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TIME-OPTIMAL MAGNETIZATION OF INDUCTORS WITH PERMANENT MAGNET CORES

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Key words: magnetization processes, pulse magnetizing devices, permanent magnets, ferrites

Abstract: Time-optimal accurate magnetization process for small magnetic cores in mass-production is presented. The procedure consists of magnetization to the saturation level, followed by optimal partial demagnetization, which sets the stable operating point of a magnet within required inductance tolerance (< 3 %). The basic topology of a pulse magnetizer/demagnetizer is described and some improvements in algorithm to calculate optimal demagnetization voltage are suggested. Thus, proper magnetization of a core can be achieved in less than 4 s per piece. Additionally, the production waste is drastically reduced.

Časovno-optimalno magnetenje dušilk z jedrom iz trajnega magneta

Kjučne besede: magnetilni postopki, impulzne magnetilne naprave, trajni magneti, feriti

Izvleček: V članku predstavljamo časovno-optimalni postopek natančnega magnetenja v velikoserijski proizvodnji majhnih magnetnih jeder. Postopek sestoji iz magnetenja do nasičenja, čemur sledi optimalno delno razmagnetenje, s čimer postavimo magnet v stabilno delovno točko. Pri tem dosežemo induktivnost dušilke, ki je znotraj predpisanih toleranc (< 3 %). Opisana je še osnovna topologija impulzne magnetilne/razmagnetilne naprave, prav tako pa je predlagan izboljšani algoritem za izračun optimalne razmagnetilne napetosti. S postopkom dosežemo želeno namagnetenost v manj kot 4 sekundah po kosu, pri čemer pa velja omeniti tudi znatno zmanjšanje izmeta.

1. Introduction

In this paper we will focus on accurate magnetization ("calibration") of the permanent magnet that is attached to a coil with soft-ferrite core in so-called "linearity corrector" (Fig. 1). The correctors are used for horizontal linearization of a picture in CRTs and TV sets, where the coil's desired inductance is selected by the dc current. The deviation in physical dimensions of ferrite correctors from the same manufacturing batch is up to 3 %, which results in an inductance variation of up to 23 %. To provide their equal performance in an application circuitry, it is more convenient to magnetize each single magnet to appropriate level in order to obtain magnet's desired effective height /1/. Namely, mechanical grinding would be inadequate for mass-production, because it is cost-and-time consuming.

Permanent magnet's desired operating point can be achieved by magnetization to the saturation level, followed by one or more consecutive partial demagnetizations, where gradually higher magnetic field strength is applied. Thus, stable magnetization is provided, i.e., during normal operation in an application circuitry, the magnet's operating point cannot be affected /2/. However, if eventually too high magnetic field strength is used for demagnetization, we cannot reach stable operating point by any partial magnetization. On the contrary, the magnet has to be magnetized to the saturation level again and thereafter demagnetized to the desired level by applying proper magnetic field strength.

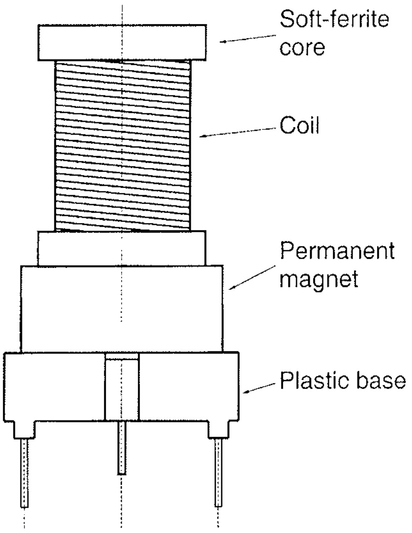

Fig. 1. Linearity corrector consists of a ferrite permanent magnet, attached to a coil.

Speed of described magnetization and demagnetization procedures is very important, since they have to be performed in the mass-production of linearity correctors. Therefore, the most suitable principle to magnetize and demagnetize such a permanent magnet, considering also the power consumption, is the pulse method /3/, /4/, where appropriate capacitor voltage is discharged on magnetizing/demagnetizing coil, into which the permanent magnet (corrector) is placed.

Fig. 2 shows the coil's inductance as a function of the dc control current through the coil. Calibrated correctors (with properly magnetized permanent magnets) should have the same characteristics, as close as possible to the "reference corrector" (left curve). The inductance limits are tightest in the reference point (with reference control current I_{C_ref}), where 5 % or even 3 % accuracy is required. On the other hand the relative limits are wider at no current (e.g. 10 %) or at higher current (e.g. 14 %). A characteristic for corrector with saturated permanent magnet is also shown (right curve) in order to illustrate, how the curve has to be moved to the "left" by partial demagnetization(s) after prior magnetization to the saturation level.

