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EXPERMINETAL RESEARCH FOR IDENTIFYING INDUSTRIAL PROCESSES BY STATISTICAL METHODS

Stela RUSU-ANGHEL, Gelu Ovidiu TIRIAN

"Politechnica" University of Timisoara, Faculty of Engineering of Hunedoara,
Department of Electrical Engineering and Industrial Informatics, ROMANIA

Abstract:
This paper work refers to the results of an identification of the clinker furnace, by using statistic methods. We have obtained a mathematical model who describes the processes inside the furnace very accurately (more than 90%). Due to their complexity, the analytical shaping-up is impossible.
Keywords:
identification, clinker furnace, statistics, software.

1. INTRODUCTION

The analytical identification of the process during the fabrication of the concrete is difficult because this process is highly complex and they have helped us obtain some accurate mathematical methods who allow an effective conventional management.

According to the current evolution of the calculation techniques and of the process' management principles, the experimental identification based on statistic data is an alternative we should consider.

The most usual methods are the system, the linear, and the discrete models who enclose the effect of the random disturbance, such as in Figure no.1 [1].

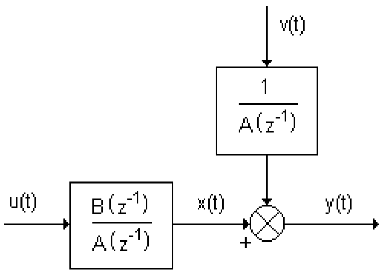

Figure no. 1

Synthetically speaking, z(t) is uptaken to this process (the parameter is the discreet time t). Because y(t) contains some noise (in addition), it is considered as such (it encloses a determination element x(t)). The statistic features of the output we have measured - y(t) - are determined by the statistic features of the noise z(t), or v(t), according to Figure no. 4.1. Due to the fact that the identification experiment does not use – for economic and engineering reasons – all the accomplishment of the noise, and/or either of the y(t) output, it does not acknowledge the identification methods of the output, because they need some statistic properties (hypothesis) which help them identify the PFD pattern. This is not possible after only one significant experiment (for off-line identification methods) or after continuous process, but they have the same properties (for on-line identification methods).

2. PROCESS PATTERN

This process is described in Figure no. 2.

The reason of this experimental identification is represented by the pattern of the operator controlled-segment [2], [3], and [4].

The process inside the furnace is steady, but the relation between the cooling grating and the furnace causes some vacillations of the temperature (heat) inside the furnace. The only way to eliminate this is to keep up a constant temperature of the combustion gas, by adjusting the energy flow. Therefore, the temperature of the combustion gas could be considered a process output variable.

Besides that, one of the outputs should enclose information about the quality of the clinker. Because the quality of the clinker is measured (off-line) after the material gets out of the furnace, after a thorough analysis (for practical purposes) - after two hours -, it is difficult to use a quality control of the material. We have found out that the force of the motor that makes the furnace work is correlated to the temperature of the combustion area and the quality of the clinker. We could consider it is a second output for the process pattern we are about to identify.

An important effect of the temperature transfer and of the chemical reactions inside the furnace is the combustible matter flow. This is the first control variable. The material flow is the second control variable.

