

PERFORMANCE OF NORMAL CONDUCTING STRUCTURES FOR LINEAR COLLIDERS

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In the present paper are described the status of the design, fabrication and various performance studies such as the high-field characteristics and the wake fields on the accelerating structures for the linear collider linacs in such projects as CLIC, VLEPP, NLC, JLC and SBLC[1].

The structure design and the fabrication of the structures for the single-bunch machine has almost finished, while those of the structures for the multi-bunch operation are in progress. For the design of the latter structures, various calculation methods of the long-range wake field are being discussed in addition to the experimental evaluation of the HOM parameters.

A direct measurement of the long-range wake field in a detuned structure was successfully performed and was proved to be a nice tool for the evaluation of design and fabrication of the structure. In addition, the beam induced dipole modes coming out of the coupler into wave guide was measured which makes it possible to use the accelerating structure as the BPM.

A heavily damped choke-mode structure at S-band was tested at high power showing stable operation at more than 50MV/m. Another choke-mode structure with integrated damping loads is in progress.

Stable operations of the disk-loaded structures from S-band to 30GHz were verified at the design fields.

Fabrication studies are proceeded in all projects focusing on various issues such as a good alignment, cheapness and less dark current.

I. INTRODUCTION

A review paper on the linear collider structures was presented by the author at the previous conference[2] and the present paper is focused on the later progress.

Accelerating structures for linear collider main linac are designed as at a high frequency as possible from the structure efficiency point of view. However, higher frequency structures cause larger wake fields which increase the emittance both in single-bunch and multi-bunch machines. Though there are various beam-based correction schemes proposed to suppress these effects, the structure should also be designed to suppress the wake field itself.

The designs of the structures for the single-bunch machines were almost fixed. The fabrication of the prototype structures were finished[3,4] and the high power performance of those structures are in progress.

On the other hand, the design of the structure for the multi-bunch operation should have significant considerations of the higher order modes in the structures and various designs are still discussed. Even in CLIC, the feasibility study on the

multi-bunch operation by re-designing of the structure has been started in order to increase the luminosity[5].

A straightforward way of reducing the long-range wake field, damping HOM field heavily toward outside accelerating cell, was proposed in a choke mode structure. An S-band choke-mode structure was tested in high power and proved the stable operation at 50MV/m[6].

Another idea to reduce the long-range wake field, cancellation among the wake fields of all modes by detuning of HOM frequencies of the cells, has been considered[7]. To accomplish the cancellation, it is necessary to keep the HOM frequency distribution very well or to incorporate a medium damping mechanism. Various approaches are studied and presented in the present paper such as the possibility of pure detuned structure realized with precise fabrication technique[8], medium-damped detuned structure[9] and the detuned structure with some heavily damped cells[10].

Prototype structures have been fabricated in all of the projects. In the process, various important experiences such as the alignment of the cells in a structure are being obtained. Studies on the high field operation of those structures are also performed. It was proved that the stable operation of the structures at the accelerating field of the initial stage of the linear colliders was quite easily obtained. Some of these recent results are reviewed in the present paper.

II. REQUIREMENTS FOR THE STRUCTURE

Typical design parameters related to the accelerating structures are depicted from the parameters in reference [11] and listed in the following table for reminding in mind the rough idea of each approach. In order to preserve the single-bunch emittance, the alignment of the beam hole aperture is essential. The tolerances in the case of multi-bunch operation depend on the details of the HOM characteristics and the alignment of the cells where most of the stored energy exists. Design accelerating field are determined mainly from the available RF power generation scheme aiming at the low and initial version of cm energy of each project.

Table 1. Typical parameters of structures.

	CLIC	VLEP	NLC	JLC	SBLC
Freq [GHz]	30	14	11.4	11.4	3
Bunch Space	10	-	16	16	48
# Bunch	1-10	1	90	85	125
Field [MV/m]	80	100	50	73	21
Length [m]	0.28	1	18.	1.3	6
Filling [ns]	11.6	110	100	110	800
Align [μ m]	5	1	6	1	30

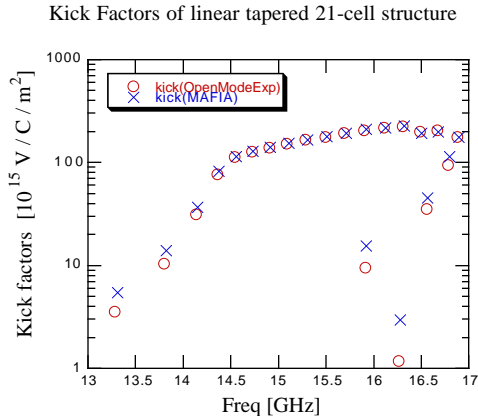


Fig. 1. Kick factors of 21-cell structure.

