**Using frequency scanning interferometry for undulator gap measurements.**

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**Introduction**

Frequency Scanning Interferometry (FSI) is a well developed method of multichannel, remote, precise and absolute distance measurements. This system is successfully used to monitor shape changes of semiconductor tracker in ATLAS detector at LHC, CERN [[1]](#footnote-1). An FSI system was borrowed by SLAC from Oxford University, UK for a few weeks. It was installed in SLAC Magnetic Measurement Facility (MMF) on Undulator A. Series of tests was performed to check applicability of the system for monitoring gap change of variable gap undulators for LCLS-II project. Most of the tests were done by Oxford team and the results will be presented in a separate report. SLAC personal had access to the system for a week to do additional measurements. This paper presents results of the measurements made by MMF personal.

**System set-up**

An FSI sensor consists of a collimator and a retroreflector as a pair. Distance measured is an optical path difference between two arms of an interferometer; one is a constant short path inside the collimator and the second one is from the collimator to the retroreflector and back. No calibration was made to relate the measured optical path difference to a distance between any outside fiducials on the collimator or the retroreflector. Therefore, all measurements were to monitor changes in distances between the collimator and the retroreflector. Ten FSI sensors were installed on the undulator, equally distributed along the length; 5 sensors were secured on front side and another 5 placed on the back side of the undulator, as shown in figure 1.



Figure 1 Sensor placement on undulator jaws.

FSI sensor consists of a collimator and a reflector. Sensors # 1÷5 are placed on the back side of the undulator and sensors # 6÷10 are on the front side. Keyence sensors secured on US and DS ends close to the center line. Curley scales and encoders are 22 cm off the magnetic axis horizontally. Jaw screws are located along the magnetic axis ~50 cm from block ends; two on top and two on the bottom jaws.

Undulator had two Curley glass scales with encoders to control the gap. They are located above the top jaw and shifted 22cm horizontally from magnetic axis. Additionally, two Keyence sensors were secured on Upstream and Downstream ends of jaws close to the magnetic axis to control the gap change. Measuring range of the Keyence sensors was limited to gap change from 8.5mm to 21mm. Distances between collimators and retroreflectors were close to 44 cm.

After the undulator gap is set by using Curley scales, FSI and Keyence measurements are done and compared to the scale readings.

FSI measurements are fast (a few seconds) but processing of the raw data takes a few minutes since the data analysis system was not made for our purposes. There was no quick feedback, like a single number for each distance measured. First, a special program was used to calculate measured distances. Second, the calculated distances should be retrieved from data files by using another program. After that, the numbers could be copied and pasted to Excel worksheet for final analysis. This issue limited number of possible experiments in the given time frame.

**Undulator gap stability**

Stability of the gap was tested by taking FSI measurements every 15 minutes over 2.5 hours. Gap was set to 20mm and all gap motors switched OFF. Results show that gap gets smaller in time at rate ~1µm/hour (see figure 2).

Figure 2 Stability of the undulator gap over time. All gap motors are off.

If FSI system would drift, all channels will show the same change since the measurements are done simultaneously. This is not the case; therefore we suppose that all differences come from mechanical deformations.

Channels on the back side of the undulator show a change twice smaller than the ones on the front side. Note that retroreflector of channel #8 was mounted on bench granite and shows the motion of the top jaw. Differences between channel #8 and channels #7 and #9 are small. It could mean that the lower jaw stays more or less in the same position and top jaw goes down. It is not a parallel motion but one with a rotation.

**Mechanical backlash**

To measure mechanical backlash of the undulator system we did FSI measurements at different gaps while opening and closing the gap. For this and the future tests positive direction of jaw motion is when gap opens and negative direction of the motion is when gap closes.

First, we set the gap to 12mm 5 times by moving jaws in positive direction from the smallest gap possible, which is 8.5mm. Then we set the gap to 12mm 5 times again by moving jaws in negative directions, starting from 20mm gap. FSI measurements were done for all 10 gap settings. Average of 5 distances measured for positive jaw motion was calculated for each sensor and taken as sensor reference distance. Differences from appropriate reference distance were calculated for all sensors and plotted separately for front and backside lines, as shown in figure 3.

Sensor # 8

Figure 3 Undulator mechanical backlash.

Measurements are repeatable to ±3µm if direction of gap setting is the same. Both front and rear sensors show huge backlash. An average of corresponding sensors; # 1 and # 10

((-14 µm –82 µm)/2 = -48 µm) for upstream end and #5 and #6 ((-12 µm - 82 µm)/2 = -47 µm) for downstream end of undulator, which gives us backlash at magnetic axis, agrees with Keyence measurements (-46µm and -44µm). Sensor #8 shows a half of backlash, which indicates that top and bottom jaw backlash are about the same.

In the next test to eliminate the mechanical backlash from the measurements we tried to set the gap by moving the jaws always in the same direction (positive). In this test gap was changed from 8.5mm to 50 mm and back. In backward motion we set the gap 1mm smaller (overshot) and then opened it back to desired value. Measurements were done for 9, 12, 15, 20, 25, and 30mm gaps. Retroreflector #8 was fixed on the granite and did not move. Differences between FSI sensor readings for the same gaps (forward – backward) are shown in figure 4.

Figure 4 Accuracy of gap setting. Jaw motion is always positive.

The rear side sensors showed different motion w.r.t. front side sensors, i.e. the jaws did not move parallel to each other (change in cant angle depends on gap). Gap at magnetic axis (an average number between front and rear sensors) could not be set better than ±5µm. Such a low accuracy in setting the gap makes it impossible to measure magnetic hysteresis in undulator poles.

**Conclusion**

FSI system proved to be a very useful tool to study mechanical deformations of undulator structure. As a non-contact and precise method of distance measurements it could be used for undulator gap control system if data processing time will be reduced to a few seconds.

The tests show poor mechanical stability of the undulator A:

- the gap drifts in time at rate 1µm/hour,

- jaws do not move parallel to each other resulting in change of cant angle between the poles,

- huge ~50µm backlash in setting the gap.

Taking into account all this, measuring of magnetic hysteresis in poles is not possible on this undulator.

1. P.A. Coe, D.F.Howell and R.B.Nickerson “Frequency scanning interferometry in ATLAS: remote, multiple, simultaneous and precise distance measurements in a hostile environment” Meas. Sci. Technoll. 15 (2004) 2175-2187 [↑](#footnote-ref-1)