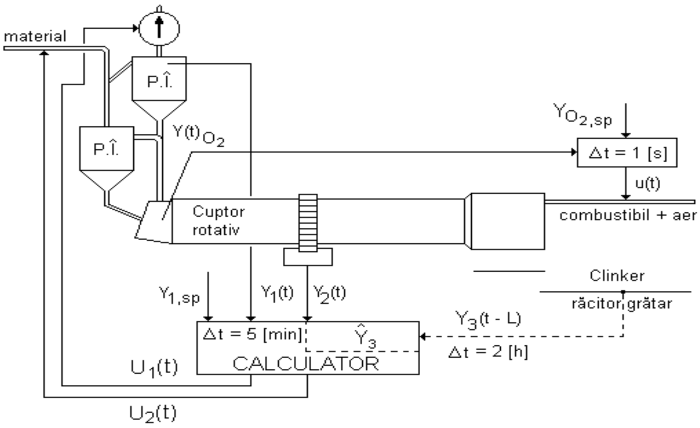

Figure no. 2

Table 1

DATA MEASURED AND CALCULATED

Speed oven nc [rot/min]	Engine speed nm [rot/min]	Computed torque M [kNm]	Measuring motor m [%]	Temperature measured Y1	Power calculated Y2	Fuel flow X1	Material flow X2	Y1 centered yc1	Y2 centered yc2	X1 centered xc1	X2 centered xc2
1,7	626,316	17671,5	45	355	269,432773	14	210	7,458	31,78077	0,4625	-18,333
1,8	663,158	16493,4	42	350	237,5	13,75	225	2,458	-0,152	0,2125	-3,333
1,8	663,158	17278,8	44	347	248,809524	13,5	225	-0,542	11,15752	-0,0375	-3,333
1,8	663,158	17278,8	44	347	248,809524	13,5	225	-0,542	11,15752	-0,0375	-3,333
1,8	663,158	17278,8	44	347	248,809524	13,5	225	-0,542	11,15752	-0,0375	-3,333
1,8	663,158	16100,7	41	347	231,845238	13,5	230	-0,542	-5,80676	-0,0375	1,667
1,8	663,158	14529,9	37	350	209,22619	13,75	230	2,458	-28,4258	0,2125	1,667
1,8	663,158	15708	40	347	226,190476	13,5	230	-0,542	-11,4615	-0,0375	1,667
1,8	663,158	16100,7	41	347	231,845238	13,5	230	-0,542	-5,80676	-0,0375	1,667
1,8	663,158	15708	40	347	226,190476	13,5	230	-0,542	-11,4615	-0,0375	1,667
1,8	663,158	15708	40	347	226,190476	13,5	230	-0,542	-11,4615	-0,0375	1,667
1,8	663,158	15708	40	347	226,190476	13,5	230	-0,542	-11,4615	-0,0375	1,667
1,8	663,158	15708	40	348	226,190476	13,6	230	0,458	-11,4615	0,0625	1,667
1,8	663,158	15708	40	348	226,190476	13,6	230	0,458	-11,4615	0,0625	1,667
1,8	663,158	16100,7	41	348	231,845238	13,6	230	0,458	-5,80676	0,0625	1,667
1,8	663,158	15315,3	39	349	220,535714	13,7	230	1,458	-17,1163	0,1625	1,667
1,8	663,158	16100,7	41	347	231,845238	13,5	230	-0,542	-5,80676	-0,0375	1,667
1,8	663,158	16493,4	42	347	237,5	13,5	230	-0,542	-0,152	-0,0375	1,667
1,8	663,158	17671,5	45	346	254,464286	13,4	230	-1,542	16,81229	-0,1375	1,667
1,8	663,158	17671,5	45	345	254,464286	13,3	230	-2,542	16,81229	-0,2375	1,667
1,8	663,158	18064,2	46	345	260,119048	13,3	230	-2,542	22,46705	-0,2375	1,667
1,8	663,158	17671,5	45	345	254,464286	13,3	230	-2,542	16,81229	-0,2375	1,667
1,8	663,158	16493,4	42	348	237,5	13,6	230	0,458	-0,152	0,0625	1,667
1,8	663,158	16493,4	42	347	237,5	13,5	230	-0,542	-0,152	-0,0375	1,667
			Arithmetic average	347,5417	237,6525	13,5375	228,3333				

There are other possible variables, but the first two are the most important and the identification process sticks to them.

We have measured it every 5 minutes and we have found out 24 values of the following elements (Table no. 1):

- combustion gas temperature- $Y_1(t)$, in [°C];

- the coupling to the motor shaft - m [%] – is used for calculating the training force - $Y_2(t)$. All the values are written in percentage of the nominal coupling;
- the revolution of the furnace - n_c, in [rot/min] – is used for calculating the training force;
- the combustible matter flow - $X_1(t)$, in [m^3/h];
- the material flow - $X_2(t)$, in [t/h].

3. THE PROPER SHAPING UP

The proper shaping-up has been performed according to the CMP criterion – using two retrogressive methods – linear and non-linear II-type.

a) *Linear retrogressive*

If we use a linear subordination of the output size, according to the input sizes, we have :

$Y_1 = A_{11}X_1 + A_{12}X_2 + B_1$, (1)

$Y_2 = A_{21}X_1 + A_{22}X_2 + B_2$. (2)

where:

$$X = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} X_{1,1}\,X_{1,2}\ldots X_{1,24} \\ X_{2,1}\,X_{2,2}\ldots X_{2,24} \end{bmatrix};\ Y = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} Y_{1,1}\,Y_{1,2}\ldots Y_{1,24} \\ Y_{2,1}\,Y_{2,2}\ldots Y_{2,24} \end{bmatrix} \quad (3)$$

Input data Output data

The mathematical pattern is the following:

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} \quad (4)$$

By using the method of the smallest squares, the constant values are:

- for output size $Y_1(t)$:

$A_{11} = 11{,}04$ $A_{12} = -0{,}1055$ $B_1 = 222{,}2$

The precision indicator of the regress pattern is: $R^2 = 0{,}9866$

- for input size $Y_2(t)$:

$A_{21} = -85{,}92$ $A_{22} = -3{,}784$ $B_2 = 2265$

The precision indicator of the regress pattern is: $R^2 = 0{,}8266$

Thus, the pattern is:

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} 11.04 & -0.1055 \\ -85.92 & -3.784 \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 222.2 \\ 2265 \end{bmatrix} \quad (5)$$

b) *II- degree polynomial regress*

If we use a II-type non-linear subordination of the output size, according to the input sizes, we have:

$Y_1 = C_{11}X_1 + C_{12}X_2 + C_{13}X_1^2 + C_{14}X_2^2 + C_{15}X_1X_2 + C_{10}$ (6)

