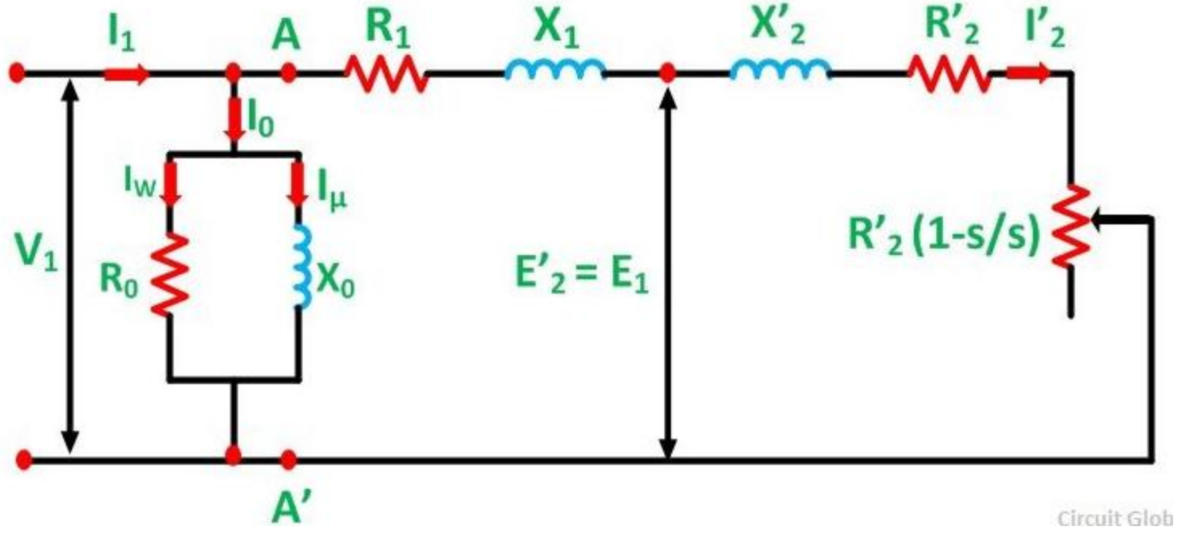
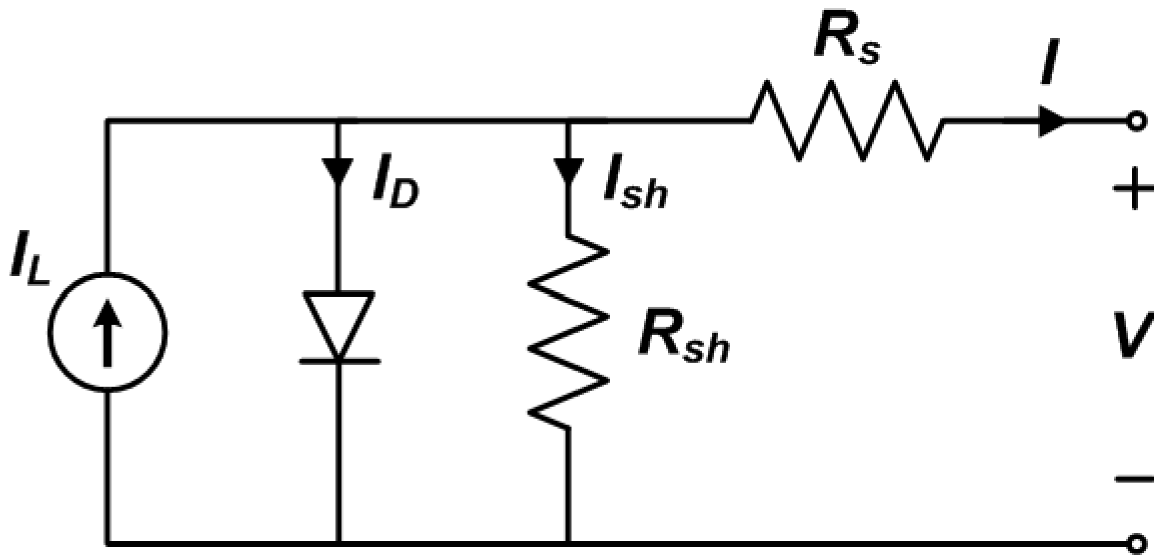
Electrical Circuits

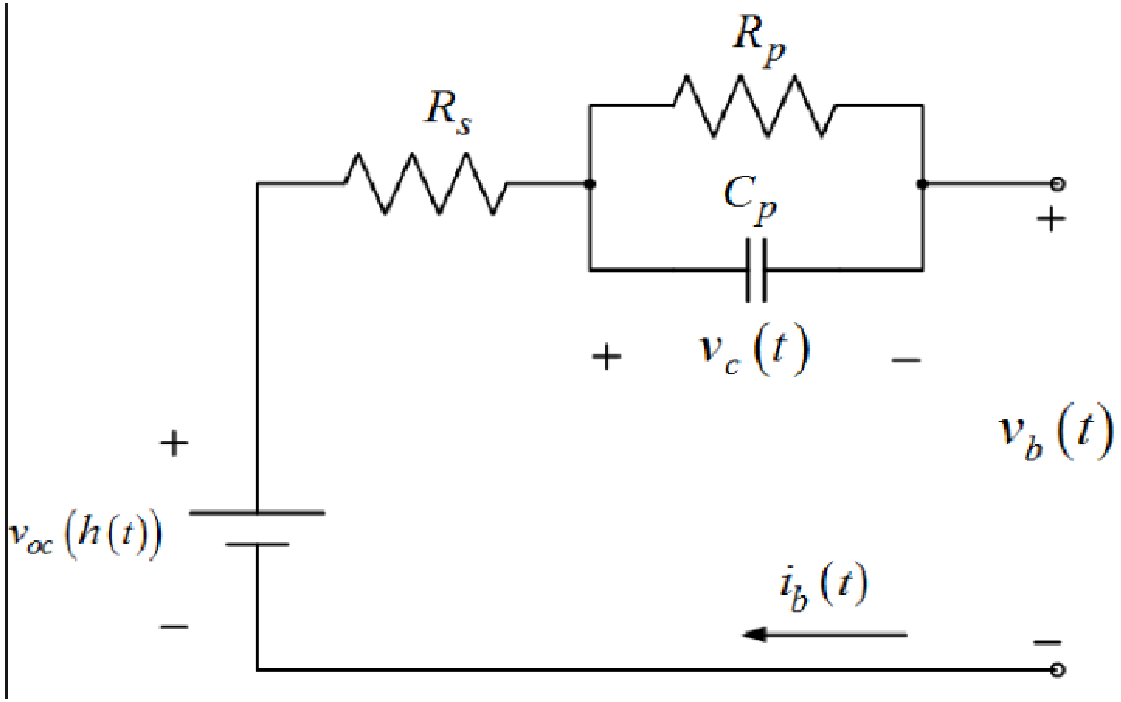
Equivalent Electrical Circuit of Motor



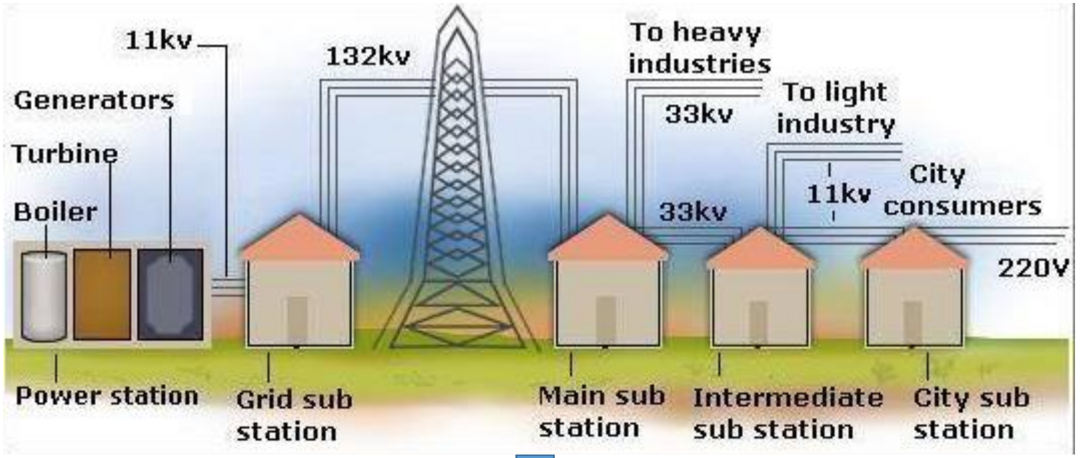
Equivalent Electrical Circuit of PV Panel

