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DIAGNOSTICS OF AIR-GAP INDUCTION'S DISTORTION IN LINEAR MAGNETIC BRAKE FOR DYNAMIC APPLICATIONS

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Abstract – This paper introduces research of magnetic fields with special attention to distortion of induction in the air-gap of a linear magnetic brake and effects of this distortion. This work is part of a research project aiming to find the most efficient and accurate method for development of linear magnetic brake for dynamic tests in industrial applications. In such applications characteristics of the braking force should be precisely defined and generated therefore control of this system requires highly reliable and accurate function definition between the braking force and the controlling current. In this part of the research dependency between the force and current is analysed, new measurement and analysing system is developed for special requirements, simulation results and real test results are presented in the paper. Results of the diagnostics are used to define braking effects and for development of compensation methods used in dynamic systems.

Keywords: magnetic brake, air-gap induction, eddy-current

1. INTRODUCTION

In some special industrial development processes dynamic brakes are widely used in prototype testing. Such industry is the electrical power tool, where automation of lifetime testing of tools performing fast alternating movement, like jigsaws is an open question. In an earlier stage of this research a tester was developed, structure of which is shown on Fig. 1. Its theory of operation is widely used in industry and known as moving coil actuator or voice coil actuator. The moving coil is situated in a narrow air-gap. It breaks magnetic circuit of the excited soft iron and generates a strong magnetic field. While current is flowing in the moving coil magnetic interaction between the coil and soft iron body is generated. But in this case instantaneous velocity and direction of movement together with instantaneous position of the moving coil is defined by an external effect which comes from the electrical power tool to be braked. Current of the coil should be controlled in each moment to rising opposite to movement direction force effect to the jigsaw. In this tester eddy currents generated in the closed aluminium coil former are also amplifying the breaking force. The other problem is the mass of the moving coil which should be compensated in order to make available unloaded test phases in cyclic lifetime test processes. For the mass compensation specially calculated and precisely generated forces should be applied and added to braking force.

Online measurement of force and analysis for control system in this highly dynamic system is not a possible solution therefore in order to develop control system of high reliability and accuracy preliminary research based on magnetic field theory, practice and measurement should be performed. Results presented in this paper give detailed information on effects of moving coil's current to air-gap induction and eddy current generation including reaction of eddy currents [1][2][3].

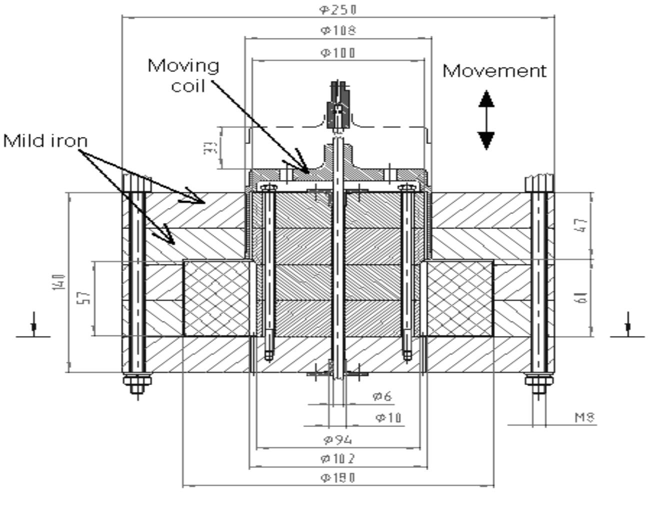
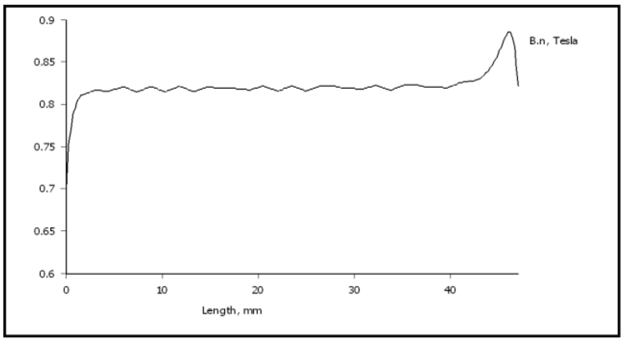


