Twisting wire scanner

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Abstract

A new type of 'two-in-one' wire scanner is proposed. Recent advances in linear motors' technology make it possible to combine translational and rotational movements. This will allow to scan the beam in two perpendicular directions using a single driving motor and a special fork attached to it. Vertical or horizontal mounting will help to escape problems associated with the 45 deg scanners. Test results of the translational part with linear motors is presented.

PACS numbers: 41.85.Ew, 29.27.Fh, 07.07.Tw

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I. INTRODUCTION

Wire scanners serve as an essential part of accelerator diagnostic systems and are used mostly for beam transverse profile measurements (for a review see [1]). Depending on scanning wire trajectory the profilers could be classified as rotational [2] or linear [3]. When its necessary to measure vertical and horizontal beam profiles at the same longitudinal position one has to use two independent scanners. Alternatively two profiles could be sampled by using a single driver mounted at 45deg with two wires stretched horizontally and vertically over a fork attached to this linear driver. However, wire vibration in the scanning direction is a known problem for the 45deg scanners [4, 5].

Different types of driver motors have been employed in order to move and control scanning wires which are normally mounted on cards or forks connected to the motors. Stepper or servo rotating motors are among the most popular drivers and linear motors are at developing stage. Here we explore commercially available translational-rotational motor units to propose a wire scanner solution which will perform beam scans in mutually perpendicular directions using a single linear-rotary motor and a simple wire hosting construction attached to it. The construction is a key-like wire holder which makes twisting (helical) motion during a 2-D scan. Next will follow a more detailed description of the translational part with linear motors. In conclusion we will estimate technical feasibility of the proposed twisting scanner.

II. LINEAR-ROTARY MOTORS

A linear-rotary motor produced by company LinMot [6] is shown in Fig. 1. The motor consists of a linear and a rotary part merged together. Translational and rotational motions are decoupled and organized independently. However, linear and rotary motion synchronization is foreseen by motor controller logic. The motors are provided in different configurations with variable sizes and strengths reaching up to 1 kN linear force and 7.5 Nm rotating torque. Motor controllers use advanced and flexible software/firmware which should help to perform slow or fast scans with minimal programming efforts. An operational voltage of 72VDC and maximal current of 15A complies to general Electro-Magnetic Interference (EMI) requirements in accelerator environments. Described features make the linear-rotary motor as an attractive tool for driving the proposed twisting wire scanner. A closer look to

TABLE I. LinMot PR01-52x60-R/37x120F-HP-100 Linear-rotary Motor Parameters

Parameter	**Value**
Linear Motion	
Extended Stroke ES mm (in)	100 (3.94)
Standard Stroke SS mm (in)	100 (3.94)
Peak Force E12x0 - UC N (lbf)	255 (57.3)
Cont. Force N (lbf)	51 (11.5)
Cont. Force Fan cooling N (lbf)	92 (20.7)
Force Constant N/A (lbf/A)	17 (3.8)
Max. Current @ 72VDC A	15
Max. Velocity m/s (in/s)	3.9 (154)
Position Repeatability mm (in)	±0.05 (±0.0020)
Linearity %	±0.10
Rotary Motion	
Peak Torque Nm (lbfin)	2 (17.7)
Constant Torque (Halt) Nm (lbfin)	0.5 (4.4)
Max. Number of revolutions Rpm	1500
Torque Constant Nm/Arms (lbfin/Arms)	0.46 (4.07)
Max. Current @ 72VDC Arms	6.2
Repeatability deg	±0.05

specifications of a linear-rotary motor LinMot PR01-52x60-R/37x120F-HP-100 is presented in Table I as an example. Listed values for the Repeatability are quoted for built-in, internal position and angle sensors. One can improve these parameters considerably by using external, finer sensors which is foreseen by controller software. In following we demonstrate that for linear motors.

III. KEY-BIT SCANNER

In order to apply 2-D helical motion of a linear-rotary motor for scanning a beam, one needs to invent a suitable construction with stretched wires and a holding frame which stays out of (does not cross the) beam during the scan. For that we propose a key-bit like assembly which fulfills above requirements. The construction is schematically presented in Fig. 2.

