DTU

Ram Pump Programme

HOW RAM PUMPS WORK

TECHNICAL
15
RELEASE

How ram pumps work

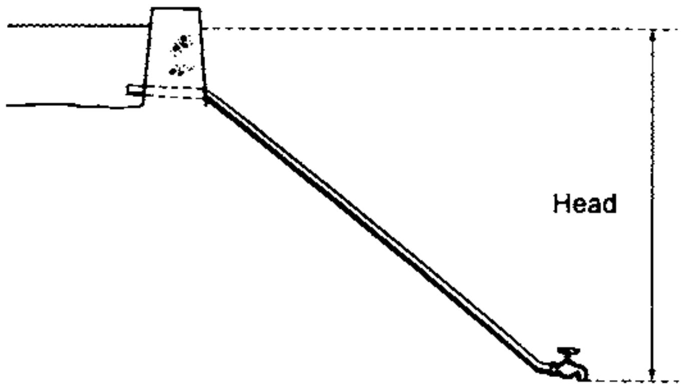
This Technical Release explains what is happening inside working ram pumps. It shows how changes in the design of a ram pump system can change its performance. It will be useful to anyone who is designing ram pump systems and to anyone who is tuning ram pumps to give the best performance.

This section begins with a few examples of simple systems and introduces the words that are used later. It also shows the way that the water flowing through pipes can be shown on a graph. Even if you are already understand terms such as *terminal velocity* in pipes, you should read all of this part so that you know the way that we are using the words.

Falling water

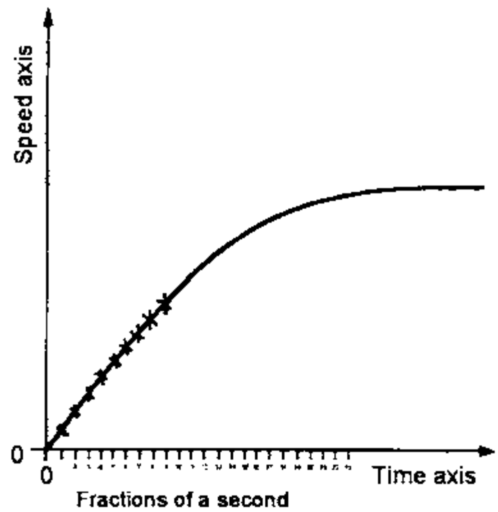
Head

In the drawing here there is a reservoir of water behind a dam. A small pipe passes through the bottom of the dam and runs down the hill. At the end of the pipe there is a tap which is closed. The height from the water level in the reservoir to the tap is called the *head*.



When the tap is opened, water starts to flow down the pipe and out through it. It flows slowly at first, but speeds up very quickly. After a short time the water reaches its maximum speed and the flow becomes steady. If the tap is left open, water will of course continue to flow steadily down the pipe from the reservoir and out through the open tap.

A graph can be drawn to show how the water coming out through the tap gets faster at first, and then flows at its maximum rate. The graph alongside shows what happens. Imagine that a stop-watch was started as soon as the tap was opened and the speed of the water in the pipe was measured every hundredth of a second. The graph has the speed of the water flowing through the pipe marked on the side axis. The time that has passed is marked along the bottom axis.

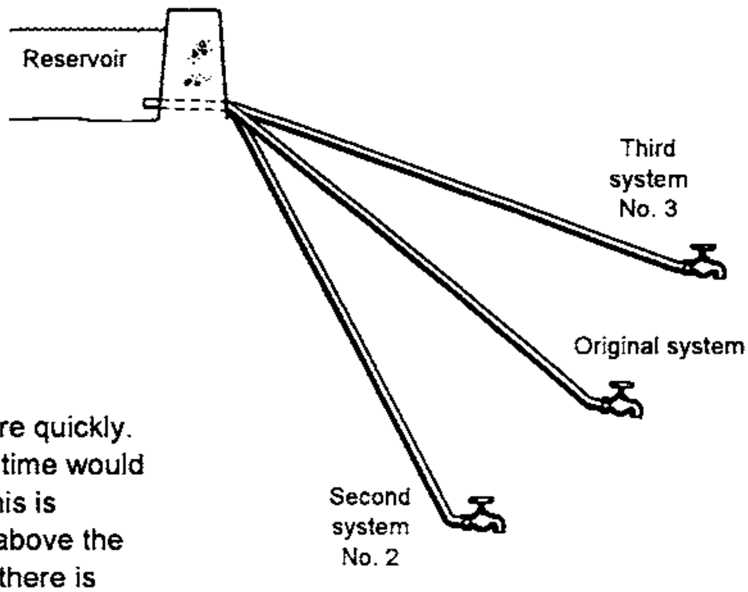


Before the tap was opened and the stop watch was started, there was no water coming through the tap. That is why the graph starts when the "Time" is zero and the "Speed" of the water in the pipe is also zero.

At first the line on the graph goes up very quickly. As the water flows it rubs against the sides of the pipe. This rubbing is usually called *friction*. As the water gets faster, the friction becomes bigger and stops the speed of the water from increasing as quickly. This is shown on the graph by the curve of the line getting flatter and flatter. After a while, the water is flowing as fast as it can and the line on the graph is flat. This shows that the water is continuing to flow out of the tap at the same speed.

A larger head

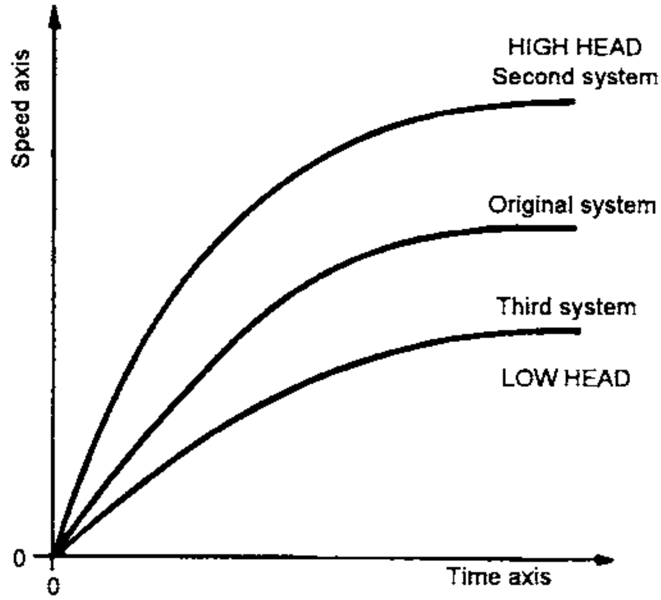
In this drawing there is a water supply with a reservoir and three pipes and taps. The pipes are labeled as the original, second and third systems. In the second system it is further downhill to the tap (the *head* is bigger than in the original system). When the tap on No.2 is opened, the water will flow down the pipe and out through the tap more quickly. The line showing speed against time would rise more steeply on a graph. This is because the reservoir is higher above the tap than it was on System 1, so there is more pressure pushing the water down the pipe and out through it.



