FREQUENCY-FIELD DEPENDENCE OF TOTAL ELECTRICAL RESISTIVITY OF MAGNETICALLY-SOFT CONDUCTORS

A. F. Prokoshin, A. G. Kozlov, and A. P. Krotov

The frequency-field dependence of total electrical resistivity is studied for thin magnetically-soft alloy conductors with a crystalline and amorphous structures, and it is compared with the giant magnetoresistance effect observed for superlattices.

Recently interest has increased in the so-called giant magnetoresistance effect, i.e., a change with magnetization in a field \( H \) of active resistance \( dR/R = 1 - R(H)/R(0) \) reaching 50% in superlattices [1]. In addition, with magnetization of a ferromagnetic conductor through which an alternating current passes with frequency \( f \) there is a change not only in active \( R \), but also inductive resistance \( R_t = 2\pi fL \), where \( L \) is conductor inductance. For a single rectilinear conductor of round cross section and radius \( r \) with \( f >> 1 \) [2]

\[
L = \frac{d}{2\pi} \left( \ln \frac{2l}{r} - 1 \right) + 0.6 \frac{l}{2\pi r} \sqrt{\frac{\mu}{2\pi f/d}},
\]

where \( \mu_0 \) is a magnetic constant; \( \mu \) is absolute magnetic permeability determined from the main magnetization curve for the conductor material with magnetic field intensity \( H = l/2\pi r \) (here \( l \) is the effective current value); \( \sigma \) is conductor material conductivity. Since permeability depends on \( f \) and \( H \) it is probable that the total resistance of the conductor

\[
R_t = \left( R^2 + 4\pi^2 f^2 L^2 \right)^{1/2}
\]

will also depend on these parameters.

The aim of the present work* is to study this dependence for magnetically-soft material with low magnetostriction constants \( \lambda_5 \) whose chemical compositions are given in Table 1.

The study was performed on straight thin sections of conductors of round and rectangular cross section of magnetically-soft alloys with a crystalline (alloy 1) and amorphous (alloys 2 and 3) structures [3]. Wire of diameter 0.36 mm of alloy 1 was annealed at 1100°C for 2 h, and wire of amorphous alloys 3 (diameter about 10 \( \mu \)m) and 2 (diameter 0.19 mm) and also tape of alloy 2 (120 \( \mu \)m thick and 0.4 mm wide) were in the melt-quenched condition. Magnetization \( \lambda_5 \) for all of the test alloys was < \( 10^{-6} \). Alternating current with frequency \( f = 1 \) kHz-10 MHz from a G3-112/1 generator was passed through the test conductor 0.05 m long. Voltage \( U \) in the conductor during magnetization of it along the axis was measured by a F5263 millivoltmeter in magnetic fields with intensity up 64 \( kA/m \) created by means of a small solenoid. The change in voltage \( U = F(f, H) \) was determined by the change in frequency \( f \) and field \( H \) of the total resistance of the conductor section. Total resistance \( R_t \) and inductance \( L \) at a frequency of 1 kHz were measured by means of L, C, and R-meters type E7-8.

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TABLE 1

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<tr>
<th>Alloy</th>
<th>Ni</th>
<th>Mo</th>
<th>Ti</th>
<th>Co</th>
<th>Cr</th>
<th>Si</th>
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<tr>
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<td>-</td>
<td>58</td>
<td>-</td>
<td>11</td>
<td>16</td>
</tr>
</tbody>
</table>

Note. In all of the alloys the balance is Fe; the content of all elements is shown in wt. %.

Fig. 1. Change in relative values of total resistance \( R_t(H)/R_t(0) \) and inductance \( L(H)/L(0) \) with magnetization of a conductor 0.36 mm in diameter of alloy 1 along the axis. Frequency \( f = 1 \) kHz.

The change in \( R_t \) and \( L \) with magnetization of a conductor made of alloy 1 along its axis is shown in Fig. 1. The value of \( L \) decreases with an increase in magnetic field intensity \( H \) as a result of a reduction in \( \mu(H) \) to the limiting value independent of the field value determined by the first term in Eq. (1). The value of \( R_t \) decreases in accordance with Eq. (2) and also it tends toward a limiting value close to that for active resistance \( R \).

The dependence of \( dU = 1 - U(H)/U(0) \) on frequency with magnetic field intensity \( H = 64 \) kA/m for the test conductors is presented in Fig. 2. It can be seen that all of the curves \( dU = F(f) \) have a maximum whose position and height depend mainly on the conductor transverse dimensions: the smaller the diameter or the cross-sectional perimeter, the greater is the frequency corresponding to the maximum on curves and the higher is the maximum. It should be noted that for alloy \( dU = 76\% \) which exceeds the value of the giant magnetoresistance effect for superlattices [1].

It can be seen in Fig. 3 that with high frequencies (1-10 MHz) the value \( U(H)/U(0) \) increases at first and it is most marked (at 70\%) for alloy 2, and then it decreases. With lower frequencies (0.1 MHz) a sharp reduction in \( U(H)/U(0) \) is observed exceeding 70\% for alloy 1.

It is difficult to describe analytically the frequency dependences observed. Qualitatively they may be explained as follows. As follows from Fig. 1, the relationship \( R_t = F(H) \) only develops with the condition \( 2\pi fL >> R \), i.e., with quite high frequencies and permeability. This may explain the increase in \( dU \) with an increase in frequency (Fig. 2). Active resistance \( R \) also increases with an increase in frequency as a result of a surface effect and loss in hysteresis and eddy currents. At the same time the value of \( \mu \) with an increase in frequency decreases as a result of the same factor. In view of this the total resistance changes uniformly with a change in frequency and it passes through a maximum whose position is determined by...