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Modularity and Service Robustness of ePAT 601 Blend Monitor

Purpose

This document describes the testing of the ePAT 601 with regard to modularity and service robustness. Document 601-RR-20-0011-C in section 8.0 Risks and Failure Mode, identified a number of components that could fail which would need a service replacement. Replacement of optical components in particular could have an effect on the quality of the spectra.

Scope

In order to give a fast servicing ability, Expo have taken the approach to define field replaceable units (FRUs) instead of trying to troubleshoot a part on the customer site. In this case, there are robustness issues if a major component is replaced which might have an effect on the quality of the spectra. It will never be possible to guarantee that the customer's calibrations will never be affected after servicing, but the effects of changing a component should be minimised. Major FRUs identified were: spectrometer module, probe head, umbilical, embedded computer stack, status display board and fans. The only components that were identified as having an impact on spectral quality were the spectrometer and head/umbilical. Robustness issues therefore concentrated on the effect of swapping these components on the quality of spectra obtained.

Test Procedures

Various combinations of spectrometers and heads with different umbilicals were tested. Standard validation tests were performed in the NovaPAC software to check instrument performance. Repeatability of the x and y axes between instruments was deemed to be the best way of testing that spectra were similar before and after replacing a component.

1. Wavelength Accuracy

If the spectra are accurately fixed on the x-axis, then the peak position between components will be good. This is the first step to ensuring data is as close as possible between units. The wavelength accuracy was tested with the traceable Avian VisNIR standard.

2. Photometric Linearity

The photometric linearity test deals with repeatability of the y-axis, 6 absorbance standards (5, 10, 20, 40, 60, 80% reflectivity) were measured and compared. This can be over time on the same instrument or between spectrometers and heads. The absorbance values of the standards were measured at 1600 nm.

Test Results

1. Wavelength Accuracy

The results from various spectrometers and heads (40 mm spot) are tabulated below:

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S'meter S/N	Probe S/N	Temperature °C	Delta 1534.6 nm	Delta 1681.4 nm	Delta 1757.6 nm
105	BP007	~20	-0.65	0.78	0.43
105	BP006	~20	-0.62	0.74	0.43
118	BP006	~20	-0.63	0.74	0.43
118	BP007	~20	-0.64	0.79	0.44
138	BP007	22	-0.66	0.80	0.44
138	BP007	10	-0.64	0.78	0.44
138	BP007	32	-0.64	0.77	0.44
*138	BP007	~22	-0.59	0.70	0.43
*138	BP007	~22	-0.61	0.72	0.44
153	BP006	~20	-0.66	0.77	0.44
153	BP022	24	-0.66	0.78	0.43
154	BP022	25	-0.68	0.80	0.43
		Range	**0.09**	**0.10**	**0.01**

*The results for 138/BP007 were after the probes had been removed and replaced.

This data shows excellent reproducibility between different spectrometers and heads. The maximum difference between any combination of four spectrometers and two heads over a 10-32°C temperature range was only 0.10 nm.

Only one 10 mm head was available. The results after removing and replacing the head and on other spectrometers are tabulated below:

S'meter S/N	Probe S/N	Temperature °C	Delta 1534.6 nm	Delta 1681.4 nm	Delta 1757.6 nm
138	BP018	~22	-0.58	0.67	0.43
138	BP018	~22	-0.58	0.67	0.43
138	BP018	~22	-0.57	0.67	0.44
153	BP018	23	-0.64	0.76	0.43
154	BP018	23	-0.64	0.76	0.44
		Range	**0.07**	**0.09**	**0.01**
		Range 10/40 mm	**0.09**	**0.13**	**0.01**

The data between replacing heads is very repeatable. The data between the 10 and 40 mm spot size heads also looks very good. The worst case was only 0.13 nm difference. This data suggests that wavelength accuracy is excellent between spectrometers and heads.

