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New CLIC-Module requirements Post-PIP

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Abstract

This document should serve as a container and a collection of requirements for a new CLIC module design to be potentially manufactured over the course of 2021-2024.

Contents

1 Introduction

This document should serve as a container and a collection of requirements for a new CLIC module design to be potentially manufactured over the course of 2021-2024. The new module design was unveiled in the CLIC-PIP [1] and the concepts discussed here are mostly based on the work done for the PIP.

2 Collection of material (to be digested later on)

- [2] Alex's presentation at the RF structures development meeting in 2019
- [3] Alex's presentation at the Structures production meeting in 2017
- [4] Henri's CLIC note
- [5] Kai's CLIC Note
- [6] Pedro's CLIC Note

3 Supporting System (Matthew)

3.1 Girder material and geometry

A detailed comparison of different options for the main beam accelerating structure support girder was carried out here. This comparison suggested the use of a 300mm by 200mm rectangular profile steel girder can be used as a suitable and cost effective main beam girder. The main beam girder is required to meet the following mechanical requirements.

Surface flatness is not a significant factor for the alignment of the SAS as the prealignment system will be mounted onto specific features machined on the girder. The deviation of these features over the length of the girder will be < 0.1mm and well within the range which can be compensated for using the SAS prealignment platforms. The top surface flatness specification of a standard steel girder is $<$ 3mm over 2m.

The bending stiffness of the girder should be greater than 5kN/mm to ensure it does not bend out of the adjustment range of the SAS prealignment system. This is easily achievable with most engineering materials, and within the specification of the proposed steel box-section girder. However, both the bending stiffness and the torsional stiffness of the girder profile are significant when considering the modal frequencies of the system. A box-section girder is proposed partly due to the increased torsional stiffness. This is discussed in more detail in Section 3.5.

Girder thermal behaviour:

- The thermal expansion of the girder in the vertical and lateral directions must be limited to less than the adjustment range of the active alignment system. This is easily achievable with standard engineering materials, such as steel.
- The longitudinal expansion of the girder from the central mounting position cannot be actively corrected for using the proposed alignment system, therefore the coefficient of thermal expansion of the girder material must be $10 \times 10^{-6}\text{K}^{-1}$ or less in order to keep the displacement less than $75\mu m$, or 1RF degree.

A breakdown of the cost of the girder and the alignment systems is provided in Table 3.1.

Table 3.1: A costing breakdown of a prototype main beam girder and the support and alignment components.

Module Component	Unit Cost [kCHF]	Number	Total Cost [kCHF]
Girder	0.1	1	0.1
Girder Machining	1.0	1	1.0
SAS Alignment Platform	20.0	4	80.0
Linear Actuator	0.0	5	0.0
WPS	0.0	4	0.0
Support Base	2.5	3	9.0
Total			91.3

Table 3.2: A costing breakdown of the final main beam girder and the support and alignment components.

Module Component	Unit Cost [kCHF]	Number	Total Cost [kCHF]
Girder	0.1	1	0.1
Girder Machining	0.5	1	0.5
SAS Alignment Platform	10.0	4	10.0
Linear Actuator	2.0	5	10.0
WPS	2.0	4	8.0
Support Base	1.0	3	3.0
Total			41.6

3.2 Girder installation and interfacing with survey system

The main beam girder requires at least three WPS mounted to the support girder. The WPS should be directed directly to the girder, or by means of an adaptor ‘arm’ of a material with the same thermal characteristics as the girder itself. Possible sensor wire locations relative to the beam location are given in Table 3.3

Table 3.3: Potential WPS locations with respect to the beam.

Module Configuration	Distance from Beam [mm]	
	Y	X
Current Lab	-170	$\pm$ 250
Rectangular Girder: Below	-380	$\pm$ 110
Rectangular Girder: Outside	Any	$> \pm$ 300

The WPS must be mounted on the underside of the girder, or on the underside of the adaptor ‘arms’ so that the fully assembled girder can be lowered onto the preinstalled reference wires.

3.3 Girder supporting system

The support girder will mounted on an adjustment system consisting of five or six linear actuators, providing the ability to re-adjust the girder position with sub-micrometric resolution over a range of $\pm$3mm. A course alignment system allowing 0.1mm adjustment over $\pm$5 during initial set-up and subsequent readjustment if required.

The girder supporting system must, in combination with the accelerating structure support system, meet the module vibration and stability requirements as discussed in Section 3.5.

3.4 Adjustable Accelerating Structure Support

Each SAS will have a six degree of freedom adjustment system allowing prealignment with the range and resolution given in Table 3.4.

Table 3.4: SAS adjustment platform range and resolution.

