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A FUZZY LOGIC APPROACH TO THE CONTROL OF THE DRYING PROCESS

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The paper presents the simulation results of an advanced control algorithm used for the control of the drying process of electric insulators. The industrial batch drier is modelled and three different approaches are taken for its control. In order to investigate its capabilities, Fuzzy Logic Control (FLC) is used for controlling the air temperature in the drying chamber. The results describing the controlled variables behaviour under the influence of some typical disturbances are compared with data obtained using Model Predictive Control (MPC) and traditional PID control.

The requested drying program consists of a ramp-constant profile, obtained by manipulating the air and natural gas flow rate. Moisture content control is actually achieved by controlling the air temperature inside the drying chamber.

Simulation results reveal clear benefits of the FLC approach over the other control methods subjected to our investigation, and prove real incentives for industrial implementation.

Keywords: batch drying, fuzzy logic, model predictive control, non linear control

Introduction

The high-voltage electric insulator production implies a two-stage batch drying process. During the first step, the moisture content of the drying product is reduced from 18-20 % to 0.4% in special gas heated chambers. The second step is carried out in high temperature ovens, in order to achieve an even lower moisture content.

Gas and air flow rates are controlled according to a special program, during a period of about 100 hours, in order to obtain the desired moisture content and avoiding the risk of unsafe tensions in the drying products.

An analytical dynamic model of the process is derived for model predictive control purposes.

Model description

Mass and energy balance equations are used to describe the dynamic behaviour of the system. The main studied outputs of the model are: moisture content of the drying product X, outlet air temperature T_0 and air humidity x_0; the input variables: natural gas flow rate $\dot{V}_F$ and mass flow rate of fresh air $\dot{m}_{ai}$. The chamber is divided into three sections as shown in *Fig.1*. Section 1 represents the air volume within the drying chamber, section 2 the direct surroundings of the drying product. Section 3 represents the drying product itself.

The mass balance of steam within section 1 is described by

$$\dot{m}_{ai}\cdot x_f+\dot{m}_a\cdot x-\left(\dot{m}_a+\dot{m}_{ai}\right)\cdot x_o=V_{aCh}\cdot\rho_a\cdot\frac{dx_0}{dt} \quad (1)$$

with V_{ach} being the volume of the air in section 1. In section 2, the steam fluxes around the drying product are modelled by

$$\dot{m}_a\cdot\left(x_o-x\right)-m_S\cdot\frac{dX}{dt}=\frac{d}{dt}\left(V_{a2}\cdot\rho_a\cdot x\right) \quad (2)$$

with V_{a2} being the infinitesimal small volume of air in section 2. Due to this fact, the last term of the equation can be neglected, which results in the differential equation

$$\frac{dX}{dt}=\left(x_o-x\right)\cdot\frac{\dot{m}_a}{m_S}. \quad (3)$$

As a result of differentiation of *Eq.(3)* and assuming that, $d^2X/dt^2\approx 0$ the *Eq.(1)* becomes:

$$\frac{dx}{dt}=\frac{1}{V_{aCh}\cdot\rho_a}\cdot\left(\dot{m}_{ai}\cdot x_f+\dot{m}_a\cdot x-\left(\dot{m}_a+\dot{m}_{ai}\right)\cdot x_o\right) \quad (4)$$

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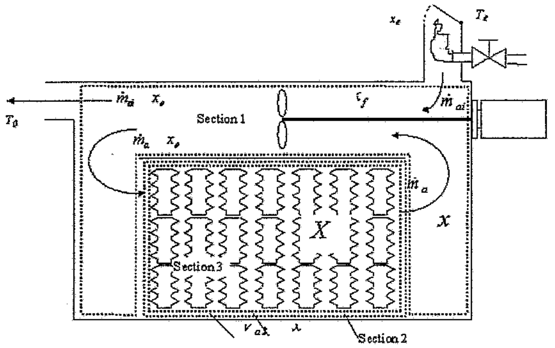

Fig.1 Description of the drying chamber

In section 3, the behaviour of the drying good itself is described with a normalised diagram by means of the following equation [1, 2]:

$$\frac{dX}{dt} = -\frac{\dot{m}_{st}}{m_S} \cdot A_S \,. \qquad (5)$$

The drying velocity for the three periods of the drying process of a hygroscopic material are characterised by the diagrams of *Fig.2* [2].