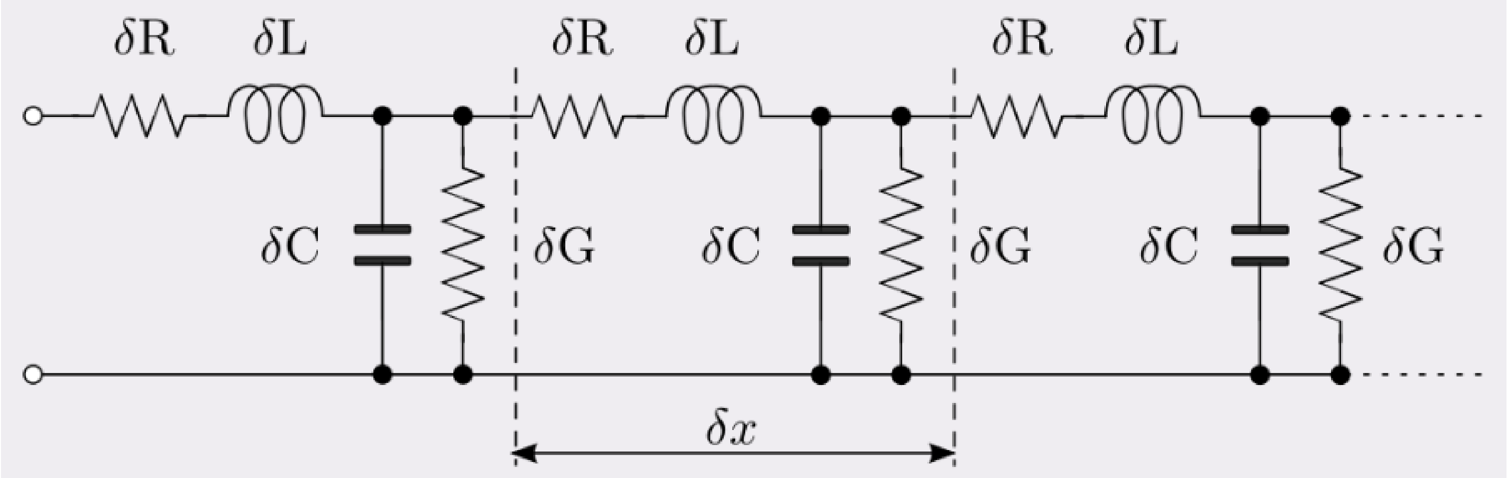


Equivalent Electrical Circuit of Battery

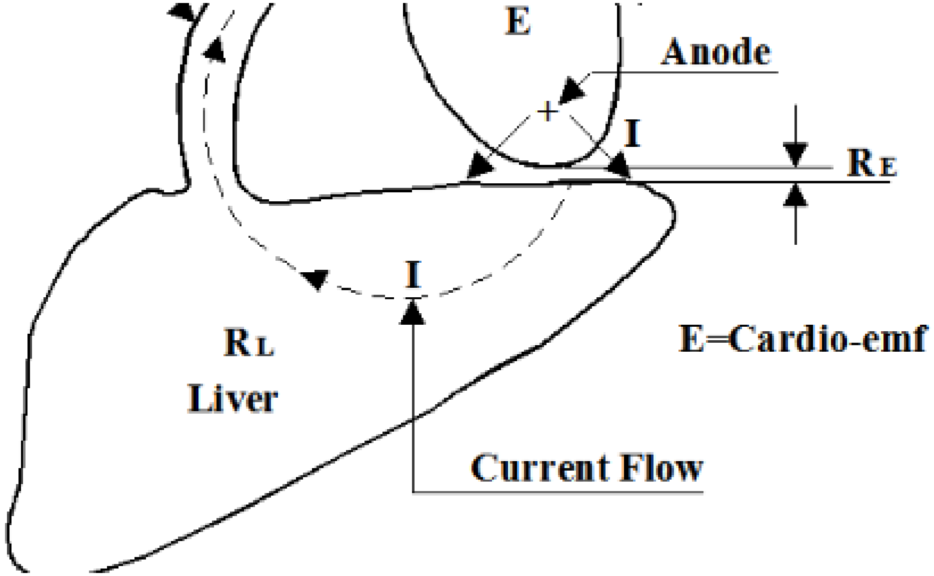


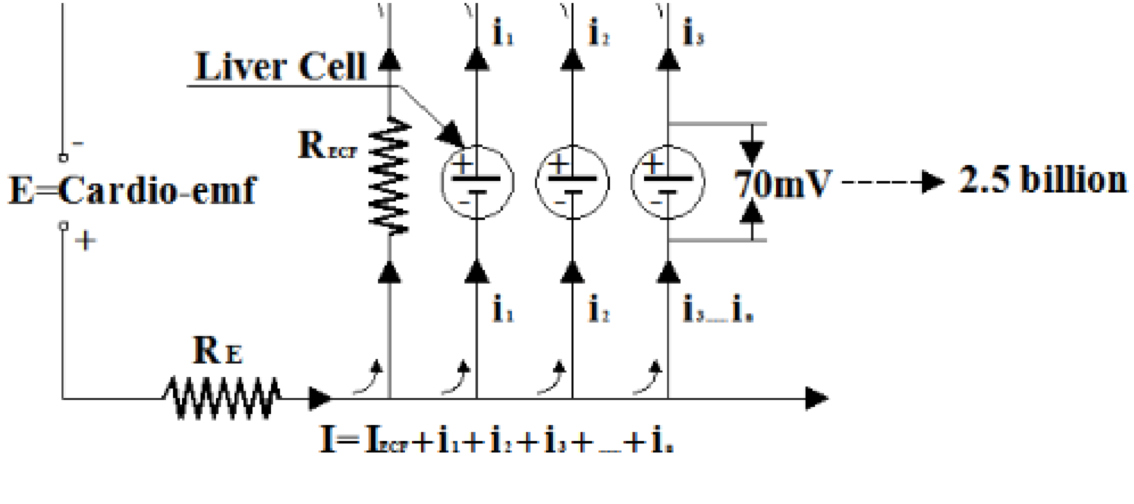
Equivalent Electrical Circuit of Transmission System





Equivalent Electrical Circuit of Transmission System





Equivalent Circuit

Circuit Analysis

- Many systems can be reduced to electrical circuits.
- Most circuits consists of three basic elements, resistors, inductors, and capacitors.
- To analyse these circuits we need to understand the basic nature of these elements.
- The nature of these elements is explained using a water analogy*.
- As any analogy, it explains most of the phenomenon but has its limitations.

*Courtesy: Douglas Wilhelm Harder (University of Waterloo)

Resistor

- Consider a pump in a closed loop of water which contains a sand filter as shown in **Fig.2**.
- The sand filter is providing a resistance to the circling water. The amount of resistance depends on the properties of the sand.

Fig 2: Loop of water with a sand filter

Resistor

- If the sand is replaced with a courser sand, as is shown in **Fig.3**, there will a corresponding lower resistance as there are larger gaps between the sand particles and consequently, the water will be able to more easily pass through the filter.
- It will, therefore, be easier for the pump to circulate the water and the current (speed of circulation) will be faster.

Fig 3: Loop of water with a coarse sand filter

Resistor

- Suppose the sand is replaced by a finer clay as shown in **Fig.4**.
- The clay is very tightly packed and will provide a much larger resistance and consequently, there will be a significant reduction in the current.

Fig 4: Loop of water with a fine sand filter

Capacitors

- Explaining a capacitor in terms of this analogy with a flow of water is more difficult; however, we will look at associating the capacitor with an unstretched membrane blocking the flow of water as is shown in **Fig.5**.

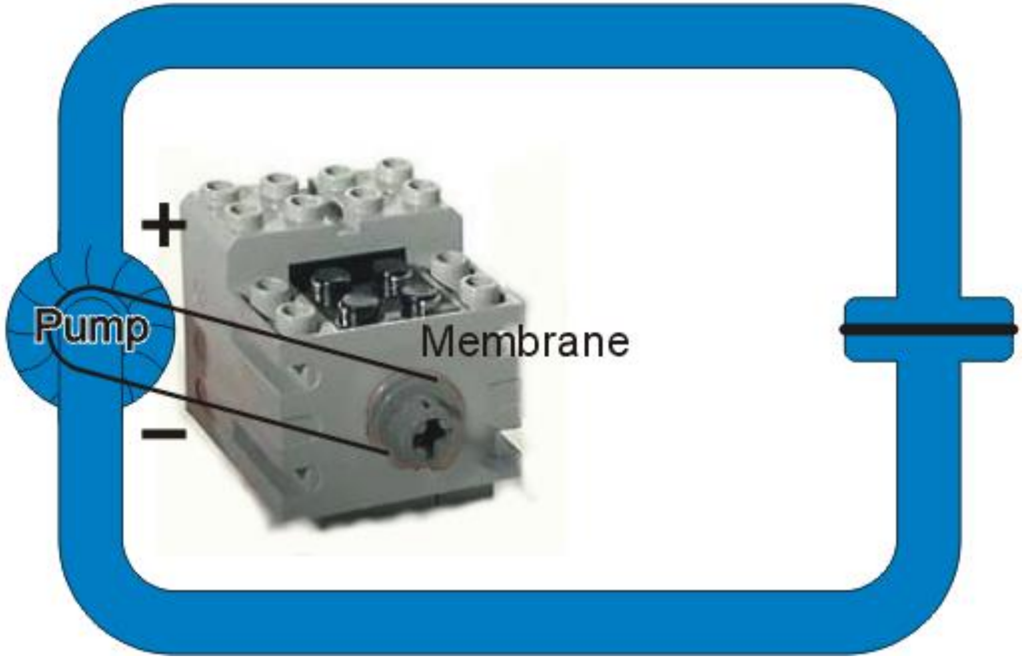


Fig 5: A pump in a closed loop with a membrane blocking the flow

Capacitors

- Suppose we turn on the pump. We now have a force which begins to move the water and consequently the membrane starts to stretch as is shown **Fig.6**.
- Since the membrane is unstretched, there is no force on it and it begins to bulge; however, soon the membrane stretches until the force from the pump equals the force pushed back by the stretched membrane.
- At this point, the initial water flow stops again.

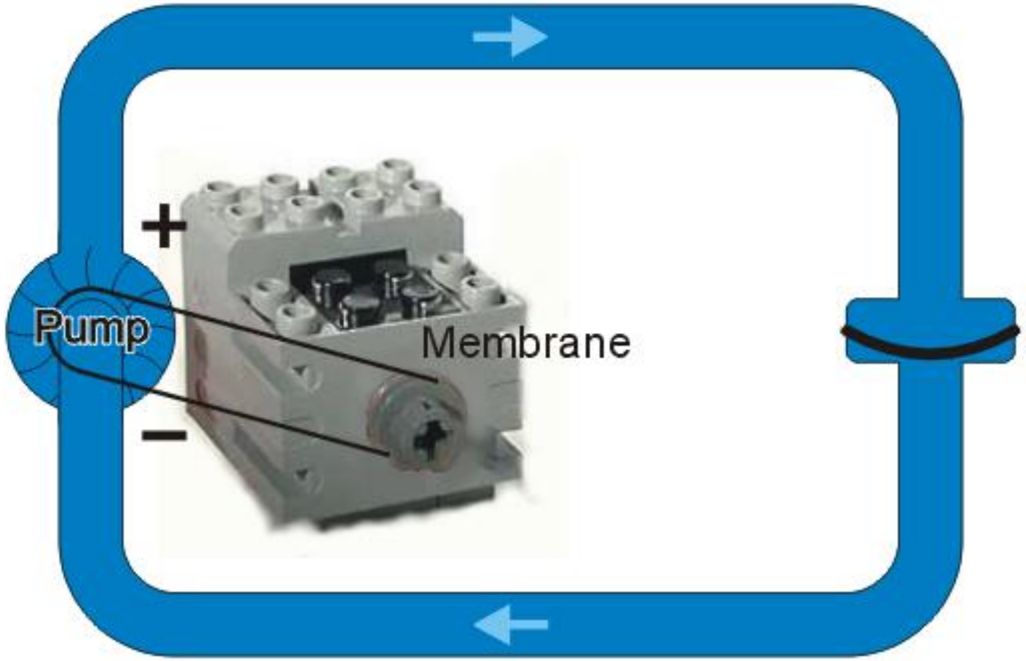


Fig 6: The membrane stretched to the point of equaling the force of the motor.

Resistor and Capacitor in Parallel

- Let us put a resistor in parallel with the membrane **(Fig.7)**.

- If the membrane is initially unstretched and the pump is turned on, the membrane will offer no resistance and thus we will have the situation where no water passes through the sand filter; however, after the membrane becomes stretched to the point where the force it pushes back with equals the force from the pump, all water flow will then be through the sand filter.

