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Calorimetric Measurements of Parasitic Mode Losses in Different RF-Structure in DORIS

by

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Introduction

When charged particle bunches pass through cavity structures, parasitic modes are excited. These have been theoretically analysed [1),2),3)]. In the proposed large electron positron storage rings EPIC, PEP and PETRA the magnitude of the parasitic mode losses in the rf-accelerating structure can be of the same order as the synchrotron radiation losses[4),5),6),7),8)].

At SLAC Linac the integrated effect of parasitic modes due to the single bunch passage through the structure was measured and analysed [9)]; at SPEAR II the entire parasitic mode losses of the ring were measured by observing the shift of synchronous phase [10)].

In order to get experimental information about the parasitic mode losses in rf-structures, calorimetric measurements with different cavity structures were carried out in DORIS. In this report the equipment is described and the results are presented. Finally an estimate of the parasitic mode losses in the PETRA rf-structure is given.

Description of the equipment and calibration

The parasitic mode losses were measured directly by a calorimetric burst method. The rf-structure was installed in a vacuum tank insulated thermally by alumina insulators (fig. 1). A cooling tube was wound around the structure and brazed to the wall. The ends of this cooling tube were thermally insulated from the vacuum tank. The gap between structure and tank flange was short circuited by a perforated 0.2 mm thick stainless steel tube, to avoid excitation of modes in this gap.

The dissipated energy of the parasitic modes, when a single bunch passes trough the structure, is stored as thermal energy. This energy is measured by switching on the cooling water and recording the temperature difference between water inlet and outlet.

To get in DORIS with single bunch operation a similar relation of revolution time and decay characteristic of the excited modes as in PETRA, the test

rf-structures were made from stainless steel instead of copper. The Q-factors of these stainless steel structures are so small that regarding parasitic mode losses the model of single bunch passage can be assumed. The test structure in its vacuum tank was installed in the DORIS storage ring at a position where the influence of synchrotron radiation on the structure is negligible.

The thermal time constants of the test structure were measured before installation in DORIS by simulating the energy dissipation of the parasitic modes with an electrically heated tungsten filament on the axis of the structure. The length of this filament was short compared with the structure length and thus more than 98 % of the radiated energy was stored in the structure. The energy U_{el} dissipated by the filament in the time interval t is given by

$U_{el} = V \cdot I \cdot t$, where $V \cdot I$ is the electrical power. After switching off the heating, the stored thermal energy in the structure is measured by switching on the cooling water at constant flow rate and observing the temperature difference ΔT between inlet and outlet. ΔT is measured by thermocouples and recorded with a strip chart recorder. U_{th} is then given by

$$U_{th} = c \int_0^\infty \Delta T \cdot dt,$$ where c is a constant factor which includes the water flow rate.

Since the measured time constant for thermal leakage was 60 times larger than the thermal discharge time constant and also large compared with the time t during which a single electron bunch passes through the structure the influence of thermal leakage was negligibly small and thus

$$U_{el} = U_{th}$$

The described method permitted to measure the power with an accuracy of 5% and 15% at levels of 100 W and 10 W respectively.

Measurements and results

The parasitic mode losses were studied in a three cell iris structure, a six cell iris structure and a three cell drifttube structure, as shown in fig.2. Each of the structures had the same overall length and diameter.

During the measurements a single electron bunch was circulating in DORIS. The beam energy was 1.8 GeV and the peak voltage of the accelerating cavities was 600 kV. Under these conditions the theoretical bunch length is $l = 2\sigma = 3{,}7$ cm. An incoherent bunch lengthening is observed, which affects the parasitic mode losses. The bunch lengthening is caused by an energy widening and a potential change of the accelerating voltage. The bunch lengthening due to the energy widening was determined by observing the horizontal beam width in a place of dispersion and the bunch lengthening due to the potential change by measuring the ratio of dipole- and quadrupole frequencies of the synchrotron oscillation[11]. At 10 mA the overall bunch lengthening at this energy amounts to a factor of 2.5. Coherent longitudinal instabilities of the dipole mode were stabilized by Robinson damping. So the bunch length at this measurements was about 9 cm.*

The losses were measured with average bunch currents of 5 mA to 16 mA ($N = 3 \cdot 10^{10}$ to $N = 10^{11}$ particles per bunch).

