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Towards an FFAG Proton Driver

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High intensity proton drivers are needed for neutron production, the Neutrino Factory, muon colliders, etc. Due to its high repetition rate, the FFAG principle offers the possibility of a unique facility, which would be capable of delivering enough beam power for multi-user needs. Various possible designs are discussed.

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1. Introduction

High intensity proton accelerators are needed for many scientific and industrial applications such as: drivers for super- and beta beam facilities, the Neutrino Factory, muon colliders, production of neutrons or radioactive ion beams, incineration of radioactive waste and energy generation in accelerator driven subcritical reactor systems. Several installations delivering high power protons in the sub-MW range have been constructed around the world showing a path of very successful achievements. The high intensity proton installation should accelerate the beam to a final energy typically in a GeV to multi-GeV range. The conventional facility consists of a linear H^- accelerator followed by a storage ring or rapid cycling synchrotron (RCS), where the beam is accumulated by charge exchange injection and accelerated further in the case of the RCS. The RCS-based accelerator facilities are based on known and proven technology, but their repetition rate is usually limited to 50 Hz. Although this is usually sufficient to fulfil the needs of a single group of users working around a single target station, higher beam power would be needed for a multiple user facility with several target stations. This difficulty can easily be overcome in a linac-based driver, but the disadvantage is the substantially higher cost of the accelerator. In this paper the prospects for using FFAG (Fixed Field Alternating Gradient) accelerators as a high intensity proton drivers for a multi-user facility are described and various schemes outlined.

2. FFAG accelerators

The principle of the FFAG accelerator was invented in the fifties [1,2], but no proton accelerator was realized until 2000, when the POP machine [3] was commissioned at KEK. Since then several proton FFAGs have been constructed and a lot of research activity in this field is underway. FFAG accelerators are based on very strong focusing lattices, where the dispersion function is very small, which allows squeezing the particle orbit excursion to limit magnet size. Acceleration is possible without magnetic field ramp, as closed orbits exist for a momentum range typically a factor of 3 between injection and extraction. This allows a very high repetition rate, which is only dictated by the RF system.

There are two main types of FFAG accelerators, which differ in magnetic field geometry used to focus the beam:

- Scaling FFAGs were the first type invented and the only ones constructed to date. The magnetic field fulfils the law $B=B_0(R/R_0)^k$ and orbits for all momenta can be drawn by photographic enlargement. The machine tunes are independent of momentum by construction and nonzero chromaticity can only be generated by deviations from the scaling law. The constant working point for all momenta is particularly beneficial as beam does not cross betatron resonances. There are still two subtypes of scaling machines radial and spiral, which differ in the shape of the magnets used.
- In nonscaling FFAGs the scaling law does not apply and the working point usually changes with momentum. The interest for nonscaling machines lies in a possibility

of obtaining even smaller dispersion than in scaling ones, which allows for more compact magnet design. Linear nonscaling FFAGs were proposed for muon acceleration [4] in the Neutrino Factory. The magnetic fields in these machines contain only dipole and quadrupole components so the working point changes as these rings have a natural chromaticity. In the context of muon acceleration there is no danger of crossing multiple resonances as acceleration is finished within a few turns.

3. FFAGs for high intensity drivers

3.1 Possible scenarios

FFAG accelerators are very good candidates for potential high intensity drivers. They can easily obtain very high repetition rates not achievable by conventional synchrotrons and enable efficient acceleration by repeated passage through the same RF system in many turns. The parameters of a high intensity driver, which could serve a broad community of users, are shown in Table 1. Already a facility working at 100 Hz, twice the repetition rate of the usual RCS-based system could achieve twice as much beam power without changing the injection conditions. In addition, in contrast to RCS, a facility based on FFAG can be relatively easily upgraded to higher repetition rates increasing the energy gain per turn. Having this in mind it is easy to imagine the multi-user facility driven by an FFAG booster accelerator, which can deliver beam in parallel for different users. Fig. 1 shows a conceptual layout of the accelerator facility based on an FFAG, which can simultaneously serve two users with independent target stations. The disadvantage of FFAG accelerators is the limited ratio between injection and extraction momenta, which dictates a need to duplicate the machines in order to achieve the necessary final energy. Taking this into consideration in the design there is a choice between a facility based on a low energy linac (about 300 MeV) followed by two FFAG rings (shown in Fig.1) or one with a higher energy linac injecting into only one FFAG ring (shown in Fig. 2). In the latter case in order to achieve the energy sufficient for muon production (above 5 GeV) and assuming a linac of 800 MeV a momentum ratio of a factor 4 would have to be achieved in the FFAG.

