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Software based RDC Using Pulse Excitation

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Abstract: Resolvers are angular position transducers used to measure the absolute angle. These are mounted on the motor shaft to measure the shaft's absolute angular position. This paper discusses the design of software based Resolver to Digital Converter (RDC) using pulse excitation and is implemented in MATLAB® SIMULINK®. In the proposed simulation model, inverse tangent algorithm is proposed to measure the motor shaft angle. The resolver rotor is excited with a pulse signal and the resolver two output signals are proportional to sine and cosine of the motor shaft angle. These modulated output signals are sampled by two Analog to Digital Converters (ADCs), with a sampling frequency equal to that of excitation frequency. The angle is measured by applying inverse tangent algorithm to the samples values of sine and cosine signals. The proposed software based RDC model is successfully implemented and the performance of the model is validated through various rotor speeds.

Keywords: Resolver, Resolver to Digital Converter, Inverse tangent, Pulse excitation, lookup table, CORDIC.

I. INTRODUCTION

Measurement of rotor shaft angle is one of the important requirements in many instrumentation and control system applications. In a noisy environment, resolvers are especially useful to get the motor shaft angle and speed. Resolvers are cost effective angular position sensors. The applications of resolvers include in the fields of robotics, radars, aviation, satellite antennas [1-3]. Resolvers has many advantages like very high noise immunity, high accuracy, immunity to extreme mechanical and temperature wear and very long distance transmission of output data before being converted to a digital format etc. [4-5].

Resolvers are mounted on the motor shaft to get the absolute angular position. Construction of resolver consists of a rotor coil as input and two stator coils which are orthogonal to each other serves as output. The reference signal which is coupled to rotor winding provides primary excitation. The output signals are amplitude modulated signal and are proportional to sine and cosine of the shaft angle. There are number techniques to implement RDCs. C. Attaianese and G. Tomasso presented a low cost RDC with ADC, DAC and Read Only Memory (ROM) [6]. A software-based RDC using a Digital Signal Processor (DSP) and a Field Programmable Gate Array (FPGA) based RDC are proposed in [1], [7-9]. In above all studies sinusoidal signal is used as primary excitation to the resolver rotor. When sinusoidal signal is used as primary excitation, the signal is generated from a high frequency Pulse Width Modulation (PWM) at 288 kHz. In all the studies, the issue of primary excitation signal of resolver is rarely discussed. This paper proposes software based RDC using signals other than sinusoidal signal.

This paper is organized into six sections. Section 2 describes the operation principle of resolver. The proposed design of software based RDC using pulse excitation in MATLAB® SIMULINK® provided in section 3. The simulation, results and discussions are presented in section 4 and section 5 respectively. Finally, conclusions are drawn in section 6.

II. PRINCIPLE OF RESOLVER

Resolvers are absolute angle transducers and are mounted on the motor shaft to get the motor's absolute angular position. Resolvers are used for angle sensing in noisy environment, due to their rugged construction and their ability to reject common mode noise. The majority of resolvers used are referred as hollow shaft resolvers. They transfer energy from stator to rotor by means of an auxiliary rotary transformer. The resolver rotor is directly mounted on the motor shaft and the resolver stator is fixed to the motor shield.

The resolver is basically a rotary transformer with one rotating reference winding and two stator windings. The reference winding is fixed on the rotor and it rotates jointly with the shaft passing the output windings. The constructional view of resolver with input and output signals is shown in Fig 1. Two stator windings are displaced by 90^0 and generate the sine and cosine voltages. The sine winding is phase advanced by 90° with respect to cosine winding.

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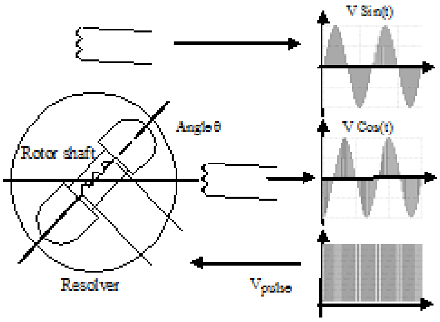

Fig.1 Constructional view of resolver with input and output signals

The reference signal is fixed in frequency represented as

$$Vpulse(t) = \sum_{n=-\infty}^{n=\infty} V\left\{u\left(t+\frac{dT}{2}+nT\right)-u\left(t-\frac{dT}{2}+nT\right)\right\}$$
(1)

