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High-Temperature Reactor Components and Systems

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Design, construction and analysis of a 1 kN permanent- magnet bearing

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Report of Progress in the Task ID-1.3 of WP3

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St. Marcel, June 16./ 17.03

General Considerations:

In his report " High-Temperature Reactor Components and Systems " (Contract N°: FIKI-CT-2001-00177) from June, 2002, Werner von Lensa has stated the necessity of reliable auxiliary machinery for the function and availability of HTRE designs. Permanent- magnet bearings (PMB) were proposed for smaller machines, as in particular for coolant gas blowers, compressors and pumps. These kind of bearings are supposed to contribute significantly to the overall reliability of the power system because of their inherent low risk of failure, missing need for maintenance and relieved conditions for back-up bearings.

In order to examine the feasibility of high load PMB's in a hardware study, a bearing with 1 kN load capacity was chosen as reasonable size, which is suited for application in high- speed machines in the 1 MW range.

First Approach:

At the WP 3/4 meeting in Zittau, a permanent- magnet bearing configuration was proposed, which was designed to meet the 1 kN load requirement at minimum volume of permanent magnet material.

The basic structure is the stator- rotor magnet assembly outlined in Figure 1.

Both, the rotor and stator magnets are composed of 5 concentric permanent magnet rings. The single rings have a cross section of h= 1 mm , w= 2 mm and fit into one another. Each multi-ring assembly is backed by an iron disk serving as a mechanical support and magnetic yoke. The magnetization of the rings is in axial direction with the same orientation for the rotor and stator magnet rings, which face each other directly. If the magnetization direction is alternately reversed for adjacent magnet rings, a maximum radial stiffness is calculated for this configuration (M. Lang, thesis).

Provisional Result:

Field and force calculations of basic PMB configurations with multi- ring magnets were carried out using the software “AMPERE” of Integrated Engineering Software (IES). The stator-rotor pair as shown in Figure 1, with outer diameter of 100 mm and 80 mm inner diameter of the 5 magnet rings on the iron yoke, yields a calculated axial load capacity of 371 N at 248 N/mm radial stiffness in case of a 0.6 mm bearing gap. (Figure 2)

This first design approach was realized in order to check the calculations and to qualify a method for assembling the delicate structure of 5 magnetized rings. Figure 3 shows a set of magnetized rings before being mounted on the iron support.
The alternate magnetization of the concentric rings is visualized by an iron-particle foil, which highlights the regions of highest field gradient at the ring boundaries. These regions correspond to the yellow spots in the field simulation plot (Figure 2)
Two of such multi-ring assemblies were furnished with an iron support and used for load and stiffness measurements in a test rig, which was set up with load cells (Höttinger Baldwin Messtechnik –HBM). The measured load capacity in axial direction (z- direction) is 370 N for the nominal air gap of 0.6 mm (Figure 4). The result confirms the calculation.
The radial stiffness was evaluated in a respective test rig with the cells mounted to monitor the loads between both bearing parts at displacement in x-direction (radial). The initial stiffness near the center position is 230 N/mm for the case of the 0.6 mm bearing gap (Figure 5), which is about 6% less than expected.
According to these results, a PMB stack of three such rotor-stator pairs would provide a combined axial load capacity of 1110 N as requested.

Alternatives:

The initial design criterion of minimum magnet material has to be revised in view of the low and still dropping prices for high performance permanent magnets.

In view of the support structure dimensions necessary for sustaining the bearing load forces, the volume of modern permanent magnet material is of secondary importance for the overall bearing dimensions.
Figure 6 shows the field and force calculation of the above 5-ring bearing with an optimized magnet height of 3 mm instead of 1 mm. The 1 kN load requirement could be met with only two of such bearing pairs, each with a load capacity of 506 N.
The joined radial stiffness of 700 N/mm of these two pairs would be comparable to the 3 pair design employing 1 mm magnets.

If lower radial stiffness and lower natural bearing frequencies can be tolerated in the specific machine application, a second alternative magnet configuration is favorable. By optimizing for maximum load capacity the number of the concentric magnet rings can be reduced to 2 (Figure 7). For this configuration a load capacity of 919 N results at a similar air gap width of 0.6 mm. In this way, the design load would be achieved by a single bearing pair. The simple structure makes this magnet assembly comfortable for manufacture.

