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Modeling – numerical simulation of a heating plant using circulation pump, having variable revolution, frequency commanded

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Abstract. It is represented a way of regulating of a heating system made up of a PID numerical regulator, kettle, thermal agent circulation pump through the installation and the heat consumer which offers the heating for an immobile .The variable debit of the circulation pump is obtained by the command of the revolution of the asincrounos three-phased engine, long bar rotor, which moves the pump. This command is received from the regulator and regulate the voltage and the frequency of the engine , and the quantity of the thermal energy through the consumer . The reference is a proportional signal to the temperature of the thermal agent at the output of the consumer (return temperature of the plant) , which should be maintained a fixed value.

Key words: **modelling, numerical simulation, LIL algorithm**

1. Introducere

The description of the thermal heating process of an immobile shown in figure 1. It is a variant of temperature regulation on the return , in a thermal plant , towards the programmed value of the temperature of the thermal agent "θ_R " ,related to estimated and determined necessity of heat of the consumer , as a function of the variation of external environment temperature.

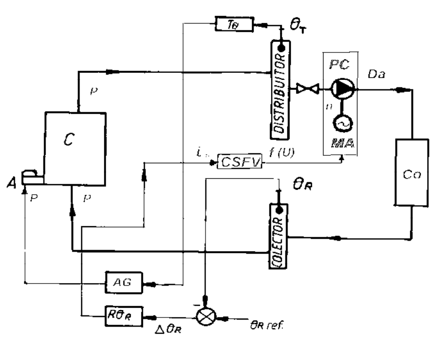

Fig. 5.23.

Fig. 1.

Presentation and justification of the schematic representation of the regulation method :
- the plant is made of a central heating kettle (C) , thermal energy consumer (Co) circulation pump (PC) centrifugal ,moved by the three-phased asynchronous electrical engine (MA). This engine is supplied with a voltage (U) , of variable frequency (f) , offered by the converter (CSFV) , commanded in unified signal (4-20 mA) , by the temperature regulator PID (RθR) .
The variable revolution of the electrical engine, reported to the command signal of the temperature regulator, allows the generation of a variable proportional debit of the circulation pump, and provides a possibility of a quantitative regulation of the thermal power through the plant.
The gas regulator(AD) provides a regulation of the fuel debit (methane gas) , in inverse relation to the output temperature(θ T) of the thermal agent of the kettle ($P_G = \alpha - \beta \cdot \theta_T$, where "α , β " are computed from the arbitrarily chosen values : ex.
θ T = 80 °C ⇒ PG = 0 and for θ T = 20 °C ⇒ PG = PGmax).

The regulation of the plant is implemented by asserting of reference values for the temperature of the thermal agent of the pe return of the plant instalației "θR Ref ", towards the exterior temperatures and towards the necessary heating program of the consumer.

2. The mathematical model.

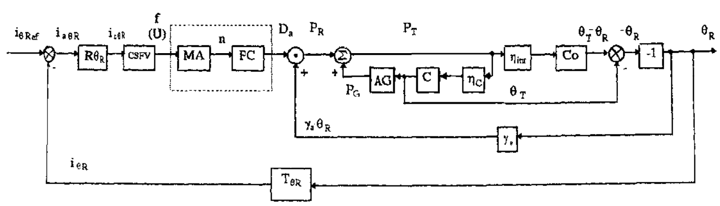

Fig. 2.

RθR - numerical temperature regulator PID , having programmable structure parameters;
CSFV - frequency converter and variable voltage ;
PC - circulation pump , centrifugal , set by a three-phased electrical engine (MA)
C - warm water kettle ;
Co - thermal power consumer set for heating and productivity of house-keeping warm water ;
TθR - temperature transducer ;
ηc , η int – kettle management efficiency , and of the consumer ;
γa - specific warmth pf the thermal agent (water) ;

The signals were denoted by :
$i_{\theta R\ Ref}$ – reference signal for return temperature of the thermal agent ;
$i_{c\theta R}$ - command signal on the output of the regulator towards the deviation " $i_{a\theta R}$" ;
f , U - frequency and voltage provided by "CSFV", proportional to "$i_{c\theta R}$";
D_a - variable debit of the circulation pump "PC" ;
$P_T = P_G + P_R$ - total output power , equal to the sum of thermal powers of the input for the kettle – generated power by the combustion of the gas and the power to enter the return circuit ;
θT , θR – temperature of the thermal agent in the distributor ,respectively in the collector of the plant (on the return);
θT - θR - the gauge of the temperature due to the thermal energy of the consumer ;

