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Variable Structure Controller for a Rotary Dryer

متحكم متغير البنية للمجفف الدوار

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ملخص:

في هذا البحث تم الجمع بين نظامين لتمثيل نظام التجفيف الدوار النظام الاساسي (4) و معادلة معدل التجفيف التي تسبب اللاخطيه في النظام (13)، يلي ذلك تطبيق نمط للتحكم المتغير البنية حيث يتم تصميم متحكم تكاملي متغير البنية عن طريق تحويل معادلة نموذج النظام وتصميم سطح انزلاقي تكاملي باختيار مصفوفة تحكم مناظرة لخرج مثالي ، وحيث ان مصفوفة التحكم ليست فريده فإن اختيار أسطح التبديل ليست فريدة. وخلافا للنهج التقليدية فإن ذلك لا يحتاج الى تحويل معادلة النموذج الأصلية الى شكل مصاحب، ومن اجل التحكم في نظام المجفف الدوار تم تطبيق الطريقة التقليديه للتحكم بغرض المقارنة، وبعد تطبيق طرق المراقبة ومقارنة النتائج في سلوك المجفف الدوار وخاصة أهم المتغيرات المراد التحكم بها وهو رطوبة المادة الصلبة المجففة، وبمقارنة النتائج بالابحاث السابقة بطريقة المحاكاة للنظام الأصلي، أظهرت النتائج أن نظام التحكم الذي تم تقديمه يعطي أداءا أفضل ،حتي عند ادخال تغيير مفاجئ علي النظام في نفس ظروف التشغيل، تم التطبيق والمحاكاه باستخدام Matlab®, and Simulink

ABSTRACT

Drying, especially rotary drying is without doubt one of the oldest and most common unit operation in industry and in this paper, the main process is drying solids, while making the Hot Mix Asphalt used in roads construction.

Drying is a very complex non-linear process; we make combination between two dynamic models of dryer plant to solve the drying rate equation which cause the non-linearity of the model.

The aim of this research is to improve dryer control by developing control system by designing of an integral variable structure controller, the design of integral sliding surface is determined by the choice of the controllability matrix and the selection of the transfer-function matrix from the reference signal to the Pseudo-output, Appling this VSC to the dryer plant to see the performance, in order to reducing the fuel and air used by the dryer, so that the efficiency of the dryer will increases.

This article compare the behavior of the plant dryer when connected with the proposed VSC with the traditional PID controller, The behavior of the control systems has been tested with simulations based on the model of a plant dryer using The Matlab®, and Simulink.

KEY WORDS: Rotary Dryer, Fuzzy control, Neuro-Fuzzy control

1- INTRODUCTION:

Rotary drying is an operation which is easy and reliable, but neither energy-efficient nor environmentally friendly. Most rotary dryers, especially older ones, are still controlled partially manual, relying on the human "eye" and experience of the operator,

Drying is an operation of great commercial importance, in all industrial applications ranging through the food, agricultural, mining and manufacturing sectors. Modern society requires better product quality, improved safety practices and more environmentally benign operations, as well as higher productivity, better energy efficiency and reduced material wastage. As drying is certainly one of the most energy-intensive operations in industry, and as most dryers operate at low thermal efficiency, the development of models and control systems to improve dryer operation and efficiency.

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1.1 Rotary drying

Large quantities of granular material with particles of 10 mm or larger that are not too fragile or heat sensitive or cause any other solids handling problems are dried in rotary dryers in the process industries. The rotary dryer is one of the most common types of industrial dryer. It is a cylindrical shell usually constructed from steel plates, slightly inclined, typically 0.3-5 m in diameter, 5-90 m in length and rotating at 1-5. It is usually operated with a negative internal pressure to prevent dust escape. Solids introduced at the upper end move towards the lower or discharge end. Depending on the arrangement for the contact between the drying gas and the solids, a dryer may be classified as direct or indirect, con-current or counter-current.

An array of lifting flights of various shapes is constructed inside the shell to shower the solids in order to ensure contact with the gas. These flight configurations vary from spirals to straight flights. The effect of the flight design i.e. the number of flights, their dimensions and their shape, on the performance of the dryer is very complicated.

