RF Impedance Calculations for Three-Dimensional Devices for HERA

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ABSTRACT

On account of the high beam current on both of the HERA rings one must be specially careful that the parasitic shunt impedances remain small. High impedance both affects the stability of the beam and causes heating of the cavity walls. The 3-dimensional code URMEL of the MAFIA-family was used to perform the calculation of the shunt impedance and obtain the field plots. In this paper the design and function of several proposed HERA kickers and diagnostic tanks are described. The final structures shown are a result of several redesign stages using these codes. The a priori calculation has proven to be an invaluable tool for keeping all parasitic side effects below the tolerable tight limit.

INTRODUCTION

a) the computer codes

Most of the kickers and monitors designed for the HERA ring have a complex three-dimensional structure, so a computer program for the shunt impedance calculations had to be used that allows structures to be defined with arbitrary material distribution in space. The three-dimensional code URMEL of the MAFIA-family was used. It consists of four programs that transfer their data by means of files. The mesh generator M3 is used to define the material distribution on a three-dimensional rectangular grid. R3 generates the frequency-domain matrix equations taking into account the user defined material properties and boundary conditions. The equations are solved in E31. This program gives a list of the lowest modes. Finally the postprocessor P3 can be used to calculate various quantities, for example the shunt impedance R or the quality factor Q, and to produce field plots. [1],[2]

b) method of presentation

– The investigation of four different HERA devices will be presented. Their stucture will be shown by a plot produced by M3. When the device is symmetrical with one, two or three symmetry planes only a half, a quarter or an eighth of the structure is used for the calculations and displayed on the plot. A short description of the function of the particular device will then be given, followed by a discussion, on the base of the computer results, of the effect of the given structure on the stability of the beam.

– In order to obtain all modes of a symmetrical structure the program must be run several times with different boundary conditions. The possible conditions are tangential E-field equal zero (1) or tangential H-field equal zero (2). When the stability of the beam is under investigation, those modes where the line integral on the beam-axis is not equal to zero are of interest.

– Several of these devices have coils that are connected with resistances outside the tube. This cannot be simulated by the MAFIA-code, but a worst case estimation can be made by calculating two extreme cases. In the first case, the connection from the coil to the outside of the tube ends in a metal block (⇒ shortcircuit) and in the second case, it ends in air (⇒ open circuit).

– To be sure that a device in the HERA proton ring does not cause beam instabilities the shunt impedance R for each resonant frequency must be lower than 100 k Ω.[7]

HERA-DEVICES

a) kicker for proton-ejection from PETRA to HERA

The kickers displayed below were designed for the proton-ejection from the PETRA- to the HERA-ring. Because the usable space for the ejection is quite small, a short magnet with a low aperture is needed. It has to be so low that the proton beam could not pass it at the lower injection energy. Only when the ejection energy is reached, is the beam small enough to fit into the kicker-aperture. Accordingly a kicker was designed with a moveable magnet that can be inserted after acceleration.[3]

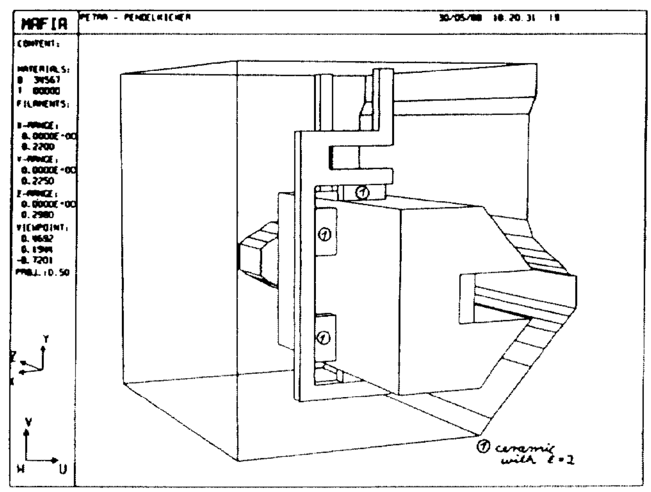

Figure 1: *First design of the removable ejection kicker All parts of the kicker are metal except those marked with 1 which are ceramic with ε=2.*