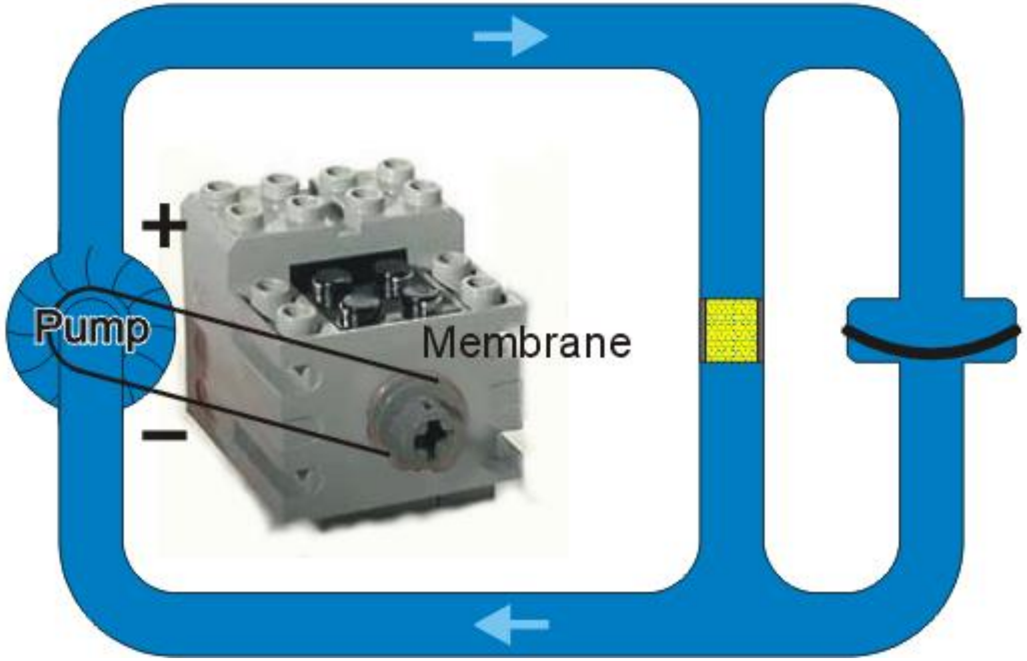


Fig 7: A membrane in parallel with a sand filter.

Resistor and Capacitor in Parallel

- Suppose we include a valve which blocks the water flowing from the pump as is shown in **Fig.8**.
- With the valve open, the membrane stretches until the force from the membrane equals the force of the pump.

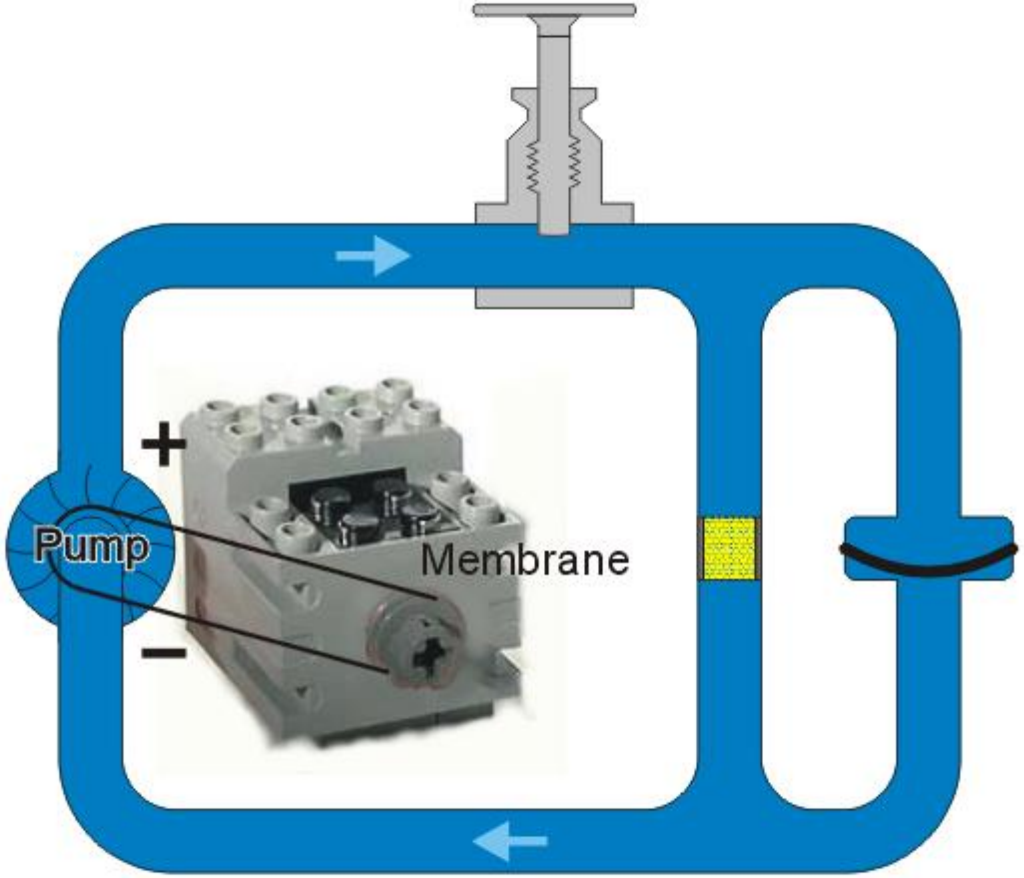


Fig 8: The addition of a valve to the circuit of water.

Resistor and Capacitor in Parallel

- When the valve is closed, the force on the membrane is now removed and it now pushes back with the same force as the pump originally pushed, as is shown in **Fig.9**.

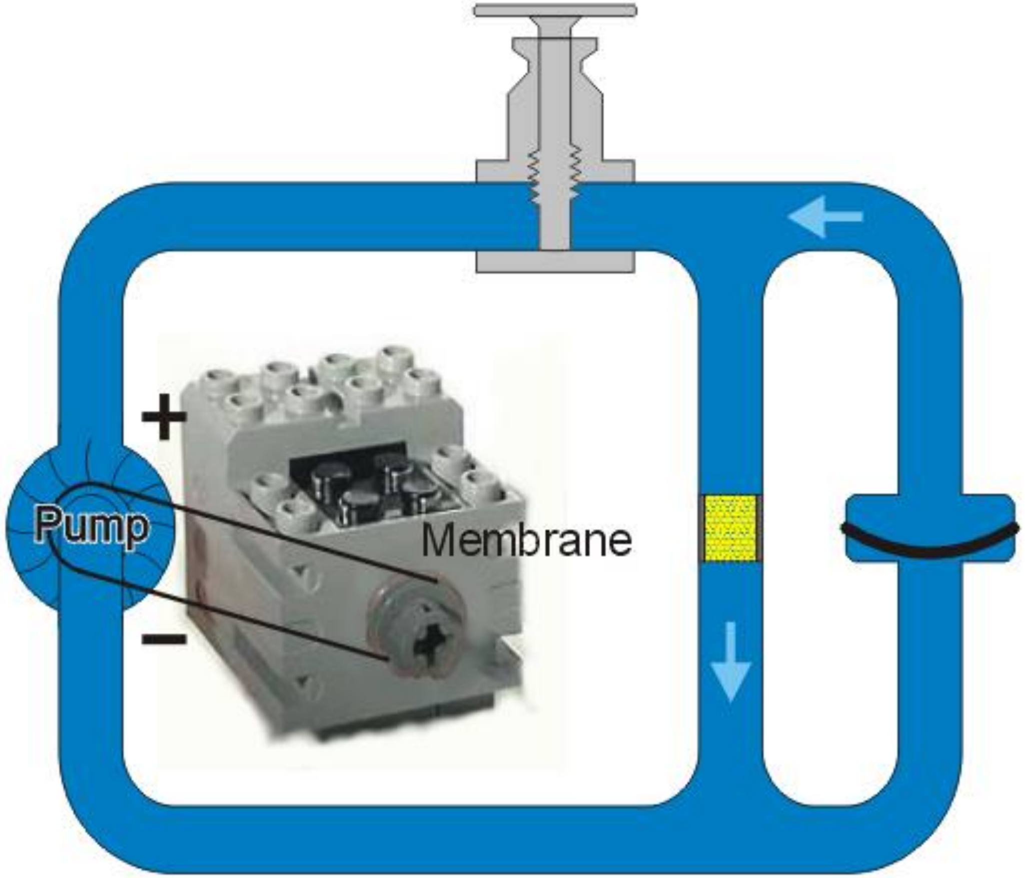


Fig 9: Closing the valve with a sand filter in parallel with the membrane.

Resistor and Capacitor in Parallel

- Once the membrane has returned to its natural position, the circulation ceases as is shown in **Fig.10**

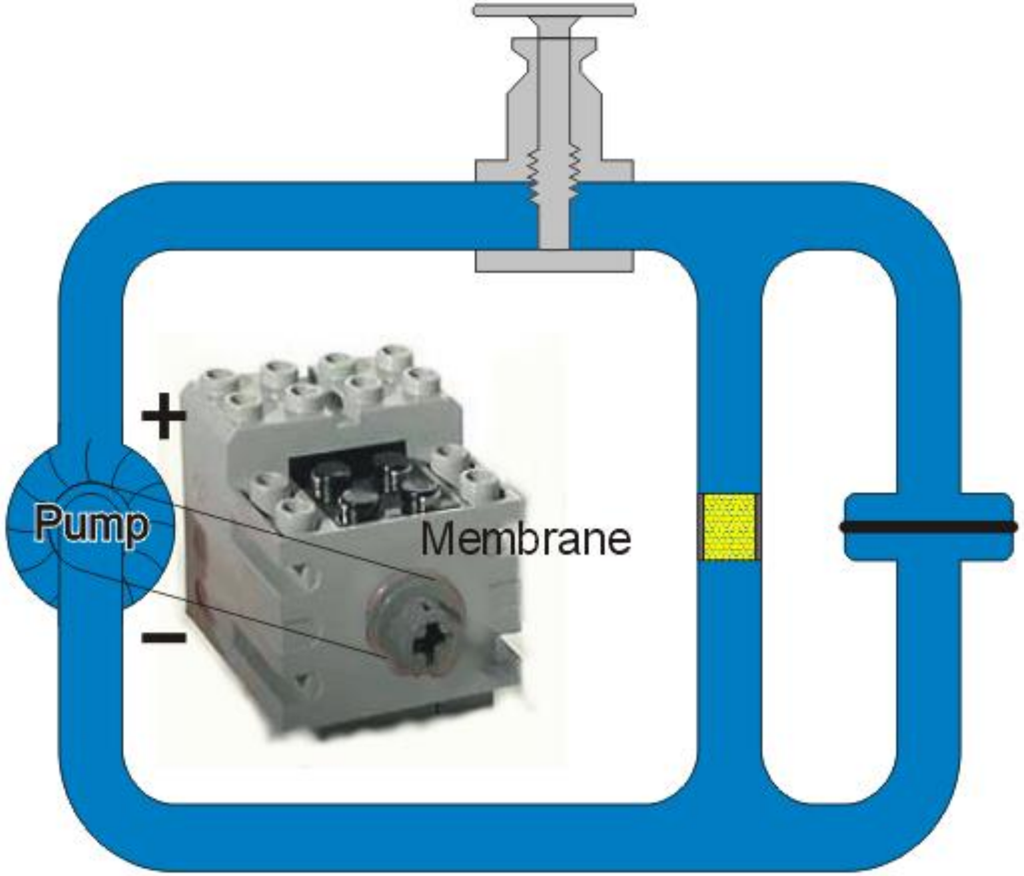


Fig 10: The flow ceasing once the membrane returns to its neutral state.

