Automated Mechanical Inspection and Calibration of Insertion Devices in APS Storage Ring

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MEDSI CHICAGO 2020

Abstract

A novel technique has been developed to automatically inspect and calibrate the 53 permanent magnet insertion devices in the Advanced Photon Source (APS) storage ring. This technique employs standard frequency domain analysis to create easily identifiable signatures in an actionable format. The mechanisms and actions taken behind various observed trends and its application for continuous monitoring and predictive maintenance of these devices will be discussed. This technique has enabled predictive maintenance and provided new insights into optimizing device performance.

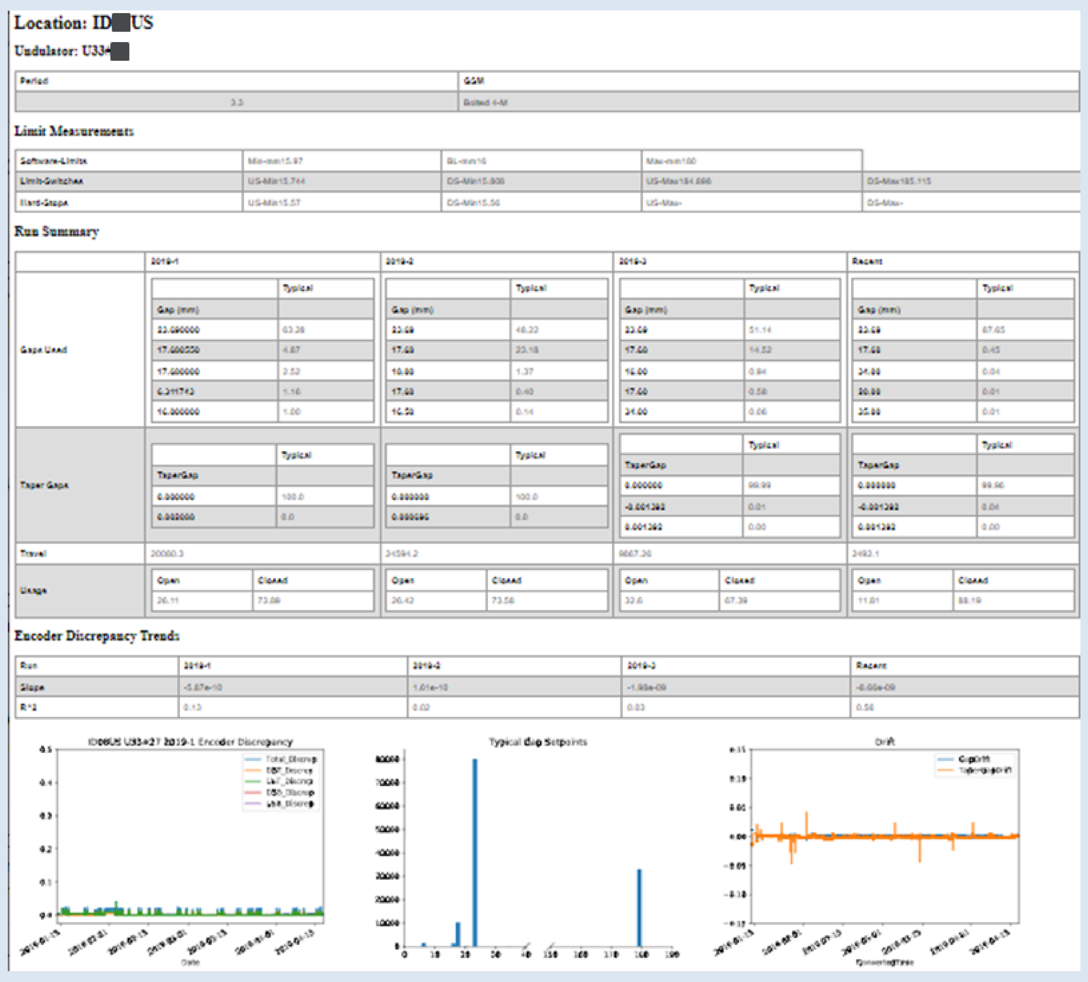
Introduction

Insertion devices require micron level accuracy and precision for correct operation. Many of the devices have been in service for more than 25 years with additional devices being added most years. Each of the 53 insertion device at the APS has four drivetrains for a total of 212 in operation 24/7. Automated condition monitoring greatly improves situational awareness enabling informed decisions on maintenance priorities and efficient effort allocation on these items. In addition, it enables the following:

