Steady-State zone and control chart for process parameters of a powder compactor

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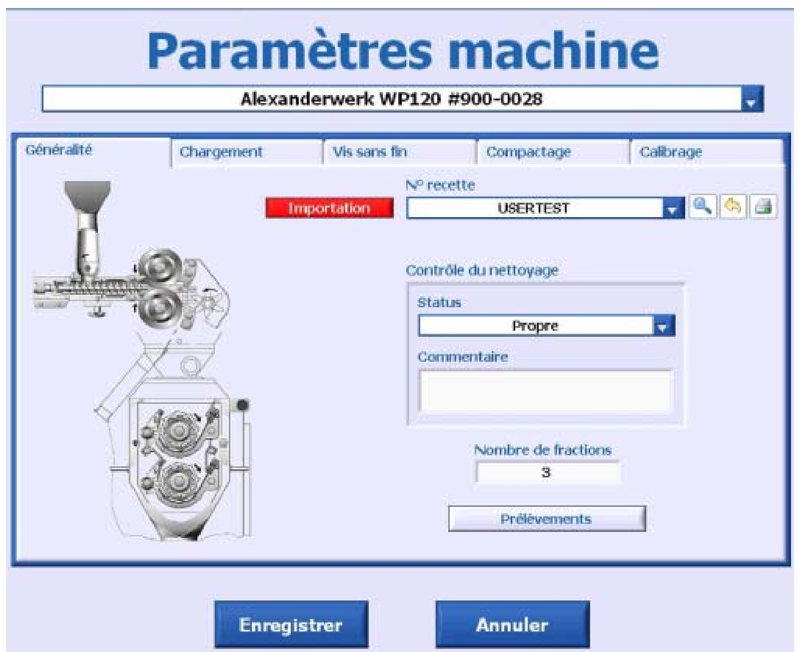
Outline

- Introduction
  - Presentation of powder compactor
  - Presentation of powder compactor monitoring software
- Steady-state
  - Definition
  - Indicator 1 : Coefficient of Variation (ICHighCV)
  - Indicator 2 : Slope
  - Indicator 3 : First derivative
- Control of mean values
  - Definition
  - Control chart 1 : with respect to target
  - Control chart 2 : build at first steady-state
  - Control chart 3: build at each steady-state
  - Alarms for the 3 control charts
- Interaction Steady-state-Control Chart
- Conclusion

Introduction

Presentation of the powder compactor

- **Objective : perform dry granulation using roller compaction**
  - To densify a powder
  - To obtain granules thanks to agglomeration process
  - Alternative process to wet granulation and drying for powders not compatible with water or high temperature (60°C)

