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THE COMPLETE WATSON CIRCUIT OR ONLY A HALF OF THIS MAGNETIC CIRCUIT?

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Abstract: *At first, there are very shortly discussed magnetic materials used at these applications. Then, normal Watson circuit with two permanent magnets, which are exciting magnetic field at working space, is discussed. In conclusion, magnetic circuit similar to Watson circuit is presented. It uses only one permanent magnet. The different varieties of this magnetic circuit are presented. In both mentioned cases, there is shown magnetic flux density distribution in longitudinal direction which enables to confront magnetic field homogeneity.*

Key words: *Magnetic circuit, permanent magnet, magnetic flux density, magnetic field homogeneity*

INTRODUCTION

It is well known that relatively homogeneous static magnetic field in biggish volume can be obtained by way of Watson circuit. In this case, the working space is open from two sides only. If we need the access to working space from the three sides and/or working space can be smaller then the space in Watson circuit, we can prove to use one half of Watson circuit. But, how to realize magnetic field homogeneity? This problem will be discussed at this paper.

Because of using of two materials (magnetically hard – permanent magnets and magnetically soft – iron) for the both magnetic circuits construction, the main properties of them will be discussed in very short at first.

1 REMARKS TO USED MAGNETIC MATERIALS

1.1 Permanent magnets

For the production of permanent magnets hard magnetic materials are used. Very important property of them is maximum energy product $(BH)_{max}$. The development of this parameter in the last century is outlined in Fig. 1. We can see that the best magnetically hard materials are SmCo and NdFeB materials. Some other important characteristics of permanent magnets are on the left upper side of Fig. 1 [2]. In Fig. 2, there is presented the comparison $(BH)_{max}$ of different these materials in dependence on temperature, starting from the room temperature. We can see that the winner (to the temperature 120°C) is NdFeB, rather $Nd_2Fe_{14}B$ [3].

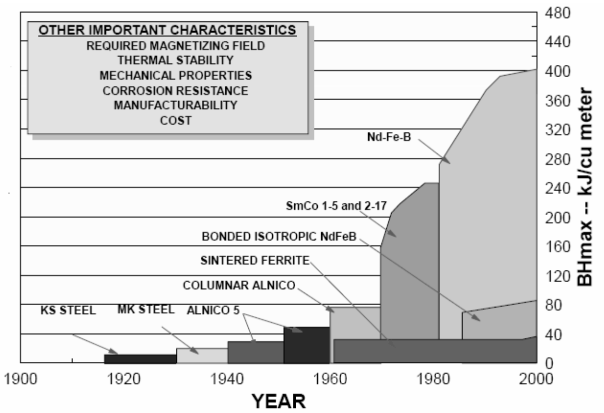

Fig.1: Maximum energy product $(BH)_{max}$ of permanent magnets in dependence on era

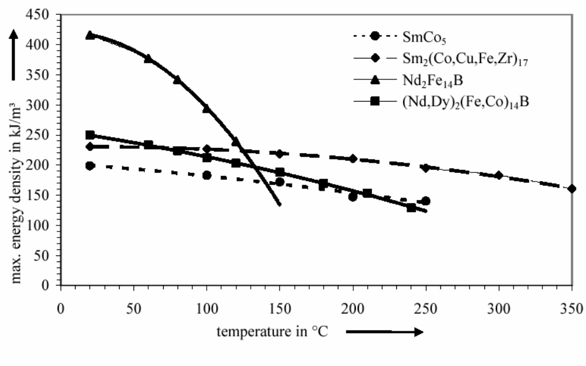

Fig.2: Maximum energy product $(BH)_{max}$ of RE permanent magnets in dependence on temperature

