The Wakefields in Superconducting Accelerating Cavities of New Type for TESLA Collider

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Abstract

The first stage of the TESLA Test Facility (TTF) superconducting electron linac is already in its final state of assembling. The large number of superconducting accelerating cavities underwent the various complicated preparation procedures and many of them reached the specified accelerating gradient of 25 MV/m. Nevertheless, as the RF accelerating system is dominating part of the future machine, an optimisation and a reduction of its cost is still very actual. Some ideas proposed by DESY team were reported at the PAC97 Conference [1] and are discussed on regular TESLA Workshops [2].

The cavities are the main source of wakefields related losses and beam instabilities in a linear collider. The part of the work concerning the wakefields generation in new structures proposed by DESY was done in our Institute. In this report the calculated longitudinal and transverse loss factors in enlarged iris cavity proposed in [1] and in the superstructure composed of four 7-cell cavities with slightly modified TTF shape are compared with the corresponding values [3] of cavities currently used in TTF**.**

1 INTRODUCTION

The experience already gained during the development of 1.3 GHz superconducting RF accelerating cavities for TESLA collider indicates that some design parameters could be reconsidered having in mind the cost reduction of the future collider. The detailed approach to that problem was reported on PAC'97 Conference [1] and on several TESLA Meetings [2] where the new shapes of accelerating cavity and cavities' arrangements were proposed.

The points considered are: the shape of the cavity and the fill factor (the ratio of the active cavity length to the total cavity length). The present design of TTF superconducting accelerating cavity consists of 9 weakly coupled cells. It operates in p mode at frequency 1.3 GHz. The string of 8 cavities, each cavity equipped with fundamental input coupler and 2 HOM couplers, is housed in the cryomodule. The shape of cavity actually used were elaborated some years ago [4, 5] and were optimised to have reasonable cell-to-cell coupling k_{cc} , high beam impedance (R/Q) for the fundamental mode and to keep the safe values of the surface peak electric and magnetic fields. The chosen iris aperture, which is a compromise between the above criteria, gives the coupling factor k_{cc} = 1.9%. As the error of field amplitude in a standing wave cavity made of N cells is proportional to N^2/k_{cc}, the small value of k_{cc} makes the actual cavities sensitive to the technological processing during cavity preparation. This has direct impact on cavity production costs.

To avoid the coupling between neighbouring cavities the 3?/2 lengths interconnecting beam tubes were chosen to get good cavity separation. This reduces the effective accelerating field by the ratio of cavity active length to the cavity total length. Two ways to solve this problem were proposed in last two years. In [1] it is proposed to enlarge the iris aperture and to enlarge also the end tube diameters of the cavity in order to facilitate the HOM damping. The second approach [2] preserves the shape of TTF cavity inner cells but limits to 7 the number of cells in one cavity. The diameter of interconnecting beam tubes is increased and their length limited to ?/2 allowing the transmission of RF power from cavity to cavity. The set of 4 cavities (superstructure) is powered by one input coupler.

The proposed changes influence significantly the wakes induced in cavities. In a linear accelerator the accelerating cavities are the main source of wakefields induced by intense electron bunches. The wake-potentials and loss factors have to be evaluated whenever the modifications of the system seen by the beam are made. The wake-potentials calculated for both proposed schemes are reported in this paper.

2 WAKEPOTENTIALS

The wakes induced in a cavities by the gaussian bunch of standard deviation s = 1 mm and 0.5 mm were evaluated by the procedure [6] used earlier for the actual TTF cavity wakefield calculations. For the case of enlarged iris cavity this enables the direct comparison with TTF cavity, regardless of possible systematic inaccuracy due to the finite size of the mesh and errors inherent to the code used for the computation.

The size of mesh in z (axial) and r (radial) direction in ABCI code[6] is limited only by the computer speed and the available memory. For very short bunches, which is the TESLA case, this time domain code gives correct results when the mesh size is not larger than 10 % of the bunch length. It can be verified [7] by running the code with different transverse off-sets of the driving bunch from the axis of a cavity .

2.1 THE LARGE IRIS CAVITY

The changes of shape proposed in [1] for a new cavity is listed in the Table1 and shown in Fig. 1.

Table1. Modifications of 9-cell TESLA cavity

	TTF 9-cell cavity	**Large iris 9-cell cavity**
R_{iris} of inner cell	**35 mm**	**51 mm**
$R_{equator}$ of inner cell	**103.3 mm**	**108.08 mm**
$R_{equator}$ of outer cell	**103.30 mm**	**106.6 mm**
R_{tube} of end cell	**39 mm**	**55 mm**

Each cell of the new cavity has elliptical shape in the equator region and circular with the 17 mm curvature radius at the iris aperture. End cells have slightly smaller equator radius to compensate the influence of the beam tube opening.

The detailed data on optimised shape of inner and outer cells were taken from authors of [1] and are listed (as they are used in calculations) in Table 2.

