EFFECT OF MAGNETIC MULTI-LAYER TO RESISTIVE PROPERTIES OF FREQUENCY-DEPENDENT RESISTOR

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ABSTRACT

Effect of magnetic multi-layer coated to the surface of frequency-dependent resistor to distribution of current's density through its section has been investigated. It has been shown that use of magnetic multi-layer increases suppression of high-frequency constituents flowing through resistor of electric current.

Keywords: magnetic multi-layer, frequency-dependent, resistor, frequency constituents.

I. INTRODUCTION

Current distribution lines through the section of conductor, arising due to well-known skin effect [5] were reviewed in previous papers [1-4] to create non-linear frequency-dependent resistor. Suspension containing particles of ferromagnetic materials were therefore used to suppress high-frequency current constituents. It was also pointed in those papers to abnormally high values of resistances, which became the result of use of layer structure of ferromagnetic materials' location [2]. Further studies showed that obtained effect is directly connected with effect of gigantic magnetoresistance frequently observed in magnetic multi-layer structures.

A big interest to experimental studies of effect of gigantic magnetic resistance in magnetic multi-layer structures as evidenced by steadily increasing number of scientific publications and emerging of new branches of studies, which are totally united by term of spin-transport-electronics, is firstly connected with wide range of fields of practical application for example as "X-ray mirrors" or as fast-acting sensors of magnetic field in data storage devices with longitudinal and vertical ways of recording. Combination of magnetically smooth characteristics with lower losses on hysteresis at high frequencies becomes quite significant at production of «heads of reading /recording for hard magnetic disks» [6]. High corrosion durability and wear strength make use of multi-layer structures as protective covers very promising [7].

As contrasted to classic magnetoresistive effect, the effect of gigantic magnetoresistance is caused not by force of Lorenz and curving of current carriers' trajectories in magnetic field, not by spin-orbital interaction of carriers with crystalline lattice and by dependence of density of states on magnetic field. In case of increase of density of states, which carriers can transform into, value of resistance decreases. Value of magnetoresistive effect in ferromagnetic metals as a rule does not exceed portion of percent, while the gigantic magnetoresistance effect for such metals can reach relative values of about tenths of percents [8].

Multi-layer magnetic structures represent a sequence of ferromagnetic layers separated by ultra-thin layers of dielectric. Effect of gigantic magnetoresistance found in such structures does not depend on relative orientation of magnetic field and current but is determined by relative orientation of magnetizations in neighbouring ferromagnetic films.

On the other hand, such structures admit current flow perpendicularly to layers separation borders. It may take place either because of spin-dependent dissemination of electrons on mixtures at separation borders well-known in metals [8, 9] or tunnel effect, despite that electric resistance of transition is not very small because of small transparency of tunnel barrier [10]. In first case as shown on [8, 9], in the most of ferromagnetic materials, zone structure has overlapping s – and d – zones at energy, which is equal to energy Fermi. If d – zone is significantly narrower – of s zone, then effective mass of electrons in s – zone is significantly less than effective mass of d – electrons, due to which s – electrons mainly contribute to electro-conductivity. As a result of exchange interaction in ferromagnetic materials d – zone for electrons with oppositely directed spins is split [11]. As a result of this, density of states for downward spins will be different from density of states for upward spins. At dissemination process with keeping spin s – electrons with downward spin can disseminate in free $s_{\downarrow}$ - or $d_{\downarrow}$ - state. Similar processes occur with s – electrons. As density of states nearby the Fermi level is different for electrons with different orientation of spins, dissemination intensity will significantly depend on orientation of spins. Mixtures can increase such difference, if mixture states possess the energy close to Fermi energy and are split.

The results of studies of distribution of current through cross-section of conductor due to skin effect for cases when its surface is covered by Fe/Cr multi-layer magnetic structure have been presented in this paper.

II.THEORY

Characteristics of frequency-dependent resistor manufactured in [4] with use of composition of conducting and non-conducting ferromagnetic materials are shown at Figure 1.

The results of measurement of resistive properties of two-layer conductor produced by method of ferromagnetic coating of aluminum wire have also been given in paper [12].

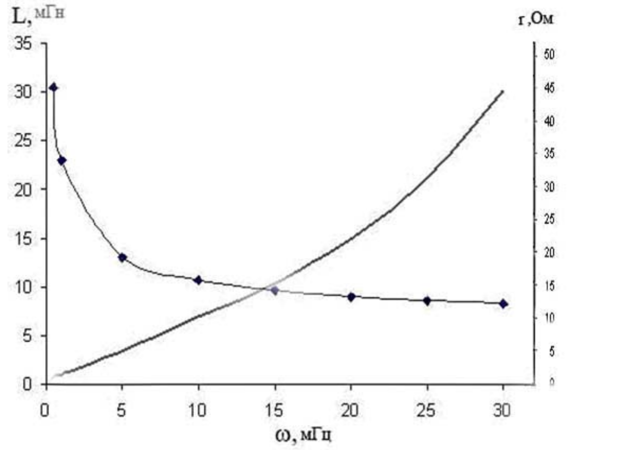

Figure 1. Frequent dependence of resistance and *L* on frequency of resistor

Frequency dependence calculations for two-component model of mixture of conducting and non-conducting phases in cubic lattice were made in consideration of conclusions of paper [13], i.e. in two-dimensional case we have the following:

