

6.3 Design and application

The purpose of this section is to provide general guidelines for the application of reciprocating power pumps.

6.3.1 Typical services

- Absorption oil charge;
- Amine charge;
- Ammonia injection;
- Boiler feed;
- Carbamate;
- Caustic injection;
- Glycol injection;
- High-pressure water cleaning and cutting;
- Homogenizing (foods, chemicals, fuels);
- Hydraulic systems in steel and aluminum mills;
- Hydrostatic test;
- Pipeline (hydrocarbons, ammonia);
- Reactor charge (nuclear power plant);
- Rerun;
- Reverse osmosis;
- Salt water disposal;
- Secondary recovery (oil field production);
- Slurry (ores, coal, soap, drilling mud) — See discussion in Paragraph 6.3.10;
- Spray drying;
- Standby liquid control (nuclear power plant);
- Transfer;
- Wash-water injection;
- Waste disposal.

6.3.2 Basic speeds

Conditions of installation and variations in design have significant influence in the selection of speed. The values which follow are intended to serve as guidelines for basic speed ratings based on pumping cold water.

Single-acting plunger-type power pumps

Stroke length		Basic speed (rpm)
inch	mm ¹⁾	
2	50	750
3	75	530
4	100	420
5	125	360
6	150	315
7	175	290
8	200	262

Double-acting piston-type power pumps

Stroke length		Basic speed (rpm)
inch	mm ¹⁾	
2	50	140
4	100	116
6	150	100
8	200	90
10	250	83
12	300	78
14	350	74
16	400	70

1) Millimeter values rounded for convenience.

For an intermediate stroke length, speed may be interpolated.

It should be noted that these speeds are intended only as reference points. Some manufacturers offer their pumps for operation at or above these basic speeds. Others recommend lower speeds.

When a pump originally designed for low viscosity fluids is used for fluids of higher viscosity, basic pump speed reduction is necessary to obtain proper valve dynamics and prevent fluid separation. The following procedure should be followed to reduce basic pump speeds when viscosity ranges from 300 to 30,000 SSU (65 to 6500 cSt). Only pumps specifically designed for high viscosity service should be used for fluids with viscosities above 30,000 SSU (6500 cSt).

- 1) Using standard selection criteria, select a pump for the required flow rate and pressure, disregarding viscosity. This determines suction valve size (area) and required operating speed;
- 2) Determine liquid viscosity at pump temperature;

- 3) Calculate the average suction valve liquid velocity for required flow rate:

$$v = \frac{.642Q}{MA}$$

Where:

v = Average valve liquid velocity, ft/sec.;

Q = Flow rate, gpm;

M = Number of suction valves;

A = Suction valve flow area, in²;

- 4) Using Figure 6.46, determine the percent of basic speed reduction required for given liquid viscosity and suction valve liquid velocity. Always select the higher liquid velocity curve when actual velocity falls between the two curves;

- 5) Multiply basic speed for pump type selected in Step 1 by the percent reduction determined in Step 4;

- 6) If the reduced basic speed is above the operating speed for unit selected in Step 1, selection is satisfactory;

- 7) If reduced basic speed is below the operating speed for unit selected in Step 1, the selection is invalid for high viscosity liquid, and a larger pump size should be selected. Repeat Steps 2 through 5 for new selection;

Once proper selection is found, the following items should be reviewed to assure reasonable pump performance for high viscosity applications:

- 8) Check power end lubrication with manufacturer when running at reduced speeds;

- 9) Ensure NPSHA is greater than NPSHR.