Fig. 1. Mechanical structure of linear magnetic brake's prototype [1]

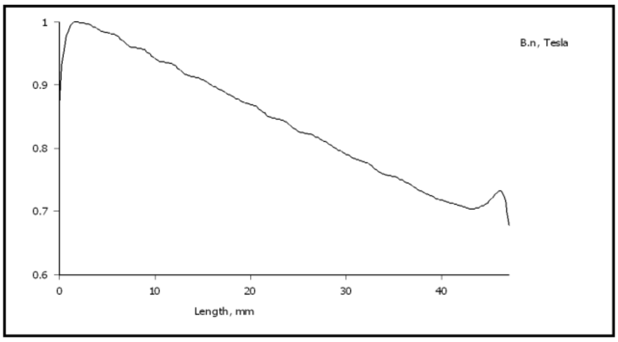
2. DISTORTION OF AIR-GP INDUCTION AND EDDY-CURRENTS IN IRON CORE

Operation of the liner magnetic brake is based on theory of interaction of current flow and stationer magnetic field. In this well know theory the magnetic field of the current flowing in a wire has no effect to the stationer magnetic field as the environment of wire can be considered as an infinitive air-gap, and so the induction resulted from multiplication of magnetic field strength of wire's current and vacuum permeability is far less than the external induction [1]. The linear magnetic brake is a special version of the above described theory where the air-gap is minimized and therefore the magnetic field of the wire disfigures air-gap induction. Because the necessary force characteristics can be generated only by alternating current in moving coil, the above described distortion also will change in time. This change besides of the air-gap will appear also in the air-gap close parts of the iron core, similarly to the phenomenon of armature-reaction in DC motors. This special effect causes eddy-current generation in the defined parts of iron body. Eddy currents are generated according to the Lenz-law, which means that they decrease induction distortion. One of the aim of simulations and measurements presented in this paper is to analyse resulting distortion in function of moving coil's current level and frequency. [4][5][6]

Distortion of the air-gap induction has effect not only to the excitation part of the system but also to the moving coil as the flux density is not homogeneous in the coil length force applied to turns is different while the current is the same. It makes more difficult to define the above described relationship



a)



b)

Fig. 2. Induction in the air-gap with (a) no current (b) 2.5A current in the moving coil

Distortion of air-gap induction is shown on Fig. 2. Simulations were performed using axle-symmetric problem solving in FEMM (Finite Element Method Magnetics) software. Geometry of the prototype was used for simulation. The following specification of prototype was used for input parameters: current values of the exciting and moving coils, type of soft iron with low carbon content (1006).

3. THE MEASURING SYSTEM

Induction changes in the air-gap were measured by a Koshawa-USB (Wuntronic GmbH) type instrument with a OW-2 type traverse probe suitable for measuring up to 2T of steady state or alternating up to 10 kHz magnetic induction. The probe inside of the air-gap was set in each millimetre for measuring. Measurement assembly is shown on Fig. 3.