As the water gets faster the friction between it and the wall of the pipe gets greater. The curve of the line on the graph begins to flatten out. When the water is flowing as fast as it can, the line on the graph is flat. Because the *head* in the second system is greater than the *head* in the first, the water flows faster in the second. This is shown on the graph at the top of the next page.

A smaller head

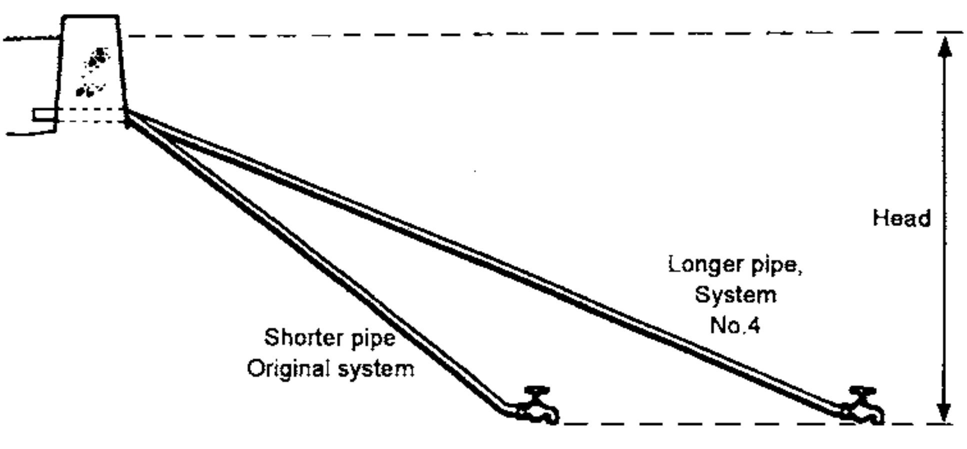
For the third system, the drop from the reservoir to the tap (the *head*) is much less than in the original system. When a graph of System number 3 is drawn, the line on the graph showing speed against time does not rise as sharply and flattens out at a lower speed. This is because there is less pressure pushing the water down the pipe and out through the tap. The speed of the water when it reaches a steady flow is the slowest of the three examples.

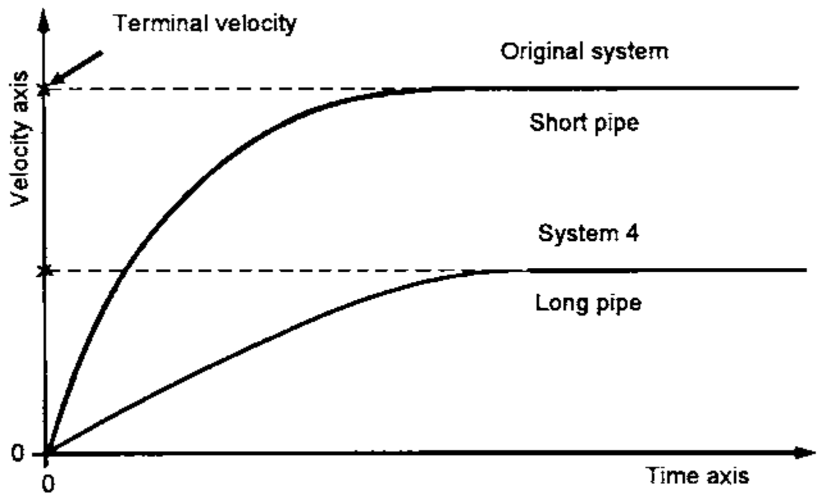


Acceleration

The rate of increase in speed is called the *acceleration*. When the tap is first opened, the speed of the water increases very quickly, so the *acceleration* is very high. As the water flows more quickly there is more friction and the line on the graph flattens out. This shows that the water is still accelerating but that the rate of acceleration is becoming lower. When the water is flowing as fast as it can, there is no more acceleration and the line on the graph is flat. This maximum speed is called the *terminal velocity*. In this case, the word *"terminal"* is used to mean *"as much as possible"*. *"Velocity"* is really just another name for *"speed"*. *"Terminal velocity"* just means *"top speed"*.

In the drawing below another pipe is installed from the reservoir. The new pipe is called System number 4. The pipe is the same diameter as the first one, but it is much longer. The height from the reservoir to the tap (the *head*) is the same. When the tap of this new system is opened, the water accelerates down the pipe and out through the tap. Because the water has to flow through a longer pipe there is more friction to slow it down, so its *terminal velocity* is not as fast.



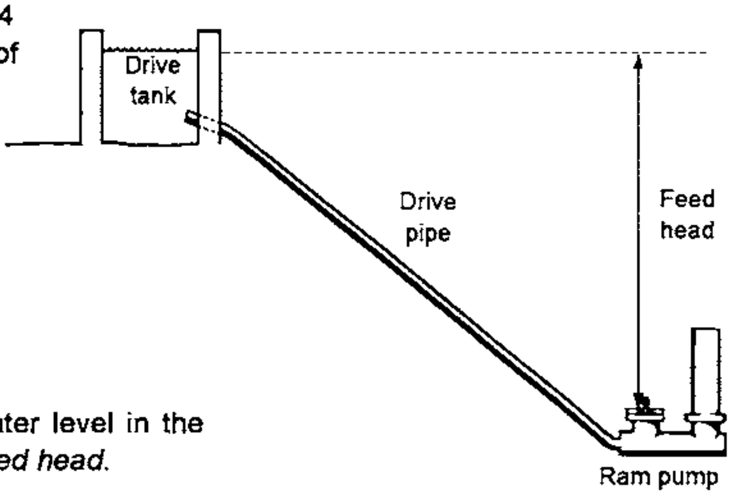


On the graph of this example above, the original system is also shown. The line on the graph flattens out at a lower speed and in a longer time.

If any one of the pipes in these systems was replaced by a pipe with a bigger internal diameter, the graph would change. This is true even if the bigger pipe were the same length and ran along the same route. When the acceleration of the water was measured again, you would find that the water reached a faster *terminal velocity*. This is because the larger pipe would have less friction. In a bigger pipe, there is more room for the water to pass through without touching the sides.

How ram pumps use the water

In the drawings of Systems 1 to 4 there was a reservoir at the top of a pipe with a tap at the bottom. From now on the reservoir is replaced by a tank and the tap on the end of the pipe is replaced by a ram pump.

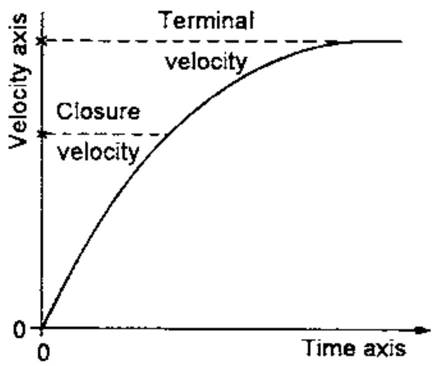


Feed head
The drop in height from the water level in the tank to the pump is called the *feed head*.

