Basis of the Variable Speed Driving Pumps Parallel Operation Modeling

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Abstract: - The paper presents the computer modeling of parallel operating of variable speed pumps, with application for heating systems. There is developed the philosophy of automatically heating system operation, taking into account the practical considerations of general heating systems. On these bases, it is introduced the new notion of controlled operation characteristic of the installation and the effectiveness of the operation design optimization.

Key-Words: - parallel operation, computer modeling, variable speed driving

1 Introduction

The heating systems are designed in two parts, for heating and for warm water. Each part has specific types of installation using the same thermal energy source. The energy and water flow depends on the constructive characteristics, users' characteristics (number, types of applications), and climate considerations. The flow has important variability, satisfied be the different procedures. Basically, there are two parallel operation pumps. These systems, like others, have to satisfy the requested flow, and the actual design philosophy has the central objective the energy consumption minimization. In this context, all pumps and pumping systems producers and providers are developing automatic operation devices. The first step is to analyze and define the real operation curve of the installation, continuing with the operation point establishing, according to the system necessities. There are different ways to operate adjustments of pumps working point, depending to the period of regime changing, the pumps power and dimensions, pumps and installation type, adjustment sharpness, etc. For definitive operation point changing, it is preferable to action on the pump itself, by using different types of impellers in the same casing, the same impeller in different casings, or providing a permanent changing to a standard pump type. For operating point changing for a long period of time, it could be used different types of diaphragms at the pump outlet or in appropriate points of the network. For short term changes, it is preferable to use special adjustable devices of the installation (vanes, by passes), of the driving engines (variable speed motors), or pump itself (adjustable impellers for axial flow pumps, or same diagonal pumps). The effectiveness of the variable speed driving can be demonstrated comparing the power consumption by vane and by variable speed operation. For the modeling purposes, using an original program, which include some other contributions [5] all the curves defined are approximated by polynomial regression, taking into consideration there can be considered parabolas of the second degree.

1.1 Operation point representation

Operation point could be obtain graphically as the intersection between the pump head-flow characteristic curve $H_p(Q)$, equation (1), with the pipe head-flow resulting characteristic curve $H_r(Q)$, equation (2), as it is presented in fig. 1[1], or analytically solving the equations system representing the polynomial approximation of the mentioned characteristics curves, as follows [2]:

$$H_p(Q) = a_1Q^2 + a_2Q + a_3 \tag{1}$$

$$H_r(Q) = b_1Q^2 + b_2 \tag{2}$$

It is to mention that the pump characteristic represent the resulting head-flow characteristic of one pump or of a whole pumping station, and the pipe characteristic represent the resulting head-flow characteristic of one pipe or a whole network. For variable speed driving motor, the pump polynomial form of the head-flow characteristic is (3), and for the pipe polynomial form of the head-flow characteristic is (4)

$$H_p(Q,n) = a_1Q^2 + a_2Qn + a_3n^2 + a_4Q + a_5n + a_6 \tag{3}$$

$$H_n(Q,x) = (b_1 + b_0)Q^2 + b_2 \tag{4}$$

where:

Q – flow at the operating point ;

n - rotation speed at the operating point,

$a_1, a_2, ..., a_6$ – polynomial coefficients for the pump head-flow characteristic,

b_0, b_1, b_2 - polynomial coefficients for the network head-flow characteristic.

1.2 Energy savings using variable speed pumps in parallel with fixed speed

There are two situations in pumping station design: one variable speed pump, working in parallel with one or more fixed speed pumps; two or more variable speed pumps, all of them, working in parallel. Generally the pumps are similar.

The savings can be estimated considering the necessary and the consumed power fro all the pumps working in the same tine together.

2 Calculation of the controlled operation parabola

The division of the flow into several variable speed pumps is used in all applications where demand fluctuates substantially and where the following requirements must be met the minimization of power consumption and compliance with minimum flow rate [3]. The fine adjustment is achieved by infinitely variable speed adjustment of one or more centrifugal pumps. In this process, the pumps operating are limited by several specific characteristics: power reserve, some unstable part of the head-flow characteristic, unaccepted low efficiency. Then, the pump could not attend the installation characteristic curve points.

The controlled-operation characteristic is defined as a theoretical curve along which the operating point should is limited. It ensures that from the minimum to the nominal flow rate, there is always sufficient pump head available to cover the piping pressure losses and the useful pressure at the consumer installation. In fig.2 are presented:

$H_r(Q)$- installation characteristic curve,

$H_{co}(Q)$ - controlled operation curve,

$H_p(Q, N_N)$- parallel operation ensemble of pumps,

$H(Q, N_N)$- one pump operation curve,

For a better understanding of the problem, the characteristics are drowning in non-dimensional parameters, which maximum values are: $Q(\%) = Q_{BN} = 100\%$, $H\% = H_{BN} = 100\%$, considering B_N normal operating point of the parallel ensemble, $B_2^{'}$- normal operating point of each pump, working in parallel, B_2 - minimum similar operating point at a different rotation speed of the nominal operating point of a pump of the ensemble, B_M - minimum operating point of one pump driven at normal rotation speed (when the system has reserve pumps and it is not possible to work in only one pump at large flow), B_F - minimum operating point at normal rotation speed (when the system has reserve pumps and it is possible to work in only one pump at large flow). Knowing the operating points B_N and B_M from the controlled-operation characteristic (parabola), it can be determined the minimum head of this curve, for zero flow, H_W, considered the origin of the parabola.