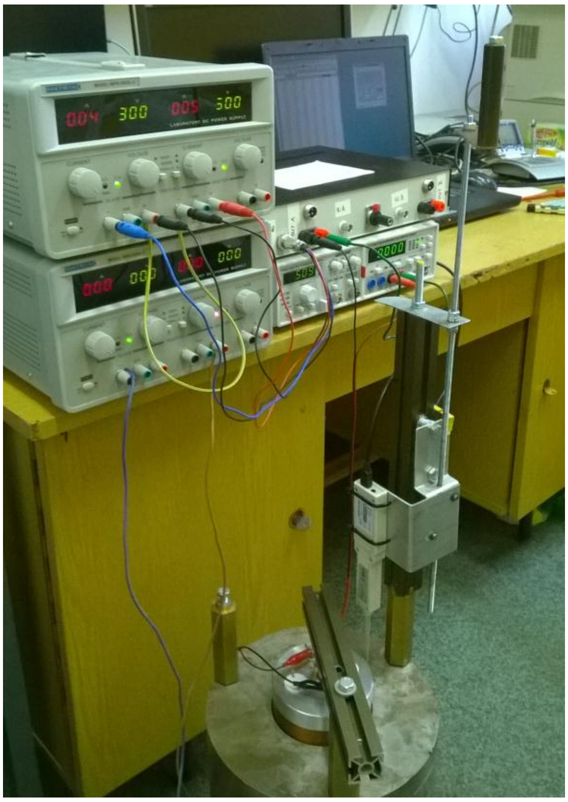


Fig. 3. Structure of the measuring system

The first measuring series was used to check repeatability and reproducibility performing 5 measuring series on 3A excitation. Results are summarised in Fig. 4.

Dispersion of field on top and bottom side is relatively high increasing deviation of measured results in this area, but it has no effect to the diagnostic results. Otherwise measurement results are comparable with simulation results.

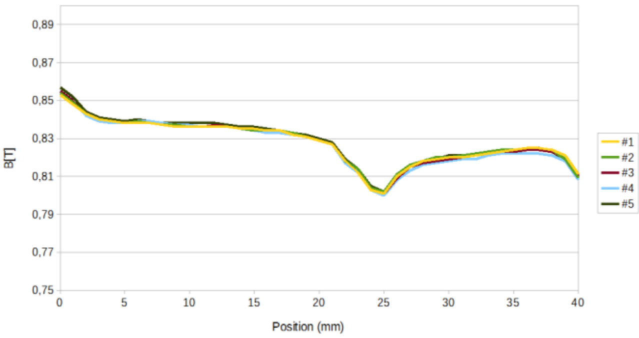


Fig. 4. Measurement results of induction distribution in the air-gap

4. TESTING DITORTION EFFECT OF THE MOVING COIL'S CURRENT

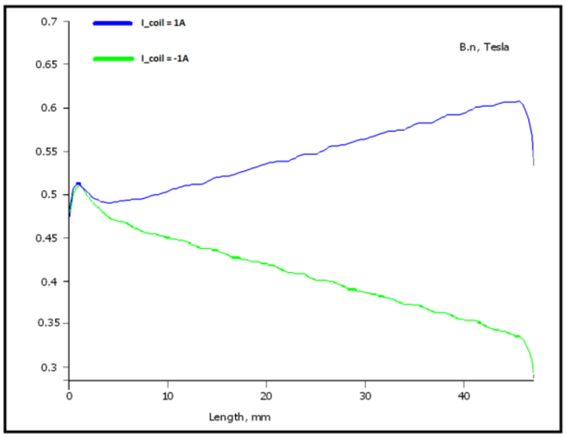
After the above described preliminary measurements tests with excited moving coil were performed. As negative current generate repulsive force, and the iron core pushes the coil out of the air-gap, we should fix the moving coil during tests. The fixing was a critical problem as the force at nominal excitation (especially at alternating currents) can be several hundred Newton, so we have limited the moving coil's current to 1 A. This limitation ensured proper fixing of the coil.

First series was performed with DC excitation current and also the distribution of induction in the air-gap was registered. Second series was performed with AC sine current pp value of which was defined according to DC excitation current. In this second case DC and RMS components of the induction was registered and the pp value calculated. In this system DC and AC excitation results are comparable and difference characterises the effects of eddy-currents generated in iron core.