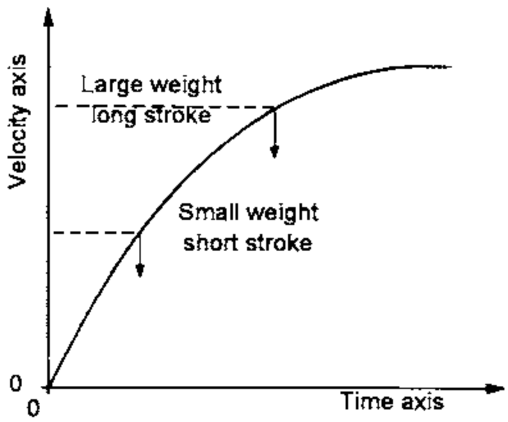
Closure velocity
When the ram pump is not working and the impulse valve is closed, there is no water coming through it. When the impulse valve is pushed down, water begins to come out through the open valve, getting faster as it accelerates down the pipe. The force of the water flowing around the impulse valve tries to lift it closed but the weight of the valve keeps it open. The force of the water trying to close the valve gets bigger and bigger.

When the force trying to close the valve becomes bigger than the weight, the valve starts to move upwards. All impulse valves will close when the drive water reaches the right velocity. What that velocity is will depend on how the impulse valve on the particular pump is tuned. The water accelerates down the pipe and out through the impulse valve until it reaches the *closure velocity* and the valve closes.

A graph can be used to show the increasing velocity in the system just as it was for the examples with the tap. If the impulse valve was held open and water allowed to flow out for a long time the graph would show it reaching a *terminal velocity* just as before. The shape of the line on this graph would depend on the feed head, the pipe diameter, the pipe length and the amount of friction through the pump. If the pump was operating normally, the impulse valve would close when the velocity reached the *closure velocity*. This point can be marked on the graph.

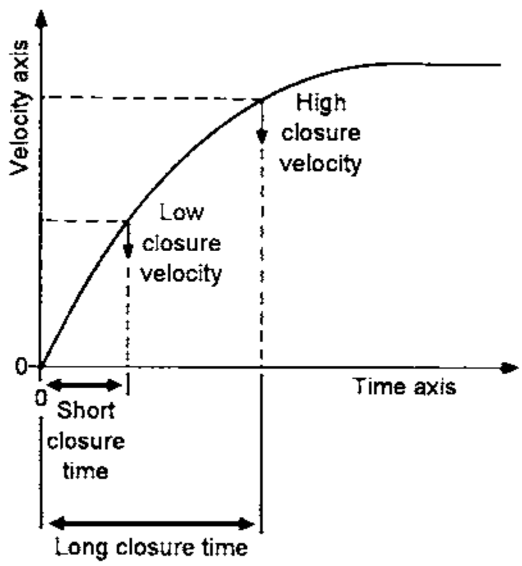


At any ram pump site the settings of the impulse valve (the stroke length and the valve weight) will decide how big the *closure velocity* is. A valve with a small weight and a short stroke has a low closure velocity. It will close when the water reaches only a low velocity. A valve with a large weight and a long stroke will need a much higher velocity to make the valve close. The *closure velocity* of the pump can be changed by making adjustments to the impulse valve — in other words, by *tuning* the pump.



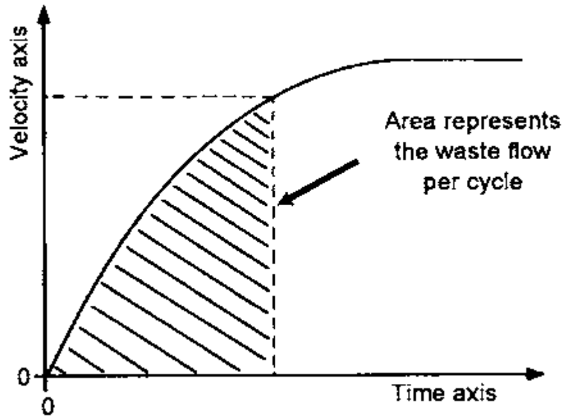
The time it takes for the water to reach the *closure velocity* can be worked out using the same graph. This is done by drawing a straight line across from the Velocity (Speed) axis at the *closure velocity* until it reaches the line on the graph. Another line is drawn from this point straight down to the bottom of the graph where it hits the Time axis. The scale on the Time axis can then be read to find out how long it takes to reach *closure velocity*.

You can see that if the pump has a high *closure velocity*, it will take a long time for the valve to close. If the stroke of the impulse valve was reduced, the velocity needed to close the valve would also be reduced and the time it would take to reach the new *closure velocity* would be less. So, reducing the length of the impulse valve stroke on a pump will make it work faster.

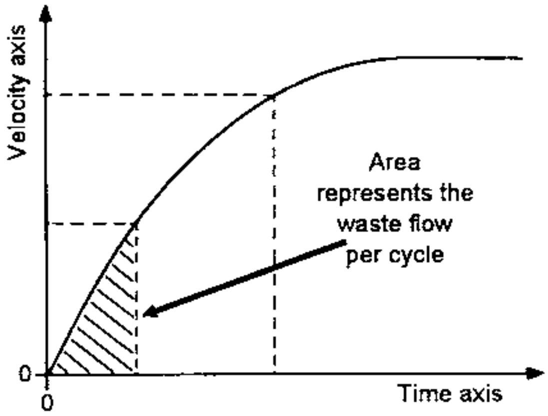


Closure velocity and waste flow

When a pump has a high *closure velocity* a lot of water will flow through the impulse valve before it shuts. This water is often called the *waste flow* for one cycle and can be represented by the area under the graph that has been shaded.

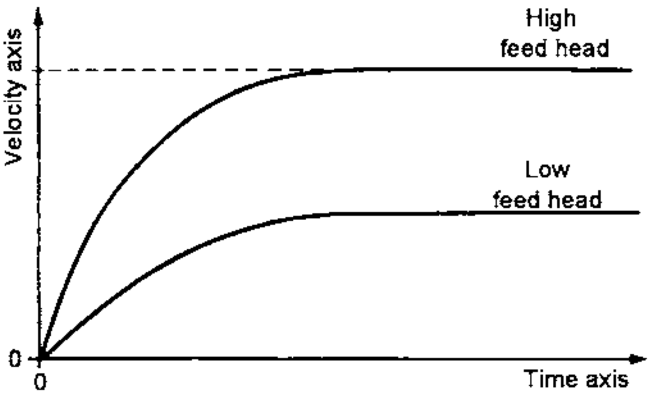


By shortening the length of the impulse valve stroke, the pump can be made to work faster and the *closure velocity* will be lower. The area representing the *waste flow* on the graph will be smaller, showing that the amount of water flowing through the pump (the *waste flow*) has gone down.

