Nanosecond modulation of Fe^{57} Mössbauer radiation

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A new method of time-dependent Mössbauer measurements is proposed and put into practice. In this method, the time at which the beam of radiation impinges upon the studied system of nuclei is determined with the use of a magnetic resonance shutter which permits a fast turn-on of the beam of Mössbauer γ rays. To devise such a shutter, the recently observed fast-response property of $FeBO_3$ crystals to remagnetization was exploited. The possibility of modulating the Fe^{57} Mössbauer radiation by rotating the magnetization of the crystal follows from the strong polarization dependence of the resonance absorption. Difficulties associated with a strong effect of magnetoelastic oscillations were resolved, and we were able to obtain Fe^{57} Mössbauer radiation pulses having a rectangular shape and a rise time $\tau_r \leqslant 10$ nsec.

All investigations of the time dependent behavior of resonant absorption and scattering of Fe^{57} Mössbauer γ rays, beginning with the first experiments of Lynch, Holland, and Hamermesh,[1] as well as subsequent experiments (e.g., Refs. 2–6), have been based on the principle of fixing the time of formation of the 14.4-keV nuclear excited state in the source. For this purpose, the method of detecting the delayed coincidence of the γ rays emitted in the 122–14.4 keV γ-γ cascade has been used. This method, however, imposes a fundamental and significant limitation on the activity of the sources, since inherent in this method is the risk of spurious coincidences. The sources that have actually been used in this sort of experiment have had activities $\leqslant 10^6$ Bq. For this reason it is not practical to use the delayed coincidence method in a number of interesting cases, such as γ-ray diffraction experiments, where it is necessary to collimate the radiation.

In this investigation we propose and reduce to practice a new method of time-dependent measurements in Mössbauer experiments based on producing a fast cutoff in the intensity of the Mössbauer radiation, the instant of this cutoff serving as the beginning of the time scan for the nuclear interaction processes being investigated. In this method the time of initiation (termination) is fixed at the instant of the fast turn-on (turn-off) of the Mössbauer radiation flux, with these fast transitions being produced by a shutter. It is obvious that the time τ_f required for the transition from one intensity level to the other in such a device for time-dependent experiments must be much less than the characteristic nuclear interaction time, which is determined by the lifetime τ_0 of the nucleus in the excited state. For the Fe^{57} nucleus, $\tau_0 = 142$ nsec. The consequent necessity of turning on or off the beam in a time the order of 10 nsec entails extreme difficulties. To the present time, attempts to make such fast-acting shutters have not been successful.[7–9]

It has been proposed in Ref. 10 that the fast response of $FeBO_3$ crystals to remagnetization,[11] which we have recently observed, be used in the solution to this problem, and in the present investigation this suggestion has been put into practice.

The possibility of modulating the intensity of the Fe^{57} Mössbauer radiation by changing the direction of the magnetization of the crystals stems from the existence of a strong polarization dependence of resonance nuclear absorption of γ rays. This dependence is described by a polarization factor in the resonance absorption cross section. In the case of Mössbauer resonance in the Fe^{57} nucleus, which involves magnetic dipole transitions, the polarization factor is

$$P_{mm_0} = (1-\delta_{mm_0}) + (-1)^{m-m_0}(\mathbf{hn})^2, \tag{1}$$

where m_0 and m are the projections of the nuclear spin of the ground ($+1/2$) and excited ($+1/2, +3/2$) states, respectively, in the direction of the magnetic field at the nucleus, $\mathbf{n}$ is a unit vector in that direction, and $\mathbf{h}$ is the polarization vector of the incident γ rays. From this formula it can be seen that in the case of polarized γ rays passing through a magnetic resonance absorber, a change in the direction of the magnetic field at the nucleus can lead to a disappearance or a restoration of the nuclear resonance absorption.

In this work we investigate the problem of the theoretically attainable speed of action and degree of modulation in shutters of this kind. We present results of experimental investigations of a shutter with $Fe^{57}BO_3$ as the active element.

OPERATING SPEED MAGNETIC RESONANCE SHUTTER

Since in the final analysis the action of the shutter is determined by the cessation or resumption of resonance absorption of the γ rays by the nuclei, in order to estimate the speed of the shutter action we may expect, we must consider three components of time which reflect the durations of the following transition processes: rotation of the magnetic field at the nucleus, establishment of the new nuclear spin state, and finally, establishment of the interaction of the γ quantum with the nuclei in the new state. Let us consider these processes in sequence.