Table 1: Parameters of a high intensity FFAG driver

Repetition rate	100–1000 Hz
Injection energy	300–800 MeV
Energy delivered to users	1–10 GeV
Accumulation method	H^- charge exchange injection
Beam power	1–10 MW

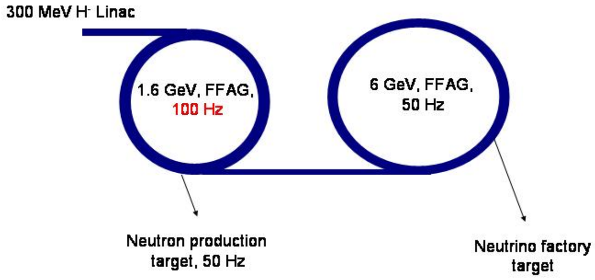

Fig 1: Layout of a multi-user facility based on two FFAG rings.

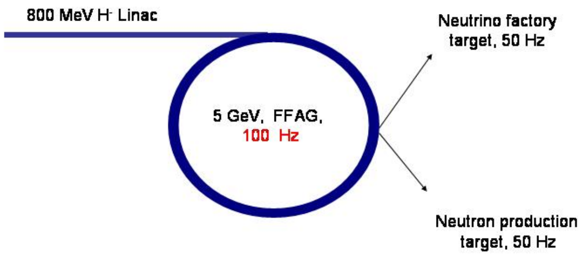

Fig 2: Layout of a multi-user facility based on a high energy linac and a single FFAG ring.

3.2 Lattice choice

Several designs have been proposed already using both scaling and nonscaling machines. The use of nonscaling machines requires the acceleration to be extremely fast and to be finished within about 100 turns. This fast acceleration can be realized in the proposed harmonic number jump scheme [4], but requires very high energy gain per turn. On the other hand slow acceleration in these machines leads to emittance blow up due to resonance crossing and hence is not suitable for high intensity drivers. Here we propose much slower acceleration in the lattice with the chromaticity close to zero without integer betatron resonance crossing. Acceleration in this machine requires RF with frequency modulation. This kind of machine can be realized either by a scaling FFAG or a nonscaling tune stabilized lattice. The scaling lattice is a very promising choice as chromaticity correction is achieved automatically by the scaling law keeping a very large dynamical acceptance. On the other hand the nonscaling lattice offers a possibility of obtaining a very small orbit excursion, which would allow for cost effective magnet design. In the nonscaling FFAG tune stabilization can be obtain by a careful introduction of nonlinear magnetic field components. The details of the chromaticity correction mechanism have to be worked out for every lattice separately. The tune stabilization mechanism in nonscaling FFAGs still remains to be studied in detail. Here we just sketch in Table 2 the parameters of a linear design of the nonscaling FFAG, which could serve as a starting point for a study. The betatron functions in one lattice cell are shown in Fig.3.

Table 2: Parameters of the nonscaling FFAG proton driver lattice

Lattice type	doublet
Number of cells	64
Machine radius	34.6 m
Magnet packing factor	0.4
Drift length	1.9 m
Tunes per cell (horizontal, vertical)	(0.26, 0.19)

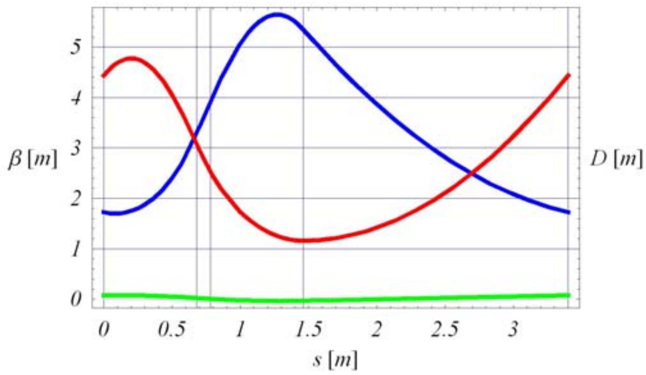

Fig 3: Betatron functions in a lattice cell for nonscaling FFAG proton driver.

4. Conclusions and future plans

FFAG accelerators are promising candidates for high intensity drivers. Although they have passed successfully the initial commissioning experiments there is still a long way towards a high intensity machine. A lot of essential topics like space charge dynamics in nonlinear FFAG lattices, injection and extraction, chromaticity correction in nonscaling machines, magnet design etc. remain to be addressed in future studies.

References

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