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MODEL MEASUREMENTS FOR THE SWITCHED POWER LINAC

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Abstract

To study some aspects of the structure of the switched power linac (or wakefield transformer), a scaled-up model with 2.4 m diameter has been built. Measurements were performed with real-time and synthetic pulses with spectral components up to 5 GHz.

Results are obtained for the achievable transformer ratio as a function of the spectral composition of the pulses and for the influence of discrete feeding at the circumference of the transformer disk. The effects of asymmetric feeding in space and time were also investigated experimentally as well as the influence of the central geometry.

Introduction

Detailed studies of specific problems related to the switched power linac (SPL) are actually under way[1][2]:

a. Pulse propagation and possible enhancement as function of different parameters for radial line transformers. Measurements on a scaled-up model are undertaken at CERN. These propagation studies are not only of interest to the SPL, but apply generally to all future accelerator schemes using the radial transformer principle (e.g. wakefield transformer).

b. Electro-optical problems of the photodiode switch are under study at BNL.

c. High voltage hold-off problems as expected for charging the photodiode, as well as in the accelerating gap, are about to start at both BNL and CERN.

Measuring Set-Up

Because of the small size of both the final SPL structure and the required measuring probes, as well as to reduce the bandwidth involved, we made a model scaled up in radius by 10:1.

It consists of a sandwich structure with two outer disks of diameter 2.4 m and a central disk separated by a 10 mm gap each side. For pulse transmission the model can be treated as a radial transmission or double sided stripline with its impedance increasing with r^{-1} from the periphery to the center.

One gap is actually fitted with probes across the diameter to study the propagation of signals. At the center a universal plug permits to use different kinds of probes with adequate spacing, adapted to the specific need of each study.

The photocathode discharge is simulated by feeding pulses from 64 equally distributed points on the circumference to the central disk. These pulses are either synthesized by using network analyzers or fast real pulses in connection with broadband oscilloscopes. Uniform feeding of these pulses is achieved with a wideband divider network.

Enhancement

The switched power linac concept can only be successful if the radial transformer can achieve the required high and reproducible accelerating gradients. At first approximation the transformer ratio is given by the geometry of the structure. In practice, a finite gap width and the risetime of the exciting pulse will prevent the enhancement to go to infinity. According to Cassell & Villa[3] the enhancement for a given outer radius R, gap g and a risetime t_r will be:

$$\varepsilon = \frac{V_0}{V_R} = 2\sqrt{\frac{2R}{g + c\,t_r}}$$

The presence of a beam aperture will reduce the electric field gradients on the beam axis and cause nonaxial field components in the accelerating gap. Mechanical imperfections will cause additional losses by creating nonaccelerating fields.

a) Without Beam Hole

By using the full 3 GHz frequency range of the network analyzer, corresponding to synthesized pulses with an equivalent risetime of 210 ps, we have measured enhancements as high as 9.4 (Fig. 1).

With real pulses of 200 ps risetime and a 1 GHz oscilloscope we obtain a gain of 8.5; about the same as for synthesized pulses of 310 ps or the network analyzer limited to 2 GHz. The difference in risetime or bandwidth is due to the different spectral composition of synthesized and real pulses.

Although about 15 to 20 % lower than calculated, all these results are in good agreement with the Cassell-Villa formula. By applying the empirically found correction one should be able to easily specify an optimized geometry for an efficient SPL structure.

b) With Beam Hole

Introducing an aperture for the beam into the structure reduces the field strenght on the supposed beam axis by 50% for a 4 cm hole and 25 % for a 2 cm hole, corresponding to a diameter on the real SPL of 4 respectively 2 mm. This loss is only a local reduction of the electric field due to the penetration of the field out of the acceleration gap. Particles travelling on axis will probably see the full voltage for acceleration. Detailed studies of the field distribution in this area are in preparation.

Looking at the pulses after having crossed the center of the structure has not revealed any difference of the pulse shape due to the hole. This might lead to the conclusion that the beam hole itself is probably not responsible for losses.

Asymmetries and Non-Uniform Feeding

An additional challenge for the SPL is the required geometric and temporal uniformity of the photodiode discharge. To simulate possible defects we have reduced the number of feeds by either disconnecting sectors (1/32, 1/16, etc.), or feeding alternate quarters to study quadrupole or dipole excitation with only one half of the structure powered.

Introducing delays into part of the feeds allowed to study effects due to different temporal response of the photodiode switch along the circumference.

In addition to data taken with the probes across the big diameter of the model, we used more closely spaced probes on the rotatable holder right in the center. Probes at the center and one, respectively two centimeters off-center proved to be adequate for studies in this area.

Data were normalized by correlating them in time to the maximum of the undisturbed enhancement rather than to take straightforward the individual maxima as done in previously published results.

Generally, the missing or delayed feeds cause an equivalent power loss in or near the center as expected. But the overall distribution near the axis is astonishingly uniform, even for extremely asymmetric feeding.

