Energy efficiency

Reducing avoidable pressure losses

Industrial plants frequently employ oversized pumps out of caution. Pressure losses, and consequently energy consumption, may thus be unnecessarily high. Dr Walter Schicketanz explains in detail how such avoidable pressure drops can be determined both theoretically and in the field, as well as examining how to reduce them.

In nearly all industrial plants, and especially in the process industry, pumping systems require a considerable share of the total energy consumption. Therefore, saving energy in an economically feasible way is a constant concern for plant managers and engineers alike. Experience shows that in existing plants pump systems are often not optimized, in particular where energy consumption is concerned, utilizing 'wrongly' sized (mostly oversized) pumps. This is the result of adding safety margins in the planning process covering uncertainties concerning pipe runs, layout, the range of physical data of the fluid, the manufacturer's tolerance, etc. In addition, the price of energy may have changed in the course of time triggering a rethink on reducing power consumption.

There are several ways to achieve energy savings in an existing plant, an important one being to trim the impeller of centrifugal pumps. Trimming, changing or even replacing the impeller of a multi-stage pump with a vaneless one (i.e. a plain disk) is likely to be economical if the pump is relatively small and running most of the time at high load.

The starting point for any consideration is of course the measurement of the actual data, namely, determining the operating point at the design load, which ought to be the maximum load. This comprises measuring flow (if necessary by means of a clamp-on flow meter), pressure and power consumption.

To achieve the design flow in a system with an oversized pump, the flow must be throttled until the design value is reached. This throttling could be performed by an operator who adjusts a manual valve. If there is a control system, the control valve is adjusted automatically. In cases where the pump system features more than one branch, every branch has to be throttled to achieve its design flow in such a way that the total pump pressure (i.e. the head) is reached. Normally one and only one branch will require the highest pressure, thus determining the pressure the pump has to deliver. If the pressure drop in this determining flow path could be reduced, the pump head could be reduced accordingly by this 'unnecessary' pressure loss, thus allowing a reduction in energy consumption. To realize this reduction this avoidable pressure loss has first to be determined.

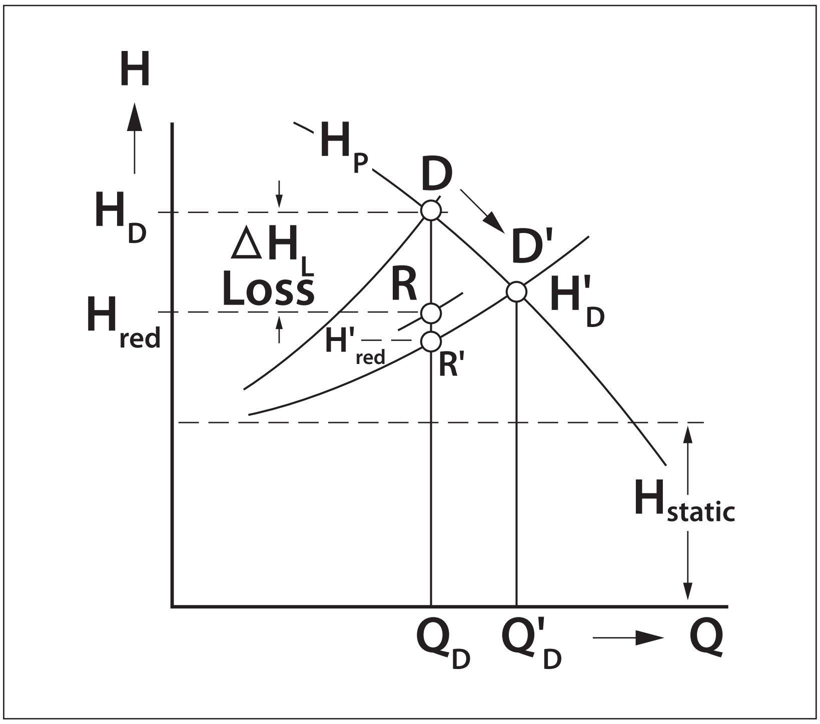

Figure 1. Determining the unnecessary pressure loss using the pump characteristic.

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Methods to determine pressure loss

Recalculation

Recalculating the pressure drop of the determining flow path of an existing system gives an indication of the unnecessary pressure drop; however, uncertainties remain due to the fact that flow resistance factors from the literature have to be used too, despite basing the calculation on a precise pipe run from isometric drawings, etc. This also applies to excessively throttled manual valves; only where control valves are concerned can the pressure drop be calculated with any accuracy. However, it is easier and more accurate to determine the unnecessary pressure drop in the field.

