INVERSE TANGENT BASED RESOLVER TO DIGITAL CONVERTER - A SOFTWARE APPROACH

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ABSTRACT

The low cost, reliable and accurate measurement of rotor shaft angle is an important challenge for numerous industries. This paper proposed the design of a software based resolver to digital converter using an inverse tangent method, to extract the rotor angle of the resolver. The demodulated resolver quadrature si gnals are sampled at the zero crossing of the excitation signal. The sampled quadrature signals are used to measure the rotor angle of the resolver. The proposed software model eliminates the hardware cost of excitation source and the results are validated through the development of model blocks in MATLAB® Simulink. The proposed model is a low cost, simpler and linear.

KEYWORDS: *Resolver, Resolver to Digital converter, Inverse Tangent method, Synchronous demodulator*

I. INTRODUCTION

Conversion of angular displacement to electrical output requires AC transducers like synchros, resolvers and linear/rotary variable differential transformers. Machine tool and robotics manufacturers use resolvers and synchros to provide accurate angular and rotational information. These devices excel in demanding factory and aviation applications requiring small size, long term reliability, absolute position measurement, high accuracy, and low noise operation. The measurement of the initial rotor position at standstill has to be achieved to gain the maximum starting torque. Synchros and resolver are the sensors that satisfy this condition. Synchros have three stator coils in a 120^0 orientation, they are difficult than resolvers to manufacture and are costly. Today, synchros find decreasing use, except in certain military and avionic retrofit applications.

The resolver quadrature signals have to demodulated and filtered to extract the angular position of the rotor [1–3]. The accuracy achieved in speed and/or position measurement by the resolvers depends on the quality of the analog signals and on the resolution of the digital converters used to interface resolvers to the control units. This conversion is made by the Resolver to Digital Converter (RDC). RDC is an Integrated Circuit (IC) that can be easily mounted on the motion control board and is used to demodulate the two resolver output signals. The RDC IC was designed to calculate the error between actual angle and computed angle. This angle error is controlled to zero, resulting in the computed angle converge to the actual one [4–6]. The main drawback of RDC IC is its cost which is same price as that of the resolver [7]. However, the price of the specific IC module is high, and the weight and power dissipation are large, therefore increasing the cost of the whole system which limits the usage of its application.

In order to avoid the use of these RDC ICs, more and more attention has been focussed on the design of software based RDCs and ways to improve the measurement accuracy [8-17]. Making instrument intelligent is a trend in the new control system which means more hardware is substituted by software.

In this paper, the design of software based RDC using an inverse tangent method is proposed. This paper is organized into five sections. Section II describes the principle of operation of a resolver. The mathematical model of inverse tangent method and design of the proposed RDC in MATLAB® Simulink is explained in section III. Section IV gives the simulation results and discussions. Finally conclusions are drawn in section V.

II. PRINCIPLE OF A RESOLVER

The resolvers are basically rotating transformers. The resolver consists of one reference winding and two output windings. The transformation ratio from the reference winding to the two output windings varies with the position of the resolver rotor. The reference winding is fixed on the stator and is magnetically coupled to both stator output windings through the windings located on the rotating shaft. The placement of the reference and output windings with respect to the shaft of a resolver is shown in figure 1.

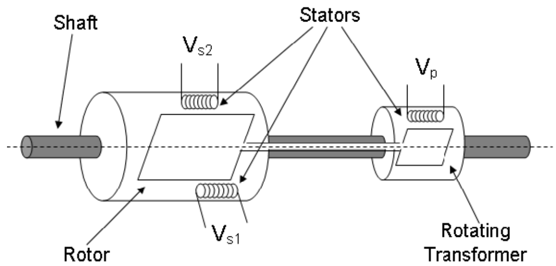

Figure 1. Internal view of a resolver

The two output windings are placed in quadrature on the stator to generate two 900 out of phase AC signals [18]. An equivalent cross sectional view of the resolver with angular position of the rotor, θ, with respect to the windings and the associated signals are shown in figure 2 and figure 3 respectively.

