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THE EFFECT OF MAGNETIC VIDE0-PULSE ON ^{57}Fe NMR SINGLE-PULSE ECHO IN LITHIUM FERRITE.

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Abstract

A study of the pinning of domain walls in lithium ferrite has been carried out under the action of an magnetic video-pulse applied between two RF pulses on the two-pulse echo and in the case of the combined action of the radiofrequency pulse and magnetic video-pulse on single-pulse echo signal, leading to the formation of a stimulated magnetic echo. A correlation is shown between the results of determination the domain walls pinning force using these two alternative methods in lithium ferrite. The effect of magnetic video-pulse on two-pulse echo confirms the fact that the magnetic echo emergence is related with the start of domain wall motion in lithium ferrite.

***Keywords**: single-pulse echo, magnetic video pulse, lithium ferrite, domain walls, pinning.*

The single-pulse (SP) echo is the spin-system resonance response to the action of single exciting radiofrequency (RF) pulse. This response is produced at time interval approximately equal to the pulse duration τ after the applied RF pulse [1].

A number of works have been devoted to the SP echo origin investigations [2], but its nature has not been so far fully clarified [3].

In work [4] the role of RF pulse fronts in SP echo method was investigated at applying of a small modulating RF field. Cobalt and lithium ferrite were chosen as objects, because in both them two-pulse (TP) echo signals having approximately the same intensity were observed and at the same time SP echo intensity in lithium ferrite was comparatively much weaker. The influence of LF magnetic field on TP echo signals was similar in both magnets and expressed in the effect of strong TP echo signal decay envelope modulations with LF magnetic field frequency.

In contrast, similar modulation effect was observed only for the SP echo in cobalt but it was completely absent in lithium ferrite. As result the conclusion was made that SP echo in lithium ferrite was formed by some new mechanism. In following works it was established that SP echo in lithium ferrite is formed by the multiple-pulse mechanism firstly studied in [5].

In this work our aim is to study the SP echo responses in lithium ferrite at application of additional magnetic video-pulse (M pulse) in the experiment similar to [6,7].

In the case of cobalt the application of M pulse within the time interval τ of RF pulse duration resulted in the formation of so-called stimulated magnetic echo (ME) signal by M pulse and by RF pulse edges in the case, when the amplitude of M pulse exceeds some threshold value H_0 [6]. At the same time SP echo signal was correspondingly reduced.

The experimental procedure is shown on the oscillogram, Fig. 1.

Fig. 2 represents the dependencies of the intensity stimulated of ME signal I_M, formed by M-pulse and by the edges of RF-pulse (*a*) and of the intensity I_{SP} of SP echo (*b*) on H_d.

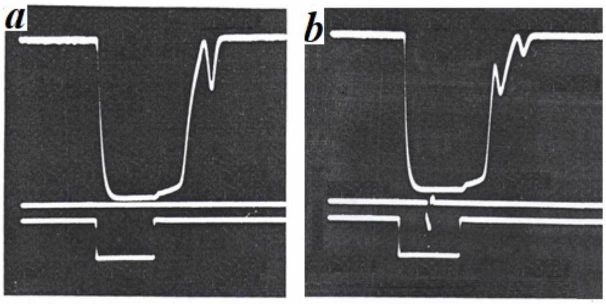

Fig. 1.

(a) Oscillogram of a single-pulse echo signal, on the upper beam on the right; (b) oscillogram of a magnetic (stimulated) echo in cobalt, formed by a magnetic pulse and two edges of the RF pulse and next a single-pulse echo signal. The middle beam shows the location and duration of the magnetic pulse. The lower beam represents the RF pulse: $\nu_{NMR} = 216$ *MHz*, $\tau = 18\ \mu s$, $T = 77$ *K.*

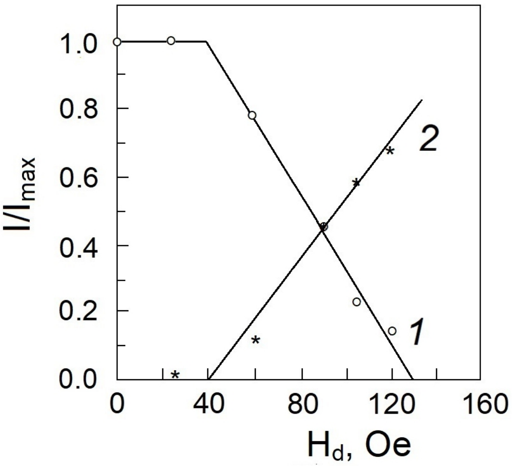

Fig. 2.