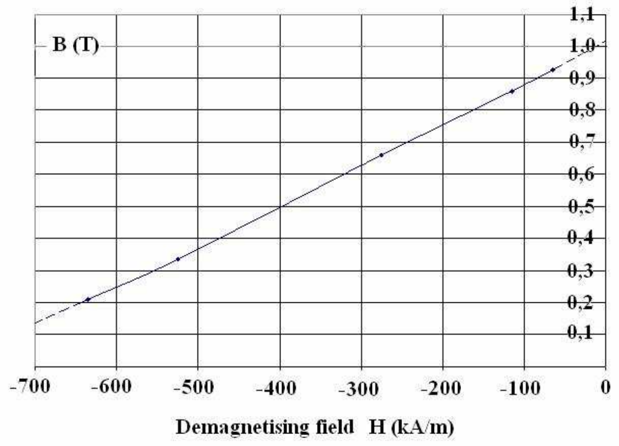

Fig.3: Demagnetizing characteristic of used NdFeB permanent magnets [3]

1.2 Magnetically soft materials

Magnetically soft iron is the best material for the application in Watson circuit. Typical magnetizing curve of this material is in Fig. 4.

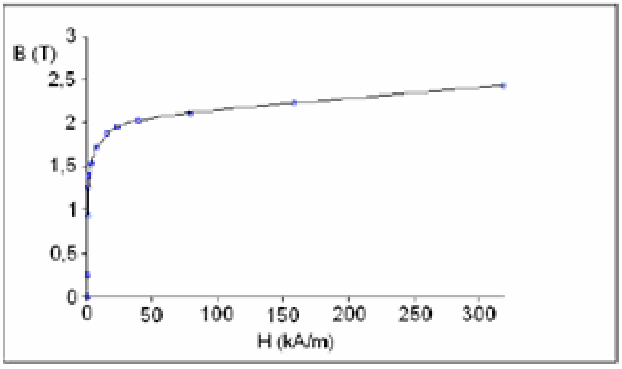

Fig.4: Typical magnetizing characteristic of soft iron

2 HOMOGENEOUS MAGNETIC FLUX DENSITY DISTRIBUTION GENERATION

2.1 Watson circuit

The arrangement of low Watson circuit is presented in Fig. 5.

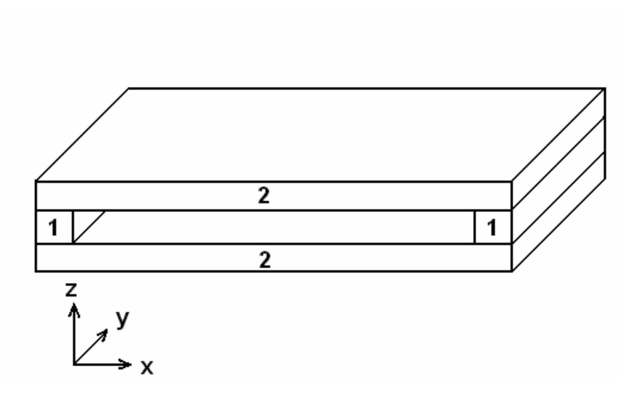

Fig.5: Watson circuit with low (10 mm) working air gap (1 – permanent magnet, 2- Fe sheet)

