Variable speed control in centrifugal pumps for closed systems

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Abstract. Energy consumption in any type of installation, whether for urban purposes, commercial or industrial, is a very important question; therefore, reducing energy consumption is of great importance. It is very important to control the rotational speed of the pumping equipment in accordance with the required consumption or requirement. For closed circuits (closed systems) it is important to ensure the required flow rate while maintaining the proper pressure or working head in centrifugal pumps. This type of control is ideal for installations with changeable curves, where different work processes are required at the same pressure or different process pressures in centrifugal pumps.

1. Introduction
HVAC pump systems with a total pump system capacity of more than 10 (Hp), including the control valves designed to modulate or opening and closing in step depending on the load, must be designed for variable fluid flow and should be able to reduce pump flow rate by up to 50% or less from the design flow rate [1]. When choosing a centrifugal pump, it is necessary to take into account factors such as pipelines and a hydraulic system through which cold water is supplied to each of the loads that are being parts of the system. Considerations about calculating of heat loads are not considered in this article, authors focus only on the selection of pumping equipment and the change in rotational speed in accordance with the volumetric flow rate. The pump system must supply water to each of the supply and exhaust systems, providing pressure in each of the coils, regardless of how far the system loads can be located relative to the centrifugal pump. We will select a pump for distributing cold water in a building that is used as an office of a large company. There is a control unit on each floor that distributes conditioning air on each floor; the greatest heat load of the system falls on the first level, which is being used as the main auditorium of the company. In table 1 we can see a summary of heat loads for each level in the building, the flow is determined in accordance with AHRI [2].

Knowing the volumetric flow rate of each processing unit, we can determine the total flow rate of the pump. A study of the losses of the system should be carried out then. All cooled and condenser water pipelines should be designed so that the estimated flow rate in each part of the pipeline does not exceed the values indicated in the table. 6.5.4.6 [1] for the corresponding total annual hours of operation. The choice of pipelines sizes for systems operating in variable flow conditions (for example, modulating two-way control valves on spools) and containing variable speed pump motors can be made from the “variable flow / variable speed” columns. The others should be made from “other” columns [1]. When we study the pressure loss in a closed hydraulic circuit, we must analyze
each of the conclusions and distribution of pipes; in this particular case, we have the most distant equipment in relation to the pump at the first level, in addition to being the largest equipment in the system. We will assume the following equipment losses [2] (loading-and-unloading units, chiller, air-separator) (Fig. 1.) as well as friction losses along the pipes and fittings.

Table 1. Heat loads on the floor

| Zone     | Heat load [Btu/hr] | Heat load [kW] | Flow rate [GPM] | Flow rate [Lt/s] |
|----------|--------------------|----------------|-----------------|-----------------|
| 7th Floor| 240,000            | 70.34          | 48              | 3.64            |
| 6th Floor| 360,000            | 105.51         | 72              | 5.46            |
| 5th Floor| 360,000            | 105.51         | 72              | 5.46            |
| 4th Floor| 480,000            | 140.68         | 96              | 7.27            |
| 3rd Floor| 420,000            | 123.09         | 84              | 6.36            |
| 2nd Floor| 480,000            | 140.68         | 96              | 7.27            |
| 1st Floor| 600,000            | 175.85         | 120             | 9.09            |

*Nominal water flow rate is determined by water temperature at nominal power. The normalized flow rate per unit of evaporator capacity is shown. AHRIStd 550-590, 2015

The total loss is 57 [ftwg] or 170.03 [kPa]. Now, knowing the necessary head and volumetric flow rate of water, we can choose a convenient pump.
For a more detailed study of efficiency, velocities and pressure differentials, it is recommended to carry out the research using the methods of computational fluid dynamics (CFD) [3]. There are various types of software using CFD, such an analysis is beyond the scope of this article.

2. Selection of pumping equipment
The pump should be selected from the manufacturer in this industry, the pump curve and the operating point should be obtained [4]. This point corresponds with the operating of the system at a maximum load of 862 [kW] (Table 1). However, one of these systems is characterized by operation at partial loads, so the pump must change its rotational speed in order to be able to supply the required amount of water at partial loads. In Fig. 2, we can see the pump curve and the system curve. This operation moment happens when the pump is operating at 100% of its capacity.

![Fig. 2. The operating point of the pump under maximum heat load](image)

Under these conditions, the pump motor has a power of 15 [Hp] or 11.2 [kW], with a speed of 1750 [rpm]. An appropriate control strategy will allow the system to save energy at partial heat loads, reducing the frequency and, therefore, the rotational speed of the pump motor.