Next Actions:

The later double-ring bearing seems most advantageous for practical application. The realization of this bearing is under way. The respective Neodymium magnets have been ordered.
The following tasks are planned after delivery of the magnets:

- verification of the load capacity
- set up of a test rig with a 100 kg test rotor suspended by a double-ring bearing configuration; axial stabilization provided by a mechanical thrust support
- rotational acceleration above natural radial bearing resonance
- examination of the rotation characteristics in case of contact with a sleeve type catcher bearing assembly.

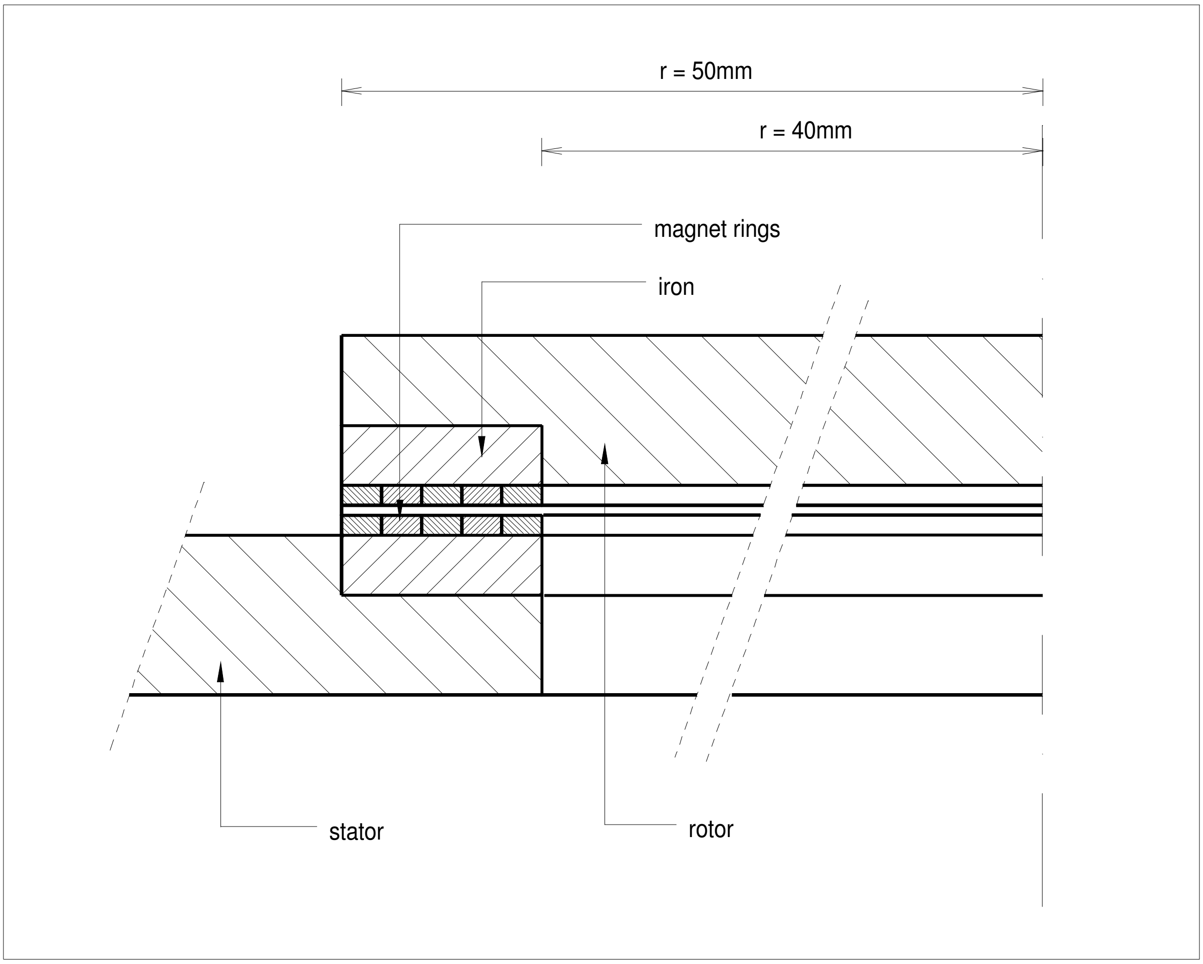
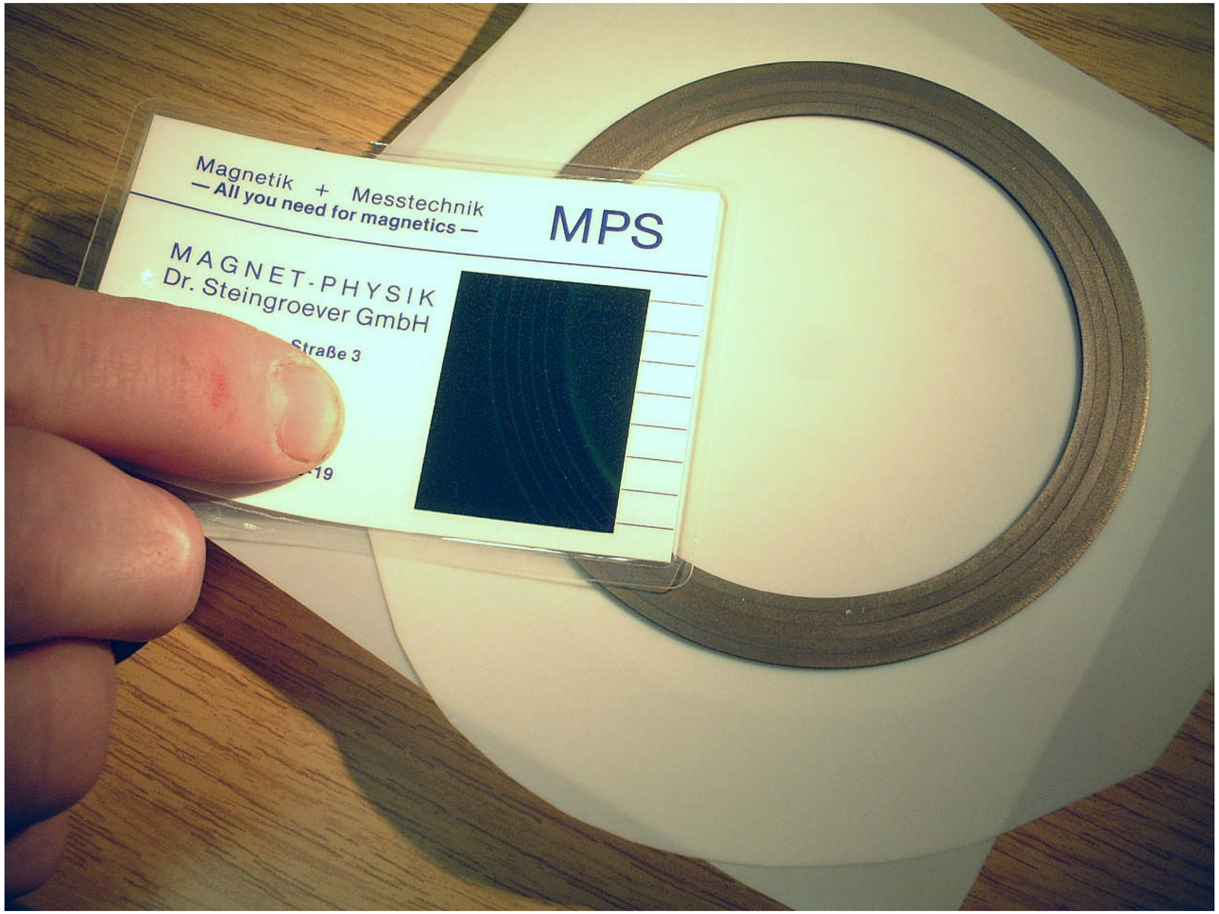


