ADS INJECTOR I FREQUENCY CHOICE AT IHEP

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Abstract

The China ADS driver linac is composed of two major parts: the injector and the main linac. There are two frequency choices for the injector: 325 MHz and 162.5 MHz. The former choice is benefit for the same frequency with the front end of the main linac. For half frequency choice, to obtain the same longitudinal acceptance of the main linac comparing with 325 MHz injector, the tune depression of the beam reaches the lower design limit of 0.5, no current upgrade opportunity is reserved; contrarily to get the same space charge effect, 16 more cavities would be the cost to get the same acceptance. However the disadvantage of the 325 MHz injector choice is the bigger power density of the copper structure CW RFQ and the smaller longitudinal acceptance of the SC section. The details of the comparing for the two frequency choices are introduced and presented.

INTRODUCTION

The China ADS driver linac is proposed to accelerate the CW proton beam up to 1.5 GeV with average beam current of 10mA. It consist two major components: the injector and the main linac as shown in Fig. 1. The injector part accelerate beam up to 10 MeV. The main linac boosts the energy from 10 MeV to 1.5 GeV. The injector is composed of an ECR source, a LEBT, a four vane type copper structure RFQ, a LEBT and a Superconducting (SC) linac. The MEBT1 undertakes the matching between the RFQ and SC section. There are two design strategies for the injector. Injector I scheme is on basis of 325 MHz RFQ and β=0.12 SC spoke cavity with same frequency. Injector II scheme is on basis of 162.5 MHz RFQ and SC Half Wave Resonator (HWR) structure with same frequency. Injector I scheme is benefit for the same frequency with the front end of main linac while Injector II has a frequency jump.

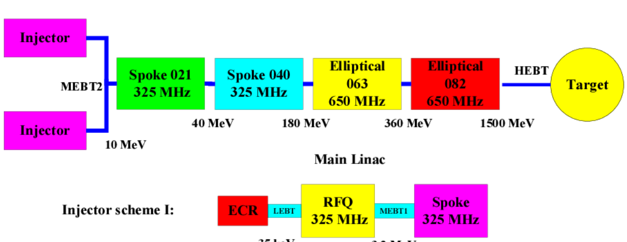

Figure 1: The general layout of the ADS linac in China.

*Work supported by Chinese Academy of Science (CAS) strategic Priority Research Program-Future Advanced Nuclear Fission Energy (Accelerator-Driven Sub-critical System).
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The frequency jump has effects to the linac design on two aspects. On the one hand, 325 MHz choice is benefited for attenuated space charge effect comparing with half frequency if the longitudinal beam size out of injector kept the same for both frequency choices. The space charge effect is very crucial for the ADS applications (with final beam power of MW magnitude). Because nonrelativistic proton beam with stronger space charge effect is more sensitive to the mismatch and has bigger possibility inducing parameter/structure and coupling resonances and finally leading to halo growth and particle losses. Although space charge effect for 10 mA average current is not so strong, higher current upgrading opportunity is necessary to be kept for the future power upgrading.

On the other hand, if keeping the space charge effect to be the same, the longitudinal beam size out of the injector has to be increased for the 162.5 MHz choice. Bigger longitudinal beam size means more cavities numbers. To keep the same acceptance, the 325 MHz choice is benefit for less cavities leading to less cost at the whole downstream linac. However there are also drawbacks for the 325 MHz RFQ and SC linac of the injector. Finally 325 MHz is adopted for the ADS injector I at IHEP. The advantages and disadvantages of this choice will be introduced.

ADVANTAGES

The utmost design goal of a high intensity linac is controlling the beam loss along the linac as low as possible. The commonly acceptance of the beam loss rate is 1 W/m considering hands on maintenance. The higher the final beam power is, the more challenging to realize it. For China ADS project, the designed beam power on target is 15 MW, this means that the particle loss rate has to be controlled down to the magnitude of 1×10^{-8} /m at high energy part, this request is much higher than existing high intensity accelerators. To control the beam loss in design stage, on the one hand is keeping big enough acceptances. On the other hand is choosing a reasonable range for the tune depression of the beam.

