9.16.3 CONSTRUCTION OF SOLIDS-HANDLING DISPLACEMENT PUMPS

WILL SMITH

APPLICATIONS

Positive displacement pumps are especially suited for many solids-pumping applications because constant high pressures and good efficiency are achieved over the full range of pump capacities. Low relative velocities between abrasive liquid-solids mixtures and the pump parts minimize erosion. With centrifugal pumps, an increase in system resistance, such as a flow blockage caused by settled solids or the apparent viscosity increase characteristic of many slurries due to momentary capacity reduction, results in a self-defeating reduction in pump flow rate.

Positive displacement pumps are popular for a number of solids-handling applications. Each application presents peculiar demands for pump features.

Solids Transport Large-capacity positive displacement pumps at moderate pressures are used to pump coal and ores over relatively long distances. Solids for transport are usually slurried with water and are pumped at ambient temperatures. Double-acting horizontal piston pumps with large, "mud pump" valves and piston rings (Figure 1) typify transport service.

Most pipelines have multiple pumping stations at intervals along the route, dictated by topography and by pipeline and pumping station first and operating cost balances. Centrifugal booster pumps are employed at the first station to deliver the prepared slurry to the displacement pumps at a sufficient pressure to satisfy their *NPSH,* including acceleration head, requirement. Subsequent stations are located at points where there is sufficient residual pipeline pressure to fulfill the displacement pump's suction requirements. The capacity of each station is adjusted by pump speed control so the next station's inlet pressure is kept relatively constant.

Most stations muse multiple positive displacement pumps in parallel, with at least one standby pump. Capacity modulation requires but one of the pumps to be operating with

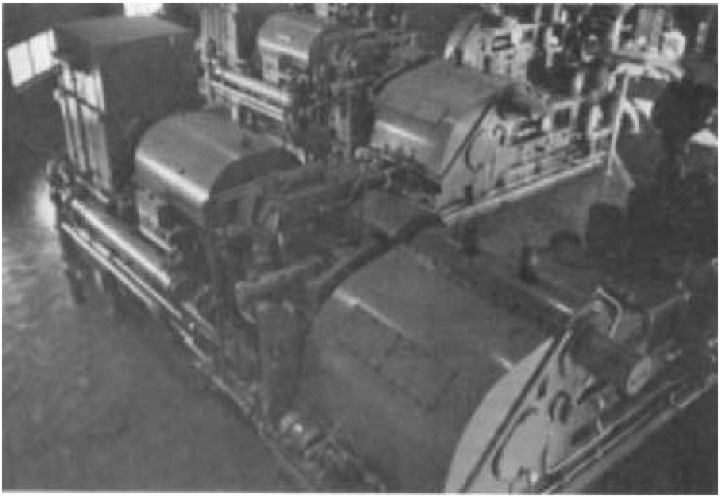

FIGURE 1 Horizontal double-acting duplex coal slurry pipeline pumps (Black Mesa Pipeline, Oil Well Div. of U.S. Steel)

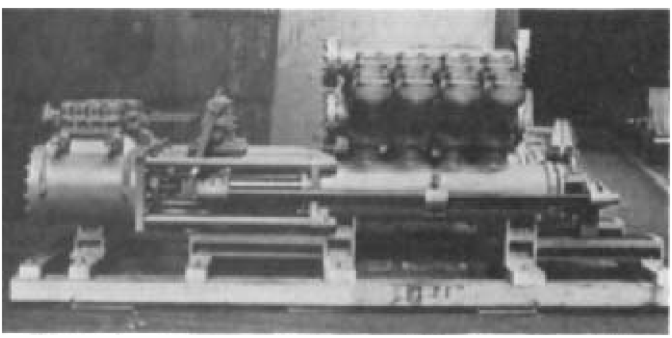

FIGURE 2 Horizontal double-acting plunger pump for slurry of grain mash and water for alcohol production (Flowserve Corporation)

speed control, although all are generally so fitted. Unlike centrifugal pumps, displacement pumps can provide full rated pressures at all speed-controlled capacities.

Process Pumping Some chemical and petroleum processes require pumping of solids to high pressures for process reactions. Typical of these are bauxite ore in hot caustic for alumina plants, ground coal in water or coal liquids for synthetic fuel production, and grain in water for alcohol production (Figure 2).

Process streams involve a vast variety of liquids and solids. Concentrations may be as high as 70% solids by weight. Temperatures can reach 800°F (427°C). Pressures from several hundred to many thousands of pounds per square inch are accommodated.