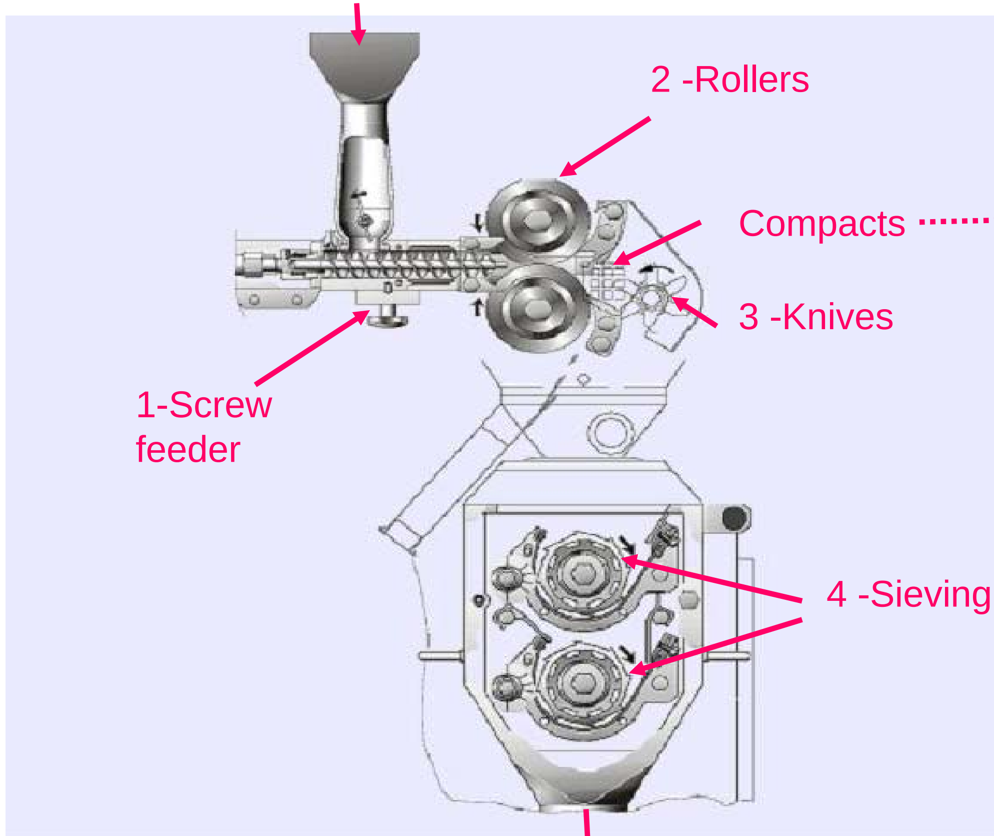


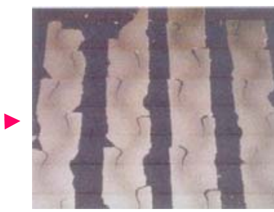
Introduction

Presentation of the powder compactor

Principle

Inputs: Raw material, powder





Outputs :Granules

Bad granules

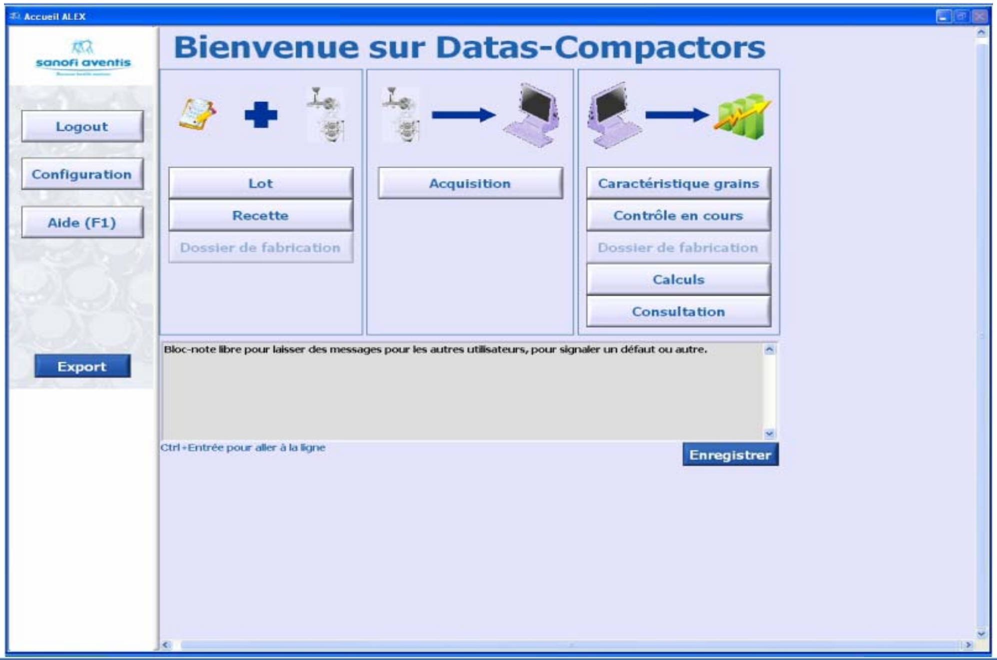
Good granules

Introduction

Presentation of the powder compactor monitoring software

Objective

- Gather on-line the process data during the compaction of a powder
- Perform on-line calculations which allow a perfect control of the process
  - comparison between manufacturing batches outputs
  - strong support for scale-up and for comparing data obtained on equipments of different sizes
  - selection of granules manufactured under controlled and stabilized conditions



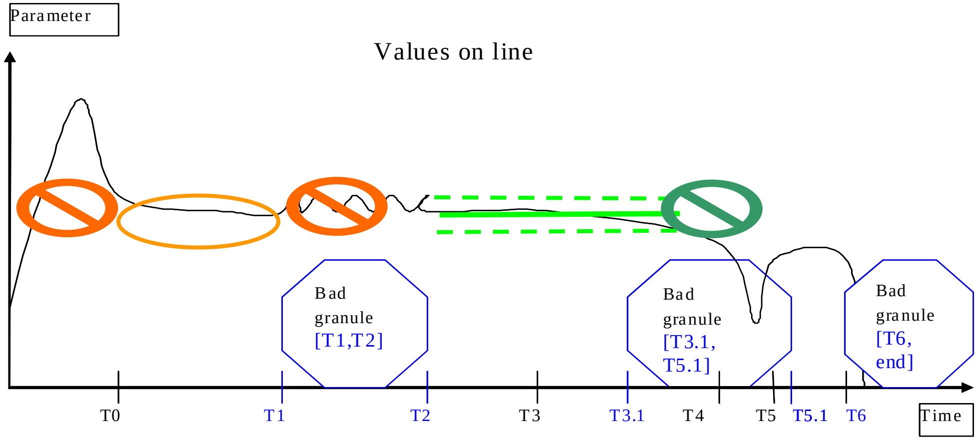
Introduction

Presentation of the powder compactor monitoring software

- **Objective of the statistical computations**
  - Determination of a stability area for manufacturing parameters
  - Control of these parameters
  - Parameters
    - GapActual (between rollers, mm), Roller Current (%), Screw speed (rpm) …

Automatic selection of corresponding good granules

- **To reach this objective**
  - Stability area of the followed parameter : steady state
  - Monitoring of values : control chart

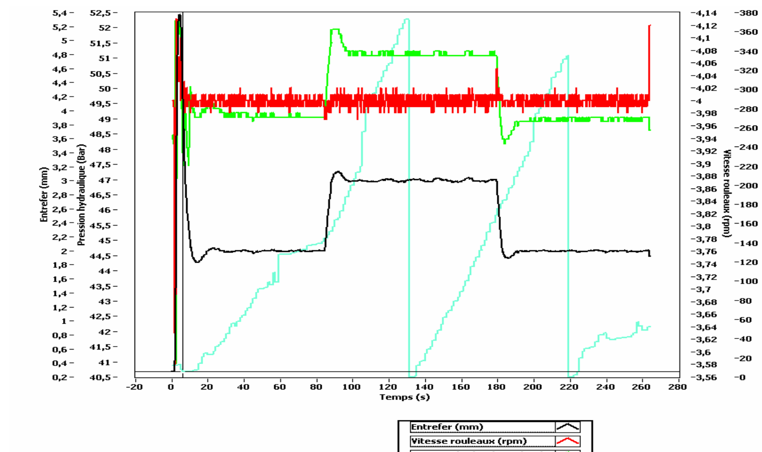


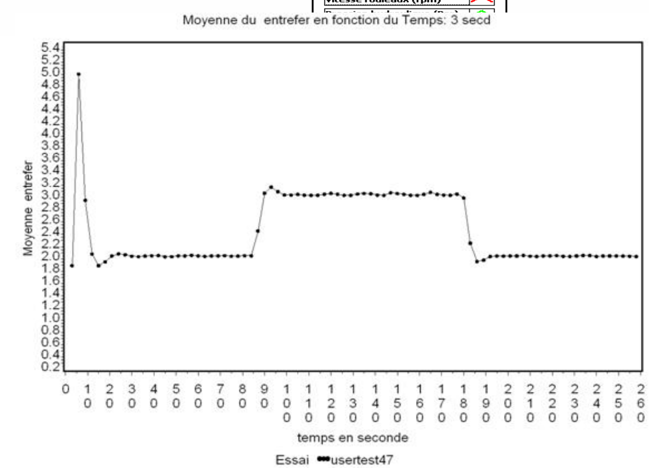
Introduction

Presentation of the powder compactor monitoring software

Basis for calculations

- Raw data :
  measurement every 0.1 second





- Data aggregation :
  data are aggregated on the basis of a user-defined step
  - **By default,** step=3 seconds