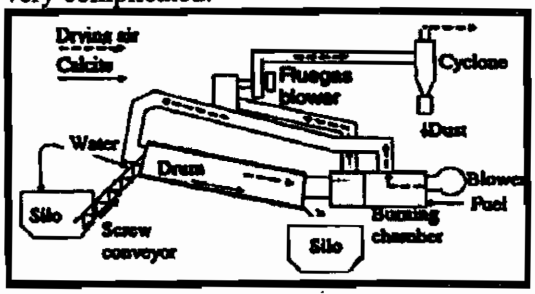

Fig. 1 (structure of rotary dryer plant)

A rotary dryer has two distinct functions: as a conveyor and as a heating device. The movement of solids through the dryer is influenced by the following mechanisms: lifting, cascade action, sliding and bouncing, as depicted in Figure.

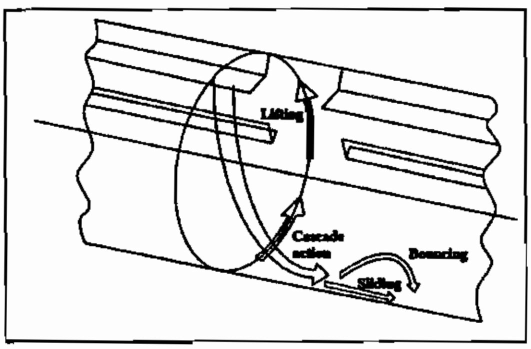

Fig. 2 (A cascading rotary dryer(Yliniemi 2002)

As the dryer rotates, solids are picked up by the flights, lifted for a certain distance around the drum and showered through the air in a cascading curtain. Most of the drying occurs at this time, as the solids are in close contact with the gas. Flight action is also partly responsible for the transport of solids through the drum.

The factors affecting the modeling of a rotary dryer can be classified to [4]:

- physical properties of the solids, such as particle size and shape, density and moisture content,
- dryer variables, such as the diameter and length of the drum and the design and number of lifting flights and
- operating conditions, such as the feed flow and temperature, the flow and temperature of the drying air and the slope and rotation speed of the drum.

1.2 The basic objectives for the development of dryer control are:

- Maintain the desired product moisture content in spite of disturbances in drying operation,
- Maximize production with optimal energy use and at minimal costs so that the costs of investment in automation are reasonable compared with other equipment costs,
- Avoid over drying, which increases energy costs and can cause thermal damage to heat-sensitive solids, and
- Stabilize the process (minimize the effect of disturbance).
- Minimize the energy cost

2- The Model for the plant dryer

2.1 Dynamic models for the plant dryer:

A rotary dryer is a distributed parameter system in which both temperature and moisture are functions of time and distance, according to the general equation:

$$f_i(x_i, l, t) = \frac{\partial x_i(l,t)}{\partial t} \pm v_i(t)\frac{\partial x_i(l,t)}{\partial l}$$

Where:

Xi: moisture or temperature in the solids or gas phase

Vi: linear velocity in the solids or gas phase

l: axial co-ordinate, **t:** time.

A positive sign for vi applies to con-current drying and a negative sign to counter-current drying.

The distributed parameter model is complex and cumbersome to handle, and the temperature and especially the content of solids and drying air inside the dryer are difficult to measure. It is therefore simplified to a lumped parameter model in which the partial derivative of the axial co-ordinate length equals to the total length of the drum.

The equation for the gas moisture content is not included in the overall model for the dryer, because it is not measured in the pilot dryer. The model is now of form:

$$\frac{dX_{s,out}}{dt}+V_s\frac{(X_{s,out}-X_{s,in})}{L}=-R_w$$

$$C_s\frac{dT_{s,out}}{dt}+V_sC_s\frac{(T_{s,out}-T_{s,in})}{L}=-\frac{U_vV_v}{F_s}(T_{g,out}-T_{s,in})-\lambda R_w$$

$$C_g\frac{dT_{g,out}}{dt}+V_gC_g\frac{(T_{g,out}-T_{g,in})}{L}=-\frac{U_vV_v}{F_g}(T_{g,out}-T_{s,out})-\lambda\frac{F_s}{F_g}R_w$$

where the meaning of symbols are, as in Yliniemi (1999):[4] $X_{s,out}$, $T_{g,out}$ and $T_{s,out}$ are the moisture content, the temperature of gas and of solids in the output.

The model is non-linear, because the drying rate Rw, which describes the course of drying inside the solids, is generally a non-linear function of solids characteristics and drying air temperature in the falling rate period, as many researchers have found in their experimental.

2.2 Drying rate equation:

As the equations above, we can notice that Rw is the drying rate of the product. This is one of the most important parameters of the model and it must be experimentally determined.