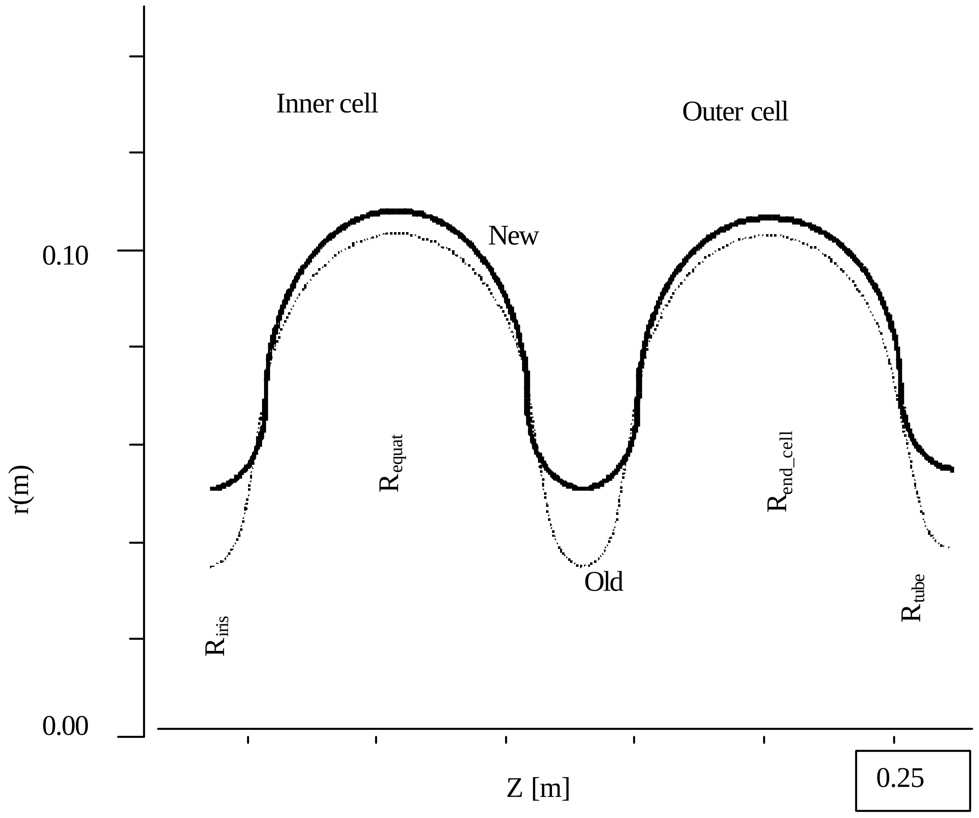

Fig. 1 The proposed modifications of shape of 9-cell cavity.

Table 2. TESLA 9-cell S.C. new type cavity shape (1/2 of cavity)

r[m]	z[m]	continued :
0.0	0.0	%3-rd iris
0.10808	0.0	-1. , 0.017
% first half ellipse		0.051 0.2882615
-3., 0.1		-1. , 0.017
0.068	0.0	0.068 0.3052615
0.068	0.0406523	%4-th ellipse
%Iris circle		-3. ,
-1., 0.017		0.068 0.3459138
% Iris1		0.10808 0.3459138
0.051	0.0576523	%equator
-1., 0.017		-3. ,
0.068	0.0746523	0.068 0.3459138
%2-nd ellipse		0.068 0.3865661
-3.,0.21		% 4-th iris
0.068	0.1153046	-1. , 0.017
0.10808	0.1153046	0.051 0.4035661
-3., 0.22		-1. , 0.017
0.068	0.1153046	0.068 0.4205661
0.068	0.1559569	% last ellipse
% 2-nd iris		-3. , 5.
-1., 0.017		0.068 0.4612184
0.051	0.1729569	0.1066 0.4612184
-1., 0.017		% last equator
0.068	0.1899569	-3. ,
% 3-rd ellipse		0.072 0.4612184
-3., 0.31		0.072 0.5018707
0.068	0.2306092	-1. , 0.017
0.10808	0.2306092	0.055 0.5188707
%equator		% end tube
-3., 0.32		0.055 0.6000

0.068	0.2306092	0.0 0.6000
0.068	0.2712615	%end of shape data

2.1.1 Wakes in large iris cavity

The longitudinal (monopole) wakes induced in 9-cell cavity by s =1 mm bunch are illustrated in Fig.2. The comparison is made between two cavities. Curve 1 shows the wake induced in the new cavity and curve 2 the wake in the old one at present in use in TTF.

The following, Fig.3, shows the monopole wakes induced by the bunch of s =0.5mm. In Fig.4 and Fig.5 the comparison is made for transverse wake induced in both cavities.

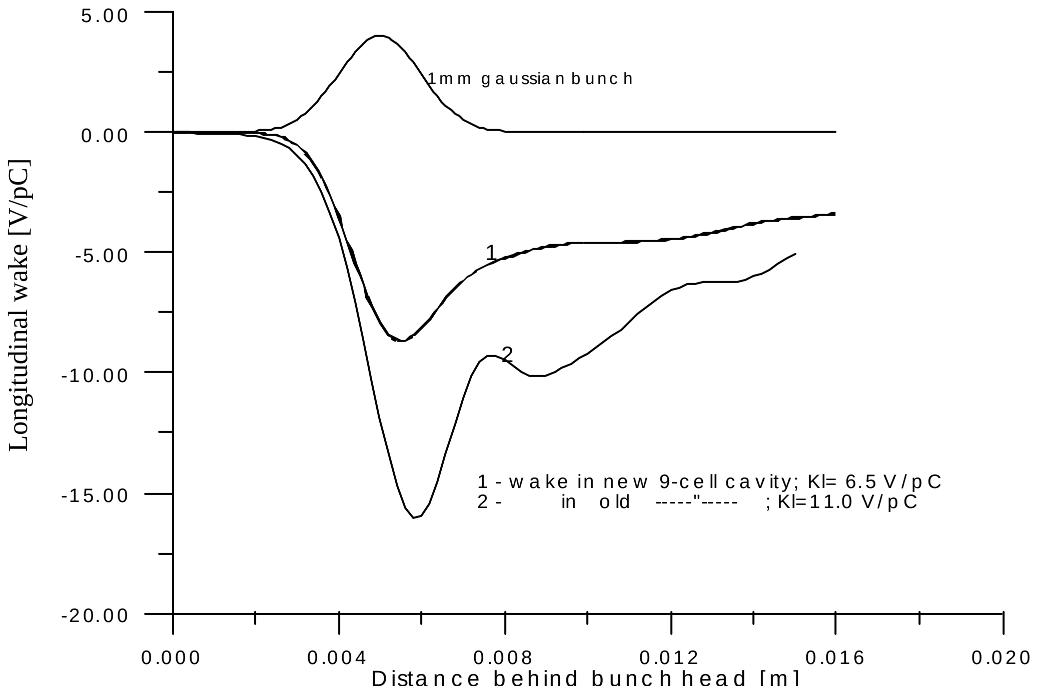

Fig.2 Longitudinal wake induced in 9-cell cavities by 1mm gaussian bunch. Comparison of the TTF cavity (1) and the enlarged iris cavity (2).