Other Specialty Services A number of specialty services employ positive displacement pumps to handle solids. Some are relatively simple applications of standard catalog pumps, and others are single-purpose developments and thus have evolved with unique characteristics.

Mud pumps are used to inject drilling mud, which transports cuttings out of wells and lubricates the drill bit during well drilling. Because of the limited duration of a drilling project, the life of expendable parts (packing, valves, rods) is compromised in favor of size and weight for portability and ease of overhaul. *Sludge disposal pumps* are common in sewerage treatment plants, and *tailings pumps* move solids out of mines.

PUMP CONSTRUCTION

Solids-handling displacement pumps differ from ordinary displacement pumps in the means used to alleviate the deleterious effects of the solids on the packing, the displacement element (whether plunger, piston, or diaphragm), and the suction and discharge check valves. To protect parts from the ravages of the solids, (1) particles are prevented from entering close clearances, (2) operation is at lower speeds to reduce the effects of erosion and abrasion, or (3) the susceptible parts are made of wear-resistant materials. Because sacrificial wear parts must be replaced more often than in clear liquid pumps, special design attention for ease of replacement of these parts is justified.

The designer's choice is between hard materials that resist wear and resilient materials that may accommodate the particles of solids. This choice is often limited by other factors, such as temperature and chemical compatibilities. Hard materials used include

Tungsten carbide
Ceramics—chrome oxide and aluminum oxide
Hardenable stainless steel
Cobalt-nickel alloys

Some common soft materials are

Synthetic elastomers
Softer metals (sacrificial)

Unlike centrifugal pumps, positive displacement pumps are more prone to abrasive than erosive wear. This is due to the much lower relative velocities between the liquid and the pump parts. Centrifugal pumps must generate high relative velocities, typically greater than 100 ft/s (30 m/s), for the dynamic specific energy that is converted to discharge pressure. Positive displacement pump velocities are kept low, limited usually by the settling velocity of the slurry, which is on the order of less than 10 ft/s (3 m/s).

There are four types of positive displacement solids-handling pumps:

1. Reciprocating piston pumps
2. Reciprocating plunger pumps
3. Diaphragm pumps
4. Hydraulic displacement pumps

Valves Common to all types are suction and discharge check valves, the purpose of which is to allow the solids-laden liquid to flow into the pump from the suction line and into the discharge line from the pumping chamber while preventing backflow. The features of slurry valves include

1. Large areas for low flow velocity
2. Smooth, unobstructed passages to avoid trapping and build-up of solids
3. Special designs to enhance sealing against pressure in the closed position
4. Special materials to minimize wear

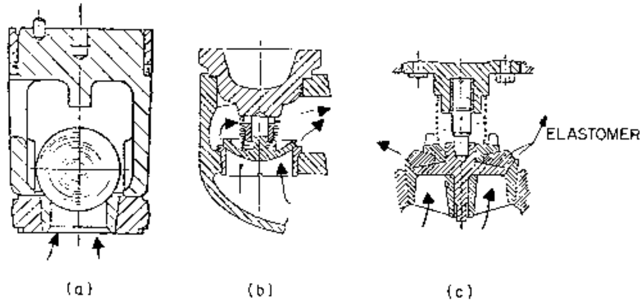

FIGURE 3A through C Three types of slurry valves: (a) free-floating ball valve, (b) spring-loaded spherical (Rollo) valve, (c) spring-loaded elastomer-seal (mud) valve

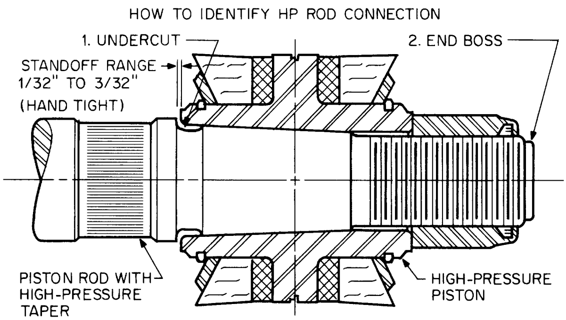

FIGURE 4 Double-acting mud pump piston. Standoff range varies between 0.030 to 0.090 in (0.75 to 2.25 mm).

