WP4: RF system

Presentations describing WP4 organization and activities were given https://indico.cern.ch/event/737161/contributions/3041345/ at the CompactLight midterm review meeting. The overall status is that strong progress has already been made in two of the tasks; "RF design and optimization" and on "Higher harmonic power sources." From the other presentations at the meeting and subsequent discussions, the task "Klystron and Modulator Technology" has identified a new medium term objective. This is to address for the linac the very high priority question if a high-energy, 6 GeV, low repetition rate, 50 Hz, facility can be operated in a low-energy, 2 GeV, high-repetition rate, 1 kHz, mode. The tasks on "industrialization" and on "Integration" made important contacts to other WPs and have plans to ramp up their activities as upstream results become available.

More detailed summaries by task are given below.

Task 1: Linac rf design and optimization

The workflow of task 4.1 has been quite clearly defined:

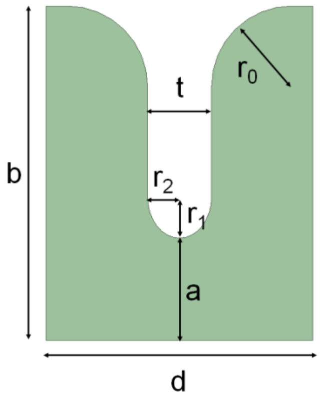
1. Chose a reference value of the accelerating field
2. Define the RF pulse compressor characteristics
3. Set the average iris radius (input from WP6 – beam dynamics)
4. Electromagnetic design and study of the regular cell
5. Find the highest effective shunt impedance structure by scanning the total length and the iris tapering to reduce the total number of power sources
6. Verify the peak modified Poynting vector values @ nominal gradient
7. Design a realistic RF module on the basis of the final energy and existing klystrons: power distribution network
8. Finalize the electromagnetic (input and output couplers) and mechanical design of the structures

Iterations cycles along the defined procedure are required, as a consequence of discussions and data exchange with other WPs. The choice of the accelerating gradient has a strong impact mainly on the steps 6), 7) and 8). Accordingly to the CompactLight Proposal (Table 1.2: Preliminary parameters of the optimum RF structure), a 65 MV/m average gradient value has been chosen as initial reference. A scan of the baseline gradient value will be anyway performed for a final optimization of the entire facility, making use of a realistic cost model.

Assuming a 65 MV/m reference gradient, the first iteration cycle has been almost completed, with the exception of point 8). Another key parameter guiding the RF structure design is the average iris aperture, which has been set to 3.5 mm at the moment, according to an inter-WPs discussion led by WP6. To compare, results obtained for the EuSPARC project of INFN Frascati, based on a 3.2 mm iris aperture, have been reported.

The regular cell has been designed and parametrized for an iris radius $\boldsymbol{a}$ in the range 2 ÷ 5 mm. Depending on $\boldsymbol{a}$ the cell radius $\boldsymbol{b}$ has been readjusted to maintain the 2π/3 mode frequency at the nominal frequency $f_{RF} = 11.9942$ *GHz*. For each value of $\boldsymbol{a}$ the cell figures of merit have been calculated, namely the shunt impedance, the Q value, the group velocity, the attenuation factor and the modified Poynting's vector at 65 MV/m.

a [mm]	2 ÷ 5
b [mm]	10.155 ÷ 11.215
d [mm]	8.332 (2π/3 mode)
r_0 [mm]	2.5
t [mm]	2
r_1/r_2	1.3 (Min Sc max for a=3.2 mm)



The full cell characterization has been exploited to compute the effective shunt impedance of the structures, choosing a linear iris tapering along the longitudinal coordinate. For a given structure length the best tapering slope is identified, and by comparing the maximum value of the effective shunt impedance, the optimal structure length is established, which result to be $L_s \approx 67$ cm for <*a*> ≈ 3.2 mm (EuSPARC case) and $L_s \approx 90$ cm for <*a*> ≈ 3.5 mm (present CompactLight baseline). In both cases the expected breakdown rate, estimated on the base of the maximum value of the modified Poynting's vector, is well below the threshold of 10^{-6} bpp/m.

	EuSPARC <*a*>=3.2 mm L_s=0.67 m	CompactLight <*a*>=3.5 mm L_s=0.9 m
Freq. [GHz]	11.9942	
RF pulse [μs]	1.5	
Average gradient <G> [MV/m]	65 MV/m	
Linac Energy gain E_{gain} [GeV]	4.5	
Linac active length L_{act} [m]	69	
Unloaded SLED Q-factor Q_0	180000	
External SLED Q-factor Q_E	22600	23000
Iris radius a [mm]	3.8-2.6	4.3-2.7
Group velocity v_g [%]	3.2-0.8	4.7-1
Effective shunt Imp. R_s [MΩ/m]	**418**	**387**
Filling time t_f [ns]	140	144
Klystron power per structure P_{k_s} [MW] (w/o attenuation)	6.7	9.8
Structures per module N_m (klystron power per module P_{k_m} [MW])	**6 (40)**	**4 (39)**
Total number of structures N_{tot}	**≈108**	**≈80**
Total number of klystrons N_k	**≈18**	**≈20**

A complete summary of the obtained results is reported in Table …. Structures can be assembled in groups of 4, and powered by a single 50 MW klystron by means of a pulse compressor. About 20 of such modules are needed, assuming a minimal contingency and without considering off-crest acceleration required by bunch compression.

The next steps are:

- alternative a more innovative pulse compression schemes to be taken into consideration to increase global efficiency;
- consider different accelerating gradients;
- go through the iteration process with different or updated starting conditions
- finalization of the electromagnetic design (input and output couplers)
- finalization of the mechanical design of the module.