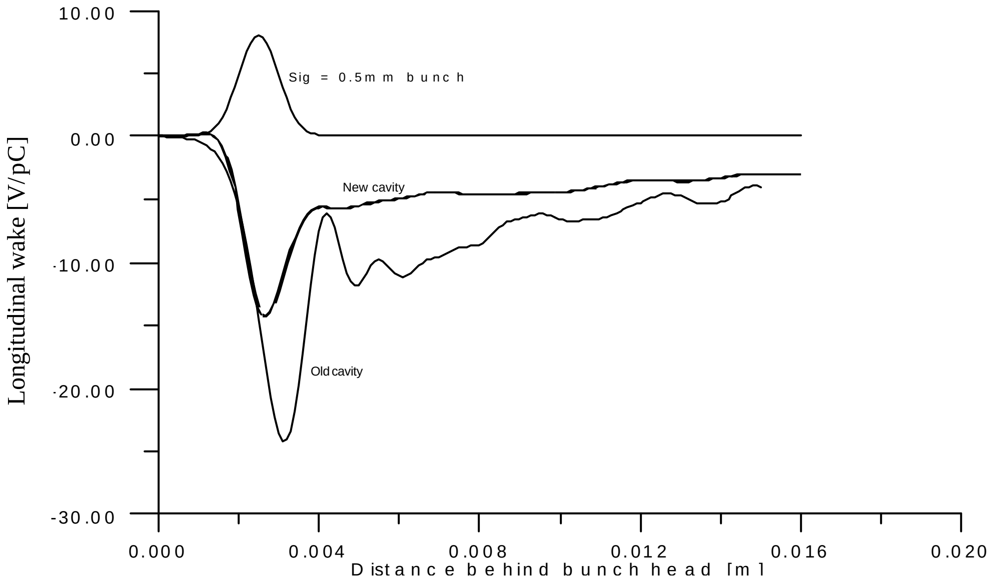

Fig. 3 Longitudinal wake induced in 9-cell cavities by the 0.5 mm gaussian bunch. Comparison of the TTF cavity (1) and the enlarged iris cavity (2).

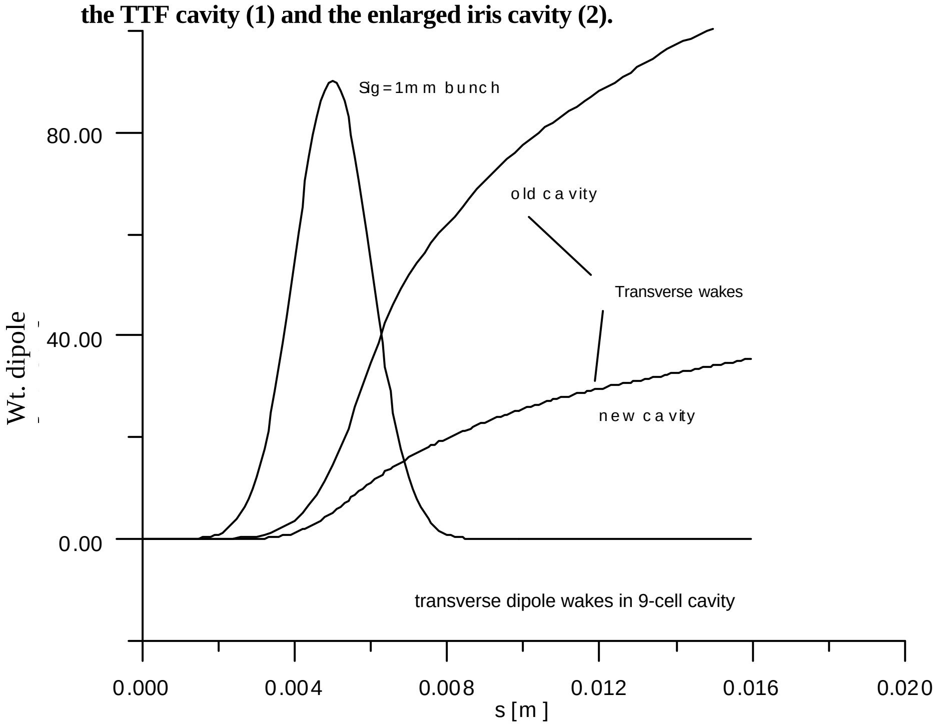

Fig. 4 Transverse dipole wake induced in 9-cell cavity by s = 1mm gaussian bunch. Comparison of the TTF cavity (1) and the enlarged iris cavity (2).