During injection and storage time of the single bunch, the cooling water was switched off and the current versus time was registrated by a calibrated strip chart recorder (fig.3). After dumping the bunch, the cooling water was switched on at the calibrated flow rate. The water circuit has the same average temperature as the environment. The temperature difference between water inlet and outlet was registrated by the strip chart recorder. The temperature burst represents the stored energy U_{th} of the structure.

The average bunch current is given by

$$\bar{I}_b = (t_1 - t_0)^{-1} \cdot \sqrt{\int_{t_0}^{t_1} \bar{I}_b^{2} \cdot dt}$$

*Additional measurement of the length of the single bunch is in preparation and will be performed shortly.

and the power of parasitic modes by

$$P_{pm} = (t_1 - t_0)^{-1} \cdot c \int_{t_2}^{t_\infty} \Delta T \cdot dt$$

The results of these measurements are shown in the diagram of fig.4, where the parasitic mode losses of the three different test structures are plotted versus bunch current.

Since the parasitic loss is also a function of bunch length which in turn depends on bunch current one could not expect the simple quadratic dependance shown in fig.4. Over the current range available for these measurements though these effects are small compared with the scattering of individual points and do not show up clearly.

Discussion of results

With the described calorimetric method it is possible to measure the parasitic losses of those modes, which are captured in the structure. At part of the total losses, which belongs to modes with frequencies above the cutoff - frequency of the iris and the attached vacuum chamber will leave the structure. Measurements with a cavity to which a long lossy vacuum chamber was attached have shown that most of the energy in the modes above the cutoff-frequency is absorbed outside the cavity.

In order to compare the measured energy loss in the structures with existing theories it is necessary to correct it for the missing part of the total loss absorbed in the vacuum chamber. The model of Chao [8)] was used to calculate the mode losses above cutoff. These losses amount to 6% for the six cell and 15% for the three cell iris structure. The total energy loss due to the excitation of parasitic modes is given by applying these corrections to the measured dates and is shown in fig.5.

Also shown in fig.5 are the calculated numbers using estimates by Sands [6)] and Chao [8)]. There is a good agreement with Chao's model for the six cell as well

as for the three cell iris structure. We find a discrepancy with the model of Sands. In this model the losses in a three cell iris structure should be larger than in a six cell iris structure, whereas the measurements show the opposite behaviour.

In several theories it was predicted that the parasitic mode losses will be smaller in a drifttube structure than in an iris structure of same dimensions. In our drifttube structure with extremly short gaps, the measured losses are 20 % smaller than in the iris structure of same cell length (Fig.4). Using the measured parasitic mode losses with the corrections of Chao's formalism [8] and the PETRA parameter as

bunch current	2 x 20 mA
No of particles per bunch	$2 \times 8 \cdot 10^{11}$
bunch length $l_{ba} = 2\sigma$	6 cm
No of cells	300

the parasitic mode losses of the PETRA rf-accelerating cavities will be 500 kW. This value is considerably smaller than the 700 kW losses assumed in the PETRA proposal.

