CONVERTER OF CONTINUOUS ELECTRICAL QUANTITIES INTO A DISCRETE CODE

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The wide application of computers in automation raises many problems of converting analog electrical quantities into discrete codes [1 and 2]. The most frequently used method for converting analog to discrete quantities consists of comparing a continuous voltage with a voltage ramp.

The null detector produces a signal at the instant the saw-tooth voltage equals the measured voltage. This method is characterized by a high operating speed, but its application in transistorized sets entails certain difficulties. The most delicate part of the circuit consists of the linear voltage generator which must be extremely stable and linear. The design of a null detector is no less difficult. The method examined below is free from these drawbacks.

The instrument's principle of operation consists in the use of an intermediate conversion of a reference voltage into a phase shift for the purpose of converting a direct voltage (or current) into a discrete code.

The voltage phase shift leads to width modulation of pulses whose duration determines the time for which the high-frequency pulse generator is connected to the counter input.

The schematic of the device is shown in Fig. 1. A sinusoidal voltage of 50 Hz (or any other frequency according to the required speed of operation) is fed simultaneously to two channels. The first channel comprises phase-shifting bridge 1 which changes the phase of the voltage according to the value of the measured dc voltage. The sinusoidal voltage is fed through the phase-shifting bridge to amplifier 2, and then to trigger 3 which forms rectangular pulses. The second channel contains only amplifier 4 and trigger 5. Thus the rectangular voltage of the first channel is shifted in phase with respect to that of the second channel. The rectangular voltages of both channels are fed to comparison circuit 6 which forms rectangular pulses with a duration proportional to the phase shift between the two voltages. The pulses thus obtained are fed through amplifier 7 to the second coincidence circuit 8 which also receives pulses from a high-frequency generator (in our case at 0.5 MHz). Thus the output of circuit 8 is provided with pulses whose number depends on the duration of the low-frequency pulses. The high-frequency pulses are fed to the input of an electronic counter.

The required linearity of transformation is obtained by using a feedback which comprises amplifier 9 and tracking system 10. A complete circuit of the converter is shown in Fig. 2.

The phase-shifting bridge contains in its three arms resistors $R_1$, $R_2$, and $R_3$, and in the fourth arm a series-connected phase-shifting transformer $PT_2$ and a capacitor. The inductance of the transformer can be changed by varying its magnetization (Fig. 3). Capacitance $C_1$ is required for series tuning at small values of inductance. At resonance the impedance of the arm becomes resistive and its phase shift equal to zero.

The initial biasing of winding $W_4$ for which the phase shift is equal to zero is provided through resistor $R_7$ from a stabilized voltage supply source. The measured voltage is fed to winding $W_3$ through manganin resistors $R_6$ and $R_8$. The applied voltage changes the phase shift of the reference voltage taken from the bridge diagonal. Figure 4 shows...
the relation between the phase angle and inductance. It will be seen from Figs. 3 and 4 that the relations between
the phase shift angle, inductance and current have a pronounced nonlinear nature. It is therefore necessary to change
the above quantities over a limited range, and to use feedback for obtaining linearity. Two arms of the phase-shift-
ing bridge contain equal resistances which makes the output bridge voltage only slightly affected by the value of the
phase shift.

![Diagram](image_url)

**Fig. 2.**

The coincidence circuit consists of two series connected transistors T9 and T10. The input of each transistor
is fed by the voltage from the corresponding channel. Positive pulses whose duration is proportional to the phase shift
are produced at the output of the circuit. The pulses are fed through power-amplifying transistor T11 to the second

![Graph](image_url)

**Fig. 3.**

![Graph](image_url)

**Fig. 4.**

coincidence circuit 8 (Fig. 1), consisting of two transistors type P16A and P401 connected in parallel. Transistor T13
is shunted by transistor T12 in the absence of a low-frequency pulse. Transistor T13 becomes operative when a pulse
is received which blocks transistor T12 for the duration of the pulse. The high-frequency pulses are then amplified
and fed to the counter.

At the output of amplifier 7 (transistor T14) pulses whose duration is proportional to the phase shift are produced
and fed to transformer amplifier 9 (transistor T1) of tracking system 10. The secondary winding of T14 is connected
to a rectifier (D6, C5, R6). The voltage across capacitor C5 is proportional to the pulse duration, since the supply
voltage 7 is stabilized by diodes D7-D10. This voltage is compared to that across resistor R6 which forms part of the
measured voltage. If the conversion is linear, the two voltages are equal and there is no current through winding W2.
In case of a nonlinear conversion the current flows through winding W2, thus correcting the phase shift and providing
the required precision of transformation.

The circuit of the above converter was assembled and tested experimentally. It was adjusted for measuring
voltages between 5 and 50 V. The referred conversion error does not exceed 0.1%. The maximum phase shift is 40°.
The converter operates normally in a temperature range of 10-40°C, since resistors R6, R6, and R6 as well as windings