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A new tracking technique for mechanical angle measurement

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ABSTRACT

Resolvers and other types of sine/cosine encoders are used for measurement of mechanical angles. These devices produce quadrature signals in the form of sine and cosine of the unknown angle, and require converters to extract the angle from their signals. This paper describes a new converter based on an angle-tracking technique that employs synchronized reference and oscillatory signals. The tracking is based on quadrature PLL without using VCO, DAC, counter and look-up tables (LUT). The proposed method makes use of reference oscillatory signals to estimate the sine/cosine of the mechanical angle. The present method is simpler than the available techniques, and may be implemented easily using digital or basic analogue electronic circuitry. Beside its simplicity of implementation and its fast tracking capability, the proposed controller exhibits a good linearity and, when used with resolvers, offers the advantage of robustness to amplitude fluctuation of the transducer excitation signal. The proposed technique results were compared to a high resolution pulse encoder. This paper describes the proposed method, its simulation and experimental results.

1. Introduction

Resolvers and other sine/cosine encoders based on Hall effect, optical, and electric principles are used for absolute measurement of mechanical angle. In general any type of these transducers produces outputs of this form:

$$\begin{cases} V_S(\theta) = V_m \sin(\theta) \\ V_C(\theta) = V_m \cos(\theta) \end{cases} \quad (1)$$

where θ and V_m are the mechanical angle to be measured and maximum amplitude of transducer output signals. For simplicity reasons, the amplitudes of the signals in (1) are assumed to be normalized in the rest of paper. For proper operation of resolver, an excitation signal and a demodulator are needed to get the above outputs (see Fig. 1) [1–3]. All sine/cosine transducers require suitable converters in order to determine the angle from their output signals.

Various dedicated open-loop and closed-loop converter schemes, with different degrees of complexity and precision, have been reported in the literature [2–25] for the measurement of θ by appropriate processing of the output signals of the transducer. Most of these schemes require the use of a processor or a Look-Up Table (LUT) technique in order to compute the mechanical angle because of the inherently non-linear trigonometric transducer signals. Some techniques based upon the tangent/cotangent of the shaft angle have been used [7–13]. In these schemes the absolute values of (1) are determined; by appropriate processing the smaller of the two values is divided by the greater, providing either the tangent or cotangent of the unknown angle. Because of the periodic nature of the tangent/cotangent, the full scale of 360° is represented by four identical cycles, each made up of a positive and a negative slope sections. For this reason three octants are computed in order to identify the interval to which θ belongs. The

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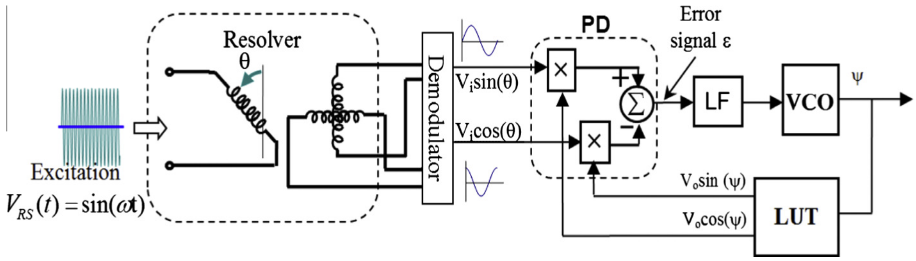

Fig. 1. Simplified diagram of the basic concept of two-phase PLL applied for resolver.

value of θ is then either computed numerically or determined from a look-up-table. The method can also be implemented using DSP and A/D converters [13,14]. The interpolation method proposed in [14] is based on the use of two-dimensional LUT. Various other schemes based on LUT have also been reported [15].

An open-loop approach, based upon the linearization of the difference between the absolute values of (1) was proposed [21]. Other schemes based on the use of the amplitudes of the pseudo-linear segments of the transducer signals have also been reported [22,23]. Other open loop approaches that are not based on the use of LUT and linearization techniques are presented in [24,25]. Many other software based converters have also been proposed [26–30].

