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BANU MUSA, THE FOUNDERS OF AUTOMATIC CONTROL IN THE 9th CENTURY

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ABSTRACT

The three sons of Musa bin Shaker (Banu Musa) lived in the 9th century AC during the Abbasid empire played an important role in the scientific revolution of the Arabic / Islamic civilization. They were pioneers in mathematics, astronomy and mechanics of machines (ingenious devices). They spent a lot of money encouraging the translation movement of scientific works. They established a remarkable research work in the areas of geometry, astronomy and applied mechanics. Their inventions in the field of ingenious devices led to the establishment of applied feedback automatic control systems for the first time in the history of technology. The paper views their scientific activities with emphasis on their book "Kitab al-Hiyal" or ingenious devices and presents two of their level control systems.

KEYWORDS

History of automatic control, Medieval centuries, Arabic sciences, Banu Musa, Level control systems.

1. INTRODUCTION

Arabic / Islamic civilization was the dominant and unique scientific civilization in the world during the medieval centuries. They took over after the Roman civilization and lasted for more than ten centuries. They translated to Arabic most of the Greek and Roman manuscripts, studied them, criticized them and added new explanations and applications. Besides, the y invented new sciences not known before them.

The Arabic civilization considered science the basis for their development, starting by basic sciences such as physics, chemistry and mathematics and ending with applied sciences such as medicine, astronomy, applied mechanics and military sciences.

Some of the western world scientists tried to deny the role of the Arabic/Islamic civilization as an international civilization flourished in the medieval centuries [1-4]. On the other hand, some of the western writers confirmed the role of Arabs and Muslims in the history of science [5-9].

A lot of schools were established in the Islamic world besides some universities in Baghdad, Cairo and Qurtoba. Libraries covered most of the Islamic World, in the east, west and Andalos. In 896 AC, there were more than 100 library in Baghdad [10], while in Qurtoba of Andalos, there were 70 library [11]. Special research academies were established in the Islamic World. Among those was "Bayt al Hikma (house of wisdom) in Baghdad established by Al-Ma'am caliph [12]. It had an outstanding library, an observatory and an accommodation facilities for scientists.

2. WHO ARE BANU MUSA?

They were three brothers: Mohammed, Ahmed and Al-Hassan. Their father was Musa bin Shaker, an astronomer, mathematician and a personal friend to Al-Ma'mun [13]. When their father died, they were children and Al-Ma'mun was abroad. So, he wrote to the authorities in Baghdad to send Banu Musa to Bayt al-Hikma under the supervision of the astronomer Yahya bin Abi Mansour [13].

Banu Musa had grown in the scientific environment of Bayt al-Hikma, and soon became a team of the most famous scientists during the Abbasid regime. Mohammed was the eldest son, then Ahmed, then Al-Hassan. The three brothers as Ibn Al-Nadim said were mainly preoccupied with geometry, ingenious devices (al-hiyal), music and astronomy sciences [15]. Mohammed worked in the sciences of geometry and astronomy. He had good knowledge about Euclid and Almagset [13]. Ahmed was an expert in ingenious devices (al-hiyal), such that he ranged further than his brothers and the ancient scientists [13]. Al-Hassan was extremely distinguished in geometry and he could solve problems unsolved before him [13].

3. BANU MOSA AND THE TRANSLATION MOVEMENT

The Arabic scientists did not start their research from zero. They started from the last level reached by the preceding civilizations of Greek, Roman and Indian. This required a sincere and enormous efforts in a translation movement led by Abbasid Caliphs themselves specially Al-Ma'mun.

Banu Musa had a distinguished role in the translation movement:

They paid a group of translators such as Hunayn ibn Ishaq, Hubaysh ibn Al-Hassan, Thabit bin Qurra and others about 500 dinars a month for translation and attendance [16].

They sent emissaries to Byzantium to bring manuscripts and translators and paid generously for such purpose [15].

The elder brother Mohammed used to travel to Asia Minor to buy manuscripts [15]. In one of his trips, he brought with him Thabit bin Qurra for translation purposes. Thabit lived and educated in Mohammed's house. He became later one of the famous mathematicians in the Islamic empire.