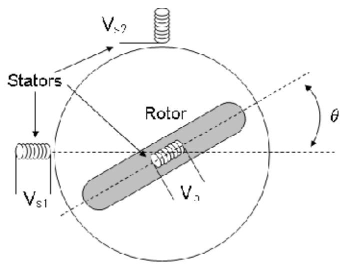

Figure 2. Equivalent cross sectional view

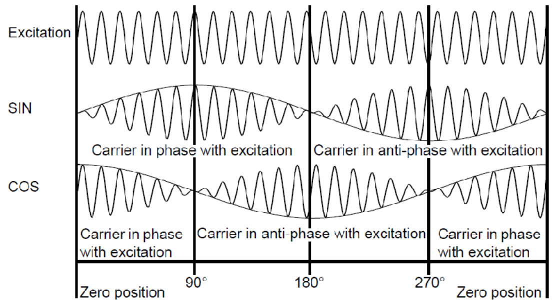

Figure 3. Resolver excitation and output signals

III. INVERSE TANGENT METHOD

The block diagram of the proposed RDC scheme using inverse tangent algorithm is shown in figure 4. In general, the resolver is excited by either sinusoidal or square wave signal with a fixed frequency. If sinusoidal signal is used as excitation signal, it is difficult to detect the adequate sampling moments of the output signals of the resolver because of the phase shift between the input and output signals. If the resolver is excited by a square wave signal then the output signals will be flat extremes that allow having an interval of time for sampling the output. For this reason, the square wave signal is preferred as excitation signal to excite the resolver and also the generation of square wave signal is easier than generating a sinusoidal signal for a processor. So, in the proposed design the resolver is excited by the square wave signal.

3.1. Mathematical Model

In the proposed design, the resolver is excited with a square wave signal, V_{REF} of peak to peak amplitude 1V with variable frequency of 1Hz–10kHz. The mathematical expression for the excitation signal is given as

$$V_{REF} = Sin(2\pi f_e t) \tag{1}$$

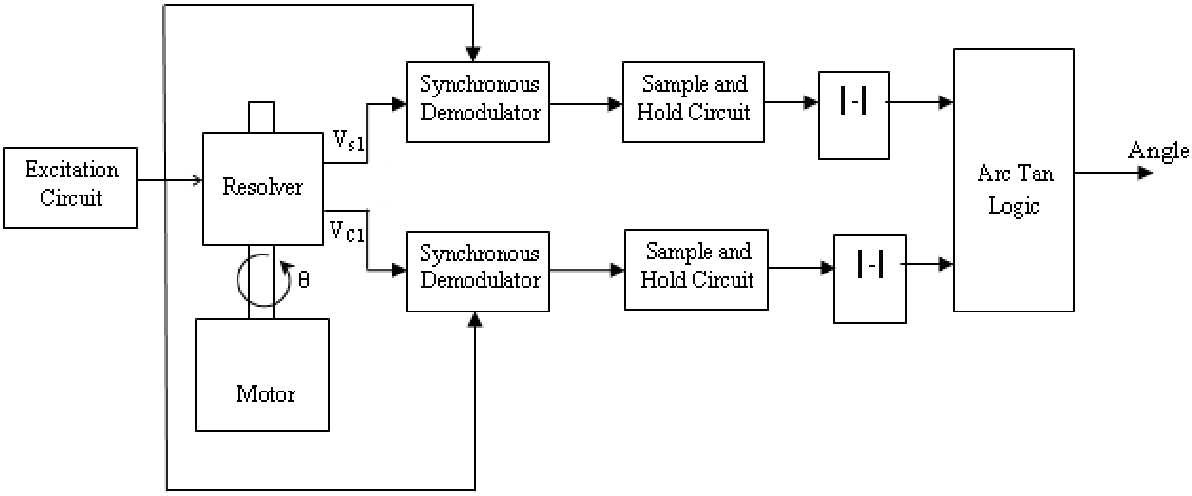

Figure 4. Block diagram of proposed RDC using inverse tangent method

The reference signal, V_{REF} modulates the sin and cosine functions of rotor shaft angles and produces two amplitude modulated signals, V_{S1} and V_{C1}, as outputs. Generally, the excitation angular frequency (f_e) of the rotor excitation is higher than the rotation frequency (f_m). So the modulated output signals of the resolver are given as

$$V_{S1} = \alpha\, Sin(2\pi f_e t) \cdot Sin(\theta) \tag{2}$$

$$V_{C1} = \alpha\, Sin(2\pi f_e t) \cdot Cos(\theta) \tag{3}$$

Where α is the resolver transformation constant and is assumed as one. The value of $\theta = 2\pi f_m t$. The rotation frequency, (f_m) is calculated depending upon the speed of the motor attached to the resolver and is also known as revolution of the resolver in one second.
The output signals of the resolver are Double Side Band Suppressed Carrier (DSB-SC) signals. The synchronous demodulator is the mostly used DSB-SC demodulation method. In synchronous demodulation method, the same excitation signal is used to remove the excitation signal presented in the outputs of the resolver. The block diagram of synchronous demodulator is shown in figure 5.