Figure 1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Dr. Steingroever GmbH
Straße 3

Figure 3

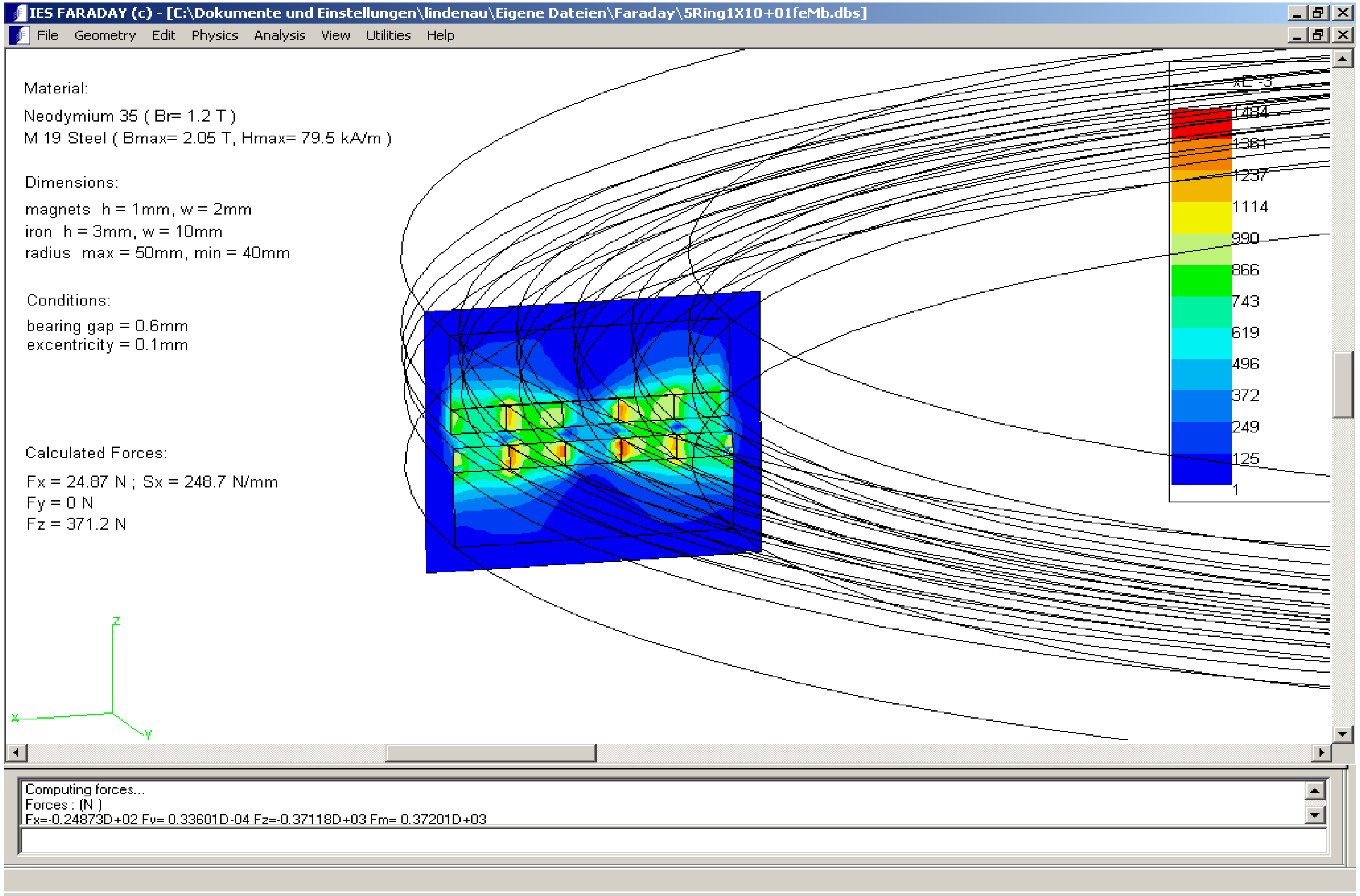
IES FARADAY (c) - [C:\Dokumente und Einstellungen\lindenau\Eigene Dateien\Faraday\5Ring1X10+01feMb.dbs]
File Geometry Edit Physics Analysis View Utilities Help
Material:
Neodymium 35 (Br= 1.2 T)
M 19 Steel (Bmax= 2.05 T, Hmax= 79.5 kA/m)
Dimensions:
magnets h = 1mm, w = 2mm
iron h = 3mm, w = 10mm
radius max = 50mm, min = 40mm
Conditions:
bearing gap = 0.6mm
excentricity = 0.1mm
Calculated Forces:
Fx = 24.87 N ; Sx = 248.7 N/mm
Fy = 0 N
Fz = 371.2 N
xE-3
1484
1361
1237
1114
990
866
743
619
496
372
249
125
1
Computing forces...
Forces : (N)
Fx=-0.24873D+02 Fy= 0.33601D-04 Fz=-0.37118D+03 Fm= 0.37201D+03