$$\sigma_{ef} = \sigma_1 (l/a)^{(t_2 - t_3)/v_3} (p - (l/a)^{-1/v_3} p_{c,2} + p_{c,3}((l/a)^{-1/v_3} - 1))^{t_2} \quad (1)$$

where $t_2 \approx 1.3$, $t_3 \approx 1.6 \div 2$, $v_3 \approx 0.9$ – critical conductivity indices; l – layer thickness. Value l shall not coincide with skin layer thickness; a – particles size; p - concentration of particles ($p_{c,2}$ and $p_{c,3}$ – in two-dimensional and three-dimensional cases accordingly);

σ - conductivity.

Comparison of obtained experimental data and calculations under formula (1) gives satisfactory coincidence. Removal of high-frequency component [3], arising at overvoltages is possible if current-conducting element is coated by cover of ferromagnetic material (μ not less than 50) of thickness not less than 4 mm. In case of extreme currents of about 20kA (tension of magnetic field about 10^5 A/m) evaluation of thickness of saturated ferromagnetic layer gives value of 2 mm.

Skin effect in structure is made of composition of two types of layers; one (external) represents already reviewed disperse material made of conducting and non-conducting ferromagnetic powder materials, and the second (internal) magnetic multi-layer is made of layers of ferromagnetic materials alternating with non-magnetic layers (orientation of spins in neighboring layers is opposite). At occurring of magnetic field oriented in parallel to layers, such system transits into microscopic state, which is equivalent to spin-flop, changing its resistance. Dependence of magnetoresistance on tension of magnetic field is shown at Figure 2. Figure 3 shows dependence of magnetoresistance on thickness (*d*) of multi-layer and number of packs (n) in it.

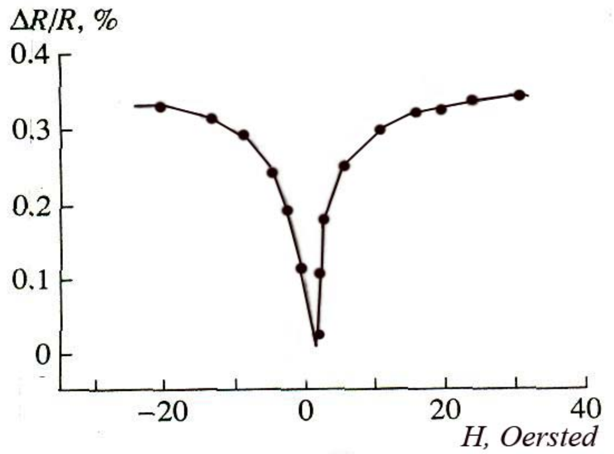

Figure 2. Dependence of magnetoresistance on tension of magnetic field

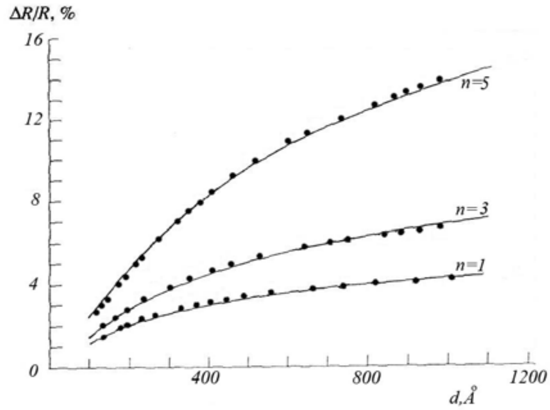

Figure 3. Dependence of magnetoresistance on thickness (*d*) of multi-layer and number of packs (n) in it

It should be noted that outcomes of our studies are well adjusted with results of papers [8, 10]. However it was indicated in paper [15] that value of magnetoresistance is also influenced by presence of tunnel current through multi-layers. Magnetoresistance of transition reached ~5% at room temperature, at good repeatability and stability in time. Current polarized through the spin and flowing through multi-layer is able to move domain borders and re-magnetize transition [16-18]. If contact area is large, current "flows" occur inside of transition at which currency's density is significantly high that average density on transition's section and reaching of re-magnetization threshold is therefore facilitated.

Figure 4 shows results of calculation of distribution of current's density on the section for studied frequency-dependent resistor with magnetic multi-layer.

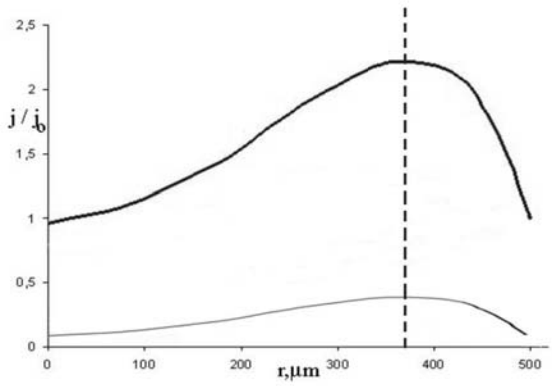

Figure 4. Radial distribution of current's density through the section of non-linear resistor for t=19 ns. Upper curve is taken from paper [3] and corresponds to radial distribution of current's density through the section of aluminum conductor.