Example: High viscosity pump selection

Given: $Q = 100$ gpm $p_d = 2000$ psi $p_s = 50$ psi
Viscosity = 10,000 SSU

- 1) Select pump based on Q and p_d , disregarding viscosity;

Selection 2.5 x Triplex $n = 327$ rpm @ 96% VE;

- 2) Suction valve area $A = 3.70$ in² (obtained from manufacturer)

$$v = \frac{.642(100)}{(3)(3.70)} = 5.78 \text{ ft/sec (use 6.0 ft/sec)}$$

- 3) From Figure 6.45, percent of basic speed for 10,000 SSU is 85%;

- 4) Viscosity corrected basic speed is .85 (360) = 306 rpm

Basic speed for 5" stroke pump is 360 rpm from table above;

- 5) Since viscosity corrected basic speed is less than required operating speed, a new selection is required. Return to Step 1;

- a) New selection 2.65 x 5 quintuplex $n = 178$ rpm @ 96% VE;

- b) Suction valve area $A = 3.70$ in² (from manufacturer);

$$v = \frac{.642(100)}{(5)(3.70)} = 3.47 \text{ ft/sec (use 4.0 ft/sec)}$$

- c) From Figure 6.45, percent of basic speed is 100%;

- d) Viscosity corrected basic speed is 1.00(360) = 360 rpm;

- e) Since viscosity corrected basic speed is greater than operating speed, selection is acceptable for high viscosity service.

6.3.3 Discussion of speeds

6.3.3.1 Factors affecting pump maximum operating speed

— *Liquid characteristics:* Temperature, viscosity, corrosiveness, compressibility, the presence of solids and the presence of dissolved or entrained gas;

— *Application details:* Available NPSH, piping design and layout, pulsation dampeners (if any), the ambient temperature, shelter, foundation, driving machinery, protective shut-down devices used, the accessibility of factory service personnel, spare parts and overhaul facilities, as desired;

— *Pump design:* Including valve material, size and type, piston, diaphragm or plunger construction, the choice of packing and packing lubrication, if any, materials used in liquid end and trim, the method of driving pump, and NPSHR.

6.3.3.2 Type of duty

— *Continuous duty:* 8 to 24 hours per day, fully loaded;

— *Light duty:* 3 to 8 hours per day, fully loaded;