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  - **Indicator 2 : Slope**
  - **Indicator 3 : First derivative**
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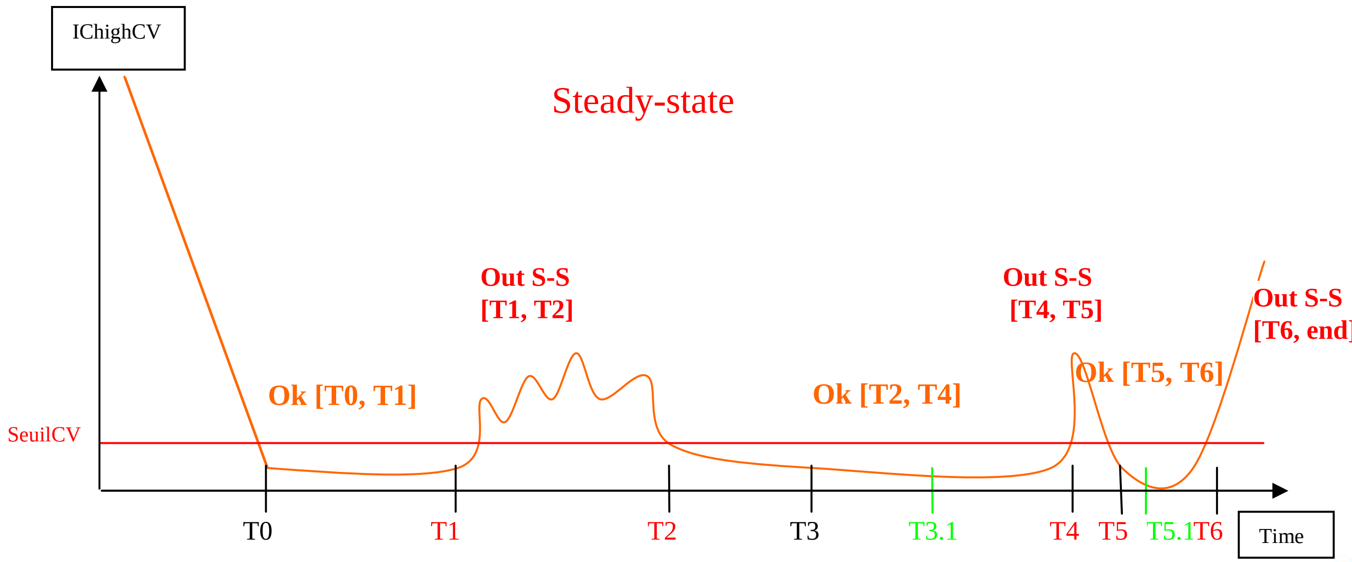
Steady-state

Definition

- **Stability area of the followed parameter : steady state**
- **Steady-state indicators**
  - IChighCV<seuilCV
  - |Slopes|<seuilSlo
  - |[Derivatives 1]|<seuilDer



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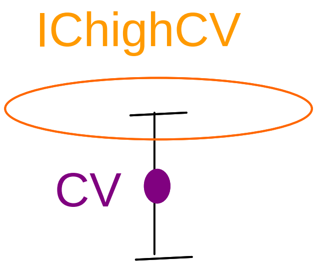
Steady-state

Indicator 1 : Upper limit of the Confidence Interval of the Coefficient of Variation

- **At each step, e.g. 3 seconds, 6 seconds, 9 seconds….**



- **CV = 100 * standard deviation / mean = 100 * s / mean**

- **Confidence interval of CV: IC(CV)**
  - IC(CV) = 100 * IC(s) / mean
  - with IC(s) = IC(standard deviation) = confidence interval of standard deviation s

- **Upper limit of IC(s) =** $s\sqrt{\frac{(n-1)}{c_{(\alpha/2,\ n-1)}}}$
  - with α = 10% fixed significance level
    and c(α/2, n-1)=percentile from χ^2 distribution with n-1 degrees of freedom

Steady-state

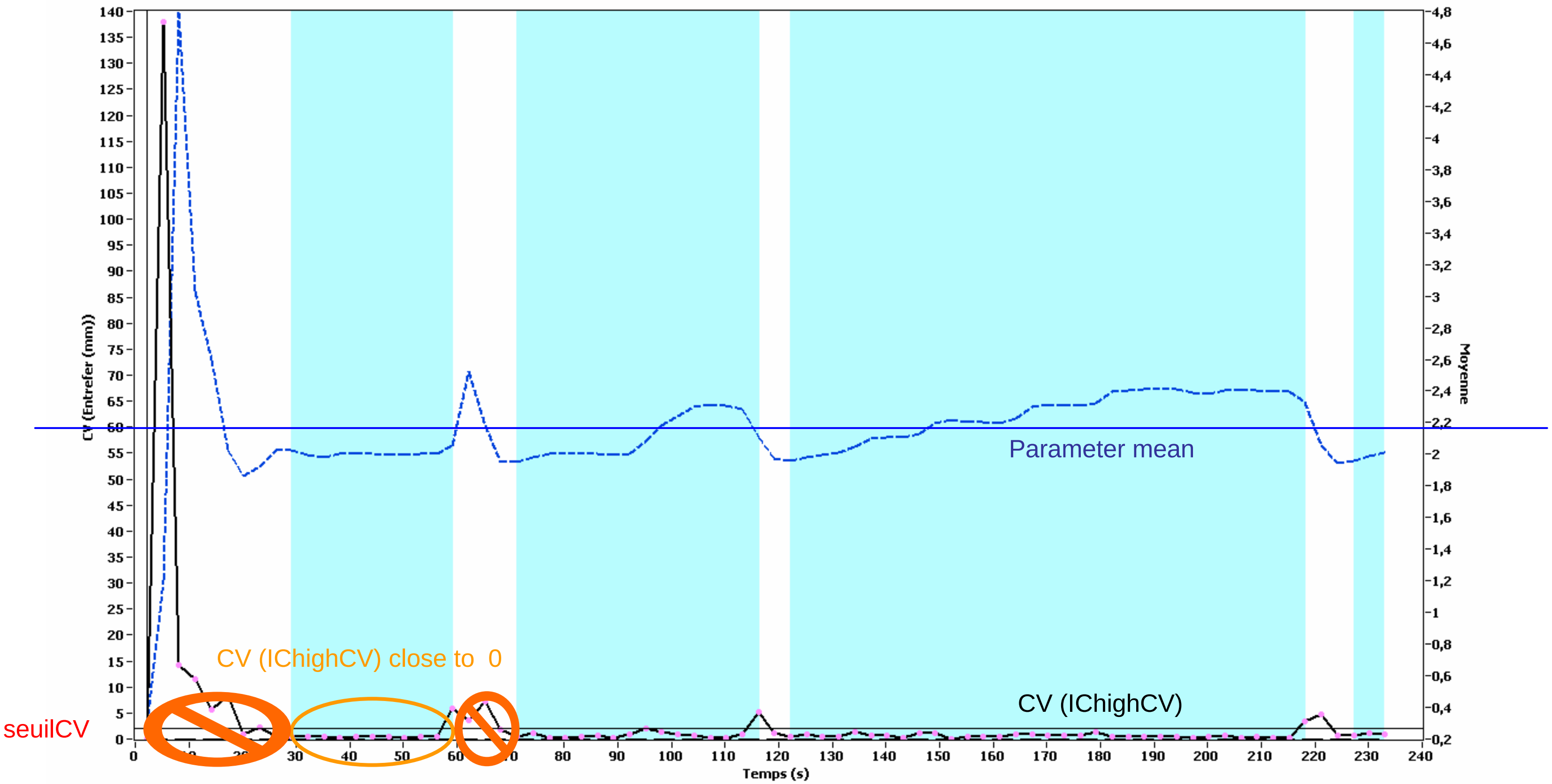
- **Indicator 1 : Upper limit of the Confidence Interval of the Coefficient of Variation**
  - **Upper limit of Coefficient of Variation Confidence Interval = *IChighCV***
    - *IChighCV* = $\left((s\sqrt{\frac{(n-1)}{c_{(\alpha/2,\ n-1)}}})/\bar{x} \right) * 100$

