Pulsation-Free, Hydraulically-Driven Piston Pump

Erik Vlot
Weir Minerals Netherland b.v.

ABSTRACT

The mining industry has recognized the advantages of high density backfill or 'paste', which is typically pumped with a hydraulically driven piston pump. Due to the discontinuous flow of this type of pump, pressure pulsations can occur in the discharge line. Pressure pulsations are an undesired phenomenon in pumping installations for a number of reasons, such as damage to the pumping system, including piping and supports, disturbing noise levels and even safety risks for operators and maintenance personnel.

This paper describes an advanced system on the GEHO® piston pumps, which will prevent pulsations from occurring, rather than merely reducing the already existing pulsations.

INTRODUCTION

The first GEHO® hydraulically driven piston pump was developed in the mid-1970s. It was an industrial design pump targeted to operate in the high-standard industrial environment with regards to operating hours per day, duties, maintenance and lifetime of the pump and spare parts. This type of pump has proven its concept and has since then been further developed to the mature technology as we know it today. The special feature of this pump type is its ability to pump extremely viscous slurry with solids content of up to some 90% by weight, at high pressures. Typically, in the mining industry, this pump is used for tailings transportation, with a focus on mine backfill and is often referred to as paste pump.

In the 1980's the hydraulically driven piston pump made its entry into the application of mine backfill, thanks to the high discharge pressure capabilities enabling the mines to pump higher density (i.e. higher solids concentration) slurries and pastes over longer distances.

Part of the ongoing development was (and still is) the increase in discharge pressure and flow capacity to comply with the ever growing demands for high power piston pumps. In line with the technological developments and increase in performance duties the popularity of this pump type increased significantly and many other industrial application areas discovered the benefits of this pump type.

Together with the increase in pump discharge pressures and flow capacities the effect of an undesired phenomenon also increased: the phenomenon of pressure pulsations. Before we go into this subject in more detail it is important to first understand the design and the characteristics of a hydraulically driven piston pump.

HYDRAULICALLY DRIVEN PISTON PUMP DESIGN

Generally there are two types of hydraulically driven piston pumps: the valve operated and the transfer tube (or S-tube) type. The difference between these two pump types is mainly in the design of the liquid end. For reasons which will be described later, this article focuses on the valve operated pump. Since its introduction this pump type has made an enormous development and is nowadays the pump of choice for various applications thanks to its advantages over the transfer tube pump. Typically the transfer tube pump will only be used in case the particle size of the solids in the slurry exceeds the capabilities of the valve operated pump.

The hydraulically driven piston pump is a positive displacement pump, meaning that it displaces a constant volume of slurry or paste through each pump motion. Through the reciprocating movement of the slurry pistons, slurry is drawn into or forced out of the pump. The movement of the slurry pistons is induced by the hydraulic cylinders. Refer to Figure 1 for a schematic of a valves operated pump.

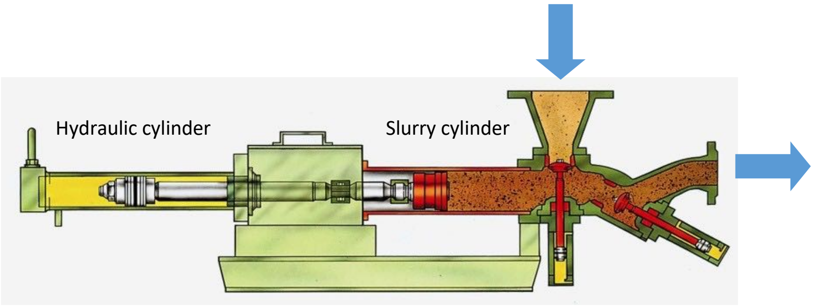

Figure 1. Schematic of a hydraulically driven piston pump with actuated cone valves

More specifically, driven by high pressure hydraulics, the slurry enters the pump by moving the slurry piston and cylinder backwards (suction stroke) and exits the pump by moving them forward (discharge stroke). Hydraulic actuated valves regulate the slurry flow in and out of the pump. In most cases the slurry is gravity fed from a storage hopper above the pump. Hydraulically driven piston pumps are commonly available in 1- and 2-cylinder versions. Also more-cylinder versions are possible. The most popular design used in the mining industry for pumping paste is the 2-cylinder type or duplex. Figure 2 shows a three dimensional drawing of an industrial type 2-cylinder or duplex pump.

