FEASIBILITY OF A COMMON PROTON DRIVER FOR A NEUTRON SPALLATION SOURCE AND A NEUTRINO FACTORY

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Abstract

A multi-MW proton driver in the few GeV energy range could be required for an upgrade to the ISIS neutron spallation source at RAL and would also be required for production of a muon beam for a Neutrino Factory. Although the requirements for the time structure of proton beams are different, we investigate in outline the feasibility of sharing the proton driver between the two facilities. We assume the beam for both facilities is accelerated in a linac followed by rapid cycling synchrotron (RCS) at 50 Hz repetition rate to 3.2 GeV. One part of the bunch train after extraction from the RCS can be sent to the neutron production target and the other part of the extracted beam can be sent to another RCS, where further acceleration and final bunch compression can be performed to meet the specification of the Neutrino Factory target.

INTRODUCTION

Neutron spallation sources are used for a wide range of condensed matter R&D, and new sources in the form of J-PARC and SNS have recently come on stream to complement existing sources such as ISIS, LANSCE and PSI. In Europe, plans have been afoot since the 1990s for a megawatt-class spallation neutron source in the form of the European Spallation Source (ESS). The UK is involved in current work towards a long-pulse ESS, and at the same time STFC is preparing plans to upgrade ISIS to a megawatt-class short pulse spallation neutron source.

The Neutrino Factory accelerator complex is optimised to store as many muons as possible in the neutrino-production rings. The muons are produced from the decay of pions produced in the bombardment of a pion-production target by a high-power (4 MW), pulsed proton beam. With the support of the STFC, the UK-led International Design Study for the Neutrino Factory (the IDS-NF) [1] is developing the baseline concept and will deliver the Reference Design Report in 2012.

It makes sense to assess the extent to which synergies between spallation neutron sources and neutrino factories could be exploited. The Front End Test Stand (FETS) [2] under construction at RAL is one example of successful collaboration of the high energy physics and spallation neutron source communities in the UK in the field of accelerators. A further possible example would be to investigate the shared use of proton drivers. While work on the particle dynamic designs for different upgrade options for ISIS (800 MeV linac, 3.2 GeV booster synchrotron) is on-going, in this paper we look towards the evaluation of possible synergies between the ISIS and the NF accelerators. Similar activities for a shared usage of proton drivers are under way at CERN and FNAL. In the present paper a first outline design is presented for an RCS bridging the gap between the 3.2 GeV proton energy foreseen for an ISIS upgrade and the ~10 GeV baseline proton energy for an NF and performing the bunch compression down to the required 1–3 ns.

ISIS MW UPGRADE PLANS

The ISIS Spallation Neutron Source has been running successfully for many years, and recently a second target station has been commissioned. Several beam power upgrade paths for the facility are under study [3]. In summary, the proposed upgrade paths could be built in stages and consist of the following options:

- Linac energy upgrade to 180 MeV to inject into existing ISIS RCS synchrotron with reduced space charge tune-shift. This could allow an increase in beam power to 0.4 MW.
- Construction of a new 3.2 GeV RCS ring with bunch-to-bucket transfer from the present ISIS RCS at 800 MeV — for beam power in the 1 MW range.
- Construction of a new 800 MeV H^- linac with direct charge exchange multi-turn injection into the previously mentioned 3.2 GeV RCS for a total beam power in the range of 5 MW.

The parameters of the reference design for the 3.2 GeV RCS for the ISIS MW upgrade [4] are given in Table 1, and the betatron functions for the proposed design are shown in Fig. 1. The ring design is flexible enough to accommodate the requirements of both the second and third bullet points immediately above. The H^- stripping foil is centred in one of the arcs, and optical functions are provided to allow for beam painting.

COMMON PROTON DRIVER

The last option in the path towards ISIS upgrade is of particular importance for the possible future facility capable to deliver the high power proton beams for both neutron production target of the spallation source and the pion production target of the Neutrino Factory simultaneously. While the level of beam power is close to the requirements of the neutrino facility, the extraction energy is not sufficient as the optimal energy for pion production is estimated to be rather in the range 10 ± 5 GeV[5] with a most likely optimum around 6-8 GeV.