Resistor and Capacitor in Series

- Suppose we start with Figure 1 but put a sand filter in series with the membrane as is shown in **Fig.11**.

- Because the sand filter is already slowing down the flow of water, it would make sense that by adding the sand filter in series, it would take longer for the membrane to be stretched to its maximum capacity.

- As the membrane is stretching, the flow of the water is decreasing and therefore the resistance from the sand filter becomes negligible until there is no flow and the force from the membrane equals the force of the pump. Only, it will take more time**.**

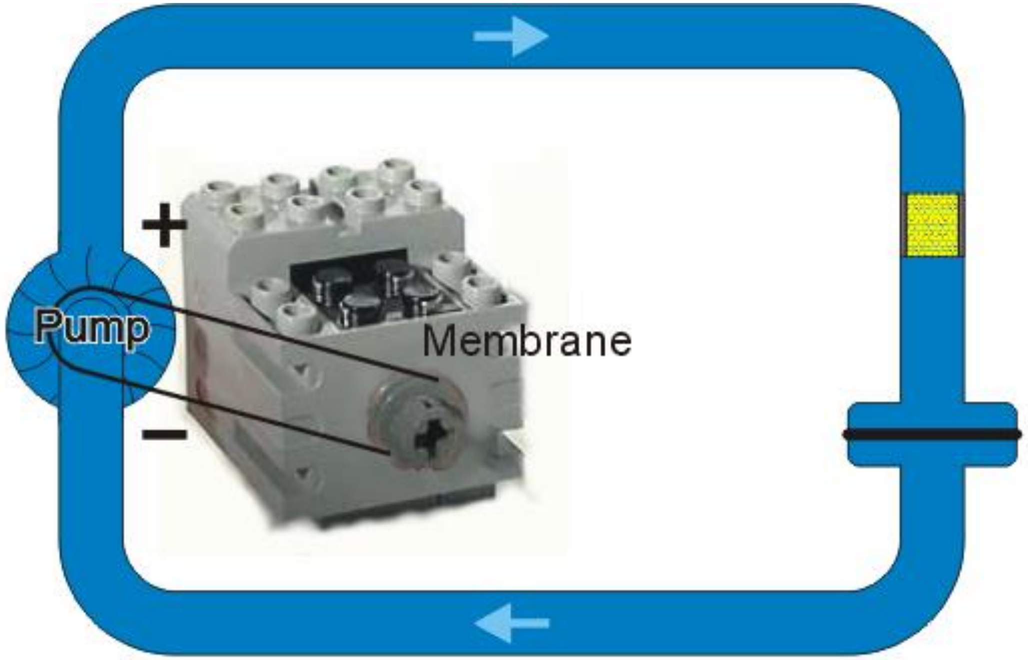


Fig 11: A sand filter in series with the membrane.

A source with a constant current

- Suppose we have an engine which we can control to ensure that the flow of water remains constant.

- In this case, as you may guess by inspecting **Fig.12**, the membrane will begin to stretch and ultimately it will rupture.

- Similarly, a capacitor will fail if placed in series with a current source. ***This analogy breaks down at this point, as when the membrane fails in this example, the water would begin to flow freely. When a capacitor is overloaded, it tends to burn out and it stops all flow.***

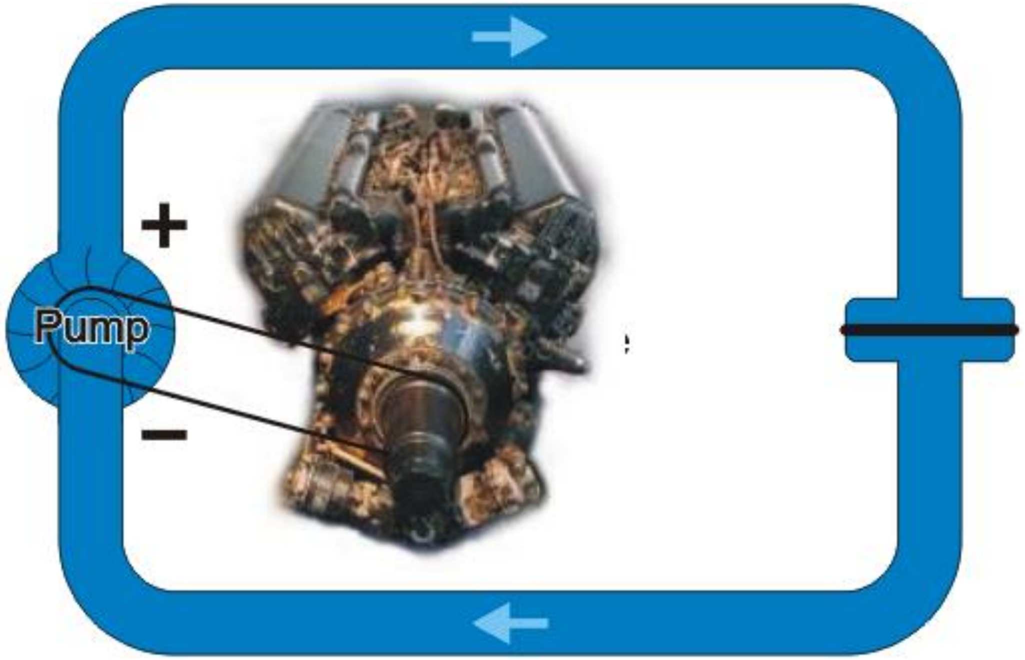


Fig 12: Using an engine which is able to provide a constant current.

Inductors

- At this point, you should understand the analogy between the sand filter and the resistor, and the membrane and the capacitor.

- Explaining an inductor in terms of this analogy with a flow of water is fortunately no more difficult than explaining a capacitor: we will associate the inductor with a water wheel which sits in the flow flow of water as is shown in **Fig.14**.

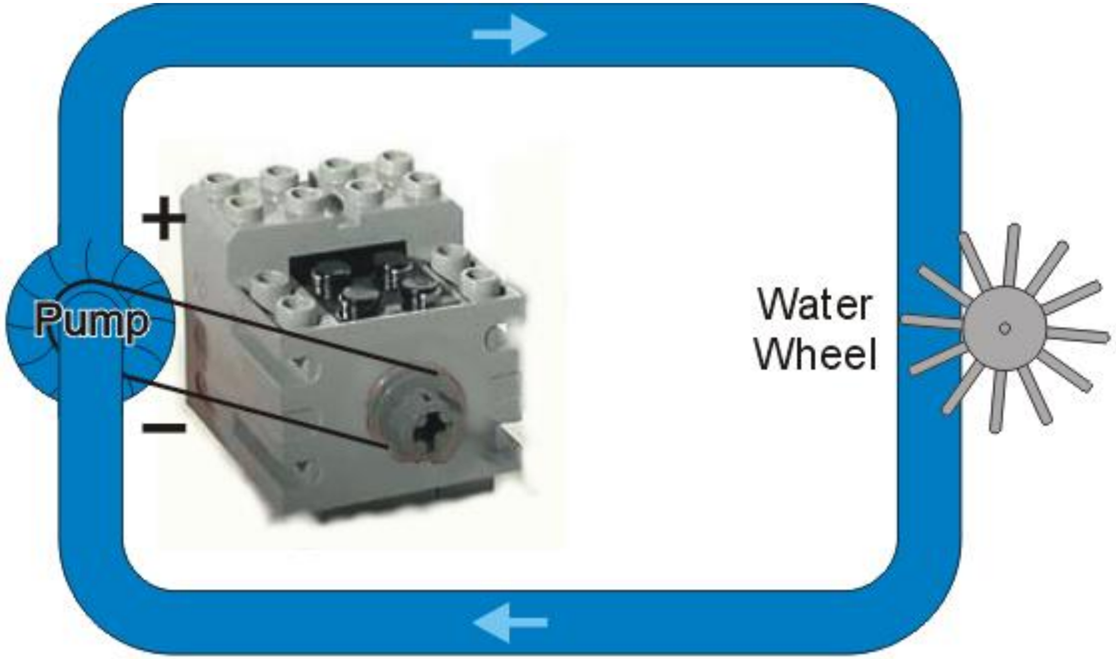


Fig 13: A water wheel in the pipe.

Inductors

- Initially, as the water wheel has mass, it does not turn (that is, it opposes the force of the pump). However, the force slowly begins to cause the wheel to turn and soon the wheel is turning at a rate equal to the flow of the water, as is shown **Fig.14**.

- If the water is not moving, the water wheel will oppose any flow. If the water wheel is moving, it will resist any change to the flow. If the power to the pump is turned off, the water wheel will continue to turn.

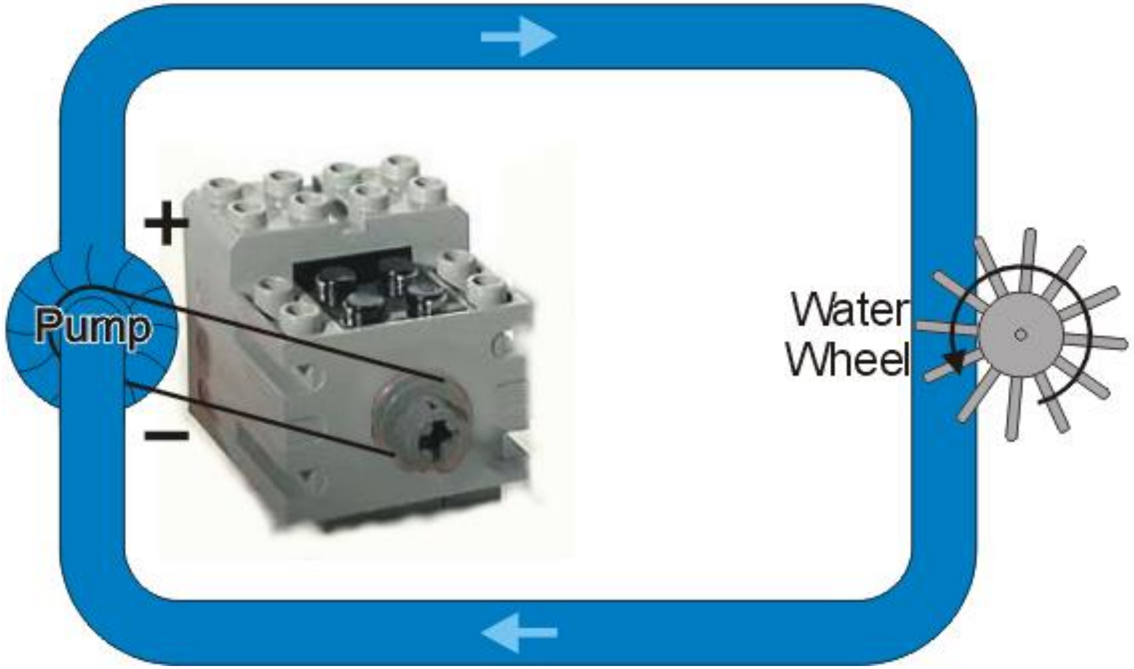


Fig 14: The water wheel in motion.