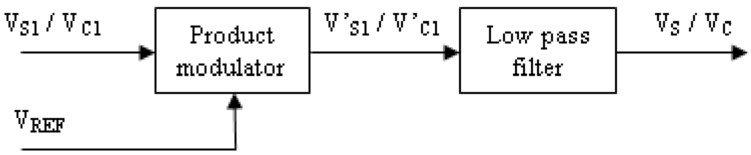

Figure 5. Synchronous demodulator

The inputs to the product modulator are V_{S1}/V_{C1} and V_{REF} and it gives the product of the two inputs as output. The mathematical representation of the output of the product modulator for $\alpha = 1$ and V_{S1} is given as

$$\begin{aligned} V'_{S1} &= V_{S1} \cdot V_{REF} \\ &= Sin(2\pi f_e t) \cdot Sin(\theta) \cdot Sin(2\pi f_e t) \\ &= \left\{ \frac{1}{2} + \frac{1}{2} Cos(4\pi f_e t) \right\} \cdot Sin(\theta) \end{aligned} \tag{4}$$

Similarly, if V_{C1} as one of the input, then the output is represented as

$$\begin{aligned} V'_{C1} &= V_{C1} \cdot V_{REF} \\ &= Sin(2\pi f_e t) \cdot Cos(\theta) \cdot Sin(2\pi f_e t) \\ &= \left\{ \frac{1}{2} + \frac{1}{2} Cos(4\pi f_e t) \right\} \cdot Cos(\theta) \end{aligned} \tag{5}$$

The product modulator outputs as in equations (4) and (5) are having a high frequency excitation signal and it has to be removed to measure the rotor angle, θ. In order to remove the high frequency carrier signal, the two product modulated output signals, V'_{S1} and V'_{C1} are passed through a low pass filer with a higher cut-off frequency equal to the rotational frequency, w_m.
The outputs of the two low pass filters are

$$V_S = \frac{1}{2} Sin(\theta) \tag{6}$$

and

$$V_C = \frac{1}{2} Cos(\theta) \tag{7}$$

The low pass filter output signals as in equations (6) and (7) contain only the angular position of the resolver. So, in order to measure the angle for every instant of time, the two signals must be sampled. The instantaneous samples of the signals in equations (6) and (7) are obtained by sampling the signals for every rising edge of the excitation frequency. The block diagram of sample and hold circuit is given in figure 6.

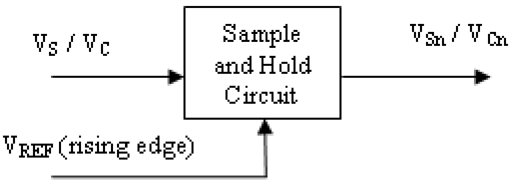

Figure 6. Sample and hold Circuit

The sampled signals of equations (6) and (7) are given as

$$V_{Sn} = \frac{1}{2} Sin(\theta_n) \tag{8}$$

and

$$V_{Cn} = \frac{1}{2} Cos(\theta_n) \tag{9}$$

The sin and cosine envelopes obtained after sample and hold circuit, as in as in equations (8) and (9) are used to compute the rotor angular rotation. The two sampled signals are fed to an absolute circuit in order to get the linearity. The computed rotor shaft angle is given as

$$\theta = \arctan\left[\frac{|V_{Sn}|}{|V_{cn}|}\right] = \arctan\left[\frac{|Sin(\theta_n)|}{|Cos(\theta_n)|}\right] \tag{10}$$

3.2. Modelling

Based on the theory, mathematical representation and information, the arctangent based RDC is implemented in MATLAB® Simulink. The simulation blocks of the RDC are shown in figure 7. This model is only based on theory and is ideal without any limitations. A square wave signal with an amplitude of 1V and a frequency varies between 1kHz to 10kHz is used to excite the resolver. The resolver output can be demodulated by using any of the synchronous demodulation techniques to avoid any delay in the extracted sin-cosine envelopes. This is achieved by simultaneously sampling the two resolver output signals at the zero crossing of the excitation signal. So, the detection of zero crossing of carrier plays an important role in the accuracy of the resolver. Synchronous demodulator is designed with a product modulator followed by a low pass filter. The magnitude and phase responses of the low pass filter are shown in figure 8.