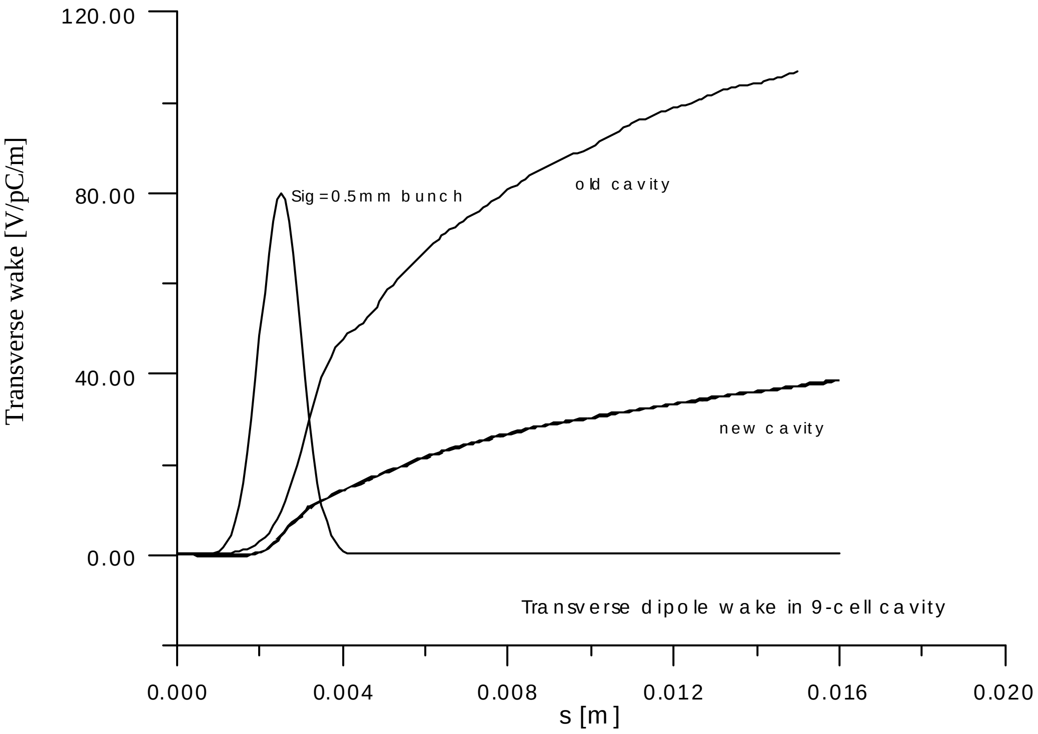

Fig. 5 Transverse dipole wake induced in 9-cell cavity by s = 0.5 mm gaussian bunch. Comparison of the TTF cavity (1) and the enlarged iris cavity (2).

The resulting loss factors for both cavities are summarised in Table 3. The listed monopole loss factors k_l, include also the loss to the fundamental mode passband.

Table 3. Longitudinal and transverse loss factors of 9-cell TESLA cavities

s $_{bunch}$	TTF cavity		New cavity	
[mm]	$k_{|}$ [V/pC]	k_{-}[V/pC/m]	$k_{|}$[V/pC]	k_{-}[V/pC/m]
1.0	11.05	20.6	6.53	6.21
0.5	15.58	12.96	10.20	4.74

2.1.2 Frequency spectrum of energy loss factor $k_{|}$ of enlarged iris cavity.

The tracing of longitudinal wake over time following the passage of the bunch through the cavity shows no longer the spurious behaviour present in the previous calculations [3]. The problem is solved by substantial lengthening of cavity end tubes ($l_{tube} \cong 2xR_{tube}$). This has to be paid for by longer computation time. To obtain result shown in Fig.6 and Fig.7 one needs about 75 hours of CPU time on CONVEX-C-3210 (the machine of capabilities comparable to SUN-Sparc10). The figures show longitudinal wake excited by σ=1mm vs. the distance behind the bunch up to 3.5 m. The $k_{|}$ loss factor frequency spectrum obtained from the Fourier transformation of this “long” wake is shown in Fig.8.

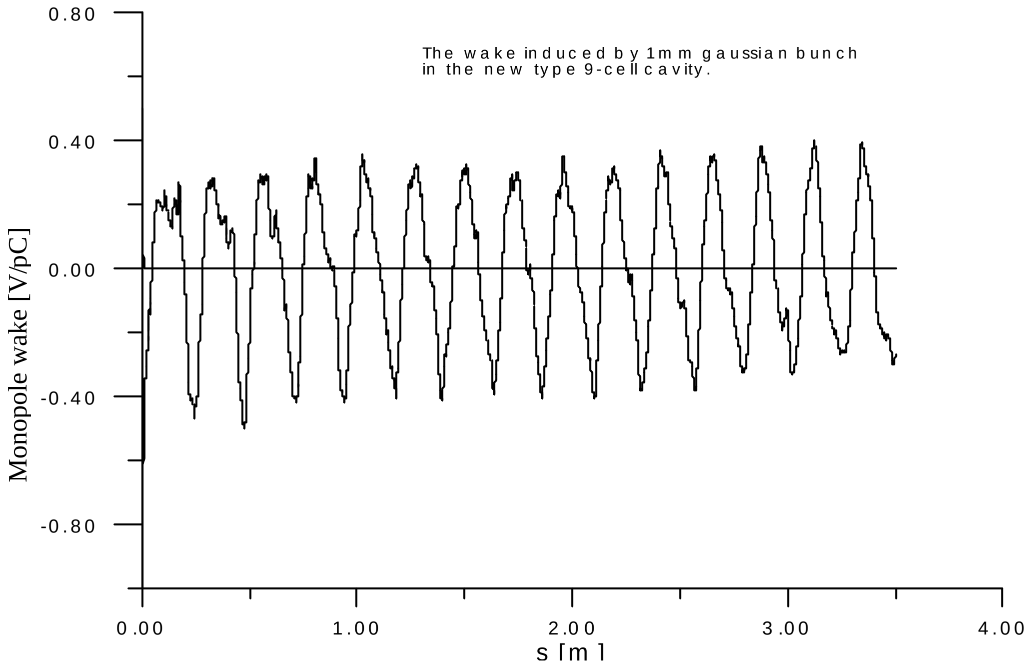

Fig.6 The longitudinal wake in the new type 9-cell TESLA cavity vs. the distance s behind the bunch front. The s_{bunch} = 1mm.