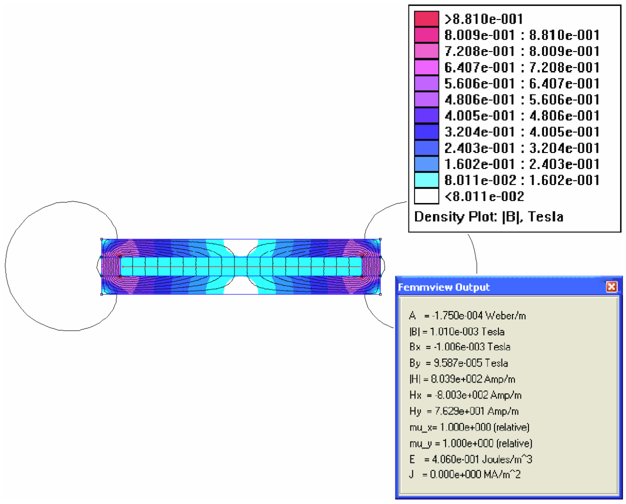

Fig.6: The map of magnetic flux density distribution

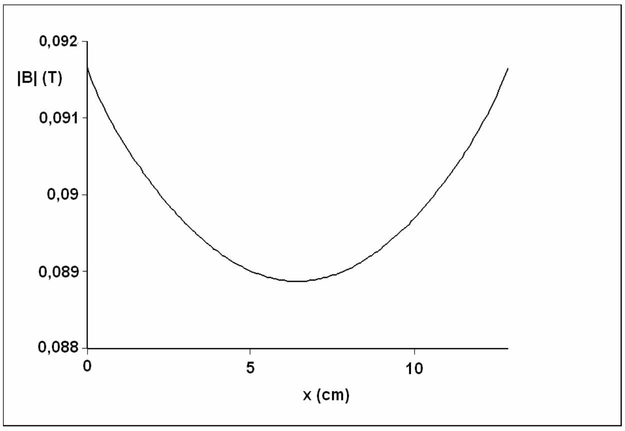

Fig.7: Magnetic flux density absolute value curve in longitudinal (x) direction – middle of the air gap

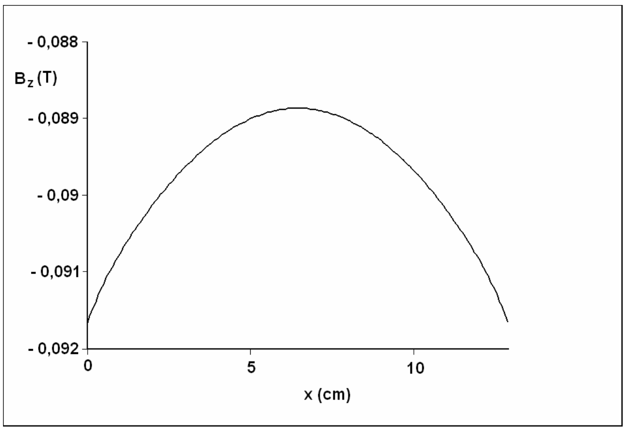

Fig.8: Magnetic flux density part B_z value curve in longitudinal (x) direction – middle of the air gap

The Watson circuit is composed of two PM blocks in line (one with the other) connected by two plates of such thickness just to avoid their oversaturation. The plates can have either constant or variable thickness. The plates can be formed in transverse direction to correct the edge effect (loss of magnetic flux density value on the edges).

The basic Watson circuit is presented in Fig. 5. Practical realization of low Watson circuit is in Fig. 10, the length of sheets is 150 mm.

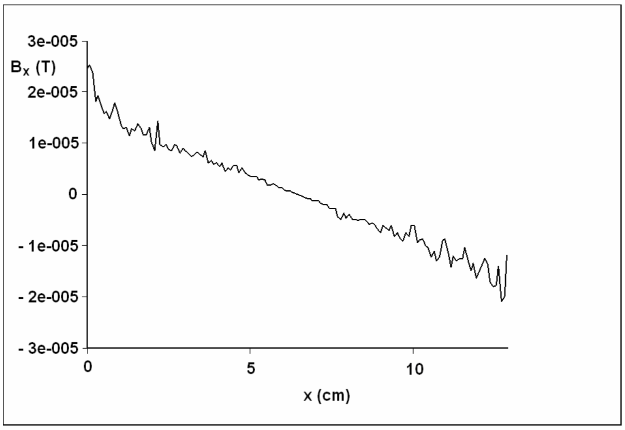

Fig.9: Magnetic flux density (part B_x) value curve in longitudinal (x) direction – middle of the air gap

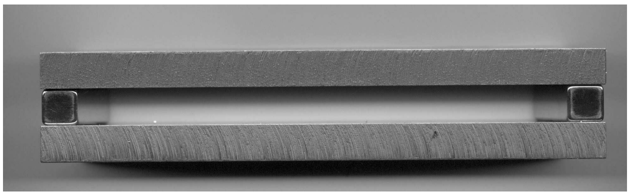

Fig.10: Practical realization of low Watson circuit (10 mm sheets thickness, 10 mm air gap)