Figure 3 illustrates some valves developed particularly for solids-handling pumps. Which valve is selected for a particular application depends on the abrasiveness, viscosity, temperature, solids size, and uniformity of the slurry. It is important that the valve lift be sufficient to pass the largest particles of solids expected. Adequate sealing in the closed position is necessary to avoid excessive back leakage, which detracts from the volumetric efficiency of the pump.

Valve materials must meet temperature, corrosion, abrasion, and mechanical strength requirements. Materials for valves and seats range from cast iron and bronze through hardenable stainless steels to solid tungsten carbide. The cost of replacement or refurbishment over the expected life, including labor and downtime, should be balanced against first cost.

Packing Protection A distinguishing feature of solids-handling displacement pumps is the means used to avoid or minimize packing wear. Five different approaches are

1. Use of conventional designs with special materials and operation at less demanding conditions, such as reduced speeds
2. Provision of a clean nonslurry environment for the packing rubbing surfaces
3. Separation of the slurry from the displacement element
4. Separation of the slurry from the pumping element
5. Total isolation of the slurry from the packing

CONVENTIONAL DESIGN WITH MODIFIED OPERATION Piston pumps usually fall into this category. By using larger pumps at speeds that are lower than those normally found with clear fluids, velocity-sensitive wear rates are reduced. *Special piston rings* (Figure 4) are used

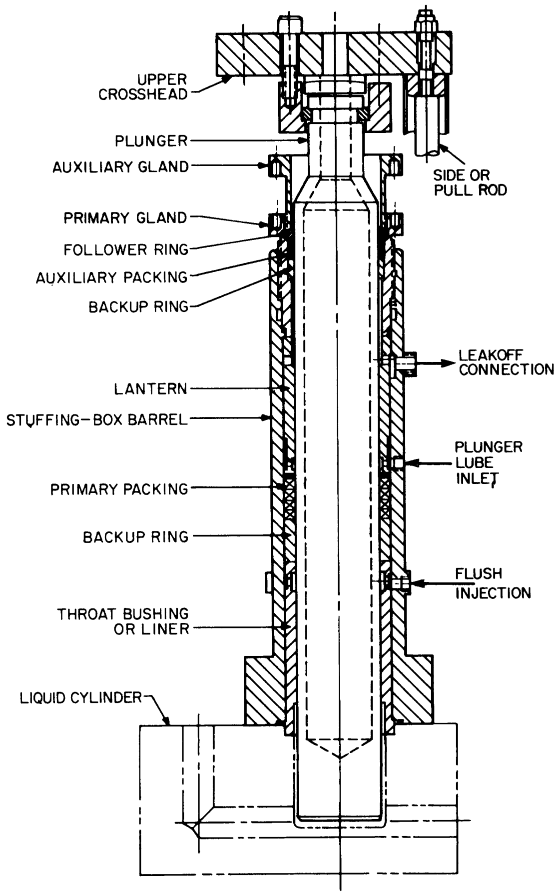

FIGURE 5 Typical flush injection

that tend to resist abrasion because they are made of zero clearance elastomeric materials and designed to scrape clean the cylinder wall. Such piston packing is a normal wear item and must be replaced at regular intervals.

CLEAN NONSLURRY ENVIRONMENT This is accomplished by the injection of clear liquid (Figure 5). Such injection may be either *continuous* or *synchronized* with the stroke of the plunger or piston. When effectively accomplished, flush injection presents essentially clear pumpage to the packing so it attains normal clear liquid packing life. Flush liquid that enters the pumping chamber dilutes the pumpage and decreases the suction volumetric efficiency.

Clear, compatible flush liquid may be scarce or expensive. Therefore special stuffing box plus flush injection systems have been developed. Required flush rates are a function of pump type and size and system employed. Satisfactory operation has been attained with flush rates of about 2 to 5% of pumped flow and even less for very large pumps. If other than a positive displacement flush pump is used, flush flow will increase as packing and throat bushings wear.