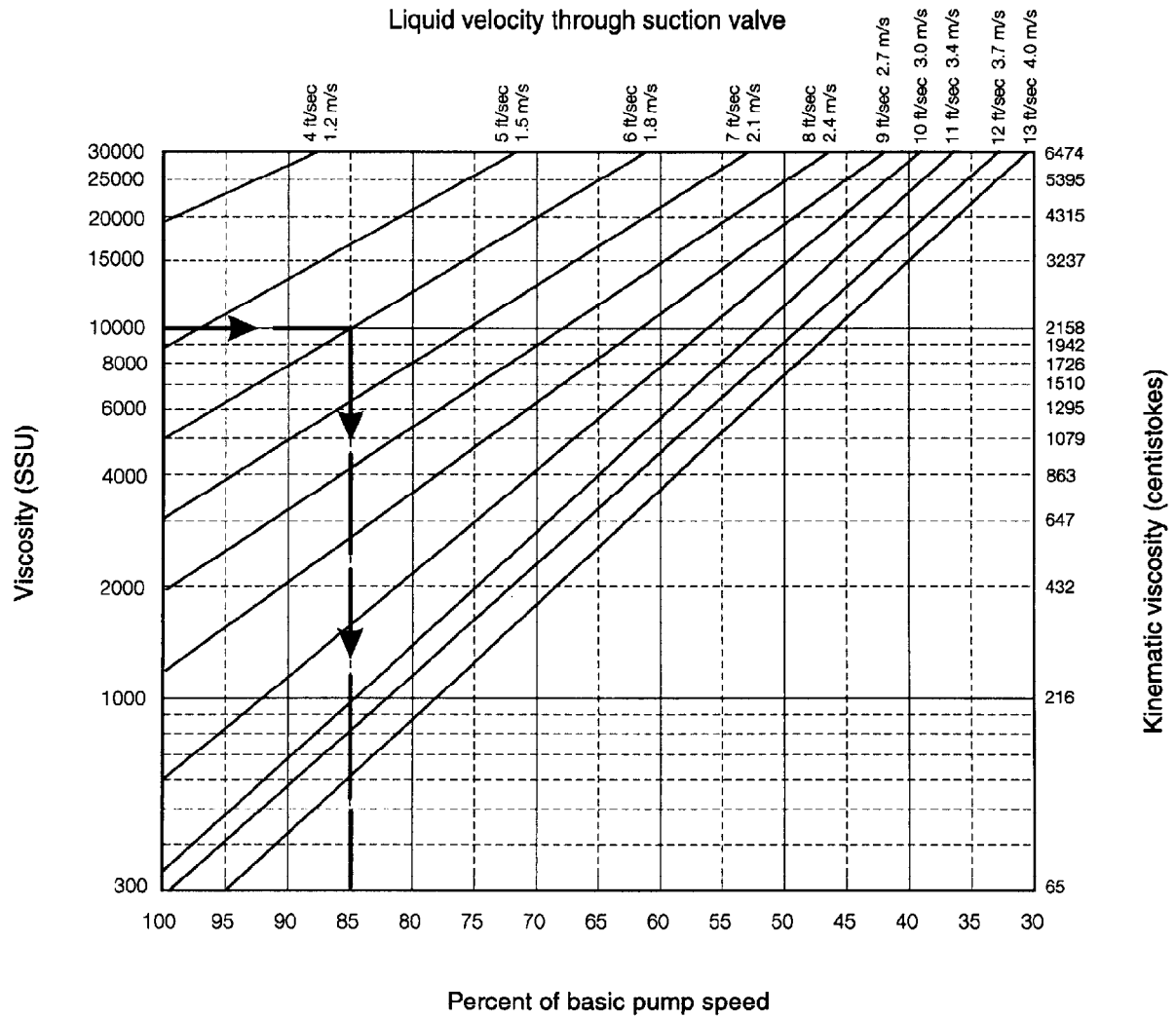


Figure 6.46 — Percent of basic pump speed as a function of average liquid velocity through suction valve (liquid velocity before derating)

- *Intermittent duty:* Up to 3 hours per day, fully loaded;
- *Cyclical operation:* 1/2 minute loaded out of every 3 minutes;
- *Maintenance level:* Attended or unattended operation. Skill, training and tools of operating and maintenance personnel.

6.3.3.3 Medium speeds

Power pump speeds at or near the manufacturer's published "rated" or "normal" curve includes those applications when clean, cold liquids are involved and provides long life and economical operation, if all important application details are carefully handled and regular, skilled maintenance is provided.

Medium speed selection requires excellent piping layout, good environment, adequate NPSHA, periodic preventive maintenance and lubrication, rigidly fixed piping, and solid pump and prime mover foundations or bases. It may require automatic safety shut-down devices, suction and discharge dampeners and plunger or piston rod packing lubrication.

Medium speeds may be too fast for slurries, marginal NPSH situations, or unattended operation.

6.3.3.4 Slow speeds

Selection of an operating speed below the manufacturer's "rated" or "normal" speed curve is often desirable when any strongly adverse factor is present, such as the following:

- Abrasive liquid (slurry);
- Hazardous liquid;
- Extreme pressure;
- Corrosive chemical;
- High viscosity;
- Unattended operation;
- Poor maintenance;
- No spare parts, or no standby pump;
- High liquid temperature;
- High ambient temperature;
- Extremely long life desired;
- High-cost downtime of related facilities;
- Extreme isolation of site;

- Radioactive liquid;
- Dissolved gas in liquid;
- Borderline suction (NPSHA) situation.

Operation at extremely slow speeds may require supplementary power end lubrication. Cooling of the power end oil may be necessary when hot liquids or ambients occur. Always consult the manufacturer when very hot or very cold liquids are involved. Revisions may be required in construction for these types of applications.

6.3.3.5 High speeds

Selection of speed above manufacturer's "rated" or "normal" curve and/or near his "maximum" or "intermittent" curve (if any) is sometimes merited when intermittent, attended service is involved. High speed selection requires very close attention to all application details, skilled operators and proper pump design. A suction booster pump may be required to obtain sufficient NPSHA.