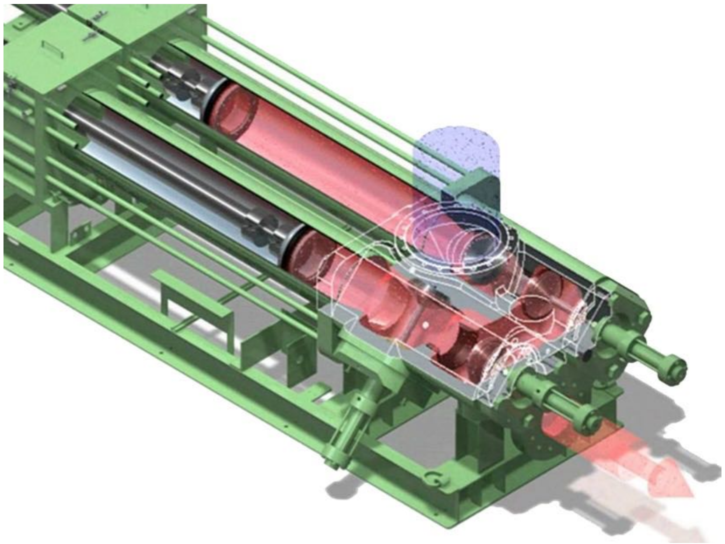

Figure 2. GEHO® two-cylinder hydraulically driven piston pump with actuated cone valves

For a “standard” pump the two hydraulic cylinders are interconnected ensuring that the two pistons always move in opposite directions at the same speed: when one cylinder is performing a suction stroke, the other cylinder is performing a discharge stroke. Typically the pump is driven by a hydraulic power pack containing one main oil pump. A schematic of the hydraulic plan is shown in Figure 3.

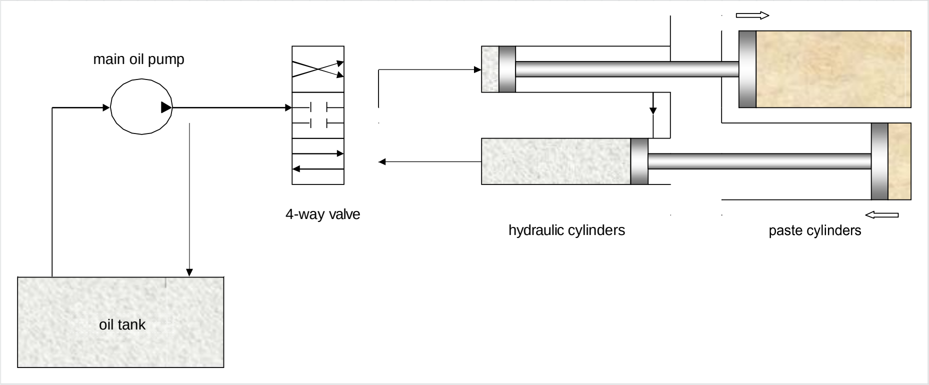

Figure 3. Hydraulic schematic of a standard piston pump

Due to the reciprocating motion of the pistons the discharge flow is discontinuous. During the discharge as well as the suction stroke the flow is proportional to the piston speed. At the reversal point of the pistons, the piston speed and resulting discharge flow is zero. During the standstill of the pistons the valves will switch from suction to discharge mode (and vice versa for the second cylinder). This is called the “switch-over time”. Figure 4 shows a typical flow versus time diagram of a standard piston pump. In the same figure the average discharge flow is indicated.