2. Photometric Linearity

The absorbance values of various standards at 1600 nm using 40 mm heads are tabulated below:

S'meter S/N	Probe S/N	5% Std	10% Std	20% Std	40% Std	60% Std	80% Std	Slope	I'cept
105	BP007	1.164	0.974	0.726	0.427	0.244	0.101	0.985	0.002
105	BP006	1.197	0.984	0.731	0.435	0.249	0.103	1.005	0.004
138	BP007	1.211	1.048	0.699	0.409	0.235	0.085	0.999	0.000
138 (10°C)	BP007	1.199	1.040	0.698	0.406	0.237	0.085	0.989	0.003
138 (35°C)	BP007	1.164	1.031	0.691	0.401	0.236	0.085	0.965	0.008
*138	BP007	1.172	0.998	0.662	0.449	0.255	0.108	1.002	0.002
*138	BP007	1.185	0.967	0.666	0.447	0.248	0.108	0.978	0.008
153	BP006	1.221	0.994	0.737	0.439	0.247	0.101	1.003	0.002
153	BP022	1.167	0.987	0.719	0.431	0.242	0.099	0.969	0.003
154	BP022	1.181	0.991	0.727	0.432	0.245	0.102	0.978	0.004
	Range	**0.057**	**0.081**	**0.075**	**0.048**	**0.020**	**0.023**		

*The results for 138/BP007 were after the probes had been removed and replaced.

A number of these results were obtained without re-standardising between spectrometer or probe changes. The results at 10 and 35^{o}C for example passed the linearity test after standardising at 20^{o}C.

Only one 10 mm head and was available. The instrument was not re-calibrated between the 40 and 10 mm heads. The results after removing and replacing the head and with a second spectrometer are tabulated below:

S'meter S/N	Probe S/N	5% Std	10% Std	20% Std	40% Std	60% Std	80% Std	Slope	I'cept
138	BP018	1.143	0.953	0.663	0.433	0.242	0.100	0.976	0.005
138	BP018	1.208	0.916	0.649	0.442	0.240	0.098	0.983	0.005
154	BP018	1.162	0.951	0.707	0.408	0.242	0.097	0.956	0.001
	Range	**0.065**	**0.037**	**0.058**	**0.025**	**0.002**	**0.003**		

The linearity of the 10 mm head is very similar to that of the 40 mm heads as the slope and intercept results passed without any changes to the absorbance values. Small changes between absorbance values after removing and replacing the head were noted.

Conclusions

Wavelength accuracy between heads and spectrometers is excellent. The maximum difference found between four spectrometers and two heads (40 mm) was 0.10 nm over a 22^{o}C temperature range. The 10 mm head was only tested on one spectrometer, but repeatability of removal and replacement was excellent. Even the wavelength accuracy between head types was very good. The maximum difference was 0.13 nm.

There are small changes between the absorbance values on different spectrometers and heads. The linearity of absorbance values between spectrometers and 40 and 10 mm heads is good. The 10 mm head will pass a test on values obtained from a 40 mm head for example.

Customers may need to change heads for a different spot size and then replace the original head. This data has shown that removing and replacing a head has very little impact on the repeatability of the x and y axes. Hence, the risk associated with changing heads is low on the integrity of the data.

Document 601-RR-20-0011-C in section 9.0 Categorization, the risk of failure of the spectrometer or head was deemed to be medium. However, the severity of a failure would be high as the system would be unusable without the spectrometer or detector working properly. The performance robustness document (601-18-0108-C) has shown that instrument tests are very specific and that poor performance would be easily detected.

The data in this document has shown that wavelength and absorbance accuracy between spectrometers and heads is close, but not identical. This is a good building block for ensuring data integrity after replacing a spectrometer or head. Whether these small changes will affect the customer's calibrations is not clear and will probably be application dependant. Hence there is a possible impact on the customer’s methods after changing a spectrometer or head.

Recommendations are that users regularly run instrument diagnostics to check that the spectrometer and head are operating properly, especially after changing a head. Users should also use a ‘check sample’ similar to the product that they are analysing with the instrument. This can be run on a day of use basis to obtain a known qualitative or quantitative result. These results can then be control charted to determine the normal variability of the result under typical working conditions. If the diagnostic tests fall out of specification, it will then be known that a service visit will be required. If a spectrometer or head then needs to be replaced, the user can then repeat the diagnostic tests and the check sample. If both results are within known limits that have been determined previously, then the system should work normally on new samples. If the diagnostics fail, that would be a continuing service issue for Expo. If the diagnostics pass and the check sample fails, the customer may have an ongoing method calibration issue. They would need to run some validation samples against their method to check for any changes. If a problem was found, then the method would need to be updated with new samples from the repaired instrument.

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