INFLUENCE OF THE MOTOR FEEDBACK SENSOR ON AC BRUSHLESS SERVO DRIVE PERFORMANCES

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ABSTRACT

This paper discusses the influence of the position feedback sensor technology in servo drive applications. Incremental encoders, resolvers, and sinusoidal encoders are considered. Different hardware and software techniques used for the processing of position measurement signals are presented. Advantages and drawbacks are discussed for each solution. The choice of the best suited position feedback sensor for a given motion control application mainly depends on the speed and position control requirements and on the motor type. The dynamic performances and the accuracy of speed and position servo loops are dramatically influenced by the position feedback sensor resolution and accuracy. These points are analyzed in detail in the paper. Stiffness, stability, servo loop bandwidth and response time are considered as performances evaluation criteria for a given servo drive equipped with various position sensors. Rotating and linear AC brushless servo motors are considered. Experimental results are given.

1) INTRODUCTION

Due to the development of automation in manufacturing processes, the demands on accurate and fast machine-tools and robots are increasing. In response to these demands, high dynamic AC brushless servo-motors tend to be adopted in motion control systems, and servo drives are expected to deal with a great variety of applications with maximum performances [1]. According to these requirements, high resolution and high accuracy are required for the motor speed and position measurement in order to close the speed and position servo loops with the maximum obtainable bandwidth. Smooth rotation at very low speed is also necessary for the most demanding applications. The particular sensor used depends on the application requirements, however incremental encoders, resolvers and sinusoidal encoders are the most popular.
An AC brushless servo drive consists of a permanent magnet synchronous motor (PMSM) equipped with a position sensor mounted on the motor shaft, as presented on figure 1. The position sensor is used for closing the speed and position servo loops and also for the motor currents commutation in order to control the motor torque. The current amplitude is proportional to the desired torque value and the current phase is tied to the rotor position.

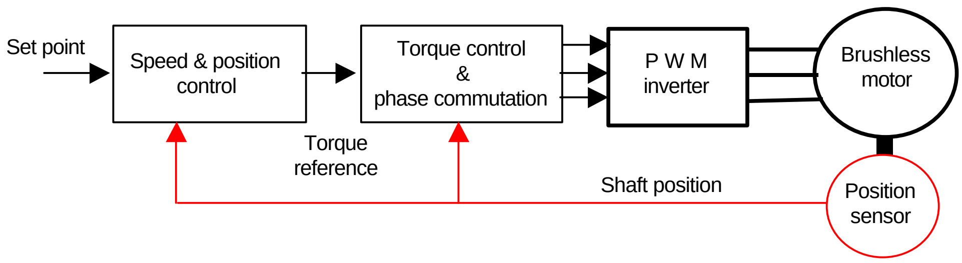


Figure 1 : Block diagram of an AC brushless servo drive

Resolvers are preferred for rotating brushless AC servomotors used in robot applications, because they are very rugged and provide absolute position value suitable for the motor commutation as well as the speed and position feedback for the servo loops. Encoders are mainly used in machine tools applications when a high position accuracy is required for contouring and machining. Encoders are also chosen for direct drive (rotating or linear), because the load is directly mounted on the moving motor part. So, a high number of pulses is necessary in order to get the required position accuracy. However, when incremental encoders are used with brushless AC servomotors, additional

commutation signals or a magnetic alignment procedure are required in order to detect the magnets position at power up.
The following characteristics must be considered in order to evaluate, for a given sensor, the ability to fulfill application requirements : resolution, accuracy, linearity, position measurement type (absolute or relative), response time (measurement delay), sensitivity to electrical noise, temperature range, sensitivity to mechanical shocks and vibrations and number of wires to be connected. Advantages and weaknesses of the encoder and resolver position sensors are discussed in the next sections.