Resistor and inductor in parallel

- Suppose we place a sand filter in parallel with the water wheel as is shown in **Fig.15**.
- A valve in front of the pump is currently open.

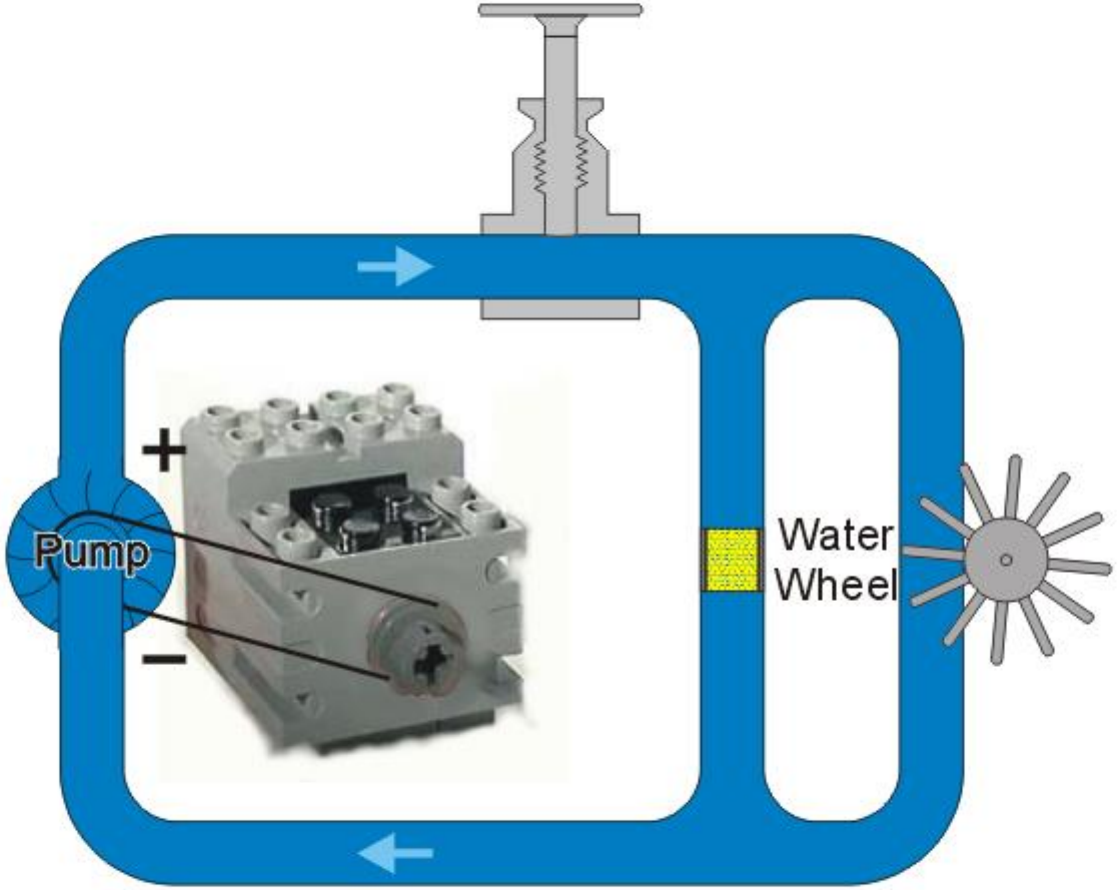


Fig 15: A valve, water wheel, and sand filter..

Resistor and inductor in parallel

- Initially, the inertia of the water wheel prevents any flow in the second pipe and therefore all of the flow is passing through the sand filter, as is shown in **Fig.16**.

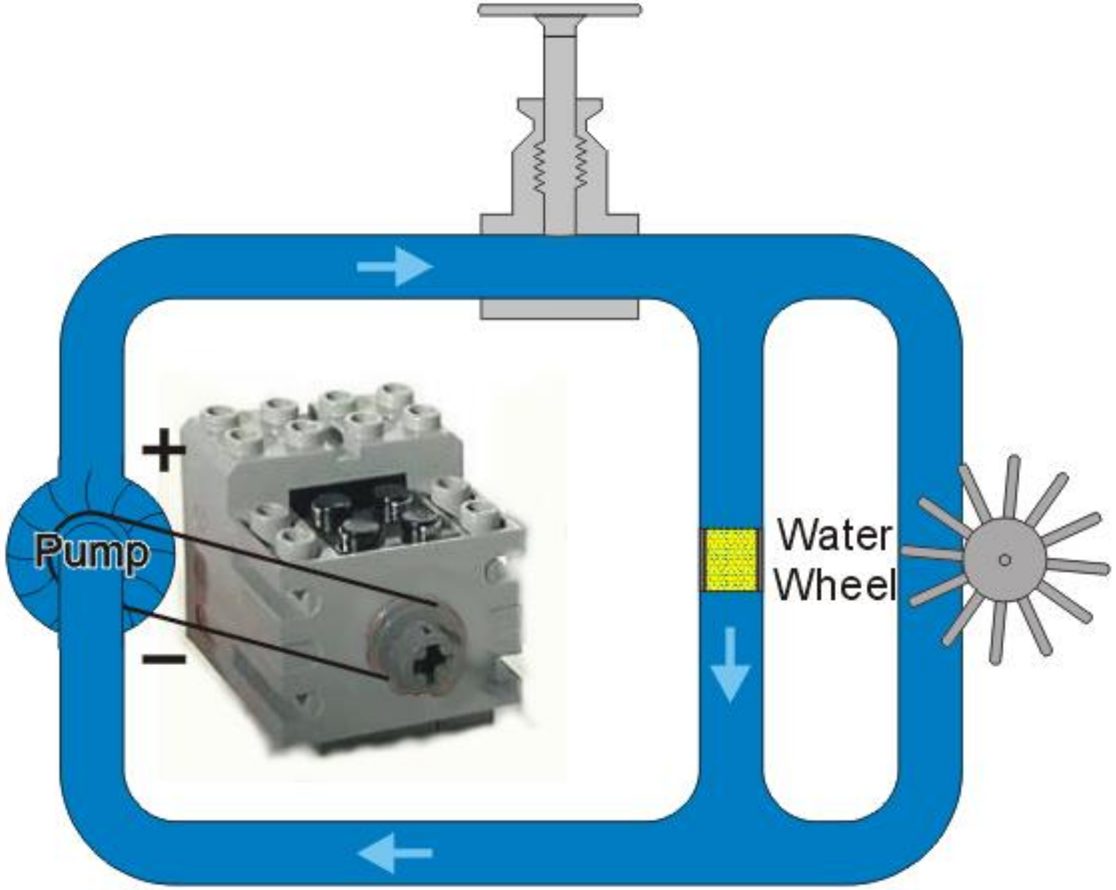


Fig 16: Initially, all flow passes through the sand filter.

Resistor and inductor in parallel

- However, as time goes on, the water wheel begins to spin and when the water wheel is turning at the same rate as the flow from the pump, no water will pass through the sand filter. This is shown in **Fig.17**.

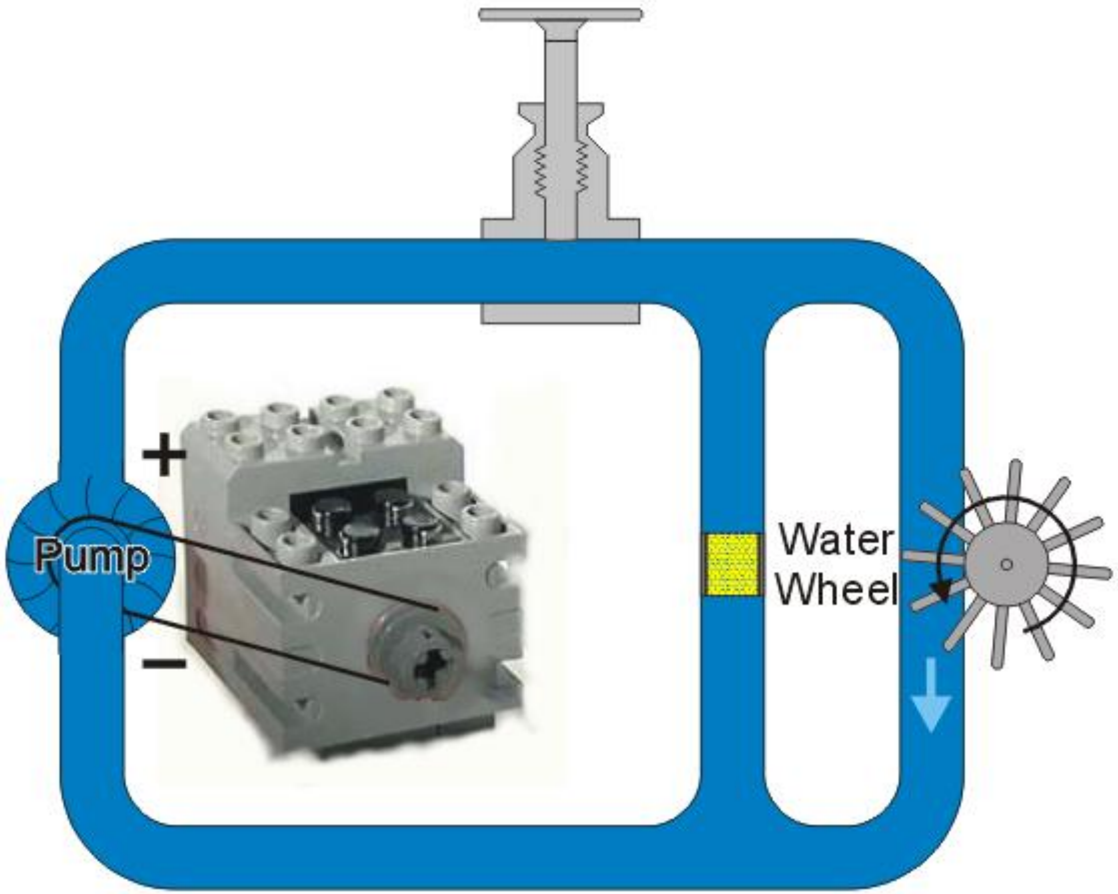


Fig 17: The water wheel is spinning and no flow passes through the filter.

Resistor and inductor in parallel

- If we now close the valve, the wheel is still spinning on its own inertia but is now pushing the water through the sand filter.

