Enhanced resolution NMR spin echo method to study cobalt nanopowders and half metals using additional magnetic video-pulse excitation

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Abstract:

The original enhanced resolution nuclear spin echo method is used to study the timing and frequency diagrams of magnetic videopulse influence on the two-pulse echo signals in case of its symmetric and asymmetric applications. It is shown that these diagrams give visualization of hyperfine fields anisotropy in studied materials, as well as reflect domain walls dynamics in these materials.

Results of the strong spin echo enhancement study at application of outer dc magnetic fields in half metal NiMnSb are also presented.

NMR is a unique microscopic tool to study different local properties of magnetic nanostructures. It provides magnetism information by hyperfine fields, domain walls parameters and dynamics measurements [1].

In this work we carry out NMR study of cobalt nanometric powders fabricated by the novel electron beam technology by evaporation of starting materials with electron beam and following condensation onto a substrate supercooled to a proper temperature [2] and two half metals Co_2MnSi and NiMnSb interesting for spintronics applications [3].

Measurements is carried out by the improved resolution nuclear spin echo method using an additional exciting magnetic field videopulse and compared them with ones for some other magnets (polycrystal cobalt and lithium ferrite, etc.).

In particular, we take frequency spectra and timing diagrams for recording of magnetic pulse influence in case of its symmetric and asymmetric application in respect to the second rf pulse [4].

In Fig.1 it is presented Fig.4 from [5] to illustrate the experimental layout and results obtained in work [5] for magnetic videopulse influence on two-pulse echo signal of ^{57}Fe nuclei in lithium ferrite.

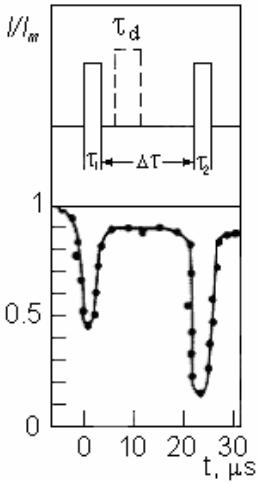

Fig. 1.

Timing diagrams of the relative intensity I/I_m dependence of the two-pulse echo (•) on the temporal location of a magnetic videopulse of H_d=5 Oe, lasting for a time interval τ_d=3 μs for ^{57}Fe NMR in lithium ferrite.

The main effect of applied magnetic pulse to multidomain magnets is the displacement of DW which is reversible at small pulse amplitudes. Therefore, if the magnetic pulse is superposed on one of the RF pulses, it changes the location of the resonating nuclei in the DW (y-direction) with respect to its center thereby reducing the nuclear enhancement factors for 180°C Bloch walls

accordingly the known dependence $\eta = \eta_o \mathrm{sech}(y/d)$, where η_o is the maximum enhancement at the center of the wall. Therefore, if in the absence of the magnetic pulse the turning angles α_i of two RF pulses $\alpha_{1,2} = \gamma h \eta \tau_{1,2}$ were equal to each other in order to maximize the intensity of TPE [5], after the application of magnetic pulse in coincidence with one of RF pulses it follows that turning angles would differ significantly what should result in a fast reduction of TPE amplitude.

Besides it, due to the dependence of nuclear resonance frequency on location in the DW in systems with anisotropic HF field, the application of magnetic pulse in the interval between RF pulses, or after the second pulse would also result in the decrease of TPE signal. This effect (the dephasing effect) arises because the frequency shift partially destroys the phase coherence reducing the effectiveness of the rephasing process.

This method gives direct and visual information on anisotropic component of hyperfine field and domain walls parameters which is not readily obtainable from usual NMR spectra thereby improving resolution of nuclear spin echo method in magnets.

We present, for example, frequency spectra and timing diagrams of magnetic videopulse influence for half metal Co_2MnSi for two its sites ^{59}Co and ^{55}Mn , correspondingly, with different hyperfine magnetic field anisotropies, and as well as that ones for ^{55}Mn for another half metal NiMnSb.

