

Optical-State Characterisation and Drift Detection in Vat-Photopolymerisation Equipment

Spatial Irradiance, Spectrum and Divergence, and the Unclosed Ageing Question

Juan Seguro

3Dresyns by Resyner Technologies S.L.

© 2026 Juan Seguro. All Rights Reserved.

Correspondence: info@3Dresyns.com · www.3Dresyns.com

ER-174 · Engineering Review · Version 0.3 · 14 September 2026

Statement of significance

Nominal wavelength and average irradiance do not uniquely define the optical excitation delivered by a vat-photopolymerisation light engine. A directly read primary study shows spatial variation in irradiance, spectrum and divergence within one LCD engine and distinguishes what grayscale correction can and cannot repair. This review turns that evidence into a bounded characterisation and drift-detection architecture while keeping ageing rates and service-life claims explicitly open.

Abstract

The optical state of an LCD-based vat-photopolymerisation system is spatial and multidimensional. Caplins et al. mapped a nominally 405 nm engine and measured position-dependent irradiance, spectral behaviour and divergence associated with changes in polymerisation extent, dimensions, fidelity and surface texture [1]. Grayscale correction reduced irradiance non-uniformity but did not correct divergence. Two identified interlaboratory working-curve studies provide context for why nominal settings alone should not be treated as proof of equivalent delivered conditions [2,3]. No numerical result from those studies is load-bearing here. ER-174 defines a measurement architecture for establishing an optical baseline and detecting change before part impact. It separates baseline non-uniformity from temporal drift and both from ageing attribution. No directly read longitudinal evidence set was recovered for light-source output decay, LCD transmission loss, spectral drift with use or release-film ageing. Accordingly, this paper specifies no ageing rate, service life, replacement interval, decay model or universal drift threshold.

Keywords: vat photopolymerisation; LCD; light engine; irradiance mapping; spectral mapping; divergence; drift detection; optical metrology; ageing evidence gap

1. Scope and amended identity

ER-174 owns characterisation of the delivered optical state and detection of change before that change reaches the part. It also defines what longitudinal evidence would be needed to convert observed drift into an ageing rate or service-life claim. The controlling master-sequence row was amended before drafting by ER174_MASTER_SEQUENCE_ROW_AMENDMENT_v0.1_20260913.md, SHA-256 19b6ce456aa366a22c187389ab34cb8362ec97dbc691895d1e3a469d483490e7.

ER-071 retains in-process sensing and closed-loop control. ER-002 retains cross-platform exposure equivalence at a point in time. ER-034 retains separation and peel mechanics, including release-film mechanics as a subject. ER-174 does not claim a release-film lifetime.

2. Delivered optical state is not one number

An exposure setting is a machine command. Delivered excitation depends on the spatial field, spectral distribution, angular distribution or divergence, mask transmission, geometry and thermal state. A scalar irradiance at one point cannot reveal whether another location receives a different spectrum or angular field.

Caplins et al. directly mapped irradiance, spectrum and divergence in a nominally 405 nm LCD light engine [1]. The observed spatial heterogeneity affected the extent of polymerisation and printed fidelity. The transferable conclusion is not a value for another printer; it is that these optical dimensions can vary independently and must be measured where they matter.

3. Spatial irradiance

An irradiance map establishes how incident power per area varies across the build field under the declared measurement geometry. The map must retain coordinate registration to the printer so that optical features can be compared with location-dependent coupon or part responses.

Reporting only minimum, maximum or average values discards spatial structure. A repeatable pattern may be calibratable; a changing pattern may indicate drift; a single average cannot distinguish them.

4. Spectrum

Photoinitiator absorption and competing absorbers make spectral distribution relevant even when two sources share a nominal wavelength. Spectral characterisation should therefore report the instrument, geometry, integration convention and spatial sampling. ER-174 does not convert spectral difference into cure equivalence; it records the delivered state needed for a formulation-specific assessment.

5. Divergence and angular state

Divergence affects lateral light transport, edge definition and the relation between mask pixels and exposure in the resin. Caplins et al. showed that grayscale correction used to flatten irradiance did not correct divergence [1]. This separates two controls that are often treated as one: equalising local intensity does not necessarily equalise ray direction or feature transfer.

6. Baseline non-uniformity, drift and ageing are different claims

Baseline non-uniformity is spatial variation measured at a declared time. Drift is a statistically and metrologically supported change from that baseline. Ageing is an attributed time- or use-dependent mechanism that explains the change. One cross-sectional map can establish non-uniformity; repeated comparable maps can detect change; neither alone establishes a decay law or service life.