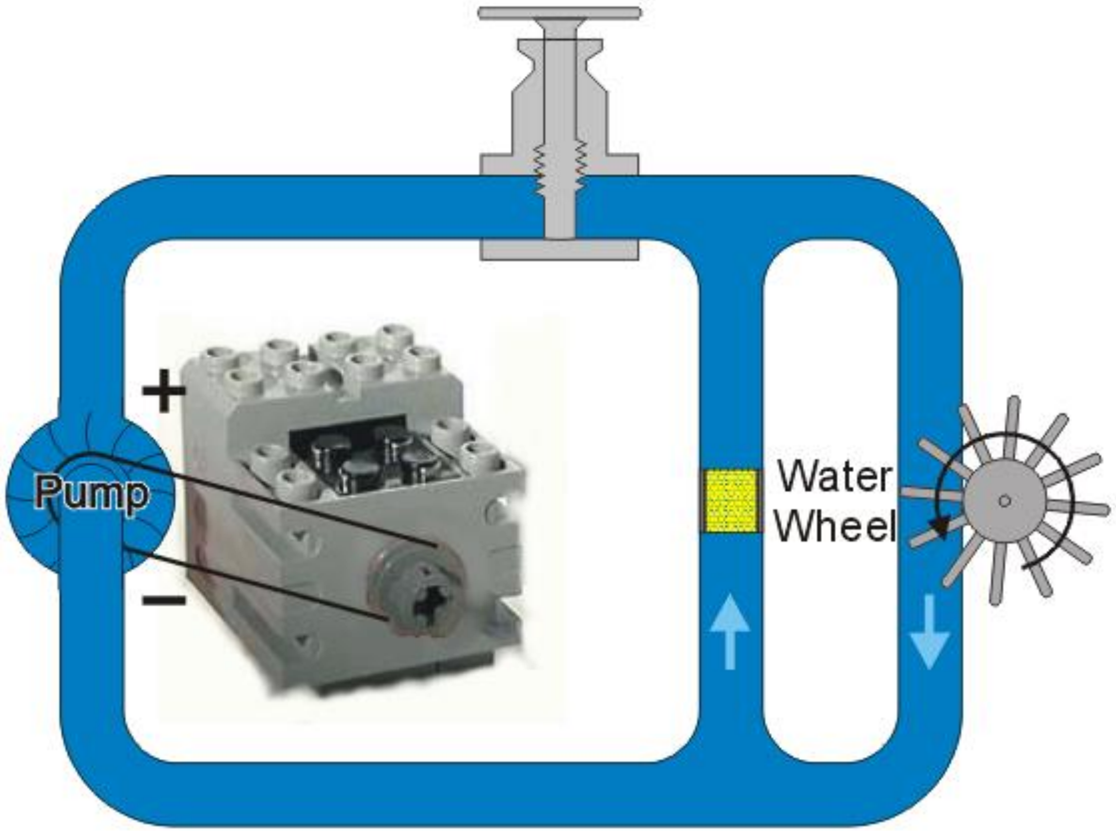


Fig 18: The wheel continues to turn when the valve is shut.

Resistor and inductor in parallel

- The sand filter is resisting the flow of water and ultimately the water wheel will stop rotating as shown in **Fig.19**.

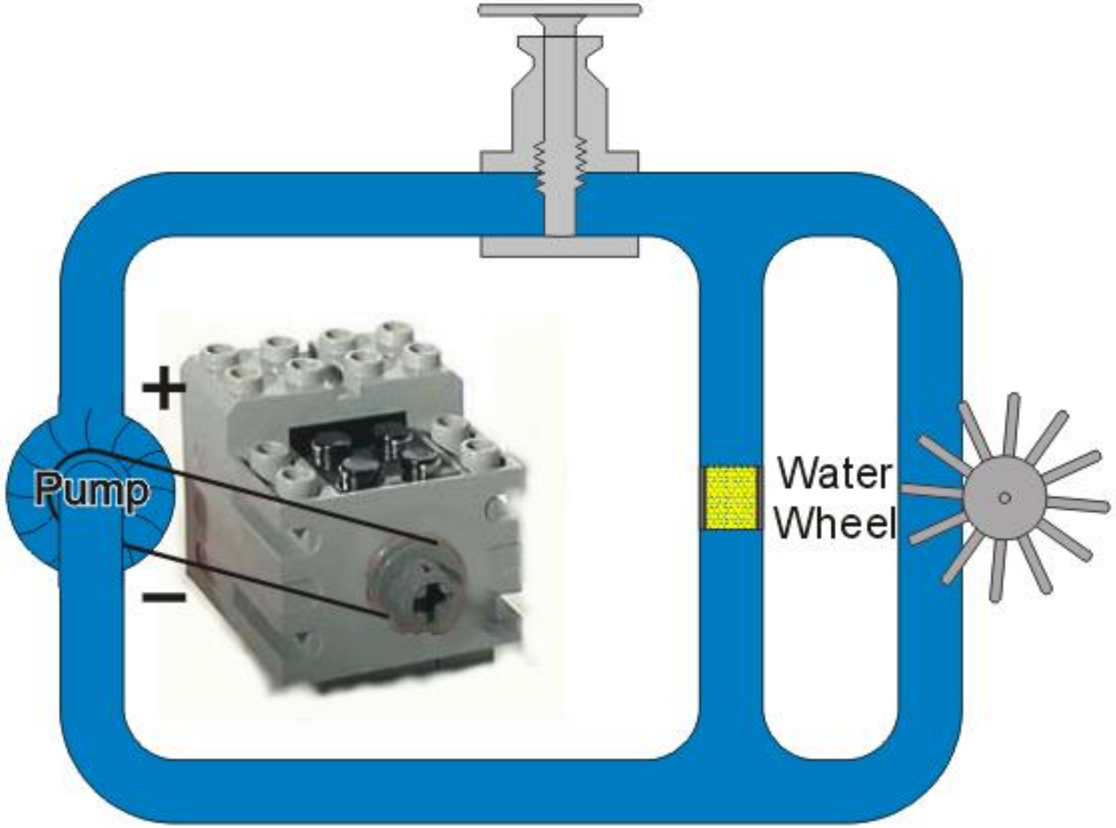


Fig 19: The energy of the turning wheel is dissipated in the sand filter

Capacitor and inductor in parallel

- Consider now a membrane and water wheel in parallel. Initially, as shown in **Fig.20**, there is a lot of resistance to flow from the water wheel while there is no resistance at the membrane.
- Thus, the entire flow starts through the pipe with the membrane.

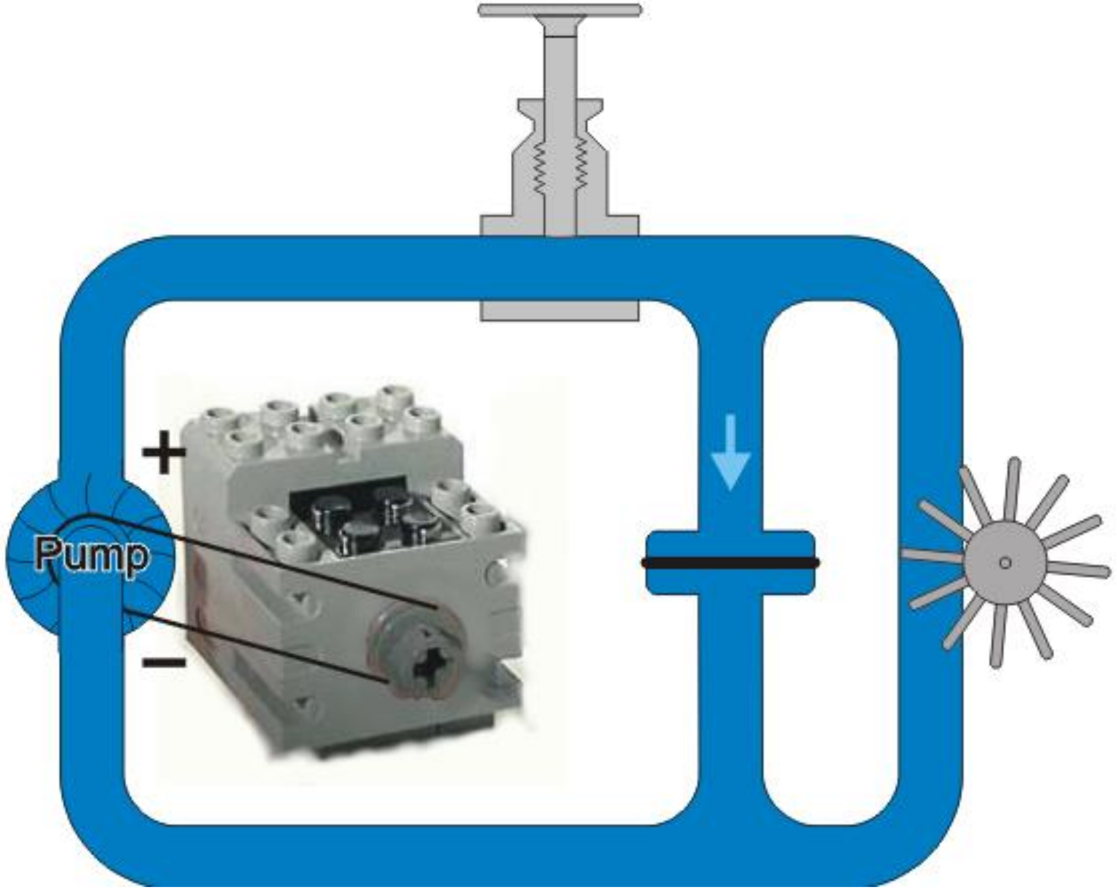


Fig 20: Flow begins through the pipe with the membrane.

Capacitor and inductor in parallel

- As the membrane becomes distorted and begins to oppose the flow of water, there is force on the wheel which begins to turn, shown in **Fig.21**.

