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PRECURSORS OF THE AUTOMATION IN THE HELLENISTIC AGE

Cesare Rossi

University of Naples "Federico II", Dept. of Industrial Engineering, Italy

ABSTRACT

Some devices conceived by scientists and engineers of the Hellenistic Age are presented. They be considered the precursors of the automation and clearly show how the concept of automation was present in the minds of ancient scientists and engineers since the II century B.C. or even earlier. The devices also clearly show the surprising modernity of the knowledge of the ancient scientists and engineers, both in conceiving the mechanical designs and the building of them. The chosen examples are presented by grouping them by inventor.

Keywords: Ancient automatic devices, Automata, History of Mechanism and Machine Science

1 INTRODUCTION

The word "automatic" comes from the ancient Greek αυτοματος, an adjective meaning literally self-moving or self-acting. So, also in ancient times, the term and the concept had practically the same meaning we use today.
Moreover, the oldest clues about these ideas are probably found in the Greek mythology. For instance, in the Iliad, it is told that the god Hephaestus (Iliad, XVIII, vv. 519-525) built some "automata" that helped him in his smith works.
Another legend tells that king Minos used a bronze mechanical giant, Talos, forged by Hephaestus, to patrol the isle of Krete.
As far as we can recognize of the past, automatic devices were first designed by the scientists/engineers of the Hellenistic Age; this is to say in the Mediterranean Area and in a period of time that strictly ranges between 323 B.C. and 31 B.C. but, from a cultural point of view ranges between the III Century B.C and the II Century A.D..
In this period of time, the human knowledge had a very considerable "jump" in almost any field of the culture and put the basis of the society in which we live today.
Concerning the scientific and technical knowledge, in particular, most of the inventions developed in this period of time were beaten not earlier than in the XVIII Century [1-15].

Contact author: Cesare Rossi

E-mail: cesare.rossi@unina.it

2 CTESIBIUS

Ctesibius (285–222 B.C.) was the director of the Library of Alexandria and is credited of a large number of inventions, several of them being automatic devices [1-5]. Among these, one of the most interesting can be considered the water clock, shown in figure 1; in the figure a virtual reconstruction and technical drawings showing the working principle are reported. To understand the reason why an automatic device was required for a water clock, we must remember that the length of a roman hour was not constant since it was defined as 1/12 of the time between sunrise and sunset during the day and 1/12 of the time between sunset and sunrise during the night. Thus, the time duration of one hour was different from day to night (except at the equinoxes) and from a given day to another one. The water clock designed by Ctesibius solved this problem [1].
A bottom tank is filled by a constant water flow from a top tank that is permanently maintained full. A yarn, wrapped in coil around the pointer axle, is connected to a floater and to a counter weight. The bottom tank is drained daily and the cycle starts again. The dial is fitted on an off-centre shaft on which a gear having 365 teeth is fitted; once a day the float passes through a certain position and moves a rod that pushes one tooth, hence the dial completes a revolution in one year.

3 DIONYSIUS OF ALEXANDRIA AND PHILON OF BYZANTIUM

The invention of the repeating catapult is tributed to Dionysius of Alexandria, (III Century B.C.) and was described by Philon of Byzantium (280 b.C. circa – 220 b.C. circa) [1, 15-19].

ISSN 1590-8844
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It can be considered as a concentration of the most advanced mechanical kinematic and automatic systems of the time, many of which are still widely used.

