Chapter 1

Milestone Inventions of Control Engineering

Throughout the history, man kind has constantly invented automated devices using the mechanism of feedback control, and used these devices to automate certain tasks. In this first chapter, we will have a closer look at some of these milestone feedback control devices namely; the water clock, self-regulating wine tug, wine straw, and fly-ball governor. These devices are elegant inventions even according to the modern standards and they clearly depict the feedback control mechanism in them, which makes it easy to comprehend their principle of operation.

1.1 250 BC Flow Regulated Water Clock

Water clock and sundial are the oldest time measuring equipments. Water clock uses a water flow into or out of a container, and the time to fill or empty the container is considered as unit of time. While filling or emptying the container, the time is indicated on a scale. One of the major problems with the early water clocks was the non-linearity of the water flow; as water level drops, the flow rate reduces, which caused a gradual slow down of the rate at which water level drops. This problems was solved by Ctesibius, a Greek inventor by regulating the water flow using a float valve feedback mechanism as shown in Fig.1.1. The operation of this water clock can be explained as follows: The inlet A has a slightly higher flow rate than that of the outlet D (when the container is full). This way, the water reserve C is kept always full, and the drain valve B keeps draining out the excess water flowing into the container. The constant pressure head on the outlet D causes the outflow rate be uniform so that the cylindrical water container E gets filled

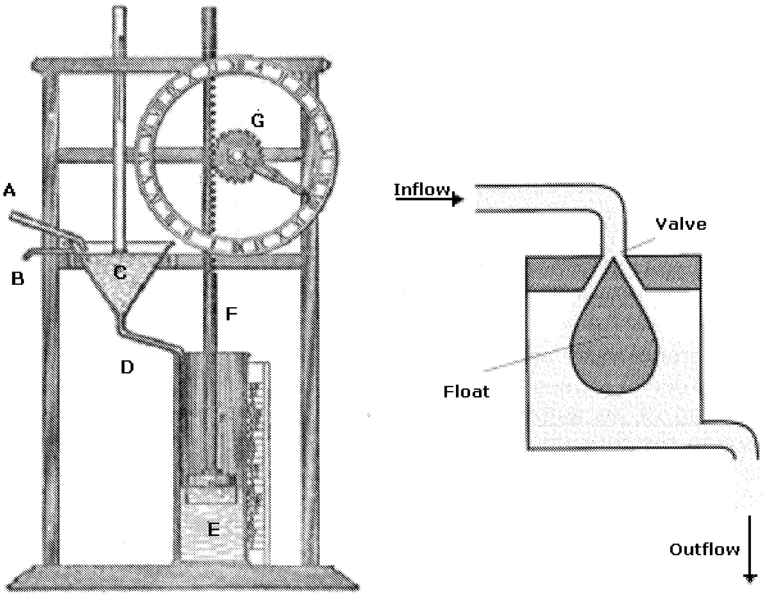

Figure 1.1: 250 BC water clock by Ctesibius of Alexandria, and his level controlled floating valve

at uniform rate and the float lever F rises turning the time indicator wheel G at uniform rate. Ctesibius further improved this mechanism introducing a float valve shown in Fig.1.1, which opens when the reservoir level drops, letting the inflow to fill it up. For a thorough account on water clocks reader is referred to [1].

1.2 200 BC Self Re-Filling Oil Lamp

Philon, another Greek inventor, one generation younger than Ctesibius invented a self re-filling oil lamp around 200 BC [2].

As shown in Fig.1.2 his invention operates as follows: as oil in the bath B is consumed by the flame, the dropping of oil level opens a gap at point V between oil surface and tube M. Air moves through this gap into the reservoir tank N, increasing inside pressure and causing its oil to drain to the bath T through capillary tubes C. The filing takes place as long as there is a drop of oil level in bath B, and it stops when the oil level rises to the desired level closing the gap at V. Capillary tubes were used to avoid air moving into the reservoir tank N through these tubes.

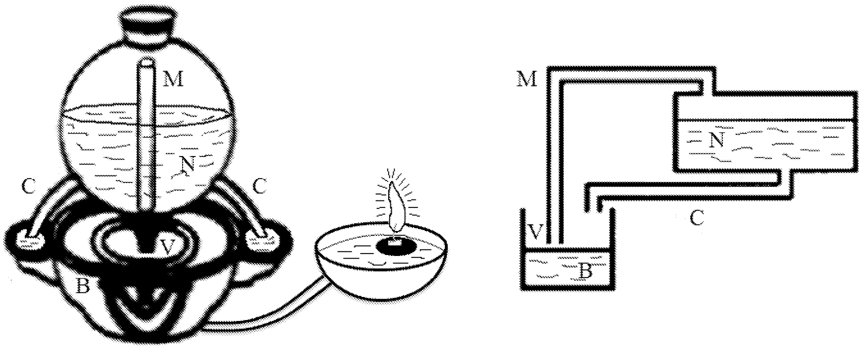

Figure 1.2: 200 BC Self re-filling oil lamp by Philon of Byzantium

1.3 1st Century AD Weight Regulated Liquid Filling Device

Heron of Alexandria developed the device shown in Fig.1.3 in the 1st century AD [2].