The effective magnetic field which acts on the nucleus has a complex nature, but its direction is correlated with the magnetic moment of the atom itself, and this, in turn, is rigidly coupled to the direction of the magnetic moment of the

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crystal. Therefore, if there is a change in direction of the latter, the direction of the magnetic field at the nucleus will change at the same time.

In experiments on the remagnetization of single crystal plates,[11] it was determined that rotation of magnetization in the (111) easy plane by 180° or 90° takes place in 2–5 nsec when pulsed magnetic fields of ≈ 5 Oe are applied. It is evident that this will also be the time of rotation of the magnetic field at the nucleus.

Let us now consider the question of the nuclear spin state in a magnetic field that is changing in direction. Assume that initially the nucleus was in one of the ground state Zeeman substates, to which corresponded definite values of spin projection ($+1/2$ or $-1/2$) in the direction of the field, and definite values of energy. After rotation of the magnetic field, the nucleus will be in a new energy state. The time required to form this new state is, clearly, determined by the rate of propagation of the interaction, i.e., the speed of light. A quantum mechanical treatment shows that the state that is produced after rotation of the magnetic axis through an arbitrary angle is a mixed state in which, with a definite probability amplitude, determined by the angle of rotation, the nucleus is found in one or another of the Zeeman substates with a spin projection $\pm 1/2$ on the new axis. Since the magnitude of the magnetic field does not change, the splitting and position of the γ resonances remain as before. Only the conditions of absorption of the γ radiation components of different polarization change in accordance with (1).

Thus, the new conditions of interaction of the nucleus with a quantum of a given polarization will be established immediately after the new steady-state direction of the magnetic field at the nucleus is set up.

The question still remains concerning how quickly the interaction of the γ rays with the nuclei in the new state is established. Assume that the incident radiation is polarized and that its energy corresponds to a specific nuclear transition. Let us consider two limiting cases. In the first case the cross section of the nuclear resonance absorption after rotation of the field takes on the maximal value, and in the second case the cross section goes to zero. The first case corresponds to turning on the interaction and closing the shutter, and the second case corresponds to turning off the interaction and opening the shutter. We shall analyze the former case first.

Although the conditions for resonance absorption are established immediately upon rotation of the field, the intensity corresponding to resonance absorption will be established with a definite time delay. Using the response function formalism developed in Ref. 12, one can show that immediately after turning on the interaction at time $t = 0$ the intensity variation $I(t)$ of the radiation transmitted through the resonance absorber is described by the expression

$$I(t)=1-[4\beta/(\Gamma+\Gamma_s)]\{1-\exp[-t(\Gamma+\Gamma_s)/2]\} \qquad (2)$$

in the case of a thin absorber ($\mu_n l \ll 1$), and by the expression

$$I(t)=J_0^2(2\sqrt{\beta t}) \qquad (3)$$

in the case of a thick absorber ($\mu_n l \gg 1$). Here $\beta = \mu_n l/4\tau_0$, where μ_n is the nuclear resonance absorption factor, l is the thickness of the absorber, τ_0 is the characteristic lifetime of the nucleus in the excited state, $\Gamma = 1/\tau_0$, and Γ_s is the linewidth of the Mössbauer source. In the calculations, the frequency distribution of the γ rays emitted by the Mössbauer source was taken into consideration.

Thus, from expressions (2) and (3) it can be seen that the characteristic time required for the intensity to come to a constant level when the absorption is turned on is determined in the case of a thin absorber by the lifetime τ_0 of the nucleus in the excited state. However, in the case of a thick absorber, the shutter operates considerably faster: for $\mu_n l = 50$, the characteristic time is already $\sim 0.1\tau_0$.

Let us turn now to an analysis of the second case. Since in this case the resonance absorption conditions are no longer satisfied after rotation of the magnetic field, there is no physical reason for a time delay, and the maximum intensity of the transmitted radiation will be established instantaneously. In addition, following this fast transition one can observe slower intensity variations due to γ-ray phase modulation effects similar to those observed in Ref. 13. However, according to our estimates, the amplitude of these variations should not be large in the present case being considered. Therefore, these effects cannot significantly change the speed of operation of the shutter. Thus the shutter should open very rapidly, for practical purposes immediately after the rotation of the magnetic field.

