Journal of ELECTRICAL ENGINEERING, VOL 61. NO 7/s, 2010, 152-155

DESIGN AND EXPERIMENTAL EXAMINATION OF NEW TYPE OF ELECTRO-PERMANENT MAGNETIC CHUCK

Jan Bydžovský* – Mojmír Kollár* – Klement Ondreička – Jozef Paľa***

The so-called electro-permanent magnetic chucks are using two types of permanent magnets with a rather different coercivity and a driving coil to change the remanent state only of the weaker of them. The two opposite stages of the chuck, *clamp* and *release*, are attained by a single current pulse. An optimized design of magnetic circuit, for effectively switching the magnetic flux in chuck, in steady-state approximation and comparison with experimental results in dynamic operation are presented.

Keywords: magnetic chuck, holding device, permanent magnet, magnetic circuit, 2D field solution

1 INTRODUCTION

In principle, an electro-permanent magnetic (EPM) chuck is a combination of electro-magnet and permanent magnet. While conventional electro-magnet is continually energized during the "clamping-stage" in electro-permanent device the energizing (current in a driving coil) is required only to change its working stage (say, to or from the "release stage") and clamping mechanical force is provided only by permanent magnet (PM) itself. This system is advantageous in several aspects (beside energy saving) namely due to independence on the power supply allowing safe operation even in case of a drop-out. Such EPM clamping devices are frequently used in many holding and anchoring industrial systems. The footing of a ferromagnetic body upon its approaching to the clamping head and its relocation is possible without feeding demands. To release the clamped part a current pulse through the demagnetizing coil is needed providing a short-time lowering of the acting force. The draw-back of such a system is somewhat "uncontrolled" grabbing of the parts and thus disqualification from a wider utilization in a variety of clamping heads of automated machining tools.

A qualitative break in working principle of the holding devices was the utilization of two types of PM having different coercivities, and the impulse switching of the remanent state (remagnetization) only of the weaker of them [1]. The two working stages are toggled by a short current pulse of opposite direction in a magnetizing coil due to a sophisticated space configuration of PMs and of the magnetic circuit yokes - to switch or redirect the working magnetic flux. The zero-holding-force during the positioning before clamping and after-release manipulation is assured and these devices are widely used particularly in the so-called Power Matrix, Quad-system technology, [2]. In case of manipulators on automated machine-tools this is, however, not so advantageous due to a higher inertial mass of the clamping device itself. This is caused by a greater mass of the yoke in comparison with the own PM mass and also by construction complexity of orthogonally magnetized salient poles of two different types of PMs. All these disadvantages are smoothed away in the proposed construction based on the rotational symmetry of all parts of the electro-permanent magnetic chuck [3].

2 DESIGN AND OPTIMIZATION OF EPM MAGNETIC CHUCK IN A STATIONARY REGIME

To design a construction of magnetic circuit of an EPM holder and its optimization with respect to the clamping force or the minimization of the stray magnetic field in the release stage are stationary problems. For new technical approach it is essential that the PM with a high coercivity is conically shaped and placed inside a conical cavity of a PM with smaller coercivity, Fig. 1.

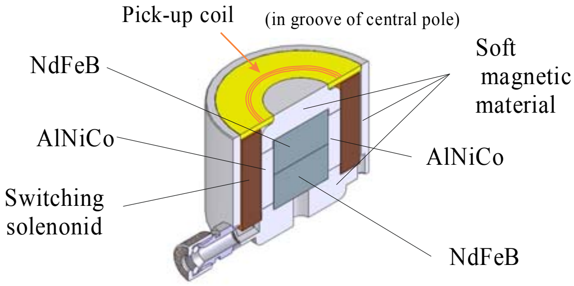

Fig. 1 The EPM clamping head with rotational symmetry

Axis-symmetrical set-up of all basic construction parts of designed EPM device is an optimal space configuration assuring smaller volume of required pole shoes than in case of orthogonal configuration, [1]. What is a difference in comparison with the previous constructions is that by the same driving coil both of PMs are magnetized. Placing the PM with higher coercivity in central part and the other PM (with a lower coercivity) closer to the driving coil windings is also effective since it produces the required magnetic field intensity by using a lower current. Also, due to cylindrical symmetry the 2D numeric solution is substantially easier, [4]. In described