It is seen from Fig. 2,4 that for ^{59}Co and ^{55}Mn sites in Co_2MnSi and MnNiSb with, correspondingly, large and small anisotropies of hyperfine fields the order of frequency diagrams for symmetric (triangle) and asymmetric magnetic pulses (square) is reversed. Similar conclusion takes place also for timing diagrams, Fig.3, 5. In NiMnSb it has been also observed interesting effect of spin echo signal enhancement (up to 5 times) in outer dc magnetic field Fig.6 (*a*), in contrast with similar magnetic field dependences in Co and Co_2MnSi Fig.6 (*b*).

Effect is maximal in the center of ^{55}Mn NMR spectra of NiMnSb.

Similar effects were observed earlier in Ni-Mn ferrites [6], in high magnetic fields and at RF fields powers ~ 100 W.

Their nature was cleared out and the effects in ferrites was connected with disappearance of domain walls structure at high magnetic fields.

In the case of NiMnSb, as opposed to the one of ferrites, the effect is seen at any small RF powers up to about ~1 W, available in these experiments.

This effect is apparently related with peculiarities of domain wall dynamics in half metallic NiMnSb and further investigations are necessary to clear out its nature.

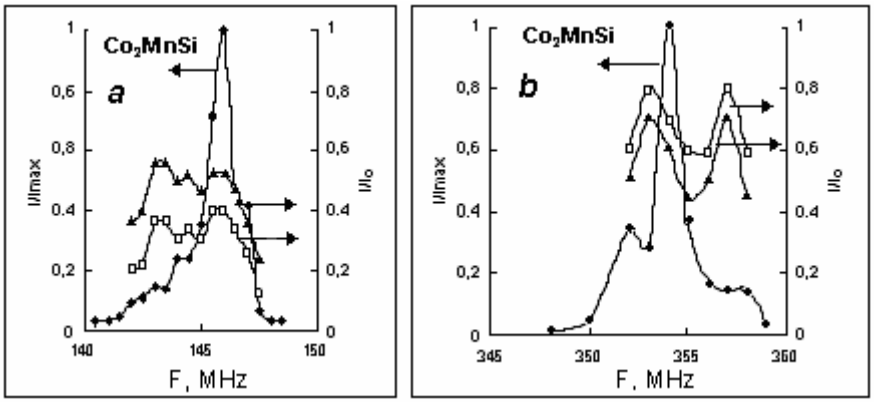

Fig. 2.

Frequency dependence of the effect of the symmetric (▲) and asymmetric (□) magnetic pulses on two-pulse echoes in Co_2MnSi for ^{59}Co NMR (a) and ^{55}Mn NMR(b) at:

a) τ_1 = 1.1 μs, τ_2 = 1.4 μs, $\Delta\tau$ = 10 μs, τ_d = 2 μs, H_d=550 Oe (^{59}Co ЯМР);

b) τ_1 = 0.8 μs, τ_2 = 1 μs, $\Delta\tau$ = 13 μs, τ_d = 4 μs, H_d=190 Oe (^{55}Mn ЯМР);

I_o – echo amplitude at magnetic pulse amplitude H_d=0. τ_1, τ_2, $\Delta\tau$, τ_d are rf pulse durations, time interval between them and magnetic pulse duration, correspondingly, I/I_{max} - corresponding NMR spectra.

Similar diagrams for cobalt nanopowders reflect finely their fabrication conditions. These effects are not seen on X-ray spectra and electron microscopy data of cobalt nanopowders making such diagrams an interesting tool for a fine control of their characteristics.

To illustrate this we present data for two cobalt nanopowder samples (grain size ~ 100-150 nm) condensed on a substrate at two different temperatures (# 1 – 240 K and # 2 – 300 K), Fig. 8-9.

For comparison, we present also similar spectra for Co polycrystal powder spectra (microsize grains), Fig.7.

It is also presented spin echo amplitude dependences on the magnetic videopulse amplitude for these nano-samples in case of symmetric and asymmetric excitations, Fig. 9.

Results for nano-samples show disappearance of NMR spectra region with could be clearly attributed to domain walls, as opposite to that of Co polycrystal case, and their dependence on substrate temperatures.

