Comparison of accelerating structures for the first cavity of the main part of the INR linac

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Abstract. For the beam power improvement of the hydrogen-ion INR linac replacement of the first four-section cavity in the main part of linac is required. Existent cavity is realized using DAW structure on 991 MHz operating frequency. The new cavity should at least not lose in parameters to the current structure and essential changes in other linac systems are not wish able. Parameters of accelerating structures possible for such application are compared.

1. Introduction

The main objective of our work is to perform a comparison between different accelerating structures which could be used in the first cavity of the INR linac, and choose the optimal option for practical realization of a single cavity. We consider both time-proven in existent intense linacs structures – Disk and Washer (DAW) structure [1], Side Coupled Structure (SCS) [2], Annular Coupled Structure [3], and promising development Cut Disk Structure (CDS) [4]. These structures are shown schematically at figure 1.

Figure 1. Artistic view of the structures: a) DAW, b) ACS, c) SCS, d) CDS

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All structures are compared for parameters of the first INR linac cavity, operating frequency $f_a = 991$ MHz, relative particles velocity $\beta = 0.4313$, aperture radius 17 mm, acceleration rate $E_0 T \cos \varphi_s = 2.5$ MV/m with synchronous phase $\varphi_s = -33$ degrees, RF pulse length 200 $\mu$s and repetition rate 100 Hz.

2. Electro dynamical characteristics

The reference DAW1 design [1], currently in use, has the maximum electric field at the drift tube surface $E_{s,max} = 0.5 E_k$ where $E_k$ is the Kilpatrick limit. Drift tube optimization has been performed to improve the value of effective shunt impedance $Z_e$. Drift tube with two rounding radiuses and optimized gap ration was applied. With $E_{s,max}$ increasing to safe value of $1E_k$ it results in approximately 10% $Z_e$ increase. The optimized drift tube shape was applied for all other structures under consideration. Calculated electro dynamical parameters of the structures are listed in table 1.

![Brillouine diagrams for the structures](image)

To compare dispersion properties the Brillouine diagrams for each structure at the same scale are presented at figure 2. The DAW structure has the maximal coupling coefficient $K_c$ but it has a set of parasitic modes near the operating frequency. The displacement of these modes requires introduction of additional components into the structure which complicates the cavity production and RF tuning. The value $Z_e$ for the DAW1 option takes into account stems for washer support and the slots for parasitic modes shift in the existing cavity. It is a reference $Z_e$ value which cannot be lowered in the new cavity. The analysis for DAW, ACS, SCS and CDS structures was performed in 3-D approximation with all geometry features taken into account. As we see from table 1, with the optimized drift tube shape, ACS, SCS and CDS structures have $Z_e$ higher than reference value of DAW1 and satisfy requirement of RF efficiency.

3. Structures cooling

In INR intense linac the first cavity should operate with rather high average heat load $\geq 7$ kW/m. Two options of cooling circuits were considered for each structure, both with external cooling.
channels only and external and internal cooling channels together (see figure 3). Preliminary study has shown that cooling with external channels only results in not tolerable temperature rise $\Delta T$ and related frequency shift $\Delta f_a$ in each structure (see for example CDS1 in table 1). Internal cooling channels are required. CDS1 option has the highest $Z_e$ value due to thin walls. In this case internal channels are not possible. The second option CDS2 with increased walls thickness was considered instead of lower $Z_e$.

![Cooling circuit](image)

**Figure 3.** Cooling circuit: a) DAW, b) ACS, c) SCS, d) CDS2

The applied cooling circuits for every structure are presented at figure 3. The complete coupled analysis was performed with procedure described in [5] and based on ANSYS software [6]. The cooling conditions were considered for the safe value of the flow velocity 2 m/s at the turbulent regime with Reynolds number $Re \geq 10^4$. Simulated temperature distributions for structures are shown at figure 4 and the main results of this thermal-structural analysis are listed in table 1.

![Thermal map](image)

**Figure 4.** Thermal map: a) DAW, b) ACS, c) SCS, d) CDS2

In DAW, SCS and ACS internal cooling channels could be only produced with brazed joints water-vacuum. It reduces reliability of long term operation. In CDS2 design we can avoid such brazed joints [4].

In the table 1 $R_e$ is the structure outer radius, $\lambda$ is the operating wavelength, $Q$ is the quality factor, $T$ is the transit time factor, $\Delta T$ is the temperature rise with respect of cooling water temperature and $\sigma_{max}$ is the maximum stress value in the cavity, assuming the Young module for fully annealed OFE copper $\sim 100$ GPa.
4. Results analysis

As we see from table 1 with the optimized drift tube shape all options exceed in \( Z_e \) the reference structure DAW1 which is now in use. DAW structures has the highest \( K_c \) value, but with a lot of HOM parasitic modes near the operating frequency. Removal of these modes requires additional efforts during structure construction and RF tuning. ACS and SCS have too low \( K_c \) providing extra requirements for precision of structure manufacturing and tuning. The CDS1, 2 options realize acceptable intermediate \( K_c \) value, which allow to avoid individual cell tuning [4].

For reliable operation internal cooling is necessary for all structures. With internal cooling expected internal stress values for all structures are below the limit of elastic deformations. In DAW, SCS and ACS internal cooling channels could be only produced with brazed joints water-vacuum. Avoiding such joints in CDS2 option will have more reliable structure operation.

As we see from figure 1, DAW, ACS and SCS structures have large outer diameter ~450 mm. Accelerating structures normally are produced using expensive material - OFE copper. Large outer diameter of DAW, ACS and SCS causes additional difficulties starting with raw material to additional requirements for processing equipment. The outer diameter of CDS structure is approximately two times lower and we can expect essential cost reduction in cavity construction of single cavity unit.

5. Conclusion

Consideration shows that in case of accepted DAW, ACS and SCS in construction of single cavity unit we will get similar problems in mechanical structure processing. Taking into account the existing experience in DAW construction and estimated parameters set, application of ACS and SCS looks not reasonable. Until now CDS is proven in electron (\( \beta = 1 \)) linacs [4]. The analysis shows that for proton acceleration with \( \beta = 0.43 \) using optimized drift tube shape, CDS satisfies the requirements for applying into the first cavity of the main part of the INR linac, even with increased wall thickness. As we see from table 1 CDS has counter-balanced set of parameters. Avoiding brazed water-vacuum joints improves cavity reliability. Smaller transverse dimensions results at least in cost reduction for cavity manufacturing. Analysis performed shows that CDS structure is the most promising for structure replacement of the first cavity of the INR linac.

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