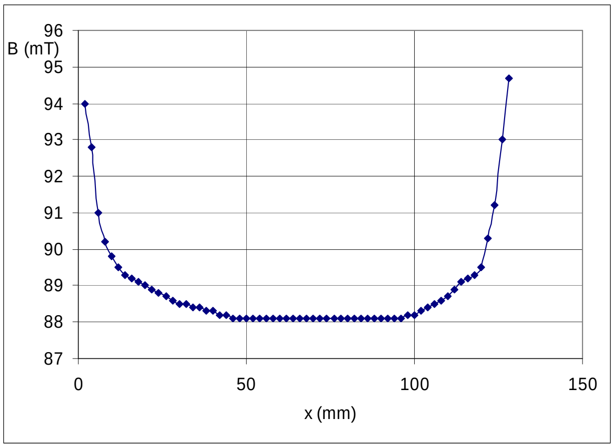

Fig.11: The result of measurement in longitudinal (x) direction (B_z part)

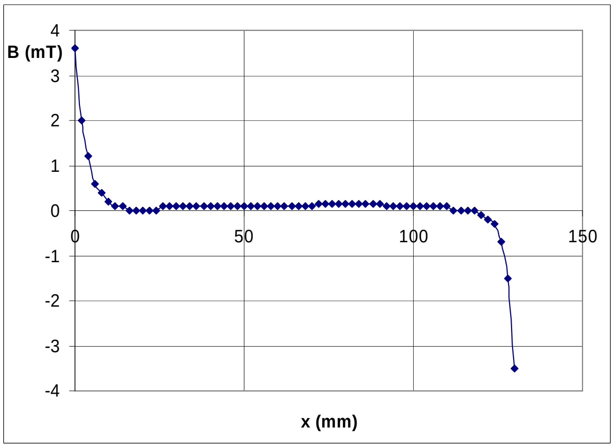

Fig.9: The result of measurement in longitudinal (x) direction (B_x part)

Permanent magnet dimensions are 10x10x39 mm, the vector of magnetization is perpendicular to the plane 10x39 mm.

2.2 *One half of Watson circuit*

There is used only one permanent magnet for magnetic field exciting (situated on the left side).

2.2.1 The arrangement without all corrections

a) The length of Fe sheets is 150 mm

The length of Fe sheets is 150 mm (as in par. 2.1), their thickness is again 10 mm. But, the exciting permanent magnet is only on one (left) side. In practical realization, it is the problem of mechanical mounting of Fe sheets (some special holder has to be realized). As in the case for "full" Watson circuit, there are the map of absolute value magnetic flux density (Fig. 12) and computed magnetic flux density absolute value (Fig. 13) presented. From Fig. 14, it can be seen that minor part (B_x) is negligible. Thus, the measured major part (B_z) can be directly compared with calculated absolute value. In comparison with value of major (B_z) part of magnetic flux density in "full" Watson circuit, we can find that now the value is less one half of the original.

