Determination And Validation Of The Spectral Power Distribution (SPD) OF Artificial Weathering (Lightfastness) Instruments

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Abstract

Automatically controlled irradiance (Ci) laboratory weathering (lightfastness) instruments were first introduced in 1970. The technology has since become universally used. Today, virtually all lightfastness standards specify irradiance control, and all major manufacturers of lightfastness instruments currently offer instruments that feature a version of irradiance control. Until now, controlled irradiance devices have been limited to maintaining and providing irradiance data at, or about, a single wavelength or wavelength range. With the introduction of Atlas Material Testing Technology's proprietary on-board, real-time full spectrum monitoring (FSM) system, the complete spectral power distribution (SPD) of the light source can now be displayed.

History And Evolution Of Light In Weathering And Lightfastness Tests

As the name obviously implies, light is the most important aspect of natural and simulated lightfastness tests. Numerous excellent studies of it's importance to the can be found in industry literature.

The first, fairly crude, laboratory weathering tests employed carbon arc lamps as the solar simulator. Instruments using xenon arc light sources, which are inherently superior solar simulators, eventually succeeded such devices. Figure 1 shows a comparison of solar radiation and filtered xenon spectra.

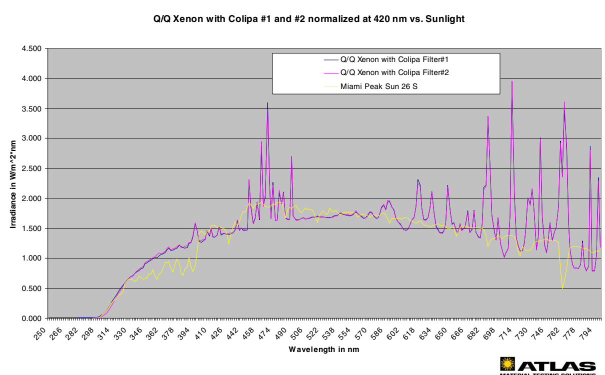

Figure 1. *Comparison of spectral power distribution of natural sunlight and filtered xenon.*

As with other light sources, the output of a xenon arc will vary with electrical input power, the stability of its enclosure and surrounding optical filters. The filters will generally tend to degrade or solarize with use. The combination of these variables will adversely affect the quality and quantity of light that impinges upon test specimens.

Resulting variations in light output will also cause unreliability in test results, given its importance to the lightfastness phenomenon. The control irradiance feature which is designed to automatically hold the output at one wavelength range constant throughout a test, is intended to maintain the irradiance, especially that in the ultraviolet range, thereby mitigating the negative impact of variable light on test results. This feature, which was introduced by Atlas Material Testing Technology LLC in 1970 represented a significant step at the time, and has since served the weathering community well. All major manufacturers of weathering instruments currently offer instruments that feature a version of irradiance control.

However, controlled irradiance technology, which, in principle, is very similar regardless of supplier, is not without some notable weaknesses. It provides information only at the single wavelength (or wavelength range) for which it is configured. Secondly, the systems have little or no flexibility. The user, for the most part, is restricted to controlling and monitoring a test at the wavelength which had been pre-selected and which may only be changed to another single wavelength (range) by tedious hardware reconfigurations often requiring complex recalibration.

Full Spectrum Monitoring (FSM)

The introduction of the Full Spectrum Monitoring (FSM) system is the first major innovation for light control in laboratory weathering instruments in thirty years. It is meant to address the weaknesses associated with standard controlled irradiance, as well as to provide researchers the critical spectral data now being demanded by progressive weathering methodologies and approaches.

In contrast to with current technology which controls and/or monitor fixed, single, discrete portions of the xenon spectrum, the Full Spectrum Monitoring (FSM) system permits control of any single user-selected wavelength, or any user-selected wavelength range, while monitoring and collecting data at all other wavelengths in the 250-800nm range. The many implications of this capability are discussed later.

The system, which is fully integrated in an Atlas Weather-Ometer®, is meant to be used on a full time basis. As such, it is necessarily designed to be robust, to withstand the inherently hostile environment in, and around weathering instruments.