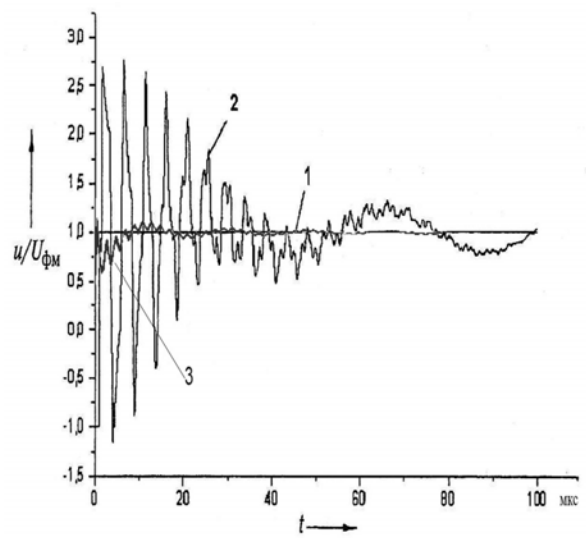

Figure 5. Calculation curves of voltages at commutation by disconnecting switch of idle bus area

For the illustration purposes, the possibilities to apply frequency-dependent resistance at limitation of high-frequency overvoltages have been considered at one-phase variant. Proposed algorithm allows performing also studies in three-phase circuit in consideration of protective devices, for example, overvoltages limiter of buses available in the system.

Fig 5 shows calculation results of high-frequency transient at commutation of idle bus system with disconnecting switches. Here 1 – voltage of source, which does not change during a small period of time; 2,3 – voltage at side of idle bus at commutation by disconnecting switches with and without consideration of studied frequency-dependent resistor accordingly.

REFERENCES

1. Kuskova N.I. Inverse skin-effect. Letters to Journal of Technical Physics, 2004, vol. 30, issue 21(in Russian)
2. Kuskova N.I., Tkachenko S.I. Radial distribution of rapidly changing currents and fields in cylindrical conductors, Letters to Journal of Technical Physics, 2002, vol. 28, issue 14, p.59-63. (in Russian)
3. Gashimov A.M., Mekhtiyev T.R., Babayeva N.R., Frequency-dependent resistor. International conference "Physics 2005", Collection of papers. June 7-9, 2005, 613-617. (in Russian)
4. Gashimov A.M., Mekhtiyev T.R., Babayeva N.R. Possibilities of limitation of high-frequency overvoltages at use of frequency-dependent resistor. International Conference Energy of Moldova – 2005, sep.21-24,2005 – Chisinau, Republic Moldova, 265-269(in Russian)
5. Landau L.D., Liphshitz E.M. Electrodynamics of continuums. M.: Nauka, 1982. 623 p. (in Russian)
6. Wall Street J. 1997, 10 November, p.B8(in English)
7. V.M.Fedosyuk, M.U.Sheleg, O.I.Kasyutich. Foreign radio-electronics, 1990, №5, p.88-97 (in Russian)
8. P.M. Levy, Sh. Zhang Current Opinion in Solid State and Mater. Sci., 1999, v.4, p.223(in English)
9. R.E. Camley and R.L. Stamps J.Phys: Condens. Matter, 1993, 5, pp.3727-3786(in English)
10. A. Fert, I.A. Cambel J. Appl. Phys., 1991, v.69, p.4768(in English)
11. V.I.Borisov, A.I.Krikunov, A.I.Chmil, P.E.Zilberman. Radiotechnique and electronics, 2004, vol. 49, No. 1, p.84-90(in Russian)
12. Blatt F. Physics of electron conductivity in solids. – M.: Mir, 1971.-470 p. (in Russian)
13. Korobeynikov S.M., Sarin L.I., Chelaznov A.A. Resistor with frequency dependence for decreasing of overvoltages. Papers of the second All-Russian scientific-technical conference. Overvoltages limitations and 6-35 kV networks' neutral grounding modes, Novosibirsk, 2002, 54(in Russian)
14. Naymark A.V. Electrophysical properties of percolation layer of finite thickness. Journal of electrotechnical physics, 1990, vol. 98, issue 2, p. 611-626(in Russian)
15. Julliere M. // Phys.Lett. 1975. V.A54. P.225. (in English)
16. Gulyayev Y.V., Zilberman P.E., Epshtein E.M. // Radio electronics, 2001, vol. 46, No.7, p.862(in Russian)
17. Gulyayev Y.V., Zilberman P.E., Elliott R.J., Epshtein E.M. //Journal of technical phsyics 2002, vol. 72, No.7., p.79(in English)
18. Elliott R.J., Chmil A.I., Epshtein E.M. et al. // IEEE Trans.2002.V.Magn.-38.#5,P.2869(in English)