Figure 2

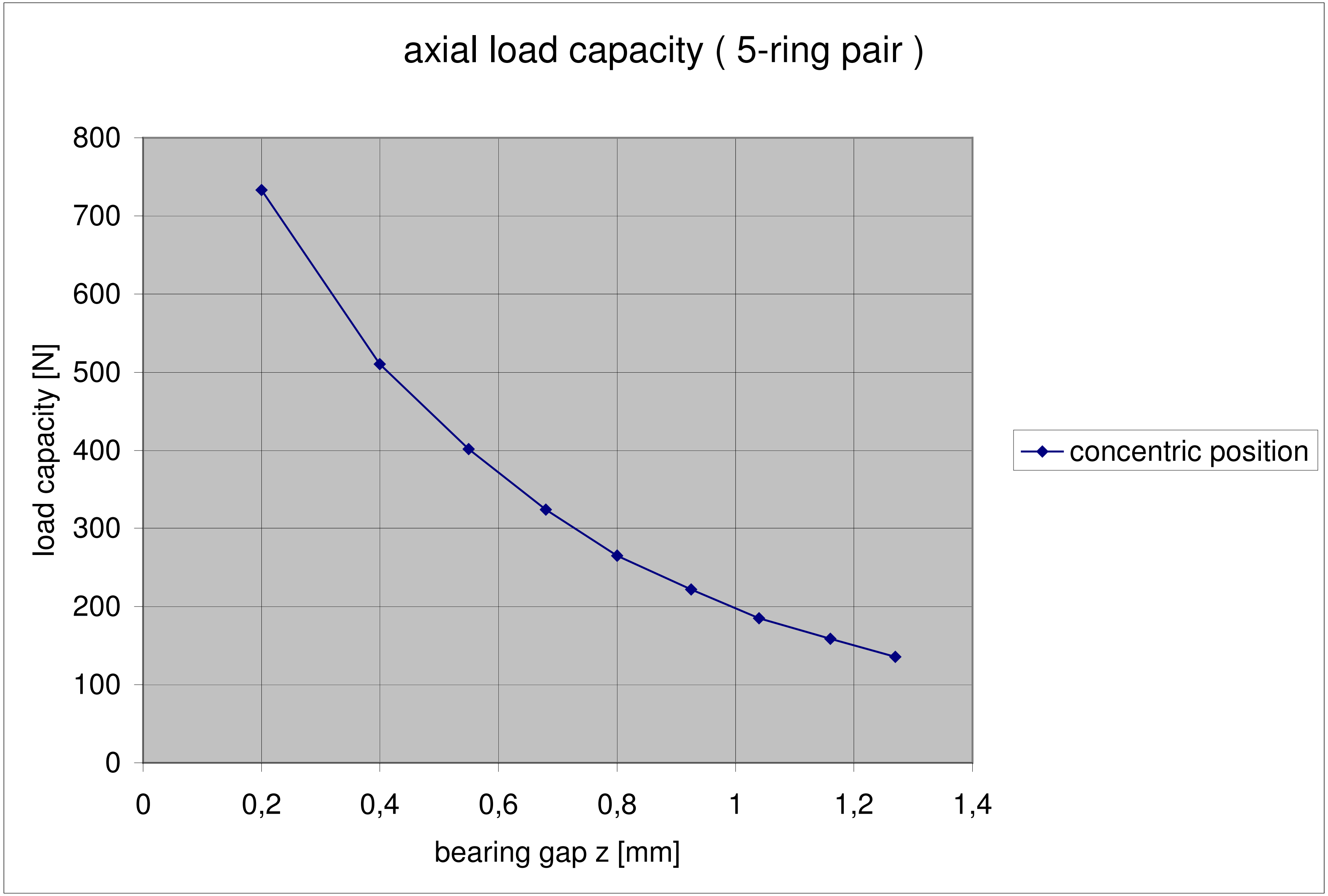
axial load capacity (5-ring pair)
load capacity [N]
800
700
600
500
400
300
200
100
0
0
0,2
0,4
0,6
0,8
1
1,2
1,4
bearing gap z [mm]
concentric position