As it's indicated by arrows, for this arrangement translational motion will first scan the beam in horizontal direction and next, when the beam will be inside the key-bit, a proper rotation will perform vertical scan. It is necessary to limit the rotation angle in order to escape crossing of the wire holder with the beam. For that there is sufficient space between the holder frame and the beam, remaining after the rotational scan is over. Denoting vertical key-bit and wire size by L and l_w respectively, the beam to holder distance could be expressed as

$$L\left(\arccos\frac{x}{L} - \arccos\frac{x}{l_w}\right)$$

where x is distance between the beam and rotational axis. Applying this formula for fast ($> 1\ m/sec$) rotational scans with some realistic accelerator parameters we obtain sufficient space to accelerate the wire while for deceleration the space is limited and one needs to use mechanical dumps to stop the scanner.

IV. 3-D KEY-BIT HOLDER FOR 2-D FAST SCANS

An improved, slightly more complicated design, for the fast scans could be achieved by tilting the second quadrant of the key-bit wire holder out of the construction's plane by some angle. A 90 deg tilted key-bit holder is sketched in Fig. 3. Scanning sequence is exactly the same as for the flat key-bit scanner with an advantage of more room after the second scan is over. This should give sufficient time to decelerate and stop the frame by the motor alone, without mechanical dumpers. In addition the tilted key-bit's moment of inertia is considerably smaller than in flat case. This will allow easier and improved handling of rotations with more ergonomic acceleration and deceleration of the key-bit structure.

V. LINEAR MOTOR PERFORMANCE AS A SCANNER DRIVER

We are developing wire scanners with linear motor drivers for European XFEL accelerator.

Here we present some of the results obtained during recent laboratory experiment with test scanners. Planned test setup is displayed in Fig. 4 while experimental realization is presented by Fig. 5. For horizontal and vertical scans two identical and independent profilers are mounted to a special vacuum chamber dedicated to beam transverse diagnostics.

Position feedback for the linear servo-motor is provided by an external Heidenhain optical system which is accurate to $1\mu m$. With the setup we have tested triggered fast scans and mechanical as well linear motors performance during/after tens of thousand scanning strokes. Important specifications of the XFEL wire scanners are shown in Table II.

TABLE II. European XFEL Wire Scanner Specifications

Parameter	**Value**
Stroke	53mm
Measurement duration	5 sec / 4 scanners
Scanning modes	Fast (1m/s), Slow
Motor to beam sync	$< 1\mu sec$ (RMS)
Position accuracy in a cycle	2 μm (RMS)
Width accuracy per cycle	2 % (RMS)
Wire positioning error	1 μm
Number of wires per fork	3 + 2 (3x90^o, $\pm 60^o$)
Wire material	Tungsten
Fork gap	15mm
Wire-wire distance	5mm (90^o)

Tests have marked most of the listed specifications as achieved. During the test mechanical design and construction precision has been justified while linear motors have demonstrated reliable performance.

To verify motor's dynamic behavior we have recorded essential parameters during nominal strokes. An example is shown on Fig. 6 where together with position and velocity also the motor's current and velocity deviation are displayed for a fast ($1m/s$) scanning stroke. An important issue for the XFEL wire profilers and fast scans in general is mechanical jitter magnitude for triggered scans. We have investigated this by recording time intervals between the trigger and fine position system reference mark traversing time.

Measurement results for many forward and backward strokes are summarized in Fig. 7. Distributions show time jitter below $1\mu sec$ which, in our case of $1m/sec$ velocity, is equivalent to a sub-micrometer mechanical jitter. This could also be quoted as a repeatability of the tested linear motor with fine position feedback and triggering systems.

VI. DISCUSSION

In the last section we have demonstrated an outstanding performance of contemporary linear motors as wire scanner drivers. We have proposed to use linear-rotary motor with attached key-bit wire card as 2-D twisting wire scanner. Estimated planes of possible oscillations of the key-bit wires differ from critical planes in 45 deg forks which should cure associated vibrational problems reported at LCLS and other centers. This will become possible mainly due to different alignment of the scanning wires relative to driver unit. In addition the vibrations are normally dumped along the motion direction.

An apparent difficulty for twisting wire scanner development is the linear-rotary motion transfer into the vacuum chamber where the key-bit card should operate. For that one should combine linear bellows with either wobble [7] or torsional [8] bellows.

ACKNOWLEDGMENTS

We are thankful to S. Vilcins-Czvitkovits, J. Kruse, A. Ziegler and M. Drewitsch for participation in preparation and running of the XFEL wire scanners' first prototyping test.

