THE KOMAC PROJECT: ACCELERATOR AND TRANSMUTATION PROJECT IN KOREA

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Abstract

The KOMAC (Korea Multi-purpose Accelerator Complex) project at Korea Atomic Energy Research Institute is to develop and build a high current proton/H^- linear accelerator capable of delivering a 1 GEV cw proton beam with an intensity of 20 mA in the final stage. The KOMAC accelerator, scheduled to be completed in 2006, will be used to support emerging nuclear research, including studies on nuclear transmutation and energy production, basic neutron and muon sciences, industrial uses, and medical applications. The study has focused on the realization of continuously sharing and extracting the beam of 100 MeV and 260 MeV at two different stages of the accelerator for low beam current applications and the beam of 1 GeV at the end of the accelerator for multiple purposes. Also, many efforts are devoted to investigating the cw-mode operation. The superconducting structure is considered a major option for development in effort to reduce operating costs and machine size for a future hybrid system. The design works are being carried out in collaboration with national institutes and universities in Korea. The project is scheduled to develop an injector, RFQ, and CCDTL in the first phase from 1997 to 2001. In the second stage from 2002 to 2006, the machine will be completed. In parallel, the transmutation technology development project HYPER (Hybrid Power Extraction Reactor) is being carried out at KAERI.

1 INTRODUCTION

Korea Atomic Energy Research Institute (KAERI) is proposing to build a 20 MW (1 GeV and 20 mA) cw (100% duty factor) proton linear accelerator under the Korea Multi-purpose Accelerator Complex (KOMAC) program. The key element of the KOMAC design is to accelerate both H^+ and H^- to 1 GeV while partially extracting H^- at 100 and 260 MeV. The major H^+ beam (18 mA and 1 GeV) will be used for nuclear-waste transmutation, energy production, and nuclear physics experiments while utilizing the minor H^- beam (2 mA) for basic science research and medical therapy. Specifically, the 1 GeV H^- beam will be used for the production of π and μ beams. The 100 MeV beam will be used for fast neutron generation, proton-therapy of eye melanomas (60-70 MeV), solar proton studies, and nuclear data. We will utilize the 260 MeV beam for deep-sited tumor therapy. We are planning to extract the partial (0-100%) beam by employing either a magnetic stripper or a laser. KAERI has full responsibilities for coordinating and managing the collaboration consisting of two laboratories (KAERI and PAL) and two universities (SNU and KAIST) and ultimately operating the KOMAC. In addition, KAERI initiated HYPER (Hybrid Power Extraction Reactor) project which may open new horizon for nuclear industry in Korea. Currently the spent nuclear fuels are becoming a bottle neck for the peaceful use of nuclear energy. The HYPER project is expected to provide a breakthrough to the current stagnant situation that the nuclear industry is facing with.

Table 1: NC Low-Energy Linac Parameters.

Parameter	RFQ	CCDTL1	CCDTL2
Frequency (MHz)	350	700	700
Input/output Energy (MeV)	0.05/3	3/20	20/100
Input/output Current (mA)	23/20	20/20	20/20
Transmission (%)	94.5	100	100
Average gradient (MV/m)	-	0.57	0.85
Length (m)	3	29.8	94.2
Synchronous phase (deg)	-(90-30)	-(60-30)	-30
Quadrupole lattice period	-	8 $\beta\lambda$	8 $\beta\lambda$
No. of quadrupoles	-	130	173
Quadrupole G · L prod. (T)	-	2.6	2.6
Trans emitt. (π mm-mrad)*	0.2/0.23	0.32	0.32
Long emitt. (π deg-MeV)*	0.246	0.57	0.60
Aperture-radius (mm)	2.4-3.6	5-7.5	10
Aperture-radius /rms-beamsize	-	4-6	8
Copper rf losses (MW)	0.328	1.15	3.43
Total rf power required (MW)	0.396	1.49	5.03
Power per klystron (kW)	750	1000	1000
Number of klystrons	1	2	6

* Normalized rms values.

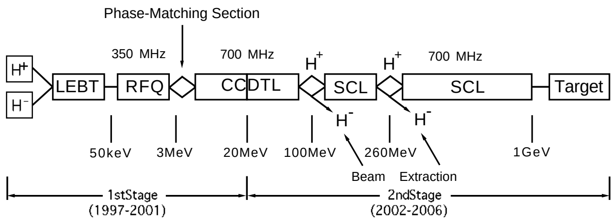

Figure 1: Schematic layout of the KOMAC linac.

