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Abstract

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A Nuclear-Resonance Generator Operating in the Earth’ s Magnetic Field

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The intensive development of studies of nuclear precession in the Earth’ s magnetic field, chiefly for magnetometric purposes, began after Packard and Varian [1] in 1954 proposed a method for observing free nuclear induction, which in the case of weak fields makes it possible to increase the signal intensity hundreds of times. In this method the free precession of the nuclear magnetization vector **M** arises as a result of the nonadiabatic switching off of a strong auxiliary field H^*, applied at the first stage of the experiment approximately perpendicular to the Earth’ s field H_0 (the increase in intensity is due to the large magnitude of the magnetization established in the strong field $H^* + H_0$). The Packard–Varian technique possesses most of the advantages characteristic of nuclear-resonance methods in magnetometry. At the same time, a rather substantial drawback of it is the damped character of the signal, observed for no more than a few seconds, which not only makes the observation discontinuous and the time required to obtain each reading comparatively long, but also limits the ultimate accuracy of measurement of the precession frequency (and, correspondingly, of the field strength).

The fundamental possibility of continuous observation of the signal was indicated by K. V. Vladimirskii [2], who considered the conditions for self-excitation of nuclear precession in a sample previously magnetized antiparallel to the Earth’ s field and placed in the inductance coil of a resonant circuit of sufficiently high quality factor*. The author points out that generation of a stationary signal is possible if, in such a system, the sample is continuously replaced. Specific variants for implementing this device are not considered in [2].

In the present work another scheme of a nuclear-resonance generator has been proposed and implemented, for which the characteristic feature is the introduction into the receiving coil of portions of a sample with an already precessing nuclear magnetization vector, deflected from the direction of the Earth’ s field by an angle of the order of 90°. The deflection of the vector **M** is accomplished by an alternating field of resonant frequency with the aid of a pair of deflecting (phase-shifting the nuclear precession) coils, which are fed by the signal of free induction arising in the receiving coil, amplified to the corresponding magnitude**.

Fig. 1

Figure 1: Fig. 1

* In this case the quality factor Q and the magnetizing field H^* must be very high; under ordinary conditions one may take the estimate $QH^* < 10^4$ oersted. If a solenoid rather than a magnet is used for magnetization (which appears highly desirable for reducing the weight of the system, and also in connection with the necessity of very accurate compensation of H^* in the region in which the weak-field measurement is made), fulfillment of the indicated relation is associated with certain difficulties.

** This device performs the functions of a feedback circuit. The presence in it of an amplifier makes it possible to satisfy the conditions for self-excitation of the system with ordinary values of QH' and to use a sample which in the initial state is magnetized along the field. It is also possible to feed the phase-shifting coils from an external source. This variant, also implemented—

The generated frequency automatically follows the field strength of the magnetic field being measured, and only when it changes significantly does a comparatively coarse adjustment of the receiving circuit become necessary.

The schematic diagram of the sensor of the nuclear-resonance generator is shown in Fig. 1. When the sample (water) flows through the magnetizing coil H, a nuclear magnetization $\mathbf{M}$ is established, proportional to the strong field $\mathbf{H}^* + \mathbf{H}_0$.

Fig. 1. Above—the schematic diagram of the sensor of the nuclear-resonance generator. The sample (water) flows from left to right. H is the magnetizing coil, HK its compensating windings, $\Phi\Phi$ the phasing coils, P the receiving coil, and PK its compensating windings. The long tube connecting points B and Γ is not shown in the drawing. The distribution of the constant magnetic field along the axis of the device and the character of the motion of the nuclear-magnetization vector are shown.

Then, through the long thin tube $B\Gamma$, the water reaches the region in which the field H_0 is to be measured; the flow velocity is chosen sufficiently high that the magnitude $\mathbf{M}$ does not have time to decrease appreciably. Since the field acting on a volume element of the sample, at any realistically attainable flow velocity, will change adiabatically, at point Γ the vector $\mathbf{M}$ is directed along the weak field $\mathbf{H}_0$. Further, during the motion between the phasing coils $\Phi\Phi$, their field, with a properly chosen amplitude, tips the nuclear magnetization through an angle of the order of 90°—exactly as occurs in the spin-echo method. The precession that then arises, gradually damping, continues while the water flows through the receiving coil P, which produces the induction in it of a continuous signal.

In the realized version of the instrument, the water-flow velocity is 320 cm^3/s, $H^* \simeq 400$ oersted, the volume inside the magnetizing coil is 1600 cm^3, and inside the receiving coil 600 cm^3. Compensation of the field H^* at the location of the receiving coil is accomplished by three windings (HK), connected in series with one another and with the magnetizing coil. They are designed so as to weaken the field at the center by no more than 20%, but to make the dipole and octupole moments of the entire system as a whole equal to zero. Since multipoles of even orders are absent by symmetry, the first uncompensated moment is the 32-pole. By using a simple adjustment system it proved possible to reduce the field H^* at a distance of 150 cm from the center of the magnetizing coil to hundred-thousandths of an oersted.

The receiving coil also has an analogous system of compensating windings (PK). With their aid it is possible to reduce the sensitivity of the device to external magnetic interference by a factor of 20–25. The position of the phasing coils was chosen so that their direct pickup on the receiving coil would be as small as possible. In this case the feedback is closed practically only through the nuclear precession in the flowing water.

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presented in this work, is less convenient, since when the magnetic-field strength changes, very precise tuning of the frequency of the phasing signal is required (to fractions of a hertz).

In tests, the oscillator operated quite stably, with the signal-to-noise ratio in some experiments reaching 20. When the feedback circuit is closed, a characteristic self-excitation process is observed. Since, however, flowing water creates something like a delay line included in this circuit, the establishment of the amplitude takes several seconds, i.e., it occurs incomparably more slowly than in an ordinary radio-frequency oscillator. As for the signal frequency, it follows changes in the field H_0 practically instantaneously.

Figure 2 shows three recordings of signals from the nuclear-resonance oscillator, obtained on a loop oscillograph at a low film speed (individual periods of the signal are not resolved). One of them presents oscillations in the steady-state regime,* while the other two show the processes occurring when the magnetizing or phasing field is switched off and on. As was to be expected, in the second case the damping and build-up of oscillations occur much faster than in the first (the effective value T_2, which includes the influence of the circuit reaction, is considerably smaller than T_1).

In conclusion, the author expresses sincere gratitude to A. V. Melnikov, A. A. Morozov, and M. M. Bryantsev, who carried out the tests of the nuclear-resonance oscillator, and to M. A. Denisov and S. V. Maryushkin, who took part in the fabrication of some of its units.

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Fig. 2. Signal photographs obtained on a loop oscillograph at a film speed of 10 mm/s. 1—continuous signal; 2—switching off and switching on of the magnetizing field; 3—switching off and switching on of the phasing signal

Figure 2: Fig. 2. Signal photographs obtained on a loop oscillograph at a film speed of 10 mm/s. 1—continuous signal; 2—switching off and switching on of the magnetizing field; 3—switching off and switching on of the phasing signal

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2. K. V. Vladimirsky, ZhETF, **33**, 532 (1957).

* The recordings were made with the phasing coils powered from an external source, small changes in the frequency of which substantially affect the signal amplitude. When a feedback circuit is used, the amplitude of the generated oscillations becomes still considerably more stable.

Fig. 2. Signal photographs obtained on a loop oscillograph at a film speed of 10 mm/s. **1**—continuous signal; **2**—switching off and switching on of the magnetizing field; **3**—switching off and switching on of the phasing signal.

Note: Figure translations are in progress. See original paper for figures.