2) RESOLVER SENSORS

The brushless resolver is a popular position sensor for AC brushless servomotors. Resolvers are basically rotating transformers which consist of a rotor coil and two orthogonal stator coils. A reference signal, supplied to the rotor winding provides the primary excitation. The amplitude of the induced voltages into both orthogonal stator windings is modulated with the sine and cosine of the shaft angle when the rotor is rotating. So, the resolver is an electromechanical component with a wide temperature range and also a reliable and robust position sensor in a hard working environment. Furthermore, the resolver is giving an absolute position information suitable for an AC brushless servomotor commutation. The methods for obtaining the digital angular position value of a resolver is known as Resolver to Digital Conversion (RDC). Different RDC schemes can be implemented according to the servo drive design [2]. The resolver primary winding is supplied with a sinusoidal excitation signal which frequency is in the range 4 kHz to 8 kHz (carrier frequency). The Sinus and Cosinus secondary winding voltages modulated by the shaft angular position can be fed to the monolithic RDC as shown on figure 2. In this case, the monolithic RDC operates as a tracking servo loop. The resolver shaft angle is the servo loop reference input and the counter digital position is the servo loop output. Because of the two integration functions given by the VCO and the PI controller, the RDC servo loop has an unity gain and no following error when the resolver is operating at constant speed. This conversion technique provides a continuous output position data with a good noise immunity because of the filtering effect of the second order transfer function. However, the filter delay must be taken into account for closing both speed and position servo loops. The servo loop error is obtained by using the following calculation : Sin(PosMot)*Cos(PosMes) - Cos(PosMot)*Sin(PosMes) = Sin(PosMot-PosMes) # PosMot-PosMes. A phase sensitive demodulation is then used in order to eliminate the carrier frequency.

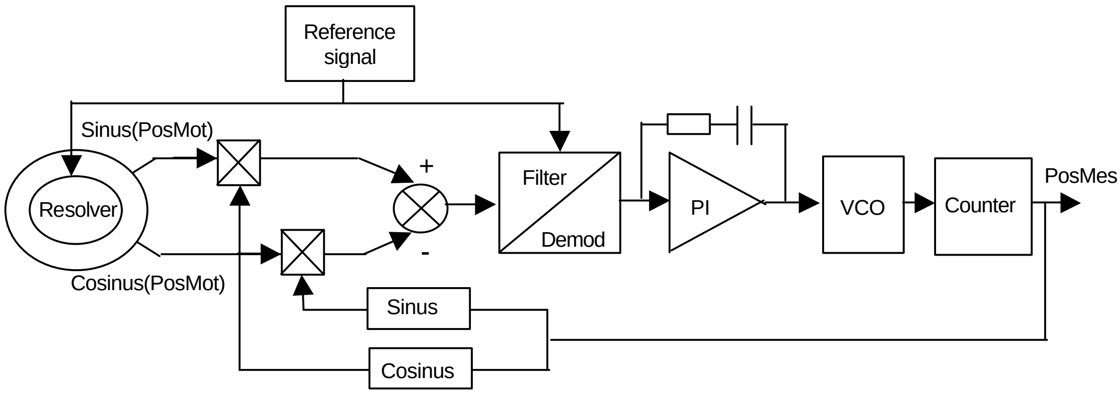


Figure 2 : block diagram of a monolithic RDC based on analog design

The resolver position conversion can also be provided by using a software solution based on a DSP computer as shown on figure 3. In this case, the Sinus and Cosinus secondary winding voltages are connected to dual Analog to Digital Converters (ADC). These signals are sampled at twice the excitation signal frequency and the sampling instant must be synchronized with the positive and negative peak of the sinusoidal excitation wave in order to provide the demodulation [3]. The resolver angular position can then be easily calculated from the Sinus and Cosinus samples into the DSP by using the inverse ArcTangent function.

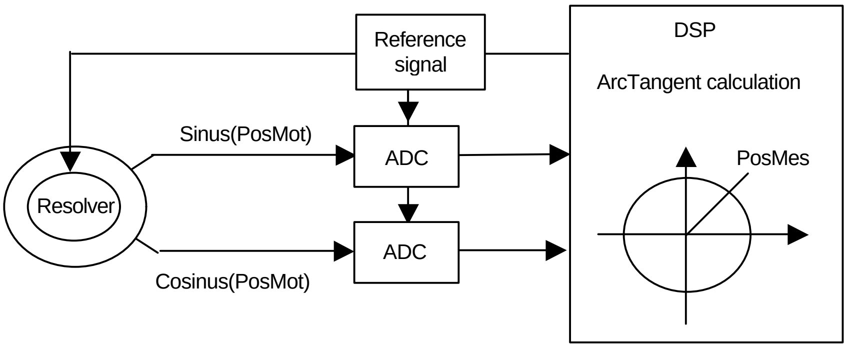
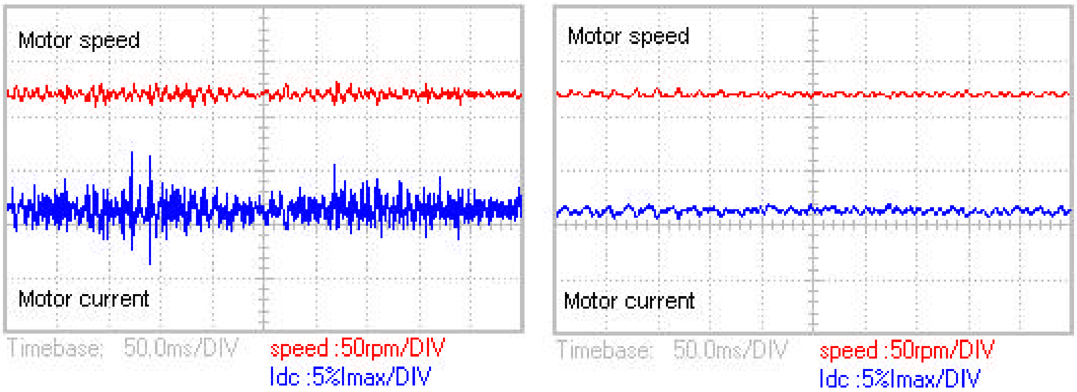


