# COMPARISON OF SYNCHROTRON AND ACCUMULATOR SCENARIOS FOR A 5-MW PULSED SPALLATION NEUTRON SOURCE *

L. Blumberg, A. Luccio, A.G. Ruggiero, A. van Steenbergen
Brookhaven National Laboratory, PO Box 5000, Upton, Long Island, NY 11973

## 1 INTRODUCTION

This paper reports conceptual design studies of a site-independent 5-MW Pulsed Spallation Neutron Source (PSNS) conducted by an interdepartmental study group at Brookhaven National Laboratory*. First, a scenario based on the use of a 600 MeV Linac followed by two fast-cycling 3.6 GeV Synchrotrons was investigated. Then we studied an Accumulator with two options: i) a 1.25 GeV normal-conducting Linac followed by two Accumulator Rings, and ii) a 2.4 GeV superconducting Linac followed by a single Accumulator Ring.

## 2 THE SPALLATION NEUTRON SOURCE

Since the beam power is the product of beam kinetic energy and intensity, the design goal of 5 MW can be obtained by trading proton beam intensity for proton energy. Accordingly, two basic approaches may be considered. One choice is a relatively low proton energy accompanied by a higher beam intensity, with a full-energy linac followed by one or more constant energy accumulator rings. This approach has the advantage of a cheaper circular component. The disadvantage is an expensive linac and higher beam intensity with consequences on cost, reliability and safety of the whole facility. The second choice is a higher proton energy at a lower beam current. At the present only fast-cycling synchrotrons seem appropriate for proton acceleration to high energy. Both scenarios have a layout schematically shown in Figure 1.

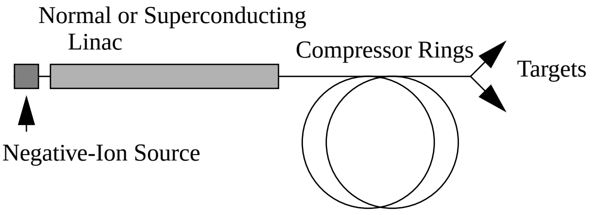

Figure 1. A Pulsed Spallation Neutron Source with Linac and Compressor Rings

Initially we have considered a scenario based on the use of a 600 MeV Linac injector followed by two 3.6 GeV Rapid-Cycling Synchrotrons (RCS). Higher beam energy was preferred because it eases many design considerations regarding beam performance. The synchrotron scenario alleviates considerably the design considerations of the injector linac, but requires careful studies of problems peculiar to synchrotrons. At the conclusion of the first period of studies, it was determined that a 5 MW synchrotron scenario holds several difficult technical issues. We thus initiated a second phase of studies for an Accumulator scenario. We found this less difficult, with only marginal cost differential. In the accumulator scenario, the beam energy choice is an open parameter, and two options have been investigated: one at 1.25 GeV which can be obtained with either a normal- or super-conducting linac, and the other at 2.4 GeV, with a superconducting linac.

## 3 THE RAPID-CYCLING SYNCHROTRON SCENARIO

The most important issue is the choice of the linac energy. One might suggest as low a beam energy as possible, with most of the energy increase to take place in the synchrotron in order to favor linac reliability and minimum cost. Yet the low-energy injection into the synchrotrons creates problems because of the space-charge effects. The scenario we have investigated takes as a compromise one 600 MeV Linac followed by two 3.6 GeV Rapid-Cycling Synchrotrons.

The number of synchrotrons is driven by two additional considerations. One is space charge: two synchrotrons in parallel, need half of the total amount of beam current and therefore half of the amount of space-charge effects. A second consideration is that the overall repetition rate of 60 beam pulses to the target per second is better achieved with two synchrotrons each running 180$^o$ out of phase at the repetition rate of 30 Hz.

The most important issues relevant to the design of high beam intensity rapid-cycling synchrotrons are: space-charge effects at injection, RF capture during injection, RF acceleration, ramping of the guide field, and vacuum.