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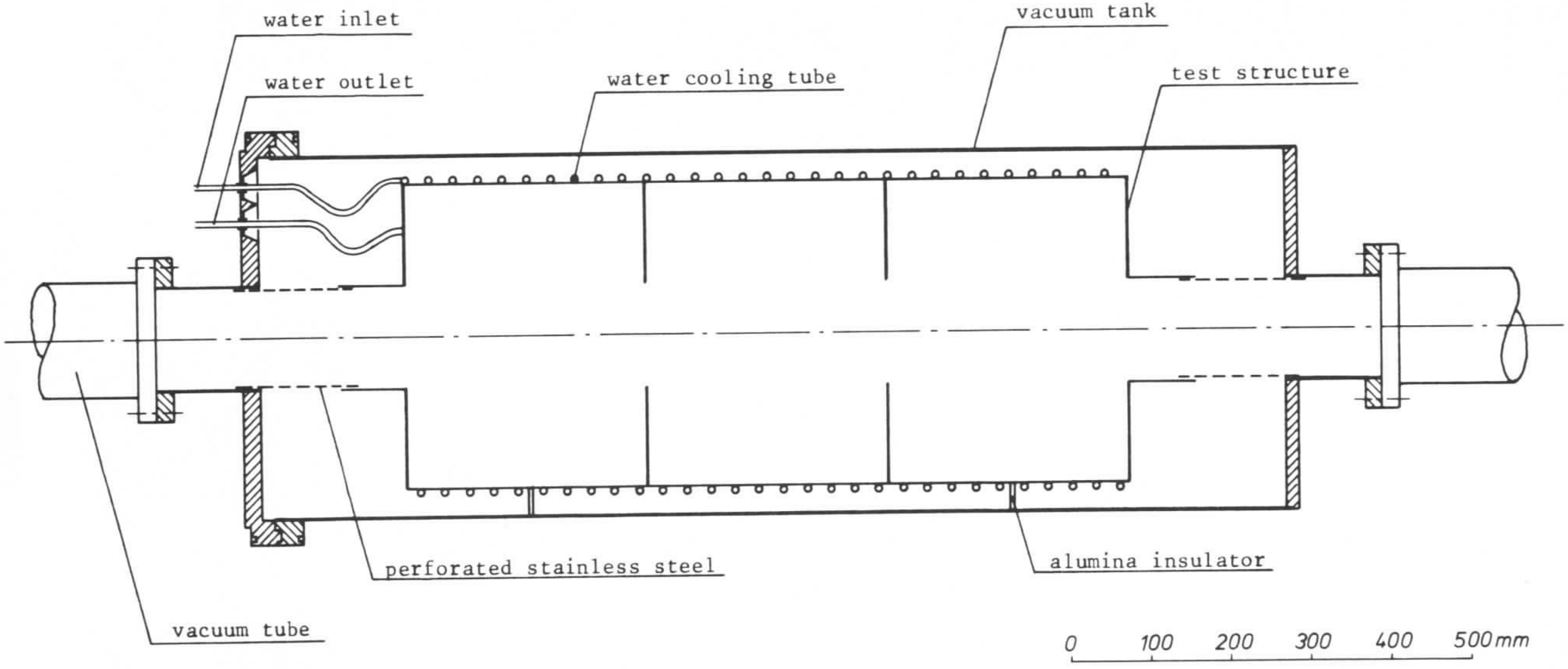
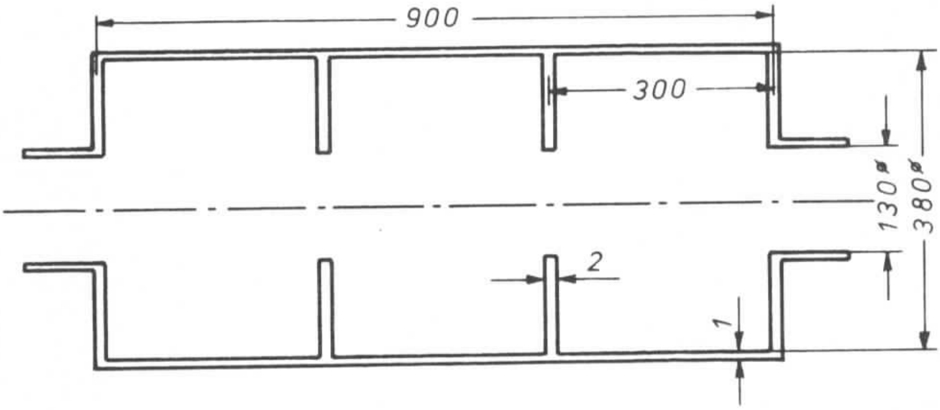
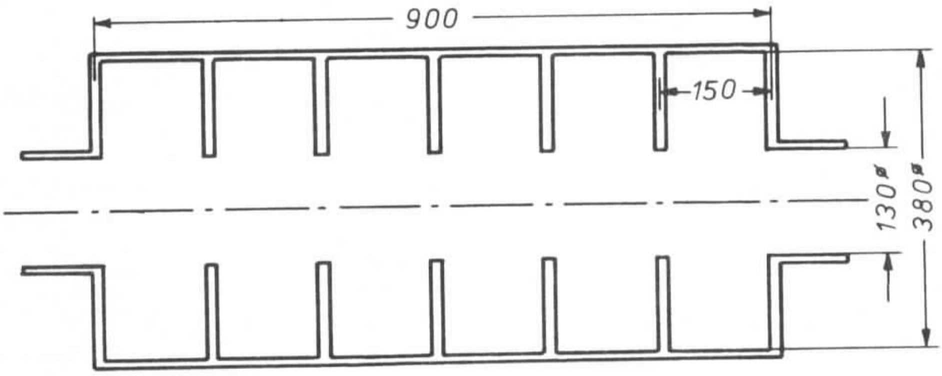