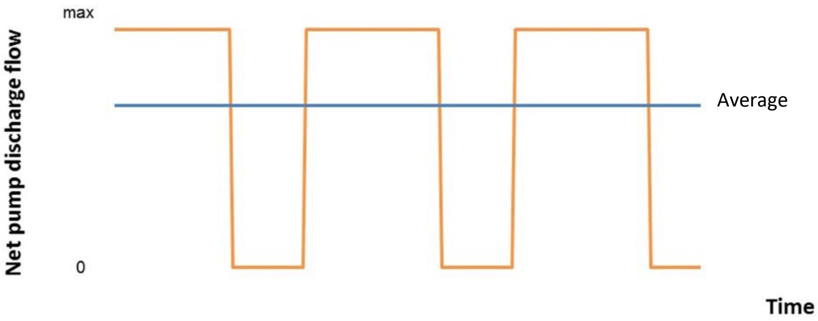

Figure 4. Typical flow characteristic of a standard piston pump

PRESSURE PULSATIONS

Generation of Pressure Pulsations

A discontinuous flow pattern will result in a discontinuous pressure pattern i.e. pressure pulsations. The effect of the pressure pulsations on the piping will depend on the design of the pipeline system after the pump - including pipe length, diameter, bends, etc.

Essentially pressure pulsations are the result of a change in flow; every start and stop of slurry in the discharge pipeline will cause pressure pulsations. Pressure pulsations can create enormous forces on the pipeline and on the pumping system in general.

In order to give an idea of the magnitude of the energy and forces involved, a typical case is presented as an example. Through a pipeline of 3 km length and 150 mm diameter slurry is being pumped with a density of 1,500 kg/m^3.

To calculate the mass of the slurry the following formula is used:

$$m = \frac{\pi}{4} D^2 L \rho \tag{1}$$

Where: m = total mass of the paste in the pipeline, D = pipeline diameter, L = pipeline length, ρ= specific weight of the paste. In this example the pipeline contains a mass of 80 metric tons. Assuming a flow speed of 1.3 m/s the kinetic energy of the paste can be calculated using the following formula:

$$E_k = \frac{1}{2} m v^2 \tag{2}$$

Where: E_k = kinetic energy, m = total mass of the paste in the pipeline, v = flow speed of the paste in the pipeline. In this example the 80 tons paste has a kinetic energy of approximately 67,000 Joule. As a comparison, this amount of energy is equivalent to a mass of 1,000 kg moving at a speed of 42 km/h (26 mph).

Effects of Pressure Pulsations

Pressure pulsations are an undesired phenomenon in pumping installations for a number of reasons:

- Possible damage to the pipeline system: typically high pulsation levels will result in high fluctuating forces on the pipeline system. If the design did not include for the pulsations, parts of the system can get damaged. Sheared-off pipeline supports are probably the most common as well as the most visible result of this. But also inline equipment such as control and isolation valves or measuring equipment can get damaged.
- Disturbing noise levels and safety risk: the noise level in combination with the related frequency spectrum can be very disturbing for personnel and possibly create an unsafe working environment. There are examples of pumping installations close to populated areas of which the noise production due to pressure pulsations was higher than the legally allowed values. Countermeasures were required to be able to run the installations. There is also the risk of injury in case equipment fails, e.g. when pipe supports shear off.
- Unplanned interruptions of the production: in case a piece of line equipment fails, such as e.g. a flow meter or a density meter, or even the rupture of a pipe, the pumping system must be shut down for repair. Besides the additional, unplanned, repair costs involved there are the costs of production downtime which can be substantial in the case of loss of minerals mining production. In case of pumping a cemented paste for mine backfill applications an additional problem will arise with regards to the pipeline being filled with a hardening paste.

The effect of pressure pulsations can be considerable and the related costs will add to the total production costs of the installation. Instead of taking the nominal design pressures, the design specifications for the equipment should be based on the maximum pressure levels and related forces that can be expected during operation, caused by the pulsations. The higher design specifications typically will make the pumping installation more expensive.

Reducing Pressure Pulsations

A possible way of reducing pressure pulsations is the use of a pulsation damper in the discharge pipeline.

A pulsation damper is basically a vessel with gas inside (usually nitrogen) and a rubber diaphragm that separates the gas from the slurry. A schematic is shown is Figure 5. The damper is placed in the discharge line, typically close the pump for optimal performance.