High speeds imply that only optimum application factors are present and reduced life may occur. Some pumps are inherently designed for high-speed, short-duration and infrequent usage. All conditions of such service should be well understood by all parties prior to the sale. Oil well fracturing, acidizing and cemented plunger pumps are examples of this type of high-speed, intermittent application.

6.3.4 Starting power pumps

6.3.4.1 Pump torque characteristics

Selection of pump driver type can be influenced by the cyclical torque characteristic of a reciprocating power pump. This is especially true when slow speed pumps are employed. Such equipment often lacks enough mechanical mass to smooth out any torque variations imposed by the pump.

Torque fluctuations imposed by reciprocating power pumps on driving equipment vary according to the kind or type of power pump, its number of cylinders and the inertia of the pump and driver rotating masses. Thus, some pumps are inherently "smoother" than others because less cyclical variations in driving torque occur.

Peak torque requirements of power pumps can often be dampened by the use of large diameter drive pulleys or sprockets with high torsional inertia. These act as "flywheels."

Reduction of peaks in power torque may be possible by reducing discharge pressure surge peaks, since torque and discharge pressure are closely related. Hence, pulsation dampeners which effectively dampen liquid surging also help smooth out torque variations.

Single-acting simplex power pumps have the most uneven torque requirement of all the types of reciprocating power pumps. As the number of cylinders and pumping strokes-per-revolution increase, the torque gets smoother. Thus, a quintuplex pump is said to be very "smooth."

Objectionable amperage fluctuations and heating in polyphase induction motors driving simplex or duplex power pumps can often be minimized by choosing NEMA Design "C" or Design "D" motors. These types of A.C. induction motors provide a "soft" driving torque that reduces line voltage disturbances caused by Design "B" motors.

Large double-acting duplex power pumps in particular tend to cause driver speed surging. This type can also cause heavy amperage surging in an induction type electric motor, unless a special motor type is used or other preventive steps are taken.

6.3.4.2 Pump torque requirements

Application of power pumps requires careful consideration of their starting and running torque demands. These affect the selection of driver motors, motor starters, engines, gear reducers, belts or chain drives, couplings and universal joints. The effect of such loads on an electrical distribution system requires thought, especially if the pump is large.

The starting torque required by a power pump usually falls into one of two general applications, as follows.

6.3.4.2.1 Starting with liquid bypass

Operating person manually opens a bypass valve, or a power-actuated dump valve programmed to open automatically, which bypasses the liquid during the start and the stop function.

A check valve is employed in the pump discharge line. It remains shut as long as the bypass (dump) valve remains fully or partly open (see Figure 6.47).

The liquid pressure exerted on the plungers (or pistons) is largely that caused by liquid mass and friction as it passes through the bypass valve and

pipng. When correctly sized, the bypass valve and piping cause low back-pressure. Only a relatively small torque is required while bypassing the liquid to a tank.

With liquid bypass, the total starting torque requirement is mainly related to the mechanical inertia of the pump, couplings, gears and motor rotor. These components are heavy, and substantial starting torque may be required. All the liquid in the pump suction line and in the bypass line must be accelerated from standstill to full liquid velocities.

The torque needed to accelerate the entire mechanical hydraulic inertia system depends on the inertia of all the moving parts, including the liquid, the rate of acceleration and the total system friction.

The rate of acceleration is very important, and the starting torque is directly proportional to it. Stated another way: peak torque is inversely proportional to the time duration of acceleration.

A few pumps are provided with mechanical suction valve unloader devices. These devices reduce the total starting torque requirement to that needed to accelerate the mechanical items, such as pump crankshaft, gears, couplings, etc. They stop liquid pumping action by mechanically holding open the pump's suction valves, allowing the liquid inducted into each liquid cylinder to be delivered back into the pump suction. Because no liquid pumping occurs, the driving machinery need provide no torque to accelerate the liquid. Only the torque to overcome mechanical inertia and friction is needed during the start.

