

THE 20M/S CERN FAST VACUUM WIRE SCANNER CONCEPTUAL DESIGN AND IMPLEMENTATION

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Abstract

In the next years the luminosity of the LHC will be significantly increased. Therefore a much higher accuracy of beam profile measurement than actually achievable by the current wire scanner is required. The new performance demands a wire travelling speed up to 20 m/s and a position measurement accuracy of the order of 1 μm . In order to minimize the error source of the wire position measurement, a challenging concept has been developed which consists of the placement of the motor rotor and the angular position sensor in vacuum. The implementation of this new concept requires the use of a magnetic brake, hybrid vacuum bearings, the design and production of very thin ($<0.5\text{mm}$) wall vacuum chamber regions and the production of titanium components by 3D additive technologies. The implementation of this new concept has required different optimization processes as the structural optimization under dynamic load of the most critical rotating elements or the optimization of the control system and the motion pattern. This contribution gives an overview of the new device design and shows the different technical solution applied to develop the new concept in a successful way.

INTRODUCTION

A wire scanner (Fig. 1) is an electro-mechanical device which measures the transverse beam density profile of a particle beam by means of moving a thin wire across the beam in an intermittent manner. As the wire passes through the beam the interaction generates a cascade of secondary particles. These are intercepted by a scintillator, which couples the photons generated by the incident particle to a photomultiplier (PMT), which provides an electrical signal proportional to the incident photon flux.

The wire is stretched by a fork directly mounted on a shaft. The wire, fork and shaft are located in a vacuum chamber while the actuator is outside that chamber. The actuator provides a motion pattern consisting of three distinct phases (acceleration, constant speed and deceleration) fulfilling a set of requirements in order to achieve a suitable wire speed and position at beam crossing. Therefore the wire is crossing the beam in motion and consequently subjected to dynamic effects.

The strong peak acceleration in the motion pattern induces deflections and vibrations on the measurement chain (shaft, fork and wire) [1], which result in discrepancies between the true position of the wire and the position measured by the position sensor (Fig. 2).

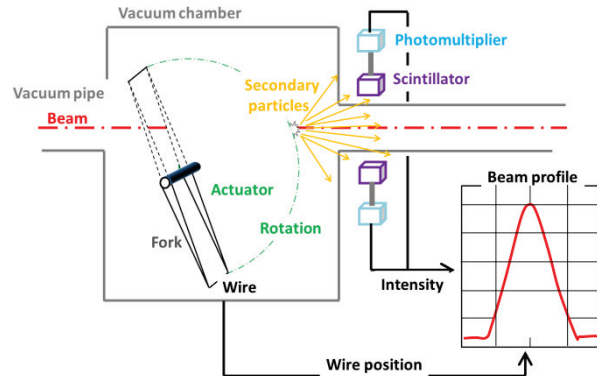


Figure 1: Illustration of the rotating wire scanner instrument.

Errors on the wire position when intersecting the beam have a direct consequence on the profile and position measurement accuracy. Thus, identifying and minimizing the uncertainties and error sources is a priority [2].

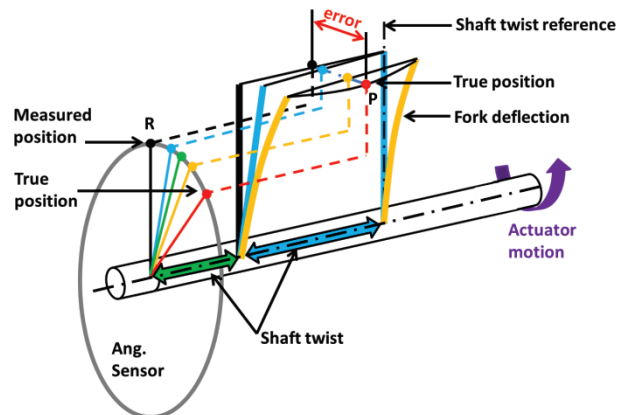


Figure 2: Deflections of the measurement chain for a rotating wire scanner.

The measurement requirement of the transverse beam distribution in the LHC rings [3] established the maximum uncertainty for the beam size determination for the LHC beam to be 1.8%. Minimum LHC beam size is in the range of 160 μm therefore the uncertainty in the beam size determination by the wire scanner has to be lower than 2.8 μm .