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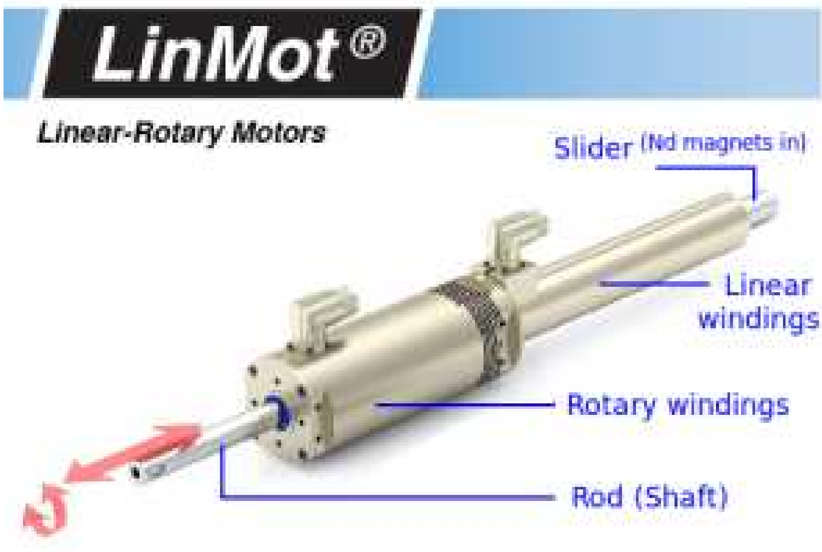

FIG. 1. Linear-rotary motor from LinMot company.

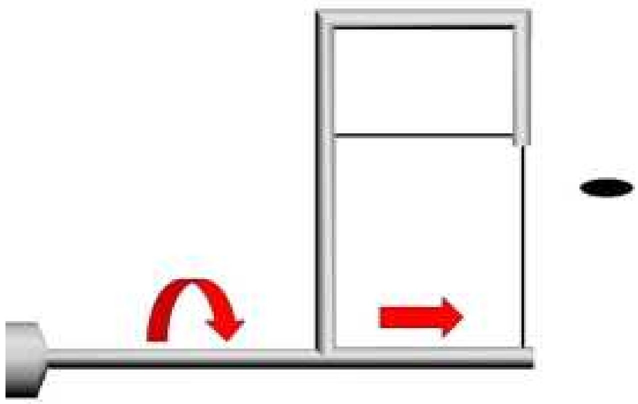

FIG. 2. A key-bit holder scheme with horizontal and vertical scanning wires. A small ellipse on the right depicts a beam running normal to the page.

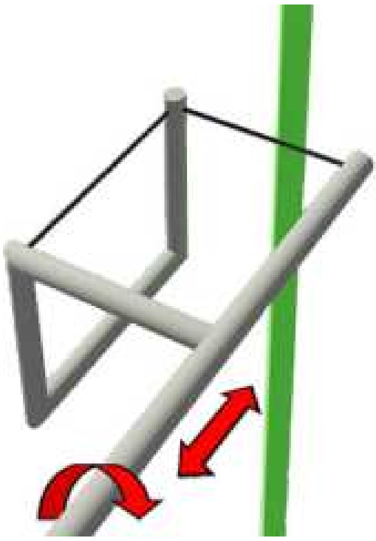

FIG. 3. Scanning scheme of a three dimensional key-bit wire holder. Vertical green line depicts the beam to be scanned.