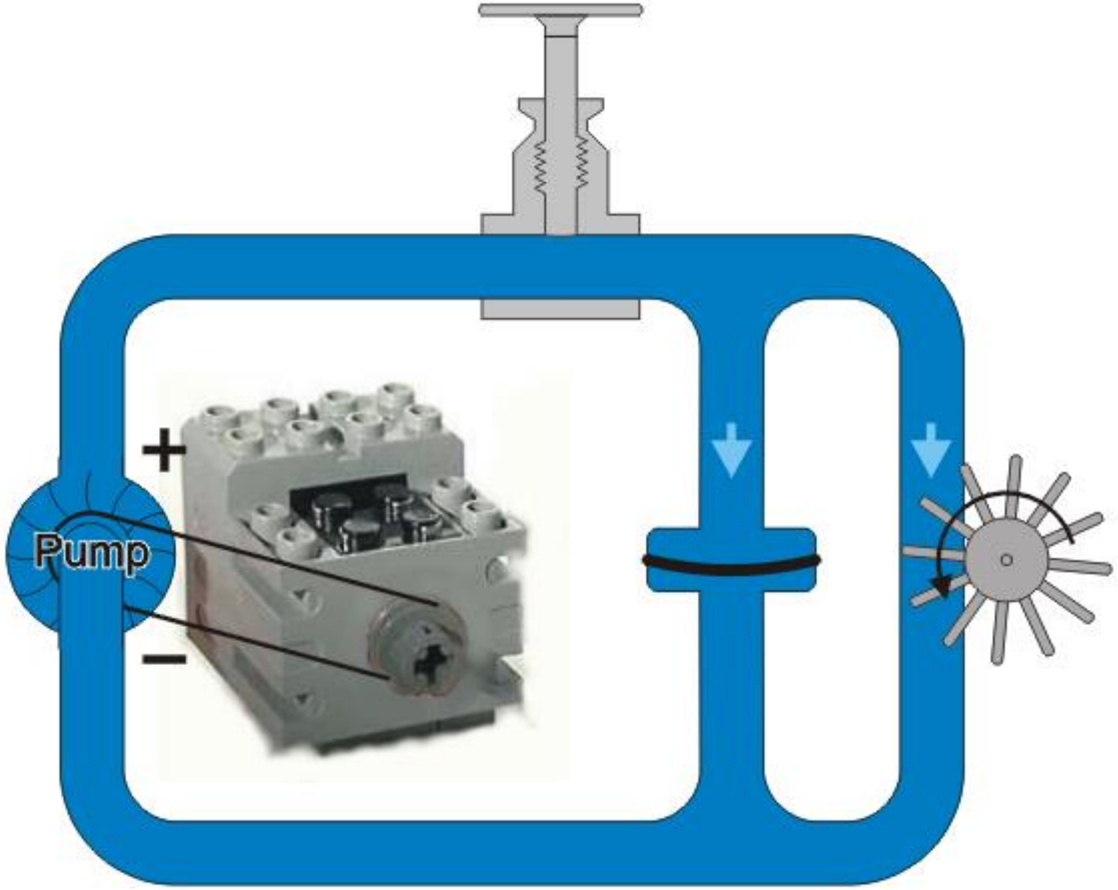


Fig 21: The water wheel begins turning.

Capacitor and inductor in parallel

- Once the water wheel begins spinning at the same rate as the flow, there is no force on the membrane and the membrane returns to its neutral unstretched position.

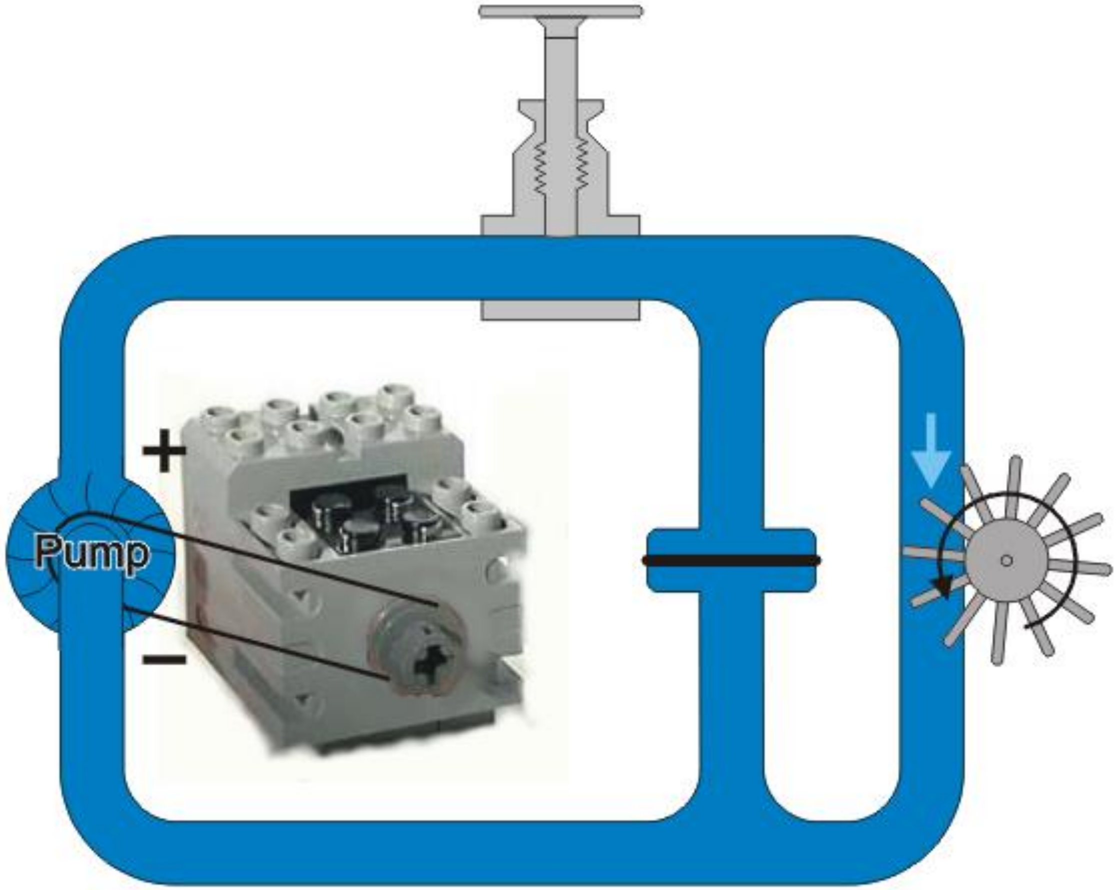


Fig 22: The wheel matches the flow and the membrane returns to the neutral position.

Capacitor and inductor in parallel

- If the valve is shut, the wheel is still turning and now it pushes the water up the pipe with the membrane as shown in **Fig.23**.
- The membrane will begin to stretch in the opposite direction.

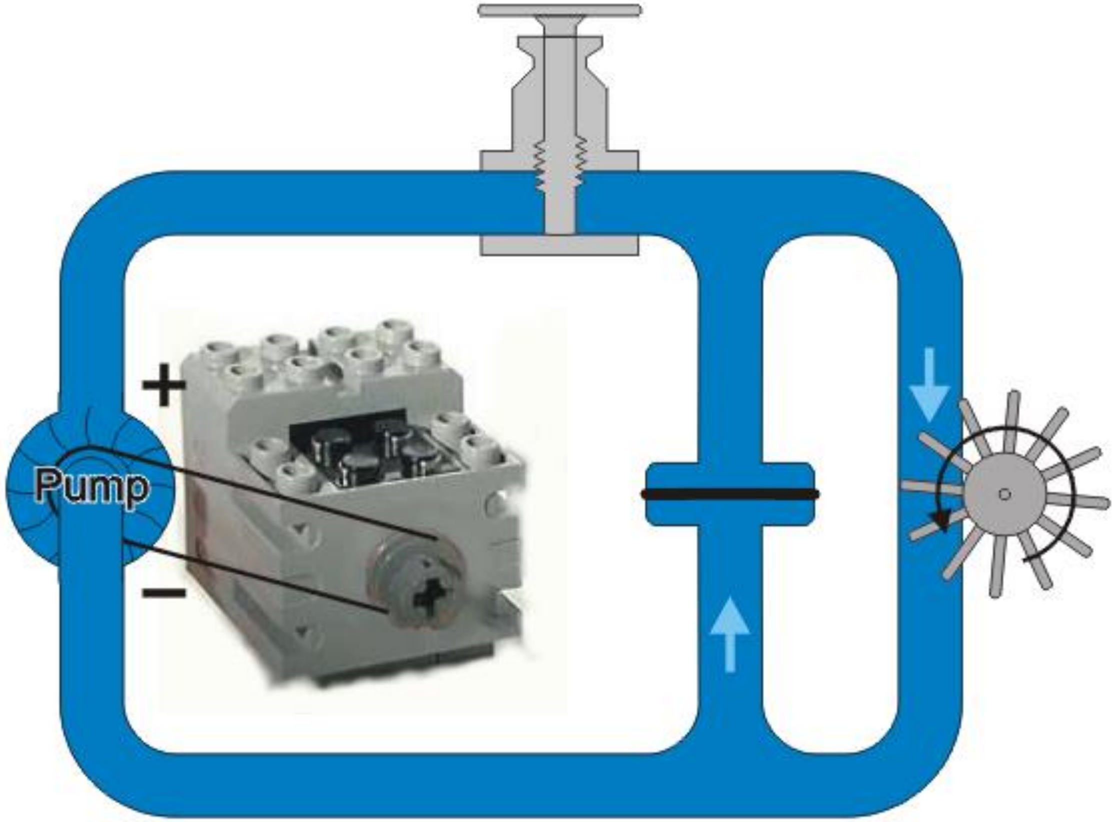


Fig 23: With the valve shut, the water is forced to flow up the first pipe.

Capacitor and inductor in parallel

- As the membrane is stretched, a force is exerted in the opposite direction which opposes the rotation of the wheel until the membrane is fully stretched and the water wheel stops, as is shown in **Fig.24**.

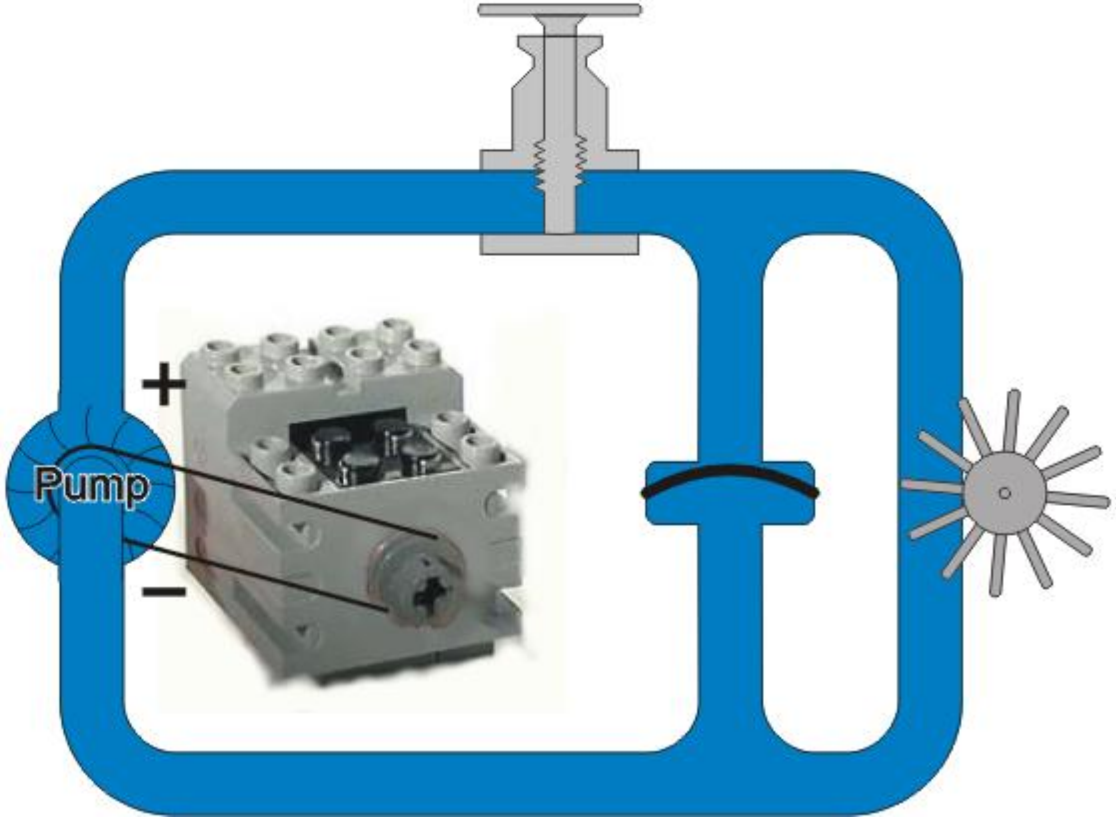


Fig 24: A fully stretched membrane.