This diagram *a)*, only available by experiments and valid for the certain conditions can be normalized to *b)* according to:

$$\dot{v}(\eta) = \frac{\dot{m}_{st}}{\dot{m}_{stI}} \qquad \eta = \frac{X - X_{equ}}{X_c - X_{equ}} \qquad (6)$$

It is assumed that X_c is constant, not depending on the drying conditions, and that X_{equ} only depends on relative air humidity, but no other factors. It is also assumed that all diagrams of the drying velocity for different drying conditions are geometrically similar.

The equilibrium humidity X_{equ} in dependence of the relative air humidity φ, for clay, was considered by a correlation equation. The saturation humidity of the air, x_{sat}, is dependent of temperature T_o. For low partial pressures of steam a simple equation for $\dot{m}_{stI}$ was considered:

$$\dot{m}_{stI} = k \cdot (x_{sat} - x) \qquad (7)$$

with the mass transfer coefficient k determined by experiment data.

Two energy balance equations, for the chamber:

$$\begin{aligned} &\dot{m}_{ai} \cdot \left(c_{pa} \cdot (T_i - T_o) + x_f \cdot (h_v + c_{pst} \cdot T_i) - x_o \cdot (h_v + c_{pst} \cdot T_o)\right) + \\ &+ m_s \cdot \frac{dX}{dt} \cdot (h_v + c_{pst} \cdot T_o) - C_A A_{Ch} (T_o - T_e) = \\ &= V_{aCh} \cdot \rho_a \cdot \left((c_{pa} + x_o \cdot c_{pst}) \cdot \frac{dT_o}{dt} + c_{pst} \cdot \frac{dx_o}{dt} \cdot T_o \right) \end{aligned} \qquad (8)$$

and for the burner:

$$\begin{aligned} &\dot{m}_{ai} \cdot \left(c_{pa} \cdot T_e + x_e \cdot (h_V + c_{pst} \cdot T_e)\right) + \\ &+ (c_{pF} \cdot T_e + H_F) \cdot \frac{M_F \cdot p_F}{R \cdot (T_e + 273)} \cdot \dot{V}_F = \\ &= \dot{m}_{ai} \cdot \left(c_{pa} \cdot T_i + x_f \cdot (h_V + c_{pst} \cdot T_i)\right) \end{aligned} \qquad (9)$$

are used to describe the outlet temperature change.

A dynamic sensitivity analysis was carried out on this model, indicating the most important parameters and manipulated variables. According to this analysis, they are: mass transfer coefficient *k*, heat transfer coefficient of chamber walls C_A, heating power of natural gas H_F, mass of the drying product m_S (clay without humidity), environment temperature of the inlet air T_e, environment humidity of the inlet air x_e, volume of the drying chamber V_{Ch}, surface of the drying chamber A_{Ch}, surface of the drying product A_S, critical humidity of clay X_C and specific heat of natural gas c_{pF} [3]. The scaled dynamic sensitivity analysis of the output variables with respect to the studied inputs pointed out the natural gas flow rate as the most important manipulated variable (about 10 times more important than the mass flow rate of fresh air). The control system was designed accordingly.

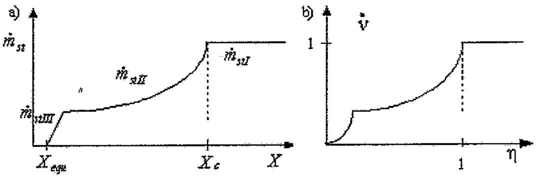

Fig.2 Drying rate in dependence of moisture content of drying product: a) absolute b) normalized

Results and Discussion

Any process controller's mission is to receive a number of inputs and compute the appropriate outputs in order to annihilate a possible error. The fuzzy controller is no exception: it receives a measured value from the system, if fuzzyfies it (assigns it a membership value), applies the system's rules, computes an overall result of all the rules and then defuzzyfies the result, converting it into a number which is an appropriate command for the system it controls. [4, 5]. The mission of the Model Predictive Controller [6] is accomplished by anticipating the outputs of the system with the aid of the mathematical model. The controller output is generated, based on the anticipated behavior of the system.