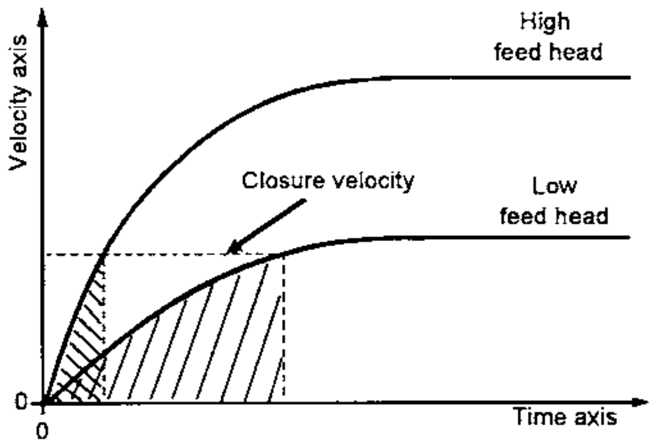


Closure velocity and feed head

You saw earlier with the reservoir, pipe and tap that when the head from the reservoir to the tap was increased, the acceleration was faster and the line on the graph rose more steeply. If the *feed head* of the ram pump system is increased, the line on the graph also rises more steeply.

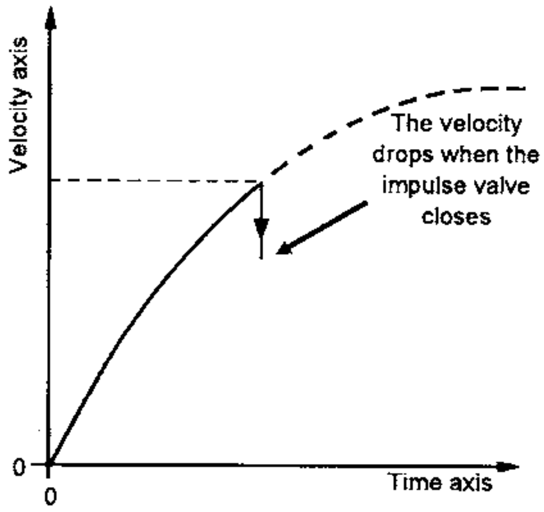


If the same ram pump system was given a different feed head, the *closure velocity* for the system would stay the same as long as the same pump was used and its tuning was not changed. The area under the line on the graph for the system with the higher feed head would be much less, showing that the waste flow was smaller. It would also take less time to reach the *closure velocity*, so the pump would work faster.



Water delivered from a ram pump

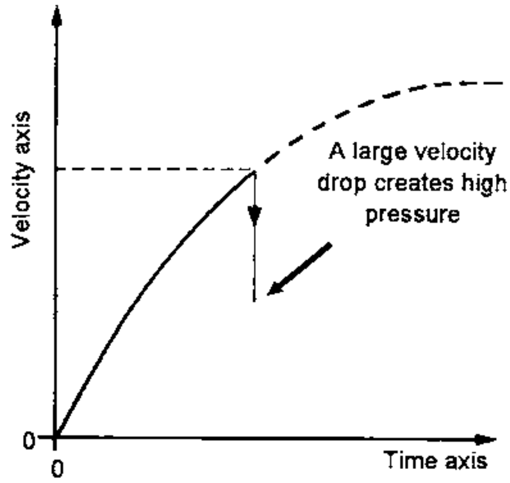
When the impulse valve on a ram pump closes, the water flowing down the drive pipe and through the pump has nowhere to go. The velocity of the water drops very quickly. As the velocity of the water drops, the energy of the moving water is turned into pressure energy. The more the velocity of the water drops the more the water pressure inside the pump rises.



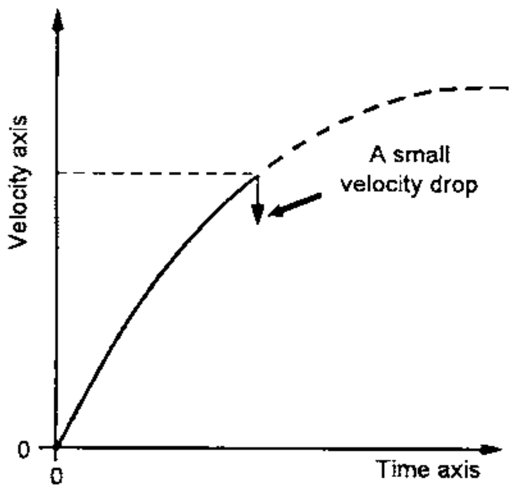
Delivery head

The velocity of the water continues to fall until the pressure in the ram pump is higher than the pressure in the air vessel. The pressure in the air vessel will depend on the height from the pump to the top of the delivery pipe. The height from the pump to the top of the delivery pipe is called the *delivery head.*

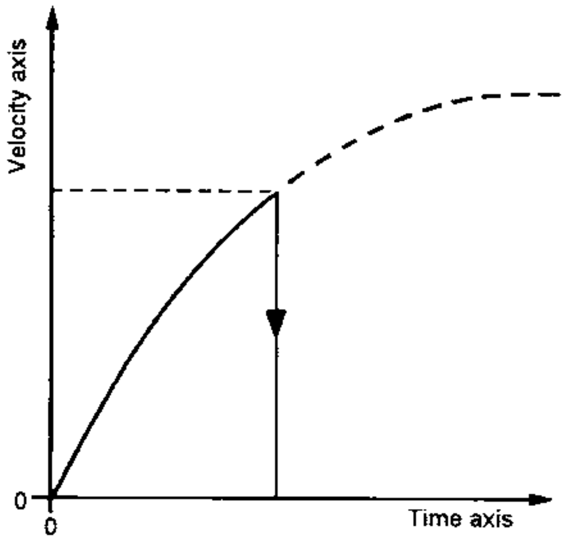
When the *delivery head* is high, there has to be a big drop in the velocity before the pressure in the pump is bigger than the pressure in the air vessel.



When the *delivery head* is small, the velocity only has to drop a small amount before the pressure in the pump is higher than the pressure in the air vessel.