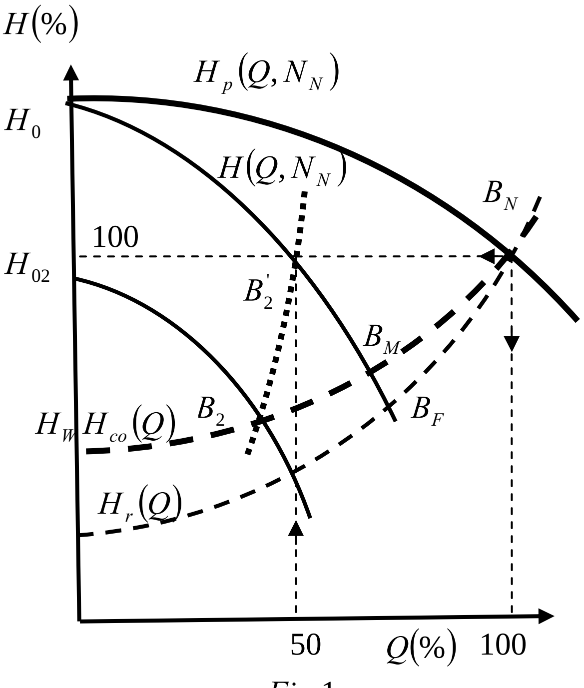
The origin of the operation parabola is shifted to the level of the set value by means of a small expansion of the affinity low equations, represented in real values and percentage of the nominal parameters.

$$H_x = H_N\left(\frac{Q_x}{Q_N}\right)^2, \quad H_x = 100\%\left(\frac{Q_x}{100\%}\right)^2 \tag{5}$$

$$H_x = \left(H_N - H_W\right)\left(\frac{Q_x}{Q_N}\right)^2 + H_W$$

$$H_x = 35\%\left(\frac{Q_x}{Q_N}\right)^2 + 65\% \tag{6}$$

This parabola is a restriction of the system operation and is important for modeling the function and the automatic operation.



$Fig.1$

For practical presentation of the method, the read off values are considered
$H_0 = 120\%, Q_{B2} = 41\%, H_{B2} = 71\%$

The normal speed is $n_N = 100\%$ and the low speed is determined following the affinity laws

$$N_2 = N_N \cdot \left(\frac{H_{B2}}{H'_{B2}} \right)^{\frac{1}{2}} = 84\% \qquad (7)$$

For variable speed driving motor, it could be determined a similar equation for each speed, but it is preferable to generate each working point using affinity lows [1], applied the ratio between current speed and nominal speed for different working point of the initial head-flow characteristic.

$$\frac{H_x}{H} = \left(\frac{N_x}{N_N} \right)^2, \frac{Q_x}{Q} = \left(\frac{N_x}{N_N} \right), \frac{P_x}{P} = \left(\frac{N_x}{N_N} \right)^3 \qquad (8)$$

3 Pumping Station with Parallel Operating Pumps

Considering the same hypothesis of a station with two pumps, the function condition is, as in fig. 2, the flow equation is

$$Q_p = Q_1 + Q_2 \qquad (9)$$

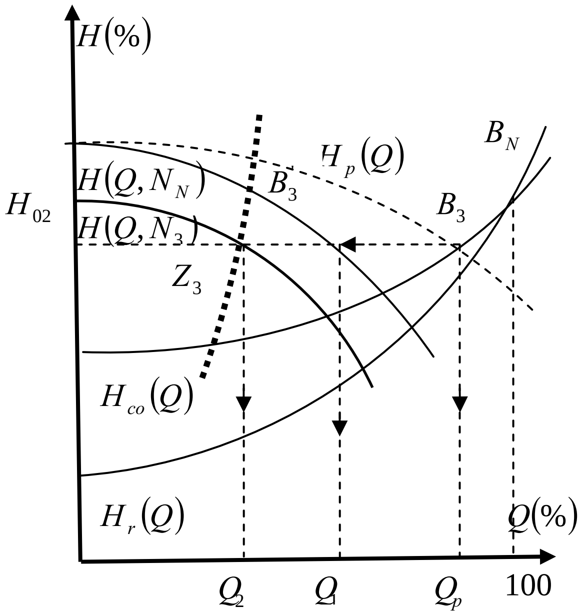


*Fig.*2

where:
Q_p – current station operation flow,
$Q_{1,2}$ – current pumps 1,2 operation flows.