Where V is the amplitude of pulse signal and $u(t)$ is an unit step function. The period of the pulse signal is T with a duty cycle d. The pulse signal *Vpulse* is utilized as a reference signal and is coupled to resolver's rotor winding. This pulse signal is utilized as primary excitation. The resolver stator output signals are proportional to sine and cosine of the rotor shaft angle θ. The mathematical expression of the two stator output signals are given in (2) and (3).

$$Vsin(t) = m \cdot sin\theta \cdot Vpulse(t) \qquad (2)$$
$$Vcos(t) = m \cdot cos\theta \cdot Vpulse(t) \qquad (3)$$

Where m is the transformation ratio of resolver and is generally around 0.5.

III. PROPOSED METHOD

The method of converting the resolver's output analog signals into digital signals and obtaining the angular position is known as RDC. There are number of RDC method available in practice. Two are most widely used methods, namely inverse tangent method and Angle Tracking Observer (ATO) method. The inverse tangent method is simple and can be implemented with lower cost compared to ATO method which is costlier to implement.

A. Inverse tangent method

The shaft angle of the resolver can be determined by calculating the inverse tangent function of the quotient of resolver output signal voltages. The shaft angle of the resolver is determined using (4).

$$\theta = Tan^{-1}\left[\frac{Vsin\,(t)}{Vcos\,(t)}\right] \qquad (4)$$

The inverse tangent calculation can be done using COordinate Rotation Digital Computer (CORDIC) algorithm [10].

B. Arc Tan Lookup Table

Using the proposed inverse tangent method, the arc tan values from 0^0 to 360^0 are to computed and are to be stored in memory. The time taken for searching the values near 0^0 and 360^0 is different i.e. in a sequential search, values near 0^o will take less time and values near 360^o will take more time to search. Hence, the execution time and memory space can be reduced with the help of lookup table while implementing the design using the hardware. This method also maintains the same execution time for all values. The arc tan lookup table for eight quadrants is given in Table I.

Table I: Arc tan lookup Table

$0^\circ \leq \theta < 45^\circ$	$0 \leq Vsin\theta$	$0 < Vcos\theta$	$\theta = tan^{-1}\lvert Vsin\theta/Vcos\theta\rvert$
$45^\circ \leq \theta < 90^\circ$	$0 < Vsin\theta$	$0 < Vcos\theta$	$\theta = \pi/2 - tan^{-1}\lvert Vcos\theta/Vsin\theta\rvert$
$90^\circ \leq \theta < 135^\circ$	$0 < Vsin\theta$	$Vcos\theta \leq 0$	$\theta = \pi/2 + tan^{-1}\lvert Vcos\theta/Vsin\theta\rvert$
$135^\circ \leq \theta < 180^\circ$	$0 < Vsin\theta$	$Vcos\theta < 0$	$\theta = \pi - tan^{-1}\lvert Vsin\theta/Vcos\theta\rvert$
$180^\circ \leq \theta < 225^\circ$	$Vsin\theta \leq 0$	$Vcos\theta < 0$	$\theta = \pi + tan^{-1}\lvert Vsin\theta/Vcos\theta\rvert$
$225^\circ \leq \theta < 270^\circ$	$Vsin\theta < 0$	$Vcos\theta < 0$	$\theta = 3\pi/2 - tan^{-1}\lvert Vcos\theta/Vsin\theta\rvert$
$270^\circ \leq \theta < 315^\circ$	$Vsin\theta < 0$	$0 \leq Vcos\theta$	$\theta = 3\pi/2 + tan^{-1}\lvert Vcos\theta/Vsin\theta\rvert$
$315^\circ \leq \theta < 360^\circ$	$Vsin\theta < 0$	$0 < Vcos\theta$	$\theta = 2\pi - tan^{-1}\lvert Vsin\theta/Vcos\theta\rvert$

The block diagram of the proposed RDC model is shown in Fig.2. The rotor shaft of the motor is coupled to the resolver rotor shaft and the resolver provides the two amplitude modulated signal $Vsin\theta$ and $Vcos\theta$ when it is excited with a pulse signal. The amplitude of these two modulated signals are proportional to the angular position of the motor shaft. The resolver output signals are sampled with a sampling frequency equal to the frequency of excitation signal. The angle is measured from the ratio of the sampled $Vsin\theta$ and $Vcos\theta$ using the lookup table.