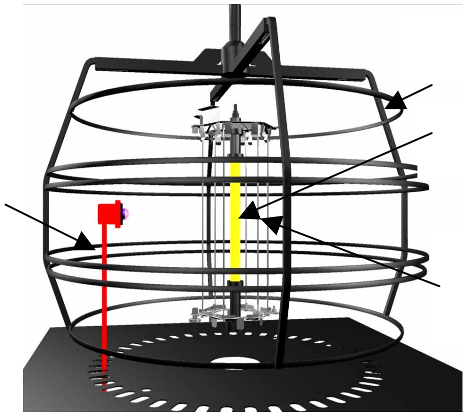

Figure 2. Graphical display of the lightfastness chamber interior. CCD array spectroradiometer is mounted below the test chamber.

Detailed specifications are proprietary, but in general the FSM system is comprised of a CCD array spectroradiometer with one nanometer resolution over a range of 250 – 800 nm, including order-sorting filters to ensure appropriate stray light rejection. Figure 2 shows the mounting of the input optics in the weathering chamber. The input optics system incorporates a sealed robust cosine receiver and patented quartz diffuser. An on-board industrial computer manages the system with customized software for system calibration, data management and user interface.

Comparison of FSM and Conventional Spectroradiometer:

ASTM G-138-03, *Calibration of a Spectroradiometer Using a Standard Source of Irradiance* [1] has become the normative standard for the calibration of spectroradiometers. A traditional spectroradiometer requires typically several pieces of hardware to comply with the ASTM standard, including a NIST-traceable irradiance standard, a calibrated digital voltmeter, a calibrated current shunt, wavelength calibration source, very stable power supply, etc. After calibration is complete, spectral irradiance measurements in a Weather-Ometer® are done as in situ in the weathering chamber. Both steps require a skilled operator.

Comparisons have been made between a standard spectroradiometer and the system used in the FSM configuration. The standard spectroradiometer (in this case, an Optronic Laboratories OL754) was calibrated by the ASTM procedure and set-up to make measurements in situ as described in the previous paragraph. The FSM was calibrated by its unique and proprietary technique. The FSM was used to make measurements immediately following the OL 754's measurement of different filter combinations, in the same Weather-Ometer and under identical conditions.

For each xenon filter combination, the spectral power distribution plots measured and produced by each system are virtually indistinguishable. In each case, numerical data at selected wavelengths and wavelength ranges also show excellent agreement for repeated, alternating measurements. See Figure 3 as a comparison between the two measurements. Numerical outputs of the two systems are shown at the bottom of the figure.

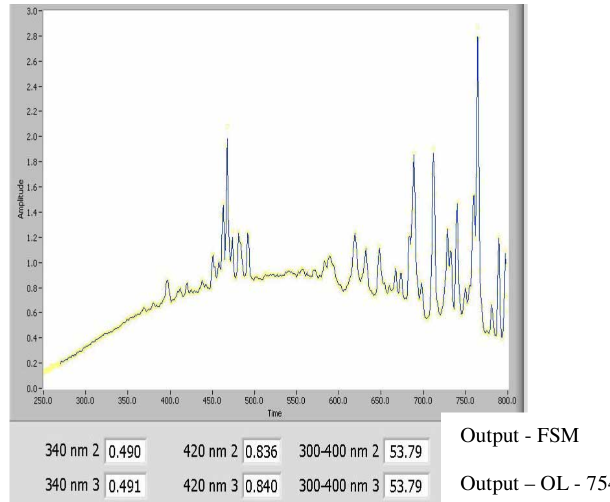

Figure 3. *Comparison of conventional spectroradiometer output with FSM system*

FSM Capabilities

User Selected Control Points

Current instruments are limited to controlling irradiance at a predetermined wavelength, or wavelength range that is likely not to coincide with a test material's critical wavelength(s). Critical wavelengths are those at which a material demonstrates heightened sensitivity to light. In addition, a lamp undergoing temporal changes not captured by a single-wavelength-monitoring system will compound the problem. This has implications for repeatability and reproducibility. For example, replication of current tests that monitor and integrate irradiance data at non-critical wavelengths will indicate that the tests are identical. However, assuming there are changes to the lamp (there always are – small and gradual for the most part) at the critical wavelengths not "seen" by current instrumentation, true radiant dosage replication, where it matters most, is not accomplished. The flexibility of FSM system allows unprecedented utilization of activation spectra data, to control and monitor tests at material-specific critical wavelengths to ensure more repeatable and reproducible tests.

