configuration and the electrical and rf power system performance
- Generation of detailed component inventory that includes all accelerator systems and dedicated facilities
- System reliability, availability, maintainability (RAM) modeling for estimation of operational availability and the cost of component replacement and/or refurbishment
- Cost analysis capability which encompasses capital, construction, and annual operating costs, resulting in a single net present value life cycle cost estimate.

ASM allows the user to consider many linac configurations and technology trades, in a limited time, using a complete set of data and a consistent set of modeling algorithms.

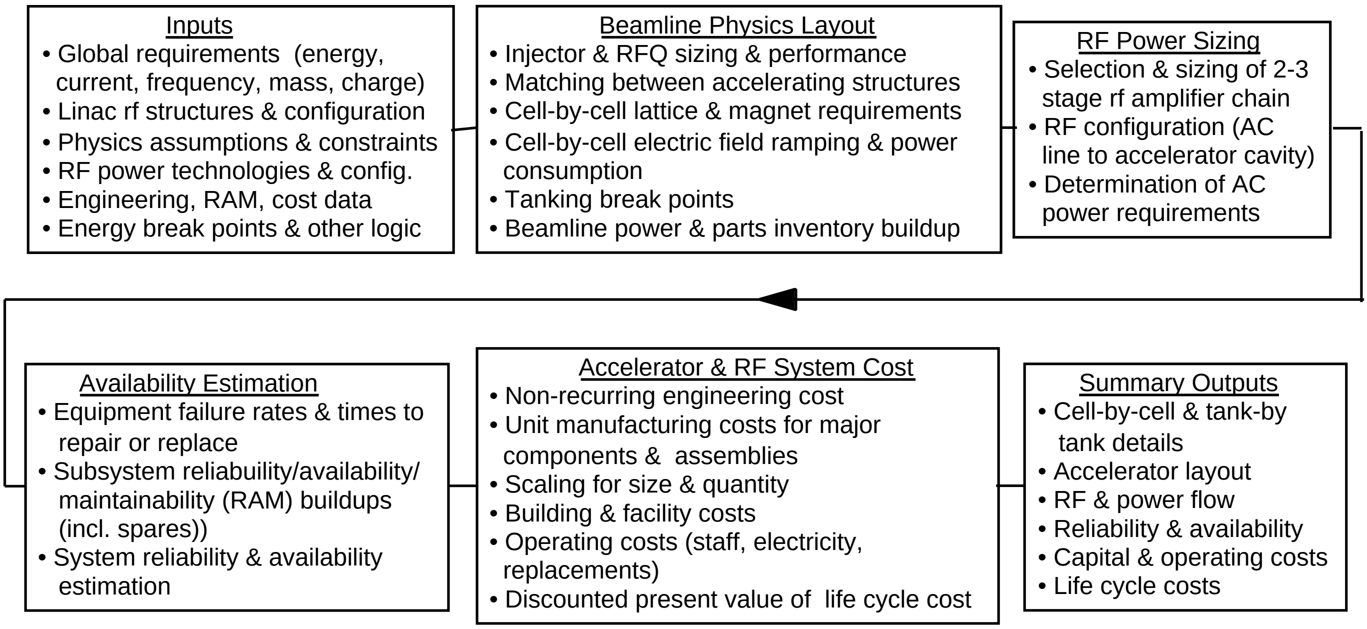
The on-going physics and engineering modeling effort of ASM is now concentrating on improvement of existing models (e.g., diagnostics, instrumentation and control and cryogenics), implementation of an automated capability for parameter trades, and adaptation of the code for pulsed ion linacs. Future ASM variants dedicated to applications involving electron beam accelerators, free electron lasers, ion cyclotrons and ion storage rings are envisaged.

ASM Calculational Flow

The ASM code is driven by a Macintosh™ Graphic User Interface (GUI) that provides a user interactive, on-screen format for data input. In addition, the code reads several formatted files that convey engineering, cost and RAM data.