For the station nominal operation, $Q_p = Q_N$.

The largest part of is offered by the pump working at the nominal speed, n_N considered Q_1, and the difference, by the pump working at the smaller speed, n_2 , considered Q_2.

$$Q_2 = Q_p - Q_1 \qquad (10)$$

The current system operation point is marked on the controlled-operation characteristic $B_3(Q_p, H_p)$, with Q_p requested by the user, and H_p is the corresponded head on the controlled-operation characteristic.
The first pump working point is $Z'_3(Q_1, H_p)$, from the pump characteristic $H(Q, N_N)$. Consequently, the second pump working point will be, on the pumps characteristic $H(Q, N_3)$, with $N_3 < N_N$. In order to estimate the second pump necessary speed, will be consider the intersection of the Affinity parabola through Z_3 and the pump characteristic (1).

$$H(Q) = \left(\frac{H_p}{Q_2^2} \right) \cdot Q^2 \qquad (11)$$

Results $B'_3(Q'_{B3}, H'_{B3})$ and, from the affinity law

$$N_3 = \left(\frac{H_p}{H'_{B3}} \right)^{\frac{1}{2}} \cdot N_N \qquad (12)$$

In non-dimensional coordinates considered example, the points coordinates are $B_3(85{,}90)$, $Z'_3(26{,}90)$, $B'_3(29{,}113)$, and the necessary speed

$$n_3 = \left(\frac{90}{113} \right)^{\frac{1}{2}} \cdot 100 = 89\% .$$

4 Power Savings Estimation for Two Pumps in Parallel

The automatic operation of the system is based on the energy efficiency criterion, considering also functioning restrictions. The proposed method introduces an effective efficiency criterion, energy savings comparing the variable speed operation with vane adjustment system.

For the ensemble with one fix speed driving pump and one variable speed driving pump. Knowing the flow rate for both pumps, it can be calculated the input power from the power-flow characteristic for nominal speed pump and, in addition, applying to the affinity laws for the variable speed pump, as follows.

$$P_1(Q_1, N_N) = d_2 Q_1^2 + d_1 Q_1 + d_0 \qquad (13)$$

$$\begin{aligned} P_{2V} &= P_2^{'} \cdot \left(\frac{N_3}{N_N} \right)^3 = \\ &= \left(d_2 \left(Q_{B3}^{'} \right)^2 + d_1 Q_{B3}^{'} + d_0 \right) \cdot \left(\frac{N_3}{N_N} \right)^3 \end{aligned} \qquad (14)$$

Then, the total power consumption is

$$P = P_1 + P_2 \qquad (15)$$

For the ensemble with both pumps have fix speed driving motors, the necessary flow Q_2 is obtained by changing the pipe characteristic changing with vane. The second pump operating point is situated on the initial head characteristic, for nominal speed. Then the system power savings are calculated as followe:

$$P_{2F}(Q_2, N_N) = d_2 Q_2^2 + d_1 Q_2 + d_0 \qquad (16)$$

$$\Delta P = P_{2F} - P_{2V} \qquad (17)$$

The total savings should take into consideration the total system consumptions, operating time and energy price.

To provide evidence of the variable speed driving system benefits, it is necessary to know the influencing factors and their effects. For the economy of a pumping system in relation to the pump output, there are: the design of the whole system; the load distribution over time of the system; the pumps characteristics the pumps power consumption from the electric grid.

5 Influence of the installation components on the automatic operation modelling

5.1 Influence of the System Design

The pumps operation points are always the points of the intersection between the system characteristics and the pumps characteristics. The system characteristics denote the pressure requirement of the system depending upon the flow rate. It always contains dynamic components that increase quadratically with the flow rate due to the flow resistances.

However, it may also incorporate additional static components. In practice, to prevent consumer installations being under supplied, the necessary pressure graph lies above the system characteristic curve. Its precise path is dependent upon the system in question.

The controlled operation curve, along which the operating point should move, must consequently lie on the above the necessary pressure line.

5.2 Pumps Influence

A pump can influence the extent pf possible savings realized by pump control different ways: path of its characteristics, different motors size required and by its design. The graph of the pump input power depends upon the gradient of the head and the graph of pump efficiency. Generally, the steeper the head characteristic curve, the flatter the power characteristic curve is.

6 Conclusion

Operation modelling based on the paper considerations, consists the main part of the original automatic pumping station operation systems proposed by the author with practical application for water and heating domestic systems.

Energy savings using variable speed engine adjustment can be estimated, considering the period of operation time during one year, the pumps number and power and efficiency. At national level, there are not reliable studies of the present situation in pumping installation efficiency. Even at the European level, the developed countries are just starting such types of inventories. But, a limited energy saving of about 10%, could lead to a general energy saving at national level of about 2%, which means a huge effect at European level.

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