Energy efficiency

Two approaches to capacity control

Pump capacity is mainly controlled by means of throttle valves or by varying the rotational speed. In this fifth article in a series on energy savings, Hans Vogelesang of PumpSupport considers the advantages and disadvantages of both methods and whether it is always useful to use speed regulation.

Capacity control

The capacity of centrifugal pumps is mainly regulated in two different ways. Traditionally, the best-known method is throttle control, which is still often applied. With this method a control valve is placed in the discharge line of the centrifugal pump, which is opened to a greater or lesser degree depending on the desired pump output.

The second method involves regulating the pump speed, which is employed increasingly since the introduction of frequency converters. But this method cannot be applied indiscriminately in all cases. The examples discussed below will illustrate this. In all cases the examples are based on a design capacity of 100%, and in all cases the same pump is used with an impeller diameter of 254 mm. With this pump, the design capacity at design speed lies exactly at the optimal operational point with the highest efficiency rate (BEP, best efficiency point). In pump performance (Q–H) graphs, such as those discussed in later sections, the pump efficiency rate is always represented by means of lines of equal efficiency. In this way the optimal efficiency rate within a given Q–H graph is immediately recognizable.

It is important to note that when controlling the capacity of pumps the output of the pump should never be less than the minimal flow as indicated by the manufacturer. The rule of thumb is 25% of the optimal capacity (Q = Q at η_max).

Throttle control

With this method a control valve is placed in the discharge line of the centrifugal pump, which is opened to a greater or lesser degree depending on the desired pump output.

Note that this is only applicable for centrifugal pumps. Throttle control cannot be used with a positive-displacement pump!

With a closed circuit, for instance a cooling water system as shown in Figure 1, the necessary differential head consists solely of friction losses. Because there is no stationary differential head, the piping characteristic has its origin at 0 m³/h and 0 m and will increase quadratically as capacity increases. If the throttle valve is fully open then,

![Figure 1. Example of a closed circuit with only dynamic losses.](image-url)
according to Figure 2, the output of the pump is 100% at the intersection of the system and pump characteristics.

If the valve is throttled it will introduce more resistance. This means that the system characteristic will describe a steeper curve and that the intersection with the pump characteristic will shift to the left, corresponding to a lower flow rate. The amount of water circulating through the system will decrease more and more as the throttle valve is throttled more and more. In this way the output of the centrifugal pump is always simply continuously variable.

The flow can be regulated in the same manner with an open system, as shown in Figure 3. But here the total differential head always consists of the stationary differential head plus the dynamic differential head; therefore the system characteristic at 0 m³/h will begin at the stationary differential head and increase quadratically at increasing flow rate. With a fully opened throttle valve, the flow of the pump is as shown in Figure 4 at the intersection of the system and pump characteristics for \( Q = 100\% \).

Because the total differential head consists of the combination of the stationary and dynamic differential heads, the system characteristic will, however, be much flatter at the same total differential head than with a closed circuit. Therefore less extra resistance is needed via throttling to achieve a similar regulating range.

**Speed control**

In the case of speed (frequency) regulation there is no throttle valve and the delivery valves are always fully open. The pump’s speed is variable. Various speed-regulated pump drives are available but in most cases a frequency converter in the power supply of the electric motor is used. This offers the possibility to vary the frequency of the power supply and with this the speed of a normal three-phase motor.

When the speed of the pump changes the pump characteristic will also change. The changes always follow a fixed pattern. This makes it easy to predict how the pump curve will change when the speed is being adjusted. A lower pump speed will result in a lower differential head at a given capacity. Therefore the pump characteristic will decrease at lower speeds. For a given pump, the pump characteristic at a variable speed will consist of a set of pump curves, as shown in Figure 5. In most cases this represents an outline of the maximum and minimum speeds of the pump. With continuously variable control, each intermediate speed and, consequently, each intermediate pump characteristic can be achieved as required. When lowering the speed the intersection with the system characteristic moves to a lower flow volume.