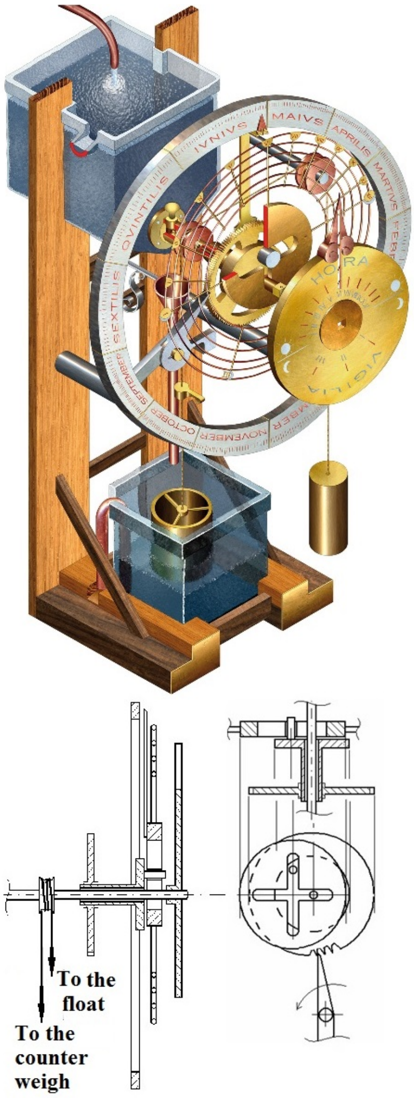

Figure 1 Ctesibius' automatic water clock. Adapted from [1].

According to the author's recent reconstruction, based on previous works and from Philon's description, the device is really automatic. Pictorial reconstruction and technical drawings of it are shown in Figures 2 and 3. The device essentially consisted in a container holding within it a number of arrows, a cylinder feeding device and movement chain. According to Philon, the arrows were located in a vertical feeder F and were transferred one at a time into the firing groove by means of a rotating cylinder C, activated alternatively by a guided cam, in turn activated by a slide. One of the longer interior teeth T of the chain pulls the slide S which in turn pulls the cord, loading the coils of the motor. In the same time, an attached cam caused a 180° rotation in the direction of the cylinder, drawing an arrow from the loader and placing it in the channel in front of the rope.

When the slide reached the rear of the weapon, the cog released it, while another opened the release mechanisms. An instant later, upon completion of sprocket rotation, the same cog coupled with the slide from underneath, pulling in the opposite direction. Near the top of the weapon, the second device closed the hook after it had retrieved the cord, while the feeder cylinder picked up another arrow from the feeder. A half rotation in the sprocket and the cycle was repeated.

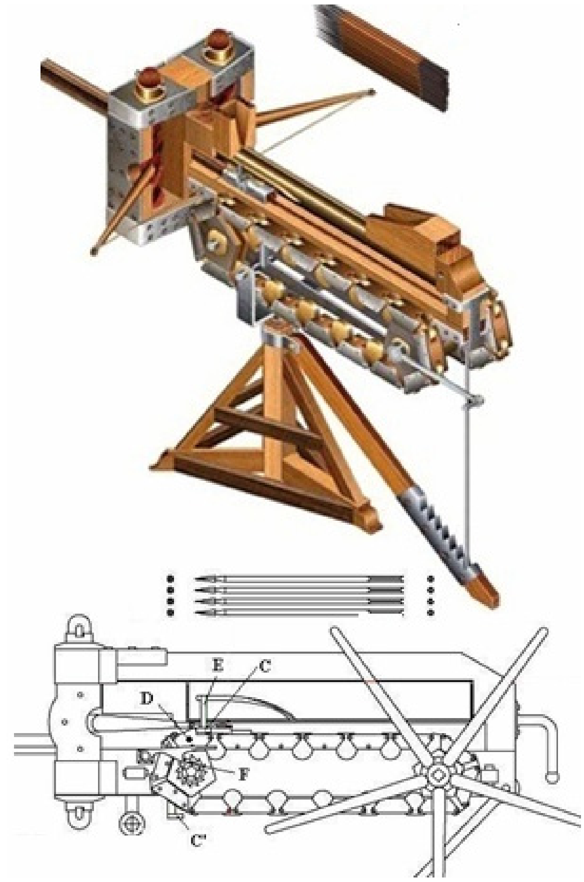

Figure 2 Pictorial reconstruction and technical drawing of the repeating catapult. Adapted from [15].