According to Yliniemi [8], it should include moisture solid equilibrium data and experimentally determined batch drying curve obtained under conditions approximating as closely as possible those of the process that it is being modeled. For rotary dryers, the batch equipment that previous researches recommended if the product does not a form hard scab when drying, are direct dryers with cross-flow of air or small rotary dryers.

In this study a thin layer dryer has been used This kind of equipment has been used to study the drying kinetic and the expressions obtained have been used to model the rotary drying process. Drying experiments of a mixture of product similar to that obtained in the wholesale market and air temperatures in the range from 50 to 150 C were made. It was found that the simple exponential equation described adequately the drying kinetic of these by-products.

The following drying rate equation was obtained (Iguaz, 2000a) [13]:

$$Rw=K(W-We)$$

K is the drying constant and it is related to the temperature of the drying air by:

$$K=0.00719\exp(-\frac{130.64}{Tg})$$

The equilibrium moisture content (We) of the product was calculated by determining experimentally the equilibrium moisture isotherms at 25, 40, 60 and 90. GAB model was selected to predict We because it was the model that better fit to experimental data. The following expression was obtained to be:

$$We=\frac{W_mCKa_w}{(1-Ka_w)[1+(C-1)Ka_w]}$$

where Wm, C and K are parameters related to air temperature by the following expressions:

$$W_m=0.0014254\exp(\frac{1193.2}{T_k})$$

$$C=0.05923841\exp(\frac{1072.5}{T_k})$$

$$K=1.00779919\exp(-\frac{43.146}{T_k})$$

where Tk is air absolute temperature (K).

Substituting for (Rw) on model equations, and set the Dryer Plant parameters as next :

2.3 Operating parameters of Plant Dryer

Parameter	Value
N_drum	1.0 r/m
Vg	0.7 m/s
Vs	4.78*10^-3 m/s
Fg	0.12 kg/m
Fs	8.77 kg/m
Tgin	472 K
Tg,out	421 K
Tsin	293 K
Ts,out	360 K
Xsin	2.4 %
Xs,out	0.01 %
Cg	1.01 kj/kg K

Cs	0.84 kj/kg K
Uv	0.27 kj/s m^3 K
Vv	0.19 m^3/m
lmd	2261 kj/kg
L	3 m
Tk	600 K

Table 1 (Operating parameters of Plant Dryer)

We can then put the plant model in the canonical form of:

$$\dot{X} = AX + Bu, \qquad Y = CX$$

Where:

$$X = \begin{bmatrix} X_{s,out} \\ T_{s,out} \\ T_{g,out} \end{bmatrix}, \quad u = \begin{bmatrix} T_{g,in} \\ T_{s,in} \\ X_{s,in} \\ V_s \\ F_g \\ F_s \end{bmatrix}$$

$$A = \begin{bmatrix} -0.0025933 & 0 & -1e-009 \\ -2.6917 & -0.008557 & 0.006961 \\ -163.61 & 0.42327 & -0.65676 \end{bmatrix}$$

B=

$$\begin{bmatrix} 0 & 0 & 0.0015933 & 0.0046667 & 0 & 0 \\ 0 & 0.0015933 & 0 & -22.333 & 0 & -0.0012185 \\ 0.23333 & 0 & 0 & 0 & -1105.3 & 15.198 \end{bmatrix}$$

$$C = [1\ 1\ 1]$$

The analysis shows that the main variable that needs to be manipulated in order to control the output moisture content of the solids is the drying air temperature which correlated to the fuel flow, and the main disturbance variable is the input moisture content.

The feed flow can be used as an auxiliary variable to be manipulated, or else it can be a disturbance variable.

The existing operating conditions are simulated first to validate the model.

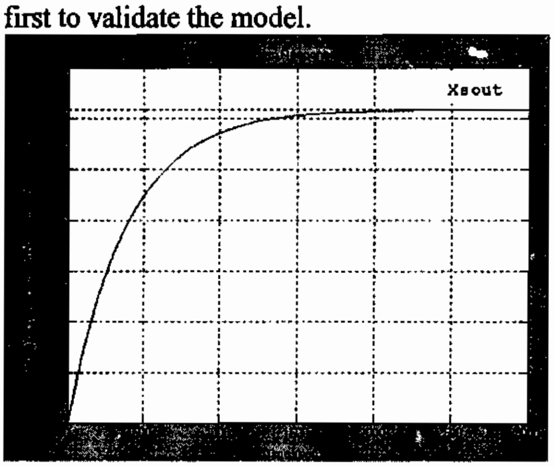

Fig.3 Simulated output responses for Xsout to a step change in the input moisture of solids from 2.4% to 4.4%.