When speed regulation is used instead of throttle control in the closed circuit illustrated in Figure 1, an output of 50% is reached at a speed of 720 rpm. The applicable system and pump characteristics are shown in Figure 6.
In a similar way, the open system shown in Figure 3 can also be controlled by decreasing the speed but, because the system characteristic curve is flatter, 50% output is already reached at a speed of 1360 rpm. The applicable system and pump characteristics are shown in Figure 7.

Advantages and disadvantages

The advantage of throttle control is that only a controllable valve is needed. Of course it has to be a suitable control valve, which has to be selected carefully for the system in question and, moreover, has to be adjustable to every desired intermediate position. Note that a normal isolation valve that is solely meant to be used for isolation is not suitable!

With a control valve, satisfactory and easily variable control of the output of a centrifugal pump is obtained but a major disadvantage of throttle control is the high energy consumption. Because throttle control moves the intersection and/or operational point to the left along the pump characteristic when throttling, the efficiency of the pump at the new operational point will always be lower than at the optimal operational point (BEP). This means that the internal losses increase at the cost of extra energy loss; when throttling the control valve, extra friction losses are deliberately generated within the system and extra friction loss also means extra loss of energy.

Of course, the amount of energy that is lost in this way by means of the throttle valve depends on the nature of the system. Compare for instance the closed circuit of Figure 1 (performance curve shown in Figure 8) with the open system of Figure 3 (performance curve in Figure 4). In both cases the control valve is fully open at the design capacity of 100% and does not result in extra friction. However, for a decreased flow of 50% a much greater friction loss has to be added in the closed circuit than in the open system.

In both open and closed systems the power consumption at a given pump capacity is the same in all cases. In the examples this is approximately 5.5 kW at a flow of 50%.

The disadvantage of speed control is the higher investment it requires. Besides a sometimes slightly adapted three-phase motor it is also necessary to buy a frequency converter. Fortunately, frequency converters have become cheaper in the past few years.

The great advantage of frequency control is generally the energy saving. This is at its highest with closed systems, as shown in Figure 1. In this system, 50% capacity is reached at a rotational speed of 720 rpm (Figure 6). The power consumption at that point is about 0.9 kW. Compared to the power consumption of approximately 5.5 kW for the same closed circuit with throttle control it is clear that there is a substantial energy saving. The higher investment costs are earned back quickly, especially with continuously operating systems.
However, it is important to be very careful when using speed control for an open system. Because the intersection and/or operational point with speed control in an open system (Figure 3) shifts along the system characteristic, this operational point will shift continuously further left on the subject pump characteristic as rotational speed drops. Figure 7 shows this shift very clearly. This will result in a decline in efficiency with accompanying higher internal losses. In spite of this, the power consumption of ca. 4.5 kW at a flow rate of 50% will always be lower than the 5.5 kW required with throttle control, but clearly the saving is lower and because of this the payback will be longer than with the closed circuit.

With the combination of a flat system characteristic and a flat pump characteristic (Figure 7) there is not only a loss of saving but also a significant risk. Only a small change in rotational speed will result in a large capacity change, making it difficult to maintain stable control. There is also the danger that the operational point will fall below the permitted minimal flow for the pump. This is very bad for the life span of the pump. In such circumstances you can limit the risk by choosing a pump with a steeper pump characteristic.

Conclusion
Especially with a closed circuit that is operational for a long time or permanently it is worthwhile to make the extra investment involved in speed control of the pump. This will result in significant energy saving.

It is also worthwhile to use speed control with an open system. But with a system in which the differential head mainly consists of the stationary differential head, and dynamic losses to a lesser degree, the saving is only small. Moreover, the characteristic of the selected pump should never be too flat because then undesired pump problems and/or unstable control will occur.

References

Contact
Hans Vogelesang
PumpSupport (NL)
Charley Tooropstraat 38
3343 RE Hendrik Ido Ambacht
The Netherlands
Tel: +31 78 682 0602
Fax: +31 78 682 1833
E-mail: info@pumpsupport.nl
www.pumpsupport.nl

About the author
Hans Vogelesang is director of PumpSupport in Hendrik Ido Ambacht, an independent consultancy for the design of pump systems. He is also a lecturer in pump engineering at several educational institutes.

This article was originally published in Dutch in Fluids Processing Benelux.