375c Effects of Sampling Rate, Metrology Delay and Process Hold on the Stability of Run-to-Run Control

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AEC/APC (advanced equipment control/advanced process control) is gradually becoming standard practice in the modern semiconductor manufacturing industry. Provided with pre-process and post-process metrologies, feedforward and feedback controls are implemented to improve yield. The discrete and repetitive nature of the process leads to run-to-run (R2R) control [1-5], with an EWMA (exponentially-weighted-moving-average) or double EWMA (dEWMA) algorithm in the feedback path for determining run-to-run adjustments. Unlike the dedicated (relatively inexpensive) process variable sensor in chemical process industries, a shared measurement tool is more common in semiconductor manufacturing, as a result of the prohibitive (millions of dollars) cost of metrology tools. Wafer sampling is therefore ad-hoc, a practice that often leads to congestion in the measurements acquisition process. The result is a feedback system, in control terminology, with variable sampling rate and variable metrology delay (measurement dead time). In addition to measurement tool problems, the process tools can be of single chamber or multiple-chamber configuration in which many wafers are processed simultaneously ("process hold"). It is well-known that a gain-only model provides a generally acceptable description of system behavior in the process steps. With only a simple EWMA (single integrator) or dEWMA (double-integrator) algorithm in the feedback path, the design and stability analysis of the overall system should be rather straightforward. However, the sampling strategy, measurement mechanism, and process configuration, when considered realistically, lead to a distinct control system analysis problem: what exactly is the effective delay unit in the feedback loop? In this work, we answer the following question: given the (unequally spaced) sampling interval, (variable) metrology delay, and, possibly, a "process hold," what is the effective delay unit in the feedback path? Note that in this work the unit of discrete time measurement is "number of wafers processed." Once the effective delay unit is available, the R2R controller can be designed accordingly. We will present results showing how an analytical expression can be derived to identify the effective delay unit. Next, heuristics for determining an effective sampling strategy, and for queue-sorting in the metrology tool will also be presented. The analyses presented tend to provide timely utilization of metrology data to ensure stable and effective feedback control. The proposed strategy is applicable to wafer-by-wafer as well as lot-by-lot processing.

References [1] G. E. P. Box and T. Kramer, "Statistical process monitoring and feedback adjustment—A discussion, "Technometrics, vol. 34, 251, 1992. [2] A. Ingolfsson and E. Sachs, "Stability and sensitivity of an EWMA controller," J. Quality Technol., vol. 25, 271, 1993. [3] R. Good and S.J. Qin, "Stability analysis of double EWMA run-to-run control with metrology delay," Proceedings of American Control Conference, Anchorage, AK May B-20, 2002. [4] E. Del Castillo, Statistical Process Adjustment for Quality Control, Wiley, New York, 2002. [5] S.T. Tseng and N.J. Hsu, "Sample-Size Determination for Achieving Asymptotic Stability of a Double EWMA Control Scheme," IEEE Transactions on Semiconductor Manufacturing, Vol. 18(1), 104, 2005.