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DETERMINATION OF DYNAMIC POLYMER PROPERTIES

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Abstract - The paper deals with equipment for plastic materials analysis. This equipment is called thermoanalyser. The general principle of analysis is based on the temperature measurement and the temperature control on the desired temperature and simultaneously on penetrating measurement of the deforming tip into microsample. From these data and from force on the deforming tip we can determinate many plastic materials properties. The first problem was measurement, the second problem was the temperature control in two furnaces. There is the pole placement algorithm (2nd and 3rd order) used. The last part of the paper deals with the storing of the materials parameters to the database.

Key words: temperature control, temperature measurement, environment application

1. INTRODUCTION

The determination of parameters and the evaluation of properties of the polymer materials in the dynamic mode are very demanding as for time and finances. For the dynamic polymer properties there was made the thermomechanical analyser, controlled by personal computer in our workplace. It is shown on Fig. 1.

2. PROPOSED SOLVING

Our solving of this equipment with the help of "the basic spectra" enables to realize the fast check of mixture stability and homogeneity at the products from polymers by means of the microsamples [1]. The elaboration and storing of "the dynamic spectra" enable to increase the application area of the thermomechanical apparatus also for the evaluation of products putting out of service after the fulfilment of the service duty.

It will provide the criterion for the decision and possibilities to use polymer wastes as the secondary raw material or the including into the group of disposed waste.

For the measuring, control and data processing there is used special program system based on the real time system. Mechanical apparatus is connected with the help of special unit with the control computer [2].

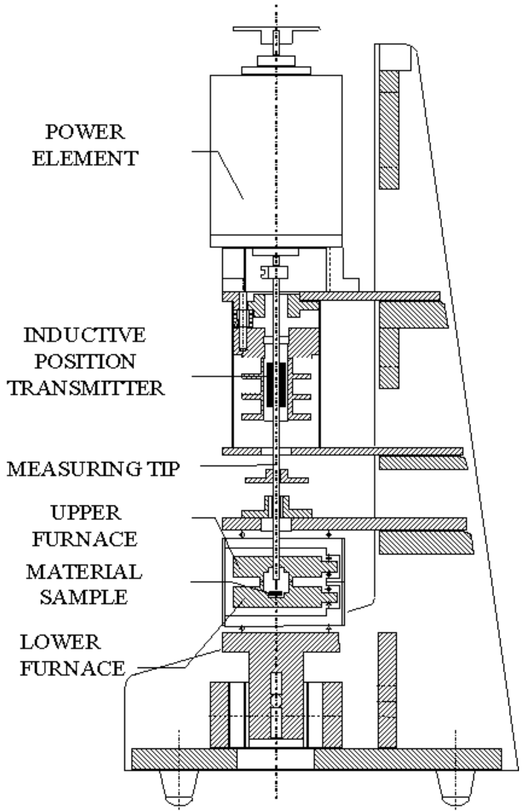

Fig. 1.Thermomechanical analyser

3. COMPUTER AND PROGRAM SYSTEM

The tasks of computer are as follows:

- the temperature control in the range up to 400 degrees,
- the measurement of the microsample temperature with the heated chamber at the contact point of the deforming tip,
- the measurement of the tip penetrating into the microsample in the range 2 mm,
- the frequency and form of the loading course,
- the evaluation of the measurement result from the measured variables in digits and graphs,
- processing material data to the databases system.

The scheme of main program modules is shown Fig. 2.

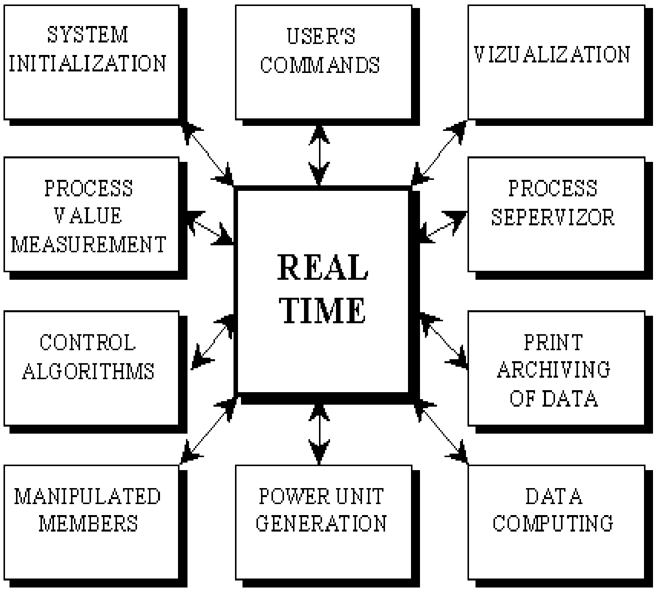

Fig. 2. Block scheme of program system

4. CONTROL OF TEMPERATURE

For the temperature control of the thermoanalyser, the PID controller is used [3], [4]. The controller parameters are derived on the basis of the pole placement approach. The controller is designed especially for process control without overshoot of the process output.