Figure 4

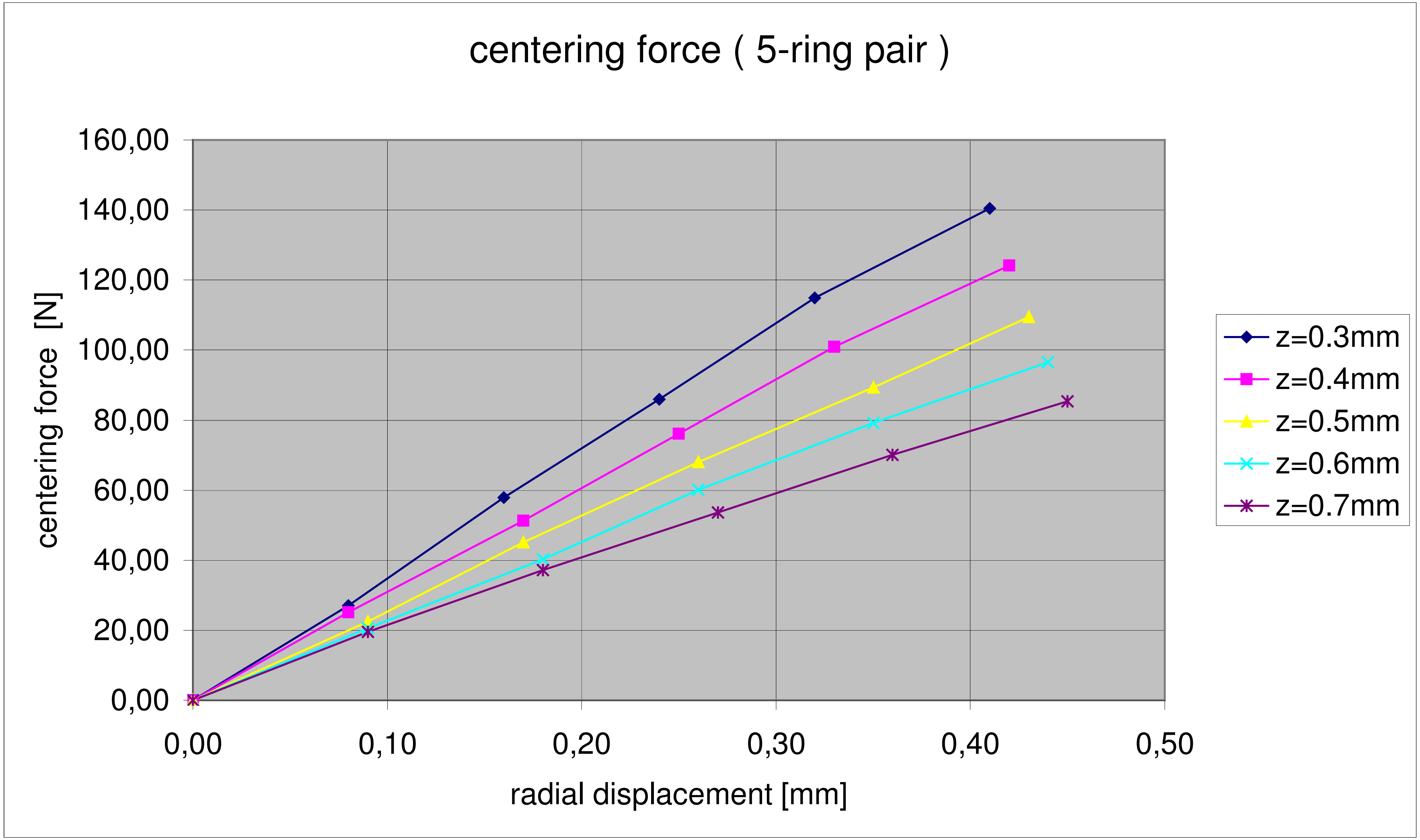
centering force (5-ring pair)
centering force [N]
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0,00
0,10
0,20
0,30
0,40
0,50
radial displacement [mm]
z=0.3mm
z=0.4mm
z=0.5mm
z=0.6mm
z=0.7mm