* Department of Electromagnetic Theory, Slovak University of Technology, Ilkovičova 2, 812 19 Bratislava, jan.bydzovsky@stuba.sk
** fy ELKO, Zavar, Slovakia

ISSN 1335-3632 © 2010 FEI STU

(and fabricated) optimized case the high-coercivity PM is NdFeB (N38, with H_C = 930 kA/m, $(BH)_{max}$ = 310 kJ/m^3,B_R = 1.255T) and low-coercivity permanent magnet is ALNICO 5 (H_C = 51 kA/m, $(BH)_{max}$ = 43.8 kJ/m^3, B_R = 1.28 T). The multi-layer magnetizing (driving) solenoid has 228 turns, the DC resistance and inductance are R_L = 1.1 Ω, L = 1.46 mH.

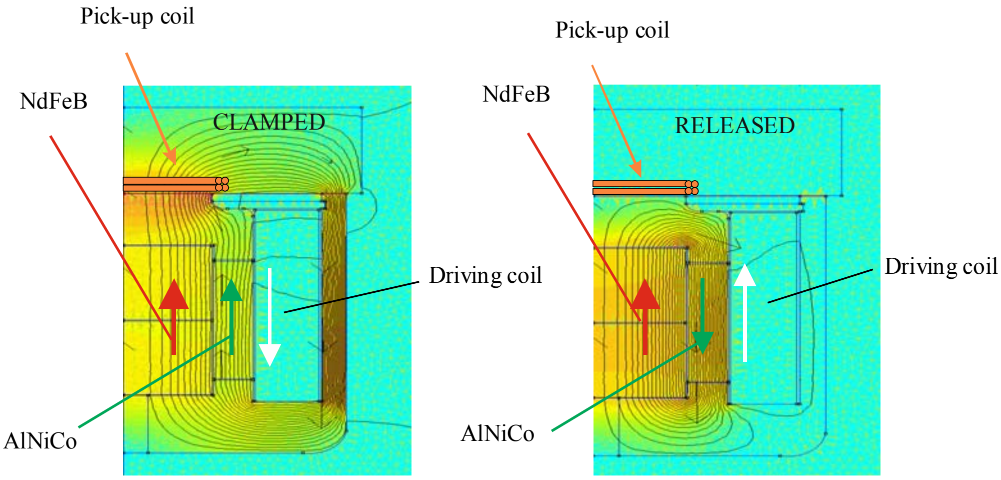

Fig. 2 Illustration of magnetic fluxes at the two „working" stages of the designed EPM, as a results of solution using FEMM: (a) − holding state or clamped, (b) − non-holding state or released

Magnetically soft material, used for the rest of construction parts *ie* the central magnetic pole, circumferential shoe as well as the dummy ferromagnetic plate (instead of any object to be clamped in the operating conditions) is a low–carbon construction steel, with the following magnetic parameters: $\mu_r^{max} \approx 1200$ and $\mu_r \approx 550$ at B = 1.2 T, that are close enough to the 1018-steel parameters of the used-software material library, [4]. At a given cross-section of the central magnetic pole 510×10^{-6} m^2 and the width of the dummy cylindrical part: h = 6 mm, dimensions of all other parts were during design optimized with an aim to get the maximal mean value of normal component of the induction at central magnetic pole. The air gaps were assessed as being around 0.1 mm between all adjacent parts, including the dummy plate. The magnetic flux at both working (remanent) stages of the designed EPM head, is illustrated in Fig. 2.