All control methods investigated in this paper obey the current control practice [7], i.e. driving the evolution of the moisture content of the drying product in the desired way by means of controlling the air temperature inside the chamber. Usually, the desired decreasing profile of the drying product moisture content is obtained by imposing an increasing ramp-constant

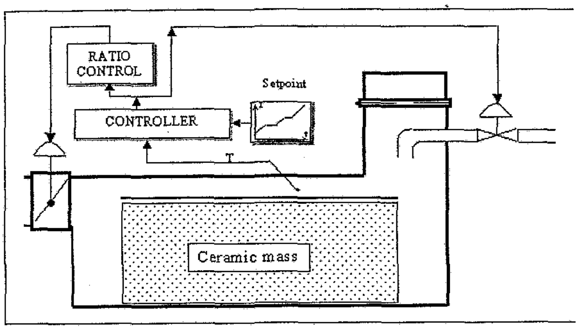

Fig.3 Structure of the control system

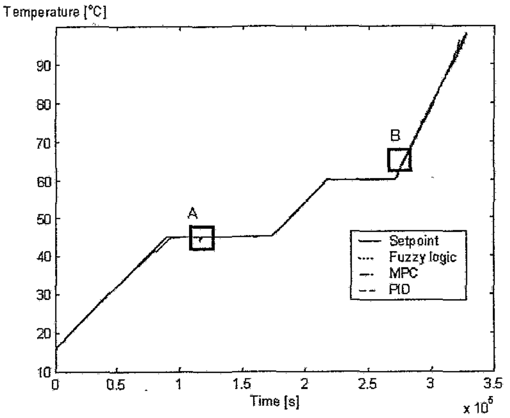

Fig.4 Comparative behaviour of FL, MPC and PID control in the presence of the heating power disturbance

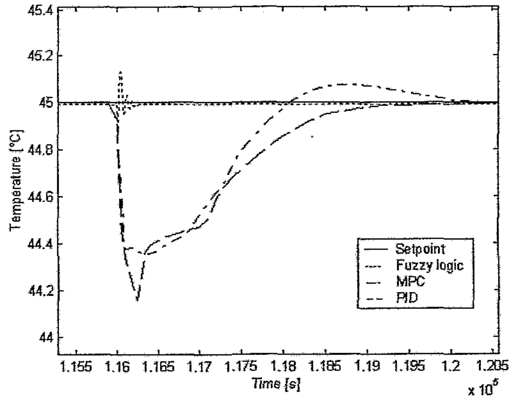

Fig.5 Detailed presentation of the comparative behaviour of FL, MPC and PID control in the presence of the heating power disturbance

profile on the air temperature. The setup of the simulated system is shown in *Fig.3*.

Performance testing was carried out for three significant disturbances typically occurring in the industrial practice: a 10 ^{0}C inlet air temperature T_e drop (from 16 ^{0}C to 6 ^{0}C), a 10 % heating power capacity H_F drop of natural gas and a 10% rise in the moisture content of the inlet air. The disturbances were introduced as steps at time $t=116000$ s. The simulation results for case of the heating power disturbance are presented in *Figs.4* and *5*.

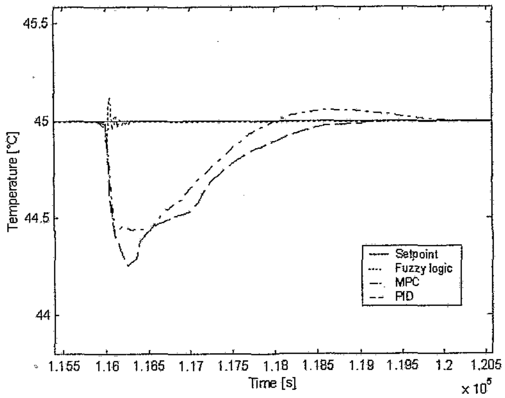

Fig.6 Detailed presentation of the comparative behaviour of FL, MPC and PID control in the presence of the air inlet temperature drop disturbance

