Journal of ELECTRICAL ENGINEERING, VOL 57. NO 8/S, 2006, 189-192

MAGNETIC FLUX DENSITY DISTRIBUTION MEASUREMENTS AND COMPUTATIONS IN WATSON CIRCUIT

Aleš Hála

This paper shortly shows some characteristics of used magnetically hard and soft materials and deals with magnetic flux density distribution computation in the centre of Watson circuit in longitudinal direction. The problem has been solved by programme FEMM (2D) based on Finite Element Method. The computation results are compared with results of measurements. Finally, there are shown results of magnetic flux density measurements transversely in air gap of the uncompensated, overcompensated and compensated Watson circuits.

Keywords: permanent magnets, magnetic flux density distribution, magnetic measurements, Watson circuit, homogeneous magnetic field

1 INTRODUCTION

Sometimes, we need to realise nearly homogeneous magnetic field in relatively large volume. In such cases, the best solution is to use so-called Watson circuit [1].

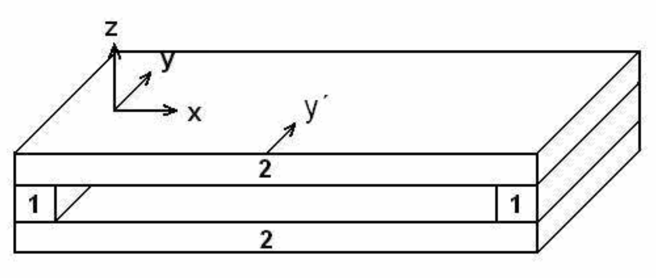

Fig. 1. Watson circuit with low air gap (1 – PM, 2 – Fe sheets)

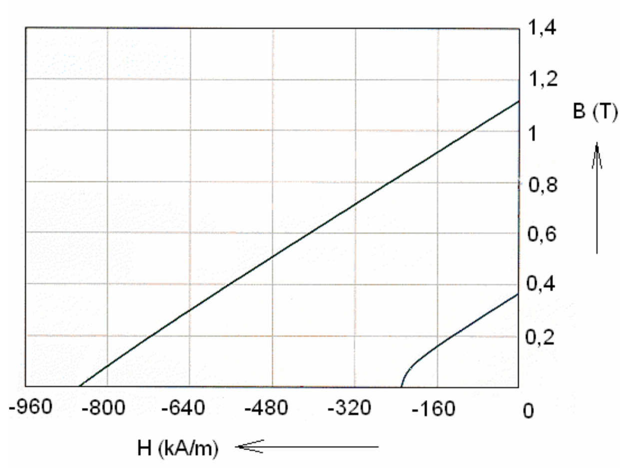

Fig. 2. Typical demagnetising curves NdFeB (above) and ferrite permanent magnet materials

The properties of main magnetically hard materials can be found in [3-5], e.g. the properties of two usable hard magnetic materials are (in form of demagnetising curves) presented in Fig.2. As the Watson circuit use is assumed in the area of temperatures close to temperature of room, there are not thermal properties of used materials discussed here.
The magnetising curve of typical material which can be used for Fe plates manufacturing is in Fig. 3.

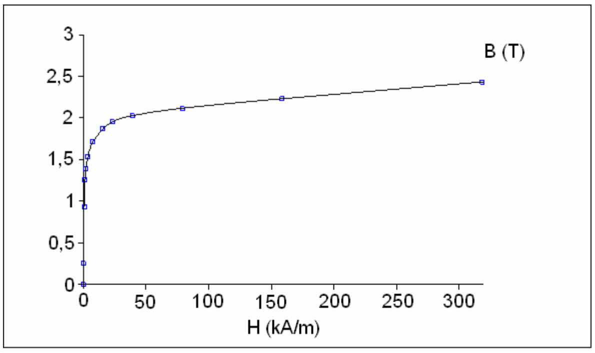

Fig. 3. Typical magnetising characteristic of construction steel

The Watson circuit is composed of two permanent magnet (PM) blocks in line (one with the other) connected by two plates of such a thickness which allows 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. 1 and practical realisation of it is in Fig. 4

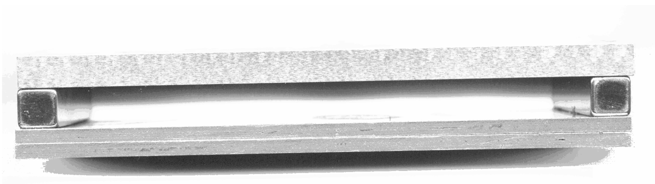

Fig. 4. Low air gap (10 mm) Watson circuit practical realisation

It always exists the possibility of magnetic flux density compensation in air gap in transverse direction. The example of Fe plates profiling in this direction used by us will be presented in next text. The other possibility of magnetic flux density correction is the use of permeable strips fitted on edges of permeable sheets.