Experimental studies have been performed in order to determine wire damage limits due to the beam-wire energy deposition [4]. The conclusions of these studies advocate a wire traveling speed on the range of 20m/s.

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CONCEPTUAL DESIGN DESCRIPTION

The most remarkable feature of the new wire scanner concept is that all the movable components of the system are under vacuum. Although the rotating elements (actuator, angular sensor, shaft, fork and wire) remain the same as in the existing designs (i.e. a fork holding the wire is mounted on a rotating shaft), the mechanical complexity of the system is highly reduced since no kinematical links are required to transmit the motion from the pressure side to the vacuum side. Additionally, all movable parts are mounted in the same shaft, which implies the suppression of the kinematic chain which typically links the wire measuring point to the angular position sensor. Avoiding these kinematic chains represents a conceptual improvement compared to the existing devices from the precision point of view, as there is no mechanical play between the different parts of the measurement chain. Therefore, the position determination of the measuring chain is much more accurate. The main parts of this new wire scanner concept are shown in Fig. 3.

DESIGN IMPLEMENTATION

In the following the main component of the new wire scanner are described.

Actuator

The actuator consists of a frameless electrical motor. In this type of motor, the rotor and stator are independent, which allows a proper embedding of the motor in the system. In the case of the new wire scanner, this type of motor has been chosen because it allows the rotor to be installed in vacuum while the stator remains outside vacuum. In the typical air gap between rotor and stator is located the vacuum barrier, which is a very thin cylindrical shell made from stainless steel. As in a standard motor, the rotor is driven by the rotating magnetic field generated by the stator. The advantage of this configuration is that the rotor (already in vacuum) is connected directly to the shaft. Therefore no mechanical transmission is required, thus avoiding elements which are fatigue-prone.

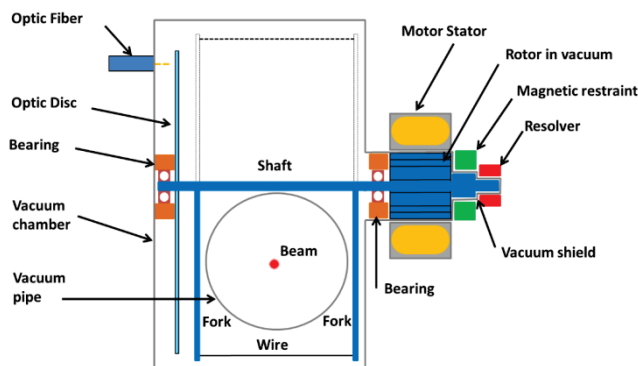


Figure 3: Conceptual design of the Fast Vacuum Wire Scanner.

Shaft

The shaft is the element driving the rotational motion of the system. The rotation torque delivered by the actuator

is transmitted to the shaft by the rotor, and provokes its rotation as well as that of all the elements mounted on it.

Resolver, magnetic restraint system, motor-rotor, the two arms and the optical encoder disk are directly mounted on the shaft.

Fork

In previous design of wire scanner instruments [5], the fork could be considered rigid in the transversal direction but it showed flexibility in the longitudinal direction to maintain the tension of the carbon wire and also provide a constant and homogeneous tension during the scan process. However, the measurements and the dynamic models developed along this work, show that longitudinal flexibility on the fork tips may enhance the transversal vibration amplitude of the wire [2]. Therefore, for the new design it has been decided to use a fork concept which is also rigid in the wire longitudinal direction. Consequently, the wire tension is guaranteed only by the wire elasticity and the initial preload tension applied at the first mounting.

Carbon Wire Fixation

To avoid this source of uncertainty in the wire position due to wire tension variations, the wire fixation system mechanically links the wire to the fork.

A suitable brazing will be applied between the ceramic isolator and the fork, as well as between the copper sleeve and the ceramic isolator (see Fig. 4). Thus, the extremities of the carbon wire will be properly bonded to the fork tips but electrically isolated.

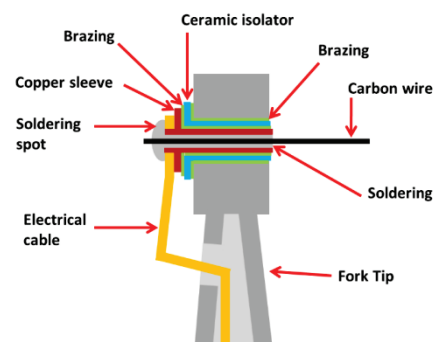


Figure 4: Wire fixation system detail.

