

DESIGN CONSIDERATIONS FOR THE ORNL 25 MV TANDEM ACCELERATOR

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Summary

Construction of a 25 MV tandem electrostatic accelerator is now planned as part of a new heavy-ion facility at the Oak Ridge National Laboratory. The design of this accelerator incorporates several unusual features. The most important of these are a folded design, in which the low-energy and high-energy acceleration tubes are contained within a single column structure, and a digital control system. Motivations for these design features are discussed in conjunction with a brief description of the accelerator.

Introduction

A new heavy ion accelerator facility¹ is now being designed for construction at Oak Ridge National Laboratory. The facility is expected to be built in two phases. Phase I, which is now under way, will consist of a new 25 MV tandem electrostatic accelerator, improvements to and modifications of the existing isochronous cyclotron, ORIC, and a building addition to house the tandem accelerator. In Phase I it will be possible to operate the two accelerators independently and also in a coupled mode in which beams from the tandem accelerator are injected into the ORIC for further acceleration. In Phase II, another more powerful booster will be added for coupled operation with the tandem accelerator. In this paper we will discuss general properties of the new electrostatic accelerator with emphasis on its unique features. Companion papers presented at this conference describe beam transport through the tandem accelerator² and conversion of ORIC to accommodate injected beams³.

The 25 MV tandem accelerator will be purchased from a commercial manufacturer. General design philosophy for the accelerator has been developed in consultation with prospective manufacturers during preparation of specifications for the accelerator. These specifications form the basis for the present discussion.

Several criteria strongly influence the design of the tandem accelerator. The most important are a terminal potential variable in the range 7.5 to 25.0 MV and acceleration of ions in the mass range 12 to 250 amu at intensities up to 1 particle microampere. In addition, the intended utilization of the accelerator as an injector requires high reliability, the ability to coordinate operation of the accelerator with operation of other accelerators, and production of pulsed beams. ORNL has retained responsibility for beam pulsing and bunching so that the specifications, in this respect, are only addressed to isochronous beam transport.

In Fig. 1, we show a simplified, preliminary layout of the tandem accelerator and in Table 1 we present

some parameters selected from specifications. As can be seen in Fig. 1, the accelerator has a folded configuration in which both "low-energy" and "high-energy" acceleration tubes are contained within a single column. In this configuration negative ions are injected into the low-energy acceleration tube and accelerated to the high voltage terminal which is maintained at positive potential. In the terminal, the ion beam first passes through a stripper, becoming positively charged. After stripping, one charge state component is bent by a magnet through an angle of 180° and injected into the high energy acceleration tube

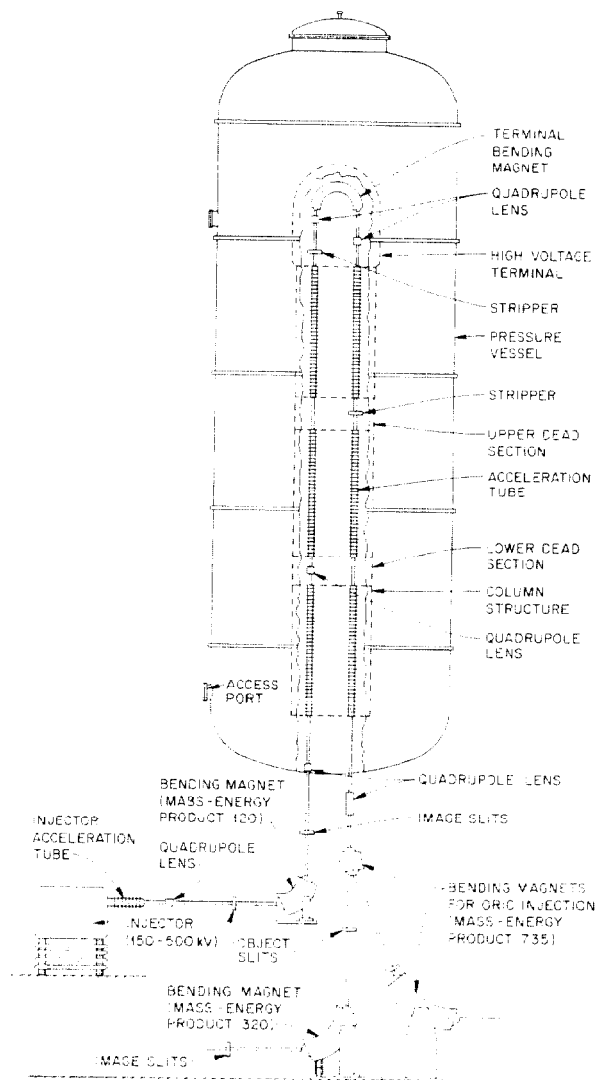


Fig. 1. A simplified layout of the tandem accelerator system.