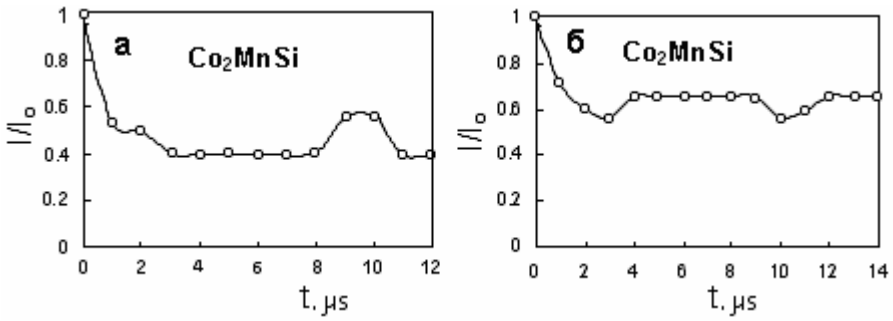

Fig. 3.

Timing diagrams and intensity dependence of the two-pulse echo I/I_o on the temporal location of the magnetic pulse with duration τ_d in Co_2MnSi for ^{59}Co NMR (a) and ^{55}Mn NMR (b) at: a) τ_1 = 1.1 μs, τ_2 = 1.4 μs, $\Delta\tau$ = 10 μs, τ_d = 2 μs, f=145,5 MHz, H_d=550 Oe; b) τ_1 = τ_2 = 3 μs, $\Delta\tau$ = 7 μs, τ_d = 2 μs, H_d=300 Oe, f=354 MHz. I_o – echo amplitude at H_d=0.

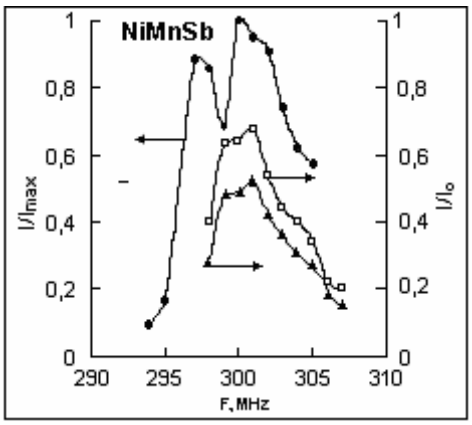

Fig. 4.

Frequency dependence of the effect of the symmetric (▲) and asymmetric (□) magnetic pulses on two-pulse echo ^{55}Mn in NiMnSb I/I_o at: $\tau_1 = \tau_2 = 2$ μs, $\Delta\tau = 10$ μs, $\tau_d = 3$ μs, H_d=150 Oe; I_o – echo amplitude at H_d=0. I/I_{max} – corresponding two-pulse echo spectrum of ^{55}Mn in NiMnSb.

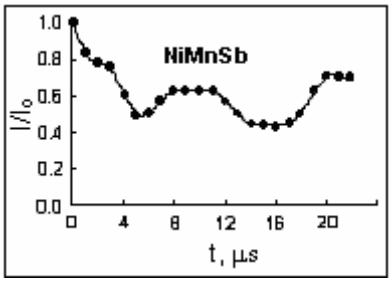

Fig. 5.

Timing diagram of the intensity dependence of the two-pulse ^{55}Mn echo I/I_o on the temporal location of the H_d magnetic pulse with duration τ_d in half metal NiMnSb at: $\tau_1 = \tau_2 = 2$ μs, $\Delta\tau = 11$ μs, $\tau_d = 3$ μs, H_d=150 Oe, f_{MW}=300 MHz, I_o – echo amplitude at H_d=0.

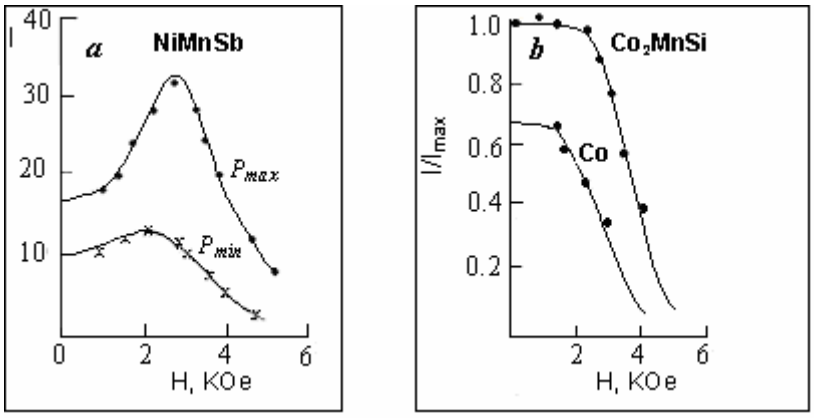

Fig. 6.