3. Pump speed control strategy
Although the project’s design engineer can propose several control options for changing the pump rotational speed, in this article we are focusing on changing the pump RPM while maintaining a constant pressure [5]. Assuming an operating condition that requires 300 [gal/min] (22.7 [L/s]). If the centrifugal pump does not have a variable frequency drive (VFD), then the decrease in flow rate is compensated by the increasing of head, the new operating point moves along the pump curve (Fig. 3). Although the braking power is reduced (Table 2), the pump motor remains the same (15 [hp]), switching to 1750 [rpm] thus, the pump efficiency is significantly reduced. When the motor has VFD, it is possible to reduce the frequency in this 4-pole motor and reduce the rotation frequency. This will lead to electricity saving [5].
Table 2. Required power

| Operating point     | Heat load [Btu/hr] | Flow rate [GPM]$^*$ | Head [Ft wg] | Bhp [kW] |
|---------------------|--------------------|---------------------|--------------|----------|
| Design load (max)   | 2,940,000          | 588                 | 57           | 7.60     |
| New point           | 1,500,000          | 300                 | 75.87        | 6.90     |
| Partial load - VFD  | 1,500,000          | 300                 | 57           | 3.87     |

When the system is operating at partial load, the volumetric flow rate is less than the design condition, for this reason, for a new flow rate of 300 g/min, the operating frequency and, therefore, the pump rotational speed must be reduced, which provides the saving energy. As mentioned above, if the pressure in the main pipe must be maintained for the new requirements for volumetric flow rate, then the known similarity principles for pumps cannot be used, because the system curve is changing.

Thus, using the following equation:

$$H_P = A \cdot \alpha^2 + B \cdot Q \alpha + C \cdot Q^2$$

Where $H_P$ — is head that must remain unchanged; $A$, $B$, $C$ constants can be determined using the initial pump curve (1750 rpm). The alpha constant $\alpha$ can be defined by the following equation:

$$\alpha = \sqrt{\frac{n}{1750}}$$

Now, using Matlab and using the iterative process, we can determine how many rotations per minute “n” are necessary for $H_P$ to be 57 [ft]. This is shown on the Fig. 4 that at this new rotational speed (1450 rpm) the pressure remains approximately constant, providing pressure on the main branch with the required flow rate. The power can be calculated using the following expression:

$$BHP_{hp} = \frac{Q \cdot H_P \cdot SG}{3960 \cdot \eta}$$
The specific gravity (SG) of water is equal to 1, and for a constant pressure of 57 [ft] we plot the power behavior depending on different water flows, as can be seen in Fig. 5.

**Fig. 4.** Required pump behavior under partial load

**Fig. 5.** Power change for a head of 57 [feet]
4. Elements necessary for speed control
To control the rotation speed of the pump, the system must have special devices - sensors that measure variables, such as pressure and flow rate. These sensors send signals to the controller, which can send a control signal to VFD and control the motor speed [6]. The pressure sensor can be used in the pump supply line at the appropriate distance, as recommended by the manufacturer. The choice of this element should take into account the maximum process pressure of the system and the operational temperature of the liquid. The pressure sensor should be a device for measuring the increase in pressure in the main supply pipe.

The flow measurement can use a diaphragm that will measure the pressure differential [7]; this differential will be transmitted to the differential pressure sensor, which will send a signal to the controller. These elements should be used to control the operating flow, which should have a lower limit. If the flow rate sensor is capable to detect a flow equal to or less than the minimum flow rate, the controller must be programmed to either stop the system or not to reduce the motor speed to values when the operating of the pump is unsafe.

Although the HVAC system has more devices [8], for monitoring and controlling all the equipment that form the system, the above elements are basic in order to be able to control the rotational speed of the pump [9]. In the case when the loads of the last three floors do not work, or another similar condition will lead to a decrease in the necessary pressure on the main branch, since there is no need to direct the fluid to these points. Therefore, the project designer should propose several options of controlling [10] that help to reduce the energy consumption of the pump system either by working at constant pressure or by reducing pressure. For all these alternatives, controllers, pressure sensors and other various sensors should be used [11]. This will be set in each of the air handling installations.

5. Conclusions
Controlling the rotational speed of a centrifugal pump using VFD provides energy saving [12]. A detailed analysis of the power, as can be seen from Fig. 5, shows that a decrease in the rotational speed to 1450 [rpm] leads to a decrease in power consumption by up to 50%, providing the necessary flow rate to the required pressure. The project designer must carry out a study of the time periods during which various equipment (supply and exhaust units) are operating, and in accordance with this establish one or more control procedures to provide the use of VFD.

Hydraulic systems with variable flow rate or individual cooled water pumps serving the systems with variable flow rate with engines having the capacity of more than 5 hp (3.7 kW) must have controls and / or devices (such as a variable speed controller) that ensure that the pump motor needs no more than 30% of the design power at 50% of the calculated water flow rate [13].

Using this type of control allows avoiding the unnecessary use of expensive control devices, such as pressure independent characterized control valves known as PICCV [14], these valves maintain a constant pressure inside the supply and exhaust system. The control system [15] maintains a constant pressure in the main pipe, thus, the required pressure inside the coil is guaranteed without requiring this type of valve.

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