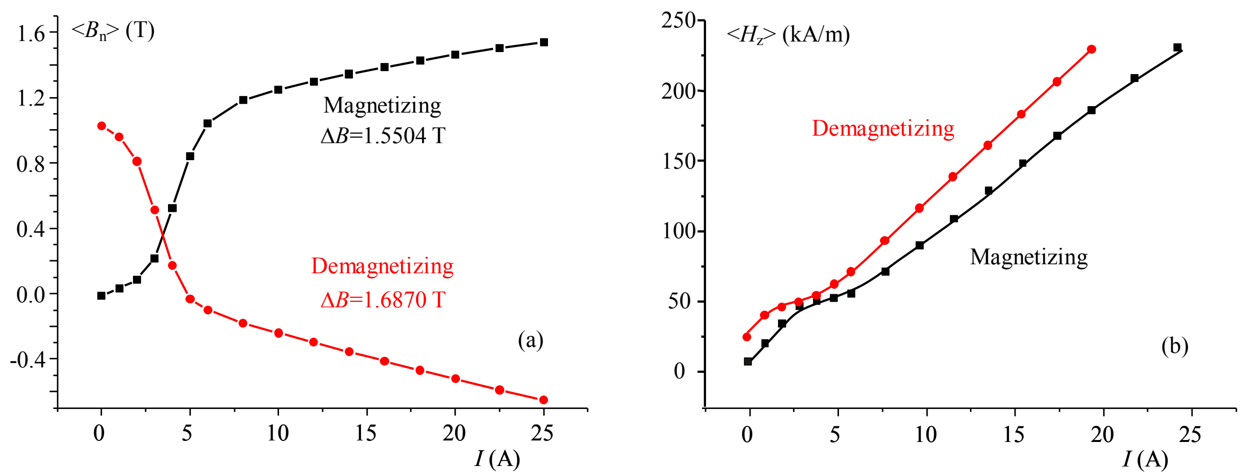

Fig. 3 Dependence of: (a) − flux density (mean value) $<B_n>$, (b) − magnetic intensity (mean value) $<H_z>$ of ALNICO PM at mean radius, both on the magnetizing current amplitude

The main results of a solution (besides other watched parameters) of magnetostatic problem are the changes of mean value of normal flux density component at the surface of magnetic poles of EPM, and of mean value of the axial magnetic field component at the mean radius of ALNICO permanent magnet, both depending on the magnetizing current amplitude, Fig. 3.The knowledge of internal magnetic field in ALNICO (Fig. 3b) is exactly what one needs for designing the electric circuit to generate a sufficient current pulse needed to complete the flux reversal (change of the remanent stage) of this PM. Further, from computed dependences it is obvious that in the merit of minimal current pulse amplitude, the magnetization process comprising the parallel alignment of PM of both types is essential. The required value of 255 kA/m, [5] was reached at current pulse amplitude of 27.5 A.

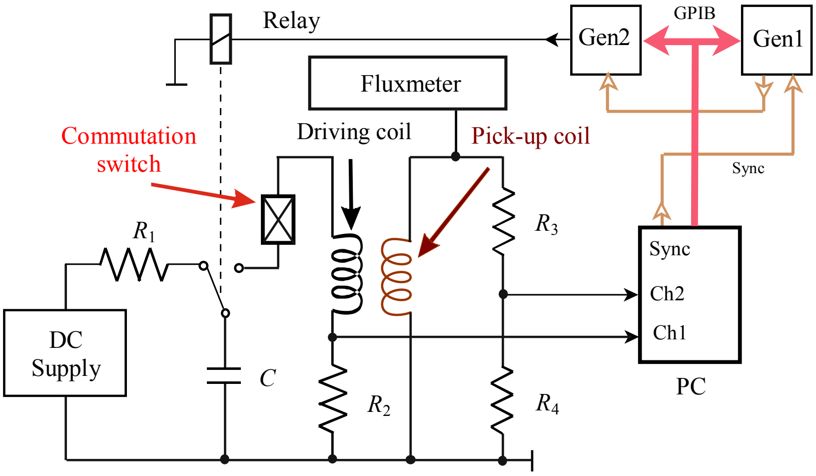

Fig. 4 The measurement setup: magnetizing current is monitored as voltage across R_2= 0.1Ω through Ch1 and the pickup voltage from divider R_3/R_4 through Ch2. The induced voltage is used also to measure the peak value of flux change by means of Fluxmeter.