2 ACCELERATOR

Since KOMAC is adopting both H^+ and H^- beams, the alignment is a crucial issue as the two beams deflect toward two different directions with a steering magnet. We are considering an independent alignment of both beams at several different places: injector region (50 keV), phase-matching section (3 MeV), and beam-extraction regions (100 and/or 260 MeV). The proposed KOMAC-linac configuration is shown in Fig. 1. The low-energy part is a normal-conducting (NC) linac which consists of an injector, RFQ, and CCDTL to achieve cw operation while the high-energy portion is a super-conducting linac (SCL) employing niobium cavities. The NC low-energy linac parameters are shown in Table 1. The SCL parameters are listed in Table 2. In the first stage (1997-2001), the NC linac up to 20 MeV CCDTL will be completed. The completion of KOMAC including the target is expected in 2006.

2.1 The Ion Source

Duoplasmatron H^+ ion source has been built at KAERI. It has a peak current of 30 mA with a normalized 90% emittance of 0.5 mm-mrad. Korea Advanced Institute of Science and Technology (KAIST) is responsible for designing H^- ion source. KAERI is responsible for an injector delivering both H^+ and H^- beams to 50 keV.

2.2 Radio-frequency quadrupole (RFQ)

The Pohang Accelerator Laboratory (PAL) is responsible for the 350 MHz RFQ, which accelerates 50 keV H^+/H^- up to 3 MeV. The total length is designed to be 3 m with a minimum aperture radius of 2.4 mm. Full-current beam acceleration will require 68 kW and because of rf power losses on the interior surfaces, we will need total power of 396 kW.

2.3 Phase Matching Section

We need a phase matching section after RFQ for H^- since the frequency of CCDTL becomes 700 MHz. This section will also be used as an alignment steer (two beams can be aligned independently). Of course we need a set of quadrupoles and bunchers for transverse matching.

2.4 Coupled-cavity, drift-tube linac (CCDTL)

KAERI is responsible in developing CCDTL, which combines the features of conventional DTL and CCL. The CCDTL will accelerate 3 MeV H^+/H^- to 100 MeV. The benefit of CCDTL is a reduction in the cost of DTL since the quadrupole magnets are located outside the accelerating cavities. It is also easy to fabricate and install it on the structure without breaking vacuum. The length of the CCDTL accelerating beam of 3 MeV to 20 MeV is 29.8 m with the total power of 1.49 MW. However, we consume 12 m of length for an energy gain of 5 MeV, so we are doing a trade-off study by replacing the first part of CCDTL with a longer RFQ. In the first phase (1997-2001) of developing KOMAC, the first part of CCDTL will be fabricated to deliver the beams to 20 MeV. In the second stage, 94.2 m CCDTL will accelerate the beam to 100 MeV.

2.5 Beam Extraction

We are planning a partial extraction of H^- beam at both 100 and 260 MeV energy regions. A magnetic-stripping[1] study shows that the threshold field of stripping an electron at 100 MeV is 1 T and one for 260 MeV is 0.8 T. This means that the steering-magnet field should be lower than the threshold field. The study also shows that a super-conducting (SC) magnet ($\sim$2.5 T) would be required for stripping a substantial fraction (50%) of H^- beam at 100 MeV. For the 260 MeV beam, a NC magnet would do the job well. Emittance growth is an unavoidable feature if we employ a stripper magnet for beam extraction. We are currently studying the feasibility of producing a smaller emittance in horizontal direction by designing a magnet with a very sharp peak-field. We will consider the laser extraction if the beam divergence is too large to handle.

2.6 Super-conducting linac (SCL)

Seoul National University (SNU) is responsible for the super-conducting linac. Compared with the normal-conducting (NC) cavity, a super-conducting (SC) cavity reduces the required rf power as well as operating and capital costs. It also allows a much larger aperture with the same gradient to reduce the beam loss. We have three designs of SC cryomodules. From 100 MeV to 140 MeV, the cavities are optimized at β = 0.45, and from 140 MeV to 260 Mev, at β = 0.53, and in the section above 260 MeV, at β = 0.71. The cryostats contain four 4-to-6-cells 700 MHz niobium cavities. The transverse focusing is done by doublet quadrupoles located outside the cryostat.