- **Steady-state when *IChighCV ≤ seuilCV%***
  i.e. when variation inside each step becomes weak

- **User defined threshold seuilCV%**
  - **By default**
    - seuilCV% = 2% for GapActual parameter (WP120)
    - seuilCV% = 3% for Roller Current parameter (WP120)

Steady-state

Indicator 1 : CV (ICHighCV)



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Steady-state

- **Indicator 2 : Slope**
  - **At each step, e.g. 3 seconds, 6 seconds, 9 seconds….**
  - **Regression model : $xi = a_0 + a_1 * ti + \varepsilon i$ for $i \in \{1,2,\dots,10,11,\dots,20,21,30\}$**
  - **The slope = a_1**

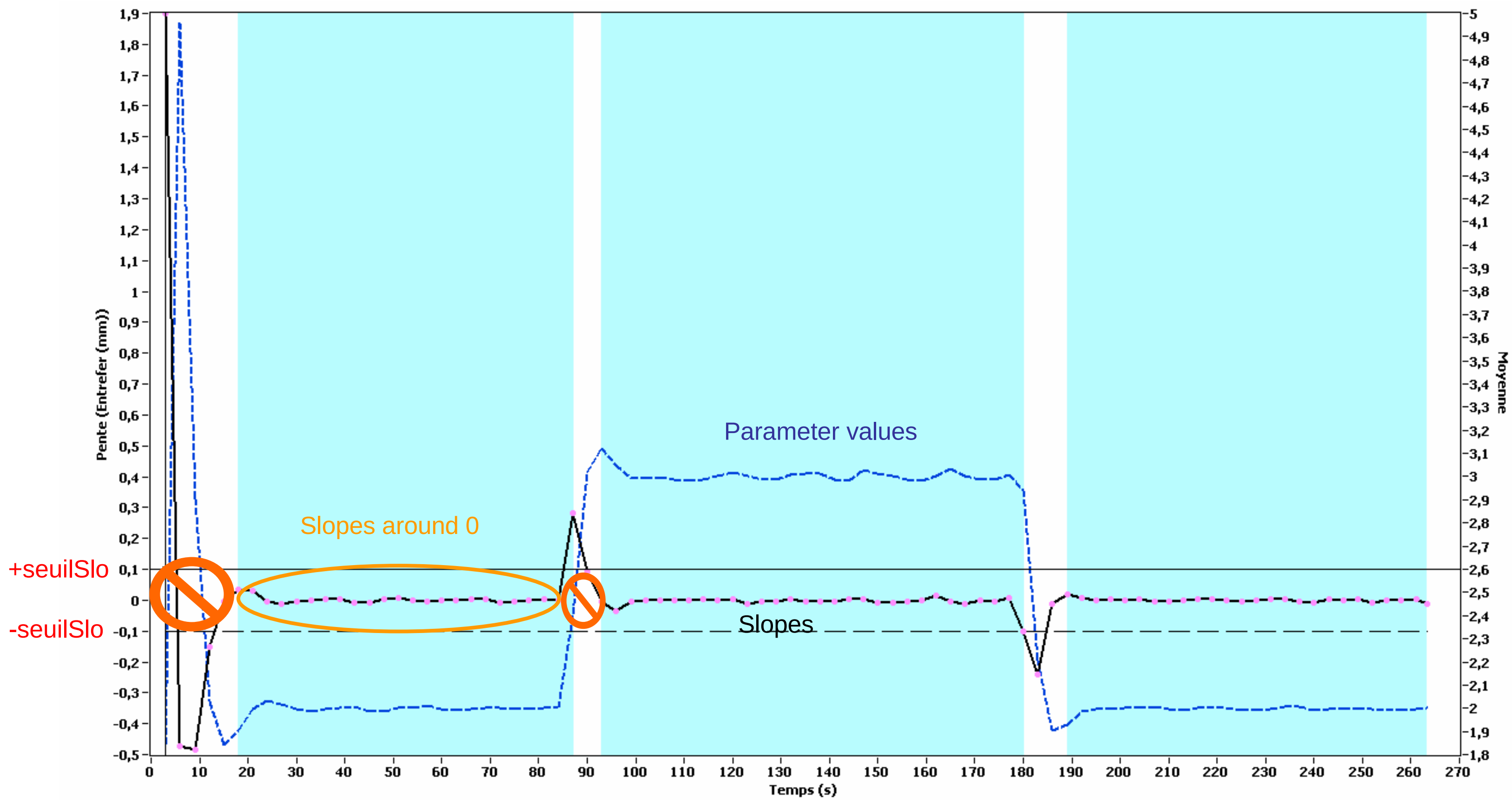
$$\hat{a}_1 = \frac{\sum_{i=1}^{n}(t_i - \bar{t})(x_i - \bar{x})}{\sum_{i=1}^{n}(t_i - \bar{t})^2}$$

- **Steady-state when** ***-seuilSlo ≤ Slope ≤ + seuilSlo***
  i.e. when evolution inside each step becomes flat

- **User defined threshold seuilSlo**
  - **By default :**
    - seuilSlo = 0.10 for GapActual parameter (WP120)
    - seuilSlo = 0.35 for Roller current parameter (WP120)