Task 2: Industrialization

Within this task, industry will give its perspective on how to industrialize an accelerator module. Ideally, these modules will become standardized components for future generation high gradient, normal conducting X-band accelerator applications. For such complex systems to become a standard, the modules should be manufactural in series-production and shipped to the end customer as fully tested turn-key products.

The deliverables in this task is a report with the industry perspective on: modular design, redesign for manufacturability, COG, maintainability, supply chain setup and management, system engineering and integration, fabrication approach. An important consideration is to be made between what is most optimal from physics versus product point-of-view. By this meant that the best solution regarding physics point of view might yield a design that does not satisfy the demands of an industrialized product e.g. on cost, reliability, manufacturability. It is important for all partners involved in WP4 to keep this in mind. Therefore part of Task 2 is to support Task 1, 3, 4 early on with manufacturability knowledge, including knowledge gained in other/comparable projects which focus on the standardization of accelerator parts.

On the other side, the work in this task will build on the work done in the other tasks and work packages i.e. as soon as (early) designs becomes available, industry is able to asses these designs. Hence, the planning is to deliver a general industry perspective in Q3/Q4 2018 and as specific design information becomes available, concentrate on the specific XLS design. Currently, the contacts with other partners are being established while working on writing down the general industry perspective.

Task 3: Modulator and klystron technology

Plans for the task:

1. Market survey for available systems and components

2. The preliminary findings of the WP2 indicate users interest in a high repetition rate FEL machine, especially for the “soft” X-FEL regime, where rate of 1kHz is desired. For “hard” X-FEL

regime 100 Hz repetition rate is requested. These are very challenging requirements for X-band RF system, increasing largely from presently operating systems like CLIC X-box2 with 50Hz repetition rate. Investigations into feasibility of the high repetition rate will therefore be a priority for the Task 4.3. We plan to proceed with two scenarios:

- Linac based on the RF unit as presented in the CompactLight Proposal, consisting of 50 MW klystron and modulator working at full power and 100 Hz repetition rate. That system is within the current state-of-the-art for X-band technology. That would be a model for "hard" X-FEL linac providing ~6GeV beam. We want to investigate the possibility of running the same RF unit sacrificing the output power in order to increase the repetition rate. With lower power, resulting in beam energies suitable for the "soft" X-FEL regime (~2GeV), we hope to be able to significantly increase the repetition rate. To explore this option and confirm it to be a viable and realizable alternative will require discussions with experts and collaboration with the companies.

- Linac based on a RF unit using klystrons with smaller power and higher repetition rate that are available on the market. The RF system layout in this case would be more complicated, requiring high level of combination and compression of the RF power. The estimation of the footprint and cost will be crucial.

3. Investigation to see if any modulator presently used for the X-band klystron could be adapted to drive a 36 GHz Gyroklystron for the harmonic lineariser.

Task 4: Power sources for higher harmonic systems

To correct the longitudinal phase space non-linearity from the X-band RF linac, compensation of the energy curvature of the electron bunch is required. CompactLight intends to use a higher harmonic lineariser to achieve that. Because of the high power capability of gyrotron devices at cm and mm wavelengths a 36GHz Gyro-klystron was designed through numerical simulations based on the Particle-In-Cell code MAGIC. An output power of 2MW at 36GHz for μs duration pulses was predicted. The numerical model was used to simulate an existing 36GHz gyro-klystron experiments operating with a $TE_{o.1}$ mode at a lower power of 250kW, and good agreement was achieved between the simulation and the experiments. With the use of a higher order $TE_{o.2}$ mode in the output cavity, the 36GHz Gyro-klystron was predicted to operate at an output power of 2MW. By combining with SLED type compression it is possible to achieve an increase in peak power to 5MW which would enable a gradient of 8MV in 25cm when an iris aperture radius of 3.2mm is used in a 3rd harmonic lineariser. However to minimise wake fields in the lineariser structure a larger aperture radius of 5mm is desirable which necessitates an increase in output power to 14MW if a single 36GHz gyro-klystron source is to be used.

In an attempt to increase the peak power in the next six months a new numerical model will be developed to design a 36GHz Gyro-klystron operating with a higher order $TE_{o.3}$ output mode. Discussion with modulator task leader will take place understand better the implications on the 36GHz Gyro-klystron design for operation at a pulse repetition frequency of 1kHz.

Task 5: Integration

Task 4.5 deals with Integration design as well as maintaining appropriate data for our WP. One key element will be a 3-D solid model of the rf linac unit. An initial version will be produced based on preliminary task 1 parameters and then kept up to date as the design evolves and advances.

Prerequisites:

· Length of an accelerating structure

· Some sort of lattice design and ”RF unit” layout

· Information on magnet dimensions/design

Start date:

foreseen 2nd half of 2018

Additional information needed along project as comes available:

· Positioning tolerances of AS

· Geometrical and thermal stability tolerances of AS

· Thermal tuning/management?

Status:

Current activity is mainly ground work establishing the appropriate communication channels to the identified key parties/persons. Additionally ongoing activities are, as far as possible, collecting and discussing linac configurations and component parameters (e.g. lattice, AS parameter, RF unit definition, etc.). Next stage will be setting up CAT files and archive structure and start with rough 3D modeling for space allocations. The final two parallel steps will include support designing for required geometrical tolerances and stability requirements, as well as inclusion of the external 3D models, such as e.g. accelerating structures and quadrupole magnets.