ABSTRACT

Spectroscopic target acquisitions with COS begin with the ACQ/PEAKXD procedure, which centers the external target in the science aperture in the cross-dispersion direction. During this procedure the external target is observed through the Primary Science Aperture (PSA) or Bright Object Aperture (BOA) and the Pt-Ne hollow cathode lamp is flashed on to produce an emission line spectrum in the Wavelength Calibration Aperture (WCA). The separation between the centroids of the WCA and PSA (or BOA) spectra is measured and compared to the known separation between the WCA and the center of the PSA (or BOA). In this way, the slew required to move the target to the center of the PSA (BOA) in the cross-dispersion direction is determined. This procedure requires an accurate measurement of the center of the WCA spectrum in the cross-dispersion direction. Each CENWAVE setting has a different distribution of emission lines from the Pt-Ne lamp on the NUV detector. Due to effects such as lamp aging and optics select mechanism (OSM) drift, the flux in the WCA spectrum for a given CENWAVE can change with time, and it is possible that some settings do not provide enough flux to reliably measure the center of the WCA spectrum. In this ISR we use all available NUV WCA data from 2010 Jan 01 through 2016 Oct 07 to determine which CENWAVE settings are optimal for the ACQ/PEAKXD procedure. These optimal settings are recommended in the Cycle 25 COS Instrument Handbook.
1. Introduction

Observers using the Cosmic Origins Spectrograph (COS) can choose from 4 different target acquisition schemes to center the target in the science aperture (Debes et al. 2016). The ACQ/PEAKXD procedure uses dispersed light from both the target and Pt-Ne (Platinum-Neon) hollow cathode wavelength calibration lamp to center the target in the aperture in the cross-dispersion direction. Aging of the Pt-Ne lamps and secular drift of the optics select mechanisms (OSMs) can alter the emission line spectrum observed with specific instrument settings over time, and because the Pt-Ne lamp spectrum is required for ACQ/PEAKXD, it is worthwhile to investigate the behavior of the Pt-Ne emission line spectra over the lifetime of COS onboard the Hubble Space Telescope (HST). Herein we focus on the NUV detector, examining Pt-Ne spectra during the period 2010-01-01 through 2016-10-07. The objective of this study is to determine whether or not each NUV CENWAVE setting is suitable for use with the currently defined ACQ/PEAKXD procedure, and to provide a table of optimal CENWAVE settings as recommendations to the COS user community.

2. Description of PEAKXD

As this report focuses on the ACQ/PEAKXD procedure, it is necessary to provide a brief overview of what this procedure does, and why. For an in-depth description of ACQ/PEAKXD, please see Penton & Keyes (2010): On-Orbit Target Acquisitions with HST+COS.

The purpose of ACQ/PEAKXD is to use dispersed light to center the science target within the primary science aperture (PSA) or bright object aperture (BOA) in the
cross-dispersion direction. The separation between the wavelength calibration aperture (WCA) and the center of the PSA (BOA) in pixels is a known quantity. By measuring the separation between the WCA spectrum and the un-centered target spectrum, the slew required to move the target to the center of the PSA (BOA) is computed. During this procedure, the WCA is illuminated by a Pt-Ne lamp which is turned on for 17 s, producing emission line spectra on the three NUV stripes. Sub-arrays that contain each of the individual stripes have previously been defined\(^1\) and a single stripe is chosen (default is stripe B) and is collapsed along the dispersion direction (i.e., sum of counts on each detector row). The position of the spectrum is found by taking the point where the cumulative distribution function of this collapsed spectrum equals 0.5. In other words, this is the median of the collapsed spectrum with half of the counts in the sub-array falling on lower rows, and half of the counts falling on higher rows. This same analysis is then performed to find the center of the science target spectrum, and the separation between the two is calculated and utilized as mentioned above. The measured separation between the WCA spectrum and PSA (BOA) spectrum includes uncertainties associated with finding the centers of both spectra. Our investigation here is focused on how well the above procedure determines the centroid of the collapsed WCA spectra.

