Accelerator Design Parameters for a European Pulsed Spallation Neutron Source.

Report from workshop for a European Spallation Source.

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Abstract

The accelerator parameters for a future "European Pulsed Neutron Source" have been discussed. Specific requirements from the neutron scatterers and the users of the high intensity synchrotron ISIS at Rutherford Appleton Laboratory (RAL) have resulted in the following accelerator parameters: an average beam power of 5 MW, at a repetition frequency of 50 Hz with a beam pulse length of less than 3 μs. Two different approaches for the accelerator system are suggested. The first is a linear accelerator (800 MeV) followed by 3 identical accumulator compressor 'storage rings', and the second, a linear accelerator (460 MeV) followed by an FFAG synchrotron (3 GeV). The design of the two options is discussed.

1. INTRODUCTION.

A panel under the auspices of the Commission of the European Community (CEC), identified the need to construct a new intense neutron source in Europe early in the next decade.

Considering a spallation source as the most promising solution, neutron experimentalists together with accelerator and spallation target designers met at a series of workshops to discuss the possible options for such a "European Spallation Source". The first of these established the basic design objectives of the neutron source and examined accelerator options. The second studied target designs and the third, instrumentation for such a source. The results of the first workshop, which are summarised here, represents the collaborative efforts of the participants from many countries , who are listed at the end of this paper.

2. NEUTRON SOURCE REQUIREMENTS.

The outline specification for the source was based on the requirements for future use of neutrons in condensed matter research together with the experience gained from running the pulsed neutron sources at RAL in the UK, Los Alamos and Argonne in the USA and KEK in Japan.

An average beam power of 5 MW is chosen to give a thermalized average neutron flux $F_{th} \approx 10^{15}\ cm^{-2}s^{-1}$, equivalent to the High Flux Reactor at ILL Grenoble. A short beam pulse of less than 3 μs is required. A very low repetition rate is desirable and 50 Hz was considered as an acceptable upper limit, with the option of diverting some fraction of the beam to a second target operating at 10 Hz. Operation of such a source will need to be as good as the best accelerator standards already achieved with a reliability greater than 90%.

3. ACCELERATOR PARAMETERS.

The beam power, pulse length and repetition rate are the basic parameters which influence the choice of accelerator. Before discussing these choices it is useful to make some comparisons with the characteristics of existing accelerators.

With the parameters given above, each beam pulse will contain 100 kJ of energy. This may be compared with the 3 MJ stored and slow extracted from the Tevatron at Fermilab, USA and the 4 MJ stored in the Intersecting Storage Rings at CERN, Switzerland.

The 5 MW of beam power may be obtained from a wide choice of kinetic energy and corresponding beam current. The choices discussed later, of 6.3 mA at 800 MeV and 1.7 mA at 3 GeV may be compared with the 1.2 mA , 1 MW achieved routinely from the 800 MeV Linac at the Los Alamos Meson Physics Facility in the USA, and the 1.5 mA, 0.9 MW, 600 MeV Separated Sector Cyclotron now being commissioned at the Paul Scherrer Institute, Switzerland.

Thus the major parameter extension is the mean beam power, placing a high premium on system reliability and on minimising and controlling beam loss.

4. ACCELERATOR OPTIONS.

The accelerators considered as possible contenders which could meet the source requirements were:

1) A linear induction accelerator.
2) A linear accelerator (linac) followed by collector rings and rapid and medium cycling synchrotrons accelerating a relatively low current (~125 μA) to a relatively high energy (>45 GeV).
3) A linac followed by a rapid cycling synchrotron.
4) A linac followed by a number of compressor rings.
5) A linac followed by a Fixed Field Alternating Gradient (FFAG) synchrotron.

The induction linac does not require the addition of a circular machine to produce the short beam pulse length. Most of the work on this type of accelerator has been for heavy ions and electrons and very little for protons. A reliable rapid cycling version was considered too speculative with present technology.

All options, apart from the induction linac, rely on the linac accelerating H^- ions and injecting into synchrotron or storage rings, using charge exchange to obtain very high injection efficiencies.

Option (2) is an interesting recent development, which forms the basis for a spallation source proposal by the Institute for Nuclear Research (INR), Moscow. It was not considered for further evaluation, because the thermal neutron flux predicted by INR for 5MW of beam power is much less than can be obtained with the higher current lower energy schemes.