As can be seen from Figs. 2 and 3 , the dipole excitation is attenuated to 5 % at r = 2 cm and only 2 % at 1 cm. For the quadrupole mode (alternate quarters disconnected) the damping is even stronger with only 3, respectively lesss than 1 %. Without the beam hole the difference is even less pronounced.

Of particular interest is that the dipole effect as measured at the center, is in phase with the simulated edge defect, whilst the quadrupole is 180° out of phase.

These variations are already of the same order as those introduced by imperfections of the actual model. For this reason detailed measurements in the area surrounding immediately the center have not been done for the higher modes.

The distribution on the structure with 1/8 of the power disconnected is shown on Fig. 4. As the probes outside the center are only fixed ones, these results have been obtained by moving the feed defect around the circumference of the model.

It is surprising to see how all these possible perturbations are finally attenuated by the radial line structure and how close the maximum of the enhanced pulse stays to the supposed beam axis.

Pulse Propagation

The behaviour of the radial line transformer and the development of the pulses propagating from the periphery to the center of the disk structure is shown in Fig. 5.

The amplitude increases steadily until the two wavefronts start to overlap at r = 7.5 cm, resulting in the expected high peak right in the center. One notes that pulses having travelled through the center look differentiated. As already stated before, the presence of a beam hole is apparently of no influence on this effect.

These waveforms are in good agreement with the simulations carried out by M.E. Jones4). Slight differences are due to different spectral composition of the pulses and the fact that our model represents a short circuit for the pulses reflected at the periphery (ct/r = 2, 4, etc.), whereas Jones' calculations are done for a more realistic open structure.

Fig. 6 shows the propagation with 1/4 of the feeds missing equally on both sides of one row of the radial probes, similar to Fig. 4. The wavefronts from the nearest working feeds arrive with an appropriate delay and a reduced amplitude with respect to the expected pulse, as indicated by the markers. Arriving finally nearly on time in the central area and after having merged with the undisturbed pulse they continue with their smaller amplitude on the other side of the structure. This is a strong indication that pulses travel across the center rather than being reflected from it.

Conclusions

So far, the actual study allows a sufficient understanding of the behaviour of the radial line transformer in order to specify parameters for a switched power linac or similar approaches.

We can size the influence of possible mechanical tolerances as well as errors arising from the optical switch. The risetime of the photodiode and its reproduciability will be of prime importance for the reliable working of a future SPL.

Our measurements were still frequency limited by the network analyzer to equivalent risetimes of 210 ps on the model, corresponding to 21 ps on the final SPL structure. Accordingly, we can expect enhancements of at least 15 for possible risetimes of 5 ps, or better. This is not as high as assumed in the early proposal but still interesting enough for a future machine.

Acknowledgements

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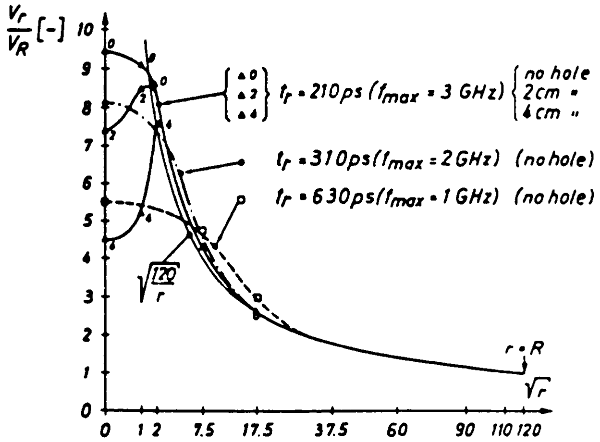