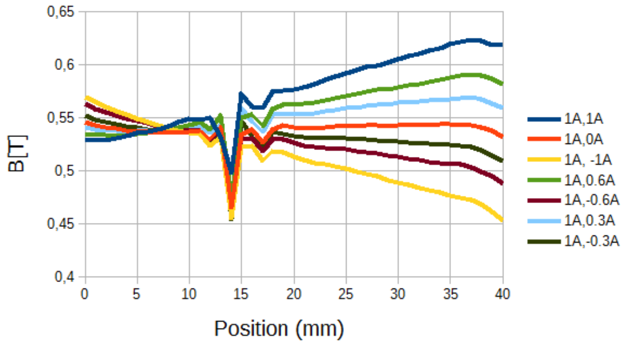
4.1. Testing with DC current excitation in moving coil

Fig. 5.b. shows the results of DC tests. Excitation current level is 1 A generating 0.53T average induction in air-gap. This is lower than the 0.85T maximum possible theoretical level, but the applied steel has relatively high saturation (>1.5T) which means that those parts close to the air-gap will not be in saturation. The results shown on the Fig corresponds to simulation results, only a small dispersion is caused some differences. [2] Different coil currents are marked by different colours on the graph. The results approximate the corresponding curves of the simulation well, these can be seen on Fig. 5.a.

The extent of the flux density's distortion is different on the top and the bottom of the air-gap as seen on the results. This difference is also appeared in case of larger moving coil currents (see on Fig. 2.b). Due to this diversion the average flux density is increased or decreased depending on the direction of the coil current. Without compensation the brake current may be asymmetrical despite of the symmetrical coil driving. First and last the created force is not proportional to the coil current, it depends on its direction.



a)



b)

Fig. 5. Distortion of induction in the air-gap for different level DC current in moving coil – simulation (a) and measurement (b)

4.2. Tests with AC current excitation in moving coil

The flux density distortion modifies the average flux density in case of DC coil current as shown on the previous results. The goal of the AC test is to find the effects of this distortion when AC coil current is applied.

Fig 6. and 7. show results of tests with AC current excitation in moving coil. Thick lines on Fig 6. show the induction distribution approximated by polynomial functions in case of different coil's current frequencies.

Results of measuring series includes DC and RMS components. Pick value is calculated from the RMS value. Maximum amplitude of the current in moving coil was 0.6A because the power supply limitations and relatively high resistance (~20 Ohm) of the moving coil.

Fig. 6. shows pick values of AC components on excitation frequencies of 20 Hz, 30Hz and 40Hz. Slope of the induction distortion calculated from the centre of air-gap is decreasing with frequency increase by 1mT/10Hz. Nonlinearity of measured values is caused by measurement method, as the probe can measure only summarised induction and the instrument electronics separates DC and AC part which means that the measuring range is not ideal for AC part measurement but some further conditioning may be used if necessary. In this case accuracy of results is in acceptable range, the approximation shows difference on the frequencies used in analysis. [6]

Fig. 7 shows summarised results of DC and AC pick components.

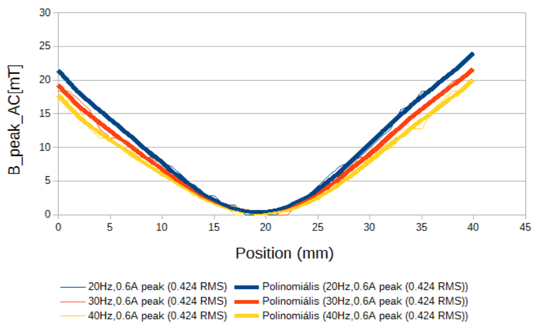


Fig. 6. AC component's pick-value distribution of induction in the air-gap and its polynomial linearization of 6th order