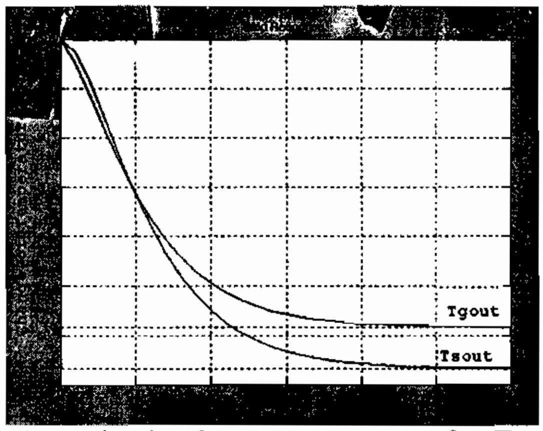

Fig.4 Simulated output responses for Tgout, Tsout to a step change in the input moisture of solids from 2.4% to 4.4%.

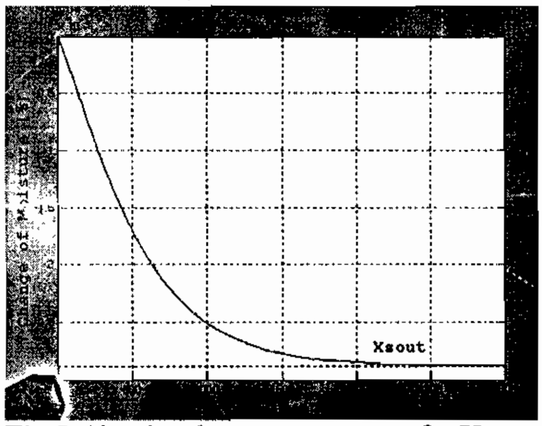

Fig.5 Simulated output responses for Xsout to a step change in the input temperature of the drying air from 463 K to 483 K.

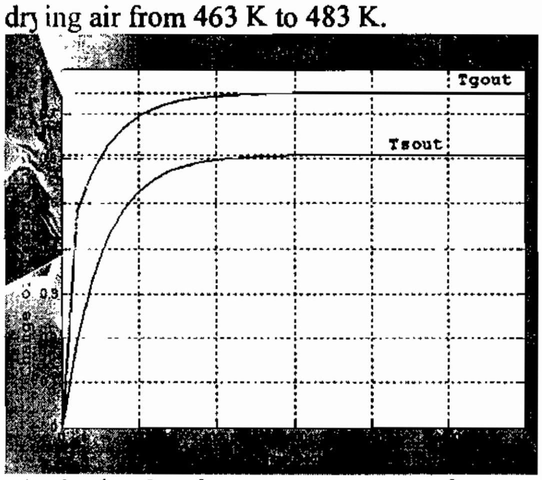

Fig.6 Simulated output responses for Tgout, Tsout to a step change in the input temperature of the drying air from 463 K to 483 K.

A sensitivity analysis shows that the main variable that needs to be manipulated in order to control the output moisture content of the solids is the drying air temperature which correlated to the fuel flow, and that the main disturbance variable is the input moisture content, the feed flow can be used as an auxiliary variable to be manipulated, or else it can be a disturbance variable.

3- Variable structure control:

The theory of variable structure systems (VSS) can be used for the design of feedback control laws for uncertain dynamical systems. VSS theory rests on the concept of changing the structure of the controller in response to the changing state of the system in order to obtain a desired response. This is accomplished by the use of a high speed switching control action which forces the trajectory of the system onto a chosen manifold in the state space, where it is maintained thereafter.

The most important merit and well known advantage of variable structure system is its robustness against parameter uncertainties and disturbances.

It is a high-speed switching feedback control system, consisting of subsystems supplied with switching rules. The control law drives the state's trajectory on to the sliding surface. The dynamics restricted on this surface are actually the controlled system's behavior.

A variable structure control (VSC) is a special class of nonlinear control. These systems differ from other control systems mainly in that their structure is not fixed but is varied during the control process.

In sliding mode, the systems can result in very good performances which are completely invariant to the matched uncertainties

Fuzzy control is a direct method for controlling a system without the need of a mathematical model, in contrast to the classical control which is an indirect method with a mathematical model. Fuzzy control has been implemented in many industrial applications.

3.1 The sliding function

There are many technique for the sliding function design, such as the Eigen-structure assignment, Lyapunov-based method, linear matrix inequalities, pole assignment method, and frequency shaping method.