From the discussion above it follows that the main contribution to the duration of the transition process, both in opening and closing (when a sufficiently thick absorber is used), is due to the remagnetization process.

As for the degree of modulation, it is determined by a number of rather simple factors: the magnitude of the resonance absorption $\mu_n l$ in the crystal, the linewidth Γ_s of the source, the amplitude of the nonresonance background, and a number of other factors that usually determine the magnitude of the effect in transmission Mössbauer spectroscopy. However, under conditions of repetitive pulsed remagnetization, a number of additional factors, which we shall examine later, can have a significant effect.

$Fe^{57}BO_3$ CRYSTALS. EXPERIMENTAL PLAN

Antiferromagnetic ordering of the magnetic moments of the iron atoms occurs in the iron borate crystals, with which the investigations into the modulation of the Fe^{57} Mössbauer radiation were carried out. However, the magnetic moments $\mathbf{M}_1$ and $\mathbf{M}_2$ of the sublattices are not exactly collinear, but are slightly canted in the (111) plane of the crystal so that a weak ferromagnetic moment $\mathbf{M} = \mathbf{M}_1 + \mathbf{M}_2$ is formed there. The magnetic fields at the nuclei coincide in direction with $\mathbf{M}_1$ and $\mathbf{M}_2$ and are almost perpendicular to $\mathbf{M}$.

In the spontaneous crystallization of $FeBO_3$ from solution there are formed in the melt single crystal plates, the surfaces of which are formed of the (111) crystallographic plane—the plane of easy magnetization. The planes have the shape of hexahedra. The samples that are usually obtained are from 10 to 150 μm thick and have an average linear dimension of ≈ 5 mm.[11]

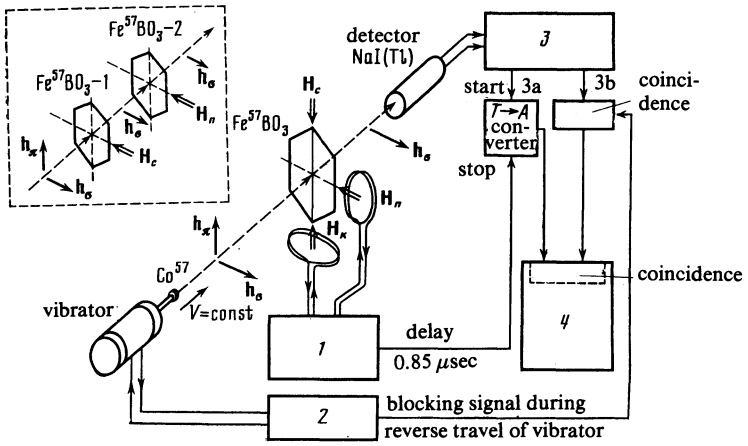

FIG. 1. Schematic diagram of apparatus for studying modulation of Fe^{57} Mössbauer radiation. 1) magnetization pulse generator, 2) vibrator control, 3) fast and slow amplifier and discriminator (3a is the fast channel; 3b is the slow channel), 4) NTA-512 multichannel analyzer. The insert depicts the final modulation scheme.

In the free state in the absence of an external magnetic field the iron borate crystals are divided into domains. In the crystals the domain walls are of two types[14,15]: parallel to the (111) plane and perpendicular to it. In the plane of the crystals the domains are separated by Néel walls, while along the direction perpendicular to the surface the sample is subdivided by Bloch walls. It is essential that the vector **M**, which rotates in passing from one domain to another, remain in the plane of easy magnetization independently of the type of domain wall. In order to convert the iron borate crystal into a single domain state, it is necessary to apply a small field in the (111) plane. For highly perfect crystals the saturation field does not exceed 3 Oe.

The crystals used in our experiments were enriched in the resonance isotope Fe^{57}.