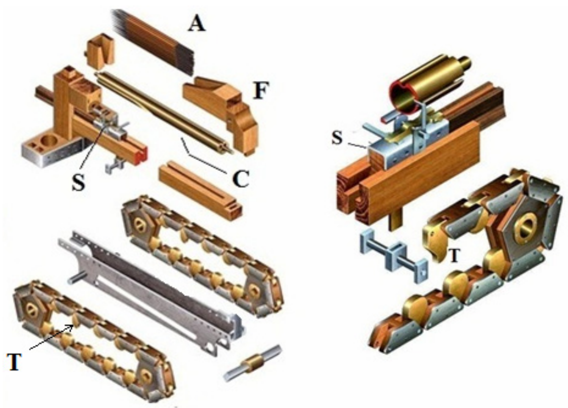

Figure 3 Mechanism of the repeating catapult. Adapted from [1].

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It must be observed that our reconstruction, based on our translation of text by Philon, is really automatic; this because, differently from previous reconstructions, a simple rotation of the crank was sufficient to move the cylinder, the slide, the slide hooking mechanism and the trigger mechanism.

4 HERON OF ALEXANDRIA

Heron of Alexandria was probably the best known designer of automatic devices in ancient times. Although very few is known about his life, he is well-known for a wide number of his inventions in different fields; probably the widest fields of his inventions is the automation [1, 20, 21].
The main treatises by Heron about automatics (Pneumatica and Automata) were translated during the Italian Renaissance by Berardino Baldi, [22] (1553–1617), and by Giovan Battista Aleotti [23] (1546-1636); both describe a wide number of automatic devices. Some of the most interesting examples are reported in the following.
The most famous automatic device by Heron is probably the mechanism to open and close the doors of a temple shown in figure 4 with a virtual reconstruction.

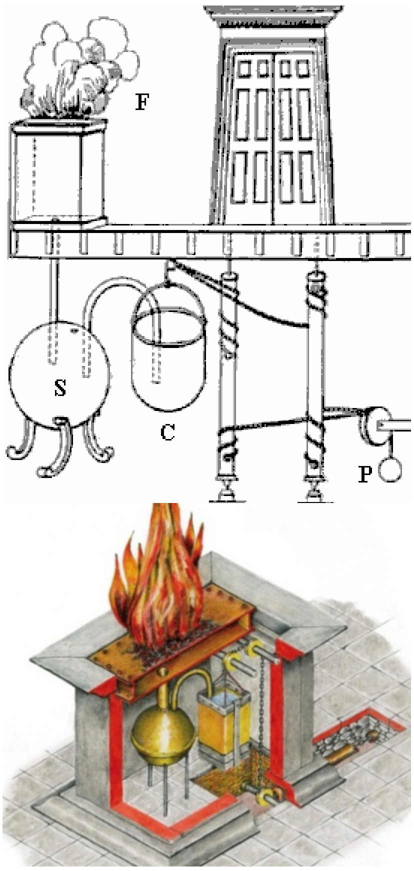

Figure 4 Heron's Mechanism for temple doors and virtual reconstruction, adapted from [20].

A fire was lit on the brazier F; so, the hot air heated the water in the pressure tank S. The pressure in this tank pushed the water in the mobile water container C through a U-shaped pipe. The mobile water container was connected to the temple doors by means of ropes or chains wrapped in coils on the door hinges. As the water container was filled with water, because of its weight the ropes were unrolled and the doors were opened. When the fire was extinguished, the steam in the pressure tank condensed, hence, the pressure in it decreased and the water was sucked up from the water container. As soon as the weight of the latter decreased enough, the counterweight P acted on the door hinges in the same way, but closing the doors.
Another interesting example of Heron's automata is reported in figure 5 where a reconstruction is shown made by G. B. Aleotti [23] of a famous Heron's automaton. This automaton was made up by two main characters: Heracles and a dragon. In few words: the dragon hisses, Hercules beats it with a club and the dragon spits on Hercules. The working principles can be deduced by Aleotti as it follows and is shown in the lower part of figure 5.