It has been shown that fuzzy logical control techniques decompose the complex system into several subsystems and use a simple control law to emulate the human control strategy in each local operating region. It is well known that sliding-mode control provides a robust approach to controlling nonlinear systems with uncertainties. A sliding mode controller is equipped with capability of handling fuzzy linguistic qualitative information. An advantage of such control is that fuzzy logic can effectively eliminate chattering through construction of fuzzy boundary layers which replace crisp switching surfaces [12, 13].

3.2 The Method of designing integral VSC for MIMO Systems

In this article, we extended the idea of design an integral variable structure controller based on the method developed in Computing the state feedback gains of multivariable systems to design integral sliding surfaces for MIMO systems. The method to design integral sliding surfaces and control function is to modify the transfer function matrix from reference input to pseudo-output based on the desired closed-loop Eigen-values[…algorithm…].

Consider the plant is a controllable and observable MIMO system:

$$\dot{X}(t) = A\,x(t) + Bu(t)$$

$$Y(t) = Cx(t)$$

where A: $Rn\times n$, B: $Rn\times v$, and C: $Rh\times n$ are all real constant matrices. $x(t)$, $u(t)$, and $Y(t)$ are the state vector, the control input, and the measured output, respectively.

The transfer-function matrix of this system can be given in:

$$G(s) = C(sI - A)^{-1}B = N(s)D^{-1}(s)$$

where $N(s)$ and $D(s)$ are polynomial matrices of dimensions $h\times v$, and $v\times v$, respectively.

Let $B = [b1 \quad b2 \; ... \; bv]$ be full rank. Since the system is controllable,

The proposed method to design the integral variable structure control is to modify the transfer-function matrix from $R(s)$ to $W(s)$. The proposed method is divided into three parts. **First**, we select a desired transfer-function matrix from $R(s)$ to $W(s)$ and determine the integral sliding surface. **Second**, we provided that the control function make the system reach the integral sliding mode. **Third**, the robustness of the actual output system is considered.

3.3 Determination of the Switching Surface

Let $W^T(t)=[w_1(t) \quad w_2(t) \quad \dots \quad w_v(t)]$

and then we consider the transfer function matrix from $R(s)$ to $W(s)$ can be expressed as we have

$$\hat{P}^{m} w_i+\sum_{i=1}^{m-1} f_{ij} \hat{P}^{m-j} w_i + f_{i,m}(w_i - f_{i,m}^{-1} r_i)=0, \quad i=1,2,\dots,v,$$

where $p^{\wedge}$ denotes a differential operator.

Now, integral controller is defined by

$$\dot{x}_{0,i} = w_i - f_{i,m}^{-1} r_i, \quad , \quad i=1,2,\dots,v,$$

Then

$$\hat{P}(\hat{P}^{m-1} w_i+\sum_{i=1}^{m-1} f_{ij} \hat{P}^{m-j-1} w_i + f_{i,m} x_{0,i}=0$$

During the sliding mode, the state of the system is constrained to subspace defined by the equation $\sigma i = 0$ therefore, the required switching surface can be simply determined

$$\sigma_i = \hat{P}^{m-1} w_i + \sum_{i=1}^{m-1} f_{i,j} \hat{P}^{m-j-1} w_i + f_{i,m} x_{0,i} = 0, \quad i=1,2,\dots,v,$$

Then we can compute:

$$\hat{P} w_i = q_i(A+\Delta A)x + q_i Bu + q_i L(x,t) \qquad , \quad i=1,2,\dots,v,$$

$$q_i(A+B\bar{\Delta A}(x))x + q_i Bu + q_i B\bar{L}(x,t)$$

$$q_i Ax + q_i B(\bar{\Delta A}(x)x + u + \bar{L}(x,t))$$

And, in general, we have

$$\hat{P}^{j} w_i = q_i A^j x, \qquad j=0,1,\dots,m_i-1,$$

By substituting , we obtain the required switching surface:

$$\sigma_i = q_i A^{m-1} x(t) + \sum_{j=1}^{m-1} f_{ij} q_i A^{m-j-1} x(t) + f_{i,mj} x_{0i}, \quad i=1,2,\dots,v,$$

$$= S_i\, x(t) + f_{i,mj} x_{0i}$$

where $S\,i$ is defined by

$$S_i = q_i A^{m-1} + \sum_{j=1}^{m-1} f_{i,j} q_i A^{m-j-1}$$

3.4 Choice of the Control Function

Once the required switching surface is obtained, we will determine the required control function that ensure the integral VSC to achieve the reaching condition.