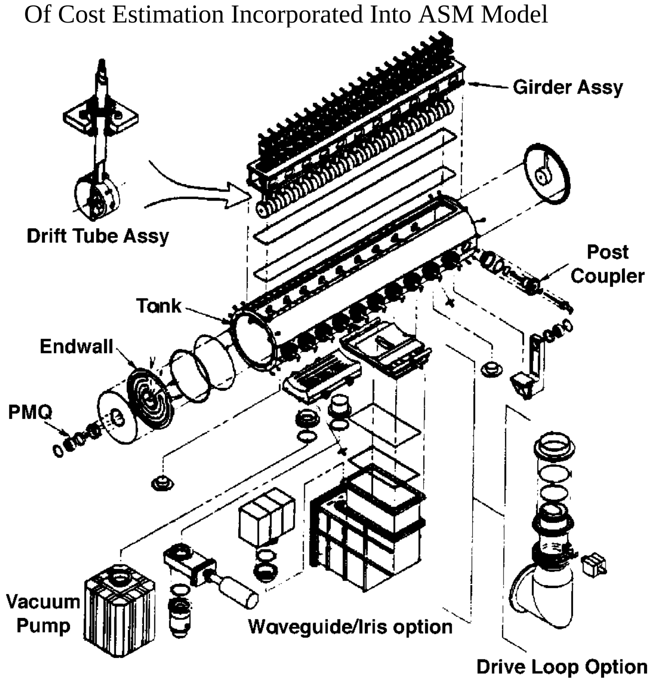
As shown in Fig. 1, the first series of Fortran routines use the input data to establish a cell-by-cell layout of the accelerator, starting at the ion injector and proceeding through all of the major rf structures, completing each at a specified energy breakpoint. A generalized set of algorithms is used to match the synchronous phase and the longitudinal and transverse phase advances from structure to structure.

Figure 1. Accelerator Systems Model (ASM) Calculational Flow



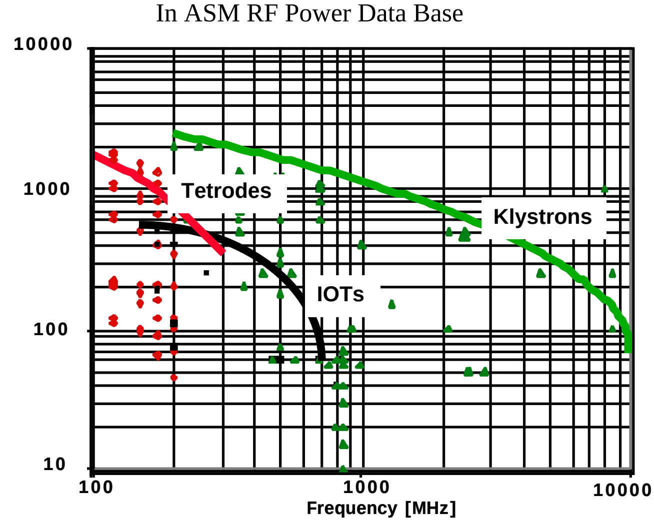
The electric field is linearly ramped within an rf tank according to any of several criteria (e.g., proportional to particle velocity, β, up to a limiting value). Tank sizing may be specified according to the available rf power, energy break points or other user inputs. When the layout is completed, the rf power requirements and an inventory of linac components (see Fig. 2) is passed to the subsequent routines.

Fig. 2 DTL Parts Identification Schematic Illustrating Level Of Cost Estimation Incorporated Into ASM Model



The next set of ASM routines are used to size and configure the rf power system, which is critical to the overall evaluation because it represents the largest cost component of the accelerator, dominates the electric power requirement and plays a major role in the system availability. As a first step, ASM reviews the required sizes and frequencies of rf sources and compares them with its rf amplifier data base, illustrated in Figure 3. The code selects the tube with the best operational efficiency, then lays out the remainder of the rf system including the driver tube(s), peripheral equipment, high voltage equipment and rf transport components. Based upon the inventory of rf components and their various rf and electrical efficiencies, the electrical power requirement of the rf system is estimated.

Fig. 3 CW-Rated RF Output Amplifiers Currently Included In ASM RF Power Data Base



A third set of ASM routines is used to estimate the overall operational availability of the accelerator (during scheduled operation). Starting with a RAM library containing the failure rates (mean time before failure, or MTBF) and repair times (mean time to repair, or MTTR) of the constituent equipment, the ASM RAM routines process the configuration and parts inventory data to develop estimates of the RAM performance of individual subsystems. These are combined (with consideration of spares and redundancies) to develop an overall estimate of the system reliability and availability. The results are also used to predict the rates of replacement of major components.