Because of symmetry only the front half of the kicker is used for the calculations. The first run was made with the magnet totally moved into the tube because this is the arrangement where the highest shunt impedances are expected. The following table shows the shunt impedances for a few modes.

mode	freq / MHZ	Q	R_s / kΩ
1	107.63	14 310	163
2	192.30	25 250	194
3	552.36	54 710	39
:	:	:	:
8	938.41	26 480	79
9	976.00	54 490	405
:	:	:	:

Table 1: *shunt impedance R_S and quality factor Q for some of the resonant frequencies of the first design for the removable ejection kicker*

Several of the R-values are higher than the acceptable limit of 100 k Ω and so the kicker had to be modified.

The next design was a kicker with an rf shielded magnet that can slide in and out of the beam path.

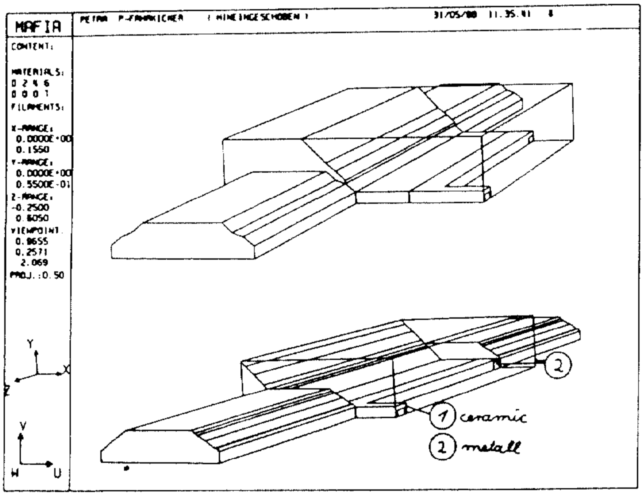

Figure 2: *Second design of the removable ejection kicker. The upper picture shows the kicker with the magnet inside the tube. The lower shows the magnet totally removed from the tube.*

Only the upper half of the kicker had to be used for the calculations because of symmetry. For two different boundary conditions calculations were carried out, not only for the kicker with the magnets moved as far into the tube as possible, but also for the kicker with the magnets moved out of the tube as far as possible. None of the resonant frequencies obtained have a shunt impedance higher than 100 k Ω. So this kicker does not threaten the beam stability.

mode	F / MHZ	R_S / kΩ	mode	F / MHZ	R_S / kΩ
1	237.66	0.00	1	112.08	2.14
2	471.83	0.00	2	345.40	0.13
3	698.32	0.01	3	582.42	0.01
4	921.99	0.01	4	820.80	0.01
5	1150.00	0.01	5	1055.00	0.03
:	:	:	:	:	:

Table 2: *Shunt impedance R_S for certain resonant frequencies of the second design for the removable ejection kicker with the magnet totally moved into the tube. The modes were found by running the program with two different boundary conditions.*

mode	F / MHZ	R_S / kΩ	mode	F / MHZ	R_S / kΩ
1	238.19	0.00	1	110.83	0.00
2	472.08	0.00	2	344.23	0.00
3	695.02	0.00	3	582.38	0.00
4	915.19	0.00	4	822.87	0.00
5	1142.84	0.00	5	1059.06	0.00
:	:	:	:	:	:

Table 3: *Shunt impedance R_S for certain resonant frequencies of the second design for the removable ejection kicker with the magnet totally moved out off the tube. The modes were found by running the program with two differnt boundary conditions.*

b) proton beam-dump kicker

The proton beam dump kicker magnets have the task of bending the protons away from the HERA-ring into an absorber block when the storage ring has to be "switched off" [4]. One quarter of the structure can be seen on the plot. Four runs with different boundary condition were needed to find all resonant frequencies. The calculated modes correspond quite well with the later measured frequencies.