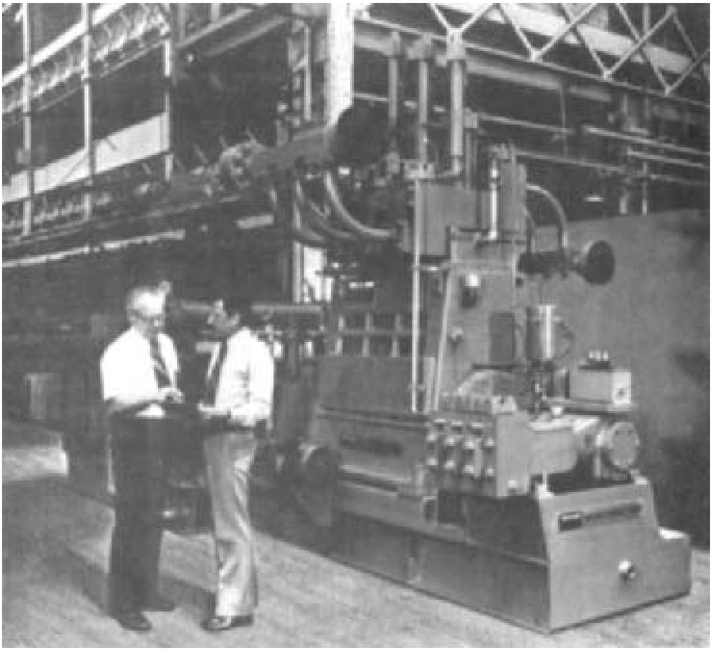

FIGURE 6 Vertical single-acting triplex plunger pump with synchronized flush liquid injection (Flowserve Corporation)

Flushing prevents incursion of slurry particles by providing a liquid velocity counter to the unwanted slurry flow in clearances and by washing solids particles from the plunger or rod surfaces as they move toward the packing. Injection systems may be as simple as a constant-pressure liquid fed to a point between the packing and the throat bushing or as complex as a sophisticated synchronized injection system involving an additional positive displacement pump driven directly from the slurry pump drive train and independently furnishing a definite quantity of flush fluid to each plunger or piston during each pump stroke (Figure 6).

Combinations of positive, independent, synchronized pumped injection, and auxiliary buffer liquids have been proposed for very special situations.

SEPARATION OF SLURRY FROM DISPLACEMENT ELEMENT One means of reducing the concentration and temperature of slurry at the pump packing is the use of a liquid, or surge, leg (Figure 7). The displacement element—plunger or piston—is separated from the suction and discharge valves by a length of pipe that is filled with clear liquid. This liquid leg communicates with the valve chambers such that, as the liquid ebbs and flows in response to the motion of the displacement element, it acts as a liquid piston, inducing and then expelling slurry through the suction and discharge valves. Make-up liquid is injected into the surge leg, preferably through a throat bushing isolating the displacement chamber from the packing so there is theoretical flow away from the stuffing box. The surge leg thus offers the packing some degree of protection from the solids and from thermal effects.

Surge legs are, however, subject to the complete span of suction-to-discharge pressure change on each stroke. Therefore they must be designed for endurance fatigue loading. When high-temperature isolation is involved, thermal expansion and contraction must also be considered. Although surge leg pumps have been demonstrated to increase piston or plunger packing life, they do not totally prevent solids migration from the pumping