Axis	Unit	Range	Resolution (Per Revolution)
X	mm	3.00	0.04
Y	mm	2.75	0.03
Z	mm	2.75	0.03
Pitch	mrad	7.64	0.08
Yaw	mrad	8.33	0.11
Roll	mrad	18.33	0.20

The structures must have three flat mounting surfaces measuring approximately 45mm square on the lower surface. One surface should be aligned with longitudinally centre plane and offset to one side of the structure by around 100mm. The other two surfaces should be on the other side of the structure and positioned as close to the front and rear of the structure as possible. Alternatively a copper base plate could be included as an interface between the structure and the adjustment platform.

Steel inserts could be integrated into the manifold of a round-disc structure as a way to increase the stiffness between the central core and the adjustment surfaces; however, this would lead to inconsistent thermal expansion and therefore introduce thermal stresses.

The structures are required to have reference surfaces machined into the external surfaces of certain the discs (or the equivalent component) and positioned to within 1μm of the irises. Accurately positioned fiducials on these surfaces will provide the prealignment reference frame for the vertical, lateral, roll, pitch, and yaw axes. Another reference surface must be included in order to provide a longitudinal reference.

The accelerating structure support system must, in combination with the girder supporting system, meet the module vibration and stability requirements as discussed in Section 3.5.

3.5 Full Module Support Stability

The module girder, passive prealignment, and active alignment systems must ensure that the modal frequencies are not likely to result significant vibration at or around the operational frequency of the CLIC main LINACs i.e. 50Hz. The higher-order modal frequencies of the assembly should be considered to avoid multiples of 50Hz, e.g. 100Hz.

- Girder and support must fulfil ground noise stability requirements

4 Vacuum System

- force balanced system exerting no additional distorting force on accelerating structures,
- system must not constrain girder movement,

- system needs to ensure sufficient pumping speed to reach < $2x10^9$ mbar on the beam position,
- system needs to interface with structure, RF-loads, and wave-guide system.
- any constraints from dynamic vacuum?

5 Interfacing with Cooling and Ventilation System

In the case of a drive beam powered module each accelerating structure uses 59.7 MW input power and has 33 cells, two of them are combined to a 0.542 m long super accelerating structure (SAS). Table 5.1 shows a summary of the power dissipated in a two beam based T0 module, in the most unfavourable condition of unloaded operation. The structure attenuation is taken into account and leads to the power dissipation in the RF loads.

Table 5.1: Power dissipation in the DB module under unloaded conditions (case of a T0 module)

Module Component	Number	Item Dissipation [W]	Total Dissipation [W]
SAS	4	772	3,088
PETS	4	11	42
SAS RF Loads	16	168	2,690
Waveguides	4	60	241
DBQs	2	171	342
Total per module			6,403

In the klystron-based module configuration the power dissipation under loaded conditions in the module can be found in Table 5.2. It is assumed that the input power can be reduced from pulse to pulse in case of no beam present. The klystron based accelerating structure has 28 cells and the input power per structure is 40.6 MW.

Table 5.2: Power dissipation in the klystron-based module under loaded conditions

Module Component	Number	Item Dissipation [W]	Total Dissipation [W]
SAS	4	1,100	4,400
SAS RF Loads	16	178	2,842
Waveguides	1	1,034	1,034
Total per module			8,276

5.1 Water cooling (Alice)

The aim of the demineralised water cooling system is to evacuate the dissipated heat generated by RF losses. This heat is localised around the irises and causes a thermal expansion of the surrounding cavity disks, which in return affects the performance of the SAS. The available volume flow rate of the coolant for a module is $11.2\,\mathrm{L\,min^{-1}}$. This leaves a volume flow rate of about $2.0 - 2.5\,\mathrm{L\,min^{-1}}$ for each SAS. The coolant enters the SAS with an inlet temperature of $T_{\mathrm{inlet}} = 27\,^{\circ}\mathrm{C}$ and it leaves the SAS with an outlet temperature of just below $T_{\mathrm{outlet}} = 35\,^{\circ}\mathrm{C}$.

In addition to the performance loss caused by the thermal expansion, the deformation of the cavity disc stack also causes affects the tight alignment: the centre axis of the SAS must be within $14\,\mu\mathrm{m}$ R.M.S. with respect to the beam axis [**Aicheler2018CLICPlan**]. Consequently, the final cooling channel layout should result in a minimised and even deformation in the cavity discs.

The proposed cooling channel layout consists of two symmetric path, meaning that the coolant is flowing in parallel and in the same direction. The cooling channels should be placed inside the cavity disks, as close to the irises as possible. The cooling channels have a diameter of $D = 4\,\mathrm{mm}$ and the coolant flows with a volume flow rate of $2.0\,\mathrm{L\,min^{-1}}$. This configuration leads to the most even temperature distribution over the length of the SAS, as well as the smallest radial deformation. The overall deformation of the cavity discs reduces as the cooling channels are placed closer to the irises.