Option (3) is similar to the operating spallation source, ISIS, at RAL. This source comprises a 50 Hz, 70 MeV linac followed by an 800 MeV synchrotron and currently operates at a beam power of 0.12 MW. A design for much higher power levels requires a linac energy around 800 MeV, and a synchrotron energy around 3 GeV, so that the synchrotron magnet apertures and the radio frequency (rf) swing during acceleration are kept within acceptable bounds. Since the injection energy is similar to that for the linac-compressor ring option, and the synchrotron is a more complex machine, it was not studied further.

A linac followed by several compressor rings is an extension of the source design, LANSCE, at Los Alamos. The beam in LANSCE is provided by a 800 MeV linac and a single compressor ring. A beam current of 0.1 mA has been achieved compared with the 2.1 mA/ring of the proposal. However, a large amount of knowledge has accumulated on the design and operation of storage rings with circulating beam currents similar to those proposed for the new source.

The FFAG synchrotron of the last option is an accelerator invented in the 1950s when prototypes were built. It was considered for use as a "Kaon Factory", or high intensity high energy accelerator, in the 1960s. In the 1980s it was reconsidered for a pulsed neutron source by KFA Jülich and also by Argonne National Laboratory in the ASPUN proposal, which was based on an FFAG with 7.2 MW of beam power.

5. LINAC - COMPRESSOR RINGS OPTION.

In this scheme, shown in Figure 1, an 800 MeV linac injects into three identical storage rings. Each ring is filled sequentially using multiturn charge exchange injection. The rings are then emptied in rapid sequence using fast extraction systems to provide three successive proton bunches within 1.5 μs at 50 Hz. This is an enhancement by a factor of 4 on the Rapallo study for upgrading the ISIS facility at RAL. Then, an 800 MeV linac of 1.3 MW was considered, injecting into a single compressor ring. Since Rapallo, more detailed considerations have been made of the optimization of H^- injection systems, which show the advantages of using a different design of compressor ring than the one proposed for the ISIS upgrade.

The main technical and design issues requiring in-depth evaluation for the compressor ring are:

a) Design of a radio frequency system to maintain a gap in the circulating beam for efficient extraction.
b) Design of magnet lattice for optimised injection and efficient beam loss collection.
c) Design of injection, extraction and beam loss collection systems.
d) Estimates of injection and extraction losses.
e) Instability assessments.
f) Development of suitable stripping foils.
g) Assess facility reliability and beam availability.

6. LINAC - FFAG OPTION.

The initial specification is a 460 MeV linac and a 460 MeV to 3 GeV superconducting FFAG synchrotron cycling at 50 Hz, as shown in Figure 2. At an energy of 3 GeV, sufficient current may be accelerated without the need for storage rings.

The FFAG synchrotron requires the development of large dc superconducting (sc) magnets and a complex rf system. The approximate magnet parameters are; a peak field of 5 T, a radial aperture of 2 m and a maximum vertical aperture of 300 mm. The rf system is on continuously and has to provide for average and peak beam powers of 4 and 5 MW respectively plus, some additional power for exciting the accelerating structures. The operating frequency is around 1 Mhz with a frequency swing of about 20%. The systems envisioned are large ferrite-loaded structures.

In addition to the issues which must be resolved for the compressor ring, the following topics must be studied for the FFAG:

h) Prototype development of superconducting magnet.
i) Acceptable level of beam loss in the sc magnets.
j) Detailed form of the field in the sc magnets.
k) Diagnostic devices suitable for use in a FFAG.
l) Control of heavy beam loading of the rf system.

7. H^- LINEAR ACCELERATORS.

Apart from the differences in final energy and accelerated beam current the linacs for the two tentative proposals are similar. Each linac comprises a H^- ion-source, matched to a radio frequency quadrupole linac operating at 400MHz. This is followed by sections of drift-tube linac (DTL) feeding into linac sections of side-coupled cavity (SCL) design. The development of a suitable H^- ion-source, with an output current ~120mA, is very important for the linacs. The basic parameters for the two linacs are listed in the Table .

To achieve loss free operation of the compressor rings the linac pulse is modulated at low energy to produce a 200 ns gap every 650 ns (revolution time in a ring). To sequentially fill the three rings without loss an additional chopper creates a gap of 10 μs every 500 μs of the 1.5 ms beam pulse. If full adiabatic capture proves to be possible in the FFAG then the use of beam choppers will not be necessary in this option.