* Operated by Union Carbide Corporation for the ERDA.

for further acceleration back to ground potential. The essential point is that a folded tandem accelerator requires only one column structure in contrast to a conventional or "linear" tandem accelerator which employs two column structures, one on each side of the high voltage terminal.

Table 1

Selected Specified Parameters

<u>Pressure Vessel</u>	
Inside diameter	> 33 ft.
Insulating Gas	SF ₆
Maximum operating pressure	125 psia
Gas cycle time	10 hrs. in or out
<u>Insulating Column</u>	
Length (excluding terminal)	> 62 ft.
Diameter	> 11 ft.
<u>Charging System</u>	
	dual, independent chain-belt with total capacity of 600 μ A plus provision for later addition of 3rd unit.
<u>Major Dead Sections</u>	
	2 at $\sim 1/3$ and $2/3$ height.
<u>Lenses Within Pressure Vessel</u>	
	2 in terminal, 1 in lower low energy dead section.
<u>Strippers</u>	
	gas and foil in terminal, foil in high energy upper dead section.

The basic size of the accelerator is determined by the voltage gradients which occur at the maximum operating potential, 25 MV. Consistent with its role as an injector, the accelerator has been sized so that these gradients are conservative. In particular, if the length of the major dead sections totals 8 feet the remaining column length will be at least 54 feet and the corresponding maximum average longitudinal gradient will be 25 MV/54 feet = 0.46 MV/ft. (1.51 MV/m). The macroscopic radial gradient on the surface of the column near the terminal will be no longer than 4.14 MV/ft (13.6 MV/m) assuming the values of column and tank diameter given in Table 1. To place these gradients in perspective we note that comparable gradients have been employed in the ORNL 5 MV electrostatic accelerator since its installation in 1951.

In several respects the new machine will be different from existing tandem accelerators. These differences include the folded configuration, the use of a large number of ion-optic and beam diagnostic elements at high potential, and the use of digital rather than analog systems for transmission of control and monitoring information. Since the ion-optic system is discussed in another contribution² we will confine our discussion to the folded configuration and the control system.

The Folded Configuration

The folded configuration was first proposed by Alvarez⁴ in a note suggesting the tandem accelerator

concept. However, to our knowledge only one such machine has been built. This is a 4 MV tandem accelerator built at the University of Auckland, New Zealand and described by Naylor⁵. The Auckland machine, however, is a special case since it was built with an existing column which happened to have an unusually large diameter to length ratio. We have recently learned⁶ that the University of Oxford has proposed conversion of their single stage injector into a folded tandem accelerator. In general, it seems clear that a folded configuration is only attractive in tandem accelerators of rather large size, a limitation related to the space required in the high voltage terminal to bend ions of interest through a net angle of 180° and, for a simple 180° terminal magnet configuration, the space required for separation of the low-energy and high-energy acceleration tubes. In subsequent paragraphs we discuss this problem in greater detail using the latter assumption.

Let $B_{\max}$ be the maximum magnetic field in kG which may be achieved in the 180° terminal magnet. Let Q be the charge state of the component of the beam which is bent in the magnet. Let S be the tube separation in cm. Let M be the ion mass in amu and let E be the ion energy after terminal stripping in MeV. In most systems E will, to a good approximation, be equal to the terminal potential V in MV.

In this approximation, ions may be transmitted when

$$SQ \geq 288 \frac{\sqrt{MV}}{B_{\max}} \quad (1)$$

We now distinguish between two cases: fully ionized (generally light) and partially ionized ions. For fully ionized ions Q/M is approximately equal to 1/2 (except for tritium) and equation 1 reduces to

$$S \geq \frac{576}{B_{\max}} \sqrt{\frac{V}{M}} \quad (\text{cm})$$

or

$$S \geq 41.1 \sqrt{\frac{V}{M}} \quad (\text{cm})$$

if we assume $B_{\max} = 14$ kG. The worst case occurs when $M = 2$ and

$$S \geq 29.1 \sqrt{V} \quad (\text{cm}).$$

For partially ionized ions, we consider the separation required to accelerate ions in the most probable charge state, Q^* , emerging from a terminal gas stripper. To estimate Q^* , we make the approximation that Q^* is equal to the average charge $\bar{Q}$ and use an expression consistent with data presented by Betz.⁷

$$\frac{\bar{Q}}{Z} = 0.481 \frac{v}{v_0 Z^{0.55}} = 0.481 v_r$$

where $v_0 = \frac{e^2}{h} = 2.188 \times 10^8$ cm/sec, v is the ion velocity in cm/sec, and v_r is defined as a reduced velocity. This expression is valid for $v_r \leq 1.0$ which at 25 MV corresponds to $Z \geq 19$. Substitution of this expression in equation 1 along with parameterization of M in terms of Z shows that in this approximation, S is essentially independent of terminal potential and an approximately linear function of atomic number Z . Fig. 2 shows the magnet radius of curvature ρ =

