THE CONFORM PROJECT: CONSTRUCTION OF A NONSCALING FFAG AND ITS APPLICATIONS

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Abstract

The CONFORM project, recently funded as part of the UK 'Basic Technology' initiative, will build a 20 MeV Non-Scaling FFAG (EMMA) at Daresbury. The experience gained will be used for the design of a proton machine (PAMELA) for medical research, and other applications for Non-Scaling FFAGs in different regimes will be explored. The successful development of this type of accelerator will provide many opportunities for increased exploitation, especially for hadron therapy for treatment of tumours, and the project provides a framework where machine builders will work with potential user communities to maximise the synergies and help this to happen successfully.

BASROC

The British Accelerator Science and Radiation Oncology Consortium, BASROC, is an association aimed at developing hadron therapy in the UK from its present low state: there is only one facility in the UK, a 60 MeV cyclotron which, due to its low energy, can only be used for treating tumours in the eye.

The association crosses disciplines, containing accelerator scientists, particle physicists, engineers, medical physicists, and physicians. Its members come from universities, hospitals, research institutes (including both the new Accelerator Science Institutes) and from industry. Full details can be found on its website[1].

The UK lags behind other comparable countries in its provision of hadron (proton and carbon) therapy in large part due to internal resistance on the grounds of cost. Although the benefits of hadron therapy through the use of the Bragg peak to minimise damage to surrounding tissue have been well disseminated[2], the sum required to construct one hadron machine could pay for many conventional linacs for X ray radiotherapy, which can be sited at local hospitals rather than at a few large central facilities. The case for more provision will be greatly boosted if the cost and size of these facilities can be reduced.

The consortium realised that the use of the Fixed Field Alternating Gradient (FFAG) accelerator could provide such a reduction in size, cost and complexity, and that the non-scaling FFAG (nsFFAG) would enable even simpler and more compact machines to be operated. It was decided that the benefits were great enough to justify developing this type of accelerator as a way of providing the most cost-effective hadron treatment, even though no nsFFAG has yet been built.

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THE FFAG AND THE NSFFAG

The FFAG was invented (and abandoned) in the 1950s. It can combine the best features of a cyclotron and a synchrotron: it can accelerate particles to relativistic energies, but the bending magnets operate at constant current: the magnetic field does not vary with time (hence 'Fixed Field') but it does vary with space. As the particle gains energy and spirals outwards it moves to a region of higher field. This spatial variation also provides quadrupole fields for focussing (hence 'Alternating Gradient').

Although not suited to very high energy operations (which is why it lost out to the synchrotron), the FFAG has many features that make it attractive for medium-energy high current machines.

- The time taken to accelerate a particle to the full energy can be very short. It is limited only by the amount of RF power that can be provided to the particle bunches, and not by the cycle time of the magnets.
- The variation in the time for a full orbit varies only slowly with energy. As energy increases the period increases due to the extra path length and decreases due to the extra velocity. These changes are both small and have opposite sign, leading to minimal (perhaps zero) variation in the required RF frequency.
- This means that injection into the ring can proceed for many turns. The duty cycle is very high.
- The beam can be delivered at any desired energy by the extraction after the desired number of turns.
- The acceptance of the injected beam into the FFAG lattice is very large.
- The DC magnet power supplies are simpler and cheaper to build; some designs even envisage the use of permanent magnets.

The availability of high-energy high-current beams of protons (or other hadrons)has very attractive clinical benefits. Higher dose rates means that patients can receive the required dose in fewer treatment sessions. If a tumour is in a part of the body which is naturally in motion (e.g. through breathing) then with many available pulses the patient does not have to be rigidly restrained; pulses which arrive when the patient is in the wrong position can be diverted magnetically.

Beams of varying energies are needed to target tumours of varying depth in the body. Extraction at the desired energy avoids the necessity of an expensive system of 'energy degraders' which can themselves produce dangerous secondary radiation.

The successful operation of proton FFAGs in Japan has encouraged their consideration for other uses. However the current designs involve a large increase in orbit size during acceleration, and the magnets are large. This lacks the compactness and low-cost that we need for their adoption in the medical community.

Recently, a new type of FFAG, the Non-Scaling FFAG was proposed[3]. These have much higher field gradients from simple magnets. They are therefore compact and cheap. This is gained by abandonment of the 'scaling' principle of classical FFAG designs, which fixed the betatron tune during the acceleration process. The fact that the tune changes during acceleration means that integer-tune and many other higher order resonances cannot be avoided. However the acceleration process is sufficiently rapid in these machines that the passage through the resonance is fast, and successive perturbations should not have the opportunity to add coherently to a dangerous level.

These assertions requires testing before a large programme is embarked on. Simulations cannot give a satisfactory guarantee, as we lack a collection of established well-benchmarked simulation tools for machines of this type, and because of the difficulty of accurately establishing what 'small' perturbations in a lattice may exist until a machine is built.