	COMPRESSOR		FFAG		
Parameters	DTL	SCL	DTL	SCL	units
Pulse Length	1.5	1.5	0.4	0.4	ms
Duty cycle	7.5	7.5	2.0	2.0	%
Average current	6.25	6.25	1.7	1.7	mA
Output energy	100	800	100	460	MeV
Frequency	400	800	400	800	MHz
Mean Gradient	3.0	5.0	3.0	5.0	MV/m
Transit time factor	0.72	0.8	0.72	0.8	
Synchronous phase	-30	-25	-30	-25	deg
Shunt impedance	30	35	30	35	MΩ/m
length	53	322	53	100	m
Cavity peak power	8.3	53	8.3	45	MW
Mean power	1.25	8.3	0.4	1.6	MW

8. CONCLUSION.

In collaboration with the neutron scattering community and accelerator and spallation target designers, the outline parameters for a 'next generation' source have been specified. Two possible accelerator systems are suggested for such a source. A number of technical issues for each need to be resolved and a basic cost comparison made before a final choice can be reached and a concrete proposal put forward.

9. WORKSHOP PARTICIPANTS.

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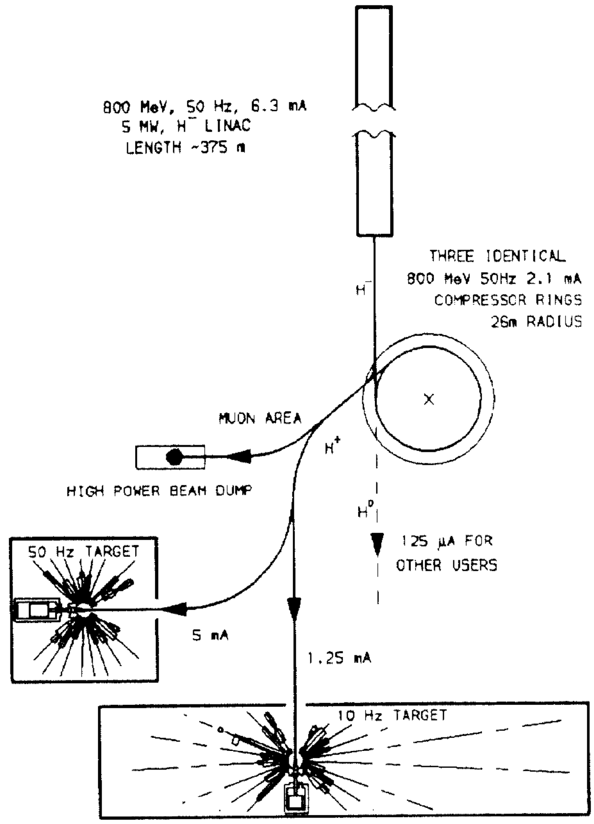

Figure 1. Linac - Compressor Rings Proposal.

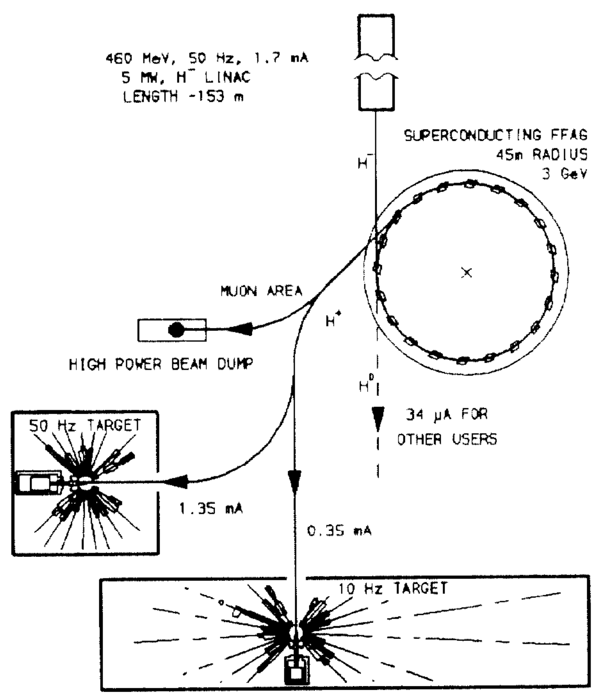

Figure 2. Linac - FFAG Proposal.