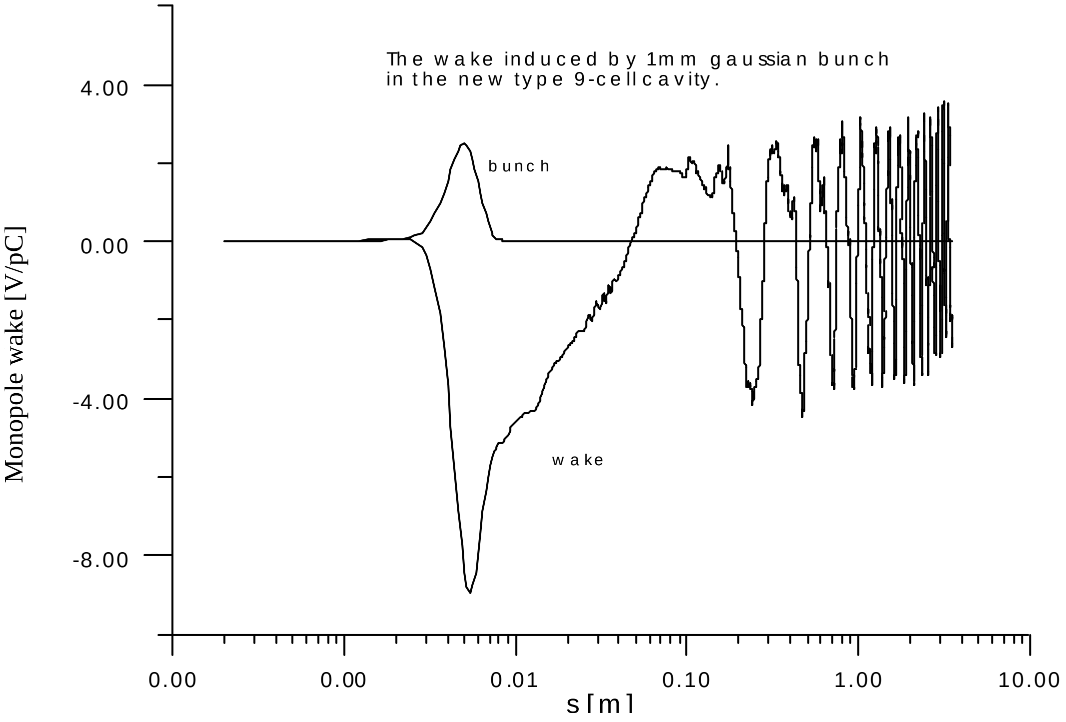

Fig. 7 The details of longitudinal wake at small values of s. s = 1 mm.

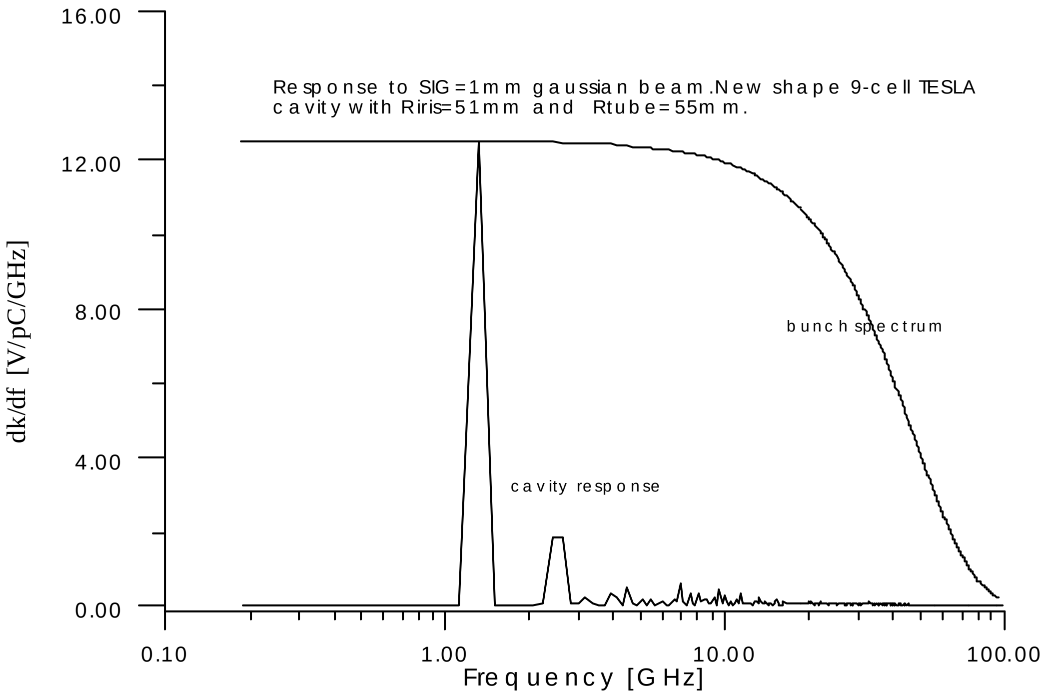

Fig. 8 Frequency spectrum of k_l in new shape TESLA cavity.

For the σ =1mm bunch, the plot of longitudinal loss factor integrated over frequency is shown in Fig.9. The clean steps on this plot correspond to the increase of loss factor due to successive resonant modes.