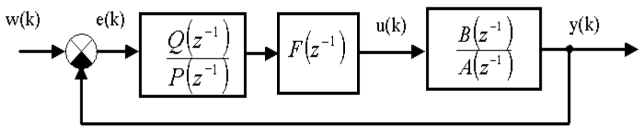

Fig. 3. Control system scheme

4. 1 The 2nd Order Controller

Let the controlled process and controller be described by transfer functions in the form (Bobál & Kubalčík, 1994)

$$G_S(z)=\frac{Y(z)}{U(z)}=\frac{B\left(z^{-1}\right)}{A\left(z^{-1}\right)},\; G_R(z)=\frac{U(z)}{E(z)}=\frac{Q\left(z^{-1}\right)}{P\left(z^{-1}\right)} \quad (1)$$

where

$$A\left(z^{-1}\right)=1+a_1z^{-1}+a_2z^{-2} \quad (2)$$

$$B\left(z^{-1}\right)=b_1z^{-1}+b_2z^{-2} \quad (3)$$

$$Q\left(z^{-1}\right)=q_0+q_1z^{-1}+q_2z^{-2} \quad (4)$$

are second degree polynomials,

$$F\left(z^{-1}\right)=\left(1-z^{-1}\right) \quad (5)$$

$$P\left(z^{-1}\right)=\left(1+p_1z^{-1}\right) \quad (6)$$

are first degree polynomials and Y(z),U(z), E(z)=W(z)-Y(z) are the Z-transforms of the process output, the controller output and the error (W(z) is the Z-transform of the reference signal). Then the transfer function G_R can be transcribed into the form

$$u(k)=(1-p_1)u(k-1)+p_1u(k-2)+q_0e(k)+q_1e(k-1)+q2e(k-2) \quad (7)$$

We derive the following transfer function for the closed loop system

$$G_W\left(z^{-1}\right)=\frac{B\left(z^{-1}\right)Q\left(z^{-1}\right)}{A\left(z^{-1}\right)P\left(z^{-1}\right)+B\left(z^{-1}\right)Q\left(z^{-1}\right)} \quad (8)$$

In the denominator of the transfer function (8), there is the characteristic polynomial. We assume the following polynomial identity

$$A\left(z^{-1}\right)P\left(z^{-1}\right)+B\left(z^{-1}\right)Q\left(z^{-1}\right)=D\left(z^{-1}\right) \quad (9)$$

with desired polynomial

$$D\left(z^{-1}\right)=\left(1-cz^{-1}\right)^4 \quad (10)$$

The characteristic polynomial (10) has a quadruple real pole $z_{1,2,3,4}=c$ $(0 \le c \le 1)$. The parameter c influences the speed of the closed control loop transient characteristic and controller output changes, too.

The polynomial identity (9) and polynomial (10) give a set of four linear algebraic equations

$$\begin{aligned} b_1q_0 &+ p_1 + a_1 - 1 = -4c \\ b_2q_0 + b_1q_1 &+ (a_1-1)p_1 + a_2 - a_1 = 6c^2 \\ b_2q_1 + b_1q_2 &+ (a_2-a_1)p_1 - a_2 = -4c^3 \\ b_2q_2 &- a_2p_1 = c^4 \end{aligned} \quad (11)$$

Solving the equations (11) we obtain four unknown controller parameters

$$q_0,\, q_1,\, q_2,\, p_1 = f\,(a_1,\, a_2,\, b_1,\, b_2,\, c) \quad (12)$$

Temperature control with controller based on pole placement approach (2nd order) is shown on the Fig. 4. and 5.