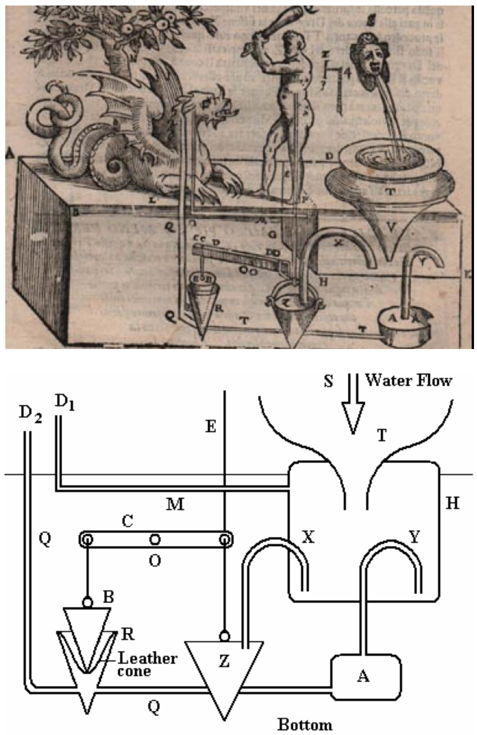

Figure 5 Aleotti's reconstruction of an Heron's automaton and working principle, adapted from [1].

A water flow from S fills a tank H through a funnel T. When the tank H is filled the air flows through a small pipe M that is linked to the dragon's mouth and this one hisses. A rocker C can rotate on a pin O; one of its arms is linked to a cone B and to a rope E, while the other arm is linked to a water container Z; the latter, if empty weighs less than cone B. As the water level in the tank goes up, the water fills the mobile water container Z through the U-shaped pipe X. When the mobile container Z is heavier than cone B, the rocker C rotates clockwise and rope E moves Hercules' arms through a simple T-shaped mechanism, not represented. In this way the club is lifted up.

ISSN 1590-8844
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At the same time, through pipe Y, tank A, pipe Q, and the cone R are filled. Since the mobile water container is conical, when it reaches the bottom, it turns upside down and the water in it is evacuated. Now cone B is heavier than container Z and the rocker rotates counter-clockwise. The rope R is tightened and the club beats the dragon's head. At the same time, cone B gets inside cone R that is full of water and so the pressure in the pipe Q rises. This pipe is linked to the dragon's mouth and so the latter spits a water jet onto Hercules. To Heron was also ascribed the water distributor that represent the ancestor of the modern drink vending machine. In figure 6 a scheme of this device is shown [23].

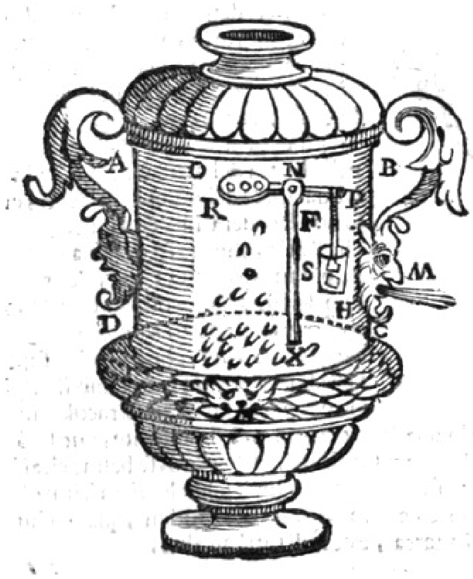

Figure 6 Aleotti's drawing of an Heron's vending machine.

The device provided an amount of water once a coin of 5 drachms was put in the slot. The weight of the coin, in fact acted on the plate R of the rocker arm N that, rotating, opened the valve S, permitting to an amount of water to flow outside from the hole M. Due to the rotation, the coin felt down and the rocker arm rotate in the opposite verse, closing the valve.
Another interesting device is the regulator for the distribution of the liquids; this device, in fact, represent a first example of feedback control.
In figure 7 a drawing by Aleotti [23] is shown. The vase on the left is the one from which the liquid is taken and the level of which must be always kept constant. The vase on the right is the one that is used for the feedback. Both the vases are connected by a pipe, so the level of the liquid inside them is the same.
Once some liquid is taken from the vase on the left, the level of the liquid tends to go down in the vase on the right also. Inside the latter a float is located that is connecter by a rod to the rocker arm H. So even a small a decrease of the level, causes the opening of the valve EF and the filling of both the vases; this until the balance is one more time reached.