Dependences of the echo signal intensity in cobalt on the amplitude of the magnetic pulse, $\nu_{NMR} = 216$ *MHz*, $\tau = 22\ \mu s$, $\tau = 0.5\ \mu s$, $T = 77$ *K in cobalt*: *1 - single-pulse echo*; *2 - stimulated (magnetic) echo generated by the magnetic field and the edges of the RF pulse* [6].

The obtained results could be explained, if we suppose [5], that in the case of cobalt the multiple-pulse excitation in the frames of SP echo method by fast displacement of a domain walls (DWs) at the application of M-pulse in the limits of RF-pulse duration takes place.

As it was shown in [5], the application of RF pulse of the complicated form is the analogy of multiple-pulse excitation of the Hahn echo, when within the pulse duration the discrete and fast changes of an effective field $\vec{H}_{eff}$ direction in a rotating coordinate system (RCS) takes place, where

$$\vec{H}_{eff} = \frac{1}{\gamma_n}(\Delta\omega_j \vec{z} + \omega_1 \vec{y}), \qquad (1)$$

and γ_n – is the nuclear gyromagnetic ratio; $\vec{z}$ and $\vec{y}$ are the unit vectors of RCS; $\omega_1 = \gamma_n H_1$ is the RF pulse amplitude in the frequency units; $\Delta\omega_j = \omega_{NMRj} - \omega_{RF}$ is the deviation between NMR and RF pulse frequencies.

Such discrete and fast changes can occur in cobalt [6], due to the anisotropy contribution to the hyperfine field, as the DW motion shifts the effective position of the nuclei at the application of M-pulse.

Another possibility of ME excitation is the direct rapid reverse of the magnetization of thin films after application of RF pulse and the magnetic reversal, due to the motion of DW. In this case the time interval for pulsed magnetic reversal should be less, than the precession period of nuclear spins

$T = 2\pi/\omega_{NMR}$. At NMR frequency $f_{NMR} = 100$ MHz it corresponds to T = 10 nsec. The echo of this type, called as nuclear inverse echo, was observed in [8].

The change of $\vec{H}_{eff}$ direction in RCS can be more simply realized technically, since these changes in this case are fast as compared $T_{eff} = \dfrac{2\tau_1}{\Delta\omega_j}$ - period of nuclear magnetization precession in RCS, where $\Delta\omega'_j = (\Delta\omega_j^2 + \omega_1^2)^{1/2}$ is an isochromate frequency in RCS, so that the condition $\Delta\omega'_j \cdot \tau_{mf}. << 1$ is satisfied, where τ_{mf} is the pulse front or the duration of the M pulse front change. This condition could be realized in the case of cobalt for nuclei arranged in DWs at $\tau_{mf} \sim 0.1$ μsec.

2. Experimental results and their discussions.

The block diagram of the experimental setup is shown in Fig. 3

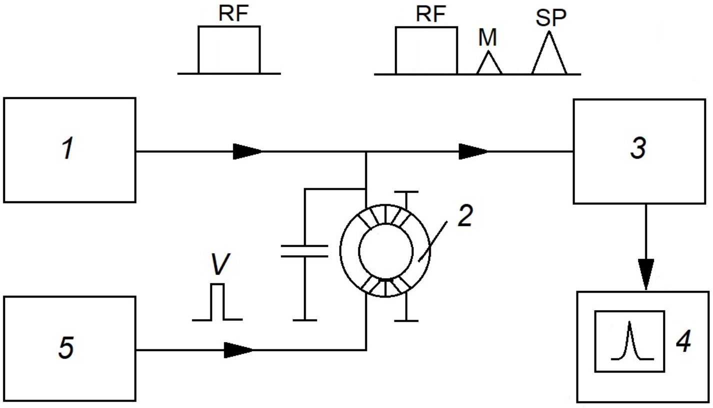

Fig. 3.

Block diagram of the experimental setup: 1 - RF pulse excitation generator; 2 - resonator with a ring-shaped sample of lithium ferrite; 3- receiver; 4- oscilloscope, 5- magnetic video-pulse generator.

RF excitation pulses are generated by generator *1*. Next, a sequence of NMR excitation echo pulses enters the resonator *2* with the ring-shaped sample of lithium ferrite used. The RF field of the pulses excites the echo signal in the upper coil of the resonator *2*. Then these pulses, together with the echo signal S, enter the receiver *3* and are recorded by the oscilloscope. Channel *5* generates additional MVP pulses to the lower winding of the resonator.