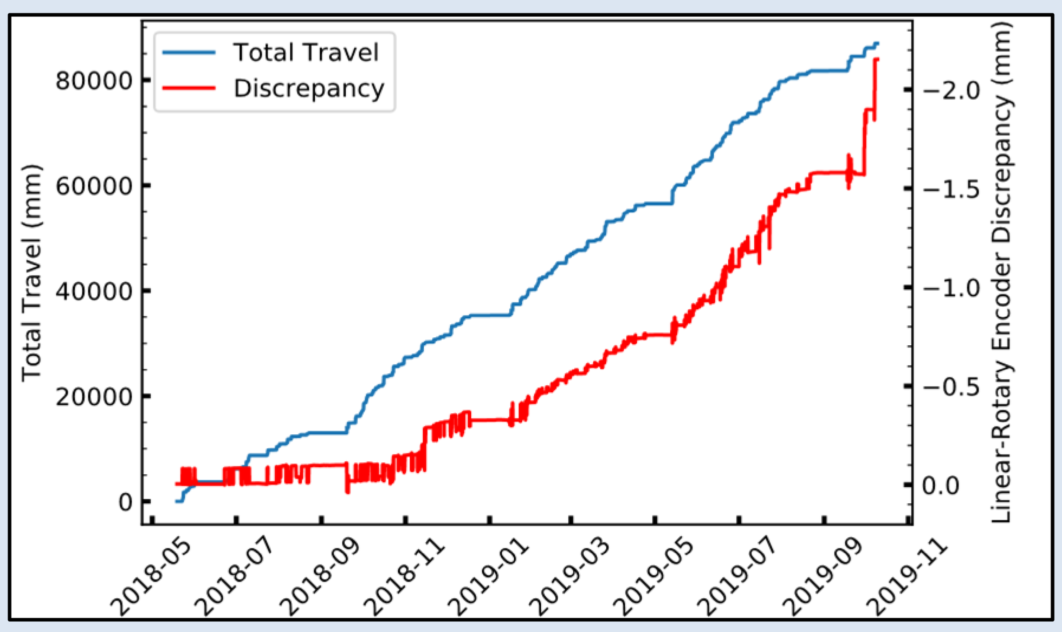
- Higher accuracy with interpolated calibration tables from collected data
- Improved quality assurance and checkout after installation
- Wear monitoring
- Better insight for areas of improvement and troubleshooting

Report Generation

During a maintenance or study period at the APS a python script sequentially commands each of the 53 devices to move at a slow speed while position data is collected over EPICS from both the rotary and linear encoders. Device specific information is pulled from Component Database (CDB) for determining appropriate variables for data collection and postprocessing. A report in html is generated using Jinja templates. The report also includes historical data on inferred total travel, typical positions, and settings used.