A diagram of the apparatus[16] used in the study of the modulation of the resonance γ radiation is shown in Fig. 1. In addition to the usual elements of a Mössbauer spectrometer, the apparatus also includes a unit for supplying the necessary pulsed fields to the iron borate crystals as well as a circuit for time-dependent spectrometry. In our experiments the single-line Mössbauer isotope Co^{57} in a chromium matrix was used as the source, which had a linewidth $\Gamma_s = 2.5\Gamma$. The vibrator was operated in the constant velocity mode such that the source line coincided with the nuclear resonance $\Delta m = 0$ in $Fe^{57}BO_3$. The state of magnetization of the crystal was set by applying a constant field $\mathbf{H}_c$ and turning on the pulsed magnetic fields $\mathbf{H}_p$ and $\mathbf{H}_k$ in the plane of the crystal. The pulsed magnetic fields were produced by 10 mm diameter double-wound coils which were fed with pulsed current from a specially designed oscillator.[17] The magnetic field pulses had an amplitude to 20 Oe, a rise time of 15 nsec, a duration T_p up to 0.7 μsec, and a repetition rate $\nu \ll T_p/2$. The radiation transmitted through the crystal was detected with a scintillation detector having a NaI(Tl) crystal. The time resolution of the detector was 10 nsec and the energy resolution for 14.4 keV γ rays was 40%. As usual, the slow channel was used to discriminate the signals corresponding to the 14.4 keV γ rays. Signals from the 14.4 keV γ rays in the slow coincidence circuit were blocked during the time the vibrator was coming up to the resonance velocity. The fast channel was used to trigger the time-to-pulse-height converter ($T \rightarrow A$) at that time that the first photoelectron, produced by the scintillation in the NaI(Tl) from a γ ray, reached the photocathode. The converter was stopped upon the arrival of a standard pulse delayed by 0.85 μsec from the leading edge of the magnetizing pulse. The converter generated a pulse with an amplitude proportional to the time interval between these events, and the pulse was then fed into the coincidence circuit of an NTA-512 multichannel analyzer. If there was a coincidence of this pulse with a signal from a 14.4 keV quantum, then the pulse was recorded in the appropriate channel of the analyzer. In this way information on the distribution of signals from the converter was stored, this information reflecting the time dependence of the resonance γ ray intensity relative to the leading edge of the remagnetization pulse.

INVESTIGATION OF 14.4 keV RESONANCE RADIATION MODULATION IN $Fe^{57}BO_3$ CRYSTALS

In the first experiments the 90° mode of remagnetization of the iron borate crystals was used for the modulation of the polarized γ radiation, as this mode corresponds most closely to the modulation principle discussed above. This mode of operation was implemented in the following way: the crystal was magnetized by a constant field $\mathbf{H}_c$ in the vertical plane (in this way the magnetic field at the nuclei was aligned in the horizontal direction), and this configuration permitted resonance absorption of σ-polarized γ radiation. At a given time two magnetic field pulses were applied to the crystal: a compensating field $\mathbf{H}_k = -\mathbf{H}_c$, and a remagnetizing field $\mathbf{H}_r \perp \mathbf{H}_c$. As a result of the action of the pulsed field the magnetic field rotated by 90° and the crystal was made transparent to σ-polarized γ rays. The remagnetization process was monitored by the emf induced in a special removable coil surrounding the crystal. The time behavior of the intensity after applying the pulses was recorded by the method described above.

With uniform rotation of the magnetization it was possible to modulate only polarized γ rays, and so in the first