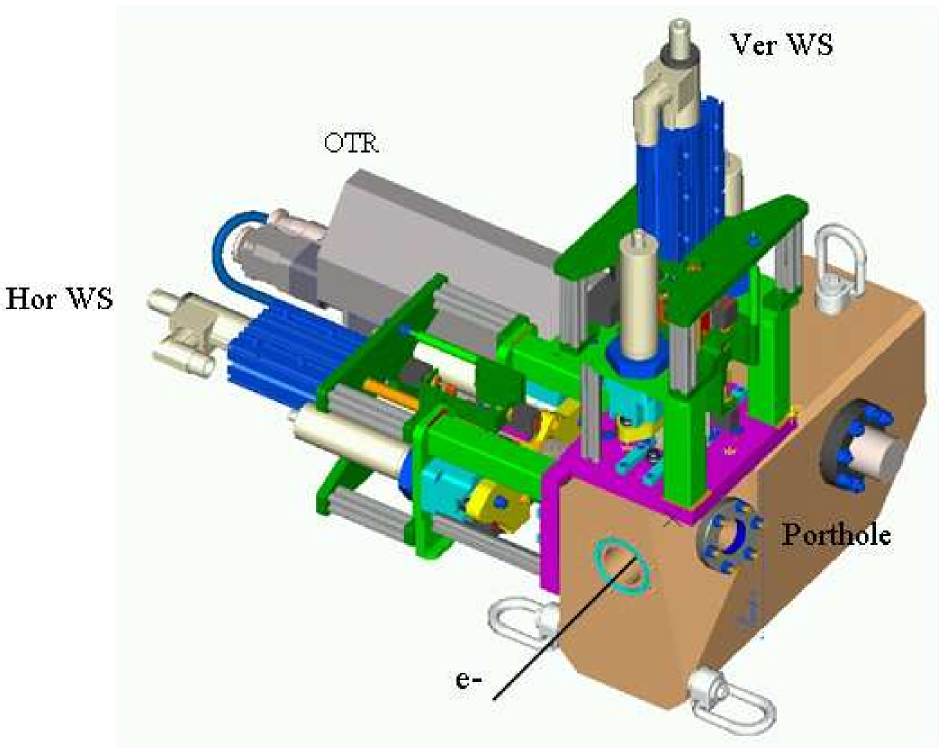

FIG. 4. Designed horizontal and vertical wire scanners mounted on vacuum chamber.

FIG. 5. XFEL wire scanners' test setup

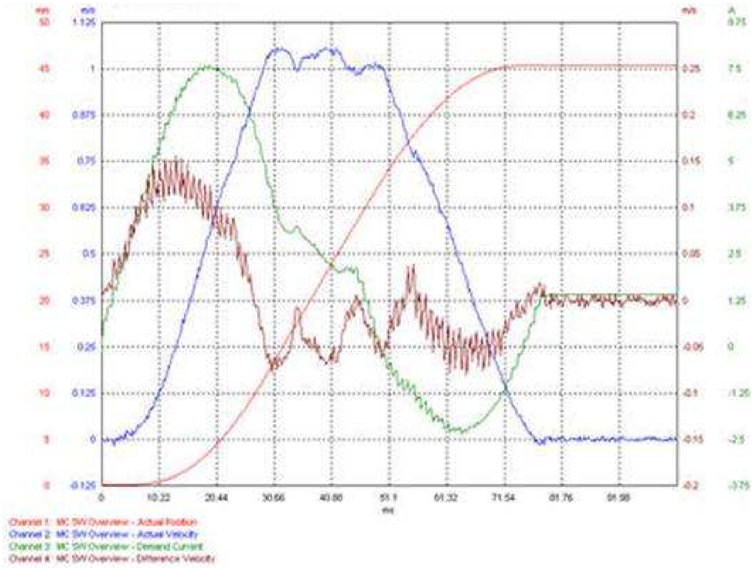

FIG. 6. Linear motor parameters recorded during a stroke: position(mm, red), velocity(m/s, blue), current (A, green), demand and actual velocity difference (m/s, brown)

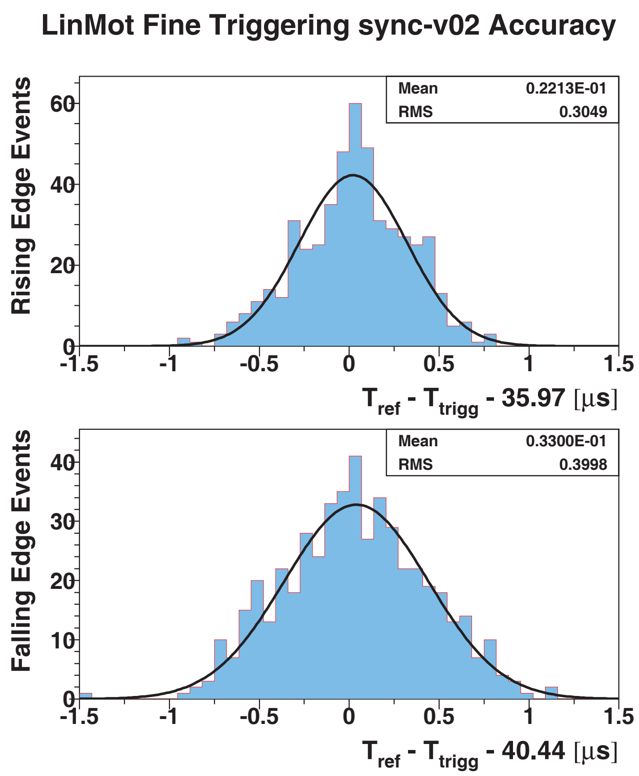

FIG. 7. Motor triggering mechanical jitter distribution for the forward (upper plot) and backward (lower plot) strokes. Superimposed are shown fitting gaussian functions with displayed RMS (one sigma) values.