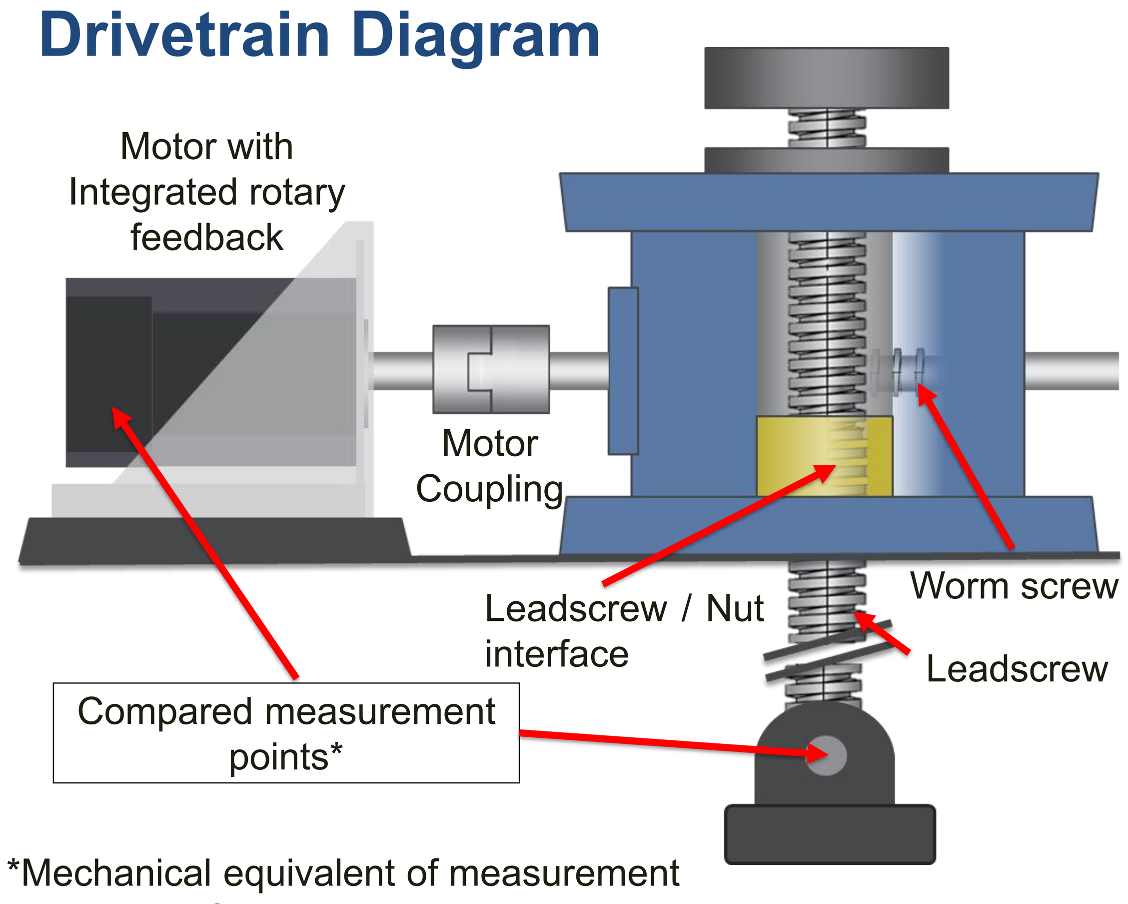


Example page contained in the automated report

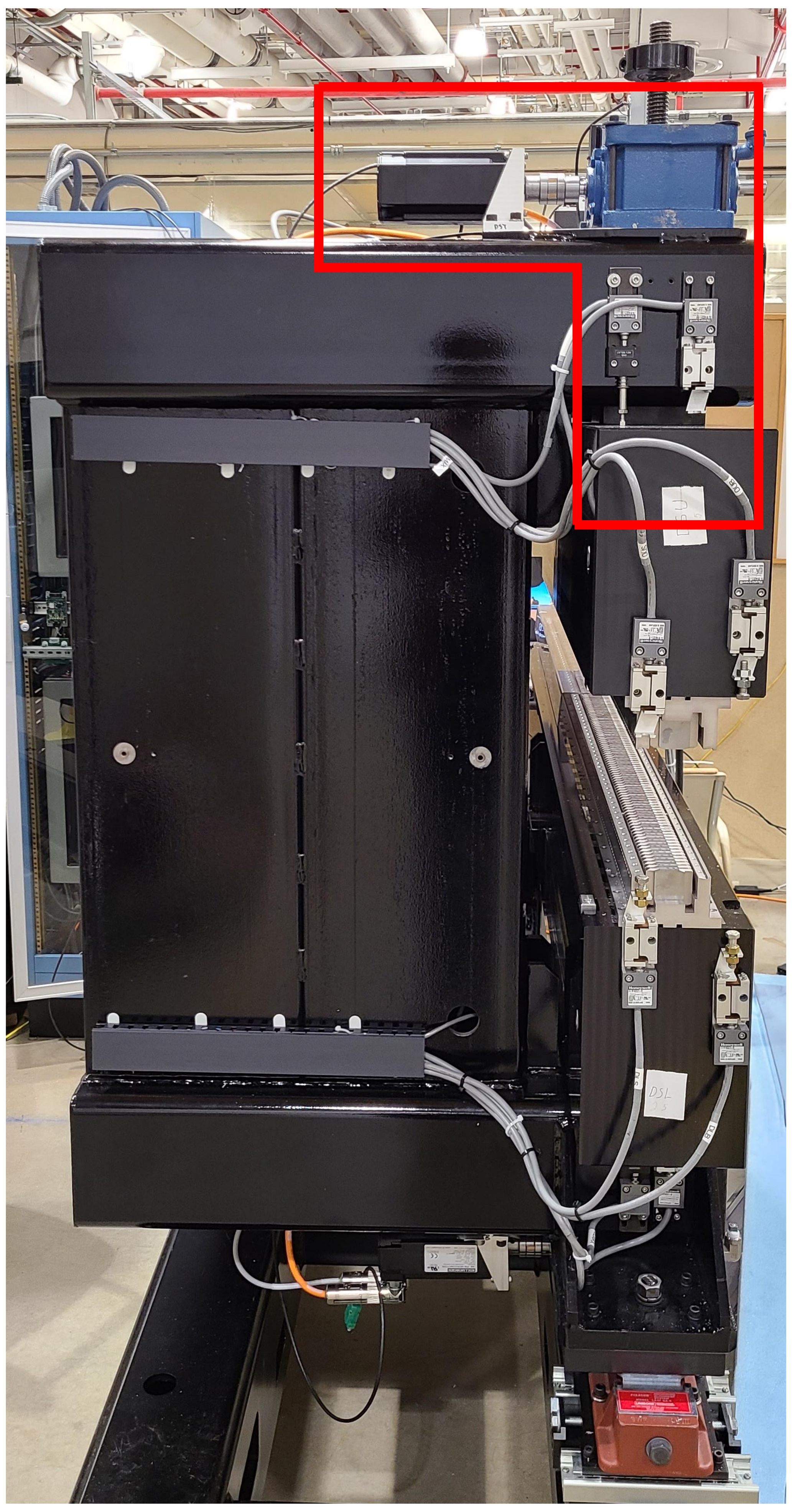


Graph showing wear that occurred undetected before the implementation of this work.

Drivetrain Diagram



*Mechanical equivalent of measurement point shown for linear encoder in diagram



Hybrid Permanent Magnet Undulator (HPMU) outside of the APS storage ring

Component	Repetition Distance [μm]	Amplitude [μm]
