TESTS OF A NEW OSCILLATING ARM WIRE SCANNER FOR HIPA AT PSI

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Abstract

The Oscillating Arm Wire Monitor (OAWM) is a new type of Wire Scanner designed to operate at maximum speeds exceeding 4 m/s, which is needed to perform scans of beam at maximum intensity. This paper summarizes the comprehensive tests and measurements performed on the OAWM, focusing on both its operational endurance and its underlying mechanical dynamics. We detail extensive endurance tests, accumulating thousands of scans to validate long-term system reliability in high-intensity beam environments. We analyze vibrations of the fork at various speeds and observe the vibration damping. Successful first running tests were conducted in the 870 keV injection beam line of HIPA to ensure signal quality metrics are maintained under actual operational conditions. The results validate the suitability of reduced inertia and optimized gear ratios for achieving faster, more stable, and highly reliable beam diagnostics.

INTRODUCTION

In the beam wire scanners, increasing the scan speed reduces the exposure time of the wire to the particle beam, thereby enabling the diagnostics of high-brightness beams while preventing thermal damage to the wire [1, 2]. At the Paul Scherrer Institut (PSI) High Intensity Proton Accelerator (HIPA) facility [3], the 870 keV beamline operates at a nominal beam current of approximately 10 mA. Currently installed, legacy wire scanners are limited to operating at a maximum of 20% of this intensity. Consequently, a novel, high-speed wire scanner has been developed to overcome this limitation [4]. A primary constraint for this new diagnostics device was the requirement to integrate seamlessly into compact vacuum chambers in densely filled beamline. The device features a low-inertia arm with a mass of only 22 g, driven by a gearless, direct-drive motion transfer mechanism coupled directly to the motor.

Prior to beamline installation, the new wire scanner prototype underwent extensive laboratory characterization. It was installed in a dedicated vacuum chamber and evaluated under both atmospheric pressure and vacuum conditions. The system was tested with and without a pre-tensioned wire. These tests have been carried out using a stepper motor model PKP245D23A2 from Oriental Motors managed by an EtherCAT Motion Control (ECMC) system [5]. Motion profiles were triggered either directly via the ECMC or through a custom System-on-Module CAM (SoM-CAM) device [6]. The acceleration trajectory was systematically optimized to ensure smooth motion transfer and minimize mechanical jerk, following the methodology described in [7]. Although the arm assemblies were fabricated from both stainless steel and titanium, the experimental campaign presented in this study was conducted exclusively utilizing the titanium arm configuration.

After lab tests, the scanner has been installed on 870 keV beamline of PSI HIPA facility and tested with nominal beam current.

TRANSVERSE VIBRATIONS

During the very first tests, performed in December 2025 with partially assembled arm, large transverse (i.e. perpendicular to the direction of the scan) vibrations of the arm have been observed. The amplitude of these vibrations was a concern because of potential collision with the other arm in parked position or with the vacuum chamber.

In order to measure these vibrations we have chosen optical measurement method. That was possible because the vacuum chamber is equipped with a viewport at 45° angle, which offers a good view to the arm tip in its end position, where it stops after the scan. The vibrations have been registered using Fujifilm X-T50 camera with 60 mm/f2.4 Fujinon macro lens. The camera has been set in slow motion mode (240 fps). The resulting video has been analyzed using Tracker [8] program which allows to quantify the motion from a video file.

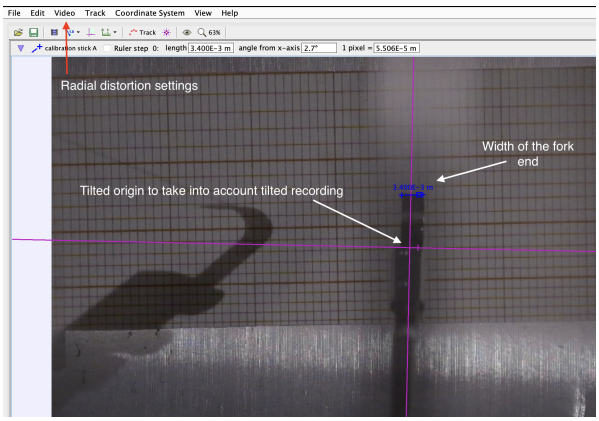


Figure 1: The photo of the arm tip from a video file opened in Tracker program. The shape on the left is a shadow of the arm tip.

At first the millimeter paper placed behind the arm was used to find the scaling factor of the image, however later

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the actual tip size was used to calibrate amplitude of the oscillations. This way there is no need to correct for parallax error.