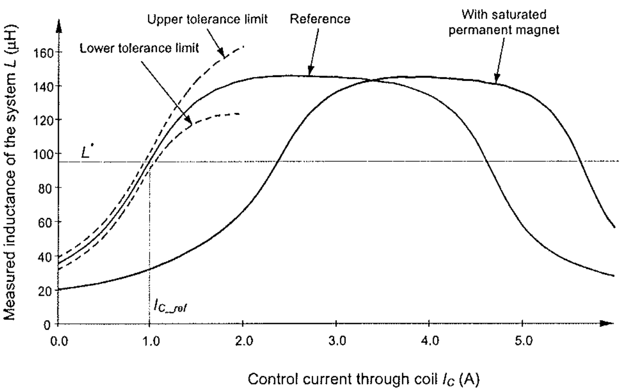

Fig. 2. Tolerance range for calibrated corrector and characteristic of the saturated corrector.

2. Magnetization Method

Permanent magnets can be magnetized to the desired level in many different ways. Under operating conditions it is important, that the magnetization is stable, i.e. that external magnetic fields do not affect the working point of the permanent magnet. This can be achieved by magnetization to the saturation level, followed by partial demagnetization. An operating point of permanent magnet is defined in an intersection between the magnetizing curve, that is specific to the material, and straight load line p_o, which represents the geometry of entire magnetic system (Fig. 3) /2/. When the permanent magnet is magnetized to the saturation level, the operating point is point 0 (H_o, B_o). An external demagnetizing force H_1 reduces flux density B to the point 1_D. After disengagement of this external field, flux density follows the curve 1^* (lower part of the recoil loop) and reaches the point 1 on the line p_o. Now only demagnetizing force H_2, which is stronger than previously applied H_1, can move the operating point by the curve 1^{**} (upper part of the recoil loop) and demagnetization curve to the point 2_D; after its disengagement the new operating point will be 2. Note that any partial magnetization cannot move the operating point upward the load line, i.e., from point 2 to point 1; full magnetization to the saturation level is required instead, followed by partial demagnetization, as described.

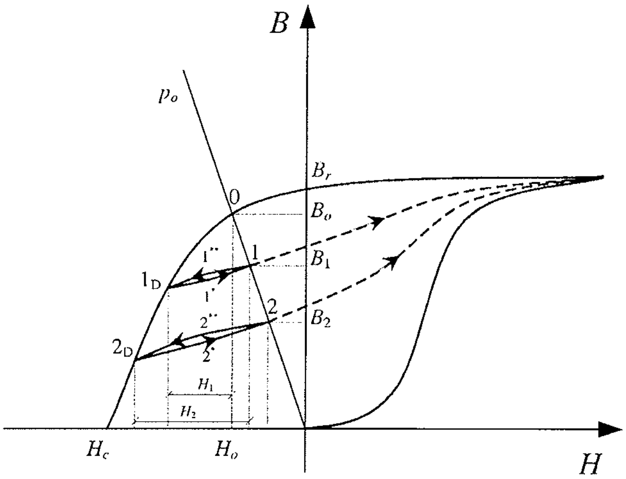

Fig. 3. (De-) magnetization curve and load line determine the operating point of a permanent magnet.

From the energetic point of view the most suitable principle to magnetize and demagnetize a permanent magnet is the pulse method. Magnetization can be achieved by the circuitry from Fig. 4, which releases energy, stored in "magnetizing" capacitor C_M, in an aperiodic current transient:

$$i_L(t)=\frac{U_{CM0}}{\omega L}e^{-\delta t}\sin(\omega t)\quad \text{for}\quad t\le\frac{T}{4} \tag{1}$$

$$i_L(t)=\frac{U_{CM0}}{\omega L}e^{-\delta\frac{T}{4}}e^{-\delta(t-\frac{T}{4})}\quad \text{for}\quad t>\frac{T}{4} \tag{2}$$

with

$$\omega_o^2=\frac{1}{LC_M},\qquad \delta=\frac{R}{2L}, \tag{3, 4}$$

$$\omega=\sqrt{\omega_o^2-\delta^2},\qquad T=\frac{2\pi}{\omega} \tag{5, 6}$$

When the "magnetizing" capacitor voltage is at its reference value U_{CM0}, charging is stopped and the charger is disconnected. Thyristor T_M is triggered, allowing the current i_L to flow through the magnetizing inductor L, in which the permanent magnet is placed, and the diode D. The aperiodic transient is shown in Fig. 5. Load current reaches its maximal value at $t = T/4$:

$$I_{L\max}=i_L(t=\frac{T}{4})=\frac{U_{CM0}}{\omega L}e^{-\delta\frac{T}{4}} \tag{7}$$

