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BEAD-PULL MEASUREMENT PROCEDURE FOR AREAL LINEAR ACCELERATOR ACCELERATING STRUCTURE

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Abstract

In this paper, the widely used RF measurement bead-pull technique for the S-band accelerating structure pre-tuning of the AREAL linear accelerator is presented. Bead-pull measurements were conducted before brazing with various group sets of accelerating cells to evaluate the effectiveness of "smart combinations" for AREAL accelerating structures. The "smart combination" technique represents the grouping of cells with corresponding lengths to achieve the same length sets (triplets for 2π/3 mode) as it is possible. Cell lengths were measured in advance based on TM resonance frequencies measurement. This procedure will significantly reduce the tuning routine required after brazing.

INTRODUCTION

AREAL 50MeV is the electron linear accelerator for generation ultrashort electron beams with <1 mm mrad emittance. At this stage AREAL accelerator operated with laser driven RF Photogun with 1.5 cell accelerating structure, which providing beam with 5 MeV energy (Fig. 1). For upgrade AREAL accelerator up to 50 MeV beam energy at CANDLE SRI the accelerating structures designed [1]. The plan involves the operation of two 1.6m 42 cell travelling wave accelerating structures. The design parameters of AREAL electron beam is presented in Table 1. The cells manufactured and the mechanical testing was done at home. Additional cell geometry RF measurement was done, to evaluate the accuracy of the preparation and to classify the cells according to geometrical dimensions. [2].

Precise tuning of the geometric dimensions of the accelerating structure is indeed crucial for effective operation, especially when dealing with travelling wave structures. The tuning procedure is crucial for adjusting both the phase advance and resonant frequency. Proper tuning ensures that the phase advance and resonant frequency are optimized to maximize energy transfer to the particles.

Table 1: AREAL Beam Main Parameters

		Phase 1		Phase 2	
		Single Bunch	Multi Bunch	Single Bunch	Multi Bunch
Bunch Charge	(pC)	10-100	30	10-100	30
Bunch length rms	(ps)	0.5-4	0.5-4	0.5-4	0.5-4
Number of Bunches Per Pulse		1	16	1	16
Norm. transv. Emittance	(mm-mrad)	<0.3	<0.3	<0.3	<0.3
Beam Energy	(MeV)	5	5	20	20

To measure the amplitude and phase distribution of travelling waves at the cells, a bead-pull measurement is utilized. The combination of the bead pull measurement technique and perturbation theory is a commonly utilized method for fine-tuning the field of accelerating structures. The tuning procedure involves calculating the field distribution of the scattered wave from each cell of the structure [3-5]. The test stand for bead-pull measurement was established in the CANDLE SRI RF lab to conduct preliminary measurements on a 9-cell prototype of a 42-cell (1.6 m) accelerating structure (Fig. 2).

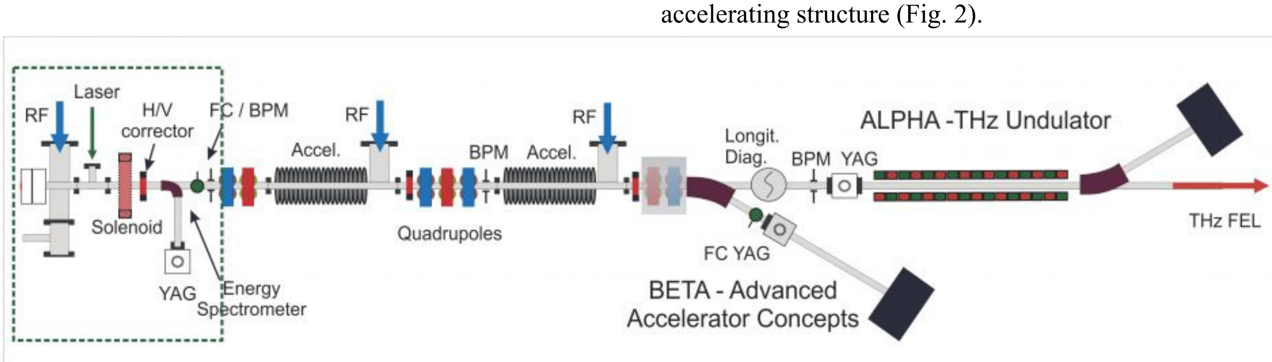

Figure 1: AREAL 50 MeV schematic layout.

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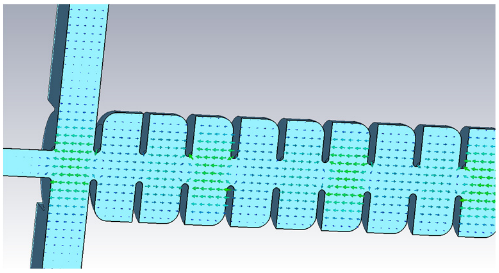

Figure 2: Electric field distribution of the TM01 mode in a cross section of accelerating structure.