Rotary feedback	84.67	<< 1
Motor Coupling	84.67	< 1
Worm Drive	5080	< 3
Leadscrew / Nut	5080	< 4
Linear Encoder SDE	64	< 4

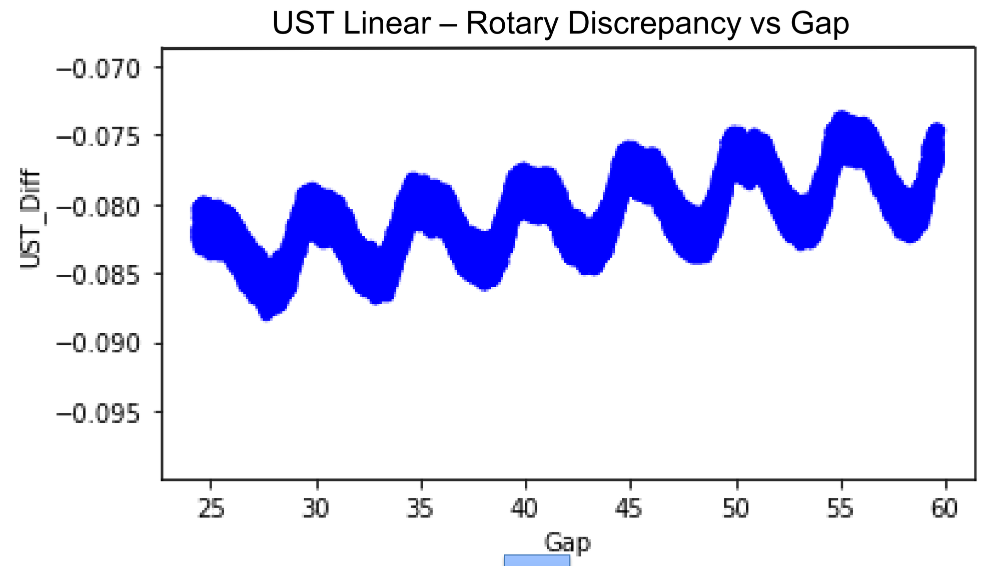
Table showing expected contribution and repetition cycle of various drivetrain components based on manufacturing and installation tolerances

Acknowledgements

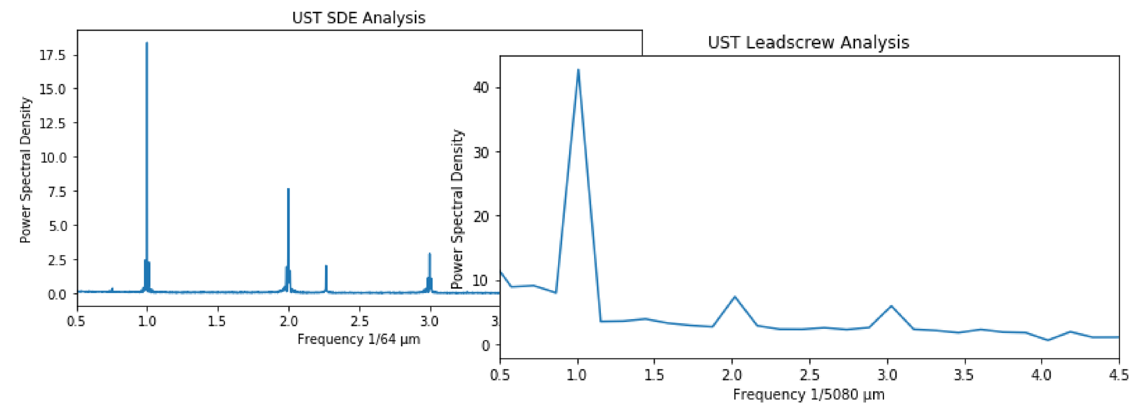
Work was supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357