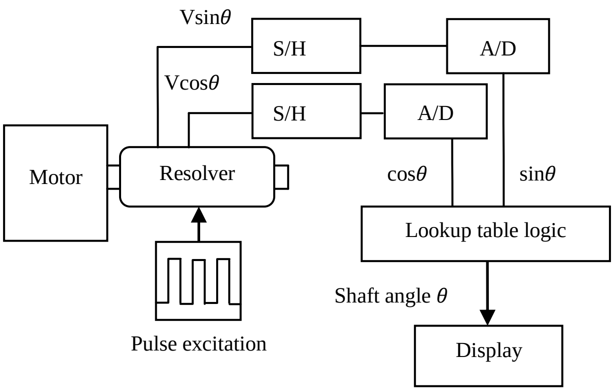

Fig.2 Block diagram of Proposed RDC

IV. SIMULATION

The proposed inverse tangent method based software RDC using pulse excitation is implemented in MATLAB® Simulink® and is shown in Fig. 3. The Simulink® model implemented is ideal representation of the theory and no limitations are included. A pulse signal of period 100µs and a pulse width of 20µs is used as primary excitation of the resolver. The performance of the resolver is verified for various speeds of the resolver from 100 rpm to 4000 rpm. The angle position error between the measured angle value and the actual angle value is also calculated. An algorithm is developed for the lookup table in MATLAB® to extract the angle from the samples values. This lookup table utilizes the symmetry of tangent and cotangent angles and provides the angle information with values only from 0^0 to 45^0.

V. RESULTS

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The proposed software based RDC using pulse excitation and its inverse tangent algorithm are validated through different tests with various speeds of resolver. The pulse signal of 1V amplitude with a frequency of 10 kHz is given as excitation to the resolver and is same for all the resolver speeds. In Fig. 4, resolver excitation signal and output modulated signals for a rotor speed of 600 rpm are shown. The sampled sine and cosine envelops of the resolver output signals are shown in Fig 5. Fig 6 shows the sampled envelops and the measured rotor angles. The error between the actual rotor angle and the measured angle is shown in Fig 7.

