

DESIGN OF MULTI-MW RAPID CYCLING SYNCHROTRON FOR ACCELERATOR DRIVEN TRANSMUTATION SYSTEM *

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Abstract

For the practical application of Accelerator Driven System (ADS) that reduces the harmfulness of radioactive waste by nuclear transmutation, we are studying the development of a compact accelerator using a synchrotron as an accelerator capable of supplying a stable proton beam to a nuclear reactor. In this research, we aim to realize high efficiency and high reliability ring by adopting an alternating high temperature superconducting magnet and a high repetition synchrotron applying resonant beam extraction. In this paper, we report the fundamental design of the rapid cycling synchrotron.

INTRODUCTION

Treatment of spent fuel generated after nuclear reactor operation is a challenge to be solved globally. To reduce the amount of high-level radioactive waste, partitioning and transmutation of minor actinides (MA) has been studied for decades [1]. One of the promising transmutation technology is Accelerator Driven transmutation System (ADS). The ADS consists of a high-intensity proton accelerator, a spallation target and a subcritical reactor core where the MAs are loaded [2].

One of the inherent issues to operate ADS is beam-trip problem. When beam trips occur, the temperature of the reactor may fluctuate. This temperature fluctuation can cause thermal fatigue in ADS components, and reduce the lifetime of the system. The beam trip frequency of the superconducting linac for driving the ADS was estimated based on the operation data of the existing accelerator and the estimation result was compared with the allowable beam trip frequency calculated from the thermal analysis [3]. From the result of this study, it was shown that the beam trip frequency, especially for longer beam trip (> 5 minutes), is necessary to reduce down to about 1/35 of that for the existing accelerator facilities.

According to the statistics in Ref. [3], the most dominant cause of the longer beam trip is trouble of RF systems. Based on this result, the ADS so far has assumed the use of linear accelerators as high intensity accelerators, but this choice can be a serious problem. Since the linear accelerators consist of large number of RF systems, it seems to be difficult to reduce the total number of down time having the longer duration. To overcome this problem, circular accelerators can be promising candidates for ADS drivers. In the case of using

a circular accelerator, the number of high frequency power supplies would be smaller than that of a linear accelerator, so it is possible to construct a system with a low possibility of beam stop. On the other hand, for use of the circular machines in the ADS, it is a problem that the circular accelerators have lower beam current that can be generated per unit than the linear accelerator and the power consumption of the bending magnets is large. The problem of the lower current can be effectively increased by improving the output current per ring and parallelizing the accelerator system, and the power consumption of the electromagnet can be suppressed by the superconducting technology.

RAPID CYCLING SYNCHROTRON FOR ADS

As discussed in the previous section, circular accelerators have the advantage of having less number of RF system in accelerator complex, and may be suitable for the use as ADS proton drivers. Among the various kind of circular accelerators, such as cyclotron, synchrotron and FFAG synchrotron, we have chosen Rapid Cycling Synchrotron (RCS). Although the RCS has fast ramping magnets and its operation is complicated, it can provide high energy (above 1 GeV) proton beam and the high power beam acceleration has already been realized. The beam energy above 1 GeV is important for the mitigation of the heat deposition into the beam window material, since the energy loss of high energy proton beam in material has minimum value around a few GeV region of projectile beam energy [4]. The 1-MW beam acceleration has been achieved with 3 GeV RCS successfully [5], in J-PARC [6]. If the RCS with larger repetition rate, such as 100 Hz, is developed, available beam power can be increased to multi-MW per single RCS ring. By using several such RCS accelerators in parallel and merging the beam from the accelerators, it is possible to sufficiently satisfy the beam power required for the ADS.

BASIC PARAMETER OF THE RCS

In this research, an RCS is designed for an ADS proton driver. As the prototype of the driver machine, beam power was set to The beam power was set to 1.5 MW. Although this value is insufficient for practical use in the full-scale ADS, it is larger than the present high-power accelerators and sufficient for proof-of-principle experiments with smaller-scale ADS reactors.

The prototype RCS design parameters are summarized in Table 1. Proton beam is injected with 100 MeV energy and accelerating up to 1.5 GeV. The injection energy was chosen

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Table 2: Designed Lattice Parameters

Parameter	Combined Function	Separated Function
symmetry	4	4
maximum flux density in bending magnets [T]	1.40	1.47
curvature radius [m]	5.36	5.09
circumference [m]	68.9	107.2
number of bending magnets	32	16
bending angle per magnet [degree]	11.25	22.5
length of a bending magnet [m]	1.053	2.000
number of long straight section	4	8
length of long straight section [m]	6.00	5.00
momentum compaction factor	0.09	0.08
chromaticity after compensation	(-1.25, 0)	(-0.63, 0)

designed lattice was designed, respectively. Utilizing the accelerating cavity loaded magnetic alloy cores, the beam accelerating voltage up to 200/400 kV per turn would be achieved, for the combined/separated function lattice. With such a high voltage accelerating structures, beam acceleration including adiabatic capture can be done in the time shorter than 5 ms. Without the adiabatic capture, more fast beam acceleration or more low voltage operation of beam accelerating structure can be realized.

Detailed operation methods such as whether to use charge exchange injection and beam structure from the injector are not decided at the present moment, but the optimal operation pattern will be studied.

CONCLUSION

In order to construct reliable nuclear transmutation system, a Rapid Cycling Synchrotron was proposed for ADS proton driver. Increasing the repetition rate of acceleration up to 100 Hz, multi-MW beam power would be achieved. As the prototype of the machine, design of an RCS with 1.5 MW beam power is carrying out. In order to achieve the requirement for ADS drivers in terms of energy efficiency and reliability, application of AC superconducting technology and beam extraction with betatron resonance.

The RCS lattice was designed with combined function magnets and separated function magnets, respectively. The lattice with these magnets have advantages and disadvantages, so it is difficult to declare which one is better so far. In the near future we will design more detailed accelerator system.

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