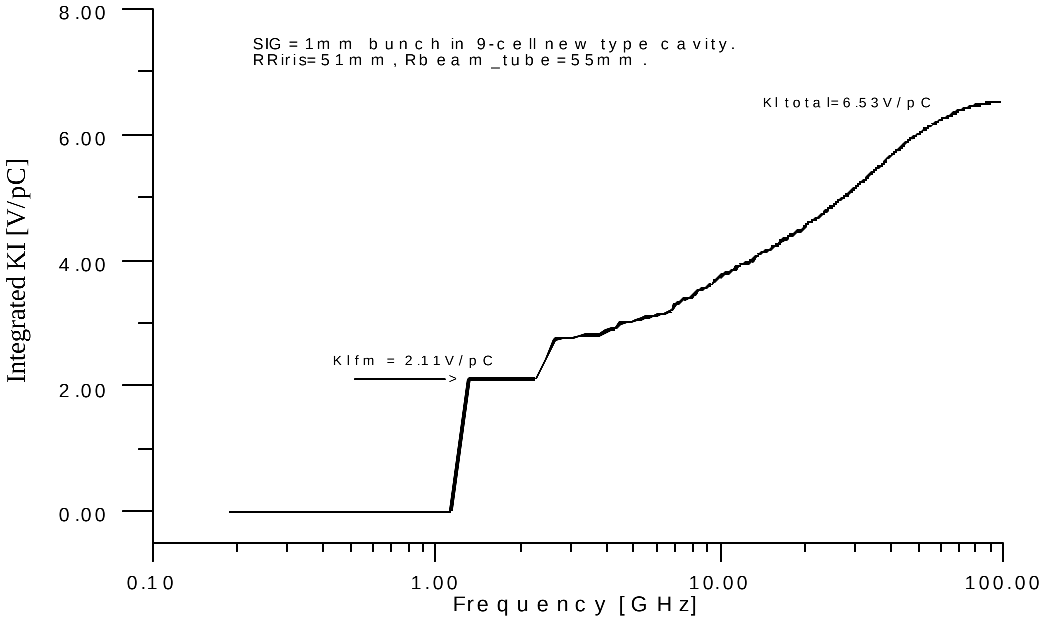

Fig. 9 Integrated longitudinal loss factor in the new type 9-cell TESLA accelerating cavity. Gaussian bunch of s = 1mm length.

The fundamental mode loss factor read from this plot is equal to 2.11 V/pC. The HOM loss factor of monopole modes is then:

$$\mathbf{k_{lHOM} = k_{ltotal} - k_{fm} = 4.4\ V/pC} \quad \text{for a new type 9-cell cavity.}$$

2.1.3 Consequences

The opening of iris and beam tube apertures of 9-cell TESLA cavity as proposed in [1] has clear advantage as far as the loss factors are concerned. Increasing the apertures to the dimensions given in Table1 reduces $k_{longitud}$ by the factor of 1.7 and k_{transv} by the factor of 3.3 when the new and old cavities are compared taking a bunch of $\sigma = 1$mm. The value of longitudinal loss factor of HOM is 4.4 V/pC in the new cavity. That parameter calculated in [6] for old cavity is 8.97 V/pC. The transverse loss factor is reduced from 20.6 V/pC/m in old cavity to 6.21 V/pC/m in the new one. These values have to be compared to the allowed TESLA collider design HOM loss factors[8] which are as follow: $k_{lHOM} \leq 8$V/pC and $k_{trHOM} \leq 18$ V/pC/m.

2.2 *Superconducting Superstructure*

The second approach to RF system optimisation preserves the shape of TTF single cell but reduces to 7 the number of cells in one cavity. The input and output cells are modified to allow the coupling of cavities for the fundamental passband modes. The interconnections between the cavities are ?/2 long and have enlarged diameter from 78mm to 114 mm. The string of 4 weakly coupled and separately tuned cavities form a basic unit (superstructure) with 28 super-modes. The number of FM power couplers is thus reduced substantially (by a factor more then 3 in the case of 4 cavity superstructure). The total length of 200GeV linac becomes shorter by ~ 20%. Those factors directly scale on investment cost reduction. The limiting of number of cells in cavity provide very important safety margin on amplitude stability in individual cells. Since the cavities in superstructure are no longer uncoupled the superstructure must be treated as one unit in wake fields evaluation. The calculations were made for single 7 cell cavity, two cavities and four cavities in superstructure. The wakes induced by 1mm and 0.5 mm gaussian bunch are illustrated in Fig.10, Fig. 11 and Fig.12.

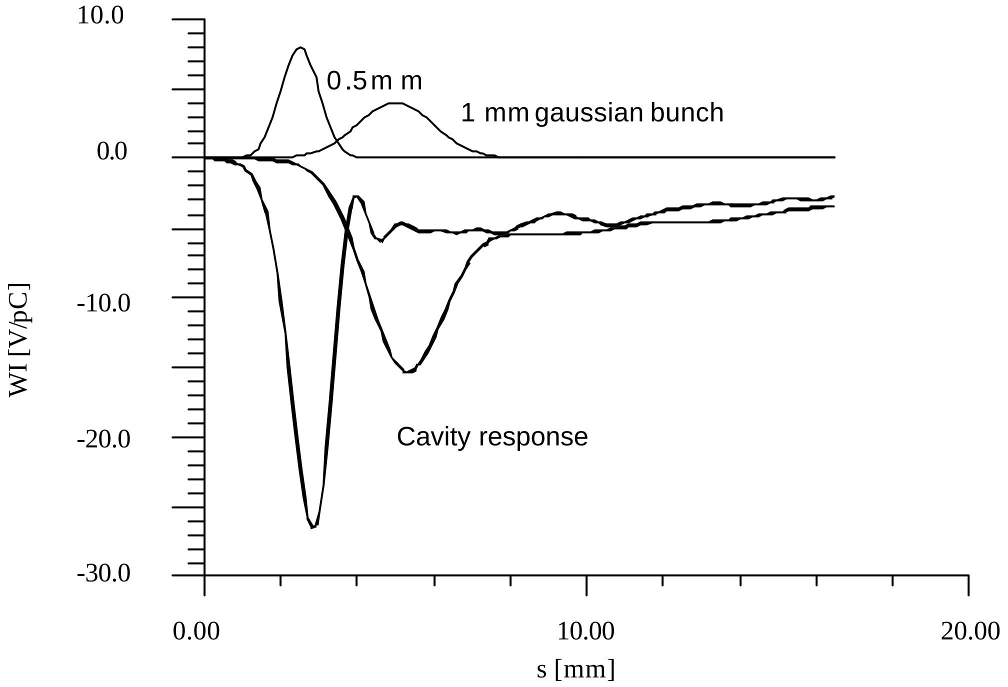

Fig.10 Longitudinal wakes for single 7-cell cavity. Gaussian bunch of s = 1mm and 0.5 mm

