# CUSTOM DESIGN OF MEDIUM ENERGY LINEAR ACCELERATOR SYSTEMS

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*Abstract*

Based on customer requirements ACCEL Instruments is designing and building turn-key Linear Accelerator Systems delivering Electron or Proton/Deuteron beams for scientific applications. Within this paper design and performance of third generation synchrotron light source electron injector linacs will be presented. Further the design of a medium energy light ion linear accelerator will be discussed. This light ion accelerator is designed with independently phased superconducting rf cavities for cw operation and acceleration of different particle species and a variable energy output.

## 100 MEV ELECTRON INJECTOR LINACS

The Swiss Light Source (SLS) pre-injector is a 100 MeV S-band linear accelerator, which has been supplied as a turn-key system by ACCEL Instruments [1] in April 2000. This design provides a successful base for modern Synchrotron Light Source pre-injectors as under construction for Diamond Light Source (DLS [2], linac to be finished spring 2005) and Australian Synchrotron Project (ASP, linac to be finished summer 2005). Within the paper a review on beam performance and reliability of the SLS linac and related improvements for DLS and ASP will be given.

### *Design of Electron Injector Linacs*

The design is based on the needs of modern booster accelerator rings, which require a certain beam current as the input energy, low emittance, low energy spread and short bunch length. To fulfil these requirements our 100 MeV electron injector linac (Fig. 1) consists out of an thermal electron source including custom made pulse-electronics, a bunching section with up to three bunching cavities and a solenoid focussing channel, two S-band travelling wave accelerating structures (Fig. 2) and a 50 MeV quadrupole focussing section. The above mentioned main components are produced inhouse, whereas supplies and standard components are bought in.

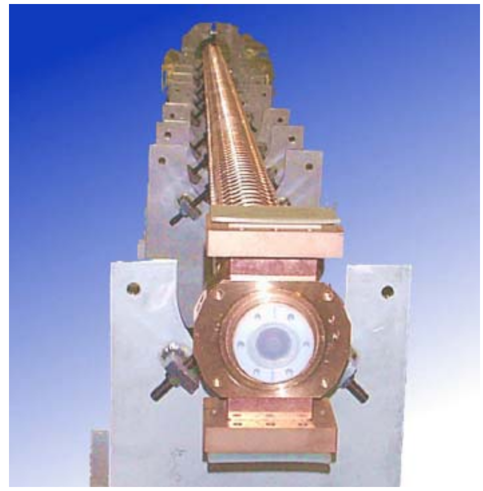

Figure 2: 5.2 m long S-band accelerating structures

### *Performance*

In Tab. 1 the performance and specification of three electron injector linacs are summarized:

Table 1: Linac performance

| **Project** | **SLS** [1] | **DLS** [2] | **ASP** [2] |
|---|---|---|---|
| Energy [MeV] | 103 | ≥ 100 | |
| Charge single/train [nC] | 1.5/2.3 | 1.5/3 | 0.38/3.8 |
| Single bunch length [ns] | 1 | 1 | |
| Multi bunch train [µs] | 0.2 to 1 | 0.3 to 1 | 0.15 |
| Pulse to pulse energy variation [% (rms)] | 0.1 | ≤ 0.25 | |
| Relative energy spread [% (rms/full width)] | 0.3 | ≤ 0.5/1.5 | |
| Repetition rate [Hz] | 3 | 1 to 5 | |
| Normalised emittance $\sigma_x/\sigma_y$ [$\pi$ mm mrad] | 40/40 | ≤ 50/50 | |