4. 2 The 3rd Order Controller

In many cases we need to control the temperature on the reference signal with Z-transforms

$$W\left(z^{-1}\right)=\frac{z^{-1}}{\left(1-z^{-1}\right)^2} \quad (13)$$

The controller is described by transfer [4] in the form

$$G_R(z^{-1})=\frac{Q(z^{-1})}{F\left(z^{-1}\right)P\left(z^{-1}\right)} \quad (14)$$

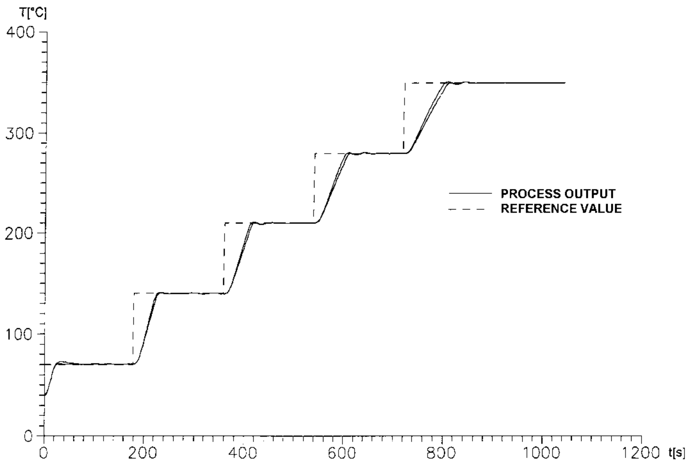

Fig. 3. Time response of the control with pole placement controller (2nd order) - step shape of the reference value

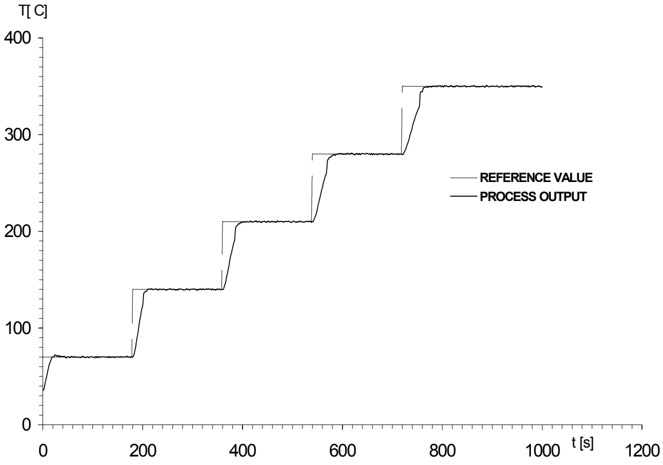

Fig. 5. Time response of the control with pole placement controller (3rd order) - step shape of the reference value

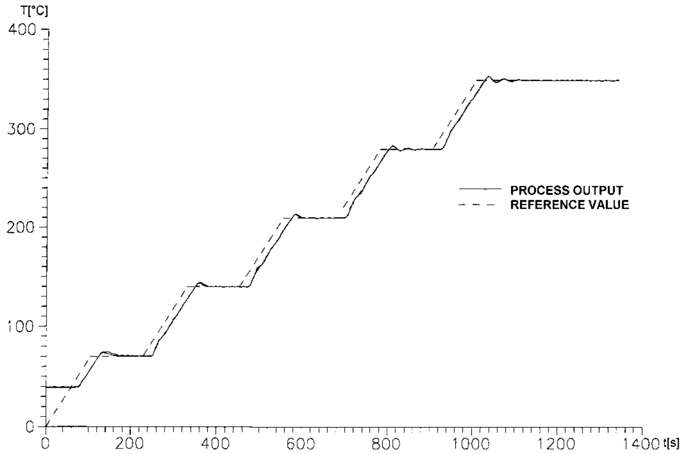

Fig. 4. Time response of the control with pole placement controller (2nd order) - ramp shape of the reference value