$$\sigma^T \dot{\sigma} < 0$$

Differentiating , we have

$$\dot{\sigma}_i = S_i(A+\Delta A(x))x(t) + S_i Bu_i(t) + S_i L(x,t) + f_{i,mj}(w_i - f_{i,mj}^{-1} r_i)$$

Then

$$\dot{\sigma} = S(A+\Delta A(x))x(t) + SBu(t) + SL(x,t) + f(w - f^{-1}R)$$

Where

$$f = \operatorname{diag}[f_{1,m1} \quad f_{2,m2} \quad \dots \quad f_{v,mv}]$$

The control function u is generated as

$$u(t) = -(SB)^{-1}(SAx + f(w - f^{-1}R_0)) - (\Omega_{\Delta A} \| x(t) \| + \Omega_L)\frac{B^T S^T \sigma}{\| B^T S^T \sigma \|}$$

First, we show that SB is invertible. Without loss of generality, we can rename the vectors $i\ b$ to meet the inequalities $p \le m1 \le m2 \le \text{L} \le m\,1$. we showed that SB is a $p \times p$ unity matrix. Hence SB is invertible. Then, it is easy to check that the reaching condition $\sigma\ T\sigma\ \& < 0$ is ensured.

Therefore, based on the perturbation bounds and disturbances estimated by Assumption 2, we obtain the required control function.

3.5 Robustness Consideration of the Actual Output

It is mentioned that the proposed integral VSC obtains a robust pseudo output W in previous sections Note that the overall transfer function from $R(s)$ to $Y(s)$ is given by

$$Y(s) = N(s)W(s)$$

$$= N(s)D_a^{-1}(s)R(s)$$

$$= \begin{bmatrix} N_{11}(s) & \cdots & N_{1v}(s) \\ \vdots & \ddots & \vdots \\ N_{h1}(s) & \cdots & N_{hv}(s) \end{bmatrix} \operatorname{diag}[F_1^{-1}(s) \quad F_2^{-1}(s) \quad \cdots \quad F_v^{-1}(s)]R(s)$$

$$= \begin{bmatrix} \frac{N_{11}(s)}{F_1(s)} & \dots & \frac{N_{1v}(s)}{F_v(s)} \\ \vdots & \ddots & \vdots \\ \frac{N_{h1}(s)}{F_1(s)} & \dots & \frac{N_{hv}(s)}{F_v(s)} \end{bmatrix} R(s)$$

Where

$$N(s) = \begin{bmatrix} N_{11}(s) & \cdots & N_{1v}(s) \\ \vdots & \ddots & \vdots \\ N_{h1}(s) & \cdots & N_{hv}(s) \end{bmatrix},$$

$$N_{ki}(s) = z_{ki,0} + z_{ki,1}s + z_{ki,2}s^2 + \dots + z_{ki,m}s^m$$

$$F_i(s) = s^{m} + f_{i,1}s^{m-1} + f\sum_{i=1}^{v} N_{ki} w_i \qquad ,k=1,2,\dots,h,$$

$$= \sum_{i=1}^{v} Z_{ki,0} w_i + Z_{ki,1} \hat{P} w_i \dots\dots\dots + Z_{ki,m} \hat{P}^{m} w_i$$

And, we have the relationship between Y and W as

$$y_k = \sum_{i=1}^{v} N_{ki} w_i \qquad ,k=1,2,\dots,h,$$

$$= \sum_{i=1}^{v} Z_{ki,0} w_i + Z_{ki,1} \hat{P} w_i \dots\dots\dots + Z_{ki,m} \hat{P}^{m} w_i$$

Where

$$Y^T(s) = [y_1(s) \quad y_1(s) \quad \dots \quad y_h(s)]$$

Hence, from the previous equations, it follows that the actual output Y is not affected by the parameter uncertainties and disturbances.