The low pass filter eliminates the high frequency component and passes only rotational frequency of the signals in equations (4) and (5). The output of this low pass filter is sampled with rising edge of the excitation frequency. The instantaneous absolute values of the sampled signals are measured and are given as input to **atan2** block to measure the rotor shaft angle of the resolver.

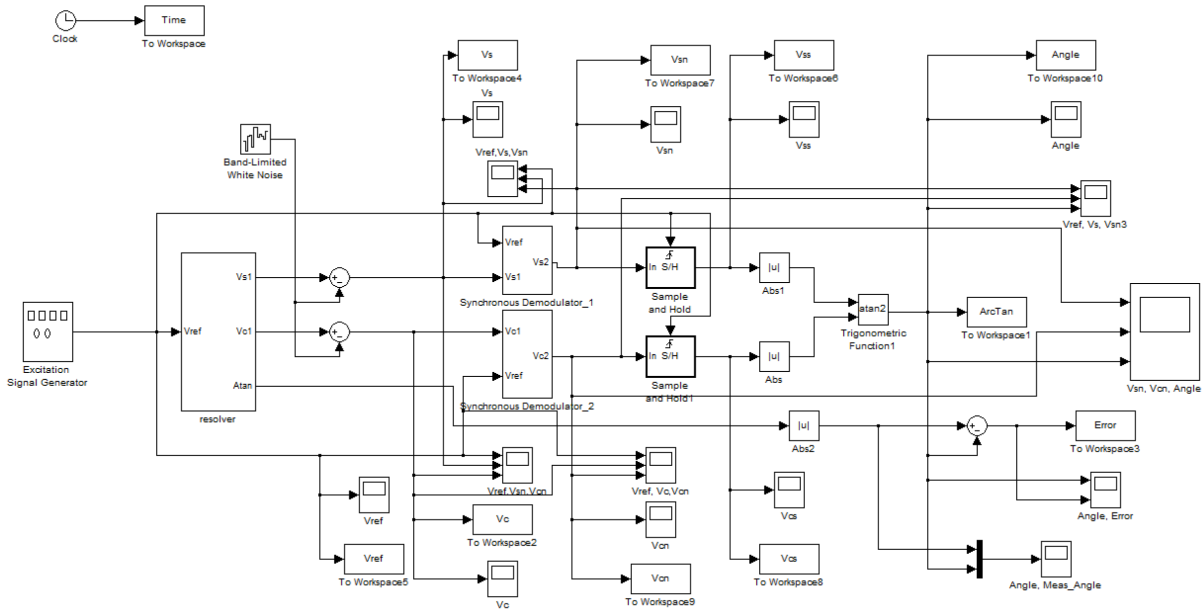

Figure 7. MATLAB® Simulink model of RDC using inverse tangent method

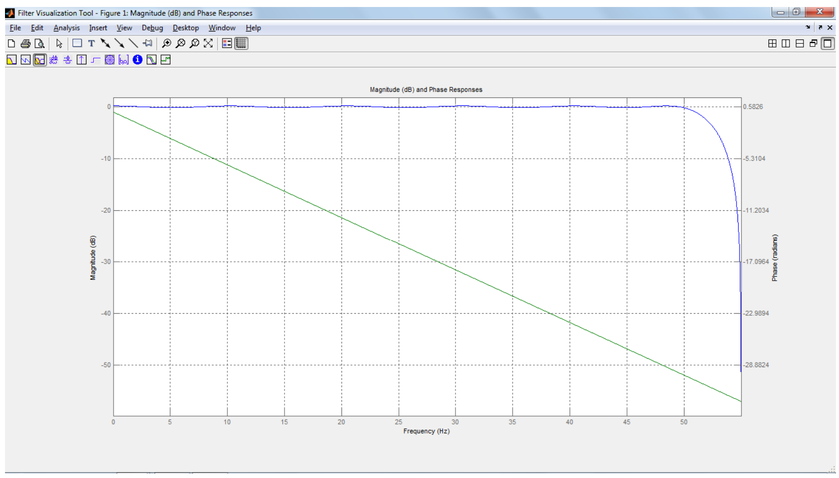

Figure 8. Frequency response of the low pass filter

IV. RESULTS AND DISCUSSIONS

The rotor angle position sensing of the proposed RDC model is developed in MATLAB® Simulink and is validated through several tests with different speeds. The resolver excitation signal with 1volt, 10kHz and the corresponding output signals for a rotor speed of 600rpm are shown in figure 9. The quadrature output signals of the resolver are amplitude modulated. These modulated signals are demodulated using synchronous demodulator and are presented in figure 10.