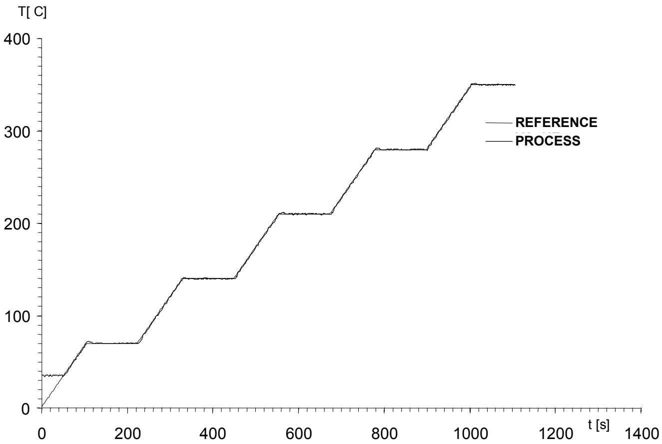

Fig. 6. Time response of the control with pole placement controller (3rd order) - ramp shape of the reference value

where $$Q(z^{-1}) = q_0+q_1 z^{-1} + q_2 z^{-2} + q_3 z^{-3} \qquad (15)$$

$$F(z^{-1}) = (1- z^{-1})^2 \qquad (16)$$
$$P(z^{-1}) = (1 + p_1 z^{-1}). \qquad (17)$$

are polynomials of diofantic equation

$$A(z^{-1})\, F(z^{-1})\, P(z^{-1}) + B(z^{-1})\, Q(z^{-1}) = D(z^{-1}) \qquad (18)$$

There are degrees of these polynomials:

$$deg(P) = deg(A) - 1 = 2 - 1 = 1 \qquad (19)$$
$$deg(D) = deg(A) + deg(P) + deg(F) = 2deg(A) + deg(F) - 1 = 4 + 2 - 1 = 5 \qquad (20)$$
$$deg(Q) = deg(F) + deg(P) = 2 + 1 = 3 \qquad (21)$$

We desired polynomial

$$D(z^{-1}) = (1 - c\, z^{-1})^5 \qquad (22)$$

The polynomial identity (18) and polynomial (22) give a set of five linear algebraic equations

$$\begin{array}{l} q_0 b_1 + p_1 + a_1 - 2 = -5c \\ q_0 b_2 + q_1 b_1 + p_1(a_1-2) + 1 - 2a_1 + a_2 = 10c^2 \\ q_1 b_2 + q_2 b_1 + p_1(1-2a_1+a_2) + a_1 - 2a_2 = -10c^3 \\ q_2 b_2 + q_3 b_1 + p_1(a_1-2a_2) + a_2 = 5c^4 \\ q_3 b_2 + p_1 a_2 = -c^5 \end{array} \qquad (23)$$

Solving the equations (23) we obtain four unknown controller parameters q_0, q_1, q_2, q_3 and p_1.

The resulting transfer function of controller is

$$G_R\left(z^{-1}\right) = \frac{q_0 + q_1 z^{-1} + q_2 z^{-2} + q_3 z^{-3}}{1 + (p_1 - 2) z^{-1} + (1 - 2p_1) z^{-2} + p_1 z^{-3}} \qquad (24)$$

Temperature control with controller based on pole placement approach (3rd order) is shown on the Fig. 6. and 7.

5. DATABASE SYSTEM

After the unknown sample parameters finding out with the help of the statistical program modules „Fig. 7“, there is possible to compare the sample parameters with the parameters of the known plastic materials stored in the database system in the MS ACCESS for Windows environment. The database system assists with the search for similar samples or with finding out the rate of the wearing of the sample. We can define the kind of the sample or we can add the sample parameters to the database.

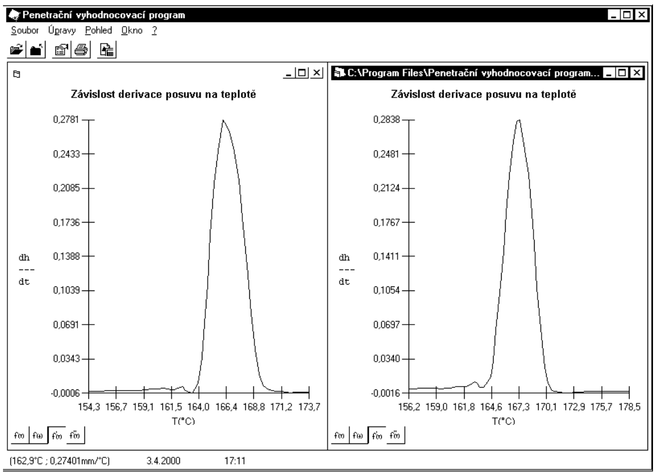

Fig. 7. The statistical modules of the control program

6. CONCLUSION

The thermomechanical analyser has proved competent for the measurement and the parameters ascertaining at polymeric materials. The next task is to fill the database with the parameters of particular plastics what takes some time yet.

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