Commercially available closed-loop converters employ the phase-locked loop (PLL) technique [16–18]. The conventional quadrature PLL systems used for resolver is shown in Fig. 1. A practical implementation of this converter is shown in Fig. 2(a) and consists of a Phase Detector (PD), a Loop Filter (LF), a Voltage Controlled Oscillator (VCO) and a LUT. These conventional converters require the computation of the sine and cosine of the estimated angle (i.e., output of the converter), usually using LUT. References [19,20] propose PLL methods that employ observer techniques. In [19], the PLL-based converter has been restructured into an observer like system in a closed loop servosystem to improve the transient by reducing phase lag in the feedback loop of the servo. The method proposed in [20] uses a hybrid observer design suitable for high-speed applications such as in brake-by-wire callipers. This hybrid angle-tracking observer guarantees stability of the closed loop estimator. Fig. 2(a) shows an implementation of the conventional PLL of Fig. 1. The PD outputs the error ε, which is input to the LF, to perform the tracking and filtering tasks of the PLL. In other words, the LF output signal forces the VCO to change its output in a direction that reduces the difference between the input and the output signals of the PLL. As shown in Fig. 2(a), an Up-Down counter, a LUT and DACs are used to close the loop of the conventional PLL. Assuming normalized input & output signals The PD operates as a multiplier and outputs the following error:

$$\varepsilon = \sin(\theta - \Psi) \tag{2}$$

Although the conventional PLL technique is capable of very high performance both at transient and at steady state, there are a number of aspects that can be improved.

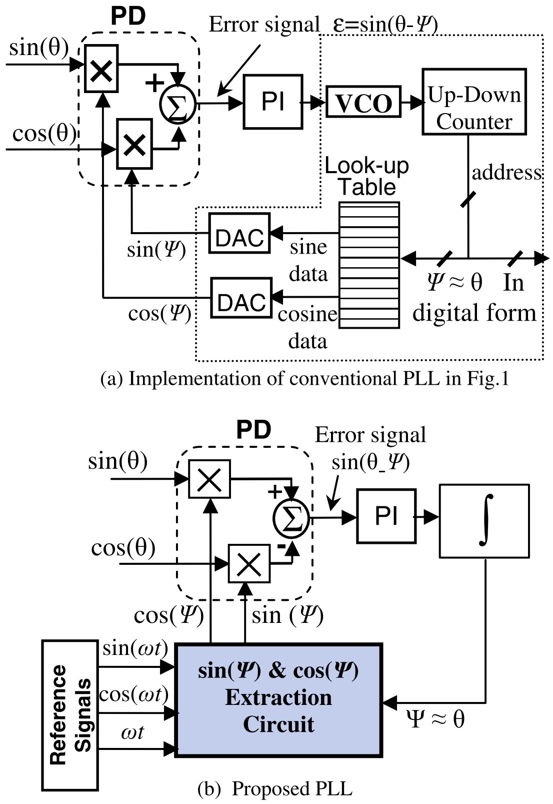

Fig. 2. PLL implementation: (a) conventional PLL and (b) proposed PLL.

The major difficulty with the conventional PLL is its complex implementation which requires mixed analog and digital circuitry. Furthermore, the required voltage-controlled oscillator (VCO) and its associated components have a maximum operating frequency which, when combined with the resolution of the converter, defines a maximum resolver angular speed in which the converter can ensure that the estimated angle tracks the true mechanical angle (θ). In addition, VCOs operate linearly only over a limited range [2].

The objective of the present work is to simplify the PLL implementation by eliminating a number of components used in the conventional PLL converters. The proposed converter operates without using VCO, DAC, Counter and LUT. The method is based on an extraction circuit that employs reference AC signals to determine the sine/cosine of the estimated angle [30–33].