Capacitor and inductor in parallel

- Now the membrane begins to push back to return to its neutral position and this in turn causes the water wheel to rotate. When the membrane is back it its neutral position, however, the the water wheel now rotating, as is shown in **Fig.25**.

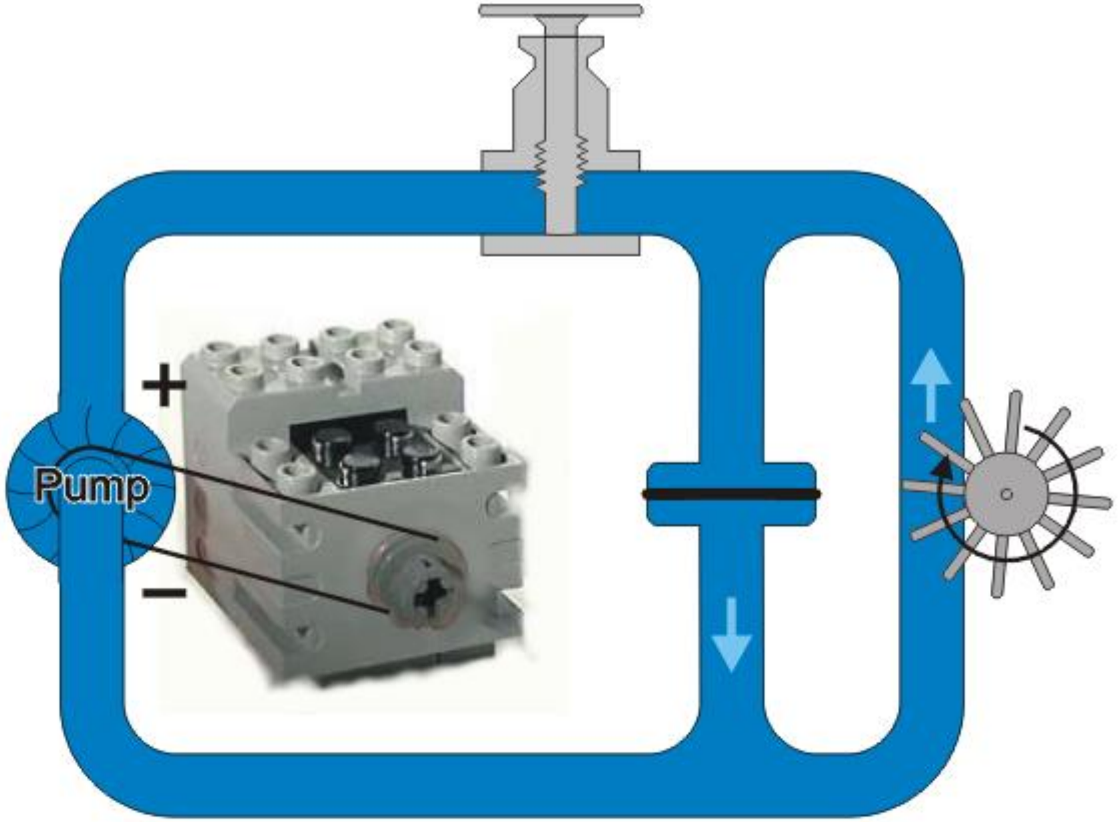


Fig 25: The membrane returns to the neutral position but the water wheel is turning.

Capacitor and inductor in parallel

- Consequently, the membrane begins to stretch in the opposite direction, as is shown in **Fig.26**.
- If there was no friction in this system and all the components were ideal, then this process would go on indefinitely; however, in reality, there is always some resistance.

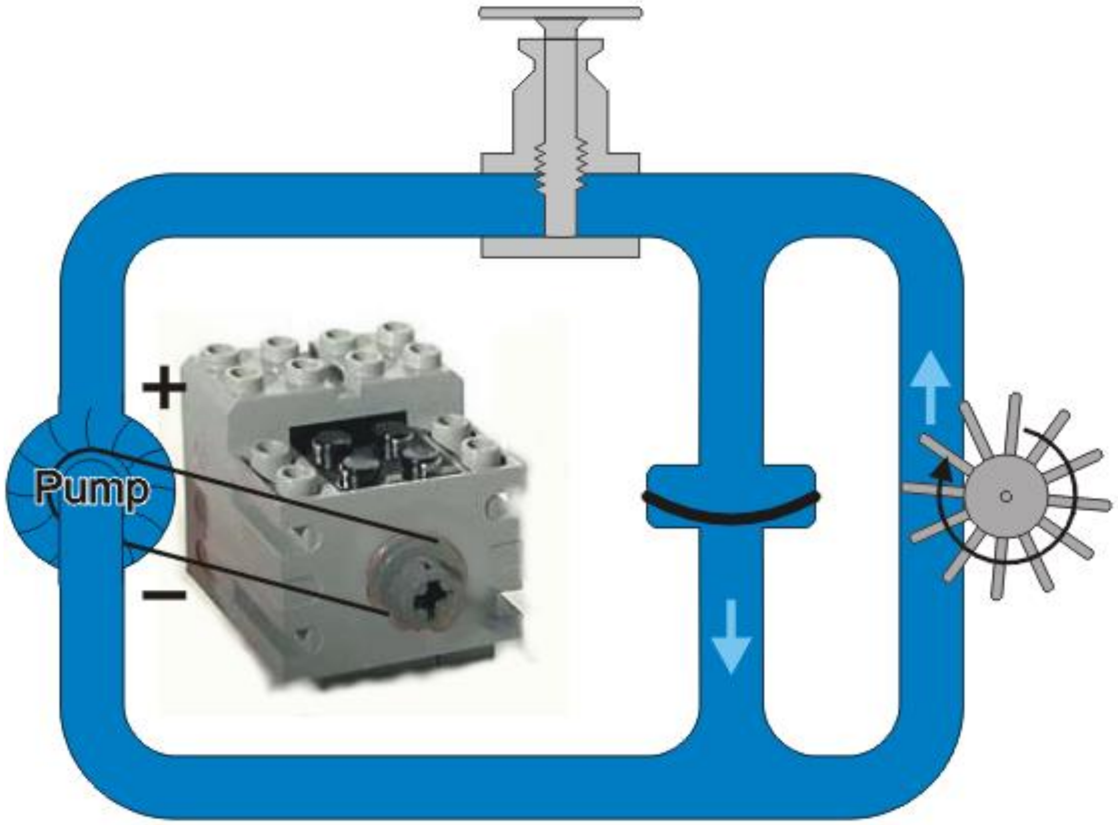


Fig 26: The membrane begins to stretch down.

Capacitor and inductor in parallel

- **Fig.27** puts a sand filter into the loop. This sand filter would ultimately absorb the energy being stored in the stretch of the membrane and the inertia of the moving water wheel until, in time, the system returns to a neutral state with no flowing water.

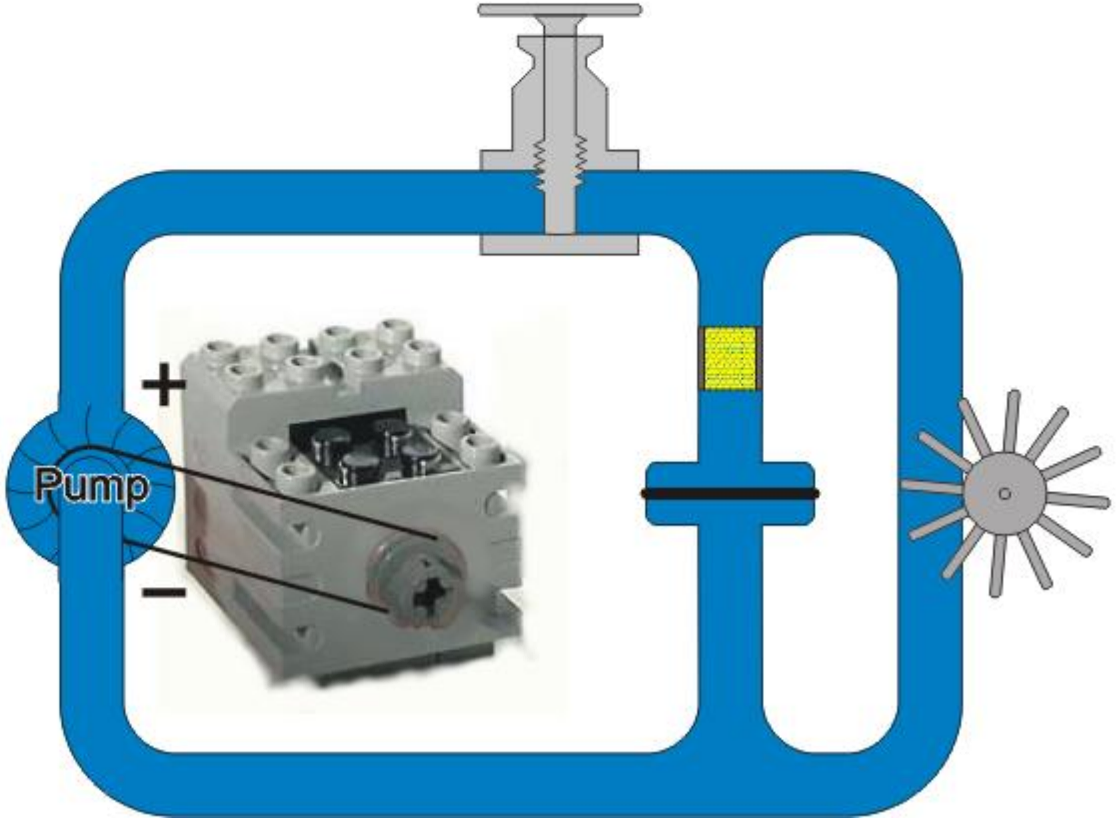


Fig 27: A sand-filter—water-wheel—membrane cycle.

Conclusion

- **This analogy intends to give an insight into three basic electrical elements: resistor, capacitor and inductor.**
- **Using this analogy, a mental image of different circuits can be build.**
- **We will be referring to this analogy time and again to gain an insight into the electrical networks.**