3. Analysis & Findings

We utilize two different methods in analyzing Pt-Ne lamp spectra, the first based on lampflash tables and the second based on rawtag tables. Lampflash tables are created from TIME-TAG data when the lamp is flashed concurrently with the science exposure, and contain 1-dimensional spectra extracted from the WCA with count rate (counts s\(^{-1}\)) as a function of wavelength (Å), with a separate spectrum for each flash of the lamp. Rawtag tables contain raw \(x\)-position, raw \(y\)-position, and time after start of exposure (s) for all events recorded by the detector. More detailed descriptions of these data products are given in the COS Data Handbook (Fox et al. 2015). Spectroscopic target acquisitions are performed using \(FP-POS=3\), so we use data exclusively with that setting in our analysis. One caveat that must be stressed is that for all of the data analyzed herein the WCA was illuminated with Pt-Ne Lamp #1, while actual target acquisitions use Pt-Ne Lamp #2. The Lamp #1/Lamp #2 count rate ratio is about 1.1 over all NUV gratings (Penton et al. 2017; in preparation), so it is expected that any conclusions should apply regardless of the lamp used.

3.1 Lampflash

Our dataset of NUV lampflash files includes those produced from observations with \(FP-POS=3\) taken between 2010 Jan 01 and 2016 Oct 07 (date of analysis). This date range excludes observations taken during the SMOV (Servicing Mission Observatory Verification) period, when non-standard settings were used. Using these data, we an-
Figure 1. Lampflash spectra taken at FP-POS=3, G185M, CENWAVE=1921 on Stripe B over the lifetime of COS. Spectra are shifted vertically for clarity, with more recent spectra appearing higher on the plot. The black dashed line at the top is the WCA template spectrum taken from the NUV LAMPTAB reference file ult1616ol.lamp.fits. Similar plots have been produced for all CENWAVE settings at Stripes A, B, and C, but we only include one here as an example.
alyze the Pt-Ne emission line spectra in the 3 WCA stripes on the NUV detector for all CENWAVE settings where data exist. A plot of all lampflash spectra taken at a single CENWAVE setting is shown in Figure 1 for CENWAVE=1921, Stripe B of G185M. Note that both ends of the spectra are padded with zeros for reasons related to the calcos pipeline.

For all of these spectra we calculate 4 metrics: deviation from template wavelength coverage, peak count rate, integrated count rate, and root-mean-squared (RMS) noise level. It is clear from Figure 1 that the wavelength coverage is not constant in time. There is an overall drift toward longer wavelengths with time, and a scatter of about ±2 Å in exact wavelength coverage between individual observations. These are due to a combination of secular drift of the OSMs and OSM position uncertainty. Because of these variations, Pt-Ne emission lines can “fall off” of the detector, thus reducing the integrated count rate for a given CENWAVE setting. The deviation from template wave-

![Graphs showing metrics from lampflash spectra.](image)

**Figure 2.** Metrics from lampflash spectra at FP-POS=3, G185M, CENWAVE=1921 on Stripe B over the lifetime of COS. **Top Left:** Deviation from the wavelength coverage of the template spectrum. **Top Right:** RMS noise level (red points) and the 1σ standard deviation (blue points) in a line-free region. **Bottom Left:** Maximum count rate in a pixel within the spectrum. **Bottom Right:** Integrated count rate within Pt-Ne emission lines in the spectrum.
length is the difference (in Å) between the shortest wavelength in a given lampflash spectrum and the shortest wavelength in the template spectrum taken at the same settings. The peak count rate is simply the maximum count rate from a single pixel within the spectrum; note that time-dependent sensitivity (TDS) corrections are not applied to the count rates reported for WCA spectra. The RMS noise level is calculated over a 2 Å window that is free of Pt-Ne emission lines at each setting. The integrated count rate is the sum of count rates in all pixels that have count rates above 3 times the RMS noise level. These 4 metrics are shown in Figure 2 versus date of observation.

In order to determine whether or not to recommend a CENWAVE setting for use in the ACQ/PEAKXD procedure we applied three criteria to the Pt-Ne lampflash spectra. A setting must pass all three criteria on the same NUV stripe to be recommended. The three criteria are:

1. The integrated count rate in a spectrum must be greater than $\sim 53$ counts s$^{-1}$. This corresponds to a signal-to-noise ratio (S/N) of 30 in the collapsed profile.

2. No emission line contributing significantly to the integrated count rate may be within 100 pixels of the edges of the detector.

3. Integrated count rates predicted for 2018 Jul 01 (75% of the way through Cycle 25) must be greater than 53 counts s$^{-1}$.