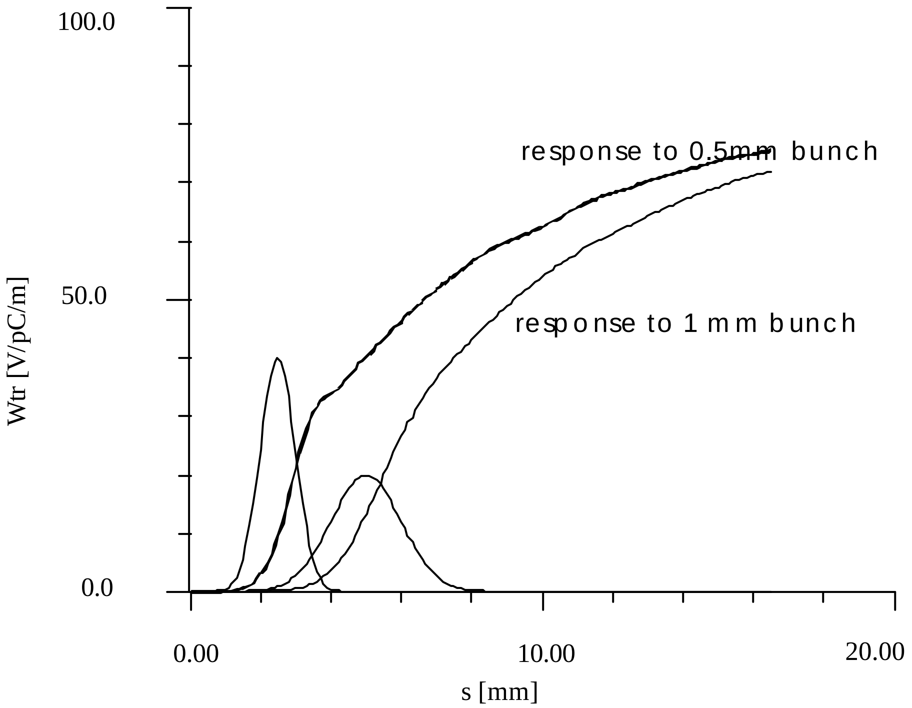

Fig.11 Bunch transverse wakes excited in 7-cell cavity by gaussian bunch of 1mm and 0.5mm standard deviation.

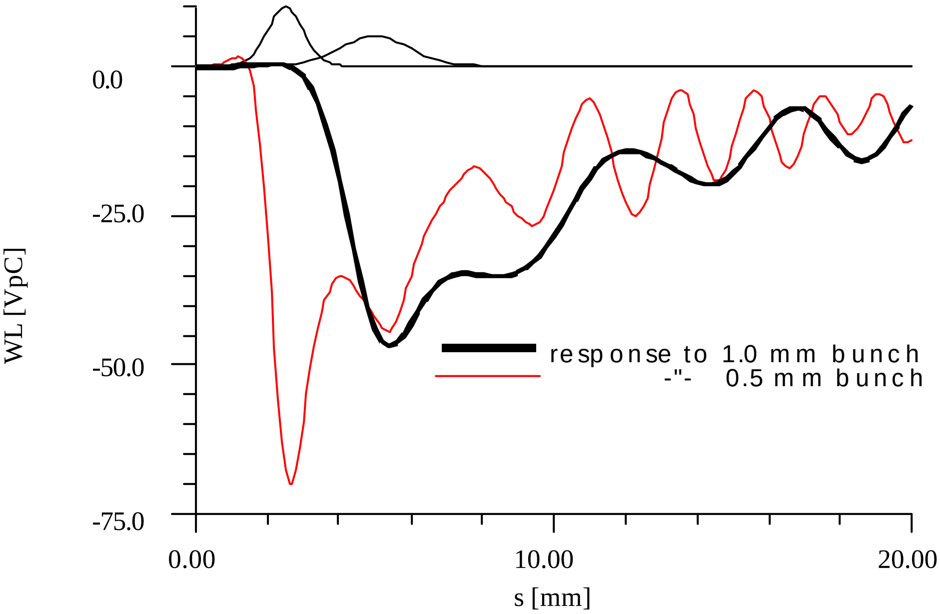

Fig.12 W¦ wakes in 4 cavities superstructure due to s =1mm and 0.5 mm gaussian bunch.

Table 3 lists the corresponding loss factors and Figs 13 and 14 show the frequency spectrum and summed up vs frequency longitudinal loss factor of 4 cavity superstructure.

Table 3. Longitudinal and transverse loss factors in superstructure

s bunch	No of cavities	k¦ [V/pC]	k- [V/pC/m]	k¦ dipole [V/pC/m²]
1 mm	7-cell	-10.65	15.29	-10350
1 mm	2x7-cell	-18.64	27.4	-19680
1 mm	4x7cell	-34.73	52.54	-39040
0.5 mm	7-cell	-18.29	11.7	-16370
0.5mm	2x7-cell	-29.17	21.01	-30600
0.5 mm	4x7cell	-51.17	38.05	-57960