The next set of ASM routines provide estimates of the capital, operating, and life cycle costs for the major subsystems of the accelerator. Using the parts inventory, these routines develop engineering, fabrication labor and materials cost estimates. The engineering estimates are comprised of both non-recurring design and development activities for the first unit and recurring engineering for subsequent units. Where large quantities of parts or components are required, learning curve techniques are used to model the decreasing cost of unit production or acquisition.

Annual operating cost estimates are developed from the electric usage, component refurbishment/replacement requirements and facility staffing estimates. A life cycle cost estimate that combines the capital costs, with projections of the facility construction costs and the annual operating costs is also developed. Standard net present value analysis is used to represent the life cycle cost as a single value.

Trades That Can Be Performed Using ASM

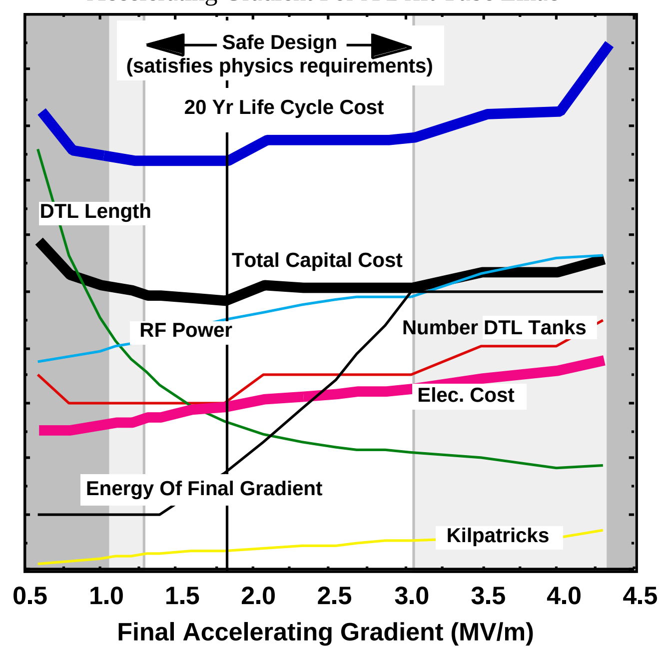
The types and applicabilities of trades currently supported by ASM are indicated in Table 1. In the table, a "√" indicates that the code has already been used to perform the indicated type of trade, a "•" indicates that the trade should be considered for the indicated application, and "N/A" indicates that the trade is not applicable.

Table 1. Current ASM Trade Study Capabilities

	Linac Application		
Candidate Trade Study	**IFMIF**	**ATW**	**NSNS**
Beam Pulse Length	N/A	N/A	•
Alternative Accelerating Structures	√	•	•
Normal vs. Superconducting	√	•	•
Transition Energies & Matching	√	•	•
Beam Energy vs. Current	N/A	√	•
Accelerating Gradient	√	√	•
RF Frequency	√	•	•
Frequency Doubling	√	•	•
Current Funneling	N/A	•	N/A
Multiple vs. Single Beamlines	√	√	N/A
Multiple vs. Single Ion Injectors	√	•	N/A
Design Optimization vs. Plant Life	√	•	N/A
RF Amplifier Technology	√	√	•
RF Tanking	√	√	•
RF Pre-Amplifier Staging	√	•	•
RF Amplifier Redundancies	√	•	•
High Voltage Power Technology	N/A	•	•
RAM Trades	√	√	•

An example of a recent trade involves the selection of the preferred accelerating gradient for a drift tube linac (DTL). As shown in Figure 4, the capital and operating costs increase at high gradient due to the increased rf power consumed in the rf structure, which leads to larger rf power requirements and larger electricity requirements. As the gradient is decreased the rf power requirement also decreases, but the DTL length and the number of rf tanks increase, decreasing the rf power per tank and ultimately increasing the overall life cycle cost. The best balance between these trends results at a gradient of 1.8 MV/m, where the life cycle cost is minimized.

Fig. 4 Example Of Use Of ASM To Determine Optimal Accelerating Gradient For A Drift Tube Linac



Acknowledgments

The Northrop Grumman Version of ASM is a product of G. H. Gillespie Associates, Inc.

Figure 2 was provided courtesy of Los Alamos National Laboratory