Fig. 1 Measured enhancement

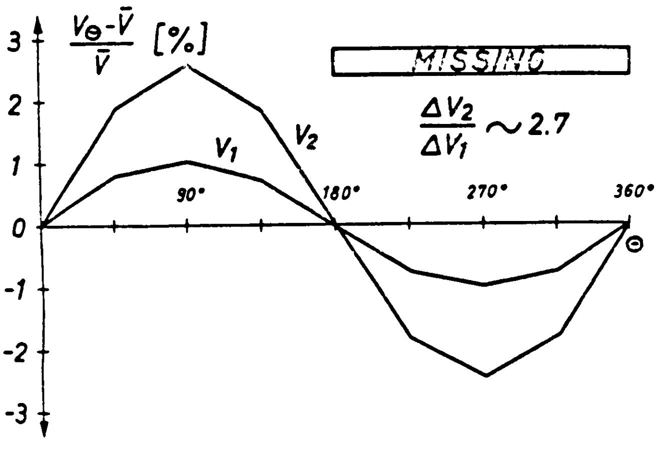

Fig. 2 Dipole excitation

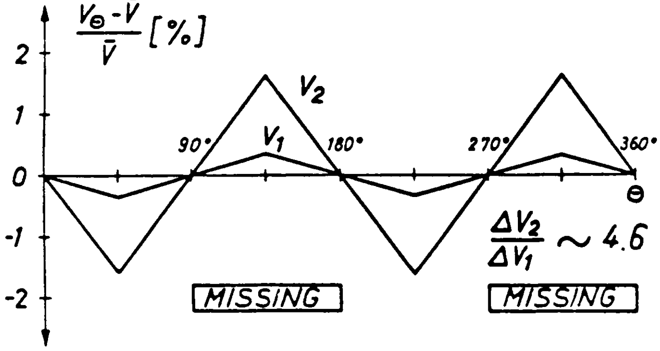

Fig. 3 Quadrupole excitation

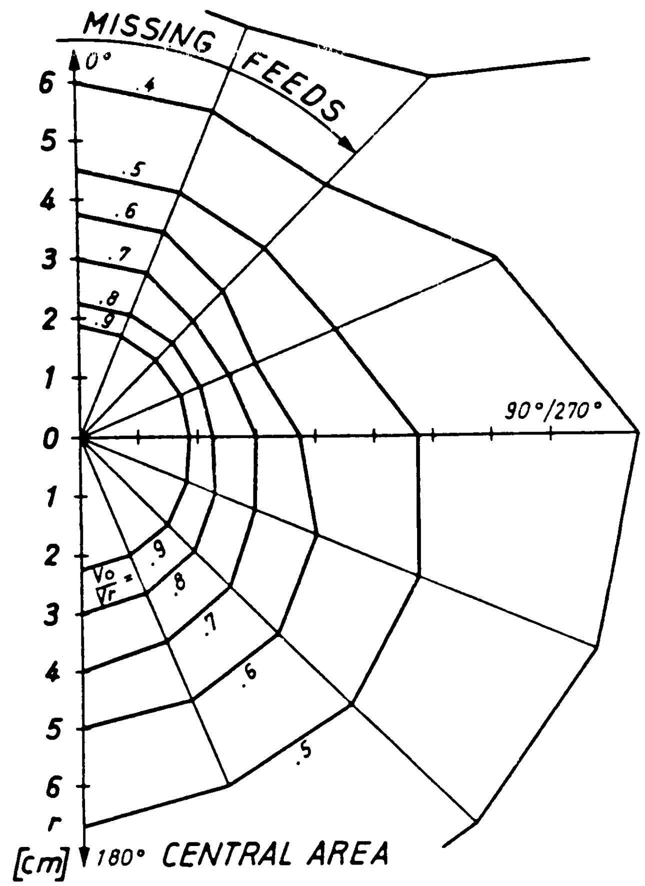

Fig. 4 Field distribution across the model with 1/8 of the feeds missing

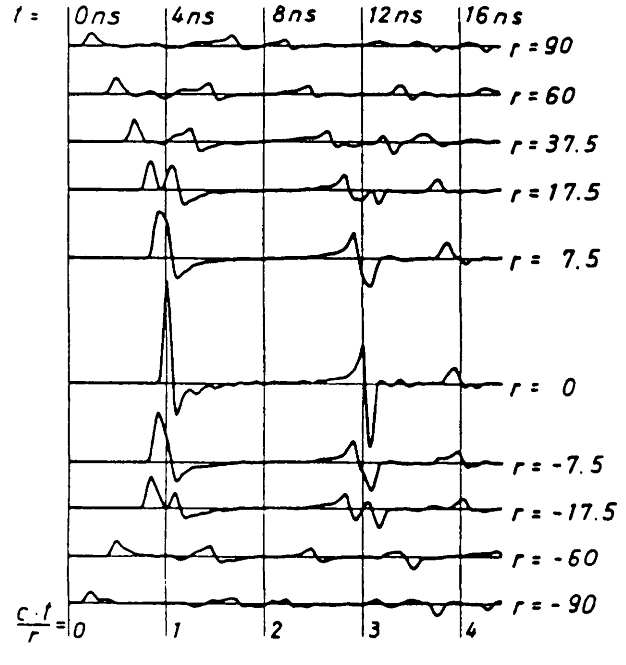

Fig. 5 Pulse propagation for homogeneous feeding

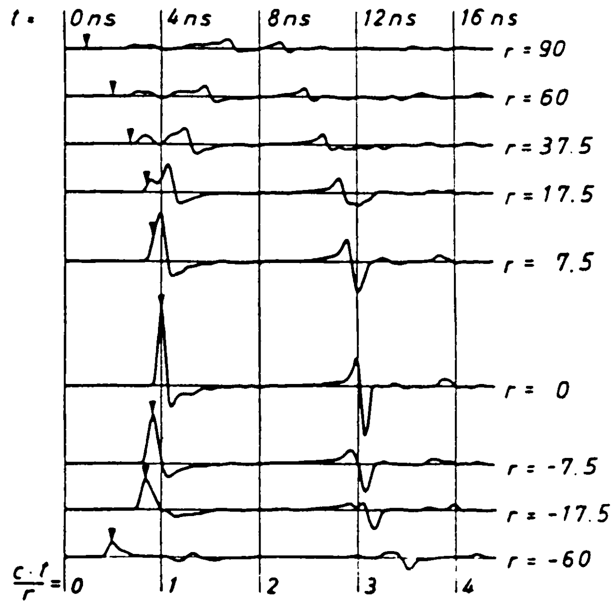

Fig. 6 Pulse propagation for 1/4 of the feeds missing