Steady-state

Indicator 2 : Slope



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Steady-state

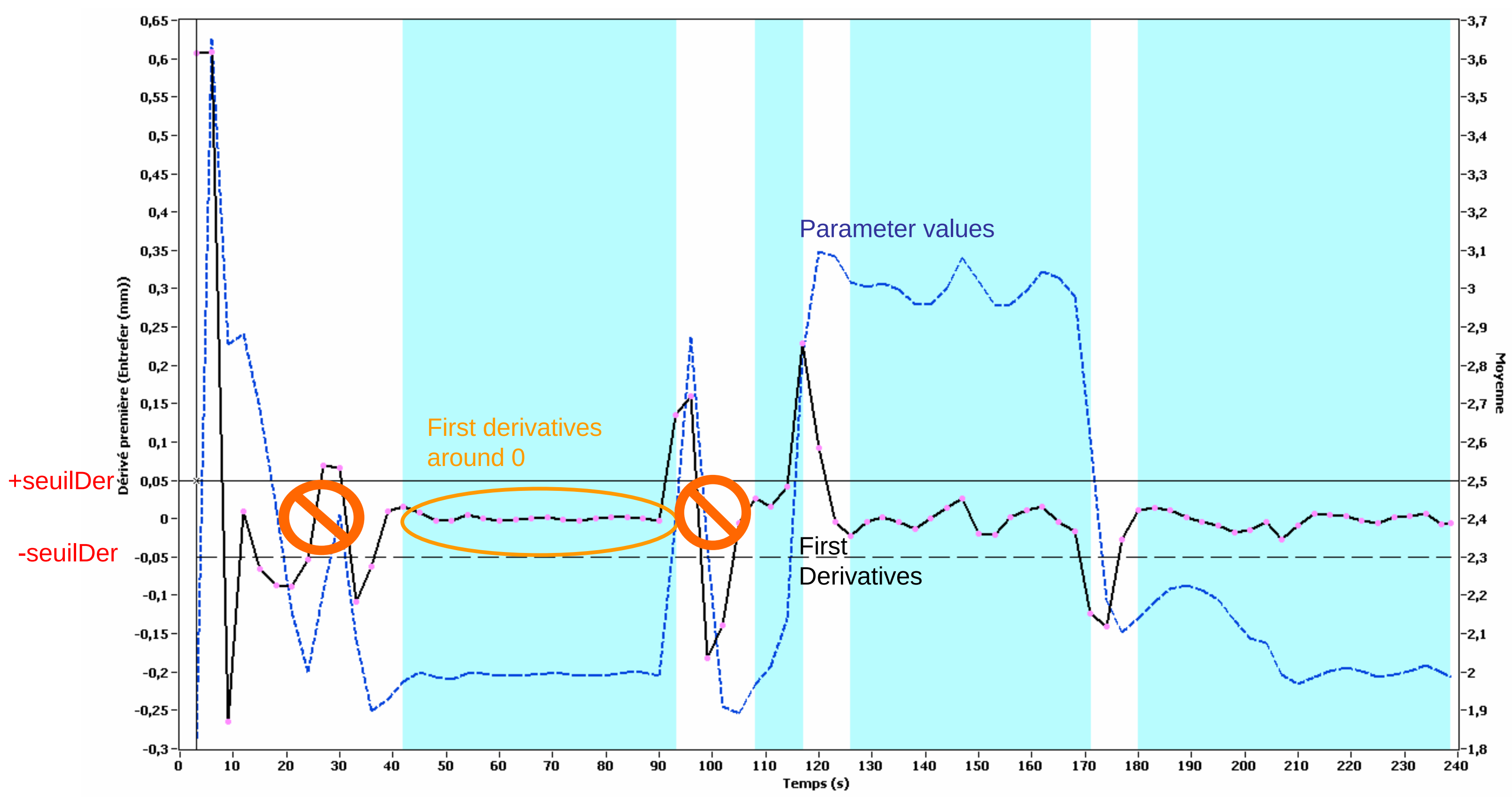
- **Indicator 3 : First Derivative**
  - **Between each step, e.g. between 6 seconds and 3 seconds, 9 and 6 seconds….**
  - **Between t_step and t_step+3:**
    - First Der= [Mean value at t_step+3 – Mean value at t_step] / [t_step+3-t_step]

- **Steady-state when** ***- seuilDer ≤ First Derivatives ≤ + seuilDer***
  i.e. when gap between steps means becomes small

- **User defined threshold seuilDer**
  - **By default**
    - seuilDer = 0.05 for GapActual parameter (WP120)
    - seuilDer = 0.15 for Roller Current parameter (WP120)

Steady-state

Indicator 3 : First derivative



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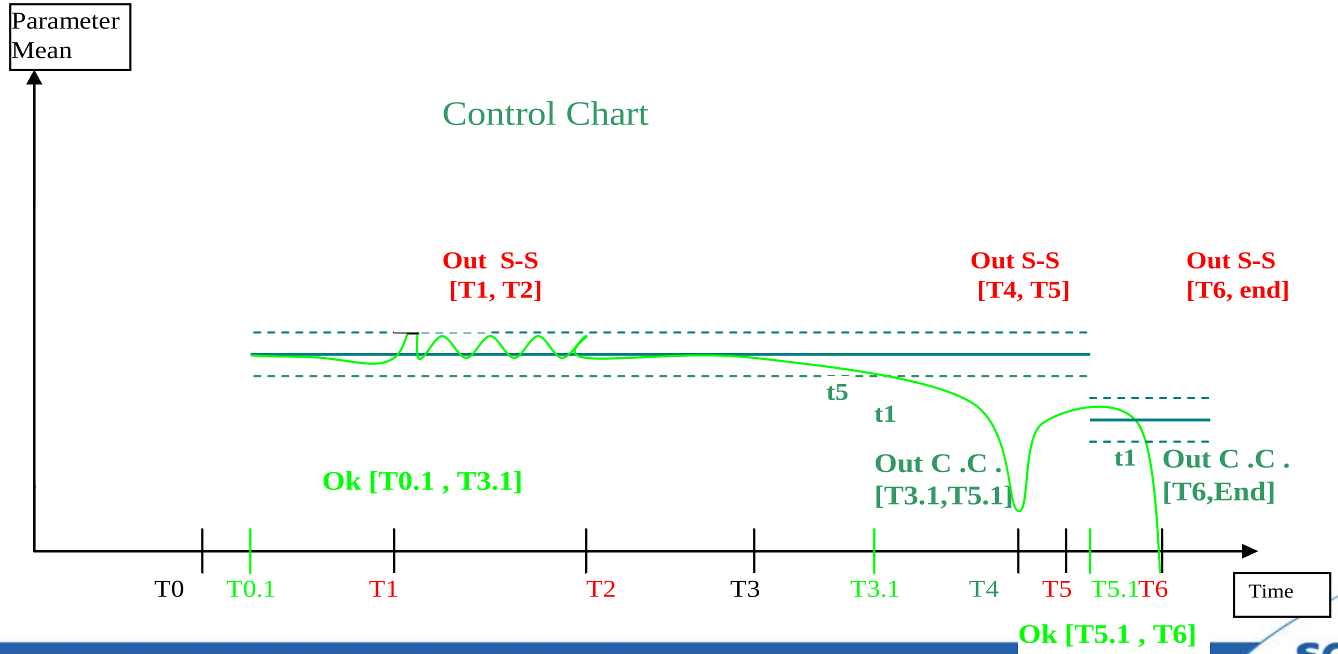
Control of mean values