Let us consider the following relations to identify the system :

a. PID regulator ($R\theta_R$) : $i_{c\theta R} = k_P \cdot i_{a\theta R} + \frac{1}{t_i} \cdot \int i_{a\theta R} \cdot dt + t_d \cdot \frac{di_{a\theta R}}{dt}$

b. frequency converter (f) voltage (U) variable (CSFV): $f = k_{CSFV} \cdot i_{c\theta R}$

c. Electrical engine (MA) :

$$u1 = R1 \cdot i1 + L1 \cdot \frac{di1}{dt} + R_m \cdot i_m + L_m \cdot \frac{di_m}{dt} \quad ,$$

$$u1 = R1 \cdot i1 + L1 \cdot \frac{di1}{dt} + \frac{R'2}{S} \cdot i'2 + L'2 \cdot \frac{di'2}{dt} \quad , \qquad (1)$$

$$i1 = i_m + i'2 \quad ,$$

d. kettle(C) : $\eta_C \cdot P_T = D_a \cdot \gamma_a \cdot \left(\theta_T + 3 \cdot T_c \cdot \dot{\theta}_T + 3 \cdot T_c^2 \cdot \ddot{\theta}_T + T_c^3 \cdot \dddot{\theta}_T \right)$,

e. Circulation pump (PC) : $D_a = \frac{D_{aN}}{n_{NN}} \cdot n$;

f. feeding fuel regulator (AG) : $P_G = \alpha - \beta \cdot \theta_T$;

g. consummer (Co) :

$$\eta_{\text{int}} \cdot P_T = D_a \cdot \gamma_a \cdot \left[\left(\theta_T - \theta_R \right) + 2 \cdot T_{\text{int}} \cdot \left(\dot{\theta}_T - \dot{\theta}_R \right) + T_{\text{int}}^2 \cdot \left(\ddot{\theta}_T - \ddot{\theta}_R \right) \right] \quad ;$$

h. temperature transducer ($T_{\theta R}$) : $i_{r\theta R} = k_t \cdot \theta_R$;

i. thermal power : $P_T = D_a \bullet \gamma a \bullet \theta T$; $P_R = D_a \bullet \gamma a \bullet \theta R$; $P_G = \alpha - \beta \cdot \theta_T$;

Note : relation (1) are borrowed from [8].
By asserting the state variables:

$$x_1 = i_{c\theta R}, x_2 = i1, x_3 = i2', x_4 = n,$$

$$x_5 = \theta_T, x_6 = \dot{\theta}_T, x_7 = \ddot{\theta}_T, x_8 = \theta_R,$$

$$x_9 = \dot{\theta}_R, x_{10} = i_{r\theta R}, x_{11} = \dot{i}_{r\theta R} \quad ;$$

$$u_1 = i_{\theta_R \text{Re} f}, u_2 = 0, u_3 = 0 \quad ;$$

it is obtained the analogical model for the system having the following form : $\dot{x}_i = F_i(x_i, u_i)$;

state vector : $X^T = [\, x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11} \,]$;
input vector: $U^T = [\, u1, u2, u3 \,]$;
state equation system:

$$\dot{x}_1 = a111 \cdot x_{11} + a110 \cdot x_{10} + a19 \cdot x_9 + b11 \cdot u_1 + b12 \cdot u_2 + b13 \cdot u_3 \;;$$

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$$\dot{x}_2 = b2 \cdot u_m + a22 \cdot x_2 + \left(a230 + a232 \cdot n1 / \left(n1 - x_4 \right) \right) \cdot x_3 \;;$$

$$\dot{x}_3 = b3 \cdot u_m + a32 \cdot x_2 + \left(a330 + a331 \cdot n1 / \left(n1 - x_4 \right) \right) \cdot x_3 \;;$$

$$\dot{x}_4 = a444 \cdot \sqrt{x_3 / \left(n1 - x_4 \right) - \left(a440 + a441 \cdot x_4 + a442 \cdot \sqrt{x_4} \right)} \;;$$

$\dot{x}_5 = \dot{\theta}_T ; \dot{x}_6 = \ddot{\theta}_T$

$\dot{x}_7 = \dddot{\theta}_T = a70 + a75 \cdot x_5 + a76 \cdot x_6 + a77 \cdot x_7 + a78 \cdot x_8$

$\dot{x}_8 = x_9 = \dot{\theta}_R ;$

$\dot{x}_9 = a90 + a95 \cdot x_5 + a96 \cdot x_6 + a97 \cdot x_7 + a98 \cdot x_8 + a99 \cdot x_9 ;$

$\dot{x}_{10} = i_{R\theta} ;$

$\dot{x}_{11} = \frac{k_T}{tt} \cdot x_8 - \frac{1}{tt} \cdot x_{11} = \dot{i}_{R\theta} .$