3.6 Apply the algorithm to dryer plant

Step 1: The controllability matrix ***M*** of dynamic model, (the Dryer Plant) is found as:

M = [b1 b2 b3]

$$M=\begin{bmatrix} 0 & 0 & 0.0015933 \\ 0 & 0.0015933 & 0 \\ 0.23333 & 0 & 0 \end{bmatrix}$$

Step 2: The pseudo state is determined as follows:

$$W(t)=\begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} X(t)$$

Where q_1 = [0 0 . 4.2857]

q_2 = [0 627.62 0]

q_3 = [627.62 0 0]

Step 3: Supposed that we set the closed-loop poles at $-1, -2$, and -1. The Closed-loop characteristic polynomial is given as

$$\alpha(s) = s^n + \alpha_1 s^{n-1} + \alpha_2 s^{n-2} + ... + \alpha_n$$

$$\alpha(s) = (S+1)(S+2)(S+1)$$

The desired transfer matrix from $R(s)$ to $W(s)$ is expressed as

$$W(s) = \text{diag}[F_1^{-1}(s) \quad F_2^{-1}(s)]\beta^{-1}\beta_0 R(s)$$

Choose the $F1(s)$ and $F2(s)$ as

$F1(s) = (s+1)$

$F2(s) = (s+1)(s+2) = s\char`^2 + 3s + 2$

Step 4: Then the state feedback gain and βo can be obtained as follows:

$$\beta=\begin{bmatrix} 0 & 0 & 0.0015933 \\ 0 & 0.0015933 & 0 \\ 0.23333 & 0 & 0 \end{bmatrix}$$

$$K=\begin{bmatrix} 7.9179 & 0 & 0 \\ -53.501 & 3.9688 & 0.023223 \\ -862.5 & 0.42327 & 1.3434 \end{bmatrix}$$

Step 5: The desired transfer matrix from $R_0(s)$ to $W(s)$ is expressed as

$$W(s) = \text{diag}[F_1^{-1}(s) \quad F_2^{-1}(s)]R_0(s)$$

$$where \quad R_0(s) = \beta^{-1}\beta_0 R(s)$$

Step 6: From the next equation, the integral sliding surface can be determined: the switching surface as:

$$\sigma_i = q_i A^{m_i-1}x(t) + \sum_{j=1}^{m_i-1} f_{ij} q_i A^{m_i-j-1}x(t) + f_{i,m_i} x_{0i}, \ i = 1,2,...,v,$$

$$= S_i x(t) + f_{i,m_i} x_{0i}$$

$$\sigma_1 = [0 \quad 0 \quad 4.2857]X + 2X_{0,1}$$

$$\sigma_2 = [0627.62 \quad 0]X + 2X_{0,2}$$

$$\sigma_3 = [627.62 \quad 0 \quad 0]X + 2X_{0,3}$$

Step 7: the control function is obtained as:

$$u(t) = -(SB)^{-1}(SAx + f(w - f^{-1}R_0)) - (\Omega_{\Delta A}\|x(t)\| + \Omega_L)\frac{B^T S^T \sigma}{\|B^T S^T \sigma\|}$$

the robustness of the actual output $Y(t)$ is not affected by the parameter uncertainties and disturbances. Also disturbances are estimated by Assumption 2 The initial state is assumed to be X0=[0.001 360 421], and reference input is $r(t)$ =[472 293 0.0024].

The actual outputs are plotted in the next simulation results It can be seen that the integral sliding mode controller enables the designed system to exhibit the desired dynamic properties Simulation Results:

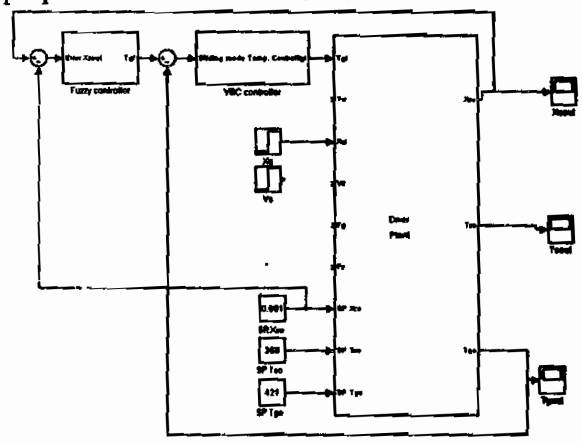

Fig. 11 Block diagram for dryer plant connected to the VSC controller

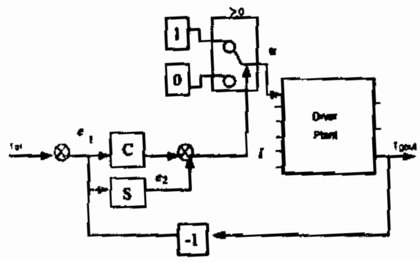

Fig. 12 The sliding mode control diagram

5- Simulation Results:

Upper bound of disturbance applying on Xs,in (input moisture content of solids) is 2.00 %, and the lower bound is 5.00 %

The normal value of Xsin is 2.4 % (operating point), Testing the system with disturbance from 6.66 % to 80 % to see the response of

Plant Dryer with difference types of controllers , (Using Matlab and simulink)

5.1 Summarizing the results:

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4.00	19	0.2500	~0
[illegible]	1.80	13.5	0.0085	0.00007

Test the system with disturbance from 6.66 % to 80 % to see the response of Plant Dryer with the introduced VSC against the traditional PID controller.