Definition

- **Monitoring of values : control charts**
- **3 control charts are of interest**
  - Control chart 1 : with regards to a predefined target
  - Control chart 2 : built at first steady-state
  - Control chart 3 : built at each steady-state



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Control of mean values

Control chart 1 : with reference to a predefined target

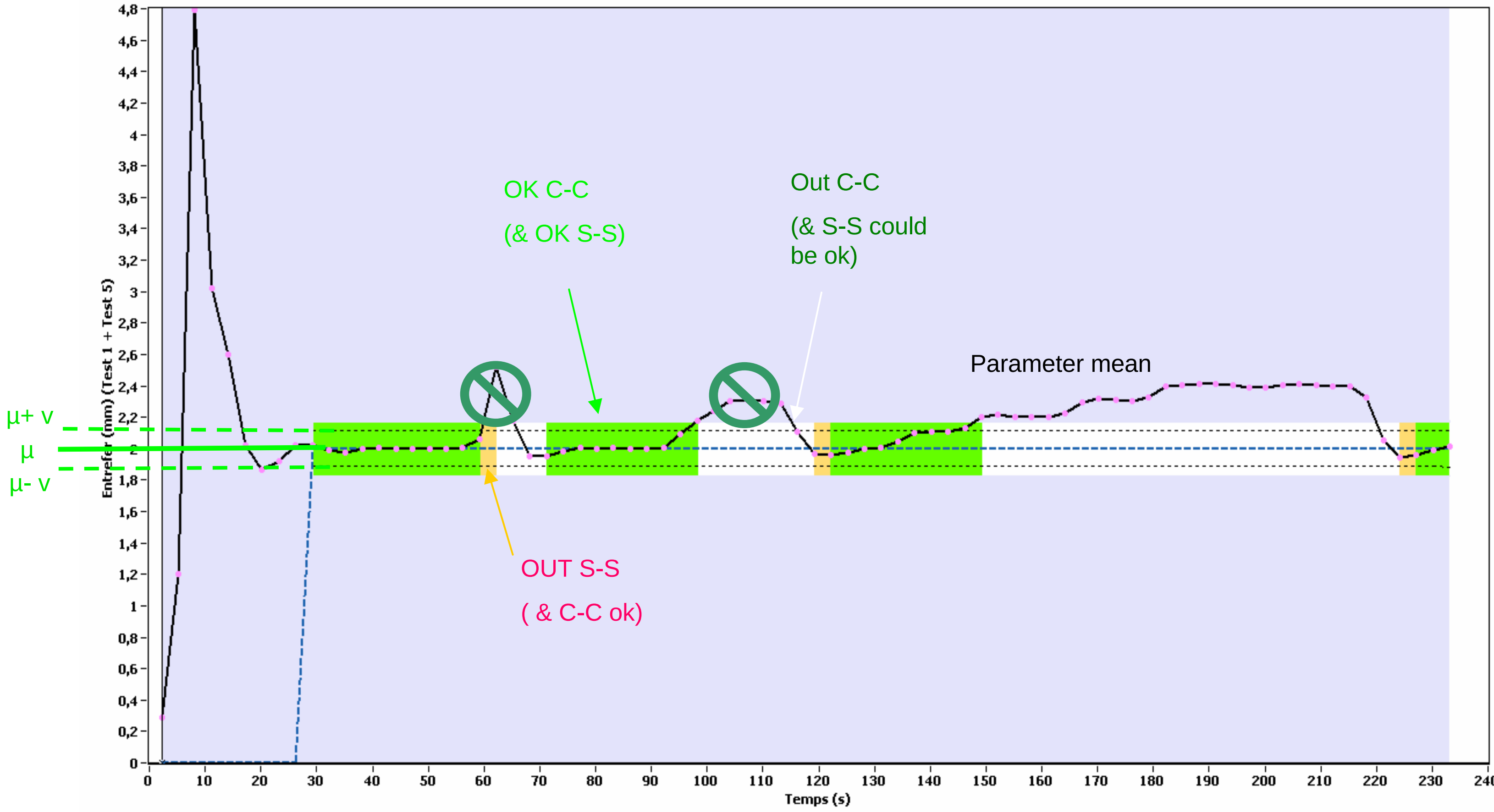
- **Classical Shewhart Control Chart, with mean μ_0 and standard deviation σ_0 known**
- **μ_0 : user-defined target for the mean values**
- **v : variability surrounding this mean μ_0**
  - The user gives it
- **$\mu_0 \pm$ v are the limits to be managed by the control chart**

- **Limits in the control chart**
  - if step=3 seconds and no missing values, n=30 :
  - Upper Control Limit = $\mu_0 + 3 * \frac{\sigma_0}{\sqrt{n}}$ = μ_0 +v
  - Central Limit= μ_0
  - Lower Control Limit = $\mu_0 - 3 * \frac{\sigma_0}{\sqrt{n}}$ = μ_0 - v

- **So σ_0 = $\frac{(UCL - \mu_0) * \sqrt{n}}{3}$ = $\frac{(\mu_0 - LCL) * \sqrt{n}}{3}$ = $\frac{v * \sqrt{n}}{3}$**
  - The program enters this value in the control chart module