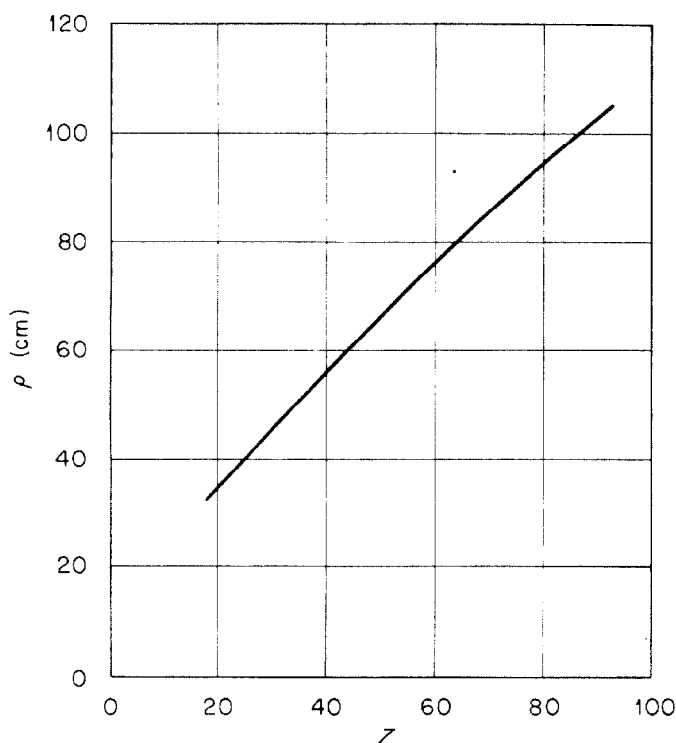


Fig. 2. The radius of curvature, ρ (cm), for the terminal magnet in a folded tandem accelerator is shown as a function of atomic number, Z , for the case in which ions of the most probable charge state emerging from a gas stripper are accelerated. The assumed magnetic field is 14 kG.

$S/2$, for an assumed maximum magnetic field of 14 kG. As can be seen, the required separation for uranium is approximately 200 cm. This basic result, independence of V and dependence on Z , would be obtained with other strippers and charge state selection criteria.

For light, fully ionized ions the required separation is proportional to the square root of terminal potential while for heavy, partially ionized ions the required separation is independent of terminal potential. Conversely, column diameter, as determined by electrostatic considerations, scales as the first power of terminal potential. Thus as the maximum terminal potential is increased there is a cross-over and the folded configuration may be used without an artificial increase in column diameter. For the conditions cited, uranium ions in the most probable charge state emerging from a gas stripper, the cross-over occurs at a terminal potential of about 22 MV. This is the worse case. With other constraints such as lower ion mass or higher charge state, the cross-over points will come at a lower terminal potential.

In our view, the principal advantages and disadvantages of the folded configuration are as follows:

Advantages

1) Use of one column structure rather than two reduces the length of the pressure vessel by 20% to 30%. This length reduction has important economic consequences, not only in the cost of the pressure vessel but also

in reduced insulating gas inventory, reduced size of the gas handling and gas storage systems, and reduced building costs.

2) The electrostatic stored energy in a linear tandem accelerator is approximately 40% greater than in a folded tandem accelerator of comparable dimensions.

3) The 180° magnet required to reverse the beam direction in the high voltage terminal serves as an excellent charge state separator for selection of a single charge state after stripping.

4) A tandem accelerator of the size contemplated here is more easily built in a vertical rather than horizontal orientation. With a linear configuration, the room housing the injection system must be located on top of the tower which houses the accelerator pressure vessel. This creates problems related to a) transport of personnel, equipment, and control information to and from the injector room, b) inflexibility due to limited room size, and c) possible differential motion of the injection system with respect to the accelerator pressure vessel which in general is supported at its base. In a folded configuration, the injection system is located near the base of the accelerator and all these problems are naturally solved or ameliorated.

5) Bremsstrahlung produced in or near the high voltage terminal is directed away from both acceleration tubes.

Disadvantages

1) The 180° terminal magnet is heavy, consumes a fair amount of power, and must be operative for the accelerator to be functional.

2) The 180° terminal magnet is a source of time dispersion for pulsed beams.

3) With a simple 180° terminal magnet configuration, the acceleration tubes are considerably displaced from the column axis and thus may possibly be more subject to damage under sparking conditions.

4) For equal sizes and similar construction a single-ended column will be less rigid than a column supported at both ends.

We believe that the advantages cited outweigh the disadvantages for tandem accelerators of the 25 MV class.