Space-charge effects are particular important to synchrotrons because of the low injection energy. The betatron tune depression $\Delta\nu$ is

$$\Delta\nu \;=\; N r_p \;/\; 2\, B \beta^2 \gamma^3 \varepsilon \qquad (1)$$

where N is the total number of protons, $r_p = 1.535 \times 10^{-18}$ m, B the bunching factor which during the early part of the

---

* Work performed under the auspices of the U.S. Department of Energy

acceleration cycle is about 0.3, and $\varepsilon$ is the full beam emittance in meter-radiant unit. We have adopted $\Delta\nu = 0.25$. Thus Eq. (1) is a relation between injection energy, beam intensity and dimension, which also determines the gap of the magnets and therefore their feasibility and cost. The choice of the two 3.6 GeV synchrotrons together with the 600 MeV linac requires a magnet gap close to 15 cm, which is technically and financially acceptable.

In the synchrotron scenario beam pulses of negative ions are accelerated to 600 MeV in the linac at the repetition rate of 60 Hz. Injection occurs by charge-exchange in a stripping foil. The beam is then accelerated to 3.6 GeV and immediately extracted to one of two experimental targets. As the beam is being extracted from the first synchrotron, the second synchrotron is being filled with an identical beam pulse from the linac which is accelerated to the same final energy and at the same repetition rate. The procedure then repeats periodically, alternating filling and acceleration from one synchrotron to the other, thus creating a beam pulse sequence at the repetition rate of 60 Hz.

It was determined that rf capture and multiturn injection is difficult to control in a rapid-cycling synchrotron because of the fast ramping of the guide field. It is important to control the total beam losses to a low level (about $10^{-4}$) during the entire acceleration cycle. In particular, it is crucial to control beam losses to a $10^{-5}$ level during multi-turn injection and rf capture. This was proven to be difficult, and eventually with no more than 300 beam turns. This required a low linac duty cycle (3%) and a large ion source beam current. General linac parameters are shown in Table 1.

Other problems also appeared in the synchrotron scenario. The rf system for acceleration should provide a peak power of 7 MW, with a total voltage of 0.8 MVolt at 1 - 1.5 MHz. The bending field is ramped at the large rate of 50 T/s. The vacuum system is complex, made of a costly ceramic vacuum chamber with screening metallic wires.

## 4 THE ACCUMULATOR SCENARIO

The accumulator scenario seemed less difficult during the feasibility study. The required beam power is entirely generated in the linear accelerator, and thus the linac is the most crucial component. On the other end, the design of the accumulator ring is simplified, and expected to be less critical. Because of the lower energy, in principle the accumulator scenario requires larger average beam current. Again, the largest energy value and the largest number of beam turns injected are preferred, since they would lead to a lower beam current and thus a less demanding ion source. there are two possible options: a normal conducting linac which cannot exceed the energy of 1.25 GeV because of cost and length, and a superconducting linac that can reach an energy as high as 2.4 GeV. In the first option one needs two accumulator rings, whereas only one should suffice for the large energy option.

With the accumulator scenario several technical problems become less important. The vacuum system is greatly simplified, by adopting a solid metallic vacuum chamber. The rf system is needed only to compress the beam in one single bunch. At most, a peak voltage of 30 kVolt is needed at the frequency of about 1 MHz. Furthermore, the operation of the accumulator ring is at constant field without pulsed excitation.

Though the injection energy is larger, nevertheless space-charge effects are still important and determine the performance of multi-turn injection as well as beam dimension and magnet aperture. Numerical simulations have demonstrated that it is possible to control beam losses to an acceptable level also with one thousand (or more) turns injected. Also, it was possible to prove that multi-turn injection by charge exchange is feasible, essentially, without appreciable negative ion stripping due to crossing of magnetic fields, also at the injection energy of 2.4 GeV.

In this scenario, a beam pulse is generated by the linac at 60 Hz. Half of the pulse is injected in one accumulator ring, and the second half in the second ring. Both beam pulses are compressed to a length of 400 ns, simultaneously in the two rings, and then extracted in sequence with a 200 ns interval. The overall pulse on the target is thus about 1 ms long. In the 2.4 GeV option, the total beam pulse can be directed, if desired, to a single target.

## 5 LINAC CONFIGURATIONS

The accumulator scenario clearly shifts the emphasis of the design to the linear accelerator. Five different linac structures are summarized in Table 1. The first column (A) is the 600 MeV normal conducting linac used in the study of the synchrotron scenario. Columns B to D describe linac configurations for the accumulator scenario.

A schematic layout of the linac is given in Figure 2. It is made of a front-end, a low-energy section, and a high-energy section.