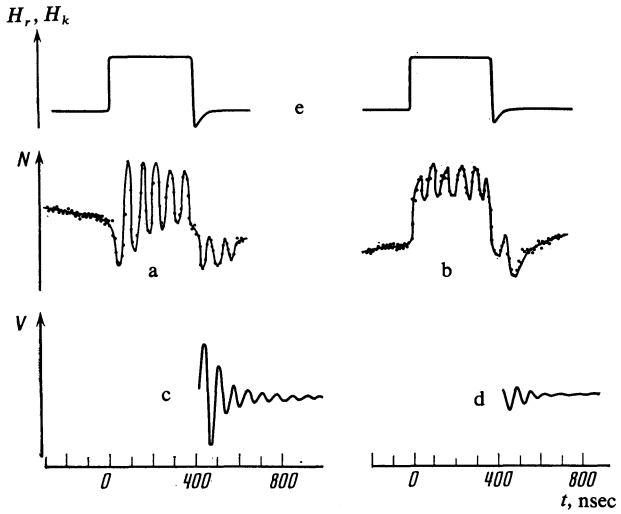

FIG. 2. a) Time dependence of the intensity of Fe^{57} radiation transmitted through $Fe^{57}BO_3$ crystal (130 μm), subjected to the magnetic fields $H_r = 10$ Oe, $H_k = 6$ Oe, and $\mathbf{H}_c = -\mathbf{H}_k$, with $T_p = 0.35$ μsec and $\nu = 0.33$ MHz. b) is the same for $H_c = 0$, c) shows a portion of the magnetic induction emf of the $Fe^{57}BO_3$ crystal upon pulsed remagnetization under the conditions of part (a) of this figure; d) is the same, under conditions of part (b), and e) shows the shape of the magnetic field pulses H_r and H_k.

experiments the incident beam was partially polarized by reflection at the Bragg angle from a graphite crystal. However, the results of even the first measurements showed that the picture of the interaction of the radiation with the nuclei in a crystal that is being remagnetized deviates somewhat from that which one should observe in the case of uniform rotation of the magnetization of the crystal. Shortly thereafter it was discovered that by the remagnetization of $Fe^{57}BO_3$ one could modulate not only polarized, but also unpolarized γ rays, and this was an unexpected result. Figure 2a shows typical experimental results for the time dependence of the intensity of initially unpolarized radiation transmitted through the crystal. The first thing that is conspicuous is the appearance of strong intensity oscillations which arise after application of the remagnetization pulse. The period of the oscillations for the crystal that was used is 65 nsec.

It could be hypothesized that the magnetic pulse generates acoustic vibrations of the nuclei in the crystal as a result of magnetoelastic coupling, and consequently a doppler shift of the resonance is produced, leading to the observed modulation. In fact, lattice shear waves are easily excited in the crystal (these waves represent the corresponding mode of magnetoelastic vibrations[18,19]) with a propagation vector into the bulk of the sample and a period T dependent on the thickness l of the sample and the speed of sound c_s in this direction: $T = 2l/c_s$. For the crystal that was used, $l = 130$ μm and $c_s = 3.8 \cdot 10^3$ m/sec,[18] so that the period corresponds to the value quoted: 65 nsec. However, the lattice deformation wave that corresponds to this mode is a transverse mode and consequently cannot produce any substantial modulation. Furthermore, acoustic oscillations of frequency ν_0 are manifest in intensity oscillations of frequency $2\nu_0$.[20] In addition to shear oscillations, membrane oscillations can also be excited.[19,20] Although these are also capable of producing acoustic modulation of the radiation, it is in an entirely different frequency range. The period of the membrane oscillations depends on the size and shape of the sample and for the dimensions quoted here is close to 1 μsec. Thus, we must exclude the doppler mechanism as a possible cause of the observed modulation.

There remains yet a second possibility of accounting for the observed picture, this is the action of magnetization oscillations. The emf signal induced in the removable coil, recorded with a sampling oscilloscope (a portion of the oscilloscope trace, recorded after termination of the magnetizing pulse, is shown in Fig. 2c) shows the existence of such oscillations. Simple considerations show that uniform magnetization oscillations could not cause any appreciable intensity modulation of the incident unpolarized radiation. In the situation that is observed, however, there is an interesting feature which leads us to hypothesize the existence of nonuniform magnetization oscillations. The falloff in intensity after application of the remagnetizing pulse indicates that the crystal has begun immediately to absorb not only the π component, but also the σ polarized component of the incident beam, and this circumstance means that a state with different magnetization orientations along the thickness of the sample had been produced in the crystal. In fact the subsequent time dependence of the intensity confirms that, as a result of the sudden application of the magnetic field, magnetoacoustic oscillations which are nonuniform through the thickness of the sample are set up in the crystal and these oscillations produce a modulation of the unpolarized radiation.

These results seriously disturbed our confidence in the possibility of producing γ-ray intensity changes close in shape to right-angle steps. There was an apparent conflict in the requirements: fast response of the crystals to remagnetization required that they be highly perfect, while the high degree of perfection made possible a high quality factor for the magnetoacoustic oscillations developed in the crystal as a result of the percussive action of the magnetizing pulses. It therefore became necessary to study these oscillations in more detail and look for a way to suppress them.