IV. DAMPED STRUCTURE

The study on heavily damped structures for linear colliders was initiated from the structure with radial slots in the disk. The structure with circumferential slots in a cell was also studied as a candidate for the heavily damped structure. However, the application of these structures for heavily damped scheme was almost closed due to the reduction of the Q value of the accelerating mode in addition to the complicated shape of the cells. However, this heavily damped cell is studied aiming at the damped cells for SABLE, where several cells out of 180 are heavily damped serving as a medium damping for particular modes of the whole structure[9].

An extreme of the above circumferential slot, i.e. opening the slot over 2π while trapping the accelerating mode inside the cell by choke, was proposed[5]. This choke-mode structure damps almost all the relevant modes in the cell with sacrificing the shunt impedance of the accelerating mode by only 25% by mainly establishing the field in the choke. An S-band choke-mode structure with 12 choke-mode cells, though without loads for HOM, and two coupler cells was fabricated for a proof of the high power operation and tested in high power[5]. The structure was conditioned up to 50MV/m and accelerated beam without any problem. A prototype structure with choke-mode cells with HOM loads equipped and collinear loads at the end of the structure, making the vacuum vessel insertion simple, is under design[12].

V. DETUNED STRUCTURE

A. Estimation of wake fields

Various codes to estimate the wake field in the structure with detuning of the HOM frequencies were reviewed in the previous paper[2]. Those estimations should be proved experimentally.

Direct MAFIA calculation[13,14] of 21-cell linear tapered structure was compared with open mode expansion method[15]. The results are plotted in the following figure. The agreement is quite nice at least for the structure with this small number of cells.

The frequencies of another structure, a 28-cell detuned structure was evaluated by using the open mode expansion technique and compared to those measured showing good agreement, while the measurement of the kick factors was too difficult to compare with those calculated[15]. The frequencies agree within 0.1% for almost all high kick factor modes. Similarly, the study on 36-cell structure was started to evaluate the kick factors[16] and compare with those calculated by such as the mode matching technique[17].

B. Damped Detuned Structure

In order to keep the wake field below the tolerable level at longer time range of say 50'th bunch or later, the medium damping mechanism seems hopeful. A simple way to realize this condition is to make the Q values of higher modes in all of the cells less than 2000 at X-band[18]. To reduce the number of loads and make them reside far from the accelerating cells, a manifold damping mechanism was proposed[8]. This structure is called Damped Detuned Structure, DDS, and seriously considered to study in fabrication, high power and wake field point of view.

C. Lossy cells

An old idea of the Kanthal coating on the copper cells near the beam hole was proposed to reduce the Q value of the higher modes while keeping that of the accelerating mode fairly small[19]. The Q values of the dipole modes can be a few thousands at S-band while maintaining the reduction of the accelerating mode less than 10%. This technique will also be applicable to replace the output coupler cell with several lossy cells.

D. Coupler designs

The extensive studies on the coupler for SBLC is continuing[20]. The coupler has symmetrical inputs which makes the transverse kick due to the accelerating mode negligibly small and also absorbs the dipole modes of one of two polarizations. The dipole modes of another polarization are absorbed into the other two ports which are opened at the position perpendicular to the input ports. These ports can be used for the beam position monitoring in the structure.

VI. MEASUREMENT OF LONG RANGE WAKE FIELD

A direct measurement of the wake field of a 1.8m detuned structure was performed at ASSET using SLC beam[21]. The results was shown in the Fig. 2 with those

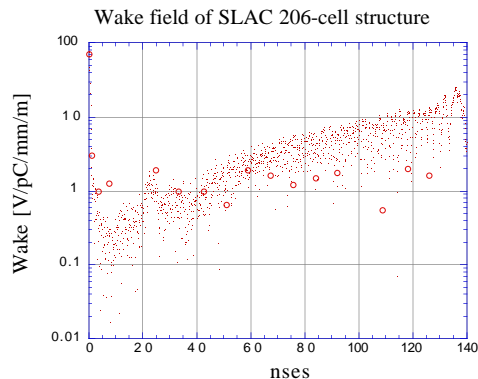


Fig. 2. Envelope of the wake field of SLAC 1.8m structure. Dots are those calculated and open circles are those measured.

estimated by open mode expansion method[15]. The measured wake field is in fairly good agreement with that calculated, showing non-negligible contribution from those of higher modes than second dipole pass bands in the region of up to 30ns. It should be noted that there still remains the disagreement later than 60ns, which should be understood.