3 TRANSMUTATION

In order to provide a type of solution for spent fuel problems, KAERI launched a research project called HYPER (HYbrid Power Extraction Reactor). The HYPER project is scheduled to develop a transmutation system in conjunction with the KOMAC program. Fig. 2 shows the schematic relationships among systems when they are integrated. The whole development schedule of the HYPER system is subdivided into two phases. The basic key technologies are scheduled to be developed in Phase I (1997-2001) and a

Table 2: SC High-Energy Linac Parameters.

Parameter	SCL1	SCL2	SCL3
Frequency (MHz)	700	700	700
Optimized β	0.45	0.53	0.71
Input/output Energy (MeV)	100/140	140/260	260/1000
Input/output Current (mA)	20	20	20
# of cells per cavity	6	5	4
# of cavities per cryostat	4	4	4
# of cryostats	4	12	74
Average gradient (MV/m)	1.64	1.64	1.64
Peak Surface field (MV/m)	< 18	< 18	< 18
Length (m)	24.4	73.2	451.4
Synchronous phase (deg)	-30	-30	-30
No. of doublet quads	4	12	74
Trans emitt. (π mm-mrad)*	0.32	0.32	0.32
Long emitt. (π deg-MeV)*	0.60	0.60	0.60
Aperture-radius (mm)	40	45	60
Aperture-radius /rms-beamsize	32	36	48
Coupler power (kW)	50	50	50
Power per klystron (kW)	1000	1000	1000
Number of klystrons	1	3	19

* Normalized rms values.

small bench scale test facility (~5 MWth) is to be designed and built in Phase II (2002-2006).

3.1 Phase I (1997-2001)

Phase I is divided into two steps; the first one is the preliminary step from 1997 to 1998 and the second one is the key technology development step from 1999 to 2001. In the first step, many basic calculations and data surveys are to be conducted to confirm and develop the following issues:

1. Motivation for HYPER system research: The HYPER system development will require a lot of research funds and manpower. In order to acquire the necessary financial support, more investigation and evaluation will have to be assigned to the system development motivation.

2. Preliminary system concept: No specific system configuration has been set up yet. Many research activities are being done to decide on the basic design requirements the HYPER system must meet[2, 3]. Based on the design requirements, the preliminary system configuration such as fuel type, cooling method and material selection, etc, are supposed to be determined.

3. Development strategy: A type of WBS (Work Breakdown Structure) for each major technical field (fuel, cooling, target system) will be produced and key technologies will be needed to be developed and confirmed for each field. International collaboration will be very effective in developing the key technologies.

In the second step, key technologies derived in the first step will be proved through experiments. A material test for the selected coolant, an irradiation test for the fuel and a spallation target test are the major experiments KAERI is considering. After the experiments on an individual component basis are completed, the whole integrated system experiments will be performed to confirm the interfacial behavior between the components under non-radioactive condition.

3.2 Phase II (2002-2006)

Phase II will start under the condition that the Phase I research produces successful results. Therefore, a complete review will be performed within KAERI and the government just after Phase I. The expected major activities are: 1) developing a theoretical model to analyze coolant system behavior, fuel system behavior, and physics behavior for the system design based on the experiments conducted in Phase I, 2) performing detail design for the bench scale facility, 3) constructing a small scale facility, 4) conducting a system safety analysis to obtain construction and operating permission from the regulatory body.

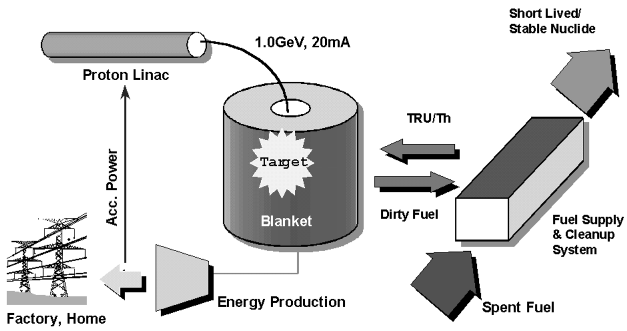

Figure 2: HYPER system concept.

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