Engineering Note: EN0114 Combining feedforward and feedback control to optimise the performance of continuous moisture conditioning systems

Summary:	A description with example of how to use both feedforward and feedback control to optimise continuous moisture conditioning systems
Products affected:	All products
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Author:	S.Cook

1 Introduction

Adding and removing moisture from materials is a common process task. This could be, for example, drying a material for long term storage, conditioning a material so that it can be processed more efficiently or to use in chemical processes.

Feedforward control is typically used in processes where a mathematical model of the process exists, and especially where changes to system parameters can take a long time to take effect for example changing the temperature of a dryer.

Feeback control is often used on systems that are unmodelled or where the model only uses a subset of process parameters. Whilst most industrial dryers are well modelled the effects of weather on the dryer efficiency is often excluded. A PID control loop using the error between the actual and expected moisture at the output of the dryer could be used to alter the process variables controlling the dryer.

The following sections describe how to implement feedforward and feedback control of a material conditioning conveyor; however, by swapping the feedforward model for a model of a different system, the same principles can be applied.

For simplicity this note uses the metric system and assumes that 1kg of water is equivalent to 1L of water.

2 System definition

The system consists of a conveyor with a spray bar to add water to the material being conveyed as it travels along the conveyor. Not all the metered water added will be successfully combined with the material, some will drain away or spray outside of the target area and this is an unknown quantity.

A moisture sensor is positioned at the beginning of the conveyor (Sensor A) and at the end of the conveyor (Sensor B). The output of Sensor A will be used as an input to a feedforward controller model to calculate the flow rate of water required to increase the moisture of the material to a target.

Sensor B measures the moisture of the material after water addition. The error between the output of the sensor and the target will be used as the input to a feedback controller to calculate a correction factor for the calculated flow rate.

The calculated flow rate can then be adjusted by the correction factor and used as the input to the proportional valve controlling the water flow rate. This system is shown in Figure 1 - Conditioning System.

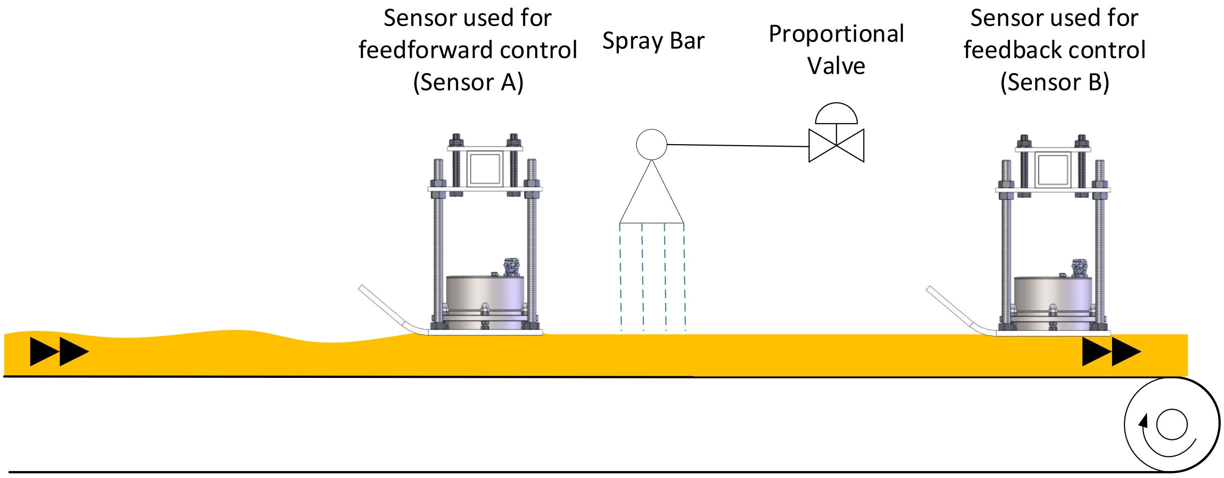

Figure 1 - Conditioning System

3 Model definitions

To calculate the required water flow rate, it is necessary to know:

- Material flow rate
- Moisture content of the material
- Target moisture
- Water flow rate required to achieve moisture increase required
- Valve position required to achieve flow rate

To calculate the compensation factor using the sensor after the spray bar it is necessary to know:

- The target moisture
- The moisture content of the material
- Current water flow rate flow rate
- Water flow rate change required to achieve the correction

3.1 Material flow rate (kg/s)

This can be calculated from the belt speed and the dimensions (height, width, depth) and density of the material being conveyed. Belt throughput is often calculated in Tonnes per hour (TPH).