Digital Control System

In the early stages of the development of criteria for the design of the control system for the accelerator it was realized that we had a propitious opportunity to start with a computer-based control system rather than to try later to computerize a "conventional" control system. Relative to a conventional system, a computer-based system offers the advantages of 1) ease of installation and maintenance, derived in large part from the use of multiplexed signal paths which actually reduce the complexity of the system outside the computer itself, 2) inherent expansion capability, 3) ease of implementing the multiple control consoles required for operation as an injector, and 4) a more tractable ground loop situation.

Actual computer control of the accelerator (putting the computer inside feed-back loops) is not seen as an early requirement. Only manual, computer-

assisted control will be implemented initially. After completion of the installation we expect to proceed at a deliberate pace to develop computer logging and retrieval of operating parameters to assist in setup, computer surveillance of operating conditions to detect and correct abnormalities, and, ultimately, actual computer control.

Significant features of the system required by the specifications are as follows:

- 1) There will be two co-equal control consoles. One will be used when the accelerator is being operated independently; the other when the accelerator is being used as an injector.
- 2) All control signals and monitoring information will be digitized, stored in a common computer memory, and transmitted from place to place over multiplexed serial data links. A large reserve capacity will be available.
- 3) A second computer will be available for off-line program development. It will also have direct access to the data stored in the control computer. It is planned to use this computer for the logging, surveillance, and control tasks mentioned above.
- 4) Extensive use of "CAMAC" hardware throughout the system will provide for easy system maintenance and modification.
- 5) Careful attention will be given to avoidance of ground loop problems.

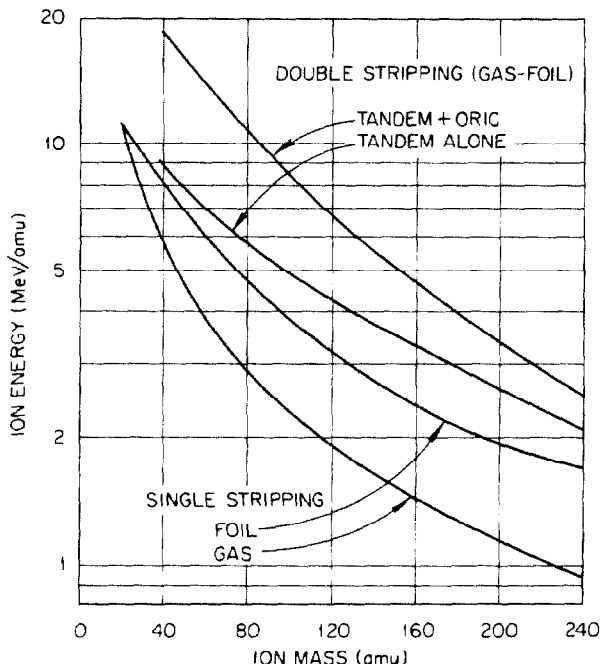


Fig. 3. Ion energy (MeV/amu) vs ion mass (amu) for several operating modes discussed in the text.

Performance

In Fig. 3 we show ion energy vs ion mass functions based on the assumption that the most probable charge state component is accelerated after each stripping process. The functions labeled "single stripping" are for operation of the tandem accelerator independently with only a terminal stripper. As mentioned above, the accelerated beam intensity is expected to be as much as one particle microampere with a gas stripper. The function labeled "double stripping, tandem alone" is calculated on the assumption that the tandem accelerator is operated independently with a terminal gas stripper and a foil stripper located in the upper dead section. The function labeled "double stripping, tandem + ORIC" is calculated on the assumption that the tandem accelerator is operated as an injector with a terminal gas stripper and that the beam is then accelerated by the ORIC using a foil stripper in the ORIC to perform the capture function. Maximum intensity in both of these modes is expected to be about 0.1 particle microampere.

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References

1. J. B. Ball, Bull. Am. Phys. Soc. **19**, 1112 (1974).
2. W. T. Milner, G. D. Alton, D. C. Hensley, C. M. Jones, R. F. King, J. D. Larson, C. D. Moak and R. O. Sayer, "Transport of DC and Bunched Beams through a 25 MV folded Tandem Accelerator", IEEE Trans. Nucl. Sci. NS-22, No. 3, 1975 (this volume).
3. R. S. Lord, J. B. Ball, E. D. Hudson, M. L. Mallory, J. A. Martin, S. W. Mosko, G. S. McNeilly, K. M. Fischer, R. M. Beckers and J. O. Rylander, "Energy Boosting of a Tandem Beam with the Oak Ridge Isochronous Cyclotron", IEEE Trans. Nucl. Sci. NS-22, No. 3, 1975 (this volume).
4. L. W. Alvarez, Rev. Sci. Inst. **22**, 705 (1951).
5. H. Naylor, Nucl. Inst. and Meth. **63**, 61 (1968).
6. K. W. Allen, private communication.
7. H. D. Betz, Rev. Mod. Phys. **44**, 465 (1972).