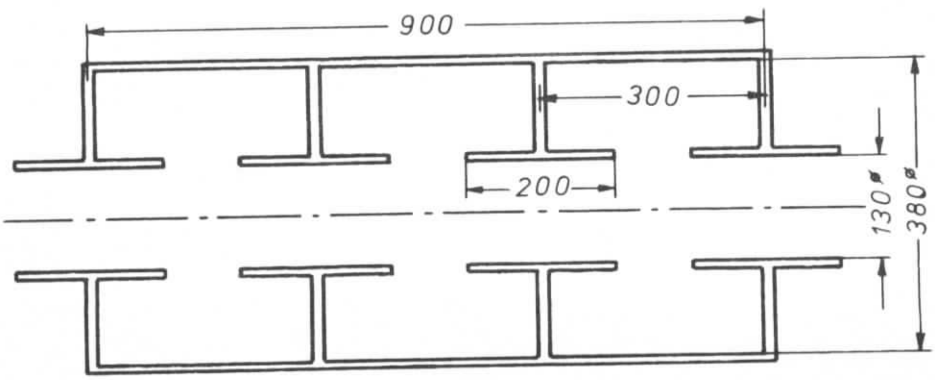
Fig. 1: Arrangement of the test structure in the vacuum tank



3-cell iris structure

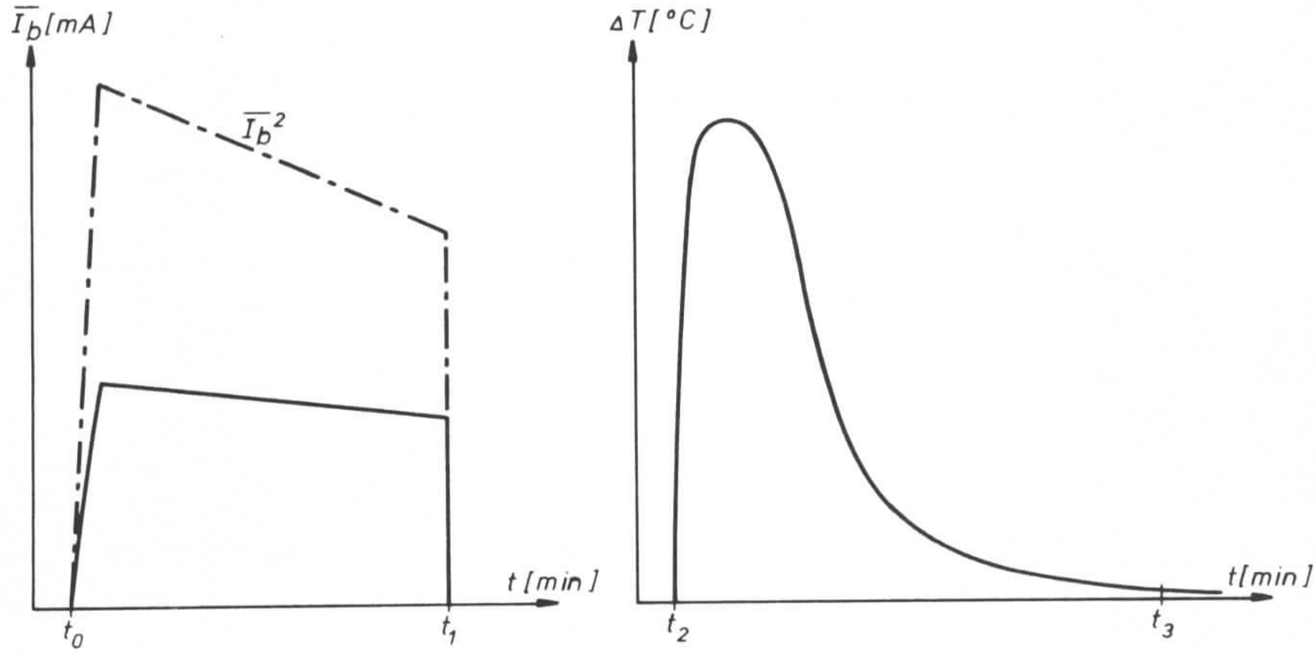


6-cell iris structure



3-cell drifttube structure

Fig. 2: Stainless steel structures to measure parasitic mode losses in DORIS



single bunch current as
function of time
(The cooling water has been
turned off)

temperature difference between
cooling water inlet and outlet
as function of time
(The circulating current is zero
during this time)