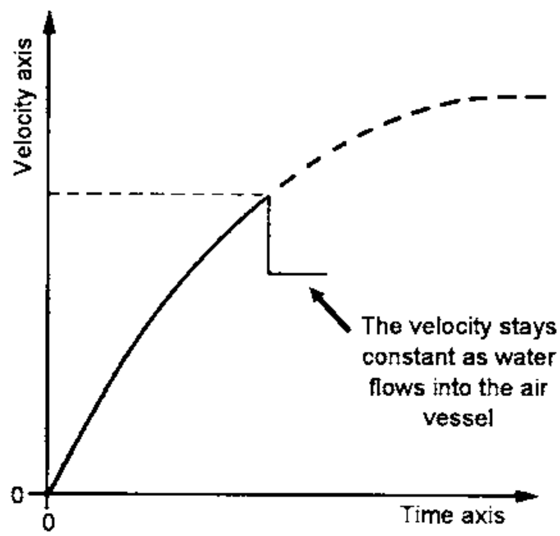


If the delivery head is very high, the closure velocity may be too small. When it is too small, there is not enough velocity to turn into pressure energy when the impulse valve closes. The pressure in the pump rises, but not enough to reach the delivery pressure. The water loses all of its velocity but the delivery valve does not open. The impulse valve may then open again and water flow through, allowing the velocity of the water to increase until the impulse valve closes again. When this happens a pump can work with the impulse valve opening and closing but without the delivery valve opening, so no water is pumped.



Delivery pressure

When the pressure in the pump is greater than the pressure in the air vessel, the delivery valve opens. Water flows through the delivery valve and into the air vessel. The water has lost velocity and gained pressure. It flows at the lower velocity into the air vessel. Water will continue to flow through the delivery valve at this velocity for a certain period of time. The amount of time will depend on the time it takes for a shock wave to travel up the water in the drive pipe to the drive tank and back down to the pump again.



This is more fully explained in the box on the next page. It is not necessary to understand all the details so you can miss out the box if it seems too complicated. All you need to know is that the water flows through the delivery valve at the reduced velocity for a certain period of time. The length of time will depend on the length of the drive pipe. If the drive pipe is short the period of time will be short. If it is long then the period of time that the water flows through the delivery valve will be longer. Remember that the pump is likely to be cycling every second or so, so the periods of time are all only fractions of a second.

More advanced explanation

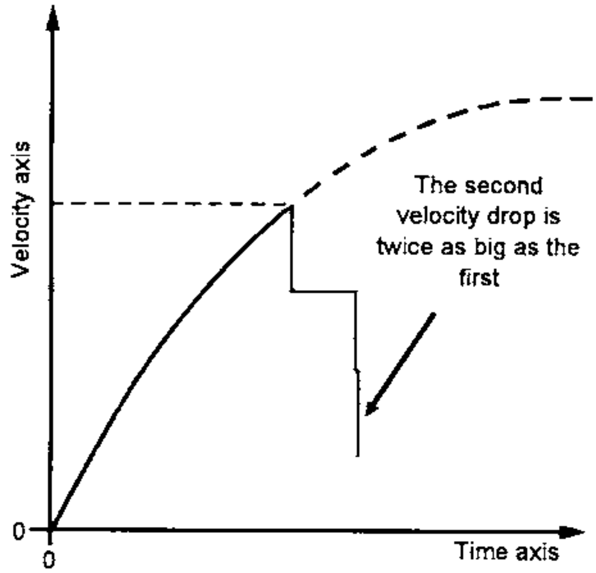
When the impulse valve closes, the water moving inside the pump suddenly slows down. When the first bit of water starts to slow down, its pressure rises. The water behind it also slows down and its pressure also starts to rise. Pressure rises along the drive pipe as all the water slows down and its pressure rises.

Try to imagine a line between the water in the pipe that has slowed down and the water that is still moving at full speed. This imaginary line travels very quickly from the impulse valve up the drive pipe to the drive tank. On one side of the line the water has slowed down and the pressure has risen. On the other side the water is still moving at closure velocity. This imaginary line is at the front of a "shock wave". The drop in velocity of the water across this shock wave is the same as the drop in velocity needed to open the delivery valve.

The shock wave travels at very high speed (usually over 1000 meters per second) up the drive pipe until it reaches the drive tank. The drive tank acts a bit like a mirror that turns things around and reflects them back. It is a low pressure shock wave which travels back down the drive pipe towards the pump.

The time taken for the shock wave to travel from the pump to the drive tank and back again will depend on the length of the drive pipe and the speed of the shock wave. The pressure in the pump, and the velocity of the water flowing through the delivery valve will remain constant until the shock wave has gone up the drive pipe, been reflected and come back down to the pump. The graph below shows that the velocity of water in the pump stays constant for a set period of time. The time will depend on how long it takes the shock wave to go up and down the drive pipe.

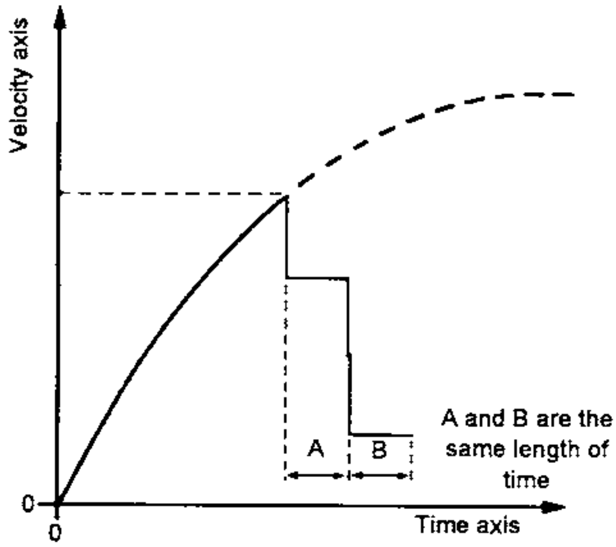
When the shock wave in the drive pipe has returned to the pump, the velocity of the water drops again. This keeps the pressure in the pump high enough to push water through the delivery valve into the air vessel. The second velocity drop is twice as much as it was the first time.



More advanced explanation

When the reflected shock wave reaches the pump the velocity there drops due to the lower velocity of the water *behind* the shock wave. It immediately drops again to recreate the pressure needed to keep the delivery valve open. Both of these drops in velocity are the same size as the first velocity drop when the impulse valve closed.

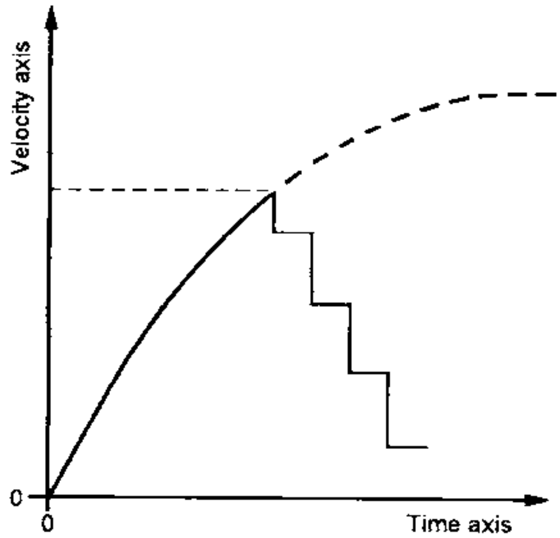
Water continues to flow through the delivery valve at the reduced velocity. It flows for the same amount of time as before, while the second shock wave travels up to the drive tank and back again.