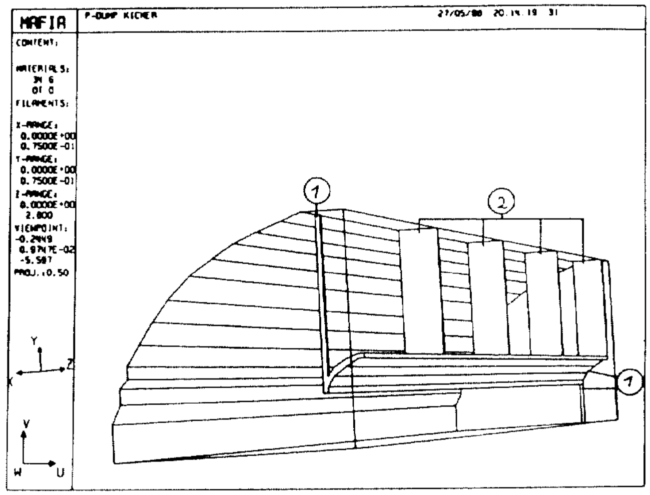

Figure 3: *proton beam-dump kicker. One quarter of the structure is shown. Parts marked with 1 are metall, those marked with 2 are dielectric with $\epsilon = 3.5$.*

mode	freq / MHZ	Q	R_s / kΩ
1	28.25	4 240	294
2	84.74	7 340	171
3	141.22	9 480	134
4	197.63	11 220	116
5	254.29	12 710	96
:	:	:	:

Table 4: *Shunt impedance R_S and quality factor Q for a set of resonant frequencies of the proton beam-dump kicker*

Only the shunt impedances of the first four resonant frequencies exceed 100 k Ω. That means that the structure cannot be used as it was originally designed. Nevertheless a model was built for measurement as techniques of suppressing the low frequency modes were available.
In the following table the MAFIA-results are compared with the measured values of the original structure.

frequency / MHZ		$\frac{R}{Q}$ / Ω		
MAFIA	measurements	MAFIA	2·MAFIA	measurements
28.25	29.18	69.3	138.6	105.0
84.74	87.40	23.2	46.4	34.0
141.74	145.91	14.0	28.0	19.0
197.63	203.89	10.3	20.6	14.0
254.29	262.08	7.5	15.0	12.0
310.63	319.76	6.5	13.0	8.9
366.98	377.10	5.6	11.2	7.9
423.17	432.99	5.1	10.2	6.3
480.24	504.61	4.0	8.0	3.1

Table 5: *Comparison of the MAFIA-results with the measured values of the proton beam dump-kicker. The measurements use a definition of the R/Q-value that is twice the MAFIA value. So the MAFIA-values multiplied by two are given in the table to simplify the comparision.*

A combination of ferrite and a low-pass-filter were installed in the model and new measurements made. The modification led to a remarkable reduction of the quality factors Q of the modes so that the modified kicker can be installed.

c) beam position monitor

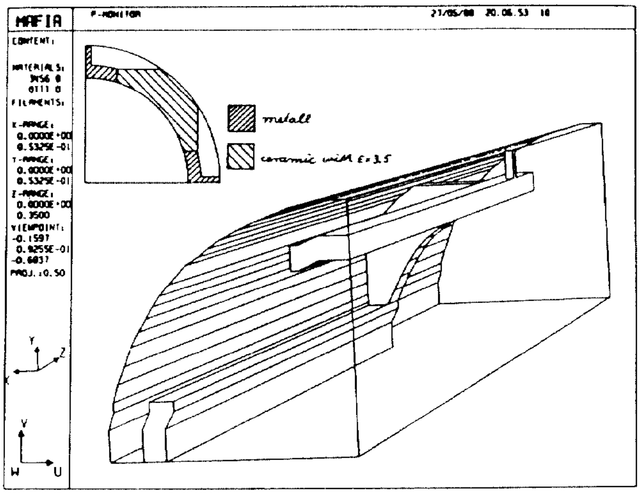

Figure 4: *Beam position monitor The figure shows one-eighth of the monitor.*

The picture shows an eighth of a monitor that is used to measure the position of a proton bunch in the straight sections [5]. Because the coils are connected to a resistance, a worst case estimation had to be done by executing two runs. In the first one a metallic connection between the coil and the metal of the tube is defined, the second one is without this connection. In both cases the shunt impedances of several modes are much higher than the given limit. Some even exceed 500 k Ω.