Figure 5

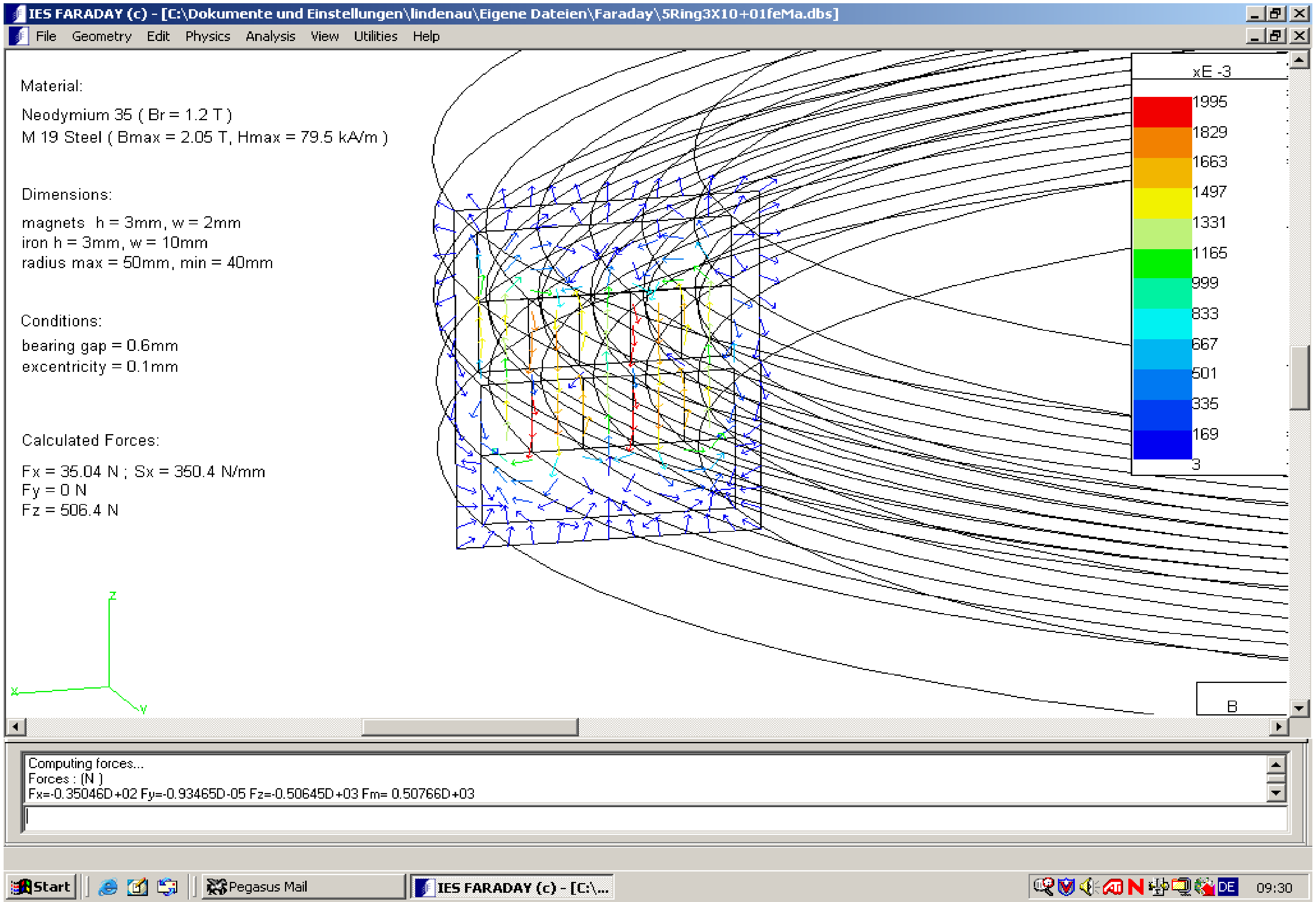
IES FARADAY (c) - [C:\Dokumente und Einstellungen\lindenau\Eigene Dateien\Faraday\5Ring3X10+01feMa.dbs]
File Geometry Edit Physics Analysis View Utilities Help
Material:
Neodymium 35 (Br = 1.2 T)
M 19 Steel (Bmax = 2.05 T, Hmax = 79.5 kA/m)
Dimensions:
magnets h = 3mm, w = 2mm
iron h = 3mm, w = 10mm
radius max = 50mm, min = 40mm
Conditions:
bearing gap = 0.6mm
excentricity = 0.1mm
Calculated Forces:
Fx = 35.04 N ; Sx = 350.4 N/mm
Fy = 0 N
Fz = 506.4 N
z
x
y
xE -3
1995
1829
1663
1497
1331
1165
999
833
667
501
335
169
3
B
Computing forces...
Forces : (N)
Fx=-0.35046D+02 Fy=-0.93465D-05 Fz=-0.50645D+03 Fm= 0.50766D+03
Start
Pegasus Mail
IES FARADAY (c) - [C:\...
DE
09:30