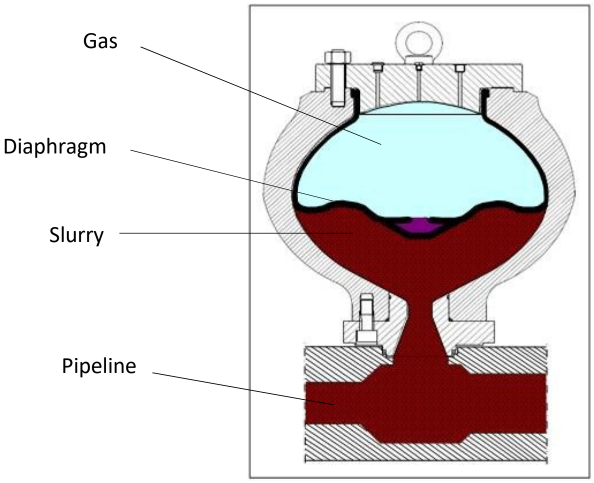

Figure 5. Pulsation damper

The gas is pre-compressed to a certain value which is determined by the operating pressure of the system. Any sudden change in pump flow will be compensated by the damper, consequently reducing the pulsation. The level of damping depends mainly onthe size of the damper. Figure 6 shows a typical dampener characteristic.

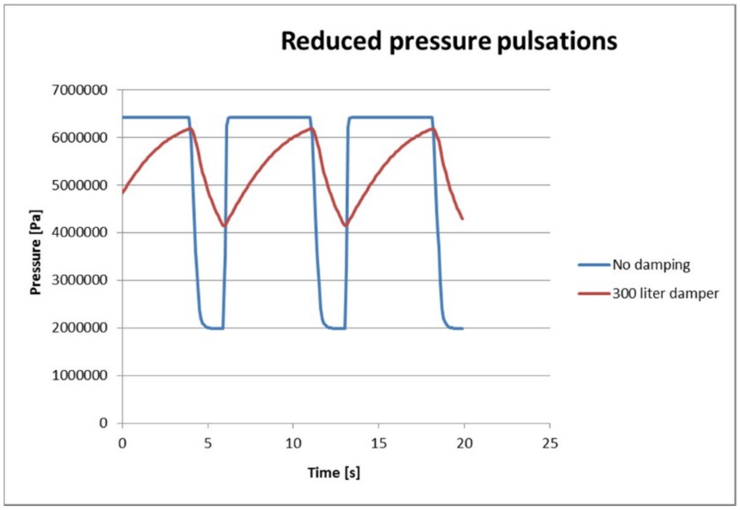

Figure 6. Typical pressure damping characteristic of a pulsation damper

Besides the fact that the pulsations are only reduced in part, a damper only works in a specific operating range. Any deviation from the operating pressure will affect the correct functioning of the damper. Other drawbacks of a damper, besides the additional investment costs, are that it is a heavy piece of equipment that needs to be installed in the pipeline and that requires regular checking and possible adjustment of the gas pressure.

As mentioned in Chapter 3.2, in the case of pumping a cemented paste for e.g. mine backfill, a damper cannot be used because the hardening slurry will block the damper over time and disable proper functioning.

In some cases other equipment can be used for pulsation damping like e.g. a controlled air vessel. The functioning of these alternatives is similar to the pulsation damper and although they have some other advantages/disadvantages they will not be further described in this paper.

THE PULSATION FREE VZ SYSTEM

Concept

Ideally the best way of dealing with the phenomenon of pressure pulsations is to avoid generating them in the first place. Basically this can be achieved by creating a constant discharge flow of the pump in spite of the reciprocating motion of the pistons. In case of a 2-cylinder pump this can be solved by driving both pistons independently of each other. Figure 7 shows a schematic of this concept. Essentially the concept is to divide the pump into two single-cylinder pumps each driven by their own hydraulic system. The individual systems are controlled by a PLC that controls the respective piston speed profiles such that the total net discharge flow is constant, thus giving a constant discharge pressure.