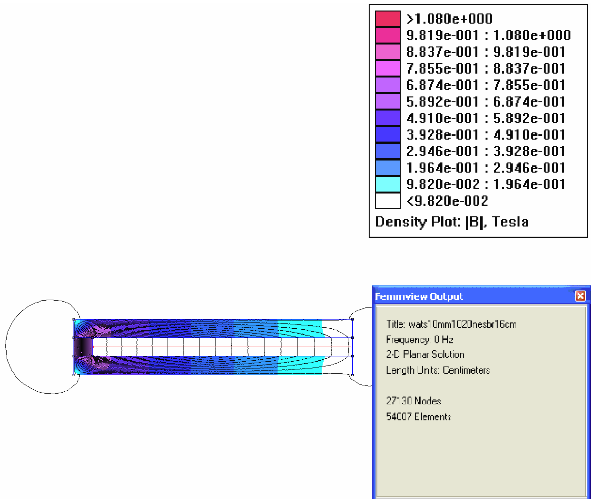

Fig.12: The map of magnetic flux density distribution

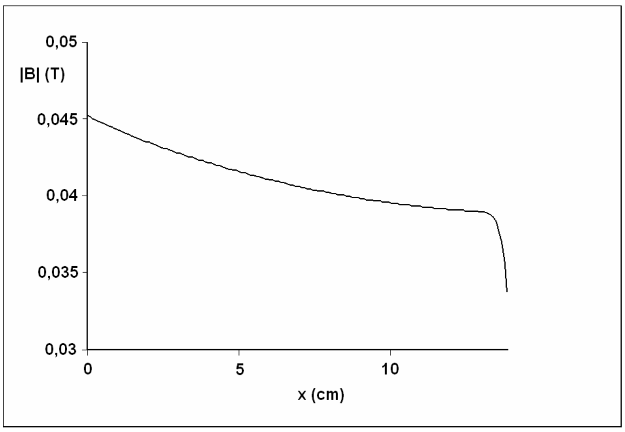

Fig.13: Magnetic flux density curve in longitudinal (x) direction – middle of the air gap – absolute value

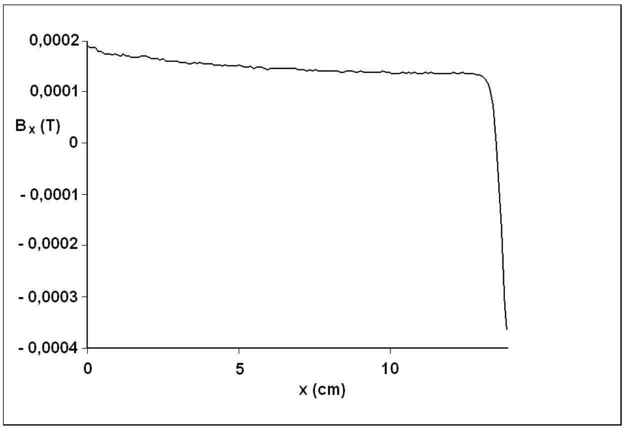

Fig.14: Magnetic flux density curve in longitudinal (x) direction – middle of the air gap – B_x part

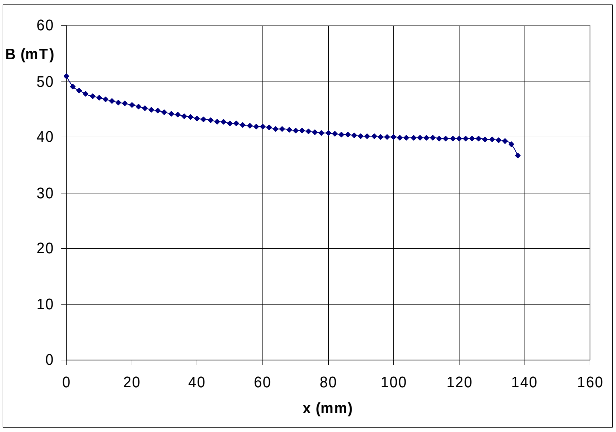

Fig.15: Magnetic flux density curve in longitudinal (x) direction – middle of the air gap - result of measurement

b) The length of Fe sheets is 80 mm

In this paragraph, there is shown magnetic circuit with sheets length 80 mm, the sheet thickness is again 10 mm. As the results, there are only the map of magnetic flux density absolute value and the curve of magnetic flux density absolute value in longitudinal direction presented. The obtained value of magnetic flux density at air gap working space is approx. 70 mT.