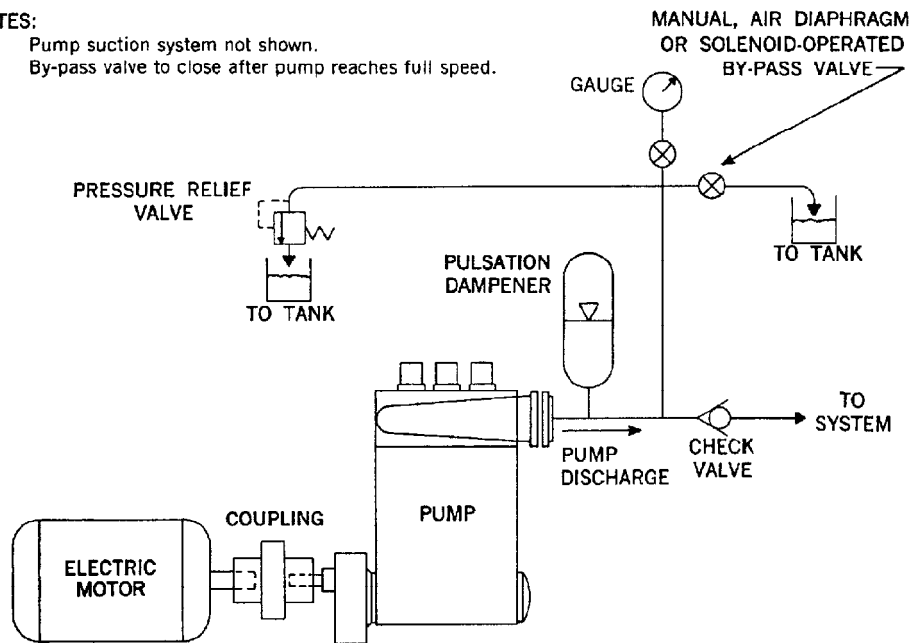
After the pump and driver have reached full speed, the suction valve unloading devices are retracted, and normal pumping action then commences. At this point, the driver must supply additional torque to accelerate the liquid system and also to meet the total running torque requirement caused by discharge pressure.

6.3.4.2.2 Starting without liquid bypass

Starting a power pump against discharge pressure may reduce the life of power end bearings and other pump and drive components and may prevent complete priming of the liquid end, resulting in rough operation and reduced capacity. This practice should therefore be avoided except in emergency situations.

NOTES:

Pump suction system not shown.
By-pass valve to close after pump reaches full speed.



Pump suction system not shown.
By-pass valve to close after pump reaches full speed.

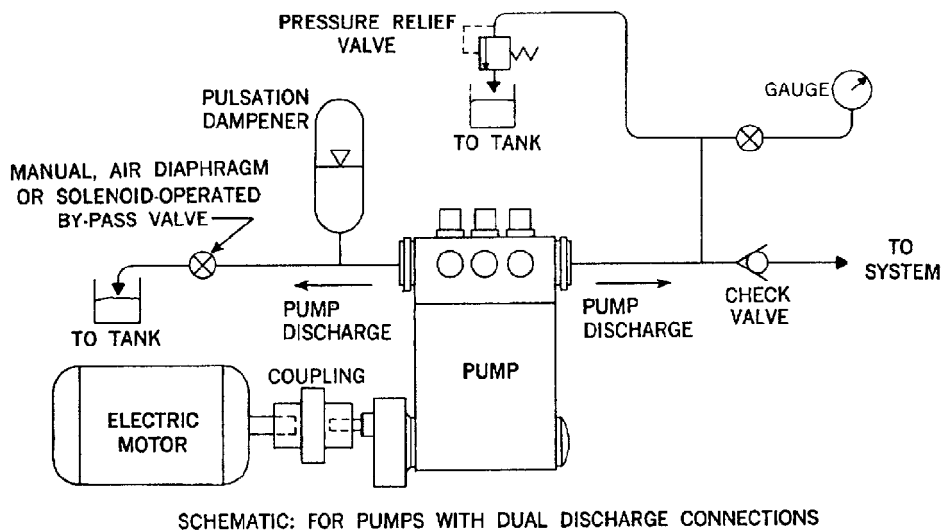


Figure 6.47 — Schematics of liquid bypass systems

Starting without liquid bypass may be divided into two categories:

First, there are multiple-pump applications where the pump must start against full line pressure.