Where the following coefficients have the expressions :

a111= - kr+td/tt; a110 = -1/ti; a19 = - td•kt/tt; b12 = kr; b11= 1/ti; b13 = td;
a22 = -rr / ll ; a230 = rm / ll; a232 = - (lm*r2p)/(l2p*ll);
b2 = (1+lm/l2p)/ll; a32 =-(r1-l1*rr/ll)/l2p;
a330= - (l1*rm)/(l2p*ll); a331 = r2p*(l1*lm/(l2p*ll)-1)/l2p;
b3 = (1-l1*(1+lm/l2p)/ll)/l2p; a444 = 60*m1*r2p/(2*pi*j);
a440 = miu0/j a441= miu1/j; a442 =miu2/j;
a70 = etac*alfa*nnn/(dan*gamaapa*tc*tc*tc);
a75 = (-etac*beta*nnn)/(dan*gamaapa*tc*tc*tc);
a751= -1/(tc*tc*tc); a78 =1/ (tc*tc*tc);
a76 = -3/(tc*tc); a77 = -3/tc; a95 = (1-etai)/(tint*tint);
a98 = -1/ tint*tint; *a96 = 2/tint;* a99=-2/tint; a119= kt / tt; a1111 = - 1/tt;
$u_1 = i_{\theta R\ Ref}$; $u_2 = 0$; $u_3 = 0$;

Numerical model can be obtained by solving the system using local-iterative linearization method (LLI) upon the model . Numerical simulation of the system , in dynamic regime , is realized using "SISTEM" utility. In figure 3-6. are represented , according to the data to be introduced in the proper application , in the numerical simulation utility "SISTEM" , time evolution to time of the main state variables which characterizes the system :

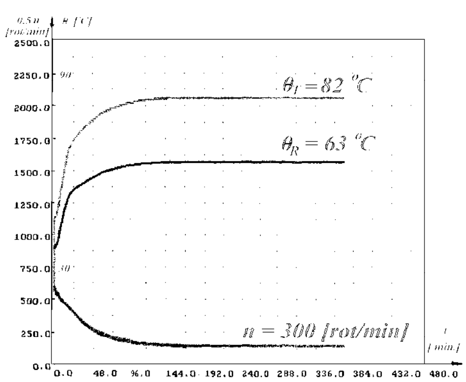

Fig. 3.

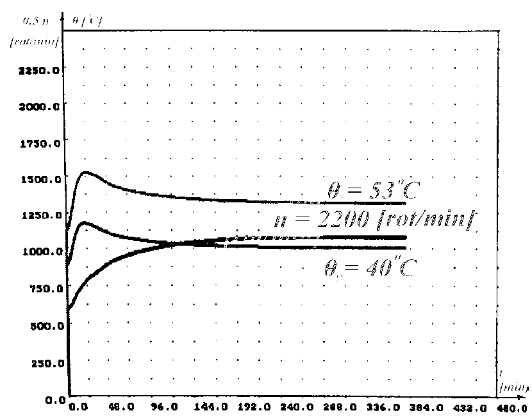

Fig. 4.

The installation was developed practically and tested , in the thermal plant which provides the heating of the central location of S.C. SIETA S.A. , Cluj-Napoca .

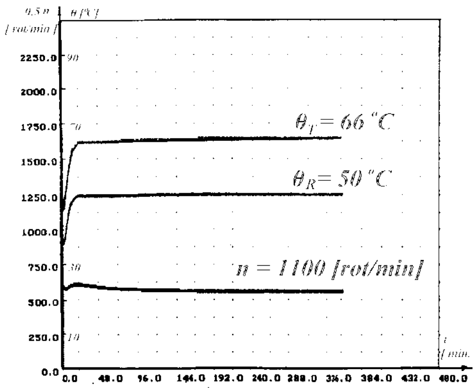

Fig. 5.

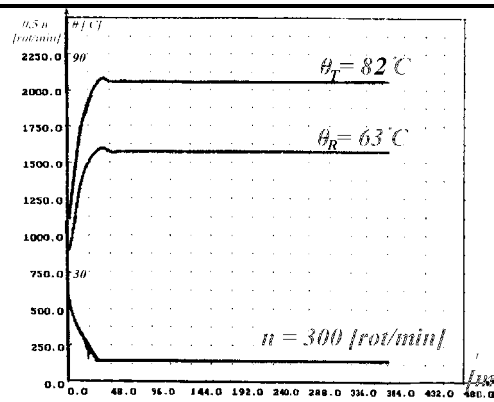

Fig. 6.