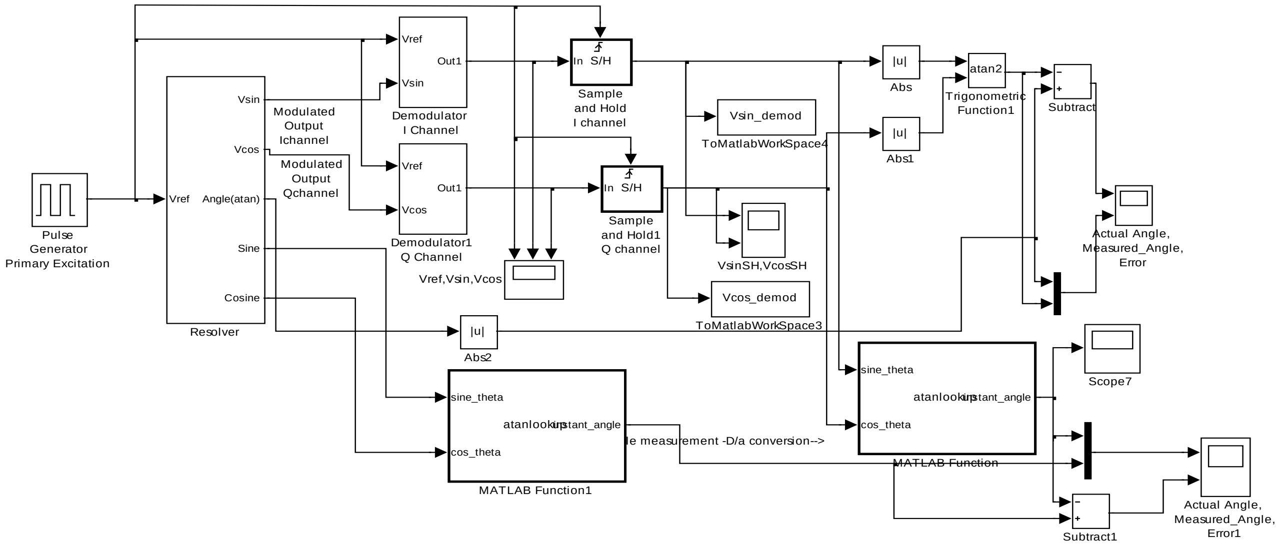

Fig.3 MATLAB® Simulink® model of RDC using inverse tangent method

The resolver pulse excitation and modulated output signals; the modulated output signals and sampled envelopes; the measured angle and angular error for a rotor speed of 3000 rpm are shown in Fig. 8, Fig. 9 and Fig. 10 respectively. The angular position error is measured for various speeds and the results are shown in Table II. Fig. 11 shows the graph between the measured rotor angle and the actual rotor rpm. From the graph, it is observed that the error between the actual and measured shaft angle is linear. Using the proposed algorithm, the error is negligible at low speeds and it increases as the rotor speed increases.

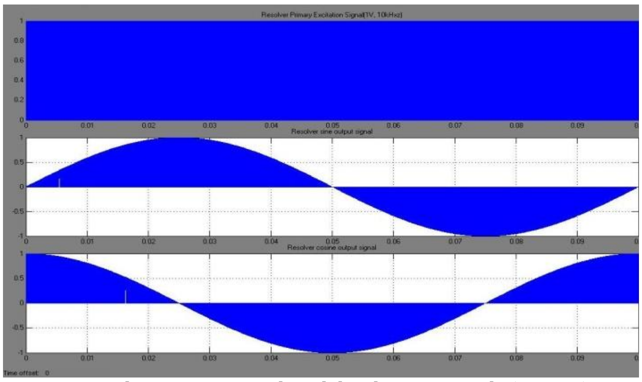

Fig.4 Resolver excitation and modulated output signals (600rpm)

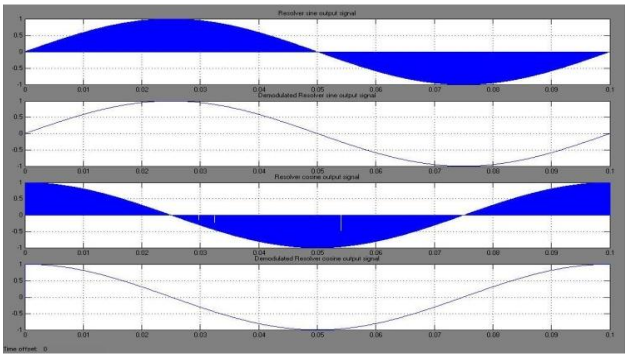

Fig.5 Modulated resolver output signals and sampled envelopes (600rpm)

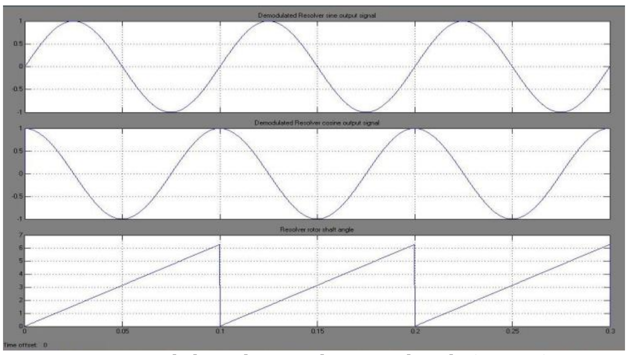

Fig.6 Sampled envelops and measured angle (600rpm)

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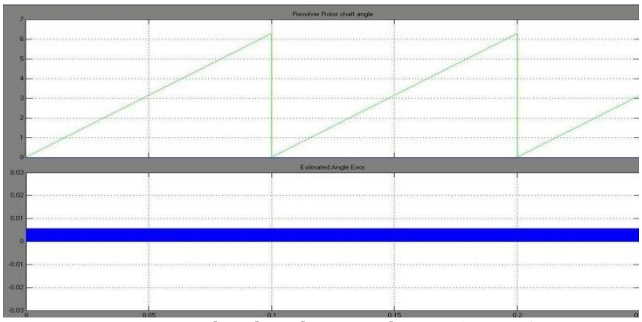

Fig.7 Measured angle and rotor angle error (600rpm)