More advanced explanation

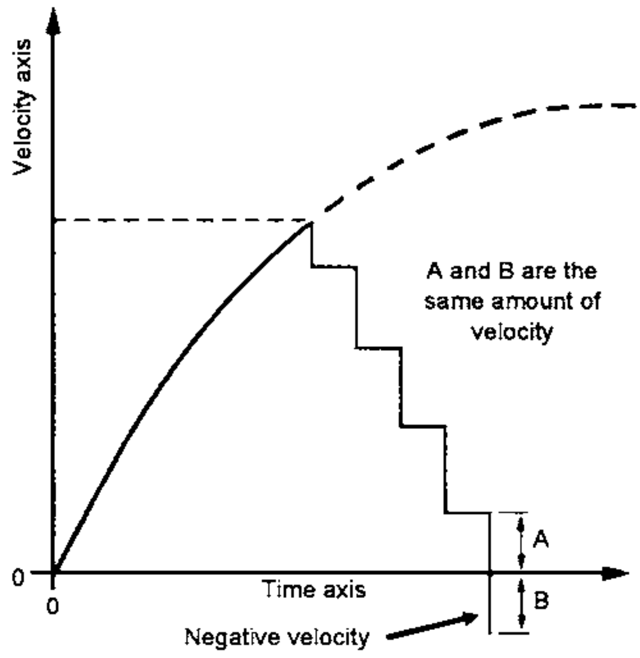
The second part of the second drop in velocity produces another increase in pressure that keeps the pressure in the pump greater than the pressure in the air vessel. Water flows through the delivery valve at the lower velocity. The increase in pressure starts another shock wave that travels up the drive pipe. The second shock wave is also reflected by the drive tank and another low pressure shock wave travels back down to the pump. Water continues to flow from the pump into the air vessel until the reflected shock wave reaches the pump.

Each time a shock wave comes back to the pump, the water's velocity drops again and a new shock wave travels up the drive pipe. Water continues to flow into the air vessel at the reduced velocity. The velocity in the pump continues to step down in this way until there is not enough velocity left to make another full step.



Recoil

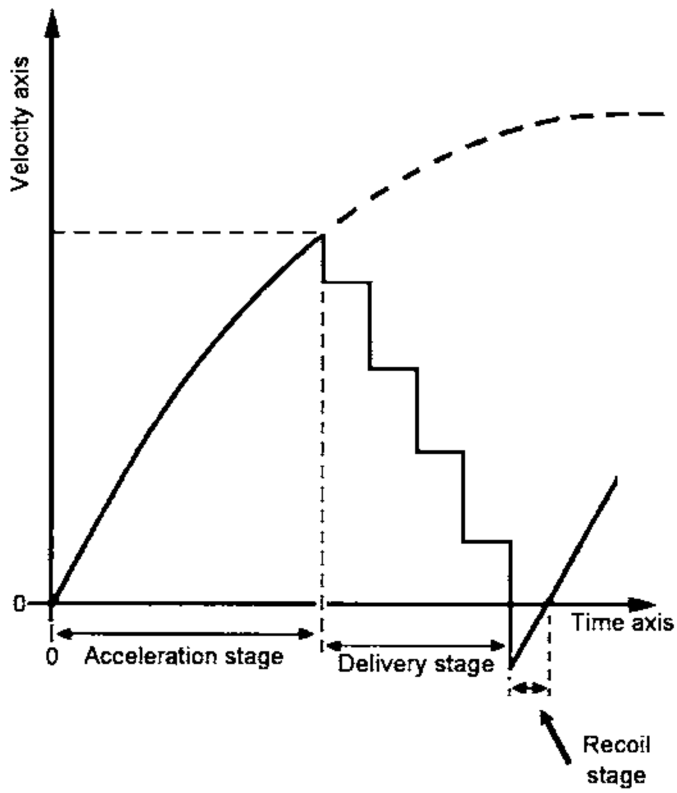
When there is not enough velocity left to make one complete step the pressure can no longer stay high enough to keep the delivery valve open, so it shuts. The water in the system is still moving with a low velocity down the drive pipe. The impulse and delivery valves are both closed so the water has nowhere to go. The water bounces back up the drive pipe towards the drive tank. The water is like a spring that is pushed against a wall so that it compresses and then is suddenly let go. It opens up and flies away from the wall.



As the water moves away from the pump it has a negative velocity, so the line on the graph goes under the base (under 0 on the Velocity axis). The negative velocity will be the same size as the positive velocity that was left when the delivery valve closed. When the water has a negative velocity it moves away from the pump towards the drive tank.

The negative velocity is shown where the line on the graph goes below 0 on the Velocity scale. The water flowing back up the drive pipe slows down and stops, then the line on the graph crosses back over the Time axis. After that, the impulse valve has reopened and the water begins to accelerate down the drive pipe. The line on the graph rises in the same way as before. The section of the graph below the line is called the "recoil" stage of the pump's cycle.

When the delivery valve closes and the water in the pump *recoils* back up the drive pipe, it is actually flowing away from the pump. This leaves a low pressure or vacuum in the pump. The low pressure lets the impulse valve drop open with its own weight.

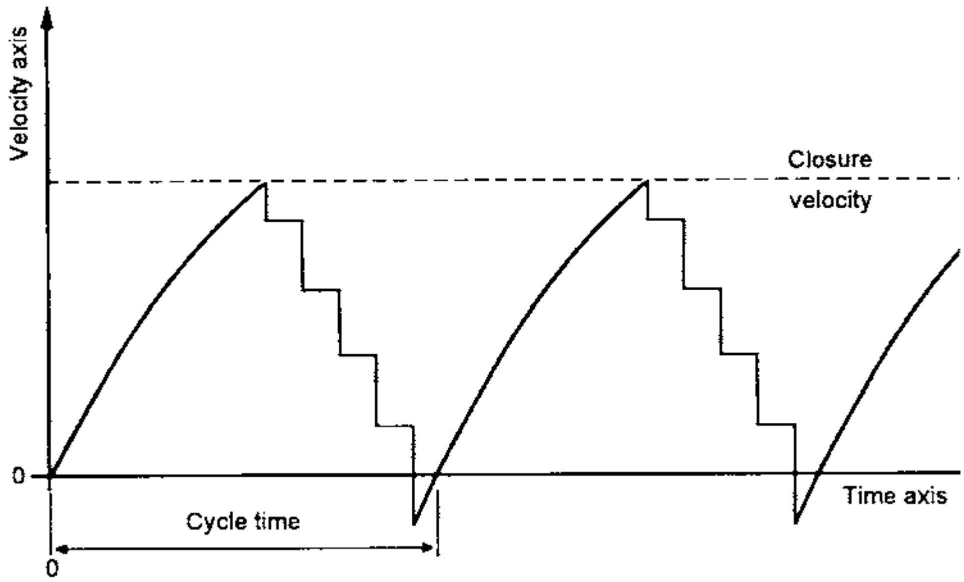


When the water has stopped recoiling, it starts to flow down the drive pipe and out through the open impulse valve again. It accelerates down the drive pipe and through the open valve as it did at the start of the pumping cycle.