Figure 2 shows result one of the measurement of the transverse vibration of the arm done right after the scan. In this case the scan has reached the maximum speed of the wire: 4.8 m/s. The obtained data has been fit with a function describing damped oscillations:

$$x(t) = A_0 \cdot exp(-\gamma t) \cdot cos(\omega t + \phi) + C \qquad (1)$$

where A_0 is the initial amplitude of the oscillations, γ is the oscillation decay rate (damping time $\tau = 1/\gamma$) and ω is angular eigen-frequency.

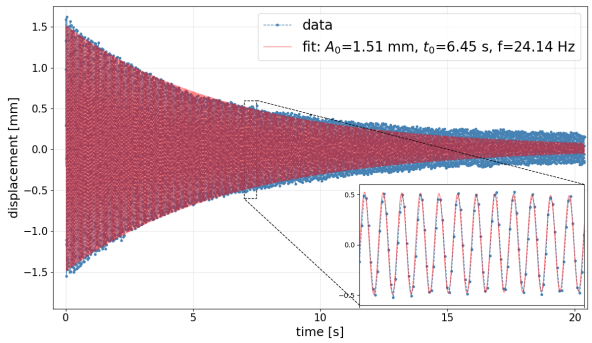


Figure 2: Measurement of the transverse vibrations of the arm right after scan with maximum velocity of 4.8 m/s. The whole picture shows about 500 oscillations, so the zoom to an arbitrary half-second region is shown to illustrate the quality of the fit. The initial scan duration is 54 ms.

As can be seen in the Fig. 2, the fitted function does not describe well the decay of the observed oscillation. This is probably because the damping force depends on the amplitude (nonlinear damping), which is not included in the model. Therefore, for further analysis, a simple maximum amplitude (A_{max}) and time to damp the oscillations down to 0.1 mm (t_{damp}) are considered.

The main oscillation frequency does not depend on the wire speed so it is an eigen-frequency of the system. The Fast Fourier Transform determines it better than the fit using Eq. 1. The FFT spectrum from in Fig. 3 shows eigenfrequency of the system with value of about 24.1 Hz. This eigenfrequency only weakly changes in the presence of air or without mounting of the wire.

Figure 4 shows how the most important features of the vibrations, A_{max} and t_{damp}, depend on the maximum speed reached by the wire during the scan. The damping time t_{damp} is two times shorter in air than in vacuum but does not depend strongly on the scan speed. The initial amplitude of the oscillations increases with the scan speed and reaches 1.5 mm at maximum.

All together the initial amplitude of the oscillations is much smaller than observed in December 2025. This has been attributed to better assembly of the arm especially a more precise alignment of the arm with the elements fixing

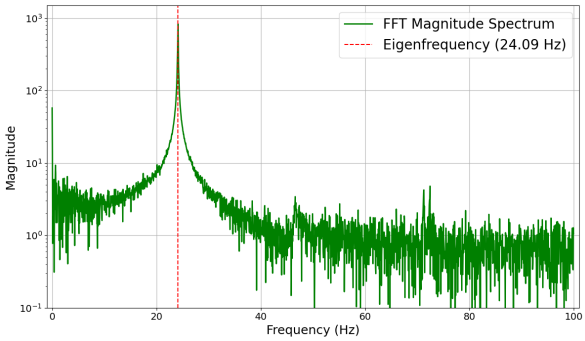


Figure 3: Fourier transform of the vibration data for scans reaching the maximum speed and in vacuum.

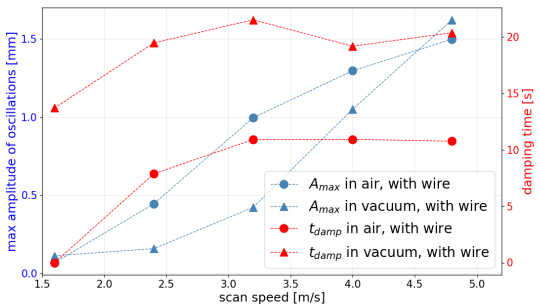


Figure 4: Oscillation parameters for scans at various wire maximum velocities.

it to the rotation axis. The maximum vibration amplitude of 1.5 mm is acceptable from mechanical perspective.

CONSECUTIVE SCANS TEST

The wire scanners in HIPA usually perform two passes through the beam every time the scan is launched. These legacy scanners often have only one end switch therefore only one defined parking position and a return scan is needed to place them in this position. In addition, analyzing both profiles, could give an insight about the phenomena of thermionic emission from the wire and help in case of limited bandwidth of the readout electronics. The new scanner has two end switches and it is in principle not necessary to do two scans every time, however a test has been done to investigate how the waiting time between the consecutive scans affect the arm oscillations. The results of this test, shown in Figure 5, suggest that the minimum waiting time of 3 s should be applied between scans in order to avoid increase of the vibration amplitude.

