DUAL-READOUT 23-BIT DIGITAL ANGLE
TRANSDUCER WITH A PRECISE-READING
MULTIPOLE INDUCTANCE PICKUP

V. M. Domrachev, G. F. Monchak, I. P. Sigachev,
and A. P. Sinitsyn

This article examines the design of a dual-readout 23-bit digital angle transducer (DAT) with two-phase
inductance pickups providing coarse and fine angle readings. The transducer is described mathematically and
the results of tests of several prototype 22- and 23-bit DATs with different precise-reading angle sensors are
reported.

Digital angle transducers (DATs) with dual-readout photoelectric sensors are widely used as the measuring element
in precision digital angle-based guidance systems. The coarse readout is obtained from a system that directly codes the angular
position, while the fine readout is produced by a scanning interpolation system. Digital angle transducers of this type are also
used for metrological purposes as standard angle-measuring instruments.

Digital angle transducers used in metrology usually operate under normal climatic conditions. Adjustments are made
to maintain their accuracy characteristics when they degrade over time or as a result of some adverse factors. These transducers
have many uses, and the high cost of DATs with photoelectric sensors (about $10,000 in U.S. currency) is not a significant
limiting factor.

The use of DATs in different digital control systems means that they must meet additional requirements: maintenance
of high metrological characteristics at high and low working temperatures and high humidity, with long periods between routine
maintenance, etc. In certain cases, the requisite accuracy must be maintained after the transducer has been subjected to potential
destabilizing factors (mechanical perturbations), with a long period of subsequent continuous operation in unattended structures.
Cost indices must also be taken into account when the transducer is used in control systems.

It is known that dual-readout DATs with two-pole and multipole angle-sensing inductance pickups and an electronic
conversion element based on servo-type amplitude conversion are quite stable versus the negative factors indicated above.
However, the relatively low conversion accuracy (on the order of $10^{11}$) and resolution (18-19 bits) narrows their range of use,
despite the low cost ($3000). These characteristics are the result of the following factors:

- the limited coefficient of electrical reduction of the precise-reading angle sensor (PRAS) — level 64 or 128 for
sensor dimensions within the practicable range;
- the quasi-sinusoidal dependence of the amplitude of the output signals of the PRAS on the angle — $U(\alpha)$; the
variation of this dependence with the transition from one electrical period of the PRAS to the next (periodicity error), as well
as from one specimen to the next (reproduction error) due to processing errors;
- the limited accuracy and resolution of serial DATs made in this country and used to the present to make the required
analog — digital conversion of the two-phase output signals of the PRAS to binary code;
- the presence of an "integral" (over time) voltage component in the output signals of the PRAS. In both the static
state and in the working rate interval (where accuracy and resolution are high), this component becomes comparable to or even
several times larger than the main (working) component. This adversely affects the high metrological characteristics that could
be achieved in PRASs of the given type.

Translated from Izmeritel'naya Tekhnika, No. 12, pp. 18-21, December, 1995.
Proceeding on the basis of 30 years of R&D work and results obtained from the use of amplitude-controlled DATs with angle-sensing multipole inductance pickups in dozens of different types of digital control systems, a group of researchers at the Central Scientific Research Institute of Automation and Hydraulics (in Moscow) has designed a 23-bit amplitude-controlled inductance-based DAT with performance characteristics comparable or superior to those of optical DATs and better cost indices.

The biggest step in the development of the new DAT was the design of a precise-reading 64-period two-phase inductance pickup with a reduced periodicity error. The solution to the problem of conversion based on the coarse readings of a dual-readout DAT with the above-indicated PRAS electrical reduction is widely known and need not be discussed here.

The precise-reading angle transducer was designed not only so as to minimize the periodicity error, but also with allowance for its suitability for industrial production without the use of special lathes. On the one hand, this approach ensured an acceptable periodicity error with a relatively low PRAS cost. On the other hand, it also had undesirable consequences — such as making $U(\alpha)$ quasi-sinusoidal. The latter is manifest mainly in the presence of odd harmonics higher than the first (third, fifth, seventh, and ninth) in the spectral composition of $U(\alpha)$. Although the higher harmonics are present, their effect on the accuracy of the conversion is insignificant due to their low amplitude.

Besides the presence of quasi-sinusoidality, the nature of the latter may change for different PRAS models due to the manufacturing tolerance of the linear dimensions of the tooth region of the PRAS rotor and stator, along with the scatter of the linear dimensions of sections of the measurement windings and field windings and the certain freedom of motion that these sections have relative to the stator and rotor teeth.

Despite these factors and the negative PRAS features discussed earlier, preference was given to this type of transducer on the basis of the following considerations. In the final analysis, the error of the DAT can be divided into two components: the low-frequency error, with a period corresponding to one complete rotation of the PRAS rotor; the high-frequency error, with a period equal to the angular length of one electrical period — $5°37'30"$ (with an electrical reduction coefficient of 64). The value of the high-frequency component depends appreciably on the quasi-sinusoidality. The decrease or disappearance of either of these components leads to an increase in conversion accuracy. A preliminary analysis indicated that it might be possible to design the system so as to eliminate or significantly weaken the correlation between the quasi-sinusoidality of the PRAS and the final conversion accuracy of the DAT. It was on this basis that we devised a strategy for building precision DATs: design a PRAS that has a small periodicity error and a tolerable degree of quasi-sinusoidality and is suited for industrial