Figure 11 shows the angular position of the resolver with their quadrature signals. The error between the actual and measured angle of the rotor position is shown in figure 12. From the graph, it is calculated that the maximum rotor angle error of the resolver is 0.0123^0. The resolver excitation signal, resolver output signals; resolver demodulated output signals, estimated angle; estimated angle and angle error; and actual and measured angle graphs are shown in figure 13, 14, 15 and 16 respectively for the rotor speed of 2400rpm. The RDC model was simulated for various speeds and its rotor angle error is presented in Table 1. For speeds less than 600rpm, this method gives a negligible error and as the speed of the rotor is increased the error will increase. The graph between rotor shaft angle error and rotor speed is shown in figure 17.

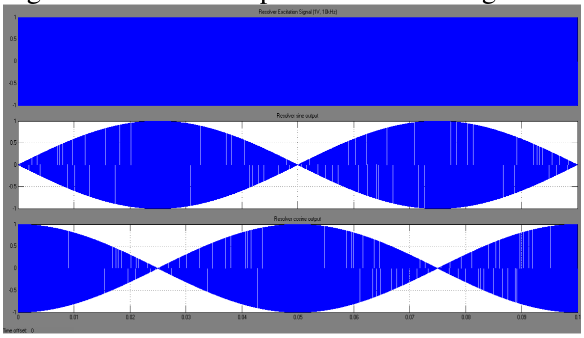

Figure 9. Resolver excitation and output signals (600rpm)

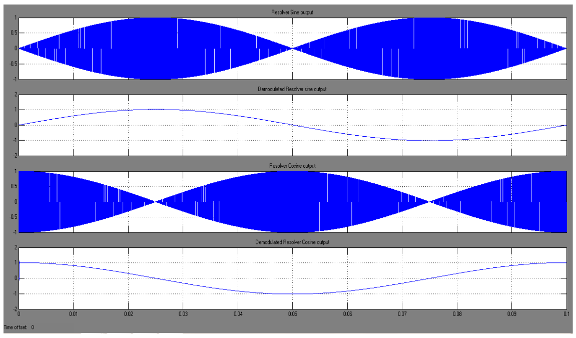

Figure 10. Demodulated resolver output signals

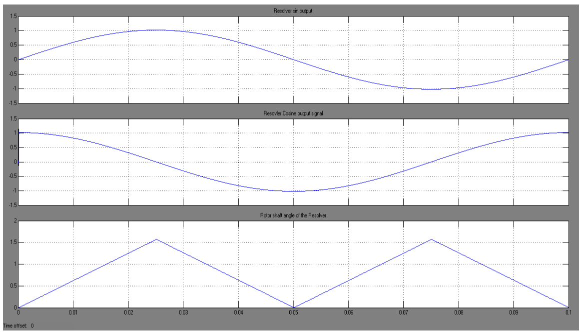

Figure 11. Resolver demodulated output signals and angle

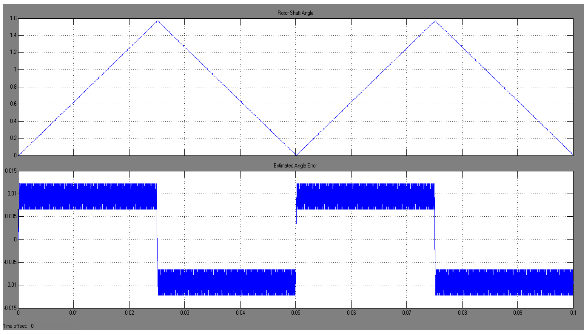

Figure 12. Measured angle and rotor angle error

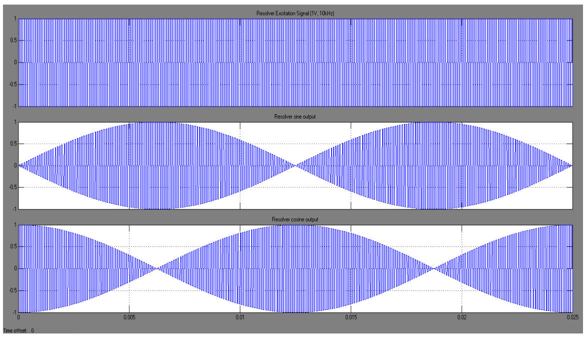

Figure 13. Resolver excitation and output signals (2400rpm)