The main conclusions to be noticed from applying of this variant of variable debit regulation plant , respectively of the practical results are the following:

3. Conclusions

1. The influence of the debit "D_a" of the thermal agent transported through the kettle, respectively through the thermal installation ,from the relation (2.17.) , for a gauge of constant temperature (θ_T - θ_R = const.) ; we observe that the variation of the thermal power of the agent is directly proportional to the variation of the debit . In other words , between the revolutions of o circulation pump "$n1_p, n2_p$" and the afferent water debits "D_a1, D_a2" , having the pressures "$H1, H2$" and the electrical power consumed to start "$P1, P2$" we have the following relations :

$$\frac{D_a1}{D_a2} = \frac{n1_P}{n2_P}; \quad \frac{H1}{H2} = \left(\frac{n1_P}{n2_P}\right)^2 = \left[\frac{D_a1}{D_a2}\right]^2; \quad \frac{P1}{P2} = \left(\frac{n1_P}{n2_P}\right)^3 = \left[\frac{D_a1}{D_a2}\right]^3;$$

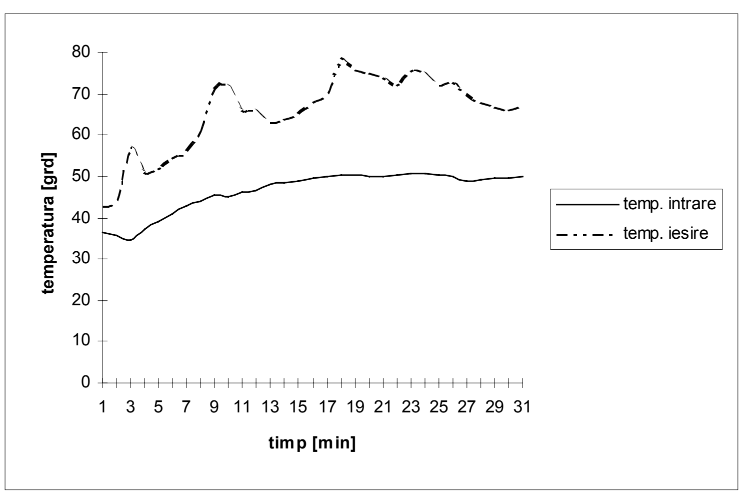

Fig. 7.

When the centrifugal circulation pump is to be chosen for the regulation of the debit of the thermal agent it is necessary that we pay attention to this relation, because ,while the pump debit decreases the pressure of the pump , too . We can easily observe that the pressure decreases proportionally to the square of the decrease of the pump. It must be avoided that the pump stops responding to the necessities by providing the minimum revolution till the debit is to be regulated using this method.

2. It is also to be noticed from the above presentation that the regulation of the debit of the thermal agent , through the plant , the best method is to apply the rule of regulating the revolution of the engine which moves the circulation pump.
   The main asset is that minimization of the of the electrical power needed to move the pump means the minimization of the consumed electrical power.

It was used a PID , "Gefran" 3300 programmable regulator , and a J100 "Hitachi" converter In fig. .7. it is represented the variation of the temperature of the thermal agent on the return circuit (θR) for a reference value θR Ref = 50 °C , having practical measured results .In fig.7. it is Represented the temperature "θT " , by the curve denoted by - " temp. ieşire ", and the temperature "θR" , denoted by - " temp. intrare " .

This type of regulation of the debit can be used to regulate the water debit of a steam kettle, as a function of the variation of the load on the conditions of the use of a level transducer of continuous output . Measuring signal is to be used as a command signal for the debit regulator which should command the revolution of the pump which feeds the kettle. This method hasn't been tested by the author yet.

4. References

1. Aström K.J. - Simple Drum - Boiler Model IFAC Sympozium Power Systems Sept 1988
2. Bogdanovici S.S. - Simulation and Modelling of Once - Trough Benson and Sulzer Steam Generators. IFAC Sympozium Power Systems p.4.2.1.Sept 1988
3. Călin S. - Reglarea numerică a proceselor tehnologiceEd. Tehnică - Bucureşti 1984
4. Coloşi T. ş.a. - Numerical Modeling and Simulation of Dynamical Systems Casa Cărţii de ştiinţă Cluj-Napoca 1995
5. Coloşi T. ş.a. - Tehnici de optimizare vol. 2,3; Tip. Inst. Politehnic Cluj-Napoca 1989

6.Douglas I.M. - Numerical Dynamics and Control vol. 1,2 Prentice Hall Inc. 1991
7.Isermann - Digital control systems vol 2.Springer - Verlag Berlin , Heidelberg 1991
8.Kelemen A. ş.a. - Acţionări electrice Ed. Didactică şi Pedag. Bucureşti 1979