The measurement sequence must therefore preserve equipment identity, operating state, warm-up, mask pattern, measurement geometry, ambient conditions, sensor calibration and time or use index. Without those controls, apparent drift can arise from the measurement rather than the engine.

7. A bounded drift-detection architecture

A defensible programme has four elements:

1. a baseline spatial map of irradiance, spectrum and, where material, divergence;
2. reference locations or artefacts that preserve coordinate registration and measurement repeatability;
3. repeated measurements at declared intervals or triggers under matched conditions; and
4. an independent part- or resin-response check selected for the intended process.

The purpose is to detect a change and localise its optical dimension. This architecture is proposed methodology, not a validated universal schedule.

8. Correction and verification

A correction must be verified against the dimension it is intended to change. A grayscale field may flatten irradiance but leave divergence, spectral variation, geometric distortion or defective pixels unchanged. Verification therefore repeats the relevant maps after correction and checks that an improvement in one metric did not conceal deterioration in another.

9. Connection to working curves and printed outcomes

Working-curve measurements are formulation- and protocol-bound. The existence of interlaboratory investigations is relevant context, but ER-174 does not use their numerical or comparative results as evidence [2,3]. Nominal machine values alone do not establish comparable critical exposure or penetration depth. An optical map can help explain spatial or inter-machine differences, but it does not replace conversion, dimensional or functional measurement in the actual resin and geometry.

10. The unclosed ageing question

No directly read longitudinal primary study was recovered that establishes light-source output decay versus operating history, LCD-mask transmission loss versus UV or thermal service, spectral drift with cumulative use, or release-film optical/mechanical ageing under controlled VPP service. Manufacturer lifetime statements were identified but remain implementation context rather than independent evidence.

The missing study would repeatedly measure the same identified hardware or consumable state under a controlled use history, with calibrated metrology, environmental and thermal controls, uncertainty, and a linked material or part response. It would need to distinguish irreversible change from warm-up, contamination, repositioning and instrument drift.

11. What cannot presently be specified

The evidence does not support a universal drift threshold, measurement interval, ageing rate, consumable lifetime, replacement interval, exposure compensation, decay model or requalification rule. A threshold must be tied to measurement capability and to the sensitivity of the specified resin, geometry and claim.

12. Conclusions

Delivered optical state in VPP is multidimensional and spatial. Irradiance, spectrum and divergence can vary within one light engine and influence polymerisation and part outcome. Flattening irradiance does not necessarily correct divergence. These results justify a mapped baseline and controlled repeated measurements for drift detection. They do not establish how fast an engine, panel or film ages. That longitudinal question remains explicitly open.

Related Engineering Review boundaries

ER-174 owns delivered optical-state characterisation and drift detection. ER-002 retains cross-platform equivalence; ER-034 separation and peel mechanics; ER-035 interpretation of critical exposure and penetration depth; ER-071 in-process sensing and closed-loop control; and ER-142 equipment-qualification architecture.

References

1. Caplins BW, Higgins CI, Kolibaba TJ, et al. Characterizing light engine uniformity and its influence on liquid crystal display based vat photopolymerization printing. *Additive Manufacturing*. 2022;62:103381. <https://doi.org/10.1016/j.addma.2022.103381>
2. Kolibaba TJ, Killgore JP, Caplins BW, et al. Results of an interlaboratory study on the working curve in vat photopolymerization. *Additive Manufacturing*. 2024;84:104082. <https://doi.org/10.1016/j.addma.2024.104082>
3. Kolibaba TJ, Killgore JP, Caplins BW, et al. Results of an interlaboratory study on the working curve in vat photopolymerization II: Towards a standardized method. *Additive Manufacturing*. 2025;110:104919. <https://doi.org/10.1016/j.addma.2025.104919>

Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. No comparative product recommendation is made.

Data availability

No new experimental dataset was generated. The directly read NIST-hosted primary article [1] is included in the review package. References [2] and [3] are retained only as bibliographically verified interlaboratory context; their complete texts are not included and no numerical or comparative result from them is load-bearing in this version.

Copyright

© 2026 Juan Segurola. All Rights Reserved. No part of this work may be reproduced, distributed or transmitted without the prior written permission of the copyright holder, except where permitted by applicable law.