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Modeling and numeric simulation of a centrifugal variable rotation pump controlled by a frequency converter

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Abstract. It is presented a version of modeling and digital simulation of an actuator system of a centrifugal pump with an electric asynchronous motor supplied with variable frequency voltage, designed for use in a heating system. The three-phase supply voltage is intended to be dependent on the frequency. A centrifugal pump using such a motor ensures parameters like: flow, pressure and power consumption – variable in a wide range – advantages that can be used in a high performance controlling system designed for thermoenergetic equipment. Analog modeling and digital simulation of the pump system will be studied as a coupled system i.e. motor and pump, underlining the electric and hydraulic dependencies of this action. The numeric integration is performed using a multi-step method (by local iterative liniarization – LIL algorithm) and one obtains a good flexibility and a short computation time.

Key words: modeling, numerical simulation, LIL algorithm

1. Introduction

The influence of thermal agent flow through the boiler through the thermal depends on the temperature variance (θe–θi = const.). This gives that the thermal power variation circulated by the agent is proportional with the variation of its mass flow. Hence, we have the following relations between the pump rotations $n1_P, n2_P$ and the corresponding water flows, $D_a 1, D_a 2$, with corresponding pressures $H1, H2$ and the powers required for their driving $P1, P2$:

$$\frac{D_a 1}{D_a 2} = \frac{n1_P}{n2_P}; \quad \frac{H1}{H2} = \left(\frac{n1_P}{n2_P}\right)^2 = \left[\frac{D_a 1}{D_a 2}\right]^2; \quad \frac{P1}{P2} = \left(\frac{n1_P}{n2_P}\right)^3 = \left[\frac{D_a 1}{D_a 2}\right]^3;$$

In figure 1 one can see the graphical representation of these relations for certain conditions: the flow and pressure variation of a centrifugal pump for nominal rpm $n1_P = 2830$ rot./min, $n2_P = 2210$ rot./min, $n3_P = 1350$ rot/min. The example is taken according to the specialized product specifications of the pump producer "GRUNDFOS" - 1997. The used notations represent:

P1 {w} – the power used by the pump when functioning in *A'* point, at the intersection of characteristic *C'* of the appliance with the pump characteristic at nominal rpm: *n1_P*, working at pressure $H1 = 10{,}6\ [m.water.column]$ and flow $D_a 2 = 15\,[m^3/h]$;

P2 {w} – the power absorbed by the same pump when working in point *B*, - intersection of characteristic *C* of the appliance with the pump characteristic at $n2_P \le n1_P$;

$Ka = \rho \cdot g \cdot \frac{1}{\eta_{popa}} \left[Kgf \cdot m / m^3 \cdot s^2 \right]$ is a constant depending on water density, gravity, and pump efficiency according to the formula of the power absorbed by the pump which can be calculated using the formula:

$$P[w] = \frac{1}{\eta_p} \cdot \rho \left[\frac{Kg}{m^3} \right] \cdot g \left[\frac{m}{\sec.^2} \right] \cdot D_a \left[\frac{m^3}{\sec} \right] \cdot H[m.watercolumn]; \; (1)$$

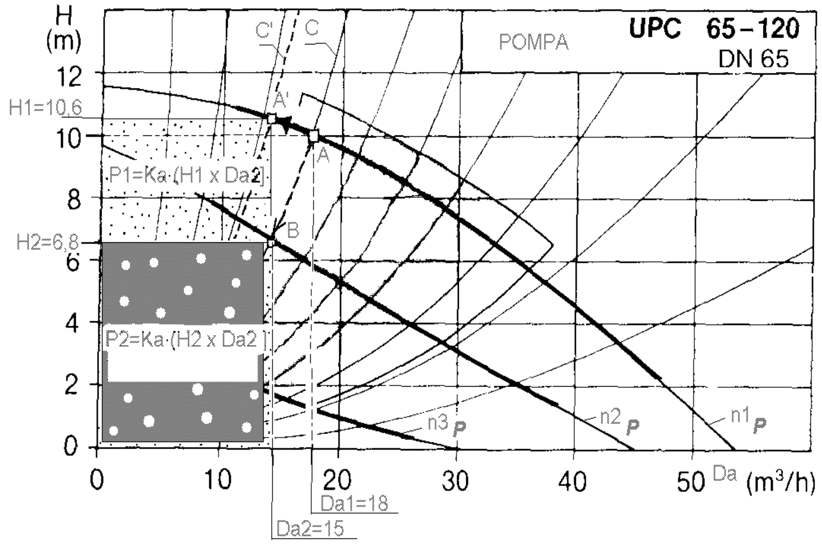

Fig. 1.

The pump works in point *A'* because of the modification of characteristic *C* of the appliance, on curve *C'*, due to the insertion of a supplementary throttling element – the control tap.

This controlling element with throttling effect is mounted to obtain a quantitative control of the heat flow through the installation.