2 MAGNETIC FLUX DENSITY SOLVING IN LONGITUDINAL DIRECTION

For a reason of magnetic flux density calculations in longitudinal direction, there were used programme FEMM

Department of Electrical Engineering, Faculty of Military Technologies, University of Defence in Brno, Kounicova 65, 612 00 Brno, Czech Republic, e-mail: ales.hala@unob.cz

(2D) based on Finite Element Method [2]. The examples of computations results in low Watson circuit are presented in Fig.5 to Fig.7 for one exciting permanent magnet and in Fig.8 to Fig.10 for two parallel exciting permanent magnets. The length of Fe plates is 150 mm, their width is 40 mm and the thickness is 10 (or 15) mm.

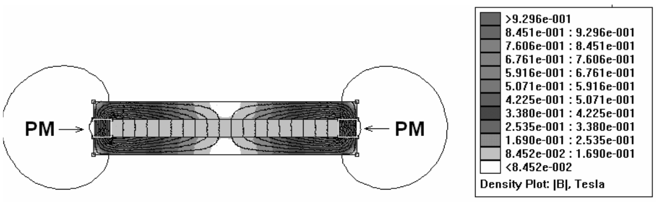

Fig. 5. The map of magnetic flux density areas in Watson circuit (1 PM, 10 mm sheets)

In Fig. 6, there is drawn magnetic flux density from left permanent magnet to permanent magnet on the right side. Used NdFeB permanent magnets have the dimensions 10x10x39 mm. They are magnetised upright to 10 x 39 mm surface. This side is connected to the Fe connecting plates. The connecting Fe plates have the thickness of 10 mm in the first case and 15 mm in the second case.

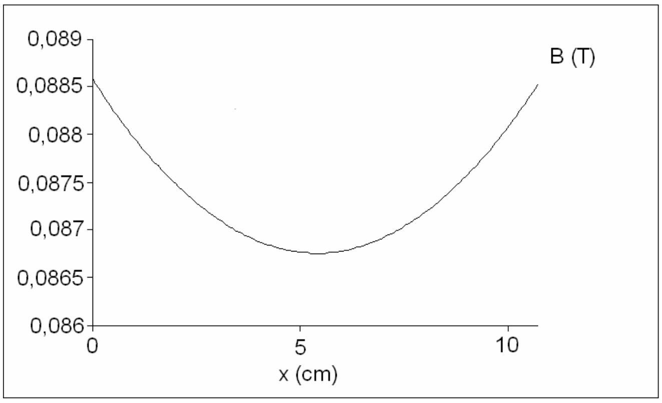

Fig. 6. Magnetic flux density curve in the middle of the air gap – longitudinal direction (10 mm sheets)

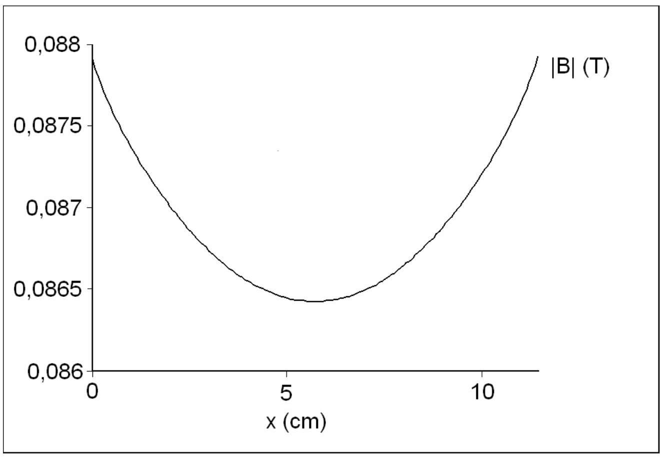

Fig. 7. Magnetic flux density curve in the middle of the air gap – longitudinal direction (15 mm sheets)

As an example of a usage of two exciting parallel permanent magnets, there is presented the case with 15 mm permeable sheets.