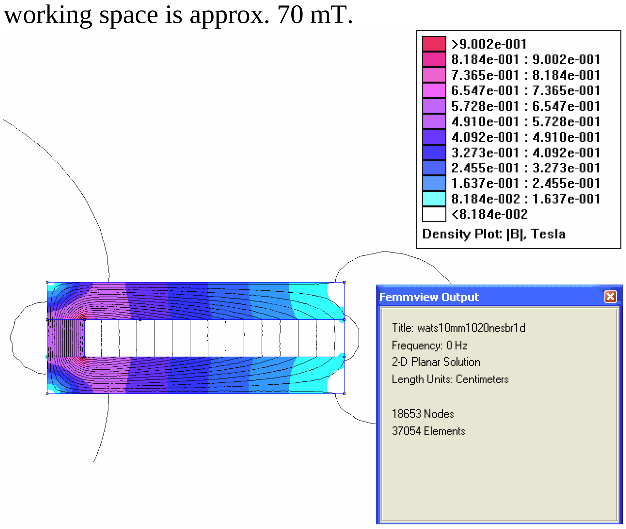

Fig.16: The map of magnetic flux density distribution

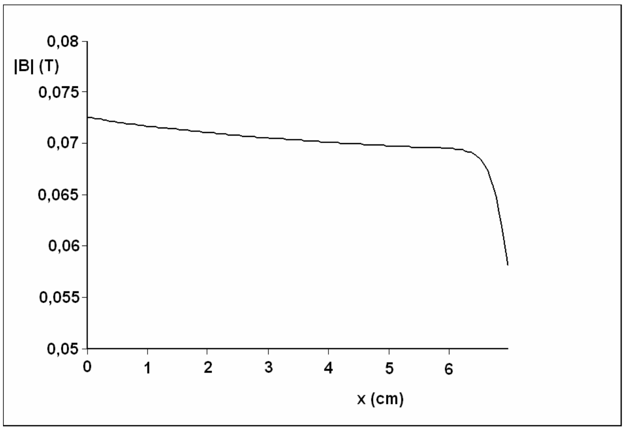

Fig.17: Magnetic flux density curve in longitudinal (x) direction – middle of the air gap – absolute value

The problem has been solved by programme FEMM for several Fe sheets lengths. The lengths were a little less (eg. 70 mm) or a little more than a half of original length for “full” Watson circuit.

2.2.1 The arrangement with simple corrections

There is shown the case with only simple Fe sheets correction. Magnetic circuit with Fe sheets of 80 mm length and variable thickness together with very small change of sheets distance is shown. All changes are linear. This arrangement is displayed in Fig.18 and magnetic flux density distribution is shown in Fig. 19 and magnetic flux density curve and its parts is presented in Figs. 21, 22 and 23. This circuit is very sensitive to very precise adjustment. The rider of this is the fact that precise mounting of Fe sheets has to be made.

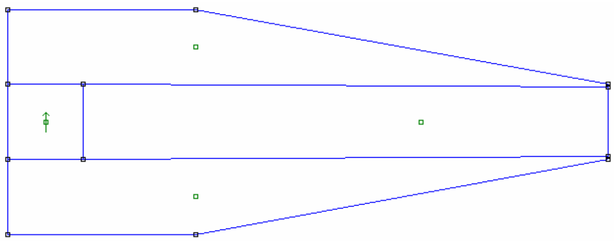

Fig.18: The model for solving by FEMM

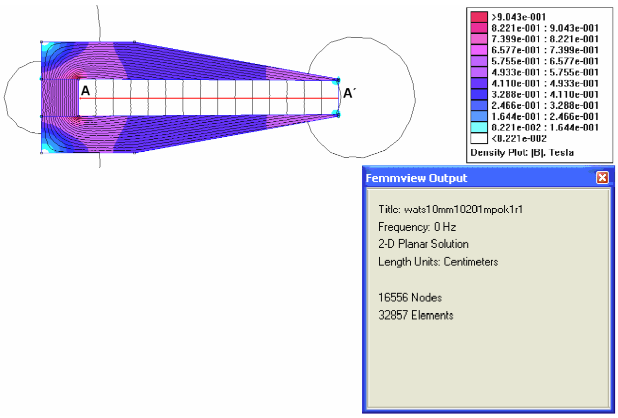

Fig.19: The map of magnetic flux density distribution

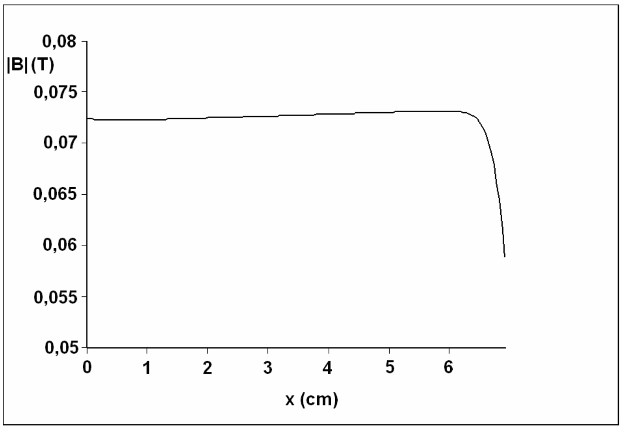

Fig.20: Magnetic flux density curve in longitudinal (x) direction – middle of the air gap – absolute value