This paper presents a smart combination algorithm for the accelerating structure in the case of a 9-cell prototype. Before combining the cells, the geometry of each cell was evaluated [2]. In the case of the 2π/3 travelling wave mode, combining with triplets is a reasonable choice (Fig. 2). A comparison of EM field distributions between random and optimal sequences of cells was presented. The optimal sequence occurs when triplets have about the same lengths.

BEAD-PULL MEAUSERMENT TEST STAND AND MEAUSERMENT TECHNIQUE

The Bead-pull test stand contains precisely guiding a small dielectric or metallic bead through a cavity while simultaneously measuring the electric field within. This task is accomplished through the assistance of a step motor and pulley system, which regulate the bead's movement, while RF measurements are conducted using a Network Analyzer. The metallic bead is chosen for measuring the distribution of the central axis electric field. To optimize this process, we devised a program leveraging Python. This software adeptly oversees the hardware aspects of the Bead-Pull system, orchestrating the step motor's motion, retrieving data from the Network Analyzer, and executing any required data processing tasks (Fig. 3).

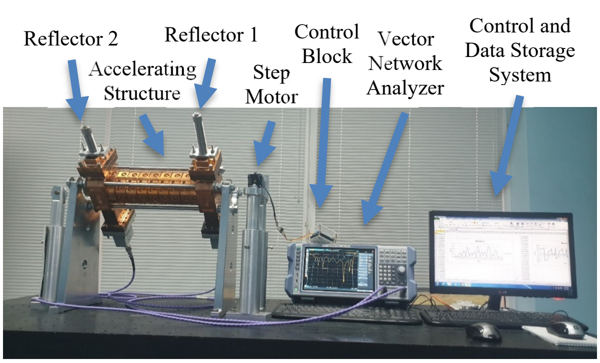

Figure 3: Bead-pull measurement test stand.

Before measurement, the adjustment by reflector 1 is done to achieve minimum S_{11}, which corresponds to load matching. After that, minimal reflection from the output coupler is provided with reflector 2, achieved through S_{12} measurement.

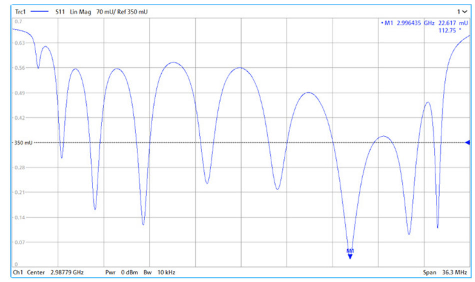

Figure 4: S11 reflection coefficient for 9 cell prototypes.

In Fig. 4, the S11 reflection coefficient measurement is presented for the minimum cases, and the 2π/3 mode frequency is determined for the given conditions (temperature, mechanical deformations, etc.), to conduct further bead-pull measurements at the determined frequency. At the end of the measurement, the determination of the 2π/3 mode frequency is repeated to ensure that the conditions have not significantly (~85 kHz corresponds to ±0.2°C) changed during the bead-pull measurement. The taken result for every point is the averaging of few measurements, which can be controlled by the program, and the step of movement is set up in the program to increase the accuracy of the measurement and to obtain the precise center of each cell.

SMART COMBINATION ALGORITHM OF CELLS

Before the combinations the cells geometry RF measurements for each cell was done to evaluate the geometrical parameters of cells [2]. The cells were ordered by the length. The cells were grouped by triplets according to 2π/3 travelling wave operation mode. The phase advance per 3 cells for operating mode is 360°. The triplets are chosen with the close length as much as possible, taking into account the errors of cells geometry RF measurements. The best triplet will be the one whose length is closest to the RF wavelength (in AREAL 50MeV accelerator is 10cm), and the worst triplet will be the one with the largest deviation. The triplets are arranged starting from the best one, and the phase advance in each triplet will likely compensated by the next triplet. To avoid the cumulative effect of deviations, phase advance compensation with triplets should be performed in a sequence of triplets with different signs relative to the RF design wavelength. The system end with the worst triplet. This will contribute decreasing of bad triplets affect due to attenuation of the field along the accelerating structure, which in turn will lead to an increase in the efficiency of energy transfer. We call this arrangement “smart combination”, which provides a phase advance pre-tuned system without any mechanical intervention. For 9 cells, this can be accomplished without automated software, but for a large number of cells, software intervention will be required.