Two-pulse echo intensity dependences in NiMnSb (a), Co_2 MnSi and Co (b) on outer dc magnetic fi eld.

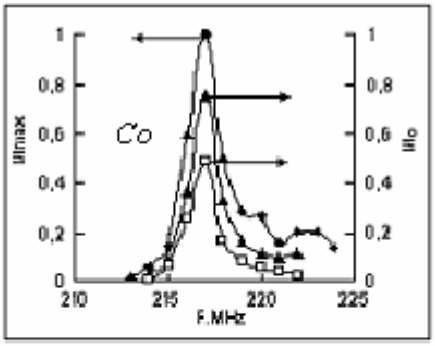

Fig. 7.
Frequency dependence of the influence of the symmetric (▲) and asymmetric (□) magnetic videopulses on two-pulse echo in polycrystal cobalt at: τ_1 = 1.1 μs, τ_2 = 1.2 μs, $\Delta\tau$ = 10 μs, τ_d = 2 μs, H_d=100 Oe. I_o – echo amplitude at H_d=0, I/I_{max} – ^{59}Co NMR spectra.

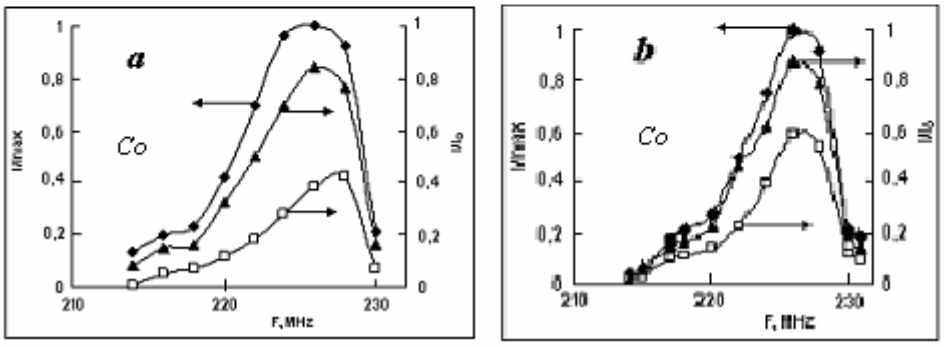

Fig. 8.
Frequency dependence of the influence of the symmetric (▲) and asymmetric (□) magnetic videopulses on two-pulse echoes in cobalt nanopowders # 1 (a) and # 2 (b) at: τ_1 = 1.1 μs, τ_2 = 1.2 μs, $\Delta\tau$ = 10 μs, τ_d = 2 μs, H_d=400 Oe. I/I_{max} – ^{59}Co NMR spectra , I_o – echo amplitude at H_d=0.

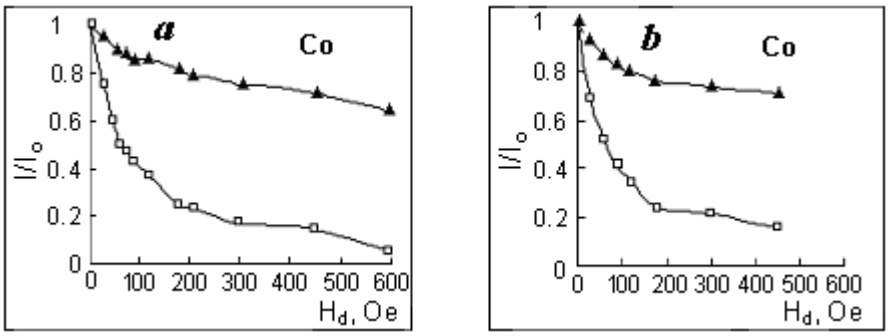

Fig. 9.
Two-pulse echo intensity dependences for Co nanosamples # 1 (a) and # 2 (b) on amplitude of magnetic videopulse amplitude H_d at 217 MHz NMR frequency, I_o – echo amplitude at H_d=0.

In conclusion, it is presented the results of study of some half metals and cobalt nanopowders by enhanced resolution nuclear spin echo method using an additional magnetic field videopulse.

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