6.5 Applying traditional PID controller

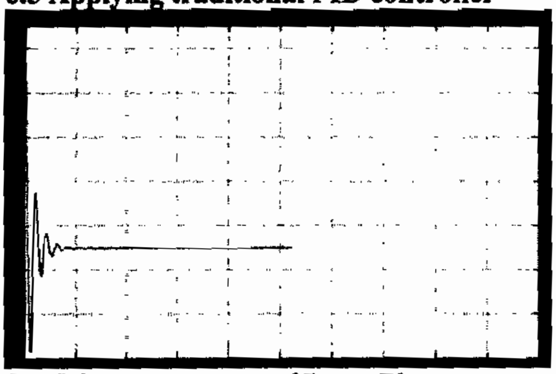

Fig.7 Output response of Dryer Plant connected to the direct PID controller.

Appling the introduced VSC:

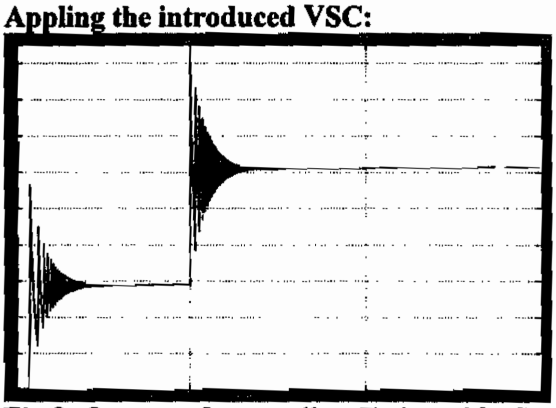

Fig.8 Output of controller T,gin with Step change of Xs,in from 2.4% to 4.4% at time of 50 sec.

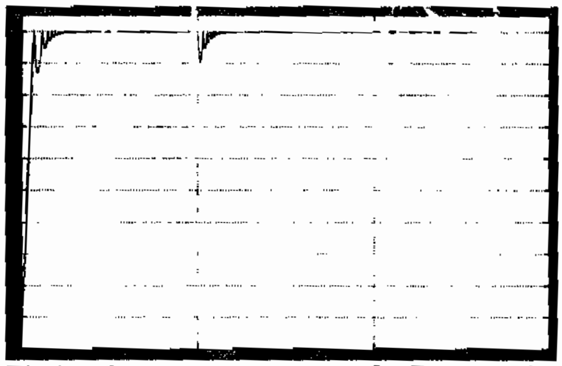

Fig.9 Output response of Dryer Plant connected to the VSC Xs,out for Step change of Xs,in (Main disturbance) from 2.4% to 4.4% at time of 50 sec.

7- Conclusion

In this paper we make combination between two dynamic models of dryer plant using the drying rate equation which cause the non-linearity of the model as in Iguaz [13], with the model in Yliniemi [4]. Then presenting method to design the integral variable structure Controllers which modify the transfer-function matrix from $R(s)$ to $W(s)$ [12, 13] and statically decouple the uncertain system. It is noticed that the design of integral sliding surface is determined by the choice of the controllability matrix and the selection of the transfer-function matrix from the reference signal to the Pseudo-output. Since the controllability M is not unique the selection of the switching surfaces is not unique. In addition, unlike the conventional IVSC approach, this not needs to transform the original plant into a companion form.

In order to control the Rotary Dryer plant process, Appling Direct PID controller and the introduced VSC, Then see the behavior of the plant specially for the main controlled variable output Moisture content of solids with the a step change in the main disturbance of input moisture content of solids.

, comparing the results by simulations when a step change in the input moisture of solids occurs, The simulation parameters are based on the pilot plant dryer Yliniemi [4]. The control results have been compared with the results achieved by the traditional PID-controller.

A simulation are presented and shows that VSC controller is better performance, and this algorithm can be applied to a different plant models.

It can be concluded that with the produced combined dynamic model of the plant dryer and the proposed VSC controller yielded a better dynamic performance in terms of Rising Time, Settling Time, Maximum Overshoot and Steady–State Error.

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