$Y_2 = C_{21}X_1 + C_{22}X_2 + C_{23}X_1^2 + C_{24}X_2^2 + C_{25}X_1X_2 + C_{20}$ (7)

The mathematical pattern is:

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12}\,C_{13}\,C_{14}\,C_{15} \\ C_{21} & C_{22}\,C_{23}\,C_{24}\,C_{25} \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ X_2 \\ X_1^2 \\ X_2^2 \\ X_1X_2 \end{bmatrix} + \begin{bmatrix} C_{10} \\ C_{20} \end{bmatrix} \quad (8)$$

By using the method of the smallest squares the constant values are:

- for output size $Y_1(t)$:

$C_{11} = -27{,}36$; $C_{12} = 1{,}628$; $C_{13} = 2{,}8$; $C_{14} = 0{,}001288$;
$C_{15} = -0{,}1642$; $C_{10} = 273{,}6$

The precision indicator of the regress is: $R^2 = 0{,}9988$

- for output size $Y_2(t)$:

$C_{21} = -298$; $C_{22} = 170{,}9$; $C_{23} = 62{,}97$; $C_{24} = -0{,}1891$; $C_{25} = -6{,}506$; $C_{20} = -16317$

The precision indicator of the regress is: $R^2 = 0{,}8576$

Thus, the pattern is:

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} -27.36 & 1.628\ 2.78\ 0.001288\ -0.1642 \\ -298 & 170\ .962\ .97-0.1891\ -6.506 \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ X_2 \\ X_1^2 \\ X_2^2 \\ X_1X_2 \end{bmatrix} + \begin{bmatrix} 273.6 \\ -16317 \end{bmatrix} \quad (9)$$

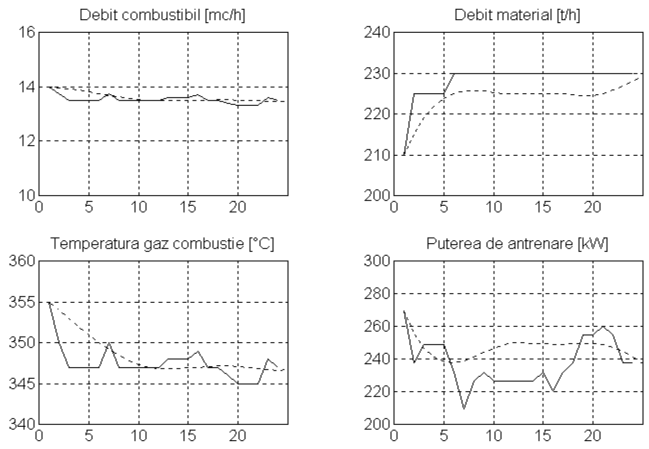

Figure no. 3 Cubic shift insertion of 0.2 step

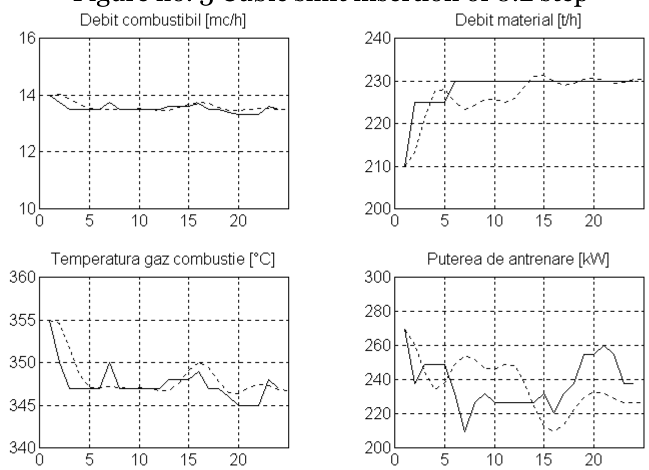

Figure no. 4 60-points FFT insertion

In order to make the calculations we have used the Matlab for Windows software, which allows us:

- to see the graphics of the sizes, according to two methods : PLOT and BAR;
- to estimate the process by the method of the smallest squares, using two regress patterns : linear and non-linear II-type regress;
- to use the data by two methods: interpolar cubic shift, where the insertion steps are: 1, 0.5, 0.4, 0.3, 0.2, 0.1 şi 0.05, and the insertion based on the Fourier fast transformation method is valid for 30, 60, 90, 120, 150, 180 and 200 insertion points. We can see the insertion curves on the monitor.

The main software is called « ie.m » and is able to perform a graphic interface with buttons – selected optionally; we could use the calculation methods of the above mentioned functions.

Figure no. 3 and 4 refer to the results of the shaping-up by two methods. The continuous line describe the data we have measured, meanwhile the dotted line refers to the determined methods.

5. CONCLUSIONS

This paperwork describes the mathematical method based on statistic methods for a clinker furnace. The accuracy of the model is very high, as far as the statistic indicators have proved it. This method is relatively simple and it has been used in experiments. We have come up with the MATLAB calculation software, but we are not able to describe them in this paperwork for space reasons.

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