Increasing flow

Assuming the valve that is throttled to achieve the desired flow can be identified, and it is possible to increase the flow, then various operating points on the pump characteristic curve can be measured. This is reflected in the head–flow (H-Q) diagram (Figure 1) for a system without branches and operating with a radial centrifugal pump. Here, the design flow, Q_D, (operating point D with head H_D) is achieved by strongly throttling a valve. Now, when this valve is opened fully, the operating point shifts on the pump characteristic curve H_P until it intersects the pressure loss curve of the system at the point D'. Following the decreasing flow on the pressure loss curve back to the design flow yields point R' with pressure head H'_{red}. It seems advisable to add a safety margin, which leads to the point R with head H_{red}. The difference in the head between the original operating point D and point R represents ΔH_L loss, namely, the unnecessary pressure loss. Point R would be the operating point of the pump if it had a trimmed impeller. Applying this method to a pump system comprising several branches, all the branches must operate at their design flows with the exception of the one on the determining flow path.

Shifting pressure drop: manual valve

However, the method just described has a serious drawback since the flow in the system has to be increased. In an operating plant this may lead to off-spec products and problems with the pump due to insufficient NPSH and/or overload of the motor in the case of a radial pump. This can be avoided by applying another method, which requires two valves in series and pressure or pressure drop measurements. An example of such a set-up is exemplified in Figure 2. Valve 1 (V1) is fully open, whereas valve 2 (V2) is used to throttle the flow to achieve its design value; the pressure drop across valve 1 is measured. The throttling valve 2 is opened stepwise, while the other is throttled simultaneously such that flow and power consumption are kept constant (consequently, the pump pressure also has to be constant). Valve 2 should be completely or almost completely opened.

This procedure keeps the operating point fixed and merely shifts the pressure drop within the system from valve 2 to valve 1. The unnecessary pressure loss is inferred from the measurement across valve 1. This is illustrated by the H-Q diagram shown in Figure 3: from the original operating point D, with head H_D, the pressure head difference resulting from the measurement across valve 1 is subtracted, yielding point R. Again, this would be the operating point of a pump with a trimmed impeller.

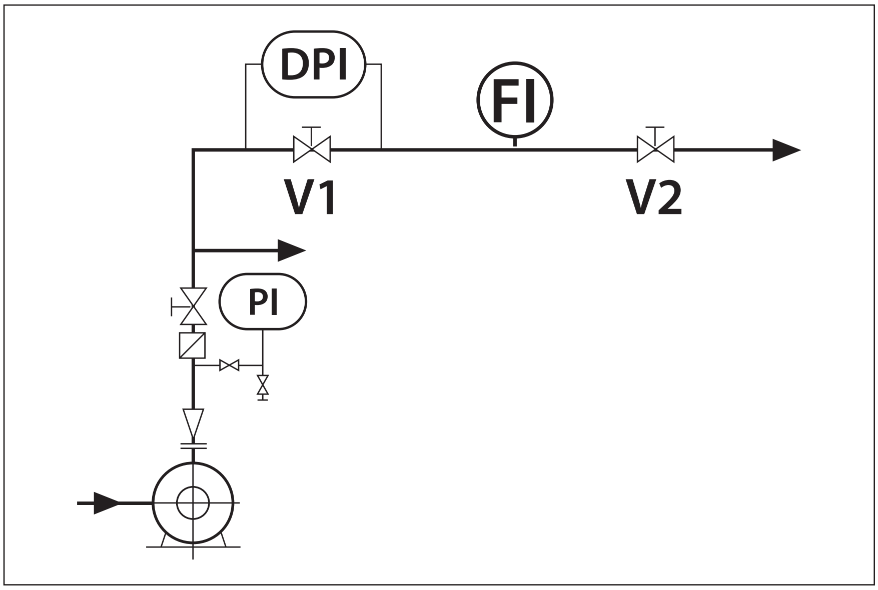

Figure 2. Set-up to determine the unnecessary pressure loss on an oversized pump (where DPI = differential pressure indicator; FI = flow indicator; and PI = pressure indicator).

Shifting pressure drop: control valve

In the process industry automatically controlled plants predominate. In such plants it would be nearly impossible to apply the above-described method of increasing flow while the plant is on stream, since increasing flow may trigger a shutdown. This is obvious when, for example, considering the reflux pump system of a continuously operating distillation at an oil refinery. On the other hand, if such a test is performed on an off-production plant, neither the liquid nor the conditions might be representative.