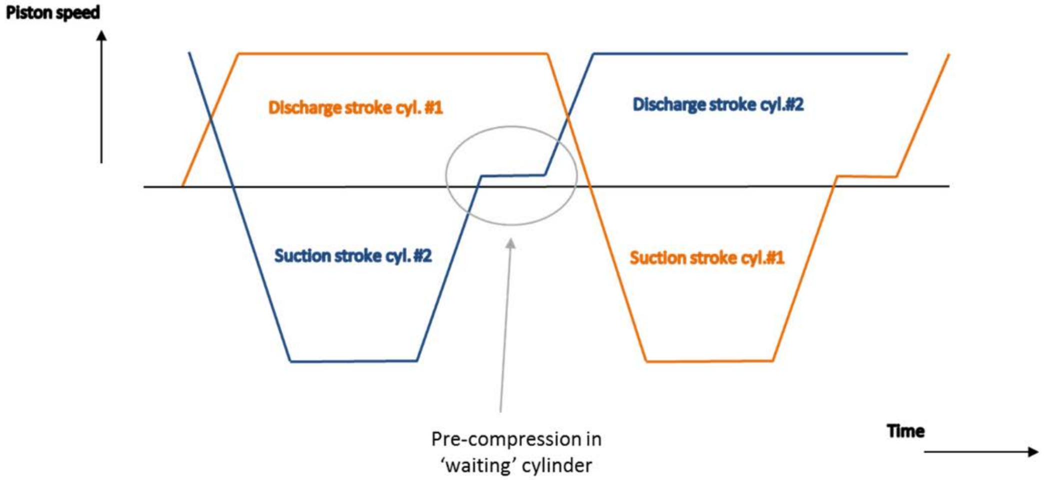

Figure 7. Independent piston speed pattern for each cylinder

System Design

The control algorithm of the piston is accordingly: while cylinder #1 is performing its discharge stroke, cylinder #2 is in suction stroke and immediately after that will prepare to take over the discharge stroke from cylinder #1. In order to prepare for this, the suction stroke is performed at a higher speed than the discharge stroke. Because of the higher speed, additional time is created to allow for pre- compression of the waiting cylinder #2, in order to bring the pressure up to level of cylinder #1. When the pressure levels in both cylinders are equal, cylinder #2 will start its discharge stroke and take over from cylinder #1. When piston #2 has reached its end position it will return to suction and cylinder #1 will take over. The above describes one pumping cycle that is constantly repeated during pump operation.

Essentially, with this approach the switch-over time has been eliminated, resulting in the generation ofa constant flow. The pistons can only be controlled by the algorithm if their respective positions and speeds are monitored continuously during the complete length of the stroke. This is ensured by means of a linear transducer system which is integrated on the hydraulic side of each cylinder. The timing of the piston speeds and the corresponding opening and closing of the valves is obviously critical for the correct functioning of the system.

It can be concluded that a VZ system is only applicable on a piston pump with actuated valves, as the pre-compression of the paste in combination with the timed takeover of the discharge stroke will only work on this type of pump.

As described above, the VZ system requires that both cylinders are driven independently of each other; each cylinder is driven by its dedicated oil pump. The hydraulic scheme is shown in Figure 8. Note that depending on the total required power, the two main oil pumps can be driven by the same electromotor.