A detailed description of the NMR spectrometer and the MVP block is given in [1,7]. The experimental results were obtained at T = 77. The echo signal amplitude was measured in the presence or absence of a MVP with an amplitude H_d.

We used samples of lithium-zinc ferrite $Li_{0.5}Fe_{1.0}Zn_{0.15}O_4$, which were rings with a diameter of 12–15 mm and a weight of 5–8 g, enriched in the ^{57}Fe isotope to 96.8 % in order to increase the intensity of the echo signal, which were produced by means of a conventional ceramic preparation technique with the ^{57}Fe iron isotope enrichment

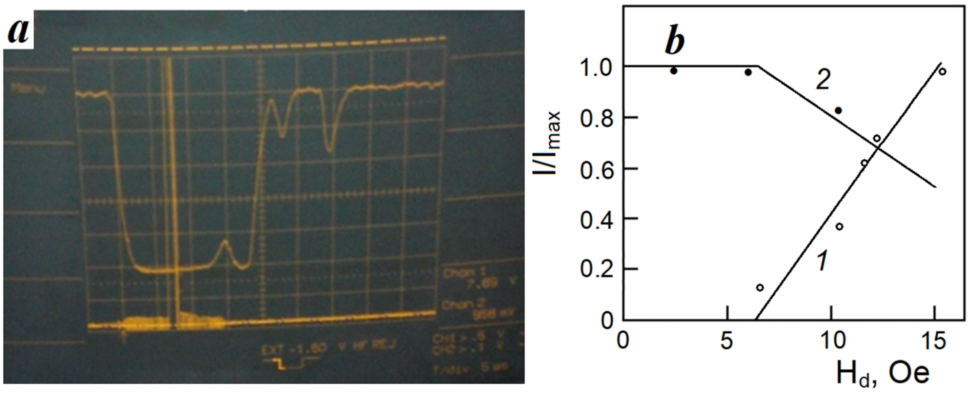

Fig. 4.
(a) Oscillogram of magnetic and single-pulse echo signals in lithium-zinc ferrite (upper beam), the lower beam shows the duration of the RF magnetic pulses as well as the amplitude of the magnetic video pulse; (b) dependences of the signals of the magnetic (1) and single-pulse (2) echoes on the amplitude of the magnetic video pulse at 71 MHz frequency.

Since the external RF field acts on the nuclei through the electron magnetic moments *m*, the explanation of the considered phenomena should be based on the study of motion the electron magnetization in the DWs undergoes under the action of the M pulse. DW displacements, even being insignificant, can be accompanied by a large rotation of m. In this case the rotation of m inside the DW is proportional to the displacement of the DW. This process is accompanied by a change in the local hyperfine field (HFF) on nuclei due to the anisotropy of the HFF in cobalt [7] and inhomogeneity of RF gain factors η [10] proportional to their displacement. The M pulse amplitude H_d at which the TP echo intensity begins to decrease, associated with the onset of the DW motion, is naturally related to the pinning force H_0, Fig. 5.