The investigations were carried out by the induction method, through observation of the emf induced in the demountable coil by the sample as it is remagnetized. We studied the effect of the steepness of the leading edge and the effect of the amplitude and frequency of the pulse sequence. We also studied the possibility of damping the oscillations by placing the crystal in various media. Finally, we studied the conditions for the excitation of magnetoacoustic oscillations in modes of remagnetization other than the 90° mode. As a result we found recipes for substantially reducing the effect of oscillations.

One of the definitive steps in this direction was the transition to the pulsed magnetization mode. Figure 2b shows the time dependence of the γ radiation transmitted through the same crystal as in the previous example (Fig. 2a) with the application of the same pulsed magnetic fields $\mathbf{H}_r$ and $\mathbf{H}_k$; the only change was the removal of the constant magnetic field $\mathbf{H}_c$. In this mode the crystal was converted from the

original unmagnetized (multidomain) state to the magnetized (single domain) state. The shape of the time dependence of the intensity of the transmitted radiation was changed substantially in comparison with Fig. 2a, and in many respects resembled the shape of the magnetizing pulse. In this case the role of the oscillations was reduced sharply. This result was due mainly to the suppression of the amplitude of the shear mode of the magnetoacoustic oscillations. This can be seen directly from a comparison of the oscillograms of induced emf signals in Figs. 2c and 2d, taken in the pulsed 90° modes of remagnetization and magnetization, respectively. The decrease in the amplitude of the oscillations in the pulsed magnetization mode can be explained in the following way. Because of the random orientation of the magnetized domains, the oscillations which are excited in the various points of the crystal are uncorrelated in phase and direction, and thus, the resultant amplitude is small, that is, the pulsed magnetization mode corresponds to the case of incoherent (over the area of the crystal) excitation of magnetoacoustic oscillations.

The general variation in γ ray intensity observed in this mode corresponds to the situation where the crystal was converted from the state in which it absorbed both polarizations because of the various orientations of the magnetization through the sample, to the state in which it absorbed only one polarization.

The second important factor in the suppression of the magnetoacoustic oscillations was the choice of sample thickness. By decreasing the thickness the period of the oscillations was reduced to a value less than the rise time of the magnetizing pulse, and this naturally led to a decrease in the amplitude of the oscillations.

Experiments in immersing the crystals in media of various viscosities showed that this procedure could partially reduce the membrane oscillations, which also have a definite effect on the shape of the γ-ray pulses that are formed. Placing the crystals in vaseline had a beneficial effect.

Returning to the question of the choice of crystal thickness, we should note that the period of oscillation becomes sufficiently small only in the case of rather thin crystals: a 15 nsec period is obtained in crystals 30 μm thick. In these and thinner crystals experiments have shown that it is not easy to observe a multilayer domain structure with different magnetization orientations in the layers, a condition necessary for the efficient absorption of both polarizations of the radiation. The problem is that the Bloch walls are an estimated 5–10 μm thick.[15,22] Therefore with one thin crystal it is difficult to achieve a high degree of modulation. In order to obtain in spite of the difficulties a large degree of modulation on the one hand and on the other hand fulfill the conditions for suppression of the magnetoacoustic oscillations by decreasing crystal thickness, it is possible to use a system of several thin crystals through which the radiation passes consecutively.

A combination of all the above-mentioned schemes were used in the final modulation device, shown in the insert to Fig. 1. The radiation was transmitted through a system of two $Fe^{57}BO_3$ crystals, each 22 ± 2 μm thick. The first crystal was placed in a constant magnetic field $\mathbf{H}_c$, and put into a single-domain state, so that it transmitted the σ polarized component of the radiation $\mathbf{h}_\sigma \| \mathbf{H}_c$. The second crystal, before application of the magnetic field pulse, was in the unmagnetized (multidomain) state and could effectively absorb the σ component of the radiation that had been separated out by the first crystal. Application of the magnetic field pulse $\mathbf{H}_\pi \| \mathbf{H}_c$ transformed the second crystal to a single domain state with magnetization parallel to the magnetization of the first crystal and in this way the system became transparent to the specified plane of polarization $\mathbf{h}_\sigma$. Figure 3 shows the time dependence of the intensity of the γ rays transmitted through the system of two crystals.