Justification for these criteria are as follows. (1) The ACQ/PEAKXD procedure must find the centroid of the Pt-Ne spectrum collapsed in the dispersion direction. The number of counts in this collapsed profile is given by the product of the integrated count rate in the spectrum and the length of time that the Pt-Ne lamp is turned on (default 17 s). With 53 counts s$^{-1}$ for 17 s, there will be $\sim 900$ counts from Pt-Ne emission lines in the collapsed spectrum providing S/N$\sim 30$. (2) The scatter in wavelength coverage between spectra—caused by non-repeatability in the positioning of the two OSMs—amounts to a particular wavelength falling somewhere within ±60 pixels of its location in the LAMPTAB reference file. A strong emission line near the edge of the detector has the potential to “fall off” of the detector during any given observation, thus reducing the integrated flux below our cutoff limit. (3) The efficiencies of the bare aluminum gratings G225M and G285M are declining with time at rates of $-3\%$ yr$^{-1}$ and $-11\%$ yr$^{-1}$, respectively, due to reaction with oxygen. As a result, the sensitivity of COS while using these gratings is also declining, and lampflash spectra that meet our $\geq 53$ count s$^{-1}$ limit at present may not in the future. Using the relations for relative sensitivity as a function of time presented by Taylor (2016) we predict integrated count rates for 2018 Jul 01. Table I gives the CENWAVE settings where at least one NUV stripe meets our 3 criteria.

While the criterion that the integrated count rate in a lampflash spectrum be greater than 53 counts s$^{-1}$ selects the best CENWAVE settings, it is possible that many Pt-Ne spectra with lower integrated count rates will still enable the ACQ/PEAKXD procedure to find the centroid of the spectral profile to within the required accuracy. The
Table 1. Recommended CENWAVE settings for use with NUV ACQ/PEAKXD

<table>
<thead>
<tr>
<th>Grating</th>
<th>Stripe A</th>
<th>Stripe B</th>
<th>Stripe C</th>
</tr>
</thead>
<tbody>
<tr>
<td>G185M</td>
<td>1882, 2010</td>
<td>1786, 1913, 1921, 1941</td>
<td>1817, 1835, 1941, 1986</td>
</tr>
<tr>
<td>G225M</td>
<td>2373</td>
<td>2250, 2283, 2306</td>
<td>2339, 2390</td>
</tr>
<tr>
<td>G285M</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>G230L</td>
<td>2950, 3000, 3360</td>
<td>2635, 2950, 3000, 3360</td>
<td>...</td>
</tr>
</tbody>
</table>

Note. — These are the CENWAVE settings recommended for use with ACQ/PEAKXD given the criteria discussed in Section 3.1. The ACQ/PEAKXD uses Stripe B as the default, so only the settings in that portion of the table are given in the Cycle 25 COS Instrument Handbook (Fox et al. 2017).

contract end item (CEI) requirement for target acquisition with COS is that the target be centered in the science aperture with an accuracy of 0.3″. With an average NUV plate scale of 23.825 mas pixel$^{-1}$ in the cross-dispersion direction (Béland & Ghavamian 2010) this amounts to $\sim$ 13 pixels. Because the centroids of both the Pt-Ne spectrum and target spectrum must be located, the allowed error in each is $6\sqrt{2}$ pixels. A more stringent requirement of centering the target to within 0.1″ ($2\sqrt{2}$ pixel error per spectrum centroid) is our nominal goal.

3.2 Rawtag

To check whether or not the ACQ/PEAKXD procedure finds the centroid of the spectral profile within $2\sqrt{2}$ pixels in the cross-dispersion direction we utilize rawtag tables. These files contain data in the same state as seen by the COS flight software when the ACQ/PEAKXD procedure is executed on orbit. We only use data from the time period when the Pt-Ne lamp is on, up to a maximum of 17 s, so as not to overestimate the contribution from dark counts. A 2-D spectral image produced from an NUV rawtag table is shown in the left-hand portion of Figure 3. Overlaid on the image are boxes showing the sub-arrays used in calculating the median position of the three NUV WCA stripes. The right-hand portion of Figure 3 shows the image collapsed in the dispersion direction, such that the total number of counts in each row is plotted as a function of detector row. Dashed grey lines mark the medians calculated within each stripe-specific sub-array. Solid orange lines mark the profile centroids calculated as