ENDURANCE TESTING

The scanners are specified to achieve an operational lifespan of several thousand cycles prior to failure. The critical components most susceptible to mechanical fatigue and degradation are the limit switches and the bellows assembly. To validate long-term structural reliability and rule out premature failures, an accelerated test consisting of 10, 000

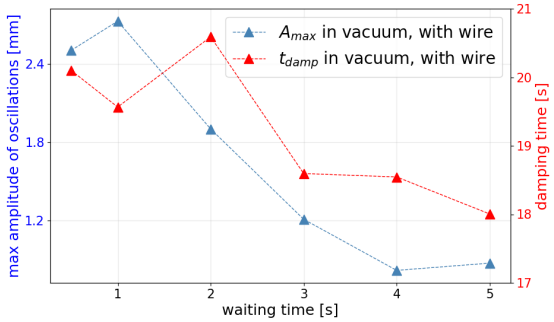


Figure 5: Oscillation parameters after the second scan as a function of waiting time between the two scans. Presented data are for scans with maximum speed.

unidirectional scan cycles (counting each single direction as one cycle) was conducted.

The test was automated but under continuous monitoring. The scanner was mounted vertically onto a standard chamber under nominal vacuum conditions. Scan speed was again 4.8 m/s and the waiting time in between the scans was set to 5 s. The complete cycling sequence was executed over a 2-working day period. Post-test inspection revealed no structural damage, mechanical wear, or performance degradation, validating the robustness of the assembly.

FIRST BEAM TESTS

Figure 6 shows the installation of the scanner on the 870 keV beamline. One can see the flange with the external mechanism including the bellow, the potentiometer and the stepper motor. For this test the wire scanner has been equipped with 40 μm tungsten wire.

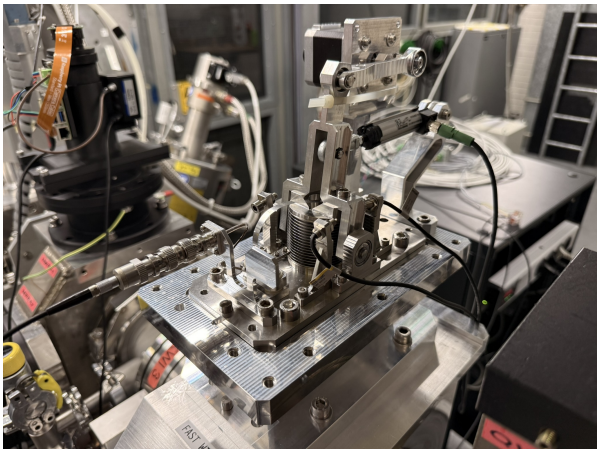


Figure 6: Photo of the first installation of the Fast Wire Scanner on the 870 keV beamline of HIPA facility at PSI.

The first test with the beam took place on June 29, 2026. The potentiometer signal, and the wire signal are read out by two of the SoM-CAM channels. Both signals are used to reconstruct the wire position. The acquisition rate was 10 kHz, which is currently a default rate used for post-mortem buffers of ionization chambers. First the beam intensity was set to 0.7 mA, which means that the beam chopper was set to 5% duty factor and the wire speed was reduced down to 1.6 m/s. The beam chopper activity was clearly observed in the measured signal. Then the beam intensity was gradually increased. Figure 7 shows the two profiles obtained at maximum beam intensity of about 9.6 mA (100% duty factor). The blue profile, obtained at wire speed of 2.4 m/s, is clearly deformed probably by the thermionic emission from the wire. The visual observation also showed intensive glow. At maximum speed of 4.8 m/s the wire glow (see Figure 8) is significantly reduced and the beam profile looks nominal. In the future the potentiometer signal will be read out by a dedicated mezzanine board of SoM-CAM.

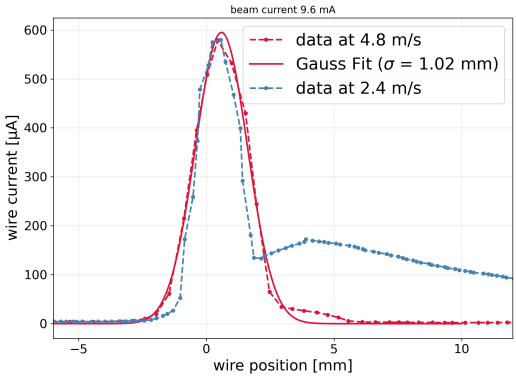


Figure 7: First beam profiles obtained with 10 kHz acquisition rate.