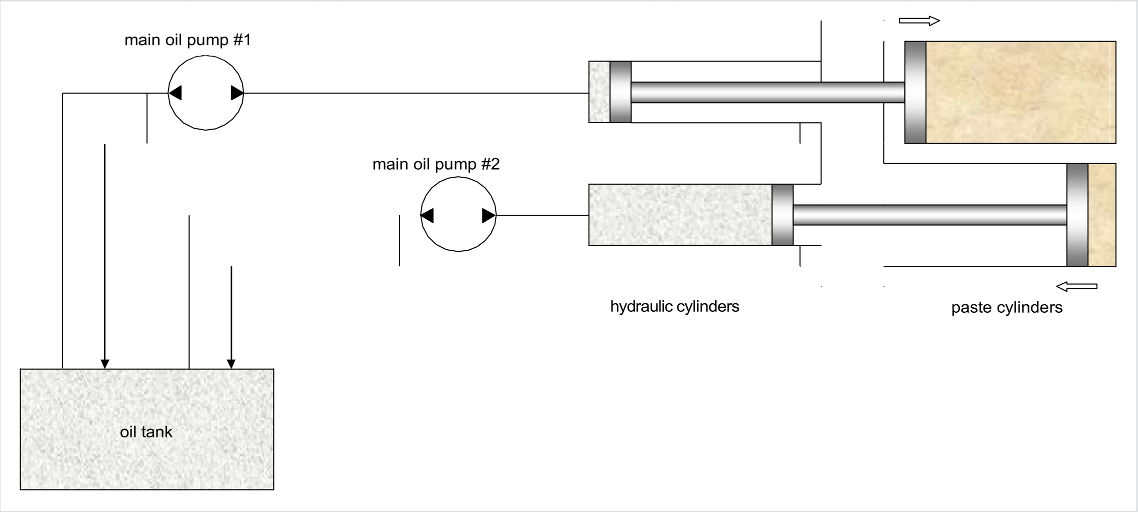

Figure 8. Hydraulic schematic of the VZ Pulsation Free system

Thanks to the specific GEHO® design of the hydraulics system, the hardware required for the Pulsation Free system is basically limited to a separate drive for each pump cylinder; additional hydraulic valve control blocks, hoses and connections are not required. This makes the system reliable, easy to install and easy maintainable at reduced costs.

ADDITIONAL BENEFITS OF THE VZ SYSTEM

Besides the targeted pulsation free discharge flow the VZ system offers some additional benefits. Thanks to the fact that peak flows can be eliminated, the average piston speed during discharge is lower. A lower piston speed typically has a positive effect on the life time of the piston cups and other wear parts.

Thanks to the VZ design, which includes a hydraulic drive for each cylinder, the pump may be operated on only 1 of the 2 cylinders, enabling to continue pumping on 50% capacity. This feature can be advantageous to complete the production shift or empty the pipeline or the feeding tank in case of a malfunction. When pumping hardening slurries like for e.g. cemented backfill this may be a useful feature.

Note that, unlike a pre-charge pulsation damper, the VZ system works in any operating range. Moreover, as the VZ system is an integral part of the pumping system, it does not require additional hardware and, as such, does not require additional inspections or maintenance.

PERFORMANCE

The performance of the VZ Pulsation Free system has been tested on an in-house test stand with a closed loop pipeline system. Figure 9 and Figure 10 show the measured results. The tests are done on a GEHO® DHC 26200 hydraulically driven piston pump including VZ system at a discharge flow of 200 m^3/h against a pressure of 9,000 kPa. The pumped medium is water.

It should be noted that the results as measured on the test loop, which uses a control valve to simulate the pipeline resistance, do not fully represent real life practice. Compared to the test loop, pumping slurry will have an increased dampening effect and consequently the pulsations will be significantly lower.

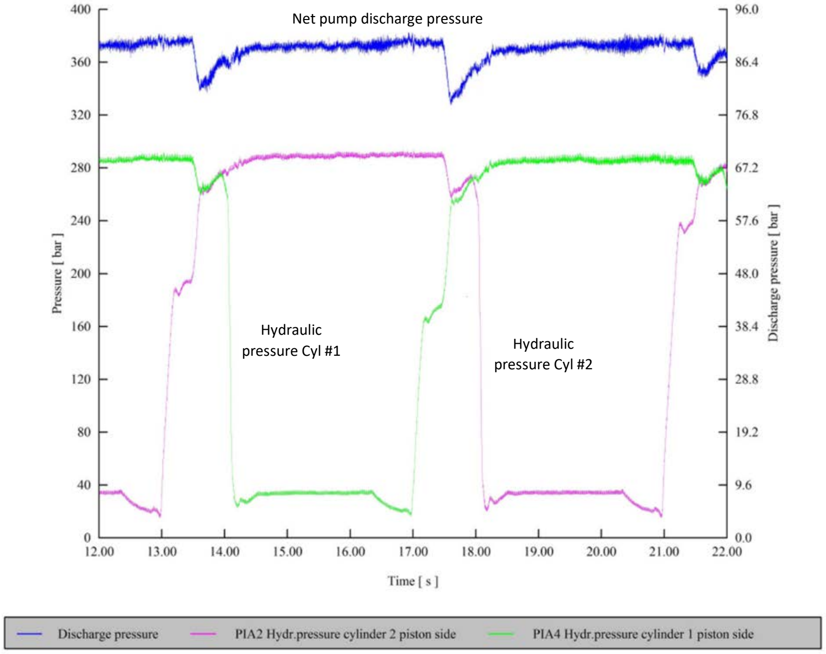

Figure 9. Measured results of VZ Pulsation Free system: hydraulic and pump discharge pressure