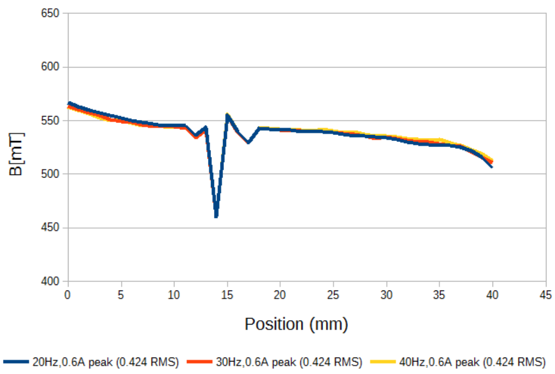


Fig. 7. Summarised results of DC and AC components pick values

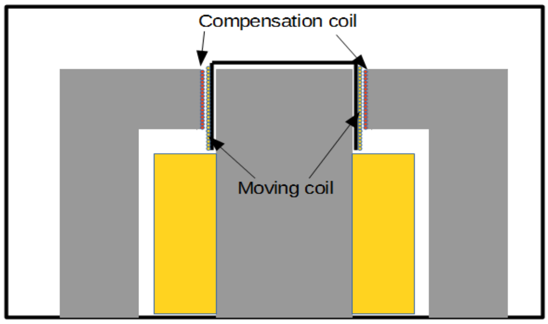


Fig. 8. Compensation method of induction's distortion

5. CONCLUSIONS

Results of tests (Fig. 6. and 7.) show that induction distortion in air-gap is decreasing with increase of the excitation current's frequency and it is relatively low comparing with DC component. As the tests were performed on relatively low excitation and moving coil's current, distortion and difference levels are much lower than the distorted flux density values in case of DC coil's current. It means that the moving coil's current doesn't cause significant asymmetry in dynamic applications. Results also underline that this analysed effect is increasing as quasi-linear function up to saturation with increase of moving coils current and starting value of air-gap induction. From the other side results are proved that distortion elimination effect of eddy currents can be detected but it is small even at 0.85T induction and 2.5A current.

On the basis of above summarised results of the suggestions is to use a special compensation coil in the air gap or in a hole besides the air-gap which is excited and controlled to provide same level but opposite direction induction to eliminate distortion effect. The solution is very close to that one used in DC motors to compensate armature reaction. Disadvantage of using such compensating coil is the increase of the air-gap causing decrease of the induction. From the other side this compensating coil may have positive effect to the necessary size and mass of the moving coil which is a critical point at industrial applications. This compensation may be needed in precise DC applications, in which we use this construction as a linear "voice coil" motor to apply constant force.

6. SUMMARY

In the presented in the paper part of the research project distortion of the induction in the air-gap of a linear magnetic brake was examined. This investigation was necessary in theoretical and practical development of the force generating system of the brake in order to providing accurate, fast and reliable system. Performed tests included DC and AC excitations of the moving coil. Results of AC excitation have shown that increasing frequency of the excitation distortion is slightly decreasing, but as precise force characteristic generation is an important requirement, this effect should be taken into consideration at design and development phase of the brake. As the force characteristics may require higher frequency components in the excitation current, further examination and tests will be done in order to define exact functions of this effect, while important point to have the iron core under saturation. In addition, the above described measurement methods can be used for testing "voice coil" type linear motors. Also automated tests has been performing in order to make accurate positioning of probes and to have computerised data acquisition.

REFERENCES

[1] Váradiné Sz A. *Linear Magnetic Break of Special Test Requirements with Dynamic Performance*. Journal of Electrical and Electronic Engineering 3:(2) pp. 237-240. (2010)

[2] Christina H. Chen, Ashil K. Higgins, Reinhold M. Strnat, *„Effect of geometry on magnetization distortion in closed-circuit magnetic measurements"* Journal of Magnetism and Magnetic Materials, Volume 320, Issue 9 pp. 1597-1656, May 2008. ISSN: 0304-8853

[3] L. Kazup, A. Váradiné Szarka, "*Control of Dynamic Linear Magnetic Break*" ENELKO International Conference on Energetics and Electrotechnics, October 2008. Romania, pp.21-25. ISSN 1842-4546.

[4] Dieter Joneit, Michael Nadler, *Correction of eddy current measurements to obtain accordance with simulation results*, NDT&E International, 2014

[5] Giovanni Betta, Luigi Ferrigno, Marco Laracca, Pietro Burrascano, Marco Ricci, Giuseppe Silipigni, *An experimental comparison of multi-frequency and chirp excitations for eddy current testing on thin defects*, Elsevier Ltd., 2014

[6] Dinesh Martien, *AC Magnetic Measurements*, Quantum Design, San Diego, California, USA