Fig.3: Diagram of strip chart recorder

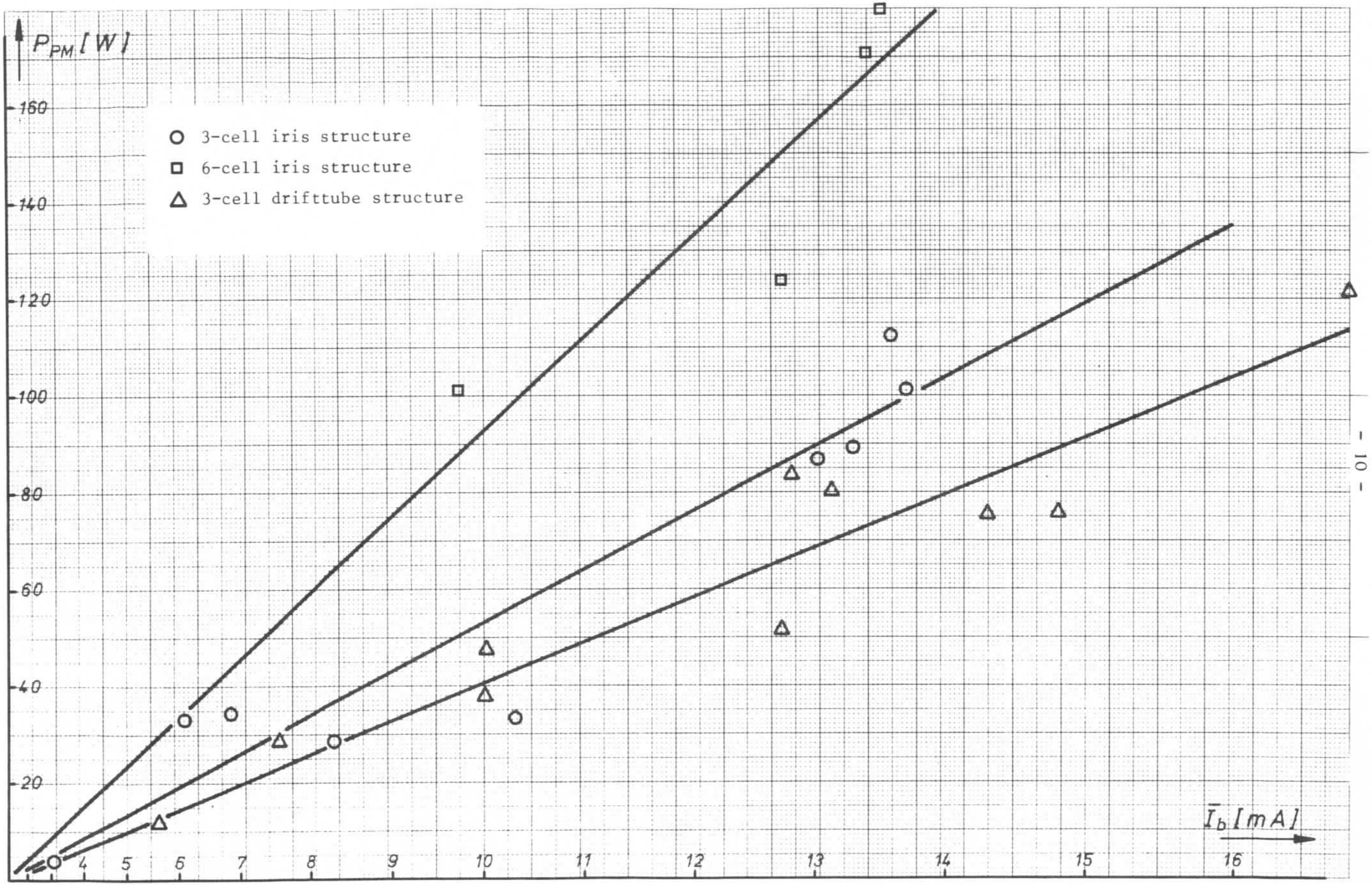


Fig. 4: Results of the parasitic mode measurements in DORIS

Structure	measured in DORIS (W)	corrected for losses above cutoff-frequency (W)	Prediction (according to[8]) (W)	Prediction (according to[6]) (W)
6 cell iris gap length = 15cm iris diameter = 13cm	90	95	94	65
3 cell iris gap length = 30cm iris diameter = 13cm	54	63	65	105

Fig.5: Comparison of measured and predicted mode losses for two different iris structures.
Bunch current 10 mA ($N = 6 \cdot 10^{10}$ particles per bunch); bunch length $l_{ba} = 2\sigma = 9$ cm.