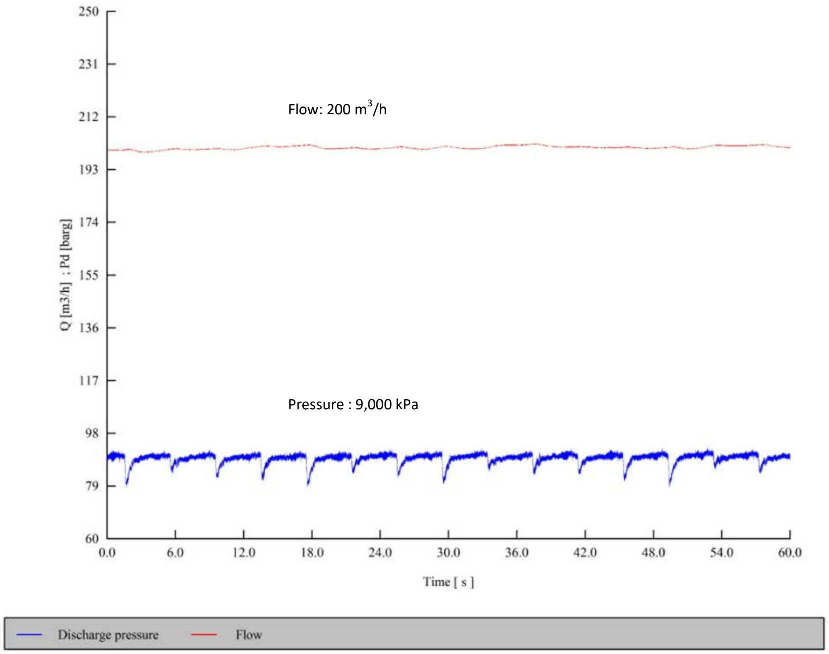

Figure 10. Measured performance of VZ Pulsation Free

Figure 9 shows graphically in time the hydraulic pressure of the respective cylinders and the pump discharge pressure. Figure 10 shows the pump discharge flow and pressure. It can be noted that the flow is nearly constant. The pressure pattern shows a pressure dip of approximately 10%. In a full scale, ‘real life’ system, while pumping slurry, the pressure dip will be reduced to between 5 and 10%.

Since its introduction, a number of pumps equipped with the VZ Pulsation Free system have been installed around the world, running in different pumping applications such as mine backfill, tailings disposal and fly ash pumping. The performance of these pumps is in accordance with the design calculations and the expectations based on the test results from the test stand: the discharge flow is nearly constant in time, resulting in virtually no pressure pulsations.

FURTHER DEVELOPMENT: THE ADVANCED VZ SYSTEM

While for most applications a small pulsation variation of between -5 and -10% is acceptable, other applications demand an even lower pulsation level. Weir Minerals is currently developing an enhanced version of the existing GEHO VZ Pulsation Free system for a targeted pressure pulsation level of ±1%. A small scale pilot pump equipped with this system has been built and is being tested in the field, delivering results as expected. The next step is to implement this design in a full scale pump.

CONCLUSIONS

The industry has recognized the advantages of hydraulically driven piston pumps for pumping of medium to high viscosity slurries and pastes which is demonstrated by the continuously increasing number of modern high density tailings operations world-wide.

Conventional pulsation damping methods do not offer a suitable solution and typically are not applicable for hardening slurries.

The GEHO VZ Pulsation Free system is a technological enhancement to the hydraulically driven piston pump design which basically ensures a constant discharge flow and consequently prevents the generation of pressure pulsations. As a result of this, the pumping system including pumps and pipeline can be designed to the lower, virtually constant pressure level.

The design of the system is such that it requires no additional equipment such as hydraulic control blocks, hoses and connections. This makes the system lean, reliable and cost effective.