Figure 3 : block diagram of the software RDC conversion

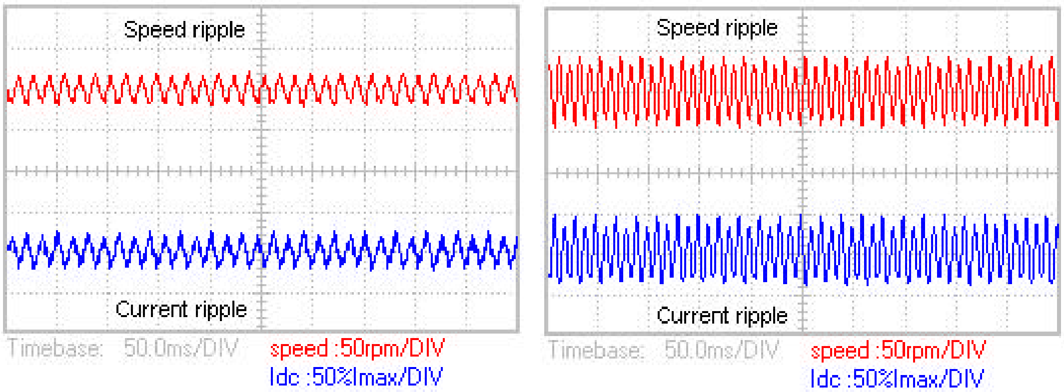
The digital position resolution value obtained mainly depends on the Analog to Digital Converters resolution (12 bit or 16 bit). The motor speed measurement value is derived from the position measurement value. So, a higher position quantification error results in higher speed measurement noise. In this case, as shown on figure 4, the speed measurement noise is transferred to the motor current by the high gain of the speed loop.



a) 12 bit resolver signals conversion   b) 16 bit resolver signals conversion

Figure 4 : Influence of the ADC resolution on the software RDC conversion

A digital second order tracking filter can improve the digital position resolution with regard to the direct ArcTangent calculation, however the position measurement delay introduced by the second order tracking filter response time is reducing the maximum obtainable speed and position servo loop bandwidth. The position measurement accuracy is mainly affected by the precision of the resolver building (coil winding assembly and excentricity in the mounting of the rotor and the stator) but also on the RDC conversion error. The electrical error given by the resolver building is about +/- 8 arc minutes for a standard resolver range. The RDC conversion error is generated by the ADC offsets and the gain mismatch between the sine and cosine channels. The total position measurement error value for a resolver based system is generally about +/- 15 arc minutes. The position measurement error is generating a speed measurement error which amplitude and frequency are increasing according to the motor speed. This results in higher speed and current ripples when the motor speed is increasing as shown on figure 5.



a) motor running at 2000 rpm b) motor running at 3000 rpm

Figure 5 : Influence of the resolver position measurement error

3) ENCODER SENSORS

Incremental encoders and sinusoidal encoders are both using similar optical scanning techniques. The light emitted by a LED passes through a rotating disk and a stationary mask to produce an electronic output signal from a photodiode array according to the pattern on the disk [4]. The output signal period corresponds to both successive transparent and opaque areas (one pitch of the rotating disk). The number of pairs of transparent and opaque areas equally spaced around the rim of the disk corresponds to the encoder resolution. The position measurement accuracy is mainly affected by the precision of the encoder mechanical assembly (excentricity in the mounting of the disk or the optic). This value is generally less than one pitch of the rotating disk, so the encoder accuracy directly depends on its resolution value (a quarter of the signal period). Thus, for an incremental encoder with a resolution of 2048 lines (number of output signal periods over one revolution), the position measurement error value is about 3 arc minutes, much less than a resolver based system. However, incremental encoders provide only a relative position measurement by counting the output signal periods from the sensor power up. So, for brushless AC servomotors, a magnetic alignment procedure is required at each power up. When this procedure cannot be executed because of the specific application requirements (motor equipped with a brake and subject to a dragging load for example), an additional commutation signal must be used. In this case, Hall Effect Sensors (HES) are generally mounted into the motor housing; they are used at the motor power up in order to start the motor commutation in six step mode. The torque controller switches then to sinusoidal commutation mode. Absolute encoders using additional commutation channels or a serial link communication for the position initialization at power up are best suited for brushless AC servomotors. However, these solutions are more expensive than incremental encoders and the number of wires to be connected is also higher.