Although the current assumption is that the most of the beam power from an upgraded ISIS would be devoted to neutron production, we explore other possibilities.

Assuming 4 bunches totaling 5MW beam power at 3.2 GeV as described in the upgrade path outlined so far offers the opportunity to send 2 bunches for the neutron production target(s) and accelerate the residual 2 bunches further to the required energy in the range between 6.2 and 10.3 GeV. Assuming slightly less optimistic scenario of 4 MW beam power from 3.2 GeV RCS at harmonic number 4 and in addition an equal power distribution between the neutron and neutrino communities, it is sufficient to accelerate the beam further by a factor of 2 to 6.4 GeV to obtain the 4 MW needed for the Neutrino Factory. Assuming in contrary the unequal beam power distribution with only single bunch available for the neutrino beam production, the 4 MW can be again obtained at 10.24 GeV, when the initial 3.2 GeV RSC reaches the 5 MW with 4 bunches. It seems that the accelerator capable to accept the bunches at 3.2 GeV, accelerate the beam to energy in the range from 6.4 to 10.3 GeV and perform the required bunch compression to 1-3 ns would be able to fulfill the goal of supplying the Neutrino Factory target quite independently from the exact intensity in the 3.2 GeV ring and details of bunch distribution scheme. It is worth mentioned, that there exist other design for the 3.2 GeV RCS with harmonic number 5, where in principle the Neutrino Factory could be served with 3 out of total 5 bunches, which would be exactly according to the recommendations given by the International Scoping Study (ISS) [5]. We shall not consider this option here and focus on the parameters of the reference design based on h=4. The Fig 2. shows the conceptual layout of the common proton driver for the Spallation Neutron Source at RAL and the Neutrino Factory.

Table 1: Parameters of the reference design for the 3.2 GeV RCS for MW ISIS upgrade.

Number of superperiods	4
Circumference	408.4 m
Harmonic number	4
RF frequency	2.4717-2.8597 MHz
Betatron tunes (Q_H, Q_V)	(6.38, 6.3)
Gamma transition	6.6202
Beam power at 3.2 GeV	5 MW for 4 bunches
Bunch area	1.8 eVs
$\Delta p/p$ at 3.2 GeV	5.3 10^{-3}
Injection / extraction energy	0.8 / 3.2 GeV
Repetition rate	50 Hz

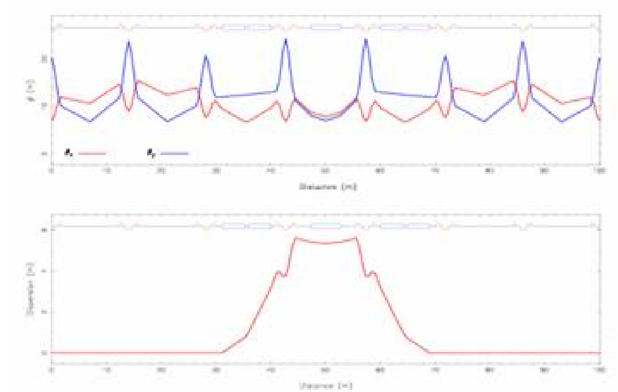

Figure 1: Betatron functions in the 3.2 GeV RCS for the ISIS upgrade.

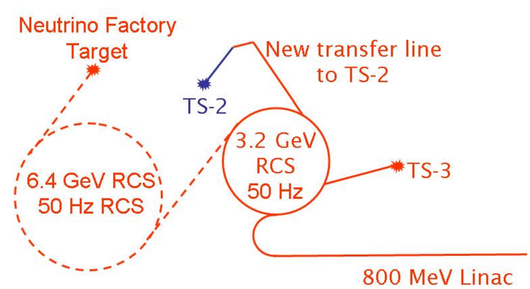

Figure 2: Conceptual layout of the common proton driver for the neutron spallation source and the Neutrino Factory based on ISIS upgrade. The solid lines show a facility studied in the framework of the MW ISIS upgrade, the dashed ones show the part which needs to be added in order to supply the Neutrino Factory.