Control of mean values

Control chart 1 : with reference to a predefined target



Control of mean values

Control chart 2 : built at first steady-state

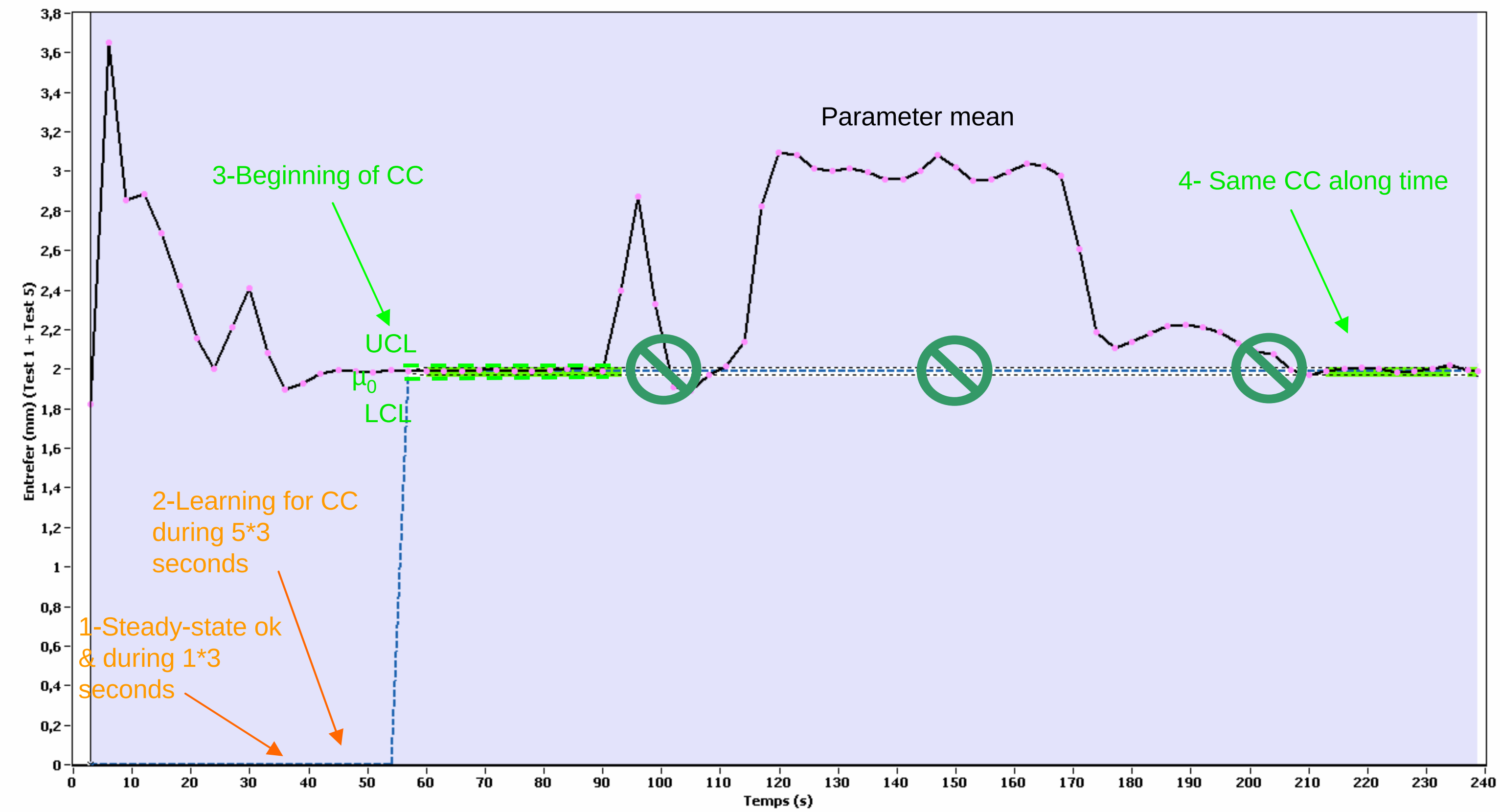
- **Classical Shewhart Control Chart, with mean μ_0 and standard deviation σ_0 known**

- **μ_0 : mean estimated on the first x*step seconds when Steady-state is validated**
  - validation of Steady-state : during 1*3 seconds by default ; user can modify it
  - the first x*step seconds : during 5*3 seconds (including S-S validation 1*3 seconds) by default ; user can modify it

- **σ_0 : standard deviation estimated on the first x*step seconds when Steady-state is validated**
  - validation of Steady-state : during 1*3 seconds by default ; user can modify it
  - the first x*step seconds : during 5*3 seconds (including S-S validation 1*3 seconds) by default ; user can modify it
  - σ_0 estimated in using the range formula : $\hat{\sigma}_0 = \text{Max} - \text{Min}$

Control of mean values

Control chart 2 : built at first steady-state



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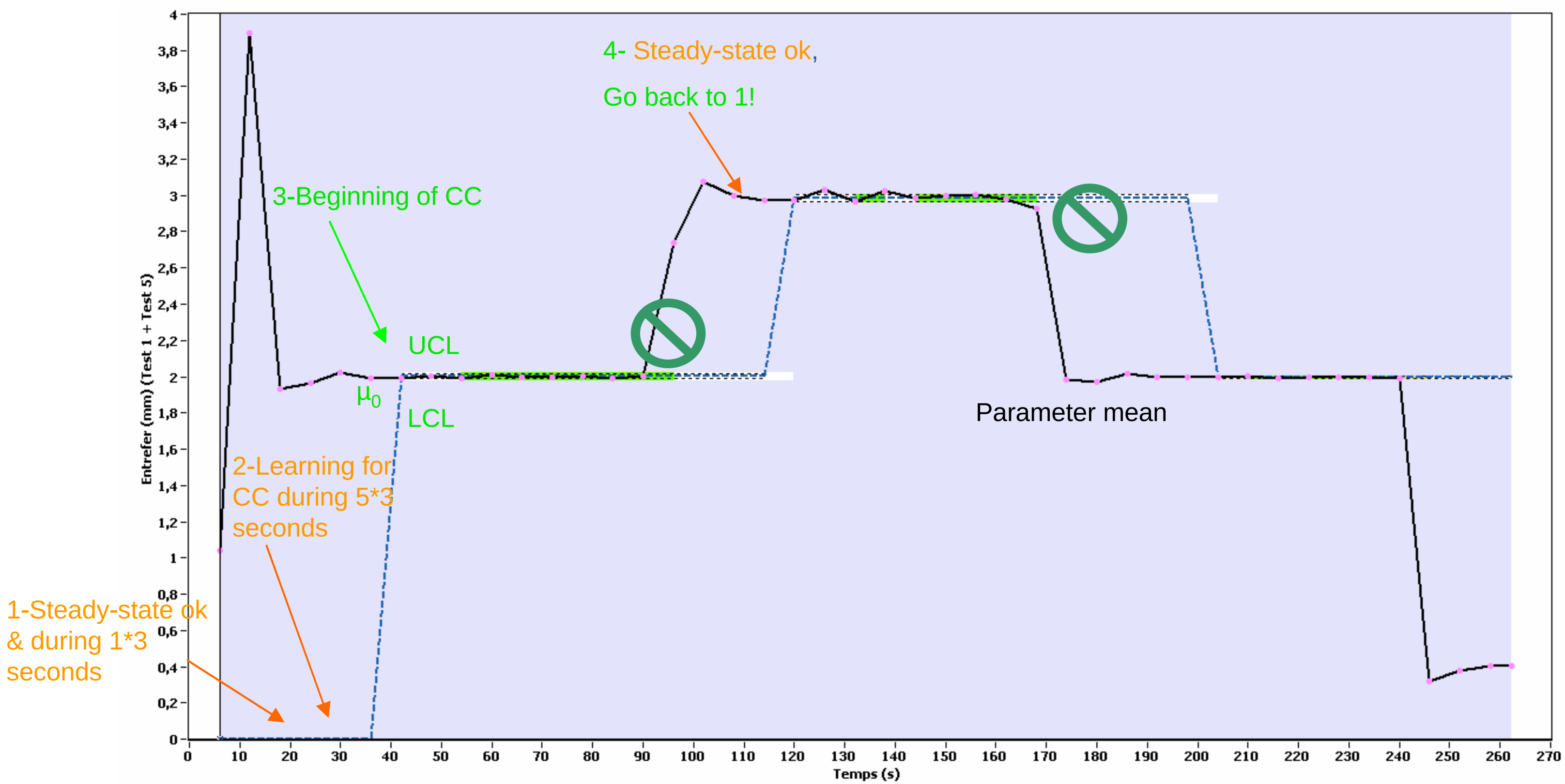
Control of mean values