It should be made clear that the selection of a control wavelength coincident with a material's critical wavelength does not limit testing to a single type of material. For while it is only possible to control at a single wavelength or range, since the full spectrum is available, data may be monitored and accrued at any other wavelength(s).

Photometric Monitoring And Control

In the photo imaging industry for example, lightfastness tests are required to maintain specified lux values, which for current instrumentation meant costly re-engineering of the controlled irradiance system. By contrast, systems with FSM could, through its software, automatically produce the lux value by convolution of its spectral irradiance measurements and the known photometric, "standard observer" weighting curve.

Performance-based Specifications

The trend towards performance-based weathering test specifications over the recent years has meant the elimination of any technical information or features relating to a specific instrument. The more traditional "hardware-based" standards specifically names by manufacturer's nomenclature, the type of xenon filters required for the desired results of the test. By contrast, performance-based standards show allowable irradiance ranges, in spectral bands, as indicated in Figure 4, taken from SAE J2412, *Accelerated Exposure of Automotive Interior Trim Components Using a Controlled Irradiance Xenon Apparatus*. [2]

Irradiance in W/m2 for Xenon-Arcs with Daylight Filters Normalized to Exactly 0.55 W/m2 at 340 nm

bandpass	mean	std deviation	minimum	maximum	lower 95% conf. Limit	upper 95% conf. Limit
250-260	0.00	0.00	0.00	0.00	0.00	0.00
261-270	0.00	0.00	0.00	0.00	0.00	0.00
271-280	0.00	0.00	0.00	0.01	0.00	0.00
281-290	0.02	0.02	0.00	0.11	0.00	0.06
291-300	0.19	0.10	0.03	0.55	0.00	0.38
301-310	0.77	0.21	0.32	1.46	0.35	1.18
311-320	1.91	0.21	1.31	2.68	1.49	2.33
321-330	3.39	0.13	2.96	3.97	3.12	3.65
331-340	4.92	0.06	4.68	5.11	4.80	5.03
341-350	6.24	0.09	5.80	6.40	6.06	6.43
351-360	7.40	0.22	6.66	7.82	6.97	7.84
361-370	8.58	0.41	7.56	9.82	7.76	9.39
371-380	9.25	0.60	8.09	11.36	8.04	10.45
381-390	9.92	0.89	8.39	13.71	8.15	11.69
391-400	11.88	1.44	9.64	18.57	8.99	14.76
300-400	64.31	3.57	57.79	78.96	57.16	71.45

Figure 4. *Example of allowable irradiance ranges in a performance-based specification.*

But for a few laboratories that may occasionally measure their instrument's SPD, there is currently no independent means of verifying and demonstrating to an auditor, or customer, for example, that the requirements are met.

The FSM is capable of generating tables of irradiance to ensure beginning (of test), and ongoing compliance to performance-based requirements. The user may configure the table's wavelength bands as he sees fit; to be consistent with that in a given specification, for example.

Filter Identification and Aging Criteria

The fact that each filter set has a unique (range of) UV transmittance is used to identify each filter set to the user. Thereby, eliminating or significantly reducing, the potentially disastrous use of incorrect filters. Similar software features are used to identify when a lamp assembly or filter set approaches the end of its useful life. Utilizing their own knowledge and experience, individual users may choose their own "end of useful life" criteria based on sample sensitivity or tolerance for confidence level in the test result.

Summary

The Full Spectrum Monitoring system for laboratory instruments represents a significant step forward for the management of light, the most critical component of photo-degradation. It can be a tool to serve leading edge researchers as they endeavor to refine service life prediction calculations. The FSM feature can also benefit everyday users wishing to realize more repeatable and reproducible tests, or to demonstrate compliance with performance-based test methods.

Acknowledgements

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[1] ASTM G-138-03, Calibration of a Spectroradiometer Using a Standard Source of Irradiance, Annual book of ASTM International Standards, ASTM 100 Barr Harbor drive, W. Conshohocken, PA, USA

[2] SAE J2412, Accelerated Exposure of Automotive Interior Trim Components Using a Controlled Irradiance Xenon Apparatus, Society of Automotive Engineers, Warrendale, PA, USA

Author Biography

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