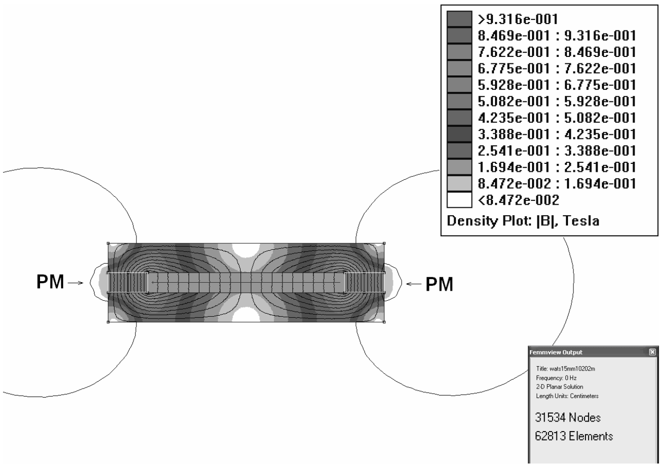

Fig. 8. The map of magnetic flux density areas in Watson circuit – longitudinal direction (2 PM parallel, 15 mm sheets)

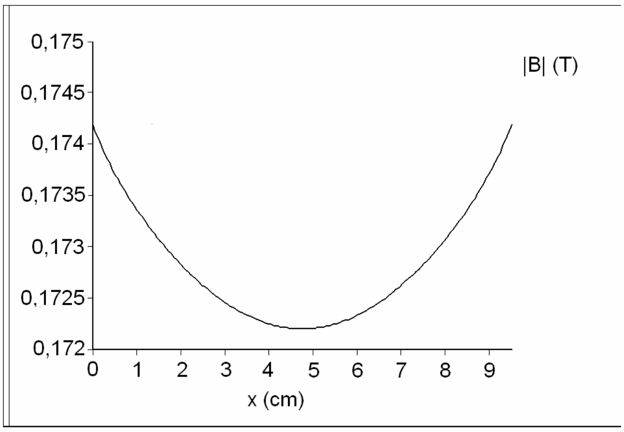

Fig. 9. Magnetic flux density curve in the middle of the air gap – longitudinal direction (2 PM parallel, 15 mm sheets)

3 SOME RESULTS OF MEASUREMENTS

3.1 Low air gap

There have been realised and measured a lot of Watson circuit configurations with small air gap depth. Some of the obtained results are presented here.

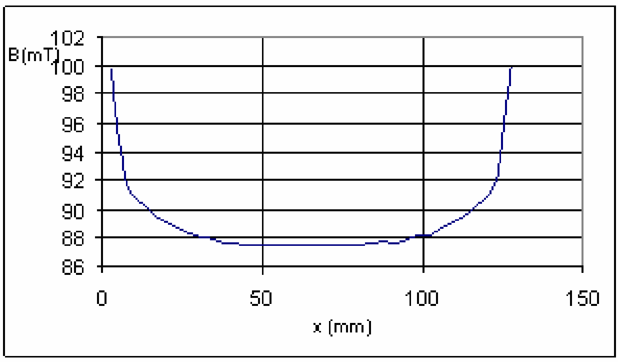

Fig. 10. The result of measurement in longitudinal direction of circuit – 10 mm sheets

In figures 10 and 11, there are presented results of calculated circuit measurements (see Fig. 6 and Fig. 7) to be able to compare them.

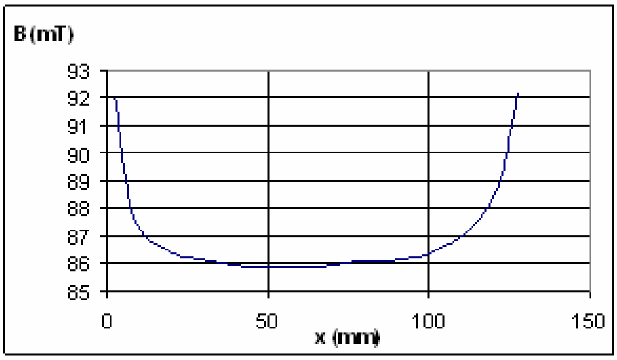

Fig. 11. The result of measurement in longitudinal direction of circuit – 15 mm sheets

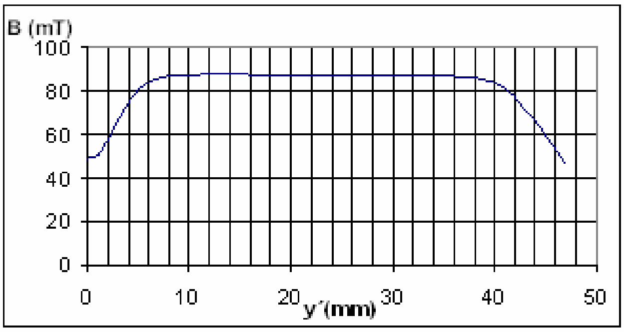

Fig. 12. The results of magnetic flux density distribution measurement in transversal (y´) direction – 10 mm sheets