3 EXPERIMENTAL VERIFICATION OF DEVICE REMAGNETIZATION IN DYNAMIC REGIME

As a standard, the impulse remagnetization of PMs is performed by discharging a capacitor bank trough magnetizing coil. Taking into consideration the magnetizing coil parameters (L, R_L) and the resistor R_2 = 0.1 Ω used to measure the current (Ch1), Fig. 4, we have chosen value of the discharge capacitor to be: C = 4.7 mF. This value, according to the transient analysis is pertinent to the aperiodic limit stage.

After completion of a closed magnetic circuit by clamping the dummy or real magnetic part of an EPM device - the situation is rather changed, and to solve the circuit with discharging capacitor is a more complex task. In first approximation we have therefore taken the verification of magnetization process and indirect measurement of the clamping force of the designed EPM device as an experimental procedure.

The change of the mean value of the normal flux component at the magnetic pole surface was measured by circular search coil (100 turns, D_1 = 25.5 mm, D_2 = 35.5 mm) placed in a grove made in the dummy closing plate.

Using a fluxmeter allowing to record the peak-value of flux change, and measuring the current pulse amplitude we were able to compare the (dynamic) experimental values with those of $<B_n>$ a I_{max} computed in stationary regime.

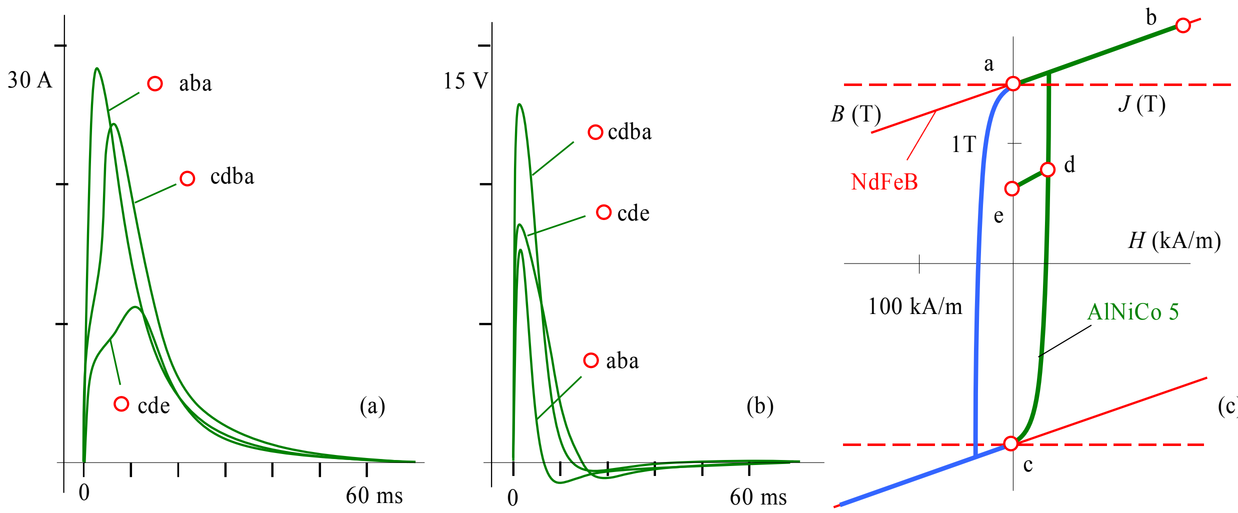

Fig. 5 Time course of: (a) – magnetizing current pulses, (b) – voltage induced in pick-up coil, and (c) – the HS loops of PMs