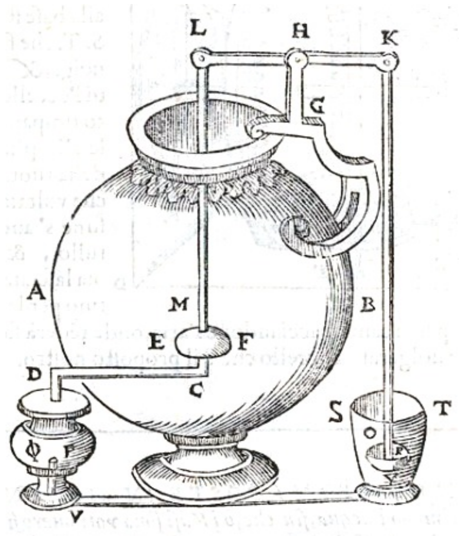

Figure 7 Aleotti's drawing of an Heron's regulator for the distribution of the liquids [23].

But Heron's most surprising automatic device is probably the programmable self-moving automata. These latter were described by B. Baldi [22] and were conceived as "actors" in a puppet theatre. On the theatre proscenium all the performance was played by those automata that were, hence, programmable. In figure 8 drawings from Baldi's work are reported, showing the working principle and the counterweight motor that moved those automata.

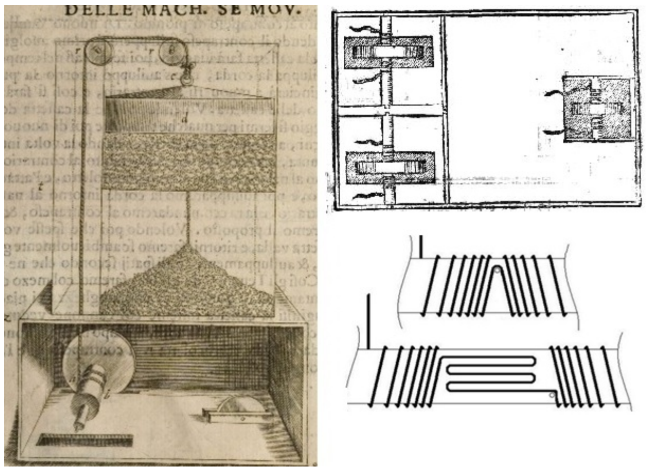

Figure 7 Heron's programmable self-moving robot

In the figure, on the left, one can observe the counterweight that is located in a tank filled with millet or mustard seeds in order to regulate the counterweight motion, hence the automaton speed. The same figure on the left shows the axle of the driving wheels divided in two axle shafts that are independent one from the other; on each one of the shaft a rope is rolled. If the rope is rolled on one of the axle shaft in a different way from the other, when the counterweight goes down pulling the rope, one of the two driving wheels will rotate in different way from the other one.

The programming of the motion was also obtained by putting some knobs on the axle shaft like shown on the bottom right of figure; by these knobs it was possible to modify the rolling of the rope, in order to obtain different laws of motion for each wheel [24-26].

4 CONCLUSIONS

Some examples of automatic devices were presented, all belonging to the Hellenistic Age. This historical period, in fact, represents a period of time during which the human thought and knowledge had a deep improvement especially concerning technology and engineering. The presented examples show how advanced were our predecessors about 2000 years ago. Most of their inventions, in fact, were beaten not earlier than in the XVIII Century [1-4]. So, we should give them a tribute for having "placed the foundation" of our knowledge and of our comfortable life nowadays. Moreover, it can be interesting (and may be also instructive) to observe how some devices represent solutions of problems that were obtained with a design showing a brilliant simplicity.

REFERENCES

[1] Rossi C., Russo F., Russo F., *Ancient Engineers' Inventions, Precursors of the present*. Springer, ISBN: 978-90-481-2252-3, 2009.

[2] Russo L., (reprint), *La rivoluzione dimenticata. Il pensiero scientifico greco e la scienza moderna*, Feltrinelli, Milano, ISBN 88-07-81644, 2003.

[3] Rossi C., On Designs by Ancient Engineers. *Journal of Mechanical Design*, Vol. 135, ISSN: 1050-0472, doi: 10.1115/1.4024362, pp. 1-2, 2013.