Data Flow for Extracting Actionable Signatures

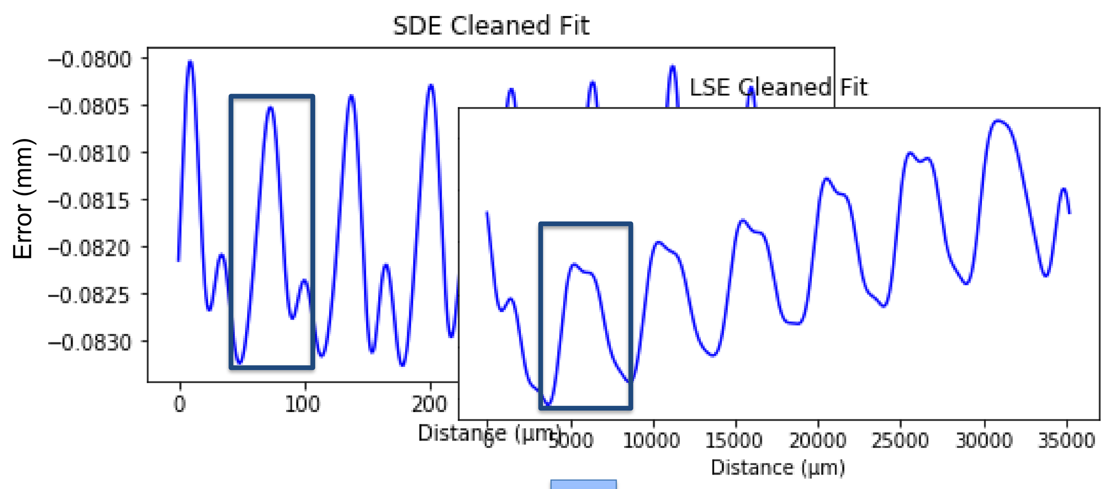
The discrepancy between rotary encoder and linear encoder readbacks is first calculated. At this stage, the graph can be used to identify major problems such as weak compensation springs, binding, or major alignment problems.



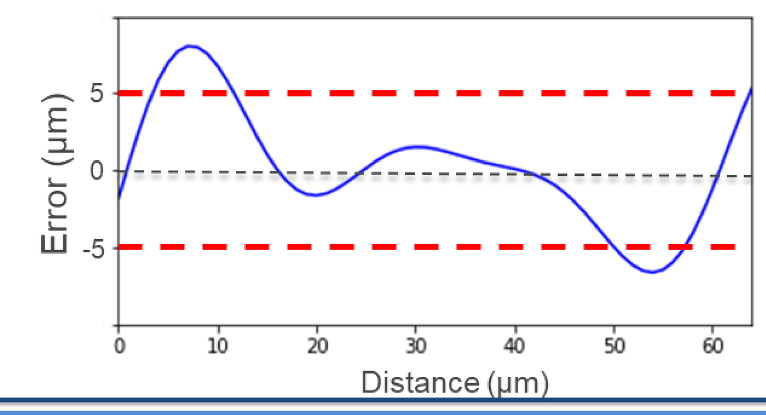
Get FFT and PSD to verify signal presence and extract key signals.



Reconstruct clean signal to isolate component signature



Clearly display component error signature with bounds



Results

Since its beta implementation in 2019 this has contributed the following to operations:

- Identified over 15 devices with mechanical defects enabling proactive repairs preventing faults during operation
- Clearly revealed value and area of opportunity for improving linear encoder assembly and design
- Discovered and pinpointed part defect in newly constructed insertion device drivetrains
- Enabled ability to prioritize maintenance items to most effectively limit on-site presence during COVID-19 restrictions
- Provided objective metric for discussion of device mechanical performance and acceptance testing

Future Work

- Incorporate machine learning for anomaly detection and automatically classifying common defects
- Develop user friendly subset for implementation at other installation locations such as the Magnetic Measurement Facility
- Incorporate auto-calibration of linear encoders in APSU ID motion control system

Conclusion

A novel technique has been developed and successfully used over the past year that has been continually adding new insights and value to operations.