S-BAND COMPACT X-RAY SOURCE WITH π/2 MODE ELECTRON LINAC

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Abstract

The compact X-ray source activity is gaining more attention due to vast applications in medical field. We propose to make a Laser Undulator Compact X-ray source (LUCX) using technology existing at KEK. The linear accelerator (linac) for electron acceleration will be π/2 mode standing wave side coupled S-band linac developed at SAMEER in India. Accelerator Test Facility (ATF) KEK type RF gun will inject bunches of electrons in the SAMEER type side coupled linac to accelerate and achieve high energy, low emittance beam. This beam will then interact with the laser in Laser cavity to produce X-rays by Inverse Compton Scattering process which can be used for various applications. Details of ATF RF gun, SAMEER linac and KEK Laser cavity chamber are listed in the paper. The use of side coupled structure will make the system more compact and π/2 mode operation will make high repetition rate operation possible there by increasing the Compton X-ray yield.

INTRODUCTION

SAMEER has developed a 15 MeV S band standing wave side coupled compact linear accelerator. The main parameters of the linac are tabulated in table 1. The design and development work was carried out to achieve 80 mA peak current at 15 MeV energy [1] [2] [3] [4]. The flange to flange length of the linac is 112 cm. A 5.5 MW Klystron is used as an RF power source at 3GHz frequency. The linac tube was successfully tested on the test bench and gives a high current of 80 mA with 6 μs pulse width. The repetition rate was 166 Hz.

If we use 15 MeV beam to produce X-rays the resultant spectrum will be broad band and hence the x-rays can be used only for radiotherapy purpose. This rules out the use of SAMEER linac for diagnostic purpose for angiography like applications which requires mono-energetic high flux X rays. With this consideration we plan to initiate collaborative research with KEK to design Laser collision chamber where laser will interact with electron beam to produce hard X-rays of 30 KeV and more energy. This paper discusses various aspects of the joint research being planned and also describes the design aspect and development of the linac tube in our laboratory.

Table 1: Machine parameters

Parameter	Value
Energy	15 MeV
Frequency	2998 MHz
Peak current	80 mA
Input Power	5.5 MW(peak)

LINAC DESIGN

The basic design parameters of linac tube are given in table 2. The cavity designed for the linac tube is shown in

Figure 1: Linac cavity

Table 2: Linac parameters

Parameter	Calculated	Measured
π/2 frequency, MHz	2997	2998
Side to main coupling %	0.03	0.0267
Shunt impedance, MΩ/m	100	87
Q (unloaded)	16000	15000
VSWR	1.4	1.56

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Fig.1 while the SuperFish profile for single cell is shown in Fig.2. The linac operates in π/2 mode, hence every alternate cavity has no accelerating fields and plays role in coupling the power only. These coupling cells are moved out of main axis of linac thus making the linac a side coupled structure. The structure is very complicated from fabrication point of view but we have successfully established the fabrication, tuning and measurement procedure for the linac. All components are fabricated and brazed in-house. The 15 MeV Linac structure contains 24 accelerating cells and 23 coupling cells. The linac tube has two buncher cavities for bunching the beam from dc gun. The linac tube is water cooled to maintain the body temperature within 1 ^{o}C.

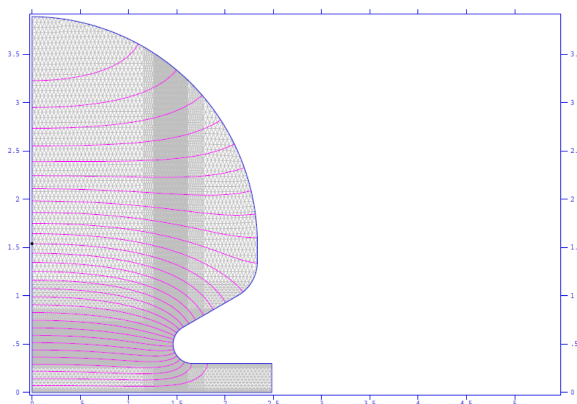

Figure 2: SuperFish plot of a single cell

The unloaded Q of the structure was found to be 15000 with shunt impedance of 87 MΩ/m measured using bead perturbation technique [5]. Fig 3. shows the brazed linac tube. The electron gun is diode gun with dispenser cathode with current density of 2 A/cm^2. The gun is made in-house while the cathode is imported. The RF window is water cooled with ceramic of thickness 2.77 mm. The window is capable of handling 10 MW peak power.

