Appendix B

Equations for On-Line Process Control

Feedback Control by Quality Characteristics (Continuous Variables; Chapter 24)

Loss Functions and Equations

$$L_0 = \frac{B}{n_0} + \frac{C}{u_0} + \frac{A}{\Delta^2}\left[\frac{D_0^2}{3} + \left(\frac{n+1}{2} + l\right)\frac{D_0^2}{u_0} + \sigma_m^2\right]$$

$$L = \frac{B}{n} + \frac{C}{u} + \frac{A}{\Delta^2}\left[\frac{D^2}{3} + \left(\frac{n+1}{2} + l\right)\frac{D^2}{u} + \sigma_m^2\right]$$

where

$$n = \sqrt{\frac{2u_0 B}{A}\frac{\Delta}{D_0}}$$

$$D = \left(\frac{3C}{A}\frac{D_0^2}{u_0}\Delta^2\right)^{1/4}$$

$$u = u_0\frac{D^2}{D_0^2}$$

Parameters

Δ: tolerance of objective characteristics

A: loss of a defective (yen)

B: checking cost (yen)

C: adjustment cost (yen)

n_0: current checking interval (unit or batch)

n: optimum checking interval (unit or batch)

D_0: current adjusting limit

D: optimum adjusting limit

u_0: current mean adjusting interval (unit or batch)

u: forecasted mean adjusting interval after optimization (unit or batch)

l: time lag of checking method (unit or batch)

σ_m: measurement error in standard deviation

Remarks

L_0: current loss function (yen/unit or batch)

L: optimum loss function (yen/unit or batch)

Feedback Control by Quality Characteristics (Using Limit Samples or Gauges; Chapter 24)

Loss Functions and Equations

$$L_0 = \frac{B}{n_0} + \frac{C}{u_0} + \frac{A}{\Delta^2}\left[\frac{D_0^2}{3} + \left(\frac{n_0 + 1}{2} + l\right)\frac{D_0^2}{u_0}\right]$$

$$L = \frac{B}{n} + \frac{C}{u} + \frac{A}{\Delta^2}\left[\frac{D^2}{3} + \left(\frac{n + 1}{2} + l\right)\frac{D^2}{u}\right]$$

$$= \frac{B}{n} + \frac{C}{u} + A\left[\frac{\Psi^2}{3}\left(\frac{n + 1}{2} + l\right)\frac{\Psi^2}{u}\right]$$

where

$$n = \sqrt{\frac{2u_0B}{A}}\frac{\Delta}{D_0} = \sqrt{\frac{2\overline{u}B}{A}}$$

$$D = \left(\frac{3C}{A\overline{u}}\right)^{1/4}\Delta = \Psi\Delta$$

Set $u_0 = \overline{u}$ when $D_0 = \Delta$

$$\Psi = \left(\frac{3C}{A\overline{u}}\right)^{1/4}, \quad u = \overline{u}\Psi^2$$

Parameters

Δ: tolerance of objective characteristics

A: loss per defective (yen)

B: checking cost (yen)

C: adjustment cost (yen)

n_0: current checking interval (units)

n: optimum checking interval (units)

D_0: current adjusting limit

D: optimum adjustment limit

u_0: current mean adjustment interval (units)

$\overline{u}$: mean failure interval (units)

u: mean adjustment interval after optimization (units)

Ψ: ratio of tolerance Δ and optimum adjustment limit D ($\Psi = D/\Delta$)

l: time lag of checking (units)

Remarks

L_0: current loss function (yen/unit)

L: loss function after optimization (yen/unit)

Feedback Control of Process Conditions (for Continuous Variables; Chapter 25)

Loss Functions and Equations

$$L_0 = \frac{B}{n_0} + \frac{C}{u_0} + \frac{A}{\Delta^2}\left[\frac{D_0^2}{3} + \left(\frac{n+1}{2} + l\right)\frac{D_0^2}{u_0} + \sigma_m^2\right]$$

$$L = \frac{B}{n} + \frac{C}{u} + \frac{A}{\Delta^2}\left[\frac{D^2}{3} + \left(\frac{n+1}{2} + l\right)\frac{D^2}{u} + \sigma_m^2\right]$$

where

$$n = \sqrt{\frac{2u_0B}{A}}\frac{\Delta}{D_0}$$

$$D = \left(\frac{3C}{A}\frac{D_0^2}{u_0}\Delta^2\right)^{1/4}$$

$$u = u_0\frac{D^2}{D_0^2}$$

Parameters

Δ: limit of process condition (x) when objective characteristic exceeds tolerance

A: loss when objective characteristic exceeds tolerance (yen)

B: unit checking cost of process condition (yen)

C: adjustment cost of process condition (yen)

n_0: current checking interval of process condition (x) (units)

n: optimum checking interval of process condition (x) (units)

D_0: current adjustment limit of process condition (x)

D: optimum adjustment limit of process condition (x)

u_0: current mean adjustment interval of process condition (x) (units)

u: optimum mean adjustment interval (forecast value) of process condition (x)

l: time lag of checking process condition (x)

σ_m: standard deviation of measurement error of process condition (x)

Remarks

L_0: current loss function (yen/unit)

L: loss function after optimization (yen/unit)

Process Diagnosis and Adjustment (Basic Equations; Chapter 26)

Loss Functions and Equations

$$L_0 = \frac{B}{n_0} + \frac{n_0 + 1}{2}\frac{A}{\bar{u}} + \frac{C}{\bar{u}} + \frac{lA}{\bar{u}}$$

$$L = \frac{B}{n} + \frac{n + 1}{2}\frac{A}{\bar{u}} + \frac{C}{\bar{u}} + \frac{lA}{\bar{u}}$$

where

$$n = \sqrt{\frac{2(\bar{u} + l)B}{A - C/\bar{u}}}$$

When $\bar{u} >> l$ and $A >> C/\bar{u}$,

$$n \approx \sqrt{\frac{2\bar{u}B}{A}}$$

Parameters

A: loss of producing unit product under abnormal process condition (yen)

B: unit diagnosis cost (yen)

C: adjustment cost (loss to bring abnormal process condition back to normal, total of process stoppage loss and treatment cost, including screening cost) (yen) [$C = C'$ (process stoppage loss) $\times$ t (mean stoppage time) + C'' (direct adjustment cost)]

n_0: current process diagnosis interval (units)

n: optimum process diagnosis interval (units)

$\bar{u}$: mean failure interval (units) [(production of a certain period) ÷ (number of failures that occurred during the period); when the number of failures is equal to zero since startup, $\bar{u} = 2 \times$ (production during the period)]

L: time lag (unit) [when a process is diagnosed as abnormal, the number of products produced from the time the product was processed to the time the process was stopped]

Remarks

L_0: current loss function (yen/unit)

L: loss function after optimization (yen/unit)

Points for improvement:

1. Prolong $\bar{u}$: Introduction of preventive maintenance or using long-life tools.
2. Reduce A: Improve defective treatment methods.
3. Reduce l: Improve diagnosis methods, improve diagnosis point.
4. Reduce C: Introduction of spare machines or spare molds.