LIVE-TIME COUNTING

APPLICATION NOTE CPC-001 (US)

Basic Concentration Calculation

Real-time single particle counters use electronics to process particle detector pulses. In order to turn the raw counts from a single-particle counter into a concentration, the following formula must be used:

$$C = \frac{\Delta N}{Q \cdot t_{sample}} \tag{1}$$

where:

- C = number concentration (particles per unit of volume)
- ΔN = number of pulses/particles counted in sample time t
- Q = flow rate through the sensing instrument
- t_{sample} = sampling time

Live Time and Dead Time

For all single particle counting instruments there is a fraction of time during which the designed detector is occupied, and no other electronic signals can be processed. During this non-detecting time, additional particle events cannot be captured, so this time is not technically part of the sampling time of the aerosol.

The non-detecting time is composed of two components: The **dead time** (t_{dead}) is the time until another particle can trigger the detector. This can be measured using a high speed clock and accumulator. Since the electronic pulses are not perfect square waves, there is an additional portion of time when the electronics are not available due to overlapping tails of adjacent particle signals. This **dead time factor** (τ) is dependent on the specific pulse output and detection scheme of the particle counter, and is therefore instrument specific. A dead time factor is used to quantify this effect.

In order to accurately represent the concentration of particles in the aerosol stream, the non-detecting time must be subtracted from the sample time, and the resulting **live-time** (t_{live}) should be used in the concentration calculations.

$$t_{live} = t_{sample} - (t_{dead} * \tau) \tag{2}$$

- t_{dead} = dead time; time until a new particle can trigger the detector.
- τ = dead time factor; additional time electronics are not available due to pulse shape.
- t_{live} = live time; sampling time minus the electronic non-detecting time.

Live-Time Counting in the TSI CPCs and WCPCs

Live-time electronics processing compensates for the finite time needed for signal processing and therefore **increases the accuracy** of the number concentration measurement. TSI's line of research Condensation Particle Counters (Models 377x) and Water-Based Condensation Particle Counters (Models 378x) feature the use of live-time counting.[1]

Anecdotal Example: TSI 3790 CPC

For each measurement time interval Δt (0.1 s), the accumulated dead time t_{dead} is measured by the signal processor, using a high speed clock and accumulator. The dead time factor for the Model 3790 CPC was determined experimentally to be 1.9. The live time t_{live} is calculated using equation (2) and represents the true measurement time within Δt. The true particle concentration is then calculated using equation (3).

$$C_D = \frac{\Delta N}{V} \times \frac{\Delta t}{t_{live}} = \frac{\Delta N}{Q \cdot \Delta t} \times \frac{\Delta t}{t_{live}} \qquad (3)$$

$$C_D = \frac{\Delta N}{Q \cdot t_{live}} \qquad (4)$$

C_D = number concentration using live-time electronics processing (particles per unit of volume) displayed by the CPC
Δt = measured time interval (0.1 s for EECPC Model 3790)
ΔN = number of particles counted in time interval Δt
V = volume measured during time interval Δt
Q = flow rate through the sensing zone of the CPC (1 l/min for EECPC Model 3790)
t_{live} = calculated live time during time interval Δt

The live time decreases with increasing particle number concentration, therefore the effect of live-time electronics processing becomes more significant with increasing number concentration. When using live-time counting, **number concentration is always higher** than the concentration calculated using the standard sample time.

[1] Requirements for vehicle certification measurements with CPCs in UN-ECE GRPE Regulation 83 allow for the use of live-time counting. Regulation 83 is based on the recommendations of the Particle Measurement Program (PMP); it is e.g. used for Euro 5 and Euro 6 certification testing.

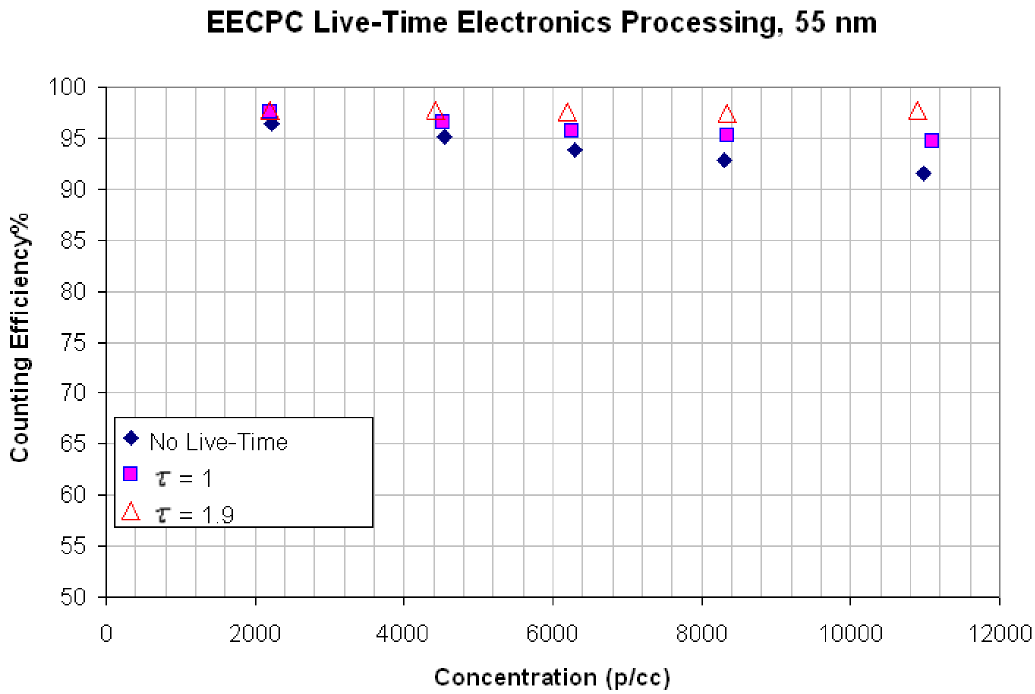

Fig. 1: Counting efficiency of the EECPC Model 3790 using different electronic processing schemes.

Figure 1 shows counting efficiency data from an EECPC Model 3790 using three different electronics processing schemes. No live-time represents data using the total sample time in the concentration calculation as detailed in equation (1). $\tau = 1$ uses equation (3) to calculate concentration, and effectively uses no dead time factor. $\tau = 1.9$ uses a dead time factor of 1.9 and is the default setting of the 3790 CPC.

***Note**: Live-time electronics processing can be turned off using the firmware command "SCC,0".*

Coincidence Error and 'Coincidence Correction'

Particle counting coincidence appears if a particle enters the particle detector's sensing zone while the previous particle is still being processed. If this occurs, the CPC will not detect the actual particle; resulting in an underestimation of the particle number concentration.

For randomly distributed particles, particle coincidence (two or more particles in the sensing zone of the particle detector) is typically described by Poisson statistics. The coincidence error increases with increasing number concentration. Live-time electronics processing does improve the accuracy of the particle counter when faced with coincidence events due to the use of the live-time in concentration calculations as opposed to the inputted sample time.