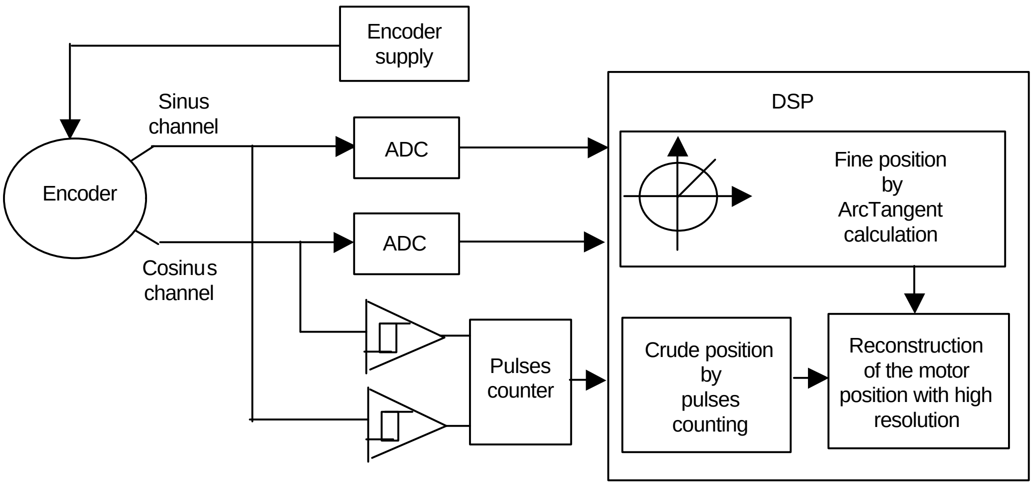


Figure 6 : high resolution position acquisition with sinusoidal encoders

In order to achieve higher resolutions with an incremental encoder, it is necessary to increase the number of lines. However, at high rotation speeds, the frequency of the encoder feedback signals becomes too high to deal with the servo drive electronics. Hence, sinusoidal encoders with analog sine and cosine output signals tend more and more to replace the conventional incremental encoders. In this case, the position information is continuously available, so it is possible to calculate the position value within one period [5]. This feature allows to get a very high position measurement resolution (higher than 1 million of increments over one revolution) with a smaller number of periods per revolution. The value of the position within one period is obtained by using a direct ArcTangent calculation after the sine and cosine signals conversion with a 12 bit ADC. This information is then combined with the encoder signal periods counter in order to get a finer position information with a high resolution, as shown on figure 6. This technique is also called fine position interpolation.

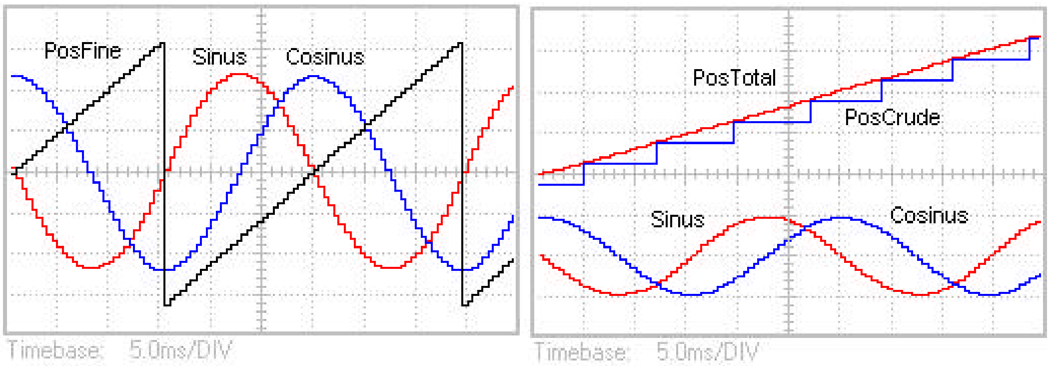
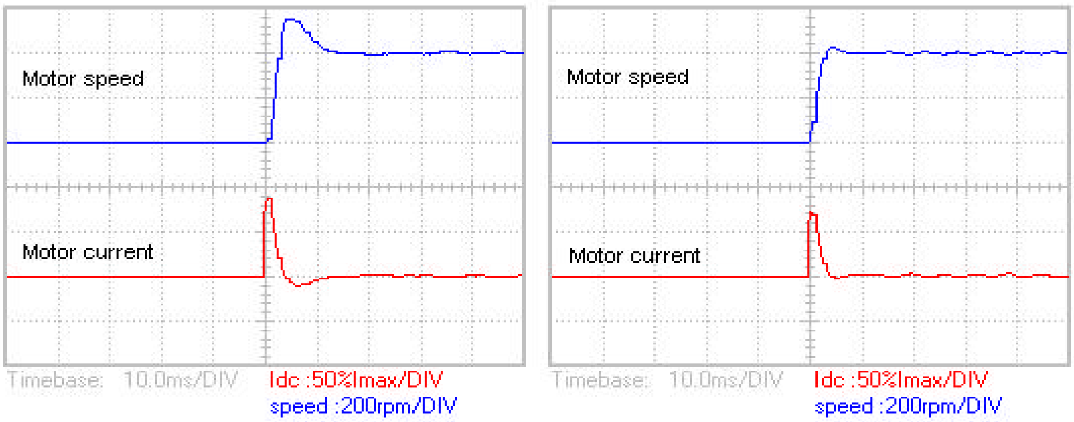