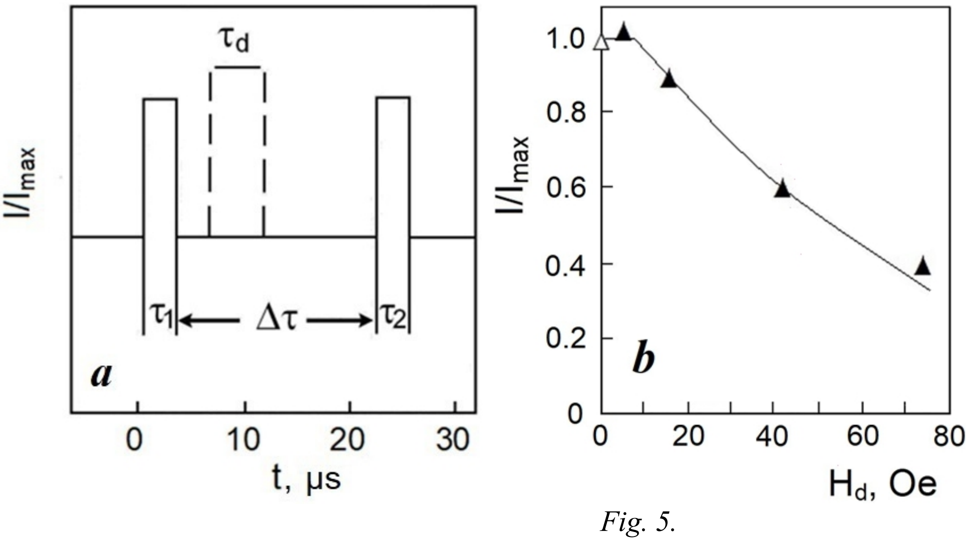

Fig. 5.
(a) - location of the M pulse relative to the RF pulses; (b) -Dependences of the echo signal intensity in lithium-zinc ferrite on the amplitude of the magnetic video-pulse on NMR frequencies 71 MHz, MVP duration $\tau_d = 0.5$ μs, T = 77 K.

Analysis of the dependence of the effect of MVP on echo signals in the studied samples show a significant, up to one order of magnitude increase in the mobility of DWs and decrease in the pinning force in lithium ferrite in comparison with cobalt. A particularly large effect of MVP is observed for the echo signal from nuclei located in octahedral B positions of lithium ferrite at a frequency of 74 MHz with more anisotropy of the HFF [11], as compared with the echo signal from nuclei in tetrahedral A positions at a frequency of 71 MHz.

In lithium ferrite the stimulated ME signals were also observed and studied, Fig. 6, similar to cobalt, Fig. 4.

The M pulse amplitude at which the magnetic echo appears, Fig. 4*b*, correlates with the M pulse amplitude acting on the TP echo, at which its decrease begins, associated with the DW pinning force, Fig. 5*b*, which gives an alternative way of measuring the DW pinning force H_o and mobility in magnets. Even more important this confirms the fact that the ME signal formation is related with DWs motion.

The observed experimental dependences of the signals of the magnetic, SP and TP echoes can be understood taking into account that, according to [12], under the action of the M pulse, the DWs reversibly shift by a distance Δx proportional to the amplitude of the magnetic video-pulse $\Delta x = \upsilon \cdot \tau_d = S(H - H_0)\, \tau_d$, when the M pulse amplitude exceeds the value pinning force H_0. In the Δx layer nuclei under the combined action of RF and M pulse experience the effect of an abrupt change in magnitude and direction of the effective magnetic field H_{eff} (1) in the rotating coordinate system (RCS) due to the change in local HFF and. Therefore, accordingly to the nonresonant model of SP echo formation, the action of M pulse is equivalent to the effect of a second RF pulse at the formation of a stimulated Hahn echo, resulting in formation of stimulated echo-response called the magnetic echo [6].

In this case, its amplitude would be proportional to the number of nuclei in the Δx layer, formed at the displacement of the DW: $I_m \sim \Delta x/L$, where L is the width of the excited section of the DW under the action of RF pulse. Correspondingly, these nuclei do not contribute to SP echo reducing it to $I_{SP} \sim (L-\Delta x)/L$. In this case, the jump-like change in the nuclear NMR frequencies in RCS must satisfy the condition $\Delta\omega'_j\, \tau_m << 1$, or in other words the precession period of nuclei in RCS should be much larger compared with τ_d. Under the action of M pulse on the TP echo in the interval between RF pulses, the condition $\Delta\omega_j\, \tau_m << 1$ is not satisfied, since RF is absent and nuclei are precessing in local HFF with frequencies $\omega_j = \gamma_n H_{HFF}$ and it should be fulfilled the condition $\omega_j\, \tau_m << 1$, requiring a nanosecond duration M pulse as in case of inverse echo to have additional magnetic echo signals [8]. Therefore, the effect of M pulse on TP echo leads only to a decrease in the intensity I_{TP} of TP echo, proportional to the displacement of the DW $I_{TP} \sim (L - \Delta x)/L$, due to the loss of phase coherence of the nuclei located in this layer. This argumentation allows us qualitatively understand the obtained experimental dependences of the magnetic, SP and TP echo signals under the influence of M pulse.

3. Conclusion

A study of the pinning of DWs in lithium ferrite has been carried out under the action of an magnetic video-pulse applied between two RF pulses on the two-pulse echo and in the case of the combined action of the RF pulse and magnetic video-pulse on single-pulse echo signal, leading to the formation of a stimulated magnetic echo. A correlation is shown between the results of determining the domain walls pinning force using these two alternative methods for measuring the DW pinning force in magnets. The effect of magnetic video-pulse on two-pulse echo confirms the fact that the magnetic echo emergence is related with the domain wall motion in lithium ferrite

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