$$y_{cen} = \frac{\sum_i N_i y_i}{\sum_i N_i}, \quad (1)$$
where \( N_i \) is the number of counts in row \( y_i \), and the sum is performed over the range \((y_{\text{max}} - 30) \leq i \leq (y_{\text{max}} + 30)\), with \( y_{\text{max}} \) being the row in the sub-array where \( N_i \) reaches a maximum. Differences (\( \Delta y \)) between the profile centroid (taken to be the true center) and median (equivalent to what the ACQ/PEAKXD procedure finds) for each stripe are also given in the right-hand side of Figure 3. In this particular case (G185M; CENWAVE=1921) the ACQ/PEAKXD routine should successfully find the Pt-Ne lamp profiles on all three NUV stripes to within 1 pixel. Stripe B at this setting is recommended in Table 1 because it has an integrated count rate of \( \sim 130 \) counts s\(^{-1}\), but stripes A and C at \( \sim 20 \) counts s\(^{-1}\) and \( \sim 40 \) counts s\(^{-1}\), respectively, do not meet our criteria. While this might suggest that we have been overly conservative in selecting a cutoff for integrated count rate, we must note that all of the Pt-Ne spectra fall near the centers of their respective sub-arrays in this example. Figure 4 shows an example where the Pt-Ne spectrum on stripe B falls near the very edge of the sub-array. Because

![Figure 3. Left: Zoom in on the portion of a rawtag image containing the WCA spectra at FP-POS=3 for CENWAVE=1921 (G185M). Dashed boxes mark the sub-arrays used in the ACQ/PEAKXD procedure for stripes A (red), B (blue), and C (purple). Greyscale stretch goes from 0 counts (white) to \( \geq 3 \) counts (black). Right: Histogram showing the spectra collapsed along the dispersion direction. Solid lines mark the \( y \)-limits of the sub-arrays. Grey dashed lines mark the medians determined for each stripe and solid orange lines mark the profile centroids—calculated as described in the text—and the values \( \Delta y \) are the absolute differences between the two.](image)
of the noise level in the collapsed profile, the median calculated in the sub-array is skewed away from the true centroid, and CENWAVE=2676 (G285M) should clearly not be recommended. The integrated count rate in the associated lampflash spectrum is \( \sim 30 \) counts s\(^{-1}\).

4. Summary

Spectroscopic target acquisitions for COS in the NUV require that the centroid of the Pt-Ne emission spectrum in the WCA be located to within \( 6\sqrt{2} \) pixels (nominally \( 2\sqrt{2} \) pixels) in the cross-dispersion direction. The ability of the ACQ/PEAKXD routine to do this depends on the total flux in Pt-Ne emission lines and the location of those lines in the sub-array over which the median position is calculated. Based on an analysis of lampflash spectra we define three criteria which must be met in order for a CENWAVE setting to be recommended. The final table of recommended settings (Table \[1\] herein) has been included in Section 2.6 of the Cycle 25 COS Instrument Handbook. As other CENWAVE settings may still provide the required accuracy for the ACQ/PEAKXD procedure, we will consider them on a case-by-case basis using the analysis presented in Section 3.2 should a user request non-recommended CENWAVE settings during Phase II preparations. Note that such a request will require justification (e.g., target exceeds...
count rate limits at recommended CENWAVE settings; time required to change from acquisition to science CENWAVE significantly impacts science goals).

References
Debes, J., et al., 2016, COS Instrument Handbook, Version 8.0 (Baltimore: STScI)
Fox, A. J., et al., 2015, COS Data Handbook, Version 3.0 (Baltimore: STScI)
Taylor, J., 2016, COS Instrument Science Report 2016-10

Appendices
The equivalent of Figures 1 and 2 for all 49 NUV CENWAVE settings on stripes A, B, and C are available online as supplementary material. Appendices A, B, and C contain the lampflash spectra taken at FP-POS=3 over the lifetime of COS on NUV stripes A, B, and C, respectively, with a separate figure for each CENWAVE setting. Appendices D, E, and F contain the various metrics (i.e., deviation from wavelength coverage of template spectrum, RMS noise level, maximum count rate in a single pixel, integrated count rate within Pt-Ne emission lines) determined from lampflash spectra over the lifetime of COS on NUV stripes A, B, and C, respectively, with a separate figure for each CENWAVE setting.

Appendix A:
Appendix B:
Appendix C:
Appendix D:
Appendix E:
Appendix F: