ENERGY EFFICIENCY PUMPING SYSTEMS IMPROVING METHODS

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Lucrarea prezintă efectele echipamentelor de pompare cu turație variabilă în comparație cu alte moduri de antrenare şi oportunitățile de reglare a punctului de funcționare. Sunt considerate situații de antrenare cu turație variabile a mai multor pompe din cadrul aceleaşi stații. Principalele contribuții ale autorului sunt: o prezentare de ansamblu a cadrului european, necesitățile şi trendurile reducerii consumului de energie şi efectele climatice, o comparație între funcționarea la turație variabilă şi o funcționare clasică din punct de vedere tehnic, energetic şi ecologic, prezentarea efectelor turației variabile asupra funcționării întregii stații.

The paper presents the pumping equipments variable speed driving effects and ways of action, comparing with other driving and working point adjustment opportunities. There are considered the situations of variable speed driving of one or more pumps of the same station. The authors' three main contribution are as follows: a holistic picture of the European framework, necessities and trends in energy savings and climate effects; a comparison between the variable speed operation and a classical vane operation system from technical, energetically and ecological point of view; the presentation of the variable speed effects on the whole station function.

Keywords: energy efficiency, new solutions, pumping systems, variable speed

1. Introduction

The paper presents the actual situation at European level in energy efficiency framework and its effect on the European commitments accomplishment: to reduce greenhouse gas emissions by 20% and ensure 20% of renewable energy sources in the EU energy mix; to reduce EU primary energy use by 20% by 2020; to accelerate the development and deployment of cost-effective low carbon and energy efficiency technologies. The energy innovation process, from initial conception to market penetration, also suffers from unique structural weaknesses. It is characterized by long lead times, often decades, to mass market due to the scale of the investments needed and the technological and regulatory inertia inherent in existing energy systems. Innovation faces entrenched 'locked-in' carbon based infrastructure investments, dominant actors, imposed price caps,

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changing regulatory frameworks and network connection challenges. Several policies and measures are already in place to drive this process, notably the Energy Efficiency Action Plan and the Freight Logistics Action Plan, and the directives on Eco-design and on Energy Labelling of Energy Using Products, on Energy Services and on Building Performance. For 2020, the technologies that will contribute to achieving the targets are available today or in the final stages of development. Energy efficient technologies tend to have high upfront costs which deter market take-up.

An important tool for attending the energy efficiency expectations is the replacement of the old working point's adjustment systems, such as vane adjustment, with variable speed driving engines. Theoretically, at national and international level, the variable speed procedure is well known and applied at different levels, taking into account the installation type, available technology and assumed costs. The paper presents one of these procedures promoted presently at international level, considering the recommended system controlled characteristic for different typical applications. Also, there are proposed some energy savings ways of evaluation, taking into consideration the most inefficient working point adjustment system, vane adjustment

2. European frame of energy efficiency innovation

Technology improvement is vital in reaching all the energy and climate change European policy objectives: to reduce greenhouse gas emissions by 20% and ensure 20% of renewable energy sources in the EU energy mix; to reduce EU primary energy use by 20% by 2020. It is important to accelerate the development and deployment of cost-effective low carbon and energy efficiency technologies. Energy industry has five clear components (resources, production, transport, distribution and consumption), each of them with specific problems and solutions. In the longer term, the solutions for decarbonizes the economy and improve energy efficiency, new generations of technologies have to be developed through breakthrough in research. Since the oil price shocks in the 70s and 80s, Europe has enjoyed inexpensive and plentiful energy supplies. The easy availability of resources, no carbon constraints and the commercial imperatives of market forces have not only left the union dependent on fossil fuels, but have also tempered the interest for innovation and investment in new energy technologies. This has been described as the greatest and widest-ranging market failure ever seen.

Intrinsic weaknesses in energy innovation

The energy innovation process, from initial conception to market penetration, also suffers from unique structural weaknesses. It is characterized by long lead times, often decades, to mass market due to the scale of the investments needed and the technological and regulatory inertia inherent in existing energy systems. Innovation faces entrenched 'locked-in' carbon based infrastructure investments, dominant actors, imposed price caps, changing regulatory frameworks and network connection challenges. The market take-up of new energy technologies is additionally hampered by the commodity nature of energy. New technologies are generally more expensive than those they replace while not providing a better energy service. The immediate benefits tend to accrue to society rather than the buyers. Some technologies face social acceptance issues and often require additional up-front integration costs to fit into the existing energy system. Legal and administrative barriers complete this innovation adverse framework. In short, there is neither a natural market appetite nor a short-term business benefit for such technologies. This market gap between supply and demand is often referred to as the 'valley of death' for low carbon energy technologies. Public intervention to support energy innovation is thus both necessary and justified.

European role in energy technologies improvement

The main global players, the United States and Japan, but also emerging economies such as China, India and Brazil, are facing the same challenges as European Union and are multiplying their efforts to develop and commercialise new energy technologies. In the past two years, Japan adopted a strategic energy technology roadmap and the US adopted climate change science and technology programmes. The EU is leading the world in responding to climate change by adopting targets and putting a price on carbon through the Emissions Trading Scheme, as well as creating a truly internal energy market. But the Union must act with equal determination and ambition on a policy for low carbon technologies. These are the conditions to catalyze a new industrial revolution.

The transition to a low carbon economy will take decades and touch every sector of the economy. Decisions taken over the next 10-15 years will have profound consequences for energy security, for climate change, for growth and jobs in Europe. As an illustration of the scale of the problem, the Stern report2 estimates that the cost of action could be limited to around 1% of global GDP per year, while inaction could result in losing 5-20% of global GDP annually. In order to achieve the European policies, it is necessary a step change in efficiency in energy conversion, supply and end-use. In transport, buildings and industry, available technology opportunities must be turned into business opportunities. It needs to fully harness the potential for information and communication technologies and organisational innovation, as well as use public policy and market-based instruments to manage demand and encourage new markets.

Energy efficiency European plans

Several policies and measures are already in place to drive this process, notably the Energy Efficiency Action Plan and the Freight Logistics Action Plan, and the directives on Eco-design and on Energy Labelling of Energy Using Products, on Energy Services and on Building Performance. Other measures are in the pipeline, for example on CO2 emissions from cars, the Action Plan on Urban Mobility, a new phase of the Emissions Trading Scheme, and the initiatives on lead markets, sustainable production and consumption and sustainable industrial policy. For 2020, the technologies that will contribute to achieving the targets are available today or in the final stages of development. Energy efficient technologies tend to have high upfront costs which deter market take-up. A twin-track approach is therefore needed: reinforced research to lower costs and improve performance; and pro-active support measures to create business opportunities, stimulate market development and address the non-technological barriers that discourage innovation and the market deployment of efficient and low carbon technologies.

Between the key EU technological challenges for the next 10 years to meet the 2020 targets are:

– Bring to mass market more efficient energy conversion and end-use devices and systems, in buildings, transport and industry, such as poly-generation and fuel cells.

– Maintain competitiveness in fission technologies, together with long-term waste management solutions.

And between the Key EU technology challenges for the next 10 years to meet the 2050 vision is: achieve breakthroughs in enabling research for energy efficiency: e.g. materials, nano-science, information and communication technologies, bio-science and computation.

Between the European regulations with an important impact to energy efficiency, are:

- New and unitary Legislation or Amending the Directive 92/75/EEC-for the global energy and environmental performance.

- Eco-design: Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005, establishing a framework for the setting of eco-design requirements for energy-using products and amending by the Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council.

- Energy-Star: Regulation (EC) No. 2422/2001 of the European Parliament and of the Council of 6 November 2001 on a Community energy efficiency labelling programme for office equipment.

- Energy Labelling: Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances.

- Eco-label: Regulation (EC) No 1980/2000 of the European Parliament and of the Council of 17 July 2000.

In the table no.1 are presented some other European regulations, connected to these above mentioned.

Table 1

Relevant European enforced regulations

No	Requirements	Directive	Decision-GD/Law
1	The labelling and energetic efficiency of household refrigeration appliances for their placing on the market	Directive 94/2/EC amended by Directive 2003/66-A; Directive 96/57/EC	GD no. 1039/2003
2	The efficiency requirements for new hot water boilers fired with liquid or gaseous fuels	Directive 92/42/EEC amended by Directives 93/68/EEC and 2004/8/EC	GD no. 574/2005
3	The energy labelling for the placing on the market of household washing machines	Directive 95/12/EC-A	GD no. 1252/2005
4	The labelling and energy efficiency requirements for the market introduction of the powered household laundry drum dryers	Directive 95/13/EC-A	GD no. 1274/2001
5	The energy labelling for the placing on the market of household combined washer-driers	Directive 96/60/EC-A	GD no. 230/2005 amending GD no.671/2001
6	The energy labelling for the placing on the market of household dishwashers	Directive 97/17/EC-A	GD no. 86/2006
7	The energy efficiency and labelling for placing on the market of the electric household lamps	Directive 98/11/EC-A	GD no. 1056/2001
8	The energy labelling of household air-conditioning appliances	Directive 2002/31/EC-A	GD no. 1871/2005
9	The energy labelling of the electric household ovens	Directive 2002/40/EC-A	GD no. 1117/2002
10	The energy efficiency for market introduction of ballasts for the fluorescent lighting sources	Directive 2000/55/EC	GD no. 1160/2003
11	The promotion system for electricity produced from renewable energy sources	Directive 2001/77/EC	GD no. 443/2003; no 1892/2004
12	The electric power	Directive 2003/54/EC	Law no. 318/2003
13	The utilization of bio-fuels and other renewable fuels for transport	Directive 2003/30/EC	GD no. 1844/2005

14	Methodological Norms for enforcing the application of Law no. 199/2000	Directive 93/76/EEC-SAVE	GD no. 393/2002
15	The for new hot-water boilers fired with liquid or gaseous fuels	Directive 92/42/EEC amended by Directives 93/68/EEC /2004/8/EC	GD no. 574/2005

3. Variable speed driving pumps solution

Pumping equipments and installations energy efficiency improvement represents a key solution, taking into consideration the percentage of about 20% from the total energy consumption.

If for the maximum efficiency of the pumping equipments at the nominal working regime is hardly to obtain significant improvements, taking into consideration the actual performances of the devices, there is an important potential to be valuated in pumping systems operation optimal adjustment. 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). Generally, the challenge is between adjustable vanes and variable speed motors for shot term changes in the majority types of installations.

Operation point representation

Operation point could be obtain graphically as the intersection between the pump head-flow characteristic curve Hp(Q), equation (1), with the pipe head-flow resulting characteristic curve Hr(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]:

$$H_p(Q) = a_1 Q^2 + a_2 Q + a_3 \quad (1)$$

$$H_r(Q) = b_1 Q^2 + b_2 \quad (2)$$

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)

$$H_p(Q,n) = a_1 Q^2 + a_2 Qn + a_3 n^2 + a_4 Q + a_5 n + a_6 \quad (3)$$

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

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.

Comparing the vane and variable speed operation adjustment efficiency

In fig 2 is represented the operation adjustment of s pumping system using the vane and a variable speed driving engine [3] from the initial flow (Q_1), to the requested flow (Q_r), where:
$\eta(Q,n)$ – efficiency characteristic of the pumps, depending the flow and the rotation speed,
WP_1 – operation (working) point of the system at the initial flow,
WP_2 – operation (working) point of the system at the requested flow, using vane adjustment,
WP_3 – operation (working) point of the system at the requested flow, using variable speed engine adjustment.

Analytical representations of the pump efficiency at different rotational speeds is the equation (5)

$$\eta(Q,n) = c_1 Q^2 + c_2 Qn + c_3 n^2 + c_4 Q + c_5 n + c_6 \quad (5)$$

where:
$c_1, c_2, ..., c_6$ - polynomial coefficients for pump the efficiency characteristic.
For the initial and requested flows, the necessary head and efficiencies are:
$H_{WP1} = H_p(Q_i n_1)$, $H_{WP2} = H_p(Q_r n_1)$, $H_{WP3} = H_p(Q_r n_2)$, $\eta_{WP1} = \eta(Q_i n_1)$,
$\eta_{WP2} = \eta(Q_r n_1)$, $\eta_{WP3} = \eta(Q_r n_2)$,

To see a procedure or equipment efficiency, it is compared the utile and consumed powers, or energy for a determined period of time.

Vane adjustment efficiency

The utile power is computed for the point WP3 and the consumed power, for the point WP2.

$$P_{WP3} = \rho g Q_r H_{WP3}, \qquad P_{WP2} = \frac{\rho g Q_r H_{WP2}}{\eta(Q, n_1)}. \tag{6}$$

Variable speed engine adjustment efficiency

Both the necessary and consumed power are computed for the point WP3 and, defining head efficiency, as follow

$$\eta_h = \frac{H_{WP3}}{H_{WP2}}, \tag{7}$$

the vane adjustment efficiency is:

$$\eta_v = \frac{P_{WP3}}{P_{WP2}} = \frac{\rho g Q_r H_{WP3} \eta(Q, n_1)}{\rho g Q_r H_{WP2}} = \frac{H_{WP3}}{H_{WP2}} \eta(Q_r, n_1) = \eta_h \eta(Q, n_1) \tag{8}$$

Variable speed adjustment efficiency compared to the vane adjustment

Both the utile and consumed power is computed for the point WP_3 [4]:

$$P_u = P_{WP3} = \rho g Q_r H_{WP3}, \tag{9}$$

$$P_c = P_{WP3} = \frac{\rho g Q_r H_{WP3}}{\eta(Q_r, n_2)}, \tag{10}$$

then, the variable speed adjustment efficiency is equal with the pump itself at Q_r :

$$\eta_s = \eta(Q, n_2) \tag{11}$$

Variable speed adjustment efficiency compared to the vane adjustment

They are compared the consumed power adjusting the flow with a vane (P_{cv}), with the consumed power adjusting the flow with a variable speed device (P_{cs}), by defining a specific efficiency (η_{vs}) or consumed power difference $\Delta P_c = P_{cv} - P_{cs}$

$$P_{cv}=\frac{\rho g Q_r H_{WP2}}{\eta\left(Q_r,n_1\right)},\quad P_{cs}=\frac{\rho g Q_r H_{WP3}}{\eta\left(Q_r,n_2\right)},\tag{12}$$

$$\eta_{vs}=\frac{P_{cs}}{P_{cv}}=\frac{H_{WP3}}{H_{WP2}}\frac{\eta\left(Q,n_1\right)}{\eta\left(Q,n_2\right)}=\eta_h\frac{\eta\left(Q,n_1\right)}{\eta\left(Q,n_2\right)}\tag{13}$$

$$\Delta P_c=P_{cv}-P_{cs}=\rho g Q_r\left(\frac{H_{WP2}}{\eta\left(Q_r n_1\right)}-\frac{H_{WP3}}{\eta\left(Q_r n_2\right)}\right).\tag{14}$$

Energy savings using variable speed engine adjustment

Considering the period of operation time during one year or other period of time, it could be calculated the energy savings as follow

$$E=t\cdot\Delta P_c=P_{cv}-P_{cs}=t\rho g Q_r\left(\frac{H_{WP2}}{\eta\left(Q_r n_1\right)}-\frac{H_{WP3}}{\eta\left(Q_r n_2\right)}\right)\tag{15}$$

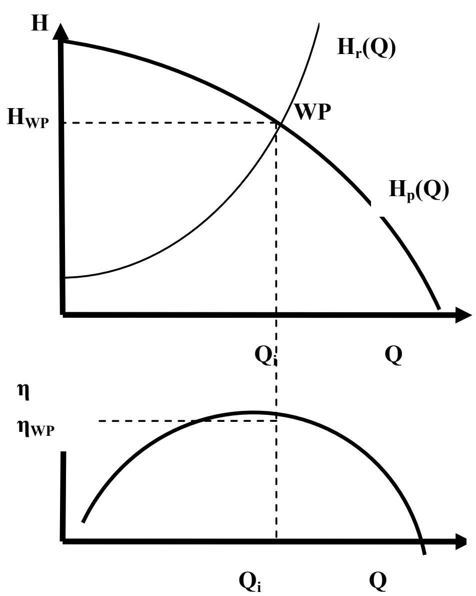

Fig. 1.

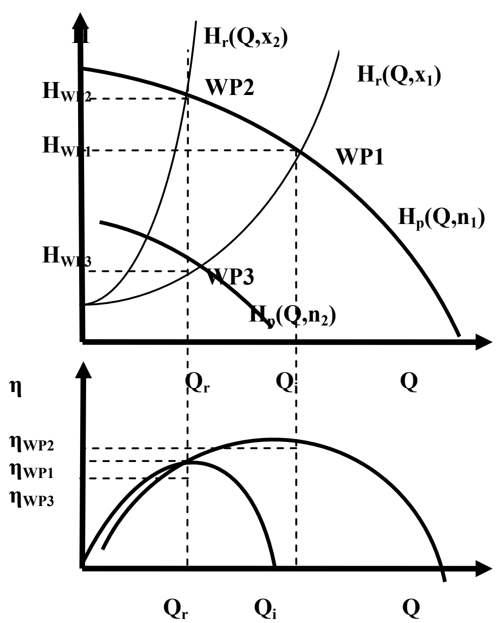

Fig.2.