In a plant equipped with a modern control system, the task of throttling is performed automatically; that is, a control unit adjusts the control valve to a set value. Increasing production or just operating the pump system at maximum flow, equal to the design flow, seldom poses a problem. The method based on a manually throttled valve can be applied in principle to test any opening of the control valve and its effect on the operation of both the pumping system and the plant. Again, it is necessary to have two valves in series, one being the control valve, the original opening position of the control valve at design flow Q_D being h_D. Flow Q_D, pump pressure and power consumption are kept constant while a manual valve is throttled, whereupon the control valve opens automatically. This continues until a certain relative stem position h_R is reached, schematically indicated in Figure 4. Instead of measuring a pressure drop, the control valve opening has to be determined. This can be done either in the field or preferably registered by a position indicator, giving a rather precise value of the valve's relative opening position h_R.

Adjusting the pump system

Using the following control valve sizing equation, the pressure drop and head between two positions h, e.g. h_D and h_R, can be calcuclated, where the valve flow coefficient k_v constitutes a function of h:

$$\Delta H_L = Q_D^2 * \{1/[k_V(h_D)]^2 - 1/[k_V(h_R)]^2\} * 100/g$$

Using the metric system, ΔH_L represents the unnecessary loss of head in metres of liquid column, while Q_D represents the flow at the design point in m³/h; k_V is the valve flow coefficient and g the gravitational constant. The k_V-value at a given opening point may either be read from the supplier's data sheets reflecting k_V over h for non-choking flow, or calculated via the nominal valve flow coefficient K_{VS} of the valve in question, its flow characteristic and opening h. Ideally, Q_D being the flow at maximum load, one may assume that a fully opened valve (that is, h_R = 100%) suffices. However, the action of the control system necessitates that flow oscillations are taken into account. That means that in order to solve the above equation the opening h_R has to be defined.

Defining h_R

In defining h_R or the maximum flow, a number of factors should be considered:

- When designing a plant, the traditional method is to allocate a pressure drop of 25–50% of the dynamic pressure drop of the system or an absolute pressure drop and fix an opening or a percentage valve flow coefficient, for example between 60% and 75%[1]. The original design value is used.
- The extent to which a further increase of flow is to be expected is estimated or calculated and the opening then required is inferred.
- An extraordinary response to the action of the control system may appear under some operating conditions such as, for example, at start-up, etc., requiring a higher flow than at maximum load.
- A margin for contingency may have to be taken into account, covering, for example, uncertainties in the data, scale formation, roughening of the pipe, a drop in the performance of the pump, etc.
- At maximum flow an opening of 90% should be acceptable, based on a globe valve[2].
- By reviewing the protocols and records of the plant it is possible to determine the deviations from the design flow caused by the actions of the control system. This reveals the maximum flow limit and maximum opening necessary, the latter possibly larger than the 90% mentioned before. This could yield a considerable energy-saving potential.

Verifying the flow limit

After assuming a value for h_R it is necessary to verify that the pump with a trimmed impeller could achieve the maximum flow, which has to be less

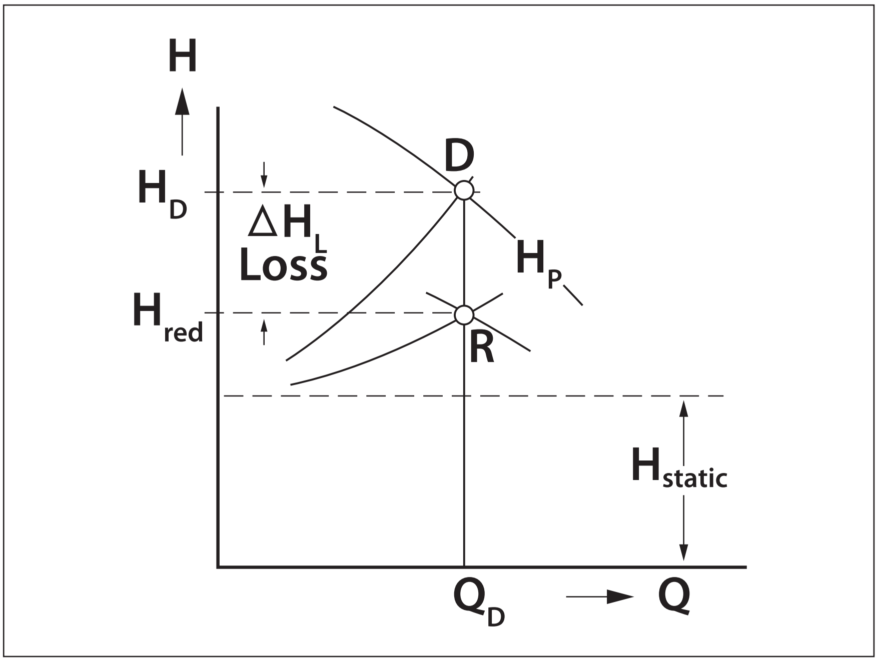

Figure 3. Determining the unnecessary pressure loss using the set-up shown in Figure 2.

than or equal to the maximum flow limit. This limit can be calculated by deriving the resistance factor of the fully opened valve from its valve flow coefficient. This resistance factor is incorporated into the pressure drop curve of the pump system. The next step would be to establish the pump characteristic of the trimmed/changed impeller through the operating point R. The pump characteristic is taken from the supplier's data or calculated as per the literature[3]. Its intersection with the system pressure drop curve yields the maximum flow limit. (To establish a sound basis it seems advisable to measure in the field not only the operating point D but also other points to verify the pump characteristic.)