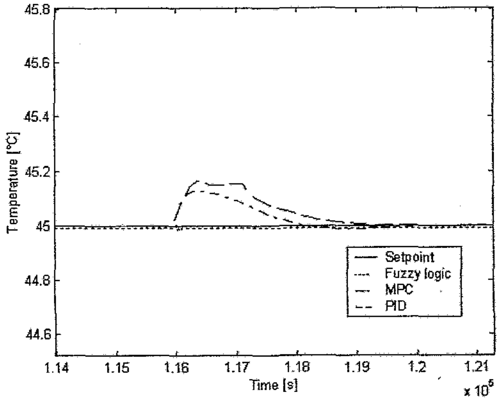

Fig.7 Detailed presentation of the comparative behaviour of FL, MPC and PID control in the presence of the air inlet humidity increase disturbance

The figures show the response of the controlled variable over the entire time interval and a detailed representation of the period when the disturbance acts and is eliminated. The behaviour of three investigated control methods (Fuzzy Logic Control- FLC, Model Predictive Control-MPC and PID control) is presented comparatively. *Figs.5-7* are magnifications of the area marked as detail A on *Fig.4*.

Fig.6 presents a detail of the controlled output temperature for the air inlet temperature drop disturbance and *Fig.7* represents in the same manner the case of the disturbance consisting in a humidity increase of the inlet air.

With respect to setpoint tracking performance, the results reveal a good behaviour in case of PID and MPC, FL control featuring superior abilities. As it can be seen, FLC is very accurate, following with precision both the constant and the ramp sections of the temperature setpoint scheduling function.

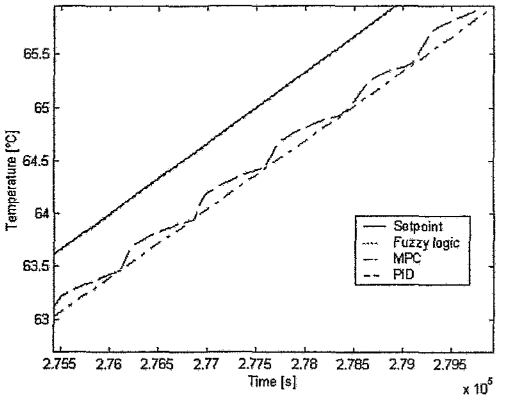

Fig.8 Detailed presentation of the ramp setpoint following performance of FLC, MPC and PID control

All control methods exhibit a low offset behaviour for the constant parts of the setpoint function. For the ramp sections, as in *Fig.8* (detail B on *Fig.4*), the MPC and PID control proved to be less accurate than FL showing a larger offset.

This accuracy of the FL control is largely due to the asymmetrical membership function definition. The definition takes into account the need for an asymmetric amplitude of the manipulated variable change (i.e. a controller response of higher amplitude to a negative error compared to a lower amplitude response for a positive error) in the ramp section of the setpoint function.

With respect to disturbance rejection performance, FL control showed a considerably shorter (more than 10 times) response time and smaller (more than five times) overshoot than the other control strategies.

Conclusions

A comparative study of three control methods for the process of drying high voltage ceramic insulators (FLC, MPC and PID) was carried out. Setpoint tracking and disturbance rejection were investigated for disturbances typically occurring in the industrial practice. Fuzzy Logic clearly stands out as the preferable control method for the considered process, due to the good setpoint tracking performance, low overshoot and short settling time. FLC is easy to implement and adapt in case of process modification due to its similarity with natural language. Also, the controller's simple structure is another argument in favour of the industrial implementation of this control method. Further research is envisioned for the control of the inferred moisture content of the drying product, with the implementation of an artificial intelligence based method for tuning the FL controller.

REFERENCES

1. VAN MEEL D. A.: Chem. Engng. Sci., *1958*, 9, 36-44
2. KRISCHER O. and KAST W.: Die wissenschaftlichen Grundlagen der Trocknungstechnik, Springer-Verlag, 1992
3. PERRY R. and CHILTON C.: Chemical Engineers' Handbook, 5. Edition, Mc Graw Hill,1973
4. Fuzzy Logic Toolbox, For Use with Matlab®, User's Guide v. 2.0, The Mathworks, Inc. Natick, MA, 1999
5. RUSSO M.: IEEE Trans. Fuzzy Systems, *1998*, 6(3), 372-388
6. GARCIA C. E., PRETT M. P. and MORARI M.: Automatica, *1989*, 25(3), 335-348
7. CRISTEA V. M., BALDEA M. and AGACHI S. P.: Model Predictive Control of an Industrial Dryer, European Symposium on Computer Aided Process Engineering-10, Florence 2000