4. Flow Rate Adjustment by a Combination of Parallel Operation and Variable Speed Operation

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.

Calculation of the Controlled operation Parabola

The controlled-operation characteristic curve is a theoretical curve along which the operating point should move. 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.

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.

$$H_x = H_N \left(\frac{Q_x}{Q_N} \right)^2, \quad H_x = 100\% \left(\frac{Q_x}{100\%} \right)^2, \tag{16}$$

$$H_x = \left(H_N - H_W \right) \left(\frac{Q_x}{Q_N} \right)^2 + H_W, \quad H_x = 35\% \left(\frac{Q_x}{Q_N} \right)^2 + 65\%. \tag{17}$$

For percentage parameters results the following pears of values:

From equation (16): $\frac{Q_x}{H_x} \rightarrow \frac{25}{6}, \frac{50}{25}, \frac{75}{57}, \frac{110}{121}$;

and for equation (17): $\frac{Q_x}{H_x} \rightarrow \frac{25}{67}, \frac{50}{74}, \frac{75}{85}$.

The value H_W is estimated, depending upon the following influencing factors: operating behavior of the consumer installation; similar load behavior over time or time-independent load behavior; system dimensioning. For the purpose of parallel operating, a pump is selected that achieves the nominal head at half the nominal flow rate. In addition, the pump characteristic curve must at least intersect the controlled-operation curve. In systems with two pumps (without a stand-by pump), in the event of the failure of a pump at least the system characteristic curve must be intersected, since otherwise the remaining pump will be overloaded.

The affinity parabola through the achieved point $\left(\frac{Q_N}{2}, H_N\right)$ has the equation:

$$H_x = H_N \left(\frac{Q_x}{\frac{Q_N}{2}} \right)^2, \quad H_x(\%) = 100\% \left(\frac{Q_x}{50\%} \right)^2, \tag{18}$$

and the pears of values are

$$\frac{Q_x}{H_x} \rightarrow \frac{15}{9}, \frac{25}{25}, \frac{35}{56}.$$

In the crossing point between the affinity parabola and the controlled operation parabola, can be estimated the pumps zero flow head on a characteristic curve at estimated speed n_2.
For example, considering the parameters $(Q_x = 42\%, H_x = 71\%)$,

$$n_2 = 100\sqrt{\frac{71}{100} = 84\%} \tag{19}$$

In the second step, the head at zero flow point H_{02} for is

$$\left(H_{02} = H_0 \left(\frac{n_2}{n_N} \right)^2 = 120 \left(\frac{84}{100} \right)^2 = 85\% \right) \tag{20}$$

Using the same calculation process as before a further point on the controlled operation curve is found, considering the necessary flow rate, quarter of the nominal one $Q^{'} = \frac{Q_N}{4}$. Considering $(Q_x = 19\%, H_x = 66\%)$, the affinity parabola is

$$H_x = H_N \left(\frac{Q_x}{\frac{Q_N}{4}} \right)^2, \quad H_x(\%) = 100\% \left(\frac{Q_x}{25\%} \right)^2, \tag{21}$$

with the pears of values:

$$\frac{Q_x}{H_x} \rightarrow \frac{10}{18{,}4}, \frac{15}{41{,}4}, \frac{20}{73{,}6}, \frac{25}{115{,}0};$$

and the speed and pump characteristic curve are

$$n_2^{'} = 100\sqrt{\frac{65}{115}} = 76\% \qquad (22)$$

$$\left(H_{02}^{'} = H_0 \left(\frac{n^{'}}{n_N} \right)^2 = 120 \left(\frac{76}{100} \right)^2 = 69\% \right)$$

The characteristic curves at different speed are established considering these points and the working points from the controlled operation curve, or are established considering the affinity equations.

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.

5. Conclusions

The paper presents some relevant methods for energy efficiency emphases of the variable speed driving of centrifugal pumps, as absolute energy savings, or by comparing with vane adjustment working point.

Also, there are presented the last trends in European approach of energy savings and energy efficiency.

R E F E R E N C E S

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