An attempt was made to locate the component of the structure which causes most disturbance. First the ceramics that hold the coils were omitted. The resonant frequencies differ slightly from those obtained in the first calculation. The shunt impedances are reduced but some are still higher than 100 k Ω.

mode	F / MHZ	R_S / kΩ	mode	F / MHZ	R_S / kΩ
1	359.47	0.00	1	714.25	0.00
2	367.04	0.27	2	731.56	0.91
:	:	:	:	:	:
8	1956.1	0.00	13	2638.4	0.00
10	2369.4	288.7	15	2773.4	213.7
12	2570.1	0.00	17	2797.9	0.00
:	:	:	:	:	:

Table 6: *Shunt impedance R_S for some of the resonant frequencies of the beam position monitor without ceramics. The seperate tables were found by running the program with two different boundary conditions*

In a third run the coils were narrowed to 3/4 of their original radius, again without the ceramics. However this change didn't bring success, the shunt impedances still reach values greater than 100 k Ω.

Because the connection to the resistance could not be simulated the shunt impedances of the real apparatus are likely to be lower than the calculated values. The next step in the investigation will be to build a model and to make measurements to find out how bad the influence on the beam stability really is. But as a result of the MAFIA-simulation some designs were developed where the ceramics are replaced.

d) a very sensitive beam position monitor

This monitor measures the betatron tune of the HERA proton ring [6]. A quarter of the structure was used for the calculations. The connection that leads from the coil to the outside of the tube is isolated from the metal of the tube-wall. It ends in a block of material that is defined as metal for one part of the calculations and as air for the other part. The monitor was designed with a distance of 80 mm between the coils. In both cases (block of metal and block of air) the resonance frequencies possess shunt impedances with values lower than 100 k Ω, except one with 109 k Ω.

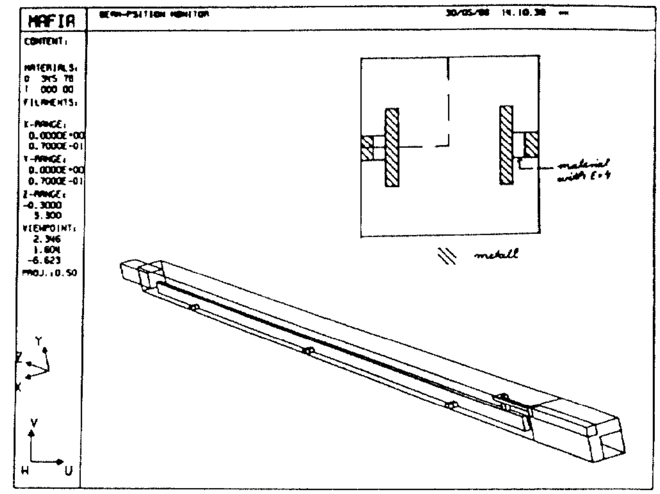

Figure 5: *Beam position monitor The figure shows one quarter of the structure.*

material block is metal			material block is air		
mode	F / MHZ	R_S / kΩ	mode	F / MHZ	R_S / kΩ
1	26.28	70.6	2	43.13	18.0
2	78.62	39.4	3	90.79	26.4
3	130.11	25.9	4	142.37	23.4
:	:	:	:	:	:
14	626.61	109.5	14	623.20	7.6
:	:	:	:	:	:

Table 7: *Shunt impedance R_S for various resonant frequencies of the beam position monitor. The values received for the run with the coils connected to metal are at the right part of the table, the left part shows the results for the connection ending in air.*

So this monitor can be used as it was designed. Additionally a run was made with a distance of 25 mm between the coils to find out if the coils should be made moveable. But in this case some of the modes reached shunt impedances higher than the given limit, so the monitor will be built with fixed coils, 80 mm apart.

CONCLUSION

Many of the computer runs have been performed on the CRAY X-MP/48 at the HLRZ in Jülich (Germany). The average CPU time per job was about 25 minutes using 50 000 meshpoints.

The examples which have been described, demonstrate how valuable the use of the MAFIA program is for the design of some HERA components. With only a little expense of time and money several modifications of a design can be examined with respect to their influence on the beam stability.

REFERENCES

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