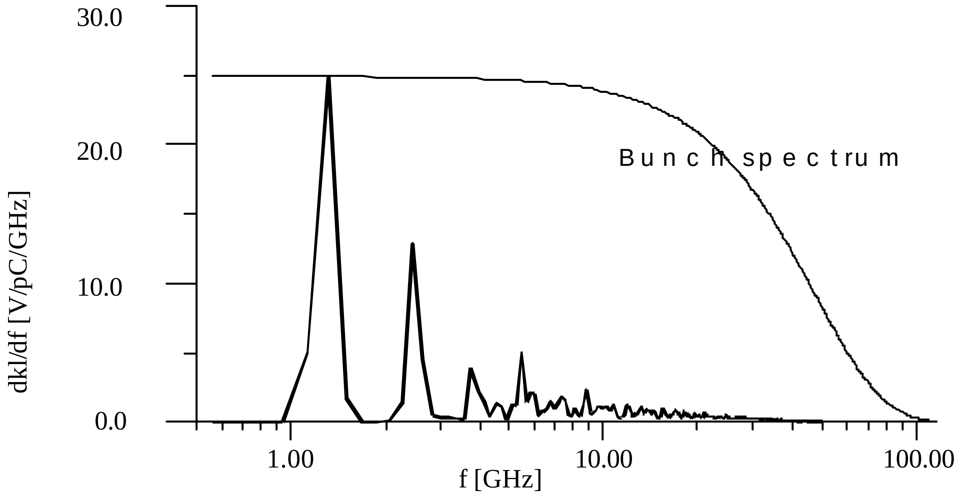

Fig.13 Frequency spectrum of k¦ of superstructure. Response to s =1mm gaussian bunch.

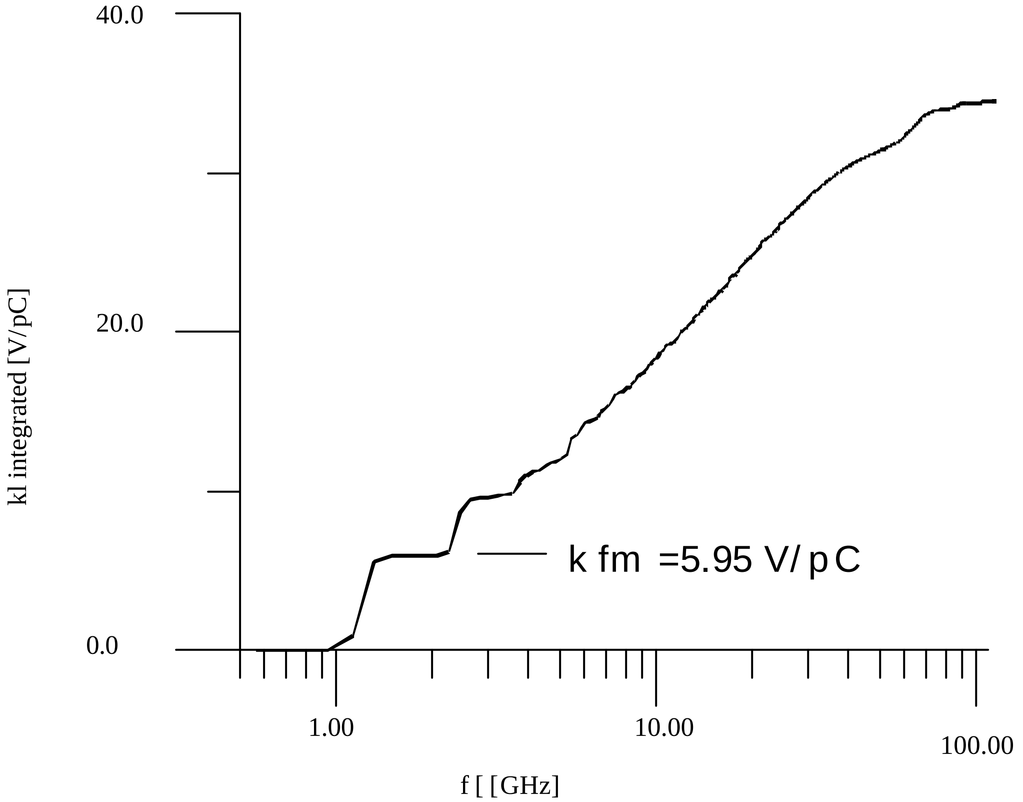

Fig.14 Integrated k¦ of superstructure composed of 4 cavities. s =1mm gaussian; k$_{¦\text{total}}$=34.56V/pC .

3 SUMMARY AND CONCLUSIONS

The wake potentials excited in proposed new schemes of accelerating cavities were evaluated and compared. The most favourable is ***large iris 9-cell cavity*** where the losses due to bunch current are lowest. The ***superstructure*** is favoured by arguments of high R/Q, safe margins on electron emission and quench level and by substantial reduction of investment costs for the TESLA collider. The room temperature models of 7-cell cavities were built in our Institute and sent to DESY/Hamburg where the working parameters of superstructure will be checked experimentally.

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REFERENCES

[1] J. Sekutowicz, D. Proch, C. Tang, “ Note on the SC Linear Collider TESLA Cavity Design”, Reports at the PAC 97, May12-16,1997,Vancouver,Canada.
see also Internal Report, DESY M97-10,August,1997.

[2] J. Sekutowicz, C. Tang, M. Ferrario, “Superconducting Superstructure for the TESLA Collider”, DESY, 1998, TESLA 98-07

[3] E. Plawski, “Wake-fields Induced by the Electron Beam Passing through the TESLA Accelerating System”, DESY,June1997, TESLA Rep. 97-12

[4] E.Haebel, A.Mosnier. “Large or Small Iris Aperture in SC Multicell Cavities” Proc.of The 5th Workshop on RF Superconductivity, Hamburg 1991

[5] E. Haebel, A. Mosnier, J. Sekutowicz, “Cavity Shape Optimisation for a Superconducting Linear Collider”, Proc. of XV International Conf. on HEACC, Hamburg,1992, p.957.

[6] Y.H. Chin, CERN-LEP/TH88-3 Report

[7] Y.H. Chin, KEK, Accel. Div., Japan [private communication]

[8] D.A. Edwards, ed., “TESLA Test Facility Linac-Design Report, DESY TESLA Rep.95.1