[4] Rossi C., Some Examples of the Hellenistic Surprising Knowledge: its Possible Origin from the East and its Influence on Later Arab and European Engineers. *Rivista Storica dell'Antichità*, XLIV, pp. 61-84, 2014.

[5] Russo F., Rossi C., Ceccarelli M., Russo F., Devices for Distance and Time Measurement at the time of the Roman Empire. *HMM Int. Symp. on History of Machines and Mechanisms*, Tainan, Taiwan, Nov. 10-14, pp. 101-114, 2008.

[6] Chondros T.G., The development of machine design as a science from classical times to modern era. *HMM Int. Symp. on History of Machines and Mechanisms*, Tainan, Taiwan, Nov. 11-14, Springer, NL, ISBN 987-1-4020-9484-2, 2008.

[7] Chondros T.G., Archimedes life works and machines. *Mechanism and Machine Theory*, Vol. 45, No. 11, pp. 1766-1775, 2010.

[8] Dimarogonas A.D., *Machine Design a CAD Approach*, John Wiley and Sons, Inc. N.Y. 2001 (Introduction - The machine: an istorical design, pp. 4-19)

[9] Rossi C., Unich A., A Study on Possible Archimede's Cannon. *Rivista Storica dell'Antichità*, Vol. 43, ISSN 0300-340X, 2013.

[10] Rossi C., Ancient Throwing Machines: a Method to Compute Their Performances. *Mechanism and Machine Theory*, Vol. 51, ISSN 0094-114X, pp. 1-13, 2012.

[11] Publius Flavius Vegezius Renatus - *Epitoma Rei Militaris*, Liber IV, cap. XVII.

[12] Penta F., Rossi C., Savino S., Mechanical Behavior of the Imperial Carroballista. *Mechanism and Machine Theory*, Vol. 80, ISSN: 0094-114X, pp.142-150, 2014.

[13] Vitruvius (I Cent. B.C - I A.D.), *De Architectura*, Liber X.

[14] Mays L., *Ancient Water Technologies*, Springer, 2010. ISBN 978-90-481-8631-0, e-ISBN 978-90-481-8632-7, doi: 10.1007/978-9

[15] Rossi C., Russo F., A Reconstruction of the Greek-Roman Repeating Catapult. *Mechanism and Machine Theory*, Vol. 45, No. 1, ISSN:0094-114X, pp. 36-45, 2010.

[16] Shramm E., *Die antiken Geshützen der Saalburg. Reprint, Bad Homburg*: Saalburg Museum, 1980.

[17] Marsden E.W., *Greek and Roman Artillery Historical Development*, Oxford University Press II, 1969.

[18] Soedel V., Foley V., Ancient Catapults. *Scientific American*, pp.101-114, March 1979.

[19] Russo F., Rossi C., Russo F., Automatic weapons of the Roman Empire. *EUCOMES 2008 2nd European Conf. on Mech. Science*, Sept. 17-20, Cassino, Italy, 2008.

[20] Russo F., Il miracolo di Erone (The miracle by Heron, in Italian). *Archeo*, n.201208, ISSN 1120-4559, Aug. 2012, pp. 96-101.

[21] Heron of Alexandria, "*Perì Automatopoietikès" Heronis opera quae supersunt omnia* ed. W. Schmidt/L. Nix/H. Schöne/J. L. Heiberg, Leipzig 1899.

[22] Baldi B., *Di Herone Alessandrino de gli avtomati ouero machine se moventi libri due. Tradotti dal greco da B. Baldi*. – Venezia, 1602.

[23] Aleotti G.B., *Gli artificiosi et curiosi moti spiritali di Erone. Bologna*. The Archimedes Project, Digital Research Library, 1589.

[24] Sharkey N. *The programmable robot of ancient Greece* - New Scientist #2611, July 4, 2007.

[25] Webb B., The first mobile Robot? *Proc. TIMR 99 Towards intelligent Mobile Robots*, 1999.

[26] Rossi C., Pagano S., A Study on Possible Motors for Siege Towers. *Journal of Mechanical Design*, Vol. 133, ISSN:1050-0472, pp.1-8, 2011.