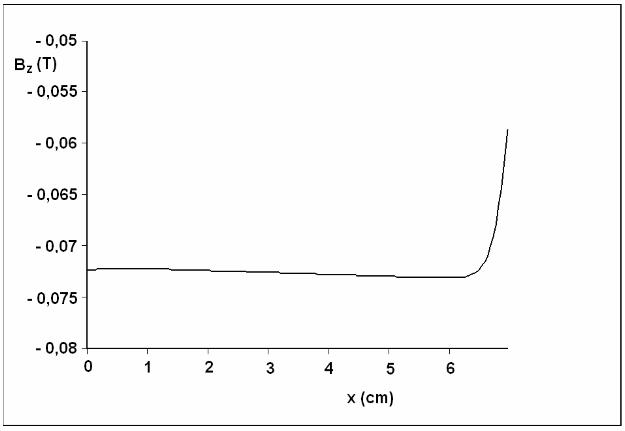

Fig.21: Magnetic flux density curve in longitudinal (x) direction – middle of the air gap (B_z part)

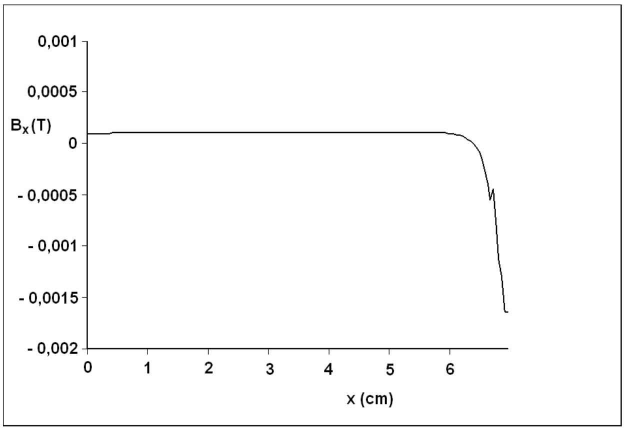

Fig.22: Magnetic flux density curve in longitudinal (x) direction – middle of the air gap (B_x part)

It can be seen that B_x part is nearly constant and very small and can be neglected.

3 Conclusions

It is clear, that it is possible to control magnetic flux density value by the Fe sheets distance adjusting. The increase of Fe sheets distance drops off magnetic flux density value in the air gap. In this case, it is however negatively affected magnetic flux density distribution on the sheets edges (in the direction of *y* axis).

As another possibility of control, it is the use of only one exciting permanent magnet together with suitable Fe sheets length. But, we have to realize the homogeneity requirement of magnetic flux density distribution at working place.

It stands to reason, that in the case at which the homogeneity requirements are not more than enough high, it is possible to use magnetic circuit excited by only one permanent magnet. Apparently, it is possible to obtain relatively good magnetic field homogeneity by habitable modification of Fe sheets.

In the cases, where test measurements have been realised, relative good agreement of measurement and computing results can be stated. Seeing that can be assumed, that computing results should be in a good agreement with results of measurements also in the case of magnetic circuit with variable thickness and the distance of Fe sheets, see paragraph 2.2.1. But, the measurements could not be realised because of absence of magnetically soft parts for realisation of magnetic circuit.

For a magnetic circuit of Watson type analysis with larger Fe sheets distance, it is essentially preferable 3D computing programme based on finite elements use, eg. FEMLAB.

In the paper, there is shown (among others) the possibility to realize relatively homogenous static magnetic field in some volume by using of only one (one block) exciting permanent magnet(s). Magnetic field homogeneity is attained by Fe sheets profiling. However, there are presented only calculated values because of physical model absence up to now.

4 References

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