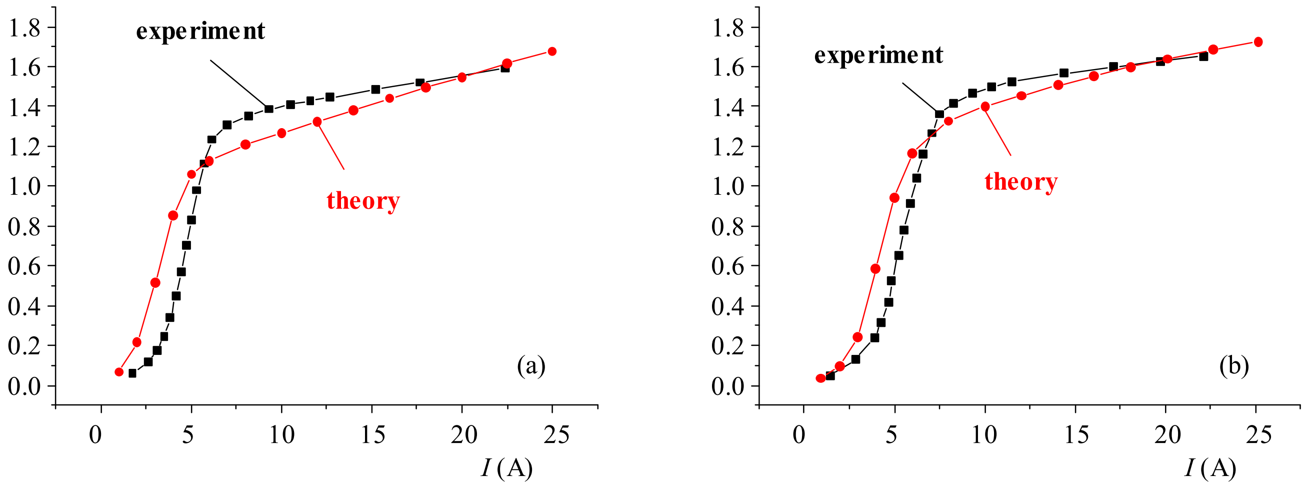

Fig. 6 The normal flux density component mean value at surface of the central pole under: (a) – clamped to released, and (b) – released to clamped stages of the EPM chuck

The computer (PC) activates measurement and data acquisition in Ch1 – the current, and Ch2 – the pick-up voltage by launching a synchronization impulse to generator Gen1 which after a required delay time (to record truly the rising edges) initiates Gen2 and consequently the discharging process of capacitor C by switching the Relay. The commutation switch is used to invert the direction of current depending on the switch-on or switch-off operation of the holding device. After about 80 ms after the launched synchronization signal the whole process is finished.

In Figure 5, there are shown typical dependences of the magnetizing current and due dependences of the induced voltage. The curve "cde" belongs to a current pulse and/or induced voltage, when the ALNICO PM is partially switched, *ie* at axial field component around the coercivity H_{CB} = 51 kA/m (U_C = 32V). The contribution of magnetic stage change of NdFeB PM to the total flux change through the central pole cross section is negligible.

Dependences "cdba" and "aba", both, belong to the magnetizing process with capacitor voltage U_C = 60V, while "cdba" is reflecting the sequence $-B_R \to +B_M \to +B_R$, case "aba" corresponds to the process $+B_R \to +B_M \to +B_R$ of the "switchable" ALNICO PM. As can be seen from dependences in Fig.~5, the rate of the remagnetization in the neighbourhood of H_{CB} (particularly in case of „demagnetization" - when a parallel juxtaposition of the stray field of NdFeB PM and of the magnetizing coil) reaches values up to 277.5 T/s. In this case, the dynamics of remagnetization is strongly influenced by the eddy-current shielding fields developing as well in PMs as in all magnetically soft parts of the EPM device.

It is interesting to note, that in spite of this complexity the experimentally observed changes of normal flux density component mean value at the surface of central pole are close enough to those according to a stationary solution, as can be seen in Fig. 6.

4 CONCLUSONS

We have proposed an optimized design of a new type of EPM chuck with rotational symmetry of all its basic parts. Presented configuration, in comparison with previous designs except construction simplicity is advantageous also from the point of the pole-shoes-mass to PM-mass ratio. The results of experimental analysis of the pulse remagnetization processes has shown that even the stationary-case solution provided relevant data for the optimized design of the device.

Acknowledgement

This work was supported by grant VEGA 1/0747/09 of the Slovak Grant Agency.

REFERENCES

[1] IT Patent 32483/82 (1982), US Patent 4.507.635 (1985)

[2] www.tecnomagnete.com

[3] BYDŽOVSKÝ, J. – KOLLÁR, M. – ONDREIČKA, K.: Proprietary registration of Utility Model in SR, in progress

[4] FEMM 4.2, www.femm.info

[5] www.magnetsales.com/Alnico

Received 30 September 2010