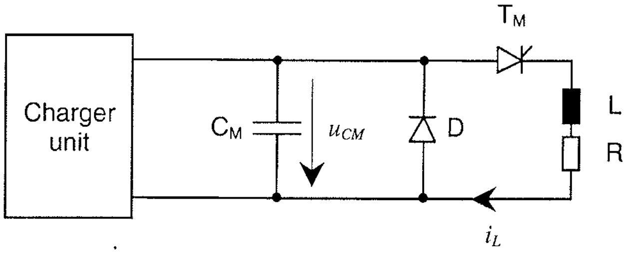

Fig. 4. Principal magnetization circuitry.

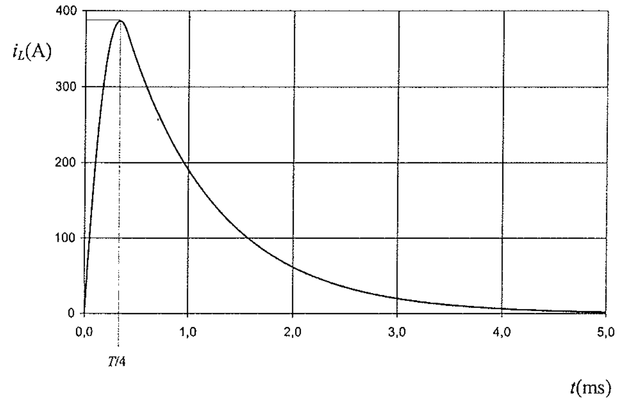

Fig. 5. Current pulse for magnetization

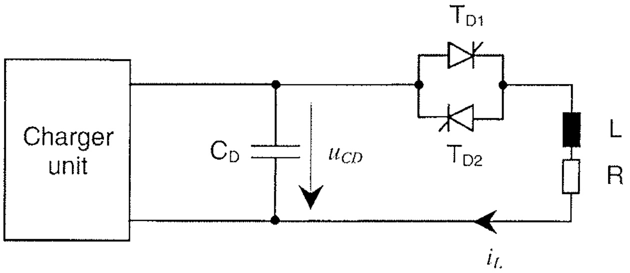

Fig. 6. Principal demagnetization circuitry.

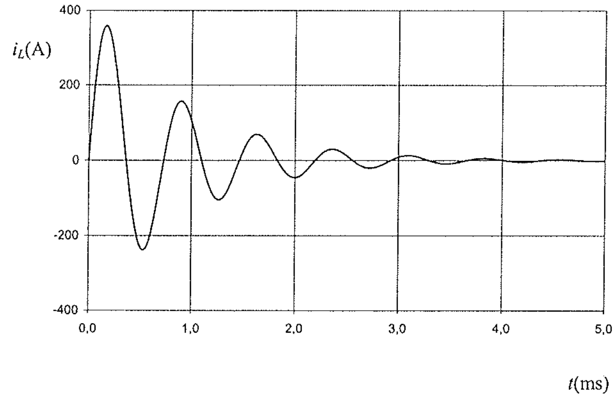

Fig. 7. Current pulse for demagnetization.

For demagnetization, dumped periodic transient can be used and applied by circuitry from Fig. 6. After charging the "demagnetizing" capacitor C_D to the desired value U_{CD0}, the charger is disconnected and thyristors T_{D1} and T_{D2} are triggered simultaneously, resulting in a current transient, shown in Fig. 7:

$$i_L(t) = \frac{U_{CD0}}{\omega L} e^{-\delta\, t} \sin(\omega\, t) \qquad (8)$$

The same charger unit can be utilized for both magnetization and demagnetization. Due to the process requirement, that the magnetization must always reach the saturation level, while the demagnetization should be executed partially and more precisely, it is reasonable to use two separate capacitors. Namely, the energy, stored in a capacitor, is controlled through its voltage. Therefore the capacitor with lower capacitance can store the same amount of energy at higher voltage, thus enabling wider voltage range with better precision. Consequently, frequencies and time constants (3, 5, 6) are different for demagnetization, where capacitance C_D has to be considered before applying their values in (8). Magnetizing inductor is nevertheless the same for both actions.