DEDICATED RCS

Based on the time structure given by the ISIS upgrade RCS only a further RCS or an FFAG can be considered as a booster ring to reach the required NF target energies. A RCS design has been developed for this purpose. As the ring is supposed to have single turn injection, the constraints from multiturn injection can be relaxed. The goal of the study is to achieve the design dedicated to the bunch compression compatible with the present day cost effective RCS technology. Ring is equipped with one type of bending magnets with the maximal field of 1.2 T, which is similar to other RCS designs. It can work with the RF system similar to the one used presently at ISIS. As a basis for the lattice design triplet structure was adopted, which allows for long 14 m straight section. The dispersion is almost suppressed at the end of the superperiod The parameters of the design for the 6.4-10.3 GeV RCS for the NF booster/compressor are given in Table 2 and the betatron functions for the proposed design are shown in Fig 3.

Table 2: Parameters of the conceptual design for the 6.4 (10.3) GeV RCS.

Number of superperiods	6
Circumference	708.788 m
Harmonic number	6
RF frequency	2.4717-2.5289 MHz
Betatron tunes (Q_H, Q_V)	(7.81, 7.78)
Gamma transition	7.9056
Beam power at 6.4 GeV	4 MW for 2 bunches
Bunch area	1.8 eVs
$\Delta p/p$ at 3.2 GeV	5.3 10^{-3}
Injection / extraction energy	3.2 / 6.4 (10.3) GeV
Repetition rate	50 Hz
Max B field in dipoles	1.2 T (at 10.3 GeV)
Length of long drift	14 m

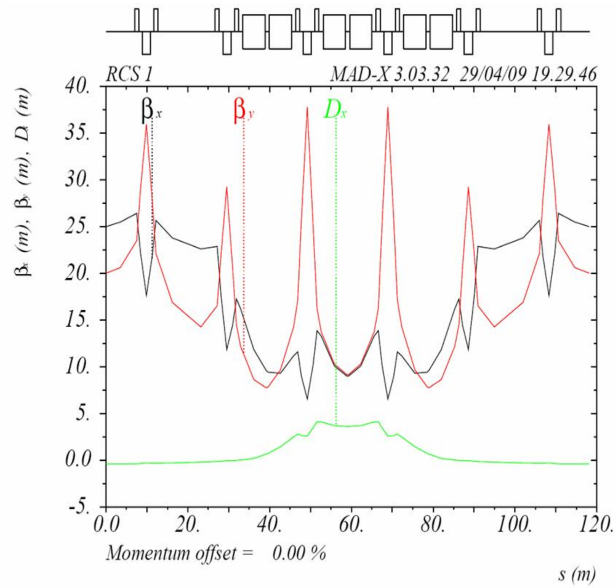

Figure 3: Betatron functions of the 6.4 (10.3) GeV RCS for the Neutrino Factory.

BUNCH COMPRESSION

In order to optimize the longitudinal muon capture in the muon front-end of the Neutrino Factory, the proton bunch at the target needs to be compressed to 2±1 ns length. Several methods have been proposed in order to reach that goal [6]:

- Adiabatic compression during acceleration, which requires relatively high RF voltage as for the RF voltage V the bunch length scales as $V^{-1/4}$. The variations of this method apply higher harmonic RF systems or lattices just below transition at the end of compression.
- Compression by the rapid phase rotation, which allows to apply lower RF gradient, but requires earlier bunch stretching to reduce the momentum spread just before the rotation and does not allow to hold the compressed bunches for many turns. The manipulations close to transition also may be applied in this scheme.

In order to address the bunch compression in the future studies the gamma transition in the RCS design was chosen to be just above 6.4 GeV, which should reduce the RF voltage required. The next step is clearly the study of longitudinal dynamics with the presence of the space charge forces.

SUMMARY

We have investigated in outline the feasibility of a common proton driver for a spallation neutron source and a neutrino factory in the context of an ISIS MW upgrade. Many accelerator stages would be identical for both facilities — ion source, RFQ, chopper, H^- linac, beam accumulation and acceleration to 3.2 GeV. However, in order to reach the energy and power needed for a neutrino factory a further RCS would be needed with bunch compression capability, and a preliminary design of such RSC has been presented. Bunch compression issues should be addressed in future studies.

REFERENCES

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