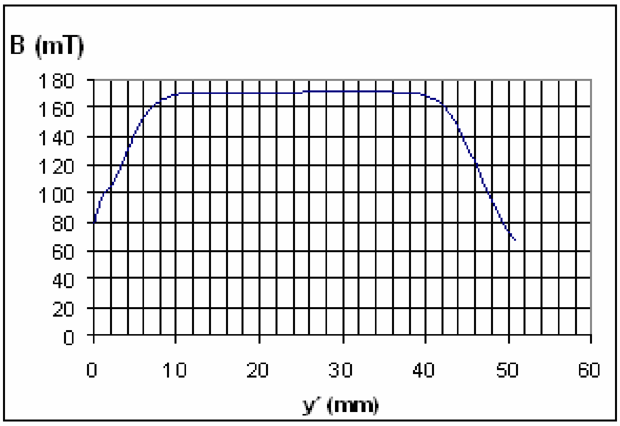

Fig. 13. The result of magnetic flux density distribution measurement in transversal (y´) direction – 2 PM and 10 mm sheets

By the comparison of Figs. 6 and 10 and Figs. 7 and 11, it is possible to state good conformity of the results. Then, the programme FEMM (or QuickField, eg) is sufficient for low air gap analysis.

Magnetic flux density distribution in transversal direction (some examples of measurements are presented in Fig. 12 and Fig. 13 - centre of Fe connecting plates is in the distance of 25 mm) do not present noticeable fall near the edges. Then, it is not necessary to analyse the problem by 3 D programme.

3.2 Higher air gap

There have been computed and realised and measured many Watson circuits with differently high air gap. One of these results is presented here. There have been measured uncompensated and overcompensated Watson circuits with higher air gap (30 mm). Only one permanent magnet was used on each side. The height of 30 mm was obtained via two identical Fe prisms on each side overcompensated circuit, see Fig. 14.

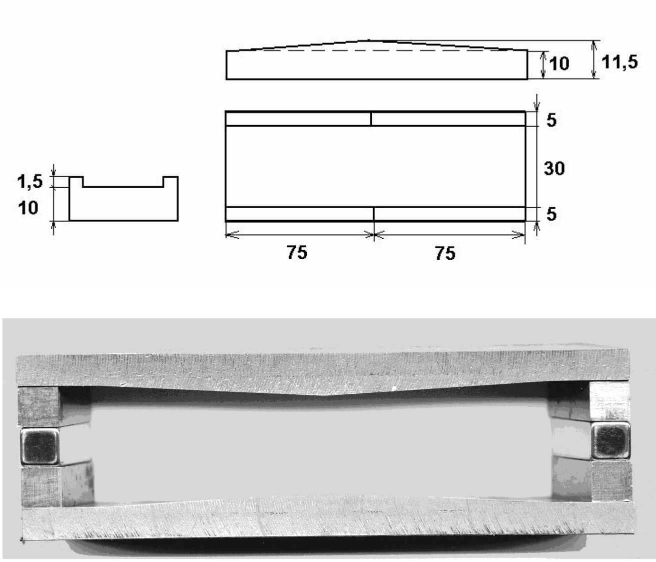

Fig. 14. The sketch and practical realisation of Watson circuit with model correction (30 mm air gap)

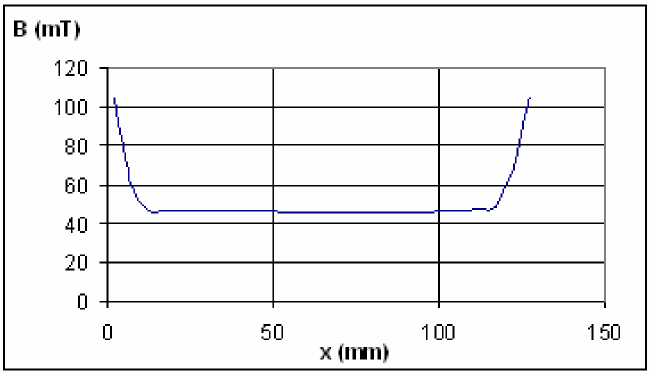

Fig. 15. Magnetic flux density curve in the middle of the air gap – longitudinal (x) direction (10 mm sheets)

In Fig. 15, there is presented magnetic flux density distribution in longitudinal (x) direction in the air gap centre. There is a good agreement with calculated results (not published here).