As one can see in the figure, the power absorbed by the pump is proportional to the highlighted surfaces corresponding to the same flow: $D_a 2 = 15 \; m^3 / h$.

As a consequence, if the suppress pressure $H2 = 6{,}8 m.water - column$, corresponding to a power *P2,* is great enough for the installation to work, this power is less by 36% than *P1* – the power absorbed by the pump when working at point *A'*, i.e. in the case of controlling with throttling tap, for the same suppress flow:

$$\frac{P2}{P1} = \frac{H2}{H1} = \frac{6{,}8}{10{,}6} = 0{,}64.$$

If the suppress flow *H2* is not great enough we need another rotation *n*, such that the point *B* moving along curve *C* to ensure a minimum working pressure. To obtain an optimum controlling range for the flow it is necessary to analyze the pump type and the power absorbed for the maximum and minimum allowed suppress powers needed for the installation to work properly.

The example chosen for the pump with the characteristics in fig. 1 is widely used in small thermal stations, and the conclusions apply for any water pumping centrifugal pump. For any other liquid, in the relation (1), one changes only the liquid density. The conclusion one can draw is that for controlling the thermal agent in an installation the best option is to control the rotation of the motor that rotates the circulating pump. The reason is that the decrease of the electric power required by the pump means decreasing the electric energy consumption. Applying this solution determines several advantages derived from avoiding the overdimensioning of the thermomecanical installation for facing greater pressures than needed; avoiding the overdimensioning the power electrical installation to face the current shocks when the pump is started; dimensioning the pump for less power, as a result of decreasing the losses in the installation due to the throttling elements required for flow control.

The practical sustaining of the conclusion determines the need to study theoretically the possibility of controlling the rotation of the asynchronous electric motor because most of the circulating pumps use such motors. The accomplishment of these motors is also simple because of the market availability of the variable frequency static converters (VFSC) designed for controlling the rotation of three-phase asynchronous motors. The reliability of these low price converters is practically proven.

2. The mathematical model

The study starts from the relations showing that for rated values for turns, flow and suppressing pressure of the pump $n1_P \equiv n_N, D_a 1 \equiv D_{aN}, H1 \equiv H_N; m_{MN}$. One obtains that for a turn count n corresponding to a flow D_a, the relations are:

$$\begin{aligned} n &= \frac{n_N}{D_{aN}} \cdot D_a = \tau_P \cdot D_a; \frac{dn}{dt} = \frac{n_N}{D_{aN}} \cdot \frac{dD_a}{dt} = \tau_P \cdot \frac{dD_a}{dt}; \tau_P = \frac{n_N}{D_{aN}}; \\ m_M &= J \cdot \tau_P \cdot \frac{dD_a}{dt} + \mu 0 + \mu 1 \cdot \tau_P \cdot D_a + \mu 2 \cdot \tau_P{}^2 \cdot D_a^2; \end{aligned} \tag{2}$$

Taking into account these relations we will present an alternative of modeling and digital simulation for an acting system of a centrifugal pump with asynchronous motor supplied with variable frequency voltage, designed to work in a central heating installation. The three-phase supplying voltage is corrected depending on the frequency. Thus, in case of a centrifugal pump driven by such a motor one ensures a flow, a pressure and a power consumption variable in a large range. These advantages can be valued in a high performance control system used in thermoenergetic equipment.

The analog modeling and digital simulation of an action system – centrifugal pump driven by asynchronous electric motor will be studied as a coupled system (motor and pump), highlighting the electric and hydraulic dependencies of this action.

The numeric integration is performed using a multi-step method (local iterative liniarization – LIL algorithm) and we obtain a good flexibility and a short computation time.

We use the notations:

$D_{a\,N}$, $D_{a\,V}$ – the rated flow (for $f_N = 50$ Hz), and variable flow (for $f \neq 50$ Hz) during pump operation in the equipment;

H_N, H_V – the rated operating pressure of the equipment and the variable operating pressure of the pump;
P_N, P_V – the rated electric power and the variable absorbed power.

The motor model represented by the relations from [4], completed with the relations for the pump will be considered to express the analog model of the pomp, as one can see below:

$$\begin{aligned}
&\dot{x} = F(u,x) \ : \\
&x1 = i1;\ x2 = i^{\copyright}2;\ x3 = \tau_P \cdot D_a; \\
&\dot{x}1 = b1 \cdot u1 + a11 \cdot x1 + \left(a120 + a121 \cdot \frac{n1}{n1 - x3} \right) \cdot x2 = F_1(u1, x1, x2, x3); \\
&\dot{x}2 = b2 \cdot u1 + a21 \cdot x1 + \left(a220 + a221 \cdot \frac{n1}{n1 - x3} \right) \cdot x2 = F_2(u1, x1, x2, x3); \qquad (3) \\
&\dot{x}3 = a333 \cdot \frac{(x2)^2}{n1 - x3} - \left(a330 + a331 \cdot x3 + a332 \cdot (x3)^2 \right) = F_3(x1, x2, x3);
\end{aligned}$$

We will consider that the variations of the suppressed pressure and the power absorbed by the electrical motor do not influence the operating conditions if the pump in the equipment.