TPH = Belt Speed(m/s) * Belt Width(m) * Material Density(kg/m^3) * Load Cross-section (m^2) / 1000

For simplification water flow rates can be expressed in kg/s

kg/s = TPH * 1000/3600

3.2 Moisture content of the material

This will be measured using the calibrated sensor positioned before the spray bar

3.3 Target moisture of the material

This will be entered by the operator or designated by the control system

3.4 Water flow rate required (L/s)

This is calculated from the material flow rate and the difference in moisture content from the target

Water Flow Rate (L/s) = Material Flow rate (kg/s) * (Moisture Target(%) – Current Moisture(%))

3.5 Valve position Required (%)

This is calculated as a percentage of the maximum flow rate achievable. If a second sensor after the water addition is not used to compensate then this output would be converted to a control signal for the value. This would typically be in mA or Voltage depending on the valve solenoid.

Valve Position(%) = (100 *Water Flow Rate Required) / Max Water Flow Rate

3.6 Valve position correction (%)

The sensor positioned after the spray bar can be used to determine the moisture content achieved. The moisture correction is determined by:

Moisture correction required = Target Moisture(%) – Current Moisture(%)

The water flow rate is again calculated using the formula in section 3.4.

The new valve position can be calculated using the formula in section 3.5 to calculate the adjustment required to obtain the target.

In its simplest form this correction can be applied directly to the valve position, however this simple system lacks being able to adjust the control more gradually to control overshoot.

3.7 Valve position correction (%) with PID Loop

Alternatively to the second calculation mentioned in section 3.6, the current valve position can be used as the process variable and the adjustment required can be used as the error value in a PID control loop. This can then be tuned to adjust how quickly the valve corrects for the error in the valve position.

The proportional gain on the PID loop will effectively replace the calculation element mentioned above.

The Integral gain factor can be used to correct long term offsets (steady state error, effectively errors in the calculation that are never compensated for).

The derivative gain is used to dampen the response, resisting rapid changes therefore limiting overshoot around the target.

Most PLC systems have PID Controllers as built in function blocks.

The Control Output for the proportional valve can be worked out using the following equation.

$$\mathrm{u}(t) = \mathrm{MV}(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

where

K_p: Proportional gain, a tuning parameter

K_i: Integral gain, a tuning parameter

K_d: Derivative gain, a tuning parameter

e: Error = Target Value (Unscaled) – Current value (Unscaled)

t: Time or instantaneous time (the present)

τ: Variable of integration; takes on values from time 0 to the present t.

MV(*t*) = Manipulated variable (or Control Output). This is limited to 0-100 in the case of a valve.

It is best to use the sensor's uncalibrated output (Unscaled) for PID loops as if the moisture calibration is changed the PID loop control will not be affected.

Example

Target = 50 Unscaled
Proportional gain, K_p = 5
Integral gain, K_i = 0.1
Derivative gain, K_d = 0

@ Time, t = 0
Current Unscaled = 30

MV(t) = 5(50-30) + 0.1(50-30) + 0(50-30)
MV(t) = 100 + 2 + 0
MV(t) = 102

>MV(t) limit therefore Control Output(C.O) = 100

@t=1
Current Unscaled = 40

MV(t) = 5(50- 40) + 0.1(50- 40) + 0.1(50-30) + 0(50-40)
MV(t) = 50 + 1 + 2 + 0
MV(t) = 53
C.O = 53

@t=2
Current Unscaled = 45 (reduction in increase as C.O is < 100 now)

MV(t) = 5(50-45) + 0.1(50-45) + 0.1(50- 40) + 0.1(50-30) + 0(50-48)
MV(t) = 25 + 0.5 + 1 + 2 + 0

MV(t) = 28.5
C.O = 28.5

@t=3
Current Unscaled = 50
MV(t) = 5(50-50) + 0.1(50-50) + 0.1(50-45) + 1(50-40) + 0.1(50-30) + 0(50-50)
MV(t) = 0 + 0 + .5 + 1 + 2 + 0
C.O = 3.5

At this point the target has been reached and the valve can be switched off. If no integral gain had been used the valve would have been shut off more as the current value approached the target thus slowing the increase significantly. This leads to longer water addition times but reduces overshoot