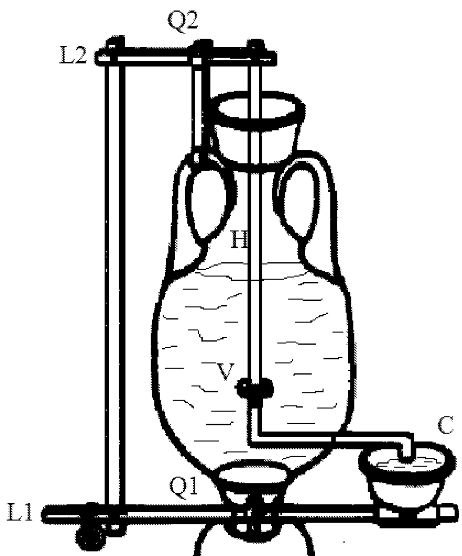

Figure 1.3: 1st century AD weight regulated liquid filling device by Heron of Alexandria, Egypt

This invention fills a cup with a liquid to a pre-specified level without operator assistance. The operation is explained as follows: WHen an empty cup in placed the level $L1$ tips around hinge point $Q1$ anticlockwise because of the weight W. This motion causes the lever $L2$ also to tip over anticlockwise around hinge point $Q2$. As a result, the rod H lifts causing valve V to open, and the liquid starts to drain into the cup. When the cup is filled to a desired level, its weight overcomes the weight of W and the lever $L1$ tips clockwise. This motion works through the linkage and pulls the rod H down closing the valve V and stopping liquid flow.

1.4 1788 AD Flyball Governor

After the first industrial Revolution, steam engines were widely used in drive systems. In vehicles and carriages it was a requirement to maintain constant speed despite uphill, downhill, lowering or lifting, as well as in view of different load levels. Speed fluctuations was a common problem that time in coal mines, where carrying carts were running at high speeds when lowering into the mine, whereas running very slowly when lifting loads and people out of the mine. James Watt together with his industrial collaborator Mathew Boulton worked out a solution and developed the centrifugal speed governor shown in Fig.1.4.

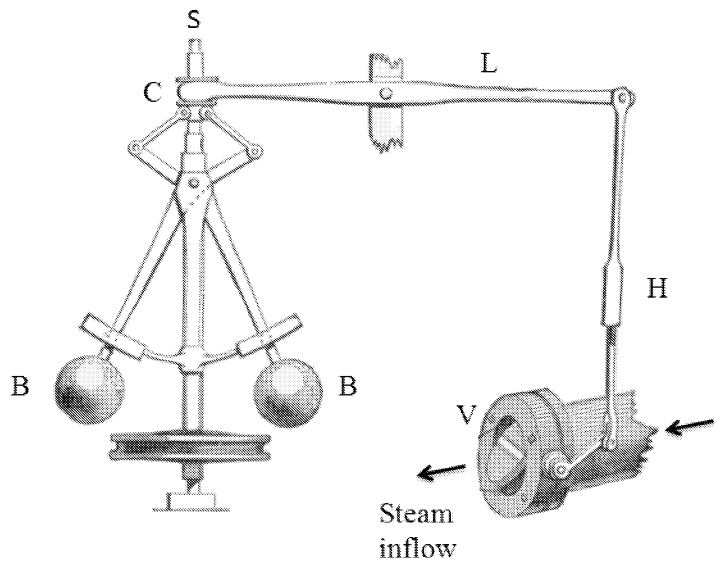

Figure 1.4: Flyball governor

The operation of the fly ball governor can be explained as follows: Lets assume that the steam engine operates at a constant speed, and the steam

valve has a constant opening. The shaft S is linked with the engine so that it turns in proportion to the speed of the vehicle. As engine speeds up the shaft S turns faster and the fly balls B swing outwards causing the hinge point C to slide downwards along the shaft S. This causes the link L to tip anticlockwise, and the linkage H lifts up; an effort to close the steam valve. As a result, steam inflow rate drops, and the engine slows down.
On the other hand, if the engine slows down due to some reason, shaft S also slows down, and the fly balls swing inwards due to gravity. This causes the sliding hinge C to slide upwards, which tips the lever L clockwise. Consequently, steam valve opens more, and the engine speeds up. This way, regulating speed at a desired value was exercised. In fact, the crude fly ball governors built early days were working to satisfactory level, but the precise fly ball governors showed unstable behavior; opening and closing of steam valve too often caused steam generating boiler to vibrate, and resonate, and blew up eventually. This problem was theoretically analyzed by Maxwell later, and showed the cause of instability. His work also showed the importance of modeling and analyzing systems and control loops to foresee the problems before physically building them. He marks the end of the intuitive design era of control systems. More information about fly ball governor and other milestone feedback control mechanisms of the past can be found in [3], whereas very early inventions based on interaction (feedback) principle can be found in [2].

1.5 Summary

In this chapter we closely observed four historical control systems. These control systems are intuition-based mechanical designs, where performance is self-regulated by mechanically feeding back the output to control the input. Careful observation of these control systems revealed us the essential concepts and principles of feedback control. Intuition is essential for the control system designer, however, intuition alone is not sufficient to design and build control systems effectively, for which modeling and analysis are indispensable as shown by Maxwell in his work of explaining the stability problem of flyball governor based engines. In contrast to the pure mechanical designs that we studied in this chapter, in modern days, we almost always design control systems with electronic sensors to monitor the performance, and use microprocessor based controllers to command the actuators what to do to regulate the system.