The time behaviour of the nsFFAG also goes into new territory. The rapid acceleration means that each turn is different from the last, and conventional small-perturbation treatment of synchrotron oscillations may not be reliable.

The consortium therefore proposed a 3 part programme. To build a proof-of-principle machine for the nsFFAG, to design a proton machine suitable for clinical use, and to explore other possible applications.

THE CONFORM PROJECT

The consortium formed a project known as CONFORM (Construction Of an NsFFAG For Oncology, Radiation and Medicine) [4]. This is a subset of the whole consortium, and will hopefully serve as a model for future projects.

The CONFORM group made a proposal to the Basic Technology Research Programme, a scheme that crosses the different funding agencies to "contribute to the development of a generic technology base that can be adapted to a diverse range of scientific research problems and challenges."

The bid to the program was successful, and £8M was awarded over a period of 3.5 years.

THE CONSTRUCTION OF EMMA

The Electron Model with Many Applications, EMMA, is a machine concept which has been around for some time and is much discussed at this conference [5, 6, 7, 8]. It is designed to accelerate electrons from 10 to 20 MeV, using 42 sectors each comprising a pair of short quadrupoles (F and D) which provide the focussing. The beam goes through these off axis, which provides the net bending.

EMMA will be sited at Daresbury laboratory, and will use the ERLP (Energy Recovery Linac Prototype) as an injector. RF will be provided so that the acceleration can be completed in as little as 16 turns. The ring will be heavily instrumented so that the machine behaviour can be studied.

The project involves the final design, construction and commissioning of EMMA, and its operation to investigate the behaviour of an nsFFAG in the relativistic regime. The stability and behaviour of betatron and synchrotron oscillation will inform the machine physicists and enable them to design the next generation of machines with confidence.

Most of the award (£5.6 M) is going to the construction of EMMA. Staff costs are the largest item, at £1.8 M, followed closely by £1.6 M for the RF. The use of existing infrastructure at the Daresbury laboratory helps greatly in reducing these numbers.

Broadly speaking the project envisages a year finalising the design, a year in construction, and a year in commissioning. The project started on 1st April 2007, and already prototypes for the magnets have been ordered. Although the design had been proposed previously[9] and might justifiably be considered mature, when actual construction was proposed considerable work turned out still to be needed, particularly in the injection and extraction systems.

THE DESIGN OF PAMELA

EMMA is purely for research. The next stage is to build a machine which will explore the possibilities for proton and ion acceleration, in the more difficult non-relativistic region, and is also useful. PAMELA (Particle Accelerator for MEdicaL Applications) is such an accelerator.

The parameters are not yet settled but will probably involve a machine with three concentric rings, delivering a range of beams from protons to carbon nuclei. The first stage will take low energy particles from a cyclotron or RFQ and accelerate them up to an intermediate energy: 70 MeV protons would be desirable as these beams could be used for interesting studies on small mammals. A second ring would accelerate protons up to the 250 MeV needed for a complete proton therapy system. The final ring would serve to bring Carbon nuclei up to the 400 MeV necessary for clinical use.

The design of PAMELA will take place in step with the design and construction of EMMA, building on the experience gained during the project. This simultaneous approach, rather than waiting till EMMA proves the nsFFAG principle before committing further resources, is a risk, but is essential if we are not to lose time. At the end of the project we will have a proven and costed design, that could be built in stages with a useful machine at each stage. This can then be presented to the medical funding agencies, seeking funds to build it on a site where it could be used for clinical treatment as well as research.

THE APPLICATIONS PACKAGE

To inform the design of PAMELA we need a better knowledge of the effects of charged particle radiation on healthy and diseased tissues. It is now possible to study the effect of single hits on individual cells and develop a more detailed understanding of radiation damage effects than was obtainable from earlier studies. (This is also relevant to our understanding of dangers from radiation exposure.) The consortium is therefore pursuing these studies, using the light ion facility at the University of Surrey.

Although we have stressed hadron therapy as an application, there are many other potential applications for accelerators with the characteristics of the nsFFAG (medium-energy, high current, high acceptance, and high duty cycle). Members of the consortium are investigating their use for

- Proton drivers for future spallation neutron sources and muon facilities for spin rotation and relaxation, used in condensed matter studies.
- Neutrino Factories - they may be useful for the proton driver and they are certainly essential for the muon acceleration system, which must raise muons to relativistic speeds in less than their 2 microsecond mean lifetime.
- Accelerator Driven Subcritical Reactors where the efficiency of an FFAG will increase the net power from these inherently safe reactors, and their simplicity lends itself to the reliability required for commercial power generation.

CONCLUSIONS

This cross-disciplinary grouping has produced a project which is a big step forward for both accelerator science and medical physics. This is not intended to be the only project: the group is open to new ideas and to new participants, and interested parties should investigate the website and approach us.

REFERENCES

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