



# Fast and High Accuracy Wire Scanner

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## Abstract

Scanning of a high intensity particle beam imposes challenging requirements on a Wire Scanner system. It is expected to reach a scanning speed of 20 m.s<sup>-1</sup> with a position accuracy of the order of 1 μm. In addition, a timing accuracy better than 1 millisecond is needed. The adopted solution consists of a fork holding a wire rotating by a maximum of 200°. Fork, rotor and angular position sensor are mounted on the same axis and located in a chamber connected to the beam vacuum. The requirements imply the design of a system with extremely low vibration, vacuum compatibility, radiation and temperature tolerance. The adopted solution consists of a rotary brushless synchronous motor with the permanent magnet rotor installed inside of the vacuum chamber and the stator installed outside. The accurate position sensor will be mounted on the rotary shaft inside of the vacuum chamber and has to resist a bake-out temperature of 200°C and ionizing radiation up to a dozen of kGy/year. A digital feedback controller allows maximum flexibility for the loop parameters and feeds the 3 phase input for the linear power driver. The paper presents a detailed discussion of the chosen concept and the selected components.

## Introduction

### Currently installed WS drawbacks

- ✓ Melting or sublimating of the wire due to energy deposited by the incident particles and the energy transferred by the beam to the wire through its accompanying electromagnetic field.
- ✓ Inaccuracy of position measurement primarily due to vibration on the mechanics and the wire.
- ✓ Vacuum leakage in the bellows.

### New demanding performances

- ✓ Wire travelling speed up to 20 m.s<sup>-1</sup>.
- ✓ Position measurement accuracy of the order of 1 μm.
- ✓ Timing accuracy better than 1 millisecond.

### Baseline solution (Figure 1)

- ✓ Motor with the permanent magnets rotor inside of the vacuum chamber and stator outside.

- ✓ A position transducer to be mounted on the rotating shaft shall provide its absolute angular position for the feedback control loop of the motor and also a highly repeatable relative position during the scan.

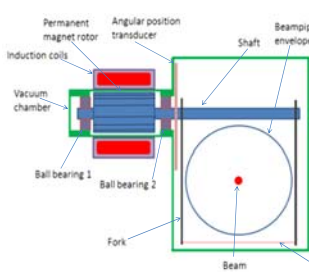


Figure 1: Simplified drawing of the future wire scanner

## Motor

### Dynamic requirements

The acceleration will be done over 90° up to a peak velocity of  $\Omega_{max} = 200 \text{ rad.s}^{-1}$  (linear speed of  $V=20 \text{ m.s}^{-1}$  with a fork length of 10 cm) and the deceleration to stop over the remaining 90° stroke (figure 2).

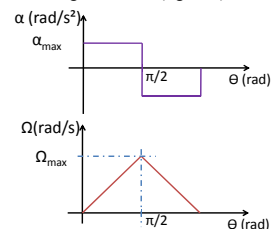


Figure 2: Theoretical angular acceleration (top) and angular speed (bottom) profile of the system.

To reach the peak velocity (200 rad.s<sup>-1</sup>) in 90° the motor must provide an angular acceleration of

$$\alpha = \frac{1 \Omega^2}{2 \theta}$$
$$\alpha = 12 \, 733 \text{ rad.s}^{-2}$$

### Environment constraints requirements

The rotor materials must have, after bake-out, a total outgassing not exceeding 10<sup>-9</sup> Pa.m<sup>3</sup>.s<sup>-1</sup>. The permanent magnets on the rotor must have a thermal demagnetizing largely superior to bake-out temperature (200°C). The whole motor must be resistive to a cumulated ionizing radiation dose of 20 kGy (roughly 1kGy/year).

### Motor choice

The chosen motor for the prototype is a Parker K500-150-5Y frameless synchronous machine proposed in two independent parts: a three phase stator and a permanent magnet rotor with six pairs of poles.

This motor can provide more than 2.5 times the acceleration needed for the wire scanner. The rotor-lamination is made of standard steel which will be made vacuum compatible. Samarium cobalt alloy has been chosen as adequate magnetic material for the rotor instead of neodymium which is less resistive to temperature. The foreseen glue based fixation of the magnets on the rotor will be replaced by a mechanical solution. The air gap between the rotor and the stator is comprised between 0.7 and 0.85 mm which is large enough to introduce the vacuum chamber barrier.