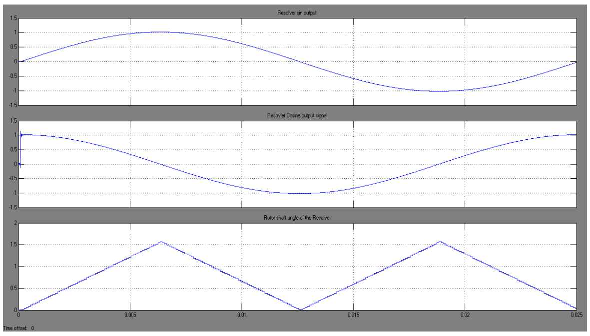

Figure 14. Demodulated resolver output signals

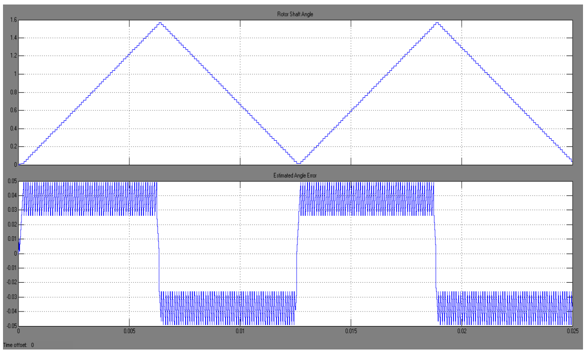

Figure 15. Measured angle and rotor angle error

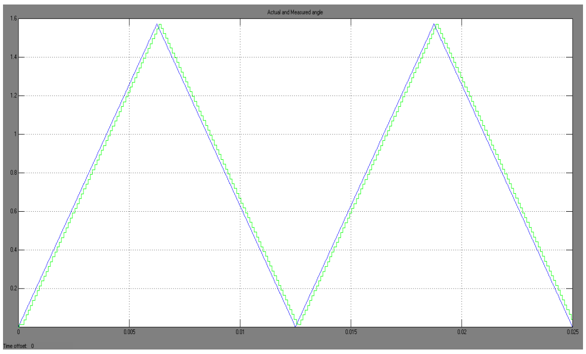

Figure 16. Actual and Measured rotor angles (green color is true angle and blue is estimated angle)

Table 1. Estimated angle error for various speeds

Rotor Speed (rpm)	Estimated error (degrees)
120	0.0025
240	0.0049
300	0.0061
600	0.0123
900	0.0184
1200	0.0245
1500	0.0307
2400	0.0490
3000	0.0613

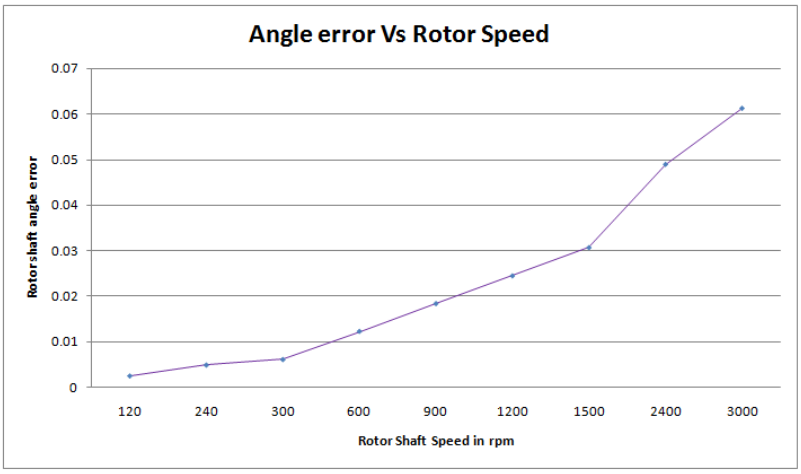

Figure 17. Graph between rotor shaft angle error and rotor speed

V. CONCLUSIONS

Software based RDC using an inverse tangent method is described and successfully simulated in MATLAB® Simulink. High performance was achieved through the mathematical performances and simulation results. The precise rotor angle of the resolver was measured using this proposed simulated RDC model and the measured rotor angle error is 0.0613 even at 3000rpm. Software based synchronous demodulation is proposed to reduce the hardware cost of the excitation source. The proposed RDC system is low cost, relatively simpler and more accurate.

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