Control chart 3 : built at every steady-state



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Control of mean values

Alarms for the 3 Control charts

- **Alarms to manage the points close or outside the Control Limits**
  - close : t5
    - Alarm if 2 means among the last 3 means are in A or beyond
    - A is area between $\mu_0 \pm 2\frac{\sigma_0}{\sqrt{n}}$ and $\mu_0 \pm 3\frac{\sigma_0}{\sqrt{n}}$
    - A area : between warning limits (2-sigma) and control limits (3-sigma)
  - outside : t1
    - alarm if one mean is outside the control limits, so outside $\mu_0 \pm 3\frac{\sigma_0}{\sqrt{n}}$
  - t1 & t5 : recommended tool

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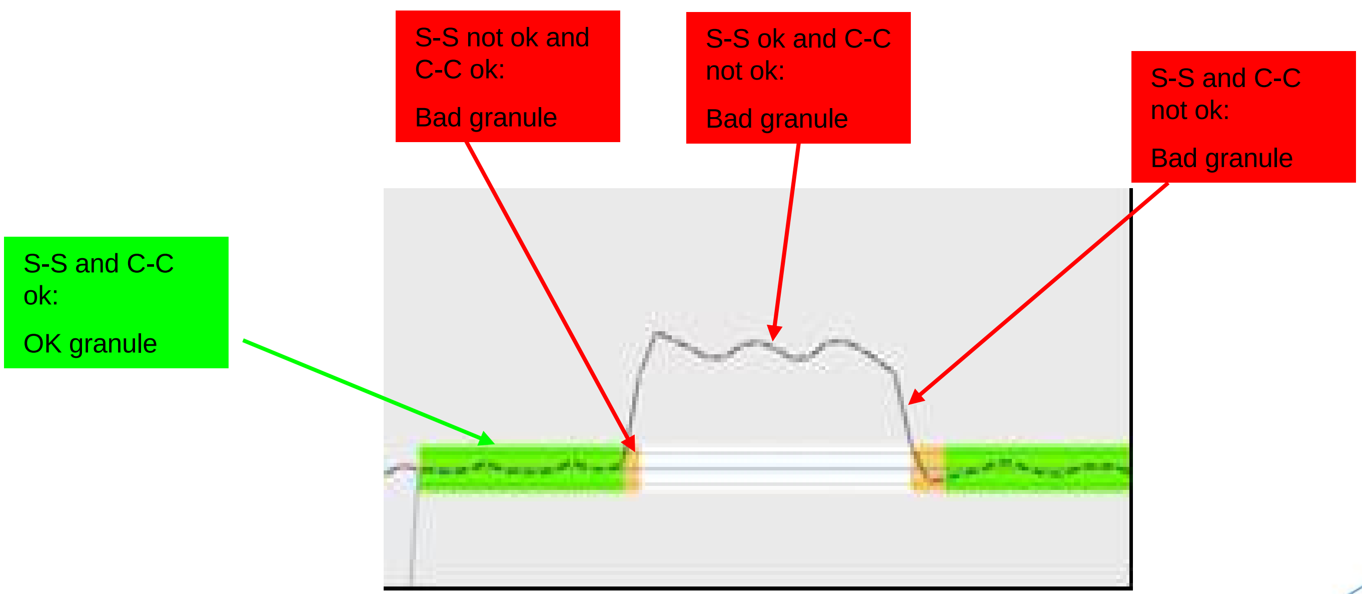
Interaction Steady-state-Control Chart

Command granule selector :

- **Ok if Steady-State ok <u>and</u> Control Chart ok**
  - Command granule selector (switch granule selector at + 15 sec by default for WP120)

- **Not ok if Steady-state not ok <u>or</u> Control Chart not ok**



Interaction Steady-state-Control Chart

Control Chart and granule selector

Interaction Steady-state-Control Chart

Control Chart and granule selector

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Conclusion

Command for granule selector

- OK if Steady-state OK and Control Chart OK

- NOT OK if Steady-state NOT OK or Control Chart NOT OK
  - Manual intervention possible

Business benefits

- To acquire process data has already enabled to :
  - identify critical process parameters that will allow to speed up optimum process parameter definition
  - decrease number of trials

- Automatic management of samples and fractions, reports generation, automatic control of process by the plot of the control chart and the retrieval of data from equipment control panel
  - save approximately ***0.5 man/day by batch***.

Conclusion

Business benefits

- Short-cut calculations for costs savings

Development stage	Without DATAS-COMPACTORS	With DATAS-COMPACTORS	Maximum Gain
Process Development (R&D)	20 to 30 batches	15 to 20 batches	***API: 2,5 to 5 kg*** ***20 man/day***
Pilot Stage	7 batches	2 to 4 batches	***API: 50 kg*** ***15 man/day***
Later stage		Helpful to implement acquisition data on industrial equipment	

- ***NB: API average cost : from 500 € to 3 000 € by Kg***

- Time savings of a day-to-day operation estimated at 0.5 day/batch
  - *For example*:
    Compound XX study plan : 56 batches performed => **23 man/day**

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