Space Charge Effect

One important design principle for high current linac is to keep the tune depression of the beam bigger than 0.5 [1-2]. If half frequency is chosen for the China ADS injector, the particle charge in one bunch would be doubled under the condition that the longitudinal beam size keeping the same. For different average currents, the tune depressions are calculated for two different frequencies as shown in Table 1 on basis of the first SC

ISBN 978-3-95450-168-7

cell of the 325 MHz Injector I design. Noteworthy the tune depression kept almost the same along the whole linac. The detail formulas for the tune depression calculation and Injector I design can be found in ref. [3]. The nomalized rms emittance out of 325 MHz RFQ are 0.20/0.16 mm.mrad transverse and longitudinally. From the table we can tell that, for 10 mA, the space charge effect is not so strong but already sited in the space charge dominated region at 325 MHz, but for 20 mA, the tune depression is already approaching the lower limit of ~0.5. From this table we can conclude that, the 325 MHz choice still have opportunity for upgrading to 20 mA, but it is not possible for the half frequency choice if the beam size is not expended.

Table 1: The tune depression of the first cell of Injector I SC section for different average beam current

Average current	325 MHz		162.5 MHz	
	Long.	Trans.	Long.	Trans.
10 mA	0.67	0.64	0.51	0.48
20 mA	0.51	0.48	0.37	0.33
30 mA	0.43	0.39	0.29	0.26
40 mA	0.37	0.33	0.25	0.22

To further investigate the space charge effect on the beam performances, the emittance growths for different beam currents with same main linac design are analyzed using the output parameters of the 325 MHz Injector I design. 30% normalized RMS emittance growths are assumed for the MEBT1-Injector I-MEBT2 section (from the exit of RFQ to the entrance of the main linac). Parabolic distributions are used as the entrance of the main lianc. The basic main linac design is published in ref. [4]. It is re-matched for different average current and the halo parameters are always kept below one to ensure a good match. TraceWin [5] program is used for the beam dymaics.

The normalized RMS emittance growth are around 5% for 10 mA and 20 mA designs but is doubled for 30 mA as shown in Fig. 2. Although few percent is commonly accepted normalized emittance growth for high intensity proton linac, 10% is still acceptable. However the maximum normalized emittance grows significantly with 30 mA average current (around 280%) while below 60% and 45% for 20 mA and 10 mA respectively as shown in Fig. 3. Similar results are obtained for the emittance growths with 99.9% & 99.99% particles. From the figure we can tell that the halo particles are still controllable for 20 mA design, but not for 30 mA. Noteworthy all the simulations are based on matched beam, situation would be even worse if mismatch factor is introduced. The tune depression for 30 mA with the injector frequency of 325 MHz is the same with 20 mA of 162.5 MHz, the beam dynamics performance would be similar.

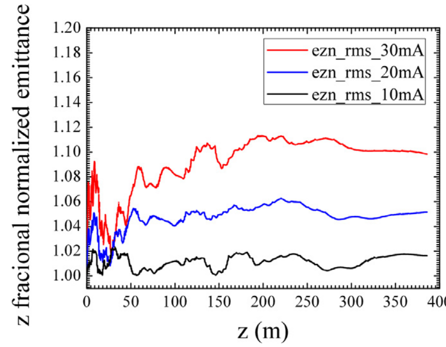

Figure 2: Longitudinal normalized rms emittance growths of the main linac basic design with different average beam current on basis of Injector I scheme.

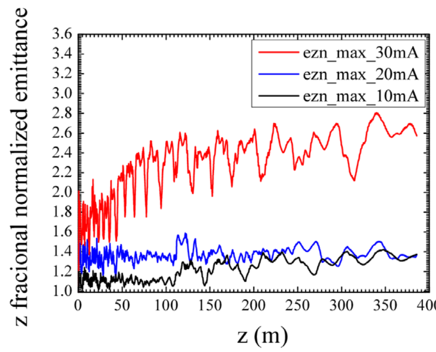

Figure 3: Longitudinal normalized max. emittance growths of the main linac basic design with different average beam current on basis of Injector I scheme.

Acceptance

To attenuate the space charge effect for the beam with 10 mA at 162.5 MHz and get the same tune depression, the longitudinal emittance out of RFQ has to be increased up from 0.16 mm.mrad to 0.28 mm.mrad. Adding additional 30% emitance growth from the exit of RFQ to the end of the SC section of the Injector, the emittance at the entrance of the main linac would be 0.36 mm.mrad. Obviously, for the same main linac design, the acceptance would be smaller. Figure 4 shows the main linac longitudinal acceptance with beam frequency of 325 MHz at the entrance of the main lianc. The acceptance emittance ratio is 22.7/0.21=108. It is lowered down to 63 times of the rms normalized emittance for the entrance beam with frequency of 162.5 MHz.