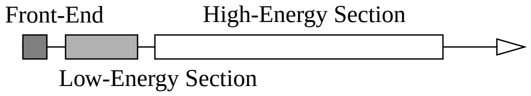

Figure 2. Schematic Layout of the Linear Accelerator

The front-end is made of a negative-ion source on a 50-kV platform, followed by either a single 2.5-MeV, 350-MHz RFQ (options A to C) or by a sequence of two 350-MHz RFQ's at energies 2 and 5 MeV (options D and E). The low-energy section is in all cases a normal-conducting 700-MHz Drift Tube Linac with the output energy of 70 MeV for cases A to C, and 100 MeV for cases D and E.

The high-energy section is a 700-MHz Cavity-Coupled Linac for options A to C, and a 700-MHz superconducting linac for options D and E. The final energy varies from one option to the other.

Configurations B and C apply to a phase mode of construction for the accumulator scenario. In a first phase the linac provides only 1 MW of average power, at the energy of 800 MeV, and it is followed by one single accumulator ring. In a second phase, the linac energy is raised to 1.25 GeV, and a second accumulator is added. At the same time the ion source intensity is increased to obtain a 5 MW beam power. Clearly, option B requires less beam current. If the number of turns injected is increased to one thousand, the required source current is 50 mA. Configuration D is the superconducting option of the 1.25-GeV, 5-MW linac, and it should be compared to option C. Though the length of the superconducting version is shorter, nevertheless a preliminary estimate has shown that they have comparable cost.

The high-energy superconducting option E, explores the possibility of larger energies. As it is shown in the Table 1, the energy of 2.4 GeV would match to an accelerated beam current of 25 mA. Of course, it may require a longer pulse length, and eventually, two accumulator rings. Nevertheless, the high-energy superconducting option is perceived as the most flexible since would allow adjustments in case higher intensity ion sources should be developed, or in case of funneling two ion sourcese.

## 6 CONCLUSION

We have compared two scenarios: one which makes use of Rapid-Cycling Synchrotrons, and the other of Accumulator Rings. We have determined that the Synchrotron presents some technical difficulties at the level of 5 MW beam average power, and that the Accumulator is to be preferred. Also, there was no major cost difference between the two approaches. Nonetheless, The Accumulator option requires a more careful study of the linear accelerator, which provides the entire beam power. In our opinion, technical risks are still represented by the development of the negative-ion source, which can be mitigated with a high-energy superconducting linac, and by the feasibility of thousand-turns injection by charge exchange. These areas require more careful evaluation and more numerical simulations.

## 7 ACKNOWLEDGMENTS

This work has been done by a BNL interdepartmental study group, which included staff members of the Alternating Gradient Synchrotron, the National Synchrotron Light Source departments, and the department of Advanced Technologies.

**Table 1: Comparison of few Linac Configurations**

| | A | B | C | D | E |
|---|---|---|---|---|---|
| PSNS Scenario | Synchr. | Accumul. | Accumul. | Accumul. | Accumul. |
| Beam Power, MW | 0.84 | 1.0 | 5.0 | 5.0 | 5.0 |
| Final Energy, GeV | 0.6 | 0.8 | 1.25 | 1.25 | 2.4 |
| H- Source Current, mA | 120 | 70 | 120 | 120 | 30 |
| Pulse Length, ms | 0.360 | 0.533 | 1.024 | 1.111 | 2.315 |
| Duty Cycle, % | 2.2 | 3.2 | 6.1 | 6.7 | 13.9 |
| Chopping Factor, % | 65 | 65 | 65 | 60 | 60 |
| Beam Current, mA | 100 | 60 | 100 | 100 | 25 |
| Beam Turns injected | 236 | 747 | 770 | 1000 | 1000 |
| RFQ, frequency, MHz | 350 | 350 | 350 | 350 | 350 |
| RFQ, energy, MeV | 2.5 | 2.5 | 2.5 | 2 - 5 | 2 - 5 |
| DTL, MHz / MeV | 700 / 70 | 700 / 70 | 700 / 70 | 700 / 70 | 700 / 70 |
| CCL, MHz / MeV | 700 / 600 | 700 / 800 | 700 / 1250 | -- | -- |
| Superc. Section, GeV | -- | -- | -- | 0.1 - 1.25 | 0.1 - 2.4 |
| Peak Power, MW | 90 | 30 | 135 | 125 | 60 |