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<http://www.lagep.univ-lyon1.fr/signatures/dufour.pascal>**

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Université de Lyon, Lyon, F-69003, France; Université Lyon 1;
CNRS UMR 5007 LAGEP (Laboratoire d'Automatique et de GÉnie des Procédés),
43 bd du 11 novembre, 69100 Villeurbanne, France
Tel +33 (0) 4 72 43 18 45 - Fax +33 (0) 4 72 43 16 99
<http://www-lagep.univ-lyon1.fr/> <http://www.univ-lyon1.fr> <http://www.cnrs.fr>

MODEL PREDICTIVE CONTROL OF THE WATER BASED PAINTING DRYING USING A HUMIDITY PROFILE SOFT SENSOR AND A TEMPERATURE MEASUREMENT (Paper AU00157)

Pascal Dufour*, Pierre Laurent, Cheng-Zhong Xu

Laboratoire d'Automatique et de GENie des Procédés (LAGEP)

Université Claude Bernard Lyon 1, UMR CNRS 5007

43 bd du 11 Novembre 1918, 69622 Villeurbanne Cedex, France

Ph: +33 4 72 43 18 78 / Fax: +33 4 72 43 16 99

*E-mail: dufour@lagep.univ-lyon1.fr

1. Abstract: This paper deals with the model predictive control (MPC) of an infrared drying process of a water based epoxy-amine painting. During the drying cycle, the control problem is to minimize the processing time (hence maximizing the drying rate m) while accounting for any constraints dealing with the drying characteristics (i.e. the temperature $T(t)$ and the humidity profile $X(\xi, t)$). This approach is based on a nonlinear dynamic unidirectional diffusional model of the infrared drying phenomena where both heat and mass transfers under shrinkage conditions are accounted for. For the on-line application, the nonlinear diffusional model is solved off-line whereas the infrared flow to apply is computed on-line by the MPC using a linearized model.

2. Knowledge based PDE model

$$\frac{\partial X(\xi, t)}{\partial t} = \frac{\partial}{\partial \xi} \left(\frac{D(X, T)}{(1 + \beta X)^2} \frac{\partial X}{\partial \xi} \right) \text{ for } 0 < \xi < \delta_{dry} \text{ and } \forall t > 0$$

$$D(X, T) = D_0 \exp\left(-\frac{Ea}{RT}\right) \exp\left(-\frac{a'}{X}\right)$$

$$\frac{\partial X(\xi, t)}{\partial \xi} = 0 \text{ for } \xi = 0 \text{ and } \forall t > 0$$

$$\dot{m}(\bar{X}, T) = \frac{D(X, T) \rho_{dry} \partial X}{(1 + \beta X)^2 \partial \xi} \text{ for } \xi = \delta_{dry} \text{ and } \forall t > 0$$

$$(\rho_c \delta_p + \rho_s \delta_s) \frac{dT}{dt} = \alpha_r(\bar{X}) \dot{q} - \dots$$

$$\dots - h_c(T - T_h) - \sigma_b(T^4 - T_h^4) - h_r(T - T_b) - \alpha_s \sigma(T^4 - T_b^4) - l_v(T) \dot{m}(\bar{X}, T) \text{ for } \forall t > 0$$

3. Optimal constrained control problem

The cost function J is:

$$\max_{\dot{q}} J(\dot{q}) = \sum_{j=k+N_1}^{j=k+N_2} \left(\dot{m}(\bar{X}, T) \right)^2$$

The constraints to satisfied are:

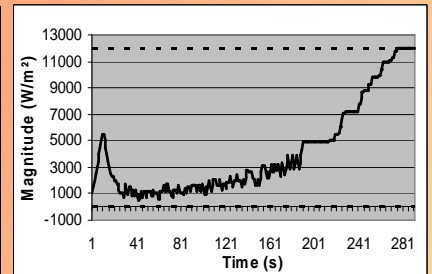
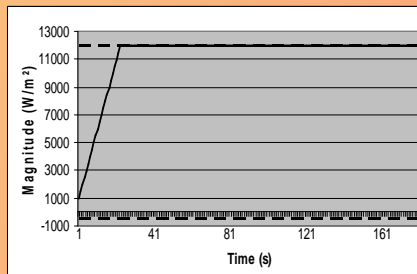
$$\begin{cases} \dot{q}_{\min} = 0 \text{ W.m}^{-2} \leq \dot{q}(k) \leq \dot{q}_{\max} = 12 \text{ kW.m}^{-2} \\ \Delta \dot{q}_{\min} = -500 \text{ W.m}^{-2} \leq \dot{q}(k) - \dot{q}(k-1) \leq \dot{q}_{\max} = 500 \text{ W.m}^{-2} \\ X(\zeta_1, k) - X(\zeta_2, k) \leq X_{\max} = 0.014 \text{ kg.kg}^{-1} \end{cases}$$

where the abscisses are:

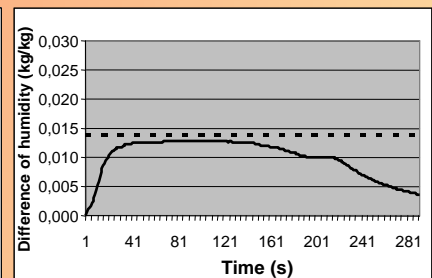
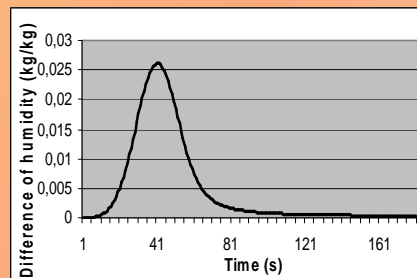
$$\zeta_1 = 0.8 * \delta_{dry}, \zeta_2 = 0.9 * \delta_{dry}$$

4. Optimal control strategies to minimize the processing time

Unconstrained (left) and constrained (right) cases



Infrared flow \dot{q}



Difference of humidity between ζ_2 and ζ_1 abscisses

The processing time is minimized: 180s when no constraints are specified and 290s when the difference of humidity constraint is accounted for and always satisfied.

5. Perspectives: No measure of the humidity profile required by the MPC is available. Therefore, an observer (model based soft-sensor) is under construction. It will estimate the entire humidity profile according to the infrared flow applied, the measured temperature and the model while real sensors are also needed for the observer validation. Moreover the constraints that really limit the processing time need to be defined before real validation of the approach.