In Fig. 16, there is presented a comparison of magnetic flux density distribution in the transverse (y´) direction for both circuits (uncompensated and overcompensated). The curve 1 is for non-compensated Watson circuit. For the overcompensated Watson circuit, there are presented two curves. The first one (labelled as 2) is for the original y´ axis of the circuit, the second one (labelled as 3) for the distance of 15 mm from the y´ axis. The centre of Fe connecting plates is in the distance of 23 mm. The result of measurements of compensated Watson circuit in transversal direction is presented in Fig. 17.

The results of magnetic flux density distribution in transverse direction have been obtained only by measurement. The 3 D programme is needed for the computation.

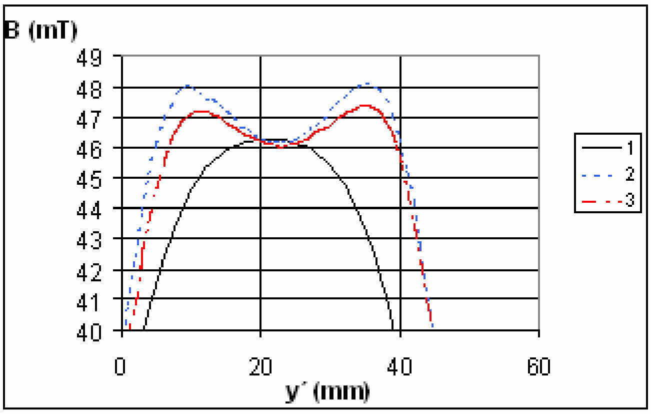

Fig. 16. The results of measurements in transverse direction

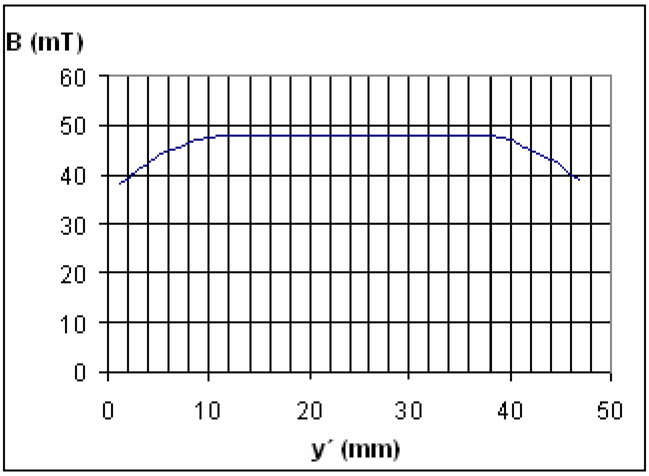

Fig. 17. Compensated Watson circuit (air gap 30 mm high) in transverse direction

4 CONCLUSION

To achieve a lower magnetic flux density value in the air gap than the original value excited by one NdFeB permanent magnet, it is necessary to increase the air gap highness. In some cases, it is possible to replace NdFeB magnets by ferrite permanent magnets.

On the contrary, the magnetic flux density increase can be obtained by using (under the condition that the air gap highness is the same) of two PM, side by side. In this case magnetic flux density value is roughly multiplied by 2.

There have been discussed some possibilities of magnetic flux density drop compensation on the edges in transverse direction. It stands to reason that it is useful to use the correction strips fixed on air gape edges or to form the sheets.

There have been computed and in some cases also tested connections of Fe sheets of different thickness. It is possible to conclude that better results are obtained for magnetic flux density distribution in air gap while using thicker sheets (there could be a problem of over-saturation). The final results of the connecting sheets thickness influence will be presented during my conference speech.

Finally, it is necessary to pay attention to an important problem, which is a precise adjustment of position of the Hall probe in all realised measurements.

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Received 8 November 2006

Aleš Hála (Ing, CSc.), born in Kutná Hora, Czech Republic, in 1945. Graduated from the Faculty of Air Forces, Air Defence and Radio Communications, Military Academy, Brno, in 1968 from radar technique. He received the CSc. degree in Electromagnetic Theory at the same University in 1985. At present he is a reader at the Department of Electrical Engineering, Faculty of Military Technologies, University of Defence in Brno. His teaching activities are mainly in Fundamentals of Electrical Engineering, Electromagnetic Field Theory and Electromagnetic Compatibility. The main fields of his research activities are electromagnetic field theory and applications and electromagnetic compatibility.