Additionally, by changing the trim (i.e. the seat and plug) of the control valve or replacing the existing valve by another with a higher nominal valve flow coefficient, it is possible to reduce the pressure drop of the fully open valve and thus increase the maximum flow limit somewhat. But this effect may be rather small, often not justifying the cost of such a control valve featuring a high turn-down ratio. In the case where such

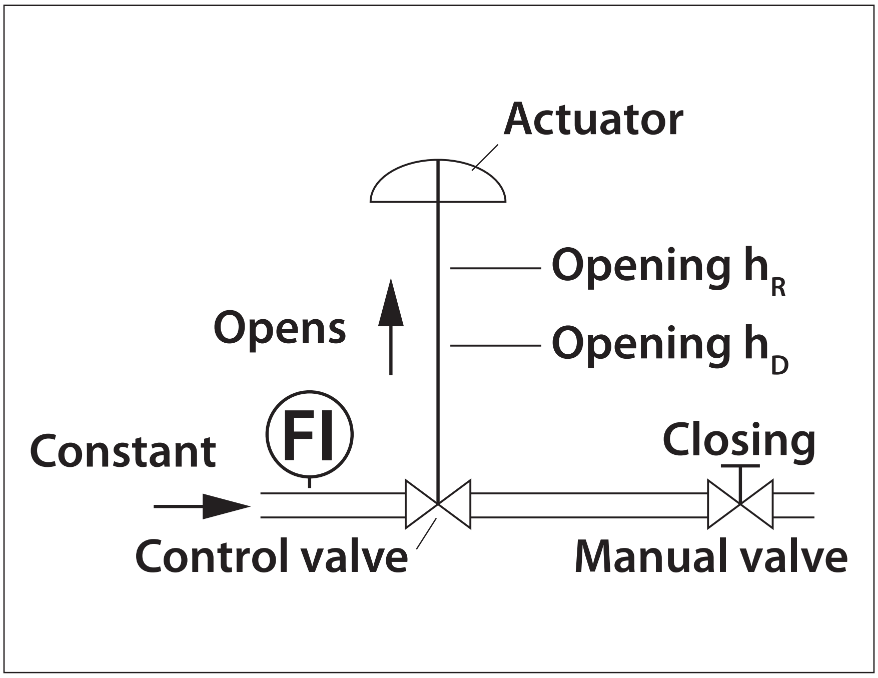

Figure 4. Method to establish the opening of a control valve through iterative testing in a pumping system.

a valve has an equal-percentage characteristic – that is, a rather steep gradient when approaching 100% open – problems may arise where controllability is concerned. It has to be borne in mind that the operating range of throttle control is influenced by the pump system's features. In relation to any operating point, the maximum flow limit decreases:

- the more steeply the pump characteristic falls, a tendency augmented by increasing specific speed; and
- the higher the dynamic pressure loss lies (without a control valve) in relation to the static pressure.

In cases where the pump system features branches where at least one branch has a dynamic pressure loss only, it is necessary to verify that this branch is able to achieve its design flow: there may be a danger that the flow decreases drastically, in extreme cases even to zero.

Reducing pressure drop in general

Data on further and/or additional possible reductions of pressure drop in the determining flow path may also be obtained by analysing its losses in detail and modifying the system. However, with existing systems, changes will seldom be economically sensible where geodetic height, static pressure, pipe diameters or pipe runs are concerned. This does not necessarily apply to fittings, valves and other associated components. Thus thought might be given to substituting a plug disk valve with a ball valve, even if it means deviating from a company's piping standard, etc. Similarly, the pressure losses of major equipment items such as heat exchangers, etc. should be scrutinized critically. In some rare cases a substitution may make sense. However, substituting in-line instruments causing a high pressure drop – for example, an orifice flow meter with a magnetic inductive one, etc. – would be economically more promising.

It should be mentioned that the procedures described in this paper could also be applied to estimate the possibilities of debottlenecking a pump system.

Conclusion

In most cases it will be possible to determine the unnecessary pressure drop for oversized pumps while the plant is operating by measurements in the field plus some calculations. This yields the operating point of the pump with a trimmed impeller. To ensure the functioning of a system utilizing a pump with a trimmed impeller, especially with regard to the response of the control system, the maximum flow limit of the system should be established. ■

References

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