ISBN 978-3-95450-168-7

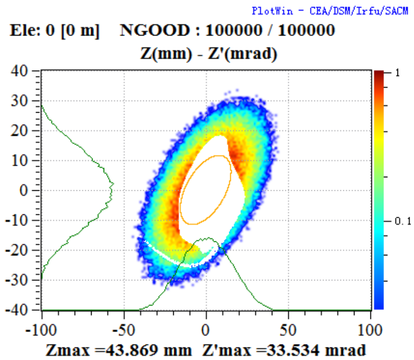

Figure 4: The main linac acceptance with entrance beam of 325 MHz, the yellow circle area in the figure is proportional to the entrance beam size.

To increase the acceptance, the absolute value of the synchronous phase for the main lianc has to be increased up. But in the mean while the longitudinal zero current phase advance cannot go beyond certain value (usually 90°). For the first few cells of the main linac, the accelerating gradient cannot be fully exploited because of the longitudinal phase advance constrain. If increasing the synchronous phase (absolute value), the cavity gradient has to be lowered down further. But to avoid the multipacting of the cavities, the cavity field level cannot be smaller than 50% of the nominal design. Two main linac designs with 325 MHz entrance beam with the entrance longitudinal rms normalized emittance of 0.2 mm.mrad and 162.5 MHz beam with 0.35 mm.mrad emittance are carried out on basis of two injector design schemes. The detailed design can be found in reference [4]. For the main linac design on basis of half frequency injector scheme with bigger longitudinal beam size, totally 16 cavities more and 28m long have to be added comparing with the nominal main linac design with 325 MHz. The total additional cost is around thirty million chinese dollars considering the fabrications and the maintenance cost is not included.

INJECTOR I DESIGN

The schematic layout of the 10MeV injector I test stand in IHEP is presented in Fig. 5. The 35 keV proton beam from the ion source is bunched and accelerated to 3.2 MeV by a 325 MHz RFQ. The SC section accelerates beam from 3.2 MeV up to 10 MeV employing β=0.12 Spoke cavities with the same frequency. Detailed design can be found in reference [3].

While operating on CW mode, the biggest issue of the copper structure RFQ is the power dissipation. For the copper structure RFQ, the power density has close relationship with frequency (f). The power dissipation is proportional to $f^{3/2}$ while the aperture is inverse proportional to f . For same cavity length, the power density would be 5.7 times bigger for 325 MHz RFQ than half frequency. This is a big challenge both for the CW RFQ and the power coupler. However, up to now, the 325 MHz RFQ is under conditioning, the maximum duty factor record during the conditioning is 99.96%. 92% beam transmission has been achieved with 90% duty factor from the entrance of RFQ to the exit.

Another disadvantage for the 325 MHz choice is the acceptance of the Injector I SC linac. The longitudinal acceptance is determined by the maximum accepted phase spread φ and maximum accepted energy spread ΔW_{max} . When the acceleration rate is small, $\varphi \cong 2\varphi_0$ (φ_0 : synchronous phase), $\Delta W_{max} \propto 1/\sqrt{f}$ [6]. Under these conditions, it is obvious that, if the longitudinal beam size for the beam out of 162.5 MHz RFQ is not twice bigger and if the accelerating gradient has no pronounced lift for 325 MHz Spoke cavities, the acceptance for the 325 MHz Spoke SC section is smaller than 162.5 MHz SC section.

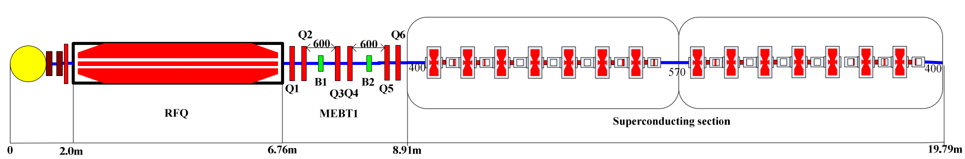

Figure 5: The schematic layout of the 10 MeV Injector I in IHEP.

CONCLUSION

Although much bigger power density of the CW RFQ and smaller longitudinal acceptance of the SC section of the Injector, 325 MHz is chosen for the Injector I design in IHEP for attenuated space charge effect leading to more opportunity of current upgrade, less possibility of halo growths and less cost for the whole main linac design. Up to now, 90% duty factor has been achieved with 92% beam transmission from the entrance of the 325 MHz RFQ to the exit, the conditioning of the RFQ is still undergoing. For the SC section, same longitudinal acceptance could be achieved if the 325 MHz Spoke cavity can reach higher gradient than half frequency HWR cavities as expected.

ACKNOWLEDGMENT

The authors express their sincere acknowledgement to the colleagues in the ADS accelerator team and especially the beam dynamics group for their comments, suggestions and discussions. Special thanks are expressed to Dr

Xiaoyu Wu from MSU and Dr Zhihui Li from Sichuan University for their profit suggestions during and beyond the review.

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