From Fig. 3 it can be seen that by this modulation scheme it was possible to obtain γ pulses almost in the shape of a step function, with a rise time $\tau_r \leqslant 10$ nsec. It can be seen that the high-frequency mode of magnetoelastic oscillation has been suppressed. The degree of modulation was $(56 + 4)\%$. In determining this value from the experimental measurements, the nonresonant background was subtract-

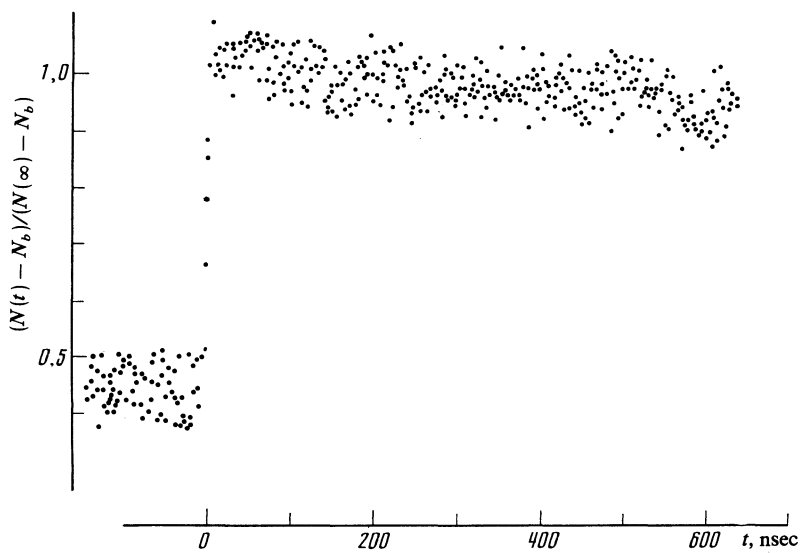

FIG. 3. Time dependence of Fe^{57} γ ray intensity obtained in the final modulation scheme. N_b is the nonresonance background, (1 channel = 1.8 nsec).

ed. The magnetic field pulses switching the crystals in this case had the following characteristics: rise time, 15 nsec; total length, $T_p = 750$ nsec; repetition rate, $\nu = 0.5$ MHz; and amplitude $H_p = 14$ Oe. The rise time of the measured γ ray pulse was determined mainly by two factors: the rise time of the magnetizing pulse and the time resolving power of the spectrometer circuit. However, it is clear that the intrinsic properties of the $FeBO_3$ crystals will allow γ ray pulses with a sharper rise time to be produced.

It should be noted that the degree of modulation obtained is somewhat less than that which follows from simple estimates using a quasistatic model of modulation. This discrepancy is due to the finite time required to establish the final multidomain state of the $FeBO_3$ crystal, a time which we have estimated to be 2–5 μsec, depending on the sample. Because of this slow mechanism, in the case of a high repetition rate of the magnetizing pulses (in our case, $\nu = 0.5$ MHz), at the time a succeeding pulse is applied, the $FeBO_3$ crystal is not yet in an equilibrium state, and therefore the amplitude of the γ-ray pulses that are obtained is less than expected. Actually, the measurements show that the amplitude of the γ ray pulses increases monotonically with decreasing repetition rate of the magnetizing pulses, and for $\nu = 0.2$ MHz it has increased by a factor of 1.5 over the amplitude for the case we have considered here. In the case of the lower repetition rate the degree of modulation is equal to that in the quasistatic mode of modulation.

These investigations have shown that the magnetic resonance shutter, which uses a $FeBO_3$ crystal for the active element makes it possible to produce Fe^{57} Mössbauer radiation pulses having a near-rectangular shape and a rise time $\tau_r \leqslant 10$ nsec, which is an order of magnitude less than the characteristic lifetime of the Fe^{57} nuclear excited state, and having a high degree of modulation at a rather high repetition rate. The last is important for reducing the time necessary to carry out experiments.

Thus, we have developed and put into practice a new method of time dependent Mössbauer experiments which extends the possibilities for investigations in this direction. At the present time this method has already been used in the study of the time dependence of resonance diffraction of γ rays by the nuclei in an ideal crystal.[23]

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