3. Time-optimal magnetization procedure

From Fig. 8 it is evident, that magnetic properties of magnets, made of the same material and with the same required dimensions, can differ significantly. Demagnetization curves for several linearity correctors of the same type were measured through pulse demagnetization. Magnets were magnetized to the saturation level and then gradually demagnetized by increasing the applied capacitor voltage. As it can be seen, the reference inductance L^* can be achieved by applying very different demagnetization voltages. Obviously the capacitor voltage, that would properly demagnetize the particular permanent magnet, has to be determined for each single piece separately.

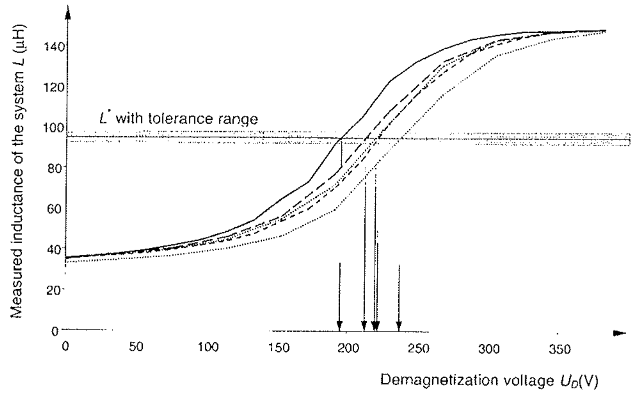

Fig. 8. Demagnetization characteristics for several permanent magnets of the same type.

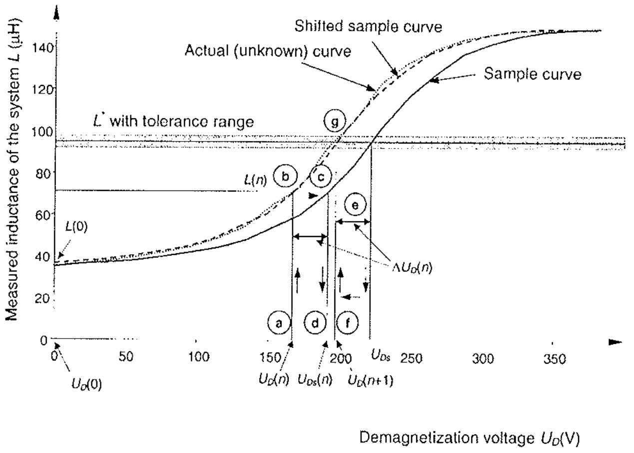

Fig. 9. Determination of demagnetization voltage.

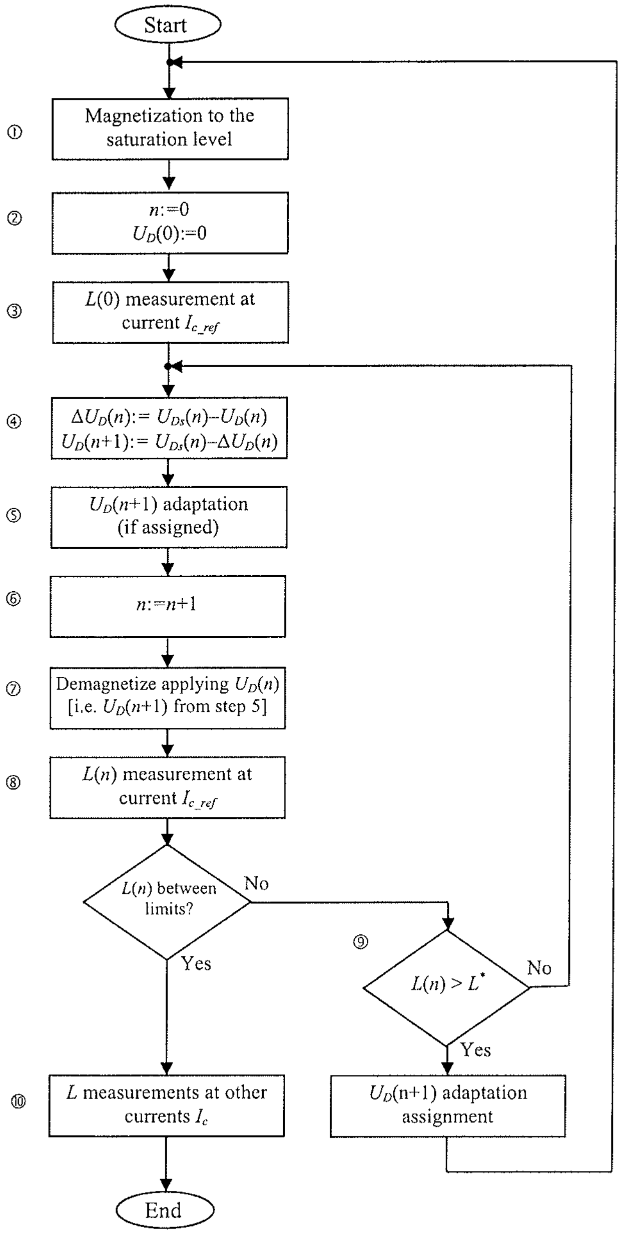

Fig. 10. Basic steps of magnetization procedure.