The modeling and the numeric simulation of the pump operation is obtained by applying the LIL algorithm on the analog model (3) and taking into account relations (2) one obtains the numeric simulation of specific parameter variation (D_{aV}, H_V, P_V – the operating characteristics) in dynamic regime, according to the rotation variations of the pump – fig. 2.

The numeric simulation was obtained by running a numeric simulator program written in Turbo Pascal, LLIDOM3 from [4], for the GRUNDFOS pump, presented in figure 2.

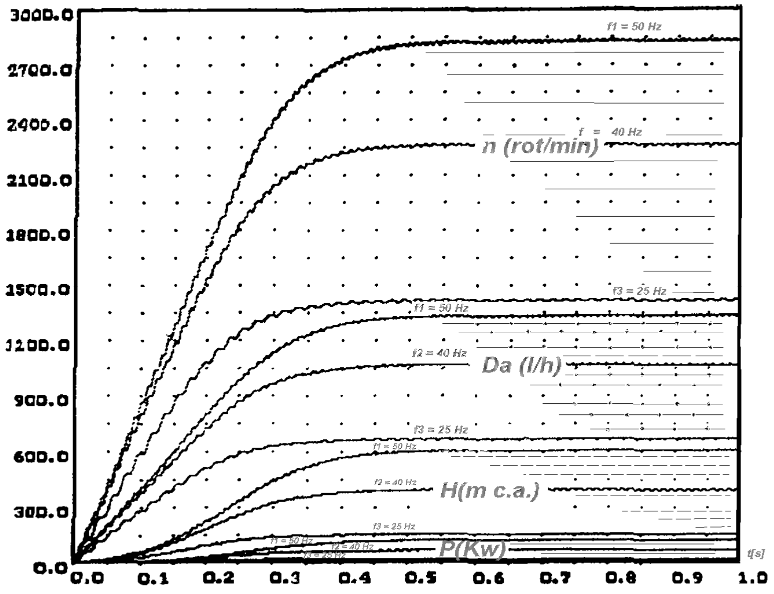

Fig. 2.

3. Conclusions

By analyzing the curves in figure 1 one can draw the following conclusions:

- The charts obtained for rotation $n = n(f_{ref})$, flow $D = D(f_{ref})$, suppressed pressure $H = H(f_{ref})$ and absorbed electric power $P = P(f_{ref})$, are measures that characterize the behavior of a pump having an electrical motor supplied at a variable frequency voltage (f1, f2, f3) in the range 25-50 Hz. The rated values which characterize the pump are: rated rotation $n_N = 2830$ rot/min, rated flow $D_N=46$ m^3/h (when operating at a pressure $H_I = 0{,}2$ m col. H_2O in the equipment), maximum rated suppressed pressure $H_{RN} \cong 12$m.col. H_2O and the motor rated electric power $P_N = 1{,}1$ Kw. Thus, one can highlight the variation of the electric, mechanic and hydraulic parameters of the motor together with pump system with respect to the supplying voltage frequency variations.

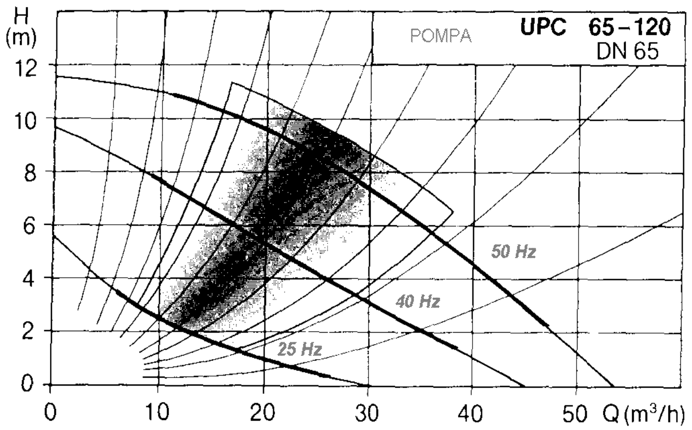

Fig. 3

- The study is a general purpose one and it can be customized for a variety of centrifugal pumps, for a wide range of powers, rotation counts, flows and pressures, each specific for different applications
- The numeric simulation program for such a pump is simple, easy to initialize and flexible in case of future changes in the structure parameters.

4. References

1. Aström K.J. *Simple Drum - Boiler Model IFAC Sympozium Power Systems Sept 1988*
2. Bogdanovici S.S. *Simulation and Modeling 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 E. *Digital control systems vol 2.Springer - Verlag Berlin , Heidelberg 1991*
8. Kelemen A. ş.a. *Acţionări electrice, Ed. Didactică şi Pedag. Bucureşti 1979*