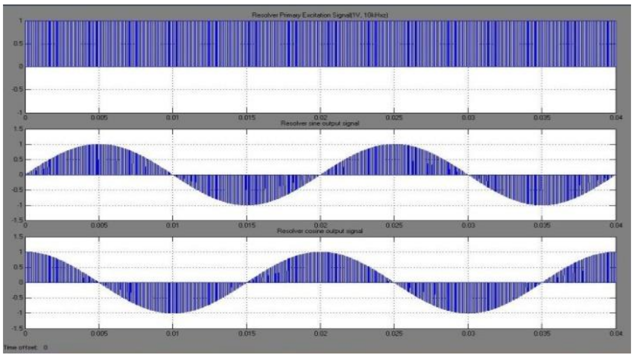

Fig.8 Resolver excitation and modulated output signals (3000rpm)

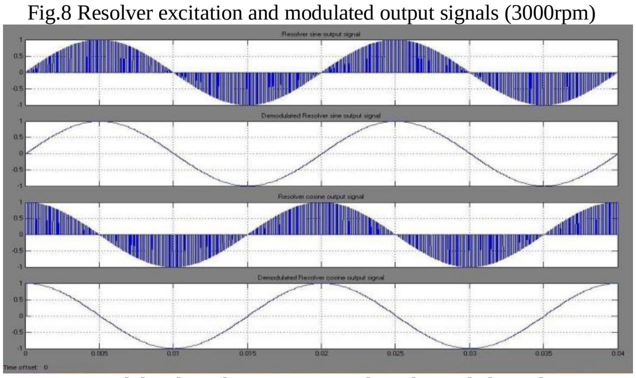

Fig.9 Modulated resolver output signals and sampled envelopes (3000rpm)

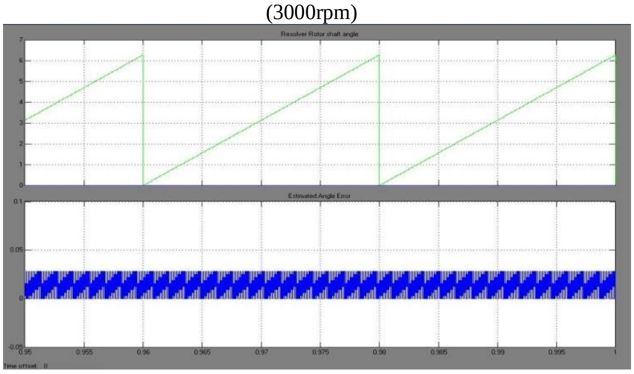

Fig.10 Measured angle and rotor angle error (3000rpm)

Table II. Measured error for various rotor speeds

Rotor Speed (rpm)	Estimated error (degrees)
150	0.0014
250	0.0024
300	0.0028
600	0.0057
900	0.0085
1200	0.0113
1500	0.0141
2400	0.0226
3000	0.0283
3600	0.0339

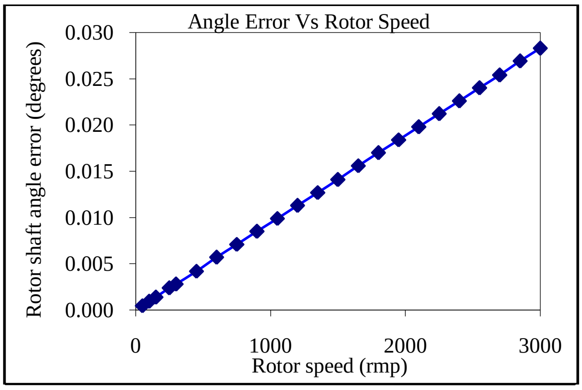

Fig.11 Resolver excitation and output signals (3000rpm)

VI. CONCLUSIONS

This paper describes the software based RDC using pulse excitation and is successfully implemented in MATLAB® Simulink®. The performance of the proposed model is verified through various speeds and the rotor angle error is also measured for various rotor speeds. This method reduces the cost and complexity of the hardware as excitation source is implemented using the software. The proposed look up table utilises less amount of memory and is used to provide the angle for complete 360^0. This RDC is simpler, low cost and accurate.

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BIOGRAPHY

G. Dorababu received the B.Tech degree in Electronics and Communications Engineering from J.N.T. University Hyderabad, India, in 2007. He is currently pursuing M.Tech in Digital Electronics and Communication Systems at JNTUA College of Engineering, Pulivendula, India. His area of interests includes embedded systems, and signal processing. He is the recipient of the GATE Scholarship.

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