A method for directly measuring the peak magnetic permeability of soft-magnetic sheet materials using an analog divider with a Hall converter is based on the induction method of measuring the peak value of flux density and the magnetic field strength with ac magnetization [1, 2, 3]. The test sample is a toroidal magnetic circuit or a bundle of plates placed in a permeameter.

In essence, the method is as follows: Signals from windings placed on the sample enter two channels for conversion, with the channel outputs connected to a dc analog divider with a Hall converter. The output signal from the divider is proportional to the peak magnetic permeability.

Figure 1 shows the circuit used to measure peak magnetic permeability with sinusoidal flux density. The circuit consists of an autotransformer $A_{Tr}$, two channels for converting the signals from the windings on the sample, and a dc analog divider with a Hall converter $AD$. The primary circuit of the toroidal sample is supplied with a sinusoidal voltage at 50 Hz from the autotransformer. A signal proportional to the magnetic field strength from the output winding of the current transformer is differentiated by the air-core transformer $M$, amplified by an ac amplifier, and detected by rectifier $D_1$. The signal from the output of rectifier $D_1$ goes to block 1 for measurement of the average value of its first derivative. The output of block 1 is connected to one of the ac analog divider inputs. The magneto-electric device $V$ reads out voltage $U_{Hm}$ from the output of rectifier $D_1$, proportional to the peak value of the magnetic field strength

$$H_m = \frac{K_1 W_1}{l_{av}} U_{Hm},$$

where $K_1$ is the transmission coefficient of the current transformer $TT$, the air-core transformer $M$, the ac amplifier, transformer $Tr_1$, and rectifier $D_1$; $W_1$ is the number of turns in the magnetizing winding; and $l_{av}$ is the average length of the magnetic lines of force in the sample.

A voltage divider is connected to the pickup winding $W_2$ on the sample. The divider output signal enters the ac amplifier. After amplification and rectification, the output voltage of rectifier $D_3$

$$U_{Bm} = K_4 K_2 f W_2 S B_m$$

is applied to the second input of the analog divider. Here $K_4$ is a form factor of the flux density curve; $K_2$ is the overall transmission coefficient of the voltage divider, ac amplifier, and rectifier $D_2$; $f$ is the frequency of the magnetizing current; $W_2$ is the number of turns in the pickup winding on the sample; $S$ is the cross-sectional area of the sample; and $B_m$ is the peak flux density.

The ac analog divider with the Hall converter $AD$ represents a static automatic control system. It consists of a Hall multiplier, a differential amplifier, and a dc amplifier. The input signals to the analog divider are voltage $U_{Hm}$, proportional to the peak magnetic field strength, and voltage $U_{Bm}$, proportional to the peak flux density. Voltage $U_{Bm}$ is compared to the Hall voltage with the differential amplifier. The signal from the output of the differential amplifier is amplified by the dc amplifier and applied to the magnetizing winding of the Hall multiplier. In the equilibrium state, current $I$, which is the output signal from the analog divider passing through the magnetizing
winding, is proportional to the peak magnetic permeability, i.e.,

$$I_{\mu} = K_3 \frac{U_{Bm}}{U_{Hm}} = K\bar{\mu}, \quad (3)$$

where $K_3$ is the transmission coefficient of the analog divider, and $K$ is the overall coefficient for measuring $\bar{\mu}$.

Keeping Eqs. (1), (2), and (3) in mind, we obtain for the peak magnetic permeability

$$\bar{\mu} = \frac{I_{av}}{K_1 K_2 K_3 K_f W_1 W_2 S} I_{\mu}.$$

The correcting circuit consisting of transformer $T_2$ and rectifier $D_2$ provides precise analog division [2]. Transformers $T_1$ and $T_2$ are introduced to separate the input and output circuits of the Hall converter.

When switch $S_3$ in block 1 is in the 1 position, the magnetoelectric device $V$ measures the average value of the first derivative of the magnetic field strength, which is proportional to the peak magnetic field. Before measuring the peak magnetic permeability, switch $S_3$ is set to position 2, thus connecting the output of rectifier $D_1$ to the smoothing filter $R_1C_1$. The signal must be smoothed for the dc analog divider to operate normally. To make the input signal of the analog divider equal to the average value of the first derivative of the field intensity after connecting the filter, device $V$ should read the same at both positions of $S_3$. This is accomplished with potentiometer $R_1$.

It is possible to measure the peak magnetic permeability with a sinusoidal magnetic field intensity. This requires changing the positions of blocks 1 and 2 in the conversion channels of the signals taken from the windings on the sample.

This apparatus was used to study toroidal samples of ferromagnetic materials with high and low magnetic permeability. Figures 2 and 3 show the resulting relationships of peak magnetic permeability $\bar{\mu}$ to magnetic field intensity $H_m$ for transformer steel type BD 2.6 K Stahlwerke Bochum and 79HMA molybdenum permalloy respectively.

The mean square error caused by the measurement circuit is calculated by $\Delta = \sqrt{\Delta K_1^2 + \Delta K_2^2 + \Delta K_3^2}$. Here $\Delta K_1$ is the error of the conversion channel for the signal that is proportional to the magnetic field intensity, equal to $\pm 3.2\%$; $\Delta K_2$ is the error of the conversion channel for signal proportional to the flux density, equal to $\pm 2.7\%$; $\Delta K_3$ is the error of the analog divider with the Hall converter, not exceeding $\pm 2.5\%$. Thus the mean square error of the measurement $\Delta$ made by this method does not exceed $5\%$. The accuracy of measurement is quite satisfactory for industrial control of ferromagnetic materials or the magnetic circuits made from them.

This method of measuring peak magnetic permeability using an analog divider with a Hall converter is very convenient for direct read-out of $\bar{\mu}$. Furthermore, it permits analog or digital readout and can be adapted to automatic equipment.