The cooling channel surface roughness directly affects the performance of the cooling system, since a higher surface roughness leads to an improved convective heat transfer between the coolant and the surrounding structure. Conversely, a higher surface roughness will also lead to higher pipe pressure losses and increase the risk of flow related damage mechanisms, such as cavitation or erosion-corrosion. Considering that the cooling system already evacuates 97 % of the dissipated heat when working under a smooth pipe assumption, the increase of the surface roughness is discouraged.

Finally, keeping in mind that the Main Linacs of the CLIC are assembled from individual modules, it is recommended to design a module based cooling layout with one inlet and one outlet that can be connected to a coolant distribution system. The four SAS in each module should be cooled in series, since this leads to lower pipe pressure losses. The cooling pipes to and from the SAS can be placed inside the supporting girder.

The performance of the cooling system is dependent on the convective heat transfer coefficient and on the temperature difference between the coolant and the surrounding structure; A flow through heater should be placed at the beginning of each module to ensure that the inlet temperature $T_{\mathrm{module,\,inlet}}$ is kept at $27\,^{\circ}\mathrm{C}$.

- specify water flow, pipe size, roughness, routing and plumbing,
- integrate and simplify plumbing with girder/water manifold
- flow through heater for module entrance for water temperature fluctuations and AS temperature tuning

5.2 Heat to air (Markus)

- numbers considered for the HVAC system in the PIP need to be considered and possibliy maintained
- Heat convection from the SAS to air: $5\,\mathrm{Wm^{-2}{}^{\circ}C^{-1}}$
- Heat radiation from SAS to air: emissivity $\varepsilon = 0.05$
- Ambient temperature: $28\,^{\circ}\mathrm{C}$

6 RF System

- flexible wave-guides for girder movement (find reference for simulations campaign we did),
- RF-Loads integrated and connected to pumping and cooling,
- single feed coupler, reduce number of flanges, integrate low loss components
- stabilize thermally the wave guides

Table 7.1: Parameters in modal analysis

Attribute	Unit	Value
Girder density	kg/m^3	7850
SAS density	kg/m^3	8940
Standard Earth gravity	m/s^2	9.8066
Remote mass	kg	150

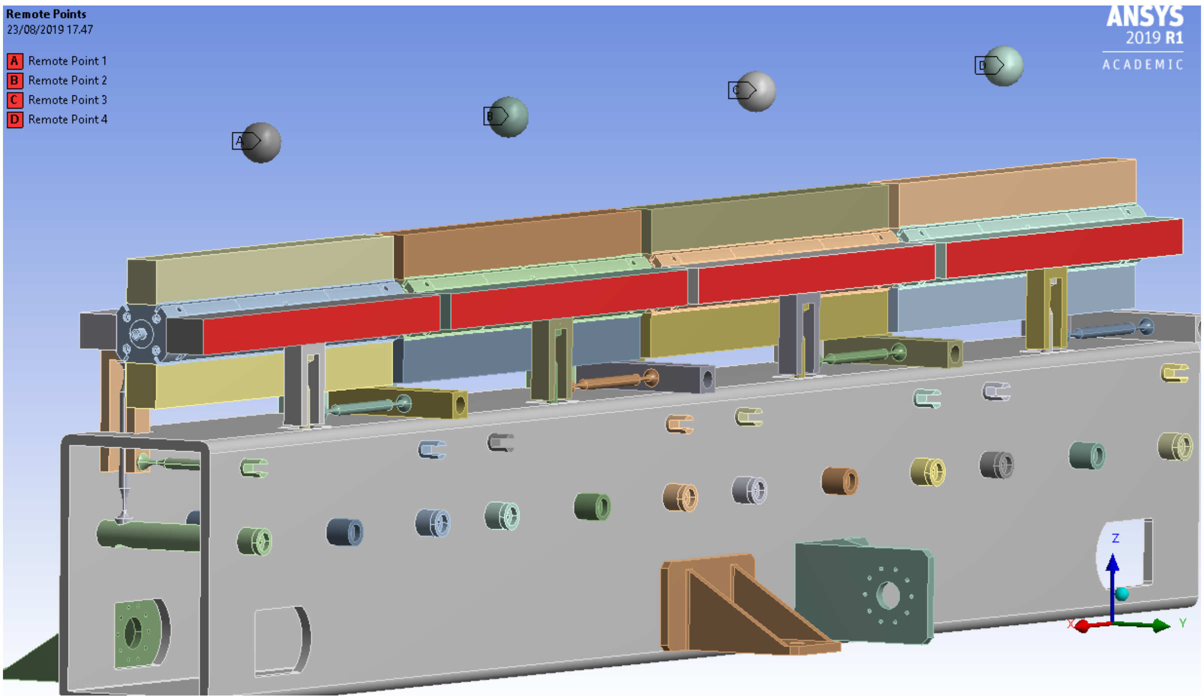

Figure 7.1: Remote mass

7 Formatting examples

References

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