The discharge pressure already exists, having been developed by the other pumps, and the starting pump must accelerate against it. No liquid bypassing or suction valve unloading is provided, and it may be termed "full-load" starting.

With full-load starting, the torque requirement is high, since the driver must accelerate itself, couplings, gears, pump crankshaft, rods, crossheads and plungers. Additionally, it must accelerate all the liquid in the pump's suction and discharge lines. It must also develop the torque required to move the plungers or pistons against the line pressure already present. If the pump is engine-driven, a clutch or drive coupling of adequate torque and thermal capacity to meet these demands is chosen.

Full-load, across-the-line motor starting can cause a prolonged in-rush of high current. Serious motor overheating or damage may result unless the motor and its starting equipment have been generously selected and sized. An A.C. induction motor provides a fixed starting torque, related to the applied voltage.

Since the starting torque developed by an induction motor is related to the applied voltage and to the size and design of the motor, an across-the-line starter provides the maximum starting torque. A given induction motor develops the same locked-rotor (starting) torque and amperage at this voltage, regardless of the nature of the driven load. High-inertia loads (within motor capability) simply require longer accelerating time than do low-inertia loads.

No advantage is really provided by specifying an induction motor with an extremely high locked-rotor torque rating. Such motors do accelerate faster, but they draw more amperage, and cause more power system disturbance during the start. An A.C. induction motor with a locked-rotor torque rating of 150% of full-load torque is usually sufficient for full-load, across-the-line pump starting. Secondly, another full-load starting situation may occur when a single pump starts with no liquid bypassing provided. Pump discharge pressure is then related very largely to pump speed, capacity and acceleration rate.

Consider a single pump which forces liquid through a nearly level long piping system. Pump discharge pressure is zero at the instant of starting. Because resistance to flow is caused by liquid inertia and by pipe friction and fitting restrictions, pump pressure increases in relation to liquid velocity, often such that pump pressure is proportional to the square of flow rate. Thus, it is proportional to the square of pump speed and to the rate of acceleration.

Analysis of the starting torque requirement is complex and depends on the inertia of the accelerating liquid, the size and length of piping, liquid viscosity and density, and the elasticity of the piping. If the mass of liquid is very large, a discharge dampener and a check valve may be advantageous, since these permit the pump and its driver to accelerate faster by first delivering liquid into the dampener, rather than into the line.

No general rules may be given as to the motor locked-rotor torque needed, because each liquid system is different. However, if a large liquid dampener is provided, pipeline pump induction motors with locked-rotor torques of 125% of rated full-load torque are usually adequate. An alternate is the automatic bypass valve and check valve arrangement, with dampener as shown in Figure 6.47.

The arrangement shown in Figure 6.47 is suitable for both single- and multiple-pump applications. It largely relieves the motor of load from liquid inertia (except suction) and isolates the pump from the discharge system pressure and inertia.

The arrangement affords a convenient means of expelling any air trapped in the pump cylinders before placing pressure load on the pump. This is desirable, especially for multicylinder pumps which sometimes become rough and "air bound" after servicing or prolonged idleness. Simply open the liquid bypass valve to allow the liquid to discharge back to the tank, thereby expelling the air. When running smoothly, close bypass valve and thus load the pump.

6.3.4.3 Use of soft start drivers

Another design used to facilitate starting is the use of a hydraulic drive coupling or eddy-current drive coupling. These cause the pump to accelerate more slowly, while the driver quickly reaches full speed. Such a drive coupling permits a reduced rate of pump and liquid acceleration, reducing the torque required.