This experiment was proved to have the sensitivity of 0.1V/pC/mm/m. Since the rule of thumb of the required damping for X-band structure is 1/100, this sensitivity is large enough to practically judge the wake field of the structure. It also makes the serious checking of the theoretical estimations possible.

The beam induced powers of the dipole modes extracted from both input and output coupler of the SLC accelerating structure were measured. Some modes were linearly correlated to the beam transverse position, indicating the possibility to use this signal for the BMP[22]. A similar experiment will be performed in the ATF for the VLEPP 14GHz structure equipped with the high precision BPMs to detect the power output from the coupler cells[23].

VII. HIGH FIELD CHARACTERISTICS

The 30GHz structure was tested in CTF by feeding the power extracted from the same type of cavity into the test cavity. The accelerating field of 94MV/m in 12nsec duration was obtained without any sign of the breakdown[10]. This field is above the design field of the CLIC.

The X-band short-length structures were proved to be operated at over than 100MV/m. The dark current from 26-cm structure at 125MV/m was 2mA, while that at 50MV/m was a few μ A[10]. The tolerable amount of the dark current and its characteristics should be studied especially in full-size structure. The high power testing of the NLC detuned 1.8m-structure showed the operation at the 50MV/m level is quite feasible and the test with more peak power is in progress.

A 5.2m-structure was fabricated as a test of fabrication and high power operation for the structure of 6m-structure of

SBLC[24]. The required level of accelerating field was easily obtained.

X-band structure showed a stop band, where no field emitted electrons cannot come out of the structure with more than 100 cells even above the critical gradient[26].

VIII. FABRICATION

The cells in any structure for the linear collider should be aligned to make the emittance preservation. The alignment tolerances for the structures above 11GHz are ranging from a micron to ten. The short stack of the cells proved to be made within several microns such as shown in the 30-cm structure[27]. A 1.2m stack of X-band cells was also tried and the alignment of better than 40 μ m was observed[28]. The structures for the multi-bunch operation with keeping the wake field low by detuning need the precise alignment. The R&D's for the better alignment during the fabrication or correction scheme are in progress.

All of the structure except JLC seem to adopt the frequency tuning after joining cells at fairly high temperature. In order to control the higher mode frequencies well and possibly reduce the mass production cost, the JLC X-band activity keeps the R&D on fabrication without tuning. The diffusion bonding seems to be a promising technique to make the bonding of the cells without large deformation of the cells resulting in a good frequency control capability. Several 30-cm structures were fabricated at various diffusion parameters and will be high power tested to examine the feasibility of high field operation. Up to now, no limitation arising from the structure itself was observed. However, the detailed studies on the prototype structures should be performed.

No evidence of breakdown of the 30GHz structure stated above may reflect the fact that the field emitted electrons cannot transmit more than one cell unless the accelerating field exceeds the critical gradient of more than 200MV/m at such a high frequency as 30GHz. The simulation results on X-band structure show the trapping of the field emitted electrons inside structure even above the critical gradient of 60MV/m for the structure with more than 100 cells while the amount of the dark current measured smoothly increases above 50MV/m[10,25].

Table 1 High-Field Experimental Results

Frequency	GHz	3	11.4	11.4	30
Length	m	5.2	0.26	1.8	0.3
Type		CG	CI	Det.	CZ
Input	MW	80	69	105	69
Eav	MV/m	21	125	55	94
Pulse	ns	SLED	150	75	12
Fill Time	ns	750	74	100	11.6

IX. SUMMARY

The design accelerating fields were already verified in the test structures in almost all of the projects. It is to be noted that the test of CLIC 30GHz structure did not show any sign of the break down. The further studies of fabrication of the prototype structures are in progress. One of the main studies being performed is to obtain the required straightness of the structure. In addition, the design studies to suppress the effect of the transverse higher modes in detuned structures are in progress. Theoretical estimations are compared to those calculated by such a code as MAFIA, those measured in cold test stack or those obtained by the actual measurement of the wake field using two beams, drive and test beam. A heavily damped structure of choke-mode type will be fabricated to study the wake field performance in addition to the high field characteristics. The design and fabrication of the prototype structures can be checked on their wake fields experimentally.

X. ACKNOWLEDGMENTS

Numerous colleagues for linear collider studies are cordially acknowledged for providing me various information, though I cannot refer independently. Many of the information comes from the recent workshop LC95[29].

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