Angular Sensor

The angular sensor is the element which serves to determine the angular position of the shaft and therefore the absolute position of the fork. This information is required to perform the beam profile reconstruction (see in the introduction chapter the functional description of the wire scanner). Moreover, the information provided by the angular sensor is needed to feedback the control system in order that the scan follows the suitable motion pattern. In the new design, the function of this angular sensor is achieved by means of two independent angular sensors, a solid rotor resolver for the motor feedback loop and an optical encoder for the beam projection reconstruction.

Resolver (motor feedback) This device measures the absolute angular position of the shaft and provides this information to the feedback control loop.

This device is relatively robust and provides angular absolute position without having to go to a home position, i.e., it provides continuous absolute angular position. The resolver device consists of a solid rotor without windings fixed to the shaft and therefore under vacuum. The stator is located on the air side. As in the actuator, a very thin cylindrical shell made of high magnetic permeability stainless steel allows this configuration.

Although the accuracy of this device is relatively low (17 mrad), it shows a high reproducibility, which allows to improve the accuracy by means of a calibration procedure.

Optical disk This part of the angular sensor is based in the incremental angle optical encoder technology and consists of a glass disk with a pattern made of high reflectivity chrome directly mounted on the shaft. An optical fiber drives the light from a laser diode to the optical disk. Using the reflectivity of the chrome pattern, the reflected light is coupled back into the same fiber, and directed to a photodiode through an optical circulator. After proper calibration, this sensor provides a resolution in the range of the requirements, i.e. 2.8 μm at the fork tip.

Magnetic Restrain System

The new conceptual design does not integrate any kind of mechanical link between the rotating parts and any other element that could block the unwanted rotation of the shaft. Bearing friction would not be enough to restrict the rotational momentum produced by the unbalanced weight of the fork. The only way to guarantee the grip of the shaft would be by means of the holding torque provided by the stator. However, in case of an electrical failure (the stator would be unpowered), The shaft could eventually rotate out of control. That situation could bring the wire in front of the beam causing the wire melting or, in the worst case, beam losses that could oblige to dump (or stop) the beam.

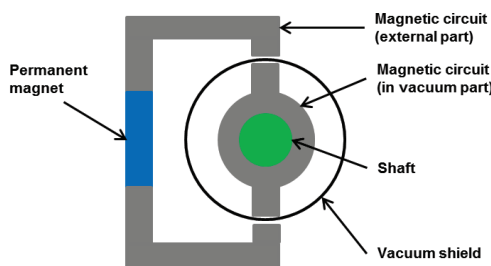


Figure 5: Magnetic restrain system detail.

The conceptual design of the magnetic restraint system, show in Fig. 5, consists on a dipolar magnetic field generated by a permanent magnet, a magnetic frame or yoke located outside the vacuum, and a ferromagnetic piece fixed to the shaft. The magnetic field (circuit) thus produced guaranties a resistive torque which avoids unwanted rotations. This resistive torque is very low compared to the torque that can be provided by the motor, therefore

this magnetic restriction cannot stop the rotation of the shaft under the action of the motor.

CONCLUSION

In this paper, the design of the new CERN Fast Vacuum Wire Scanner has been presented. The requirements for this new device, its conceptual design and the design implementation have been discussed. The most relevant component of the device has been described. As of today a first prototype of the devices has been built and installed in the CERN Proton Synchrotron Machine where operation test will be performed along this year.

A digital mock-up of the final device is shown in Fig. 6, where the design and integration of the different parts can be seen.

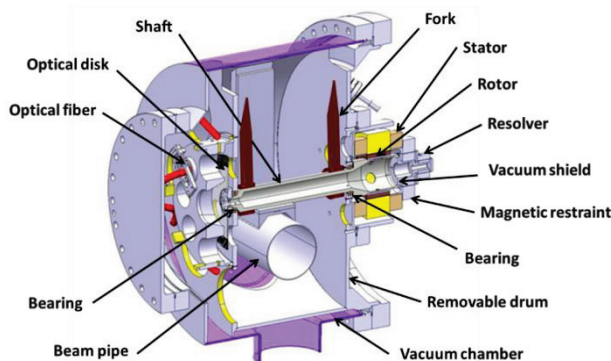


Figure 6: Digital mock-up of the device.

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