[1]measured values
[2]design or specified values

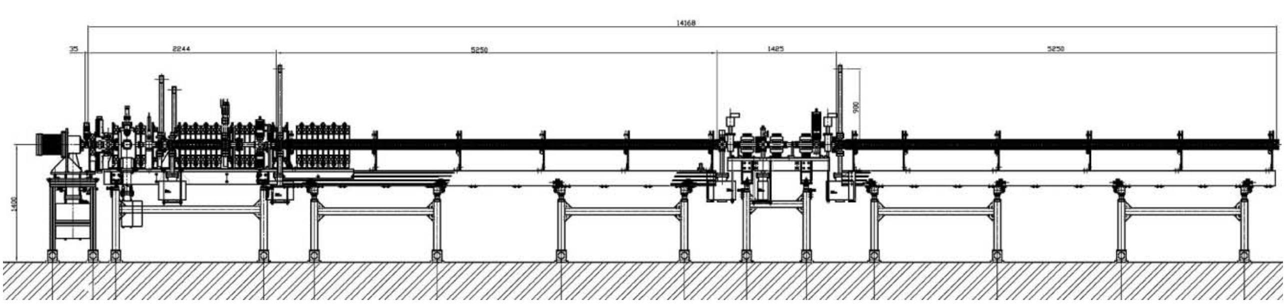


Figure 1: Design of 15 m long third generation light source injector Linac (side view showing from left to right: electron source, bunching section, accelerating section 1, 50 MeV focussing section, accelerating section 2).

### *Multipacting*

Major reason for beam degradation in the beginning of SLS operation was multipacting in the low field sub-harmonic prebuncher (SPB). A thoroughly analysis took place showing that it could only be soft multipacting, which had been overcome by clean assembly and rf conditioning. A handling and cleaning procedure was established proving the calculations.

### *Proposed Changes*

Based on the good operation experience with the SLS Linac only minor changes had been implemented for the DLS and ASP Injector Systems:

- in the drifts within the bunching section a few cm have been added to improve the mounting and maintenance possibilities. PARMELA calculations confirmed the decision
- no current transformer between bunching and acceleration section 1 will be used to avoid negative impact from ferrites in the solenoid field
- in the waveguide runs RF windows are shifted from the vertical wave guide to the horizontal; this allows adding of an additional pump between each RF window and the cavity
- SPB will be installed under clean-room conditions to reduce multipacting
- an amplifier with higher duty cycle will be included to aid SPB conditioning

### *Reliability*

Based on a list of failures which had been provided by SLS we estimated MTBF periods of the SLS linac.

32 events within the first 15.000 operation hours have been reported by the customer, the resulting MTBF is about 450 hours. A closer look shows that two events have occurred during installation, twelve are just interlocks recorded and seven could have been covered by scheduled maintenance, which now will be performed. This reduces the amount of failures to 11 and increase the MTBF to above 1300 h. While 40% of those failures had been related to the 3GHz drive amplifier it was decided to choose a different manufacturer for actual and future projects.

## MEDIUM ENERGY LIGHT ION LINAC

ACCEL Instruments has designed and is currently building a turn-key 40 MeV linear accelerator for an ion beam of 2 mA cw protons and deuterons for the Institute SOREQ NRC. (project name SARAF = SOREQ Applied Research Accelerator Facility [3]). The linac design is based on superconducting half-wave-resonators (HWR), which are individually powered and phased.

### *Specification*

The basis of the design are the specifications given by the customer which are listed in Tab. 2.

Table 2: Customers specification for ion linac

| | |
|---|---|
| Ion species | protons / deuterons |
| Energy maximal | > 40 MeV |
| Energy minimal | 5 MeV |
| Current maximal (option) | 2 mA (4 mA) |
| Current minimal | 40 µA |
| Current structure | cw/pulsed |
| Particle losses | < 1 nA/m |

### *Ion Linac Design*

The design of the linac and its components was developed and optimised with extensive use of 3D design tools as MicroWave-Studio, Ansys, Opera and Inventor.

The use of high beam current accelerators is strongly related to beam losses and resulting activation. Analysing the customer needs showed that the requirement of hands-on-maintenance drive beam performance requirements. Minimization of particle losses and beam emittances were performed with multi-particle simulations (Parmela) and in-house developed analysing software (Fig. 3).