The pump cycle

To make the operation of the pump easier to understand the pump cycle can be divided into three stages. They are called the *acceleration, delivery and recoil* stages. There is a very short pressurisation stage as well, but that can be ignored. The graph at the bottom of the previous page shows how these stages refer to different parts of the cycle.

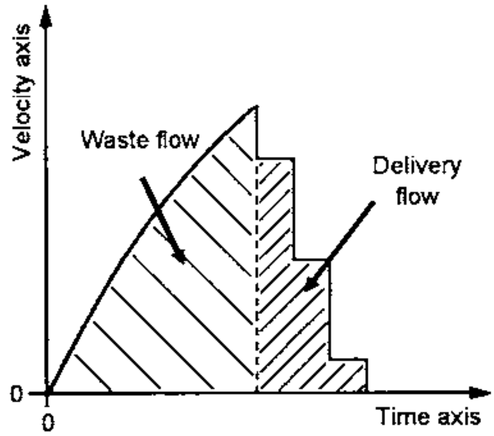
As the pump continues to operate, the same cycle is repeated. The water accelerates down the drive pipe and out through the impulse valve until the velocity of the water reaches closure velocity. Then the stages of delivery and recoil occur before the cycle starts again. The graph can be used to see the time taken for each cycle and work out how fast the pump is operating.



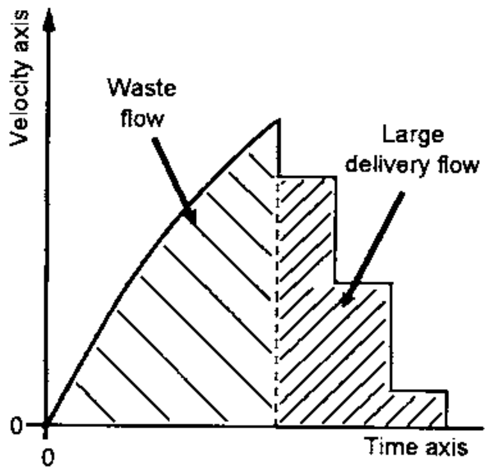
The impulse valve closes and the pump beats every time the line on the graph reaches closure velocity. For a pump working at 60 cycles a minute, the "cycle time" would be 1 second.

Delivery flow

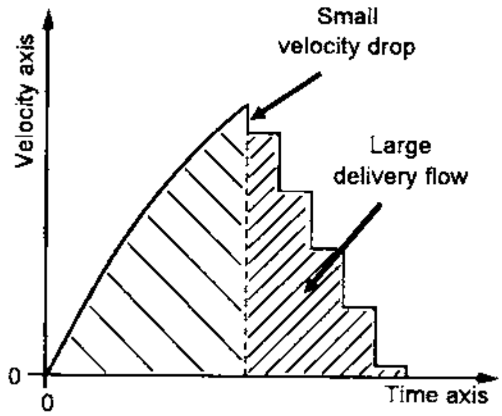
You saw on page 6 how the amount of waste flow could be represented by shading the area under the line on the graph. In the same way, the amount of water flowing from the pump into the air vessel can be represented by the area under the graph during the delivery stage. This is called the *delivery flow* per cycle.



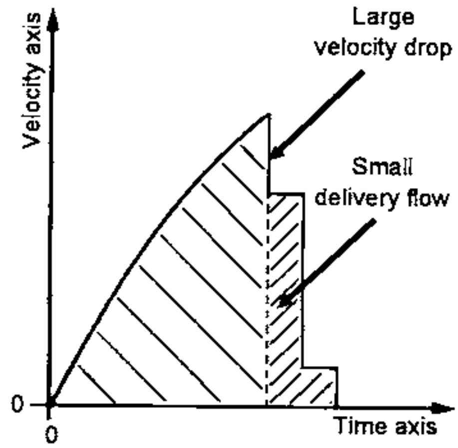
When the area under the falling part of the graph is large it means that there is a large *delivery flow*. Two things increase this area. One is increasing its height. The other is increasing its width either by having more steps or by having longer steps.



Systems with a low delivery head will only need a small drop in velocity to deliver water. The delivery stage will have many small drops in velocity before all the velocity is used up. The large area under the line on the graph shows that a large amount of water will be pumped with each cycle.



If the delivery head of the same system was increased, the acceleration of the water and the closure velocity would be the same but the drop in velocity required to reach the delivery head would be much higher. The graph shows that there would be a few large drops in velocity during the delivery stage of the cycle. The area under the graph during the delivery stage would be much smaller, showing that the flow through the delivery valve was small. Much less water would be pumped with each cycle.

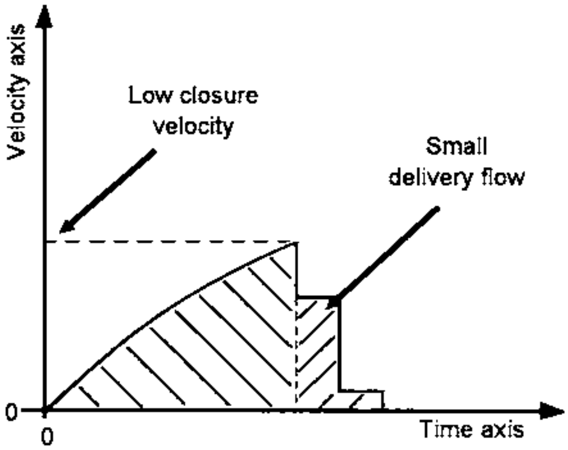


More advanced explanation

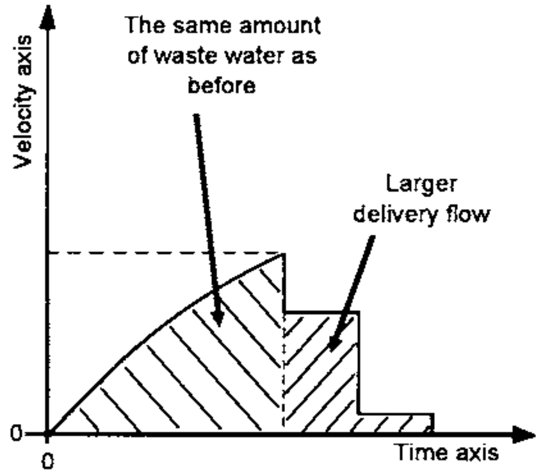
Because the drive pipe is the same length in both of the systems just described, the time taken for a shock wave to travel from the pump to the drive tank and back again would be the same. So the flat sections of the graphs, showing when the water is flowing at a steady velocity through the delivery valve, would each last the same length of time. The delivery stage of the pump cycle in a system with a low delivery head would be longer than it would be in the same system with a higher delivery head. The acceleration time would be the same in both cases and the time for the recoil stage would be very small. When the delivery head is increased, the length of the delivery stage is reduced and the pump operates faster.