Figure 6

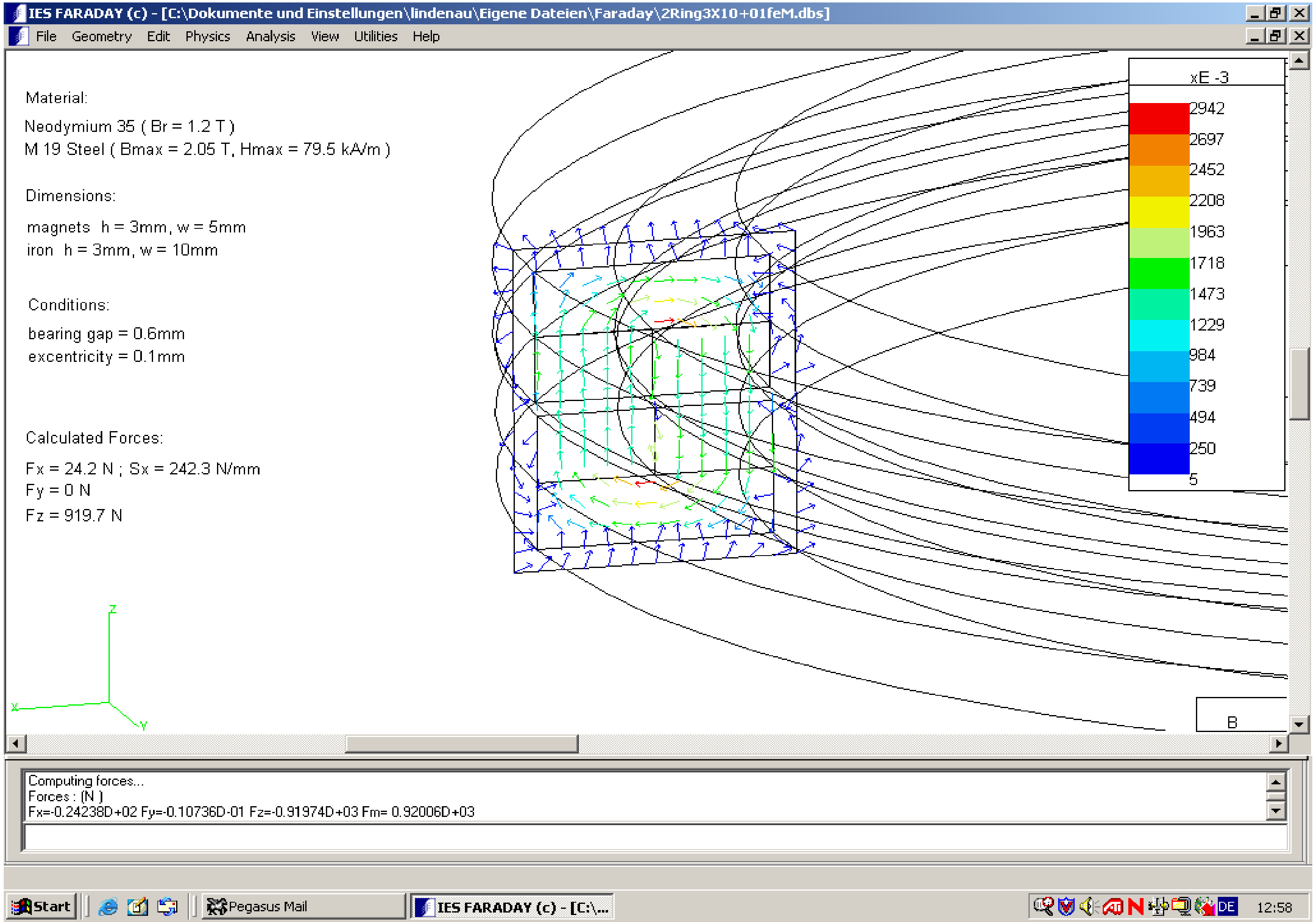
IES FARADAY (c) - [C:\Dokumente und Einstellungen\lindenau\Eigene Dateien\Faraday\2Ring3X10+01feM.dbs]
File Geometry Edit Physics Analysis View Utilities Help
Material:
Neodymium 35 (Br = 1.2 T)
M 19 Steel (Bmax = 2.05 T, Hmax = 79.5 kA/m)
Dimensions:
magnets h = 3mm, w = 5mm
iron h = 3mm, w = 10mm
Conditions:
bearing gap = 0.6mm
excentricity = 0.1mm
Calculated Forces:
Fx = 24.2 N ; Sx = 242.3 N/mm
Fy = 0 N
Fz = 919.7 N
xE -3
2942
2697
2452
2208
1963
1718
1473
1229
984
739
494
250
5
B
Computing forces...
Forces : (N)
Fx=-0.24238D+02 Fy=-0.10736D-01 Fz=-0.91974D+03 Fm= 0.92006D+03
Start
Pegasus Mail
IES FARADAY (c) - [C:\...
DE
12:58

Figure 7