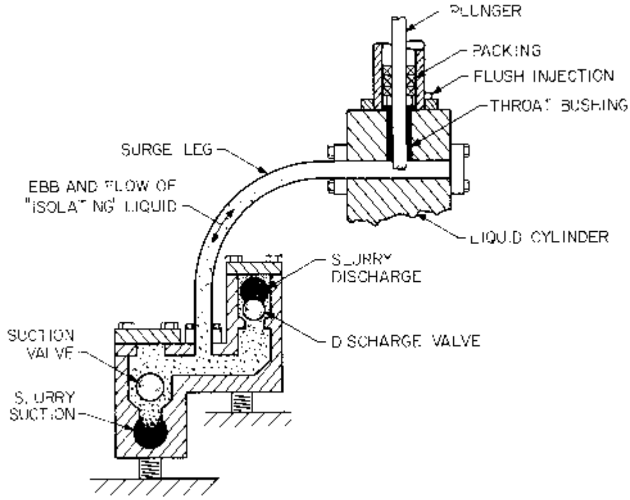

FIGURE 7 Surge leg plunger pump

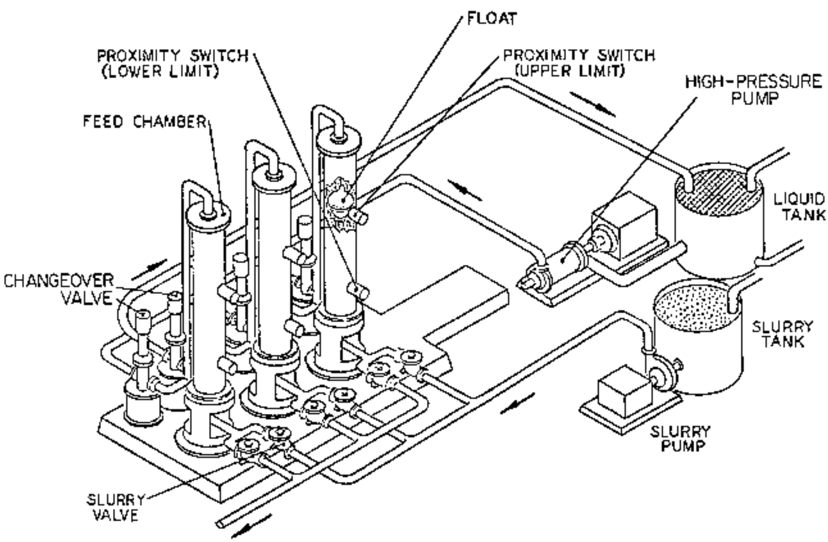

FIGURE 8 Large, low-cycle chamber feeders separate the high-pressure pumping element from the slurry (Hitachi)

chamber. Therefore special construction materials, flush injection, and reduced speeds are still appropriate.

SEPARATION OF SLURRY FROM PUMPING ELEMENT A special case of the liquid leg pump is the large, low-cycle chamber feeder (Figure 8). Although these units may or may not properly qualify as positive displacement pumps (because the motivating liquid may be delivered by a centrifugal pump), they do nevertheless have much in common with surge leg pumps.

The motivating liquid is pumped into a chamber and displaces a charge of slurry through suitable check valves. The chamber may have a moving separation barrier between the motivating and motivated liquids. When the slurry is expelled, controls cause valves to reverse the flow, filling the chamber again with slurry while voiding it of the clear liquid. By employing two or more chambers, a virtually continuous flow of slurry is obtained. Advantages of this scheme are the extra-low frequency of check valve operation, low slurry velocities, and high capacities. Centrifugal, positive displacement, or even compressed gas pumps can be used for motivation. Because the motivation pump is independent of the slurry system, it can operate at normal speed.

Two disadvantages of chamber feeders are their dependence on controls and switching valves in addition to the slurry valves and the fact that the systems are large.

TOTAL ISOLATION Many types of diaphragm pumps that completely separate the slurry from the running gear of the pump have been designed (Figure 9). Because the separating diaphragm is wetted on one side by the slurry, it is vulnerable to the mechanical, chemical, and thermal abuse that might otherwise apply to pistons, plungers, packing, and so on. Of course, the diaphragm is also subjected to full reversal loads and must be designed for fatigue life. Both elastomeric and metallic diaphragms have been used.

The severity of diaphragm failure problems has been alleviated somewhat in some designs that employ double diaphragms with intervening barrier liquids. The thesis is that there is a much reduced probability of both diaphragms failing before detection and repair.

DIAGNOSTIC SYSTEMS

Diagnostic monitoring of vibration, pressure pulsations, speed, flow rate, temperatures, and pressures may be applied to these pumps as well as other large machines. Such monitoring is relevant to slurry pumps because of the necessity to replace worn parts more frequently than is the case with clear-liquid pumps. Designers and users of displacement pumps for handling solids should consider using available monitoring equipment as an aid to maintenance and as a means to ensure the safety of personnel by warning of imminent failure. Vibration signatures are readily obtained from sensors placed in critical locations on the pump, and this information can be valuable in assessing the operating integrity of the pump. To this should be added valve wear detection, as would be indicated by a difference between the expected flow rate at the speed involved and the actual flow rate. In addition, proximity probes and vibration sensors could be used to monitor wear of plungers, piston rods, bearings, and crossheads.

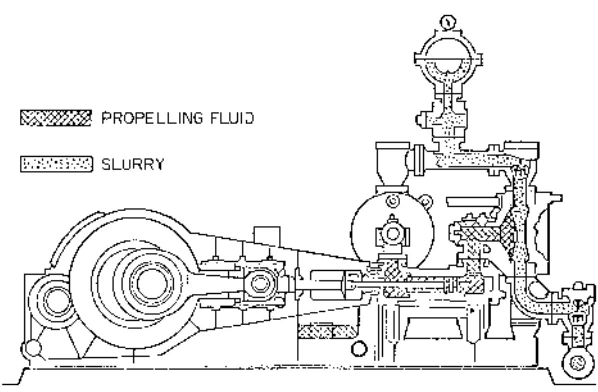

FIGURE 9 Diaphragm pump isolates slurry from packing (Geho)