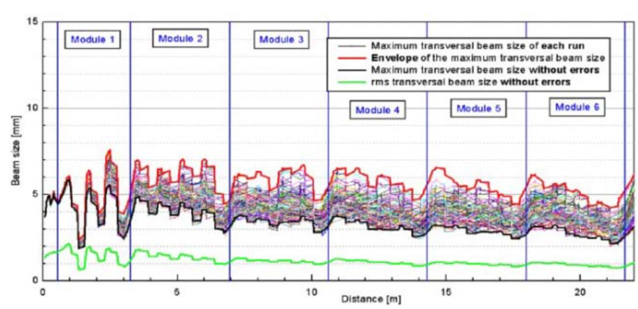


Figure 3: Simulated beam sizes along the linac (rms without errors and envelopes for 100 different error settings)

This results in a linac consisting out of 46 independent cavities divided two 176 MHz HWR families: 6 cavities with $\beta$=0.09 and 40 cavities with $\beta$=0.15 grouped in 6 respective 8 HWR per cryostat. The transversal focussing is based on superconducting solenoids, which are inserted between HWR-pairs.

Injector for the s.c. linac is a 20 keV/u ECR ion source and a 176 MHz 1.5 MeV/u normal conducting RFQ.

### *Cryostat*

The first cryostat shown in Fig. 4 houses 6 HWR ($\beta$=0.09) and 3 s.c. solenoids (6 Tesla) for focusing. It has a very compact design in longitudinal direction to avoid longitudinal emittance growth. The input energy is 1.5 MeV/u. Our novel cryostat design in this field of superconducting low beta cavities separates between cavity and cryostat insulation vacuum.

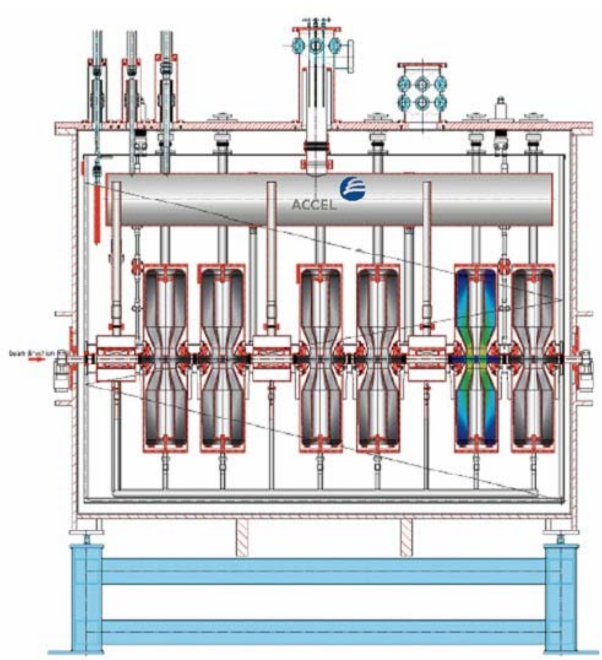


Figure 4: First cryostat containing 6 superconducting HWR ($\beta$=0.09) and 3 superconducting solenoids

### *Superconducting Half-Wave Resonator*

The design of each HWR type was optimised concerning RF properties, electro-magnetic field distribution, mechanical stiffness, micro-vibration and multipacting.

The resonator shown in Fig. 5 is a prototype HWR built out of bulk niobium (RRR > 250, thickness 3 mm) and has the parameters listed in Tab. 3.

Table 3: Parameters of HWR $\beta$=0.09

| | |
|---|---|
| Frequency | 176 MHz |
| $E_{acc}$ ($E_{peak}$=25MV/m) | 8.58 MV |
| Accelerating length $L_{acc}$ | 99 mm |
| $B_{peak}$ ($E_{peak}$=25MV/m) | 80 mT |
| $Q_0$ (4.4 K, low field) | 1.1 x $10^9$ |
| Goal $Q_0$ ($E_{peak}$=25MV/m) | >4.7 x $10^8$ |

Figure 5: Prototype HWR during chemical preparation

The prototype HWR is completely built, it has passed leak test, chemical preparation, high pressure rinsing and the cold test has just started

## CONCLUSION

It was shown that based on the use of standard design tools linacs can be designed and built according to beam specifications as turn key systems. Based on in house knowledge even complex systems can be designed and built after a prototype phase.

## REFERENCES


[1] http://www.accel.de

[2] C. Christou et al., “The pre-injector linac for the Diamond Light Source”, to be published LINAC 2004, Lübeck, August 2004

[3] A. Shor, et al., “Proton beam dynamics simulation of the SARAF linac”, to be published LINAC 2004, Lübeck, August 2004