Getting the best delivery flow

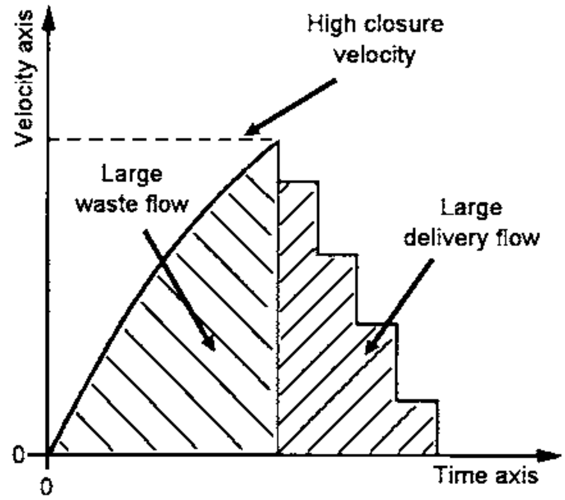
This is explained using an example. Suppose you are asked to design a ram pump site on a stream where the flow of water in the dry season is quite small. There is an obvious ram pump site but it only has a small drop, so the feed head would also be small. If a pump was installed there, the acceleration of the water would be quite low and so the graph would not rise very steeply. The impulse valve of the pump could be adjusted to use all the water available in the stream. With a low feed head, the acceleration and closure velocity would also be low. The pump would not deliver much water.



The owner of the site says that he needs more delivered water than the proposed site would give, so you have to look more carefully at the site design. Suppose that you find that you can double the feed head without too much trouble. Normally the drive pipe length will also double. By keeping the closure velocity the same, the feed flow will hardly change. The delivery head would be increased by an amount equal to the extra feed head, but this has little effect on the flows. Although the drops in velocity would be about the same as before, the steps are twice as wide and much more water would be delivered.



If the same site has plenty of water available in the rainy season, you could recommend changing the tuning of the impulse valve when the stream is full so that the closure velocity was increased. The valve would then take longer to close and much more water would flow through it. The delivery head would be the same as before so the drops in velocity would be the same size. Because the closure velocity would be higher there would be more drops in velocity during the delivery stage and more water would be pumped.



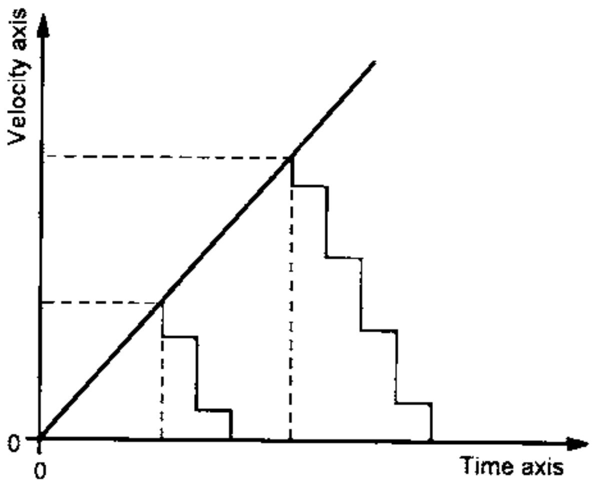
More advanced explanation

As the closure velocity is increased (by changing the settings of the impulse valve) three things happen:

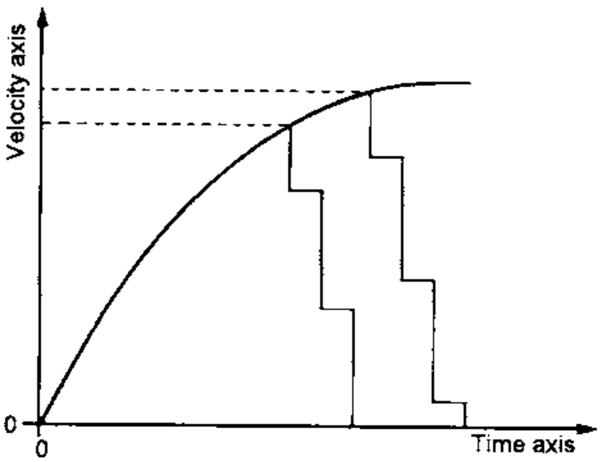
- the drive flow per cycle increases a lot
- the delivery flow per cycle increases a lot
- the pump works a little more slowly (fewer cycles per minute)

The overall effect is to increase both the delivery flow per minute and the drive flow per minute.

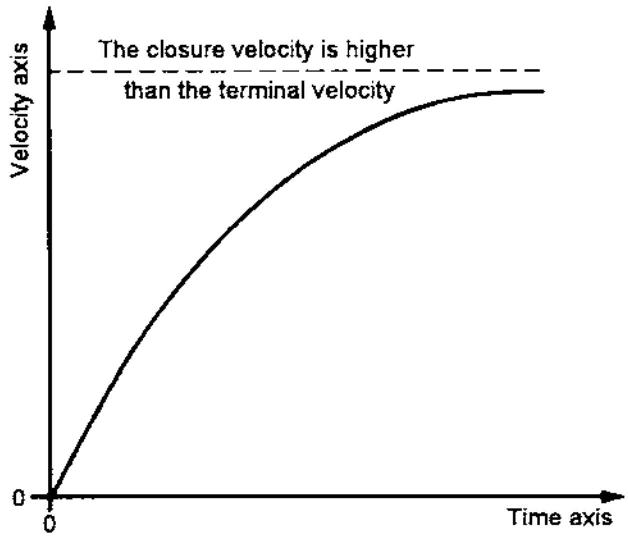
When the closure velocity is in the steep section of the line on the graph, increasing the closure velocity will increase the delivery flow per cycle and the total water delivered by the pump.



If the impulse valve was tuned so that the stroke was very long or the weight very heavy, the closure velocity would be in the flatter section of the line on the graph. The drive flow through the pump would increase a lot but the delivery flow would change very little. The time taken for each cycle would also increase so that there would be fewer cycles per minute. The pump would become less efficient and would actually pump less water per minute.



Increasing the weight and stroke of the impulse valve too much would stop the valve from closing at all. This is because the valve cannot close when the velocity needed to close it is more than the terminal velocity of the water through the pipe.



The following DTU Technical Releases give further information about ram pumps.

TR 11: The DTU S1 ram pump

TR 12: The DTU P90 ram pump

TR 14: The DTU S2 ram pump

TR 16: An introduction to hydraulic ram pumps (and the DTU range)