Figure 3: Parker frameless synchronous motor

## Angular Sensor

### Specifications

The transducer must provide information on the angular position of the shaft for two independent functions:

- ✓ An absolute position readout for the motor control with an accuracy of 30 arc minutes (8.7 milliradians) r.m.s.
- ✓ A relative position measurement for determination of the wire trajectory with accuracy of about 5 arc seconds (25 microradians) r.m.s. The signal processing may be performed offline.

### Angular sensor under consideration

The use of an analog position sensor with capacitive coupling between its fixed and moving elements to measure the angular position with high accuracy, resolution and repeatability is under consideration.

As this sensor consists of two printed flat plates (free of electronic components), almost any material can be used for the supporting plate and the conductive traces. This advantage allows making the sensor vacuum compatible and resistive to radiation and temperature.

## Simulation study

### Dynamic model of the motor

From motor manufacturer characteristics a dynamic modelling has been made (Figure 4).

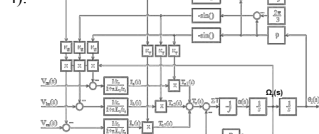


Figure 4: Electromagnetic model of the motor

### Simulation results

The following simulation parameters were used:

$$R_s = 0,245 \, \Omega, \quad L_s = 1,365 \text{ mH},$$
$$K_E = 0,2598 \text{ Vrad}^{-1}\text{s}^{-1},$$
$$p = 6, \quad J = 5,8 \cdot 10^{-4} \text{ kg.m}^2.$$

Assuming sinusoidal voltage waveforms in function of the electric angle and by using two specific functions for the initial phase and magnitude of the sine, the following waveforms of angular speed and position have been obtained.

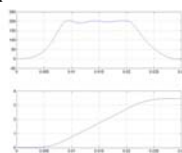


Figure 5: Simulated angular speed (top) and position (bottom) waveforms versus time in seconds

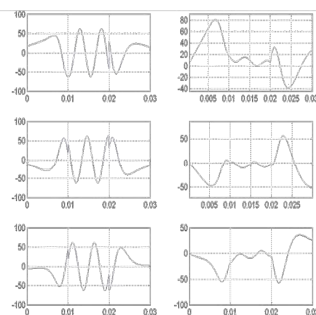


Figure 6: Simulated three phase voltage (left in volts) and current (right in amps) waveforms versus time in seconds

### Discussion

It can clearly be seen that the speed reaches a peak of  $\Omega_{max} = 200 \text{ rad.s}^{-1}$  in less than 90°, oscillates around this value and decelerates to a stop.

This behaviour fulfils the specifications of the wire scanner in terms of maximum values of speed and acceleration.

However, there are oscillations which must be minimised in the final test bench by an adequate control strategy.

This control must adapt the magnitudes and phases of the three voltage sources in order to optimise the angular speed waveform.

## Linear power amplifier

### Specifications

As the wire scanners will be mounted in EMI sensitive environment, power supplies working on the principle of high frequency switching (PWM) must be avoided. A three-phase linear power supply is currently under design.

### Linear power amplifier choice

Starting from the simulations above, the MOSFET power amplifier "PA52 by Apex" has been chosen. It can provide an output voltage of 200V and a peak current of 80A with a gain bandwidth product of 3MHz.

## Prototype and Control

A prototype of the control equipment is currently under design in order to allow the test and optimization of the control (Figure 7). A dSPACE® Controller Board with a ControlDesk® real-time graphical interface software allowing a rapid control prototyping will be used. Modelling and simulations will be used to carry out the best solution for the control. The robust control strategy will be especially focused on the strong variations of physical parameters of this device, especially the cable length (up to 250m).

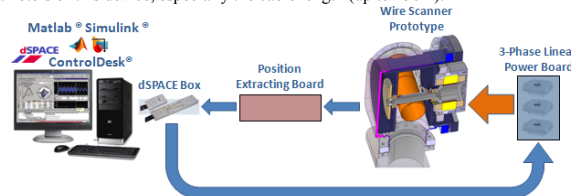


Figure 7: Synoptic view of the prototype

## Conclusion

On the basis of simulations one can say that the prototype of the fast wire scanner actuator is now ready to be built in order to optimize the control and to test the functionalities of the device. A dSPACE® Controller Board will be used as the real-time interface in the bench prototyping. Thereby, the control strategy will be optimized regarding the vibration phenomena and disparities of the physical parameters such as the circuit resistors.