Figure 7 : sinusoidal encoder operation with fine resolution

A typical sinusoidal encoder operation is shown on figure 7. In this case, the encoder base resolution (equal to 2048 periods) is multiplied by a factor of 1024 using dual 12 bit ADCs. This results in a fine position resolution equivalent to 2 millions of lines for an incremental encoder.

4) EXPERIMENTAL RESULTS

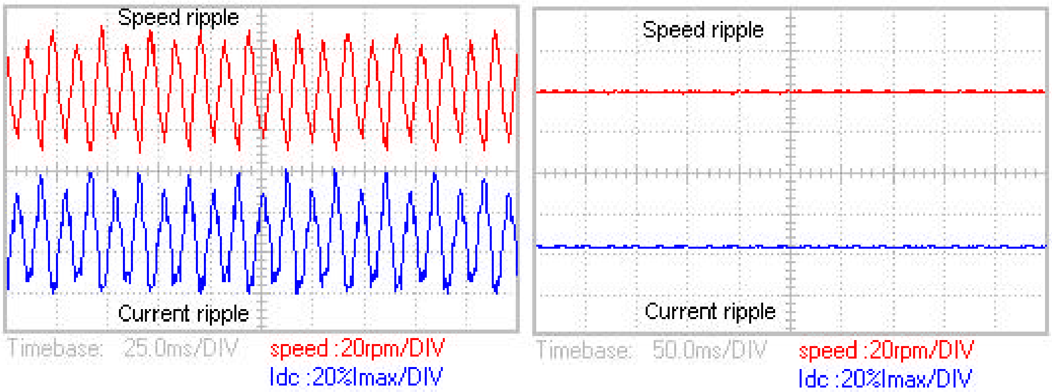
The test bench consists of an AC brushless servomotor equipped with two position sensors : a resolver and an incremental encoder with sinusoidal output signals. The industrial SMT-BD servo drive range is used to run the motor in speed or position mode [6]. This servo drive can be configurated according to the desired feedback sensor. As shown on figure 8, the response time and the speed loop bandwidth have been dramatically increased when the sinusoidal encoder position feedback is used. This is due to the high resolution on the position but also to the reduced delay in the measurement with regard to the resolver sensor using a monolithic RDC converter. Of course, the servo loop stiffness is also increased in the same ratio when the sinusoidal encoder is used.



a) Resolver with monolithic RDC b) Sinusoidal encoder with 2048 lines

Figure 8 : servo loop bandwith according to the feedback sensor

The speed regulation performances are also greatly improved when encoders are used as position feedback sensors, because the position measurement error is much lower than with a resolver, as shown on figure 9.



a) Resolver with monolithic RDC at 2500rpm b) Sinusoidal encoder with 2048 lines at 2500rpm

Figure 9 : speed regulation accuracy according to the feedback sensor

CONCLUSION

The influence of the position feedback sensor in the brushless servo drive performances have been investigated. Resolver and encoder sensors have been considered. The best servo control performances in terms of bandwidth and accuracy are obtained with a sinusoidal encoder using fine interpolation technique to increase the effective position resolution. So, the sinusoidal encoders are the best suited sensors for the most demanding applications in terms of dynamic and accuracy. However, in a hard working environment, the resolver sensor offers many advantages because it is a very rugged electromechanical component which provides absolute position feedback for the motor commutation with a minimum number of wires.

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