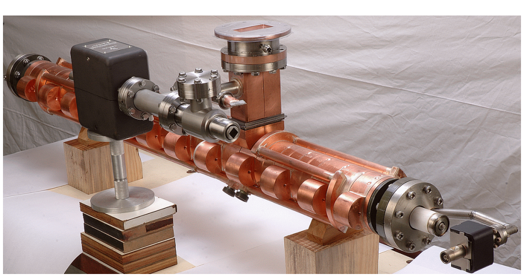

Figure 3: SAMEER made side coupled linac tube

X-RAY SOURCE PROPOSAL

With the research of compact linac successfully implemented, we will now focus on developing laser electron beam collision based Compton X-ray source using the above linac. The schematic of proposed system is shown in Fig 4. A RF gun based on ATF-MS-I gun will be developed at 3 GHz. A bunch train with 2250 bunches will be generated in the rf gun and then accelerated using 3 linac structures of 1.2 m each to reach a final energy of 45 MeV at the linac exit. The component wise details are as listed in subsequent sub sections.

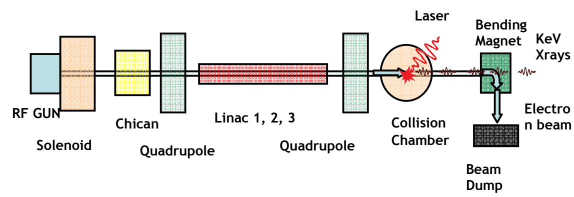

Figure 4: Layout of the proposed facility

Photo cathode RF Gun

The gun will be scaled version of the new ATF-MS gun. [6] [7]. The gun will have two cells with Pi mode frequency at 3 GHz. The zero mode frequency will be separated by 11 MHz at 2989 MHz and the Peak Half Cell to full cell field ratio called as the field balance, will be 1.0. The laser will be incident axially from full end cell side by installing a chicane after the gun to permit positioning mirror near the axis of gun. Chicane will also help in keeping low energy spread. A 10 MW klystron will be used to feed pulse power with 6 µs pulse width at 50 Hz rep rate. A Solenoid with high magnetic field will be placed at the gun exit for emittance compensation. The laser configuration is already mentioned above.

RF Gun Laser

A mode locked laser with 5W at 1064 nm will generate the laser pulses at 375 MHz. Using Pockel cell 2250 pulses will be selected, amplified and down converted to 266 nm. With CsTe photocathode, assuming quantum efficiency of 1% this laser will be sufficient to produce around 220 pC per bunch charge at the cathode.

Linac Structure

Three linac tubes, with the side coupled design mentioned earlier, will be placed starting near the focal point of solenoid. The most striking feature of the linac design is that it uses just 5.5 MW peak power to generate 0.48 uC per train of 2250 bunches. The linac is capable of operating at 166 Hz repetition rate. However to make use of commercial laser technology, in the initial stage, the repetition rate will be kept 50 Hz.

Other beam line components include quadrupole doublet for focusing the beam after linac, beam position monitors, screens and current monitors. There are gate valves to facilitate to maintain the vacuum in case of replacement or addition of components in future. The expected parameters at linac exit are listed in table 3

Laser Collision Chamber

There are various interesting features for the collision chamber. The latest chamber designed at ATF, KEK has successfully demonstrated the interaction of laser and beam to produce X-rays by inverse Compton scattering mechanism. [8]

A 1064 nm mode locked pulsed laser with 7W average power will be used to produce uniformly spaced, 2.66ns pulses. Proper synchronization and low jitter operation will enhance the ultimate performance of the X-ray source. The chamber will have horizontal and vertical movement using motorized system. This is essential to move the laser beam to collide with the electron beam. The angle of collision plays an important role to decide the energy of exit photons. With 20 deg collision at 45 MeV it will be possible to generate 35 KeV Compton X-rays. With the linac rep rate of 50 Hz and 0.45 uC charge per train, the expected flux will be high.

Table 3: Expected Parameters at Collision point

Parameter	Value
Energy	45 MeV
No of bunches	2250 per train
Charge per bunch	220 pC
Bunch spacing	2.66 ns
Transverse beam size	< 60 um
X ray flux	4.1 x 10^8 photons /sec / 1% bw

DESIGN CHALLENGES

- The main challenges come in from the laser technology. Generating 2250 pulse spacing of 2.66 ns will be a tough task especially to avoid energy sag in the train.
- The existing linac structure is at 2.998 GHz and will be redesigned for 3 GHz. The klystron available have 2.998 Ghz frequency with a bandwidth of +/- 3 MHz. Hence the Klystron will be operated near upper end of operational limit.
- The Linac cavity is re-entrant type and hence phase matching might be a problem.
- The side coupling slots appear on one side of each cavity. It is difficult to estimate the effect of these slots on emittance of the beam.
- The collision timing synchronization is a key issue that needs careful evaluation.

FEATURES AND CONCLUSION

- The linac uses 5.5 MW Klystron with no power multiplier. This will reduce the cost and power budget of the setup. These Klystrons are available off the shelf and are much cheaper as compared to 40 MW Klystrons used at LUCX facility at KEK.
- The modulator will be line type modulator designed and developed by SAMEER.
- The control console will be based on the computerized console developed for SAMEER medical linac project.
- Interlocks and other safety aspects will follow from the developmental work done at SAMEER and KEK.
- The experience of ATF, KEK in making RF Guns and laser system will be major driving force for the collaborative research.

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