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RESULTS AND DISCUSSION

From the 42 cells, 3 closest to the design parameters, 3 with medium deviations, and 3 with large deviations within permissible tolerance were selected (Table 2).

Table 2: Selected 9 Cells With Resonant Frequencies Shift From Designed One

Cell	Δf[MHz]	Cell	Δf[MHz]
1	0.195222	6	1.037222
2	-0.40178	7	-0.19178
3	-0.23278	8	-0.13678
4	0.291222	9	-1.48678
5	0.926222		

In the first case, cells are arranged arbitrarily without any preferred sequences. Then the triples were separated according to the described smart combination algorithm, and the improved system was constructed. The phase advance in the center position of couplers and cells measured for both cases (Fig. 5) and field distribution in the system on-axis were presented in Fig. 6 for the improved cases. The primary goal of the smart combination method is to improve the phase advance without external mechanical influence; therefore, changing the alignment does not significantly improve the field distribution. Before the measurements, each system is adjusted by optimal positioning of the reflector at the resonant frequency, ensuring minimum values of S11 with reflector 1 and S12 with reflector 2.

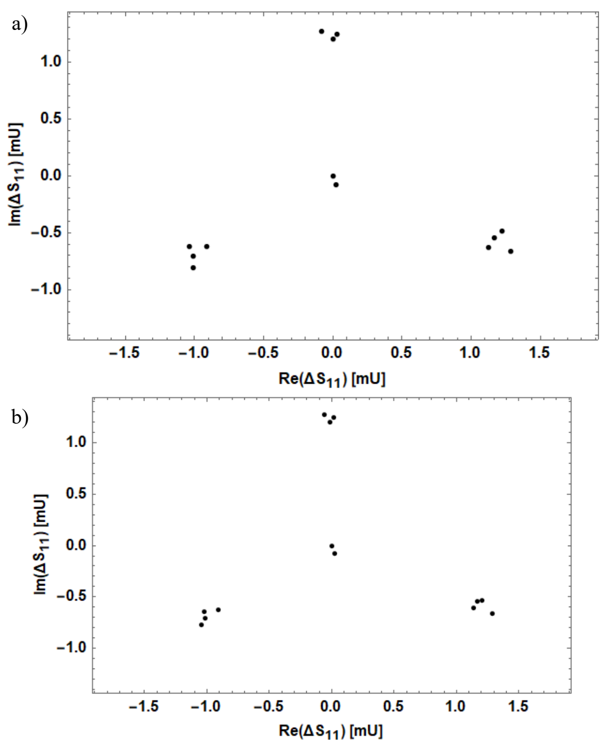

Figure 5: Phase advance in the center of couplers and cells before (a) and after (b) smart combination.

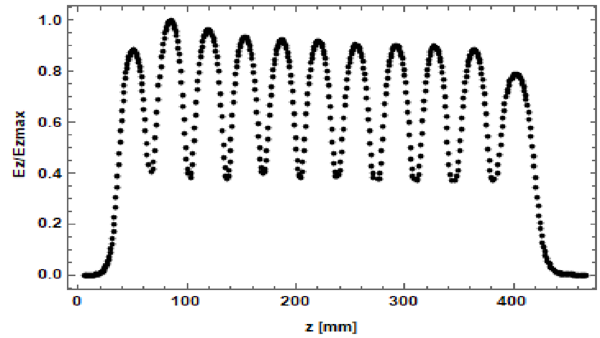

Figure 6: E_z distribution on axis in improved system.

It is shown that for the random configuration, the phase advance is ±4° for 9 cell prototypes and for the best-configured state, the phase advance is less than ±2°.

It should be noted that during the measurements they did not experience any mechanical deformation (tuning). The improvement is only a consequence of changing the alignment. This procedure is called pre-tuning and should be done before brazing to decrease the routine of tuning after brazing. Obviously, after pre-tuning, the effectiveness achieved in tuning after brazing will be more effective than without pre-tuning.

CONCLUSION

The variance between the characteristic dimensions of the manufactured cells and the design dimensions results in deviations of the phase advance from the intended 120 degrees. These deviations can accumulate with any cell arrangement, potentially resulting in significant phase discrepancies. The suggested smart combination method enables arranging the cells in a manner where one cell compensates for the phase lead shift of another, thereby reducing the average phase lead deviation. This facilitates pre-tuning before soldering, making post-soldering tuning significantly easier.

As demonstrated in the case of the 9-cell prototype, it was possible to reduce the phase advance deviation by more than 2 times. Moreover, with a large number of cells, smart combinations work more effectively. Initial simulations for 42 cells show a near phase advance deviation of up to ±1 degree. If necessary, it is also possible to replace before brazing the worst cells found, obtaining much smaller deviations.

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