It is possible to achieve the reference inductance L^* through several consecutive demagnetizations, starting from saturated magnet, by increasing the capacitor voltage in small steps. But this would result in numerous demagnetization steps, which would require too much time. Ideally, there should be only one demagnetization step, since the speed is paramount.

To provide an optimal number of demagnetization steps, it is reasonable to measure the demagnetization curve for a sample (or an average curve for several samples), which is selected randomly among the magnets from the same batch. The form of this sample curve is then used to determine suitable demagnetization voltages for all individual magnets from the batch. The recursive principle is explained in Fig. 9 and Fig. 10, as follows: After the magnet is beforehand magnetized to the saturation and then partially demagnetized by demagnetization voltage $U_D(n)$ (sign a in Fig. 9, step 7 in Fig. 10), its inductance $L(n)$ is measured (sign b, step 8) and its approximate relation to the sample curve can be established accordingly. Unknown demagnetization curve can be treated like a shifted sample curve (dashed), with the shift being estimated from the measured inductance of a magnet. Namely, the sample demagnetization curve reaches the same measured inductance $L(n)$ (sign c) at demagnetization voltage $U_{Ds}(n)$ (sign d), which is for $\Delta U_D(n)$ higher than the voltage $U_D(n)$. The same voltage difference $\Delta U_D(n)$ can be assumed at the reference inductance (sign e), i.e., the voltage, that has to be applied to this magnet, is for $\Delta U_D(n)$ lower than the voltage U_{Ds}, which provided demagnetization of the sample in order to reach the reference inductance L^* at reference control current I_{c_ref}. The new demagnetization voltage, which can provide proper demagnetization of this magnet, is now $U_D(n+1)$ (sign f in Fig. 9, step 4 in Fig. 10). Although the actual curve does not match the "shifted" sample curve entirely, the inductance after the demagnetization with voltage $U_D(n+1)$ would be set within required limits (sign g).

The most important is the demagnetization voltage $U_D(n) = U_D(1)$, which has to be applied for first demagnetization step. In the best case, this demagnetization should result with an inductance within tolerances of its reference value. Therefore, the above-described principle could be used directly after the magnetization to the saturation level (step 1 in Fig. 10); in this case the demagnetization voltage $U_D(n) = U_D(0)$ that is used in further calculation, is zero (step 2), i.e., only inductance $L(0)$ after magnetization is measured (step 3). This approach gives excellent performance on magnets whose characteristics are close enough to the measured sample curve, because only one demagnetization is needed. In practice this condition cannot be assured, so undesired excessive demagnetizations can appear, i.e. the inductance L can exceed its reference value L^*. Consequently, new magnetization is needed, but with some magnetizing devices, which require longer time to charge magnetizing capacitor, this has to be avoided. The solution towards is to apply 75 % of voltage U_{Ds} for the first demagnetization, (step 5 in Fig. 10) thus avoiding the excessive demagnetizations for the expected range of magnets.

4. Conclusion

The magnetizing procedure, described in this paper, was applied in mass production of linearity correctors with very good results. The obtained total time for the magnetization to the reference point was bellow 4 s. Beside the improved accuracy of the magnet's operating point, the production waste was significantly reduced.

References

/1/ D. Nedeljkovic, V. Ambrozic, J. Nastran, "An Improved Calibration of Ferrite Permanent Magnets in Mass-production," IEEE MELECON 2002 Proceedings, pp. 244-248, Cairo, Egypt, May 2002.

/2/ P. Campbell, *Permanent Magnet Materials and Their Application*, Cambridge University Press, 1996.

/3/ E. Steingroever, *Magnetizing, Demagnetizing and Calibration of Permanent Magnet Systems*, Magnet-Physik Brochure, Magnet-Physik Dr. Steingroever GmbH, Köln, Germany, 1988.

/4/ E. Spahn, G. Buderer, J. Wey, V. Wegner, F. Jamet, "The Use of Thyristors as Main Switches in EML Applications", *IEEE Transactions on Magnetics*, Vol. 29, No. 1, pp. 1060-1065, January 1993.

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