Figure 8: Wire glow during beam scan at maximum speed of 4.8 m/s.

CONCLUSIONS

The Oscillating Arm Wire Monitor (OAWM) has been successfully prototyped, and validated as a beam diagnostics

tool for high-intensity operations at the PSI HIPA facility. The laboratory characterization and first-beam experimental campaigns yield several conclusions:

- Successful High-Intensity Mitigation: The primary objective of operating at full beam intensity was achieved. By reaching a maximum scan speed of 4.8 m/s, the wire exposure time was reduced sufficiently to mitigate the wire damage and thermionic emission. This effectively overcomes the 20% nominal beam intensity operational threshold limiting HIPA legacy wire scanners.

- Manageable Vibrations: Transverse vibration testing revealed a first eigen-frequency of the titanium arm assembly in the range of 24–25 Hz. Although the damping behavior deviates from a pure linear viscous model due to non-linear damping effects, the initial maximum amplitude remains bounded at an acceptable 1.5 mm at peak operating velocity. Optimization of the arm assembly alignment around the rotational axis successfully constrained these vibrations well within safe mechanical tolerances, eliminating the risk of collision with vacuum chamber wall or the second arm.

- Vibration Damping: It was demonstrated that while the initial oscillation amplitude scales strongly with scanning velocity, the time to damp oscillations down to 0.1 mm is largely independent of speed. Furthermore, damping in atmospheric conditions is twice as fast as in a vacuum. Successive scanning intervals of more than 3 seconds are shown to drastically decrease residual oscillation coupling between sequential forward and backward scans.

- High Structural Reliability: Accelerated lifetime testing consisting of 10,000 continuous unidirectional cycles over a 48-hour period under nominal vacuum conditions induced no structural failures, mechanical wear, or degradation in the critical limit switches, bellows or other parts, validating the robustness of the mechanical design.

To further refine system performance and accommodate the fast transit times of the wire, future work will focus on scaling up the data acquisition frequency from 10 kHz to 50 kHz. This upgrade increase number of samples within the beam by factor 5, ensuring high-fidelity profile resolution and optimal bandwidth handling.

Additional mechanical tests will be performed with both scanners - vertical and horizontal - installed on the vacuum chamber. The behavior of arm made of stainless steel must still be investigated.

Currently it is planned to build 8 vacuum chamber with 2 scanners each to replace legacy wire scanners on 870 keV injection beam line in 2027-2028.

ACKNOWLEDGEMENTS

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REFERENCES

[1] M. Sapinski, “Beam Interaction with Thin Materials:Heat Deposition, Cooling Phenomena and Damage Limits”, in *Proc. BIW’12*, Newport News, VA, USA, Apr. 2012, paper WECP04, pp. 245–249.

[2] M. Sapinski, “About the damage mechanisms of thin targets exposed to high-power particle beams”, in *Proc. IPAC’23*, Venice, Italy, May 2023, pp. 4824–4827. doi:10.18429/JACoW-IPAC2023-THPL151

[3] J. Grillenberger, C. Baumgarten and M. Seidel, “The High Intensity Proton Accelerator Facility,” SciPost Phys. Proc. **5**, 002 (2021) doi:doi:10.21468/SciPostPhysProc.5.002

[4] R. Dölling *et al.*, “Status of oscillating arm wire monitor development”, in *Proc. IBIC’25*, Liverpool, UK, Sep. 2025, pp. 383–387. doi:10.18429/JACoW-IBIC2025-TUPCO14

[5] T. Gahl *et al.*, “ECMC, the Open Source Motion Control Package for EtherCAT Hardware at the ESS”, in *Proc. ICALEPCS’17*, Barcelona, Spain, Oct. 2017, pp. 71–75. doi:10.18429/JACoW-ICALEPCS2017-MOCPL05

[6] M. Sapinski, P.-A. Duperrex, M. Rizzi, S. Zhang, “Deployment of a new current measurement module for beam loss monitors of HIPA facility in PSI,”, these proceedings, paper MOP037

[7] R. Dölling, “Simulation of Oscillating Arm Wire Monitor Mechanics Driven by a Stepper Motor,” in *Proc. IBIC’23*, Saskatoon, Canada, Sep. 2023, pp. 383–387. doi:10.18429/JACoW-IBIC2023-WEP018

[8] https://opensourcephysics.github.io/tracker-website/