4. SAID ABOUT BANU MUSA

Δ **Al-Qafti**: "The three brothers were most proficient with geometry and ingenious devices. They wrote an astonishing book known as Hiyal Banu Musa which are devices of noble invention and are remarkably valuable [13].

Δ **Al-Nadim**: "Those people dedicated themselves to study ancient science, gave up all pleasure, wore themselves out and sent to Byzantium (Rume countries) who obtained knowledge, thus revealing miracles of wisdom"[15].

Δ **George Sarton**: "The three brothers, sons of Musa bin Shaker, mathematicians, astronomers, patrons of science" [17].

Δ **Donald Hill**: "Banu Musa used crankshafts for the first time in the history of technology 500 years before the first description of crankshafts in Europe" [18].

Δ **Zeghrid Honka**: "Banu Musa had an outstanding creative and inventioning mentality which developed the innated machines and invented new other machines" [19].
Δ **Ahmed Al-Hassan**: "The Islamic technological writings by Banu Musa, Al-Jazari, Al-Muradi and Taqi Al-Din have offered the West a relatively advanced mechanical technology" [18].

5. BANU MUSA AND ABBASID CALIPHS

- The patronage of scientists and engineers was always a deliberate policy of state as represented by the Caliph or the ruler [20].
- The Abbasid Caliphs assigned Banu Musa a number of important tasks including major engineering works such as the excavation of Ja'fary and Amoud ibn Al-Munajjim canals [16,21].
- Almu'tasim Caliph (died 842 AC) sent the elder brother Mohammed to Byzantium to investigate the cave people (ashab al-raqim) [22].
- Al-Wathig Caliph (died 847 AC) sent Mohammed to the Khazar King to examine the dam of Thu al-Qarnayn [22].
- Following the orders of an Abbasid Caliph, Mohammed traveled within an astronomical mission to Sinjar (near Al-Musil) to measure the circumference of earth.
- Al-Ma'mum Caliph (died 833 AC) was very close to his scientists. One of his clear orders was: "a geometer has to read thoroughly the Euclid [13].
- Al-Ma'mun knew from one of his scientists that Al-Hassan bin Musa read only 6 books of Euclid. Because he considered Al-Hassan as one of his great geometers, his words to him were: "Euclid is the basic of geometry…it is like a b c d for writing and reading" [13].
- Al-Mutawakkil Caliph (died 861 AC) assigned a special building to Banu Musa near his palace in Samirra for the activities of manuscripts translation under the supervision of Banu Musa [23].

6. SCIENTIFIC ACTIVITIES OF BANU MUSA

Banu Musa Observatory:

Since Banu Musa were pioneers in Astronomy, they built their own observatory where they performed very accurate astronomical calculations and observations for astronomical tables [24]. The work of Banu Musa in this field was praised by their subsequent astronomers such as Ibn Yunus and Al-Biruni [18].

Banu Musa Authorship:

They wrote in mathematics, astronomy, mechanics and philosophy. Some of their writings are [13,15]:

1. Book of circular and rectangular shapes.
2. Book of cones.
3. Book of Ghalinos geometrical shape.
4. Between Mohammed and Thabit bin Qurra.
5. Between Ahmed and Sanad bin Ali.
6. About the sphere.

7. Area of simple and spherical shapes.
8. Division of angle to 3 equal parts.
9. Book of universe initiation.
10. Book of planetary motion.
11. Book of orbits.
12. Astronomical tables.
13. Conditions of air.
14. Astrolabe.
15. The book of part.
16. Kuriston (steelyard).
17. Book of ingenious devices (Kitab al-Hiyal).
18. Book of military devices.
19. Book of automatic flute.

Banu Musa Astronomical Simulator:

Banu Musa built the first engineering simulator in the world. Their simulator was a spherical frame housing objects simulating the famous stars that can be seen in the sky by the naked eye. The simulator was driven by water power and based on very accurate astronomical and mechanical calculations. The time the real star appeared in the sky, it appeared in the same time in the simulator [25]. The production of such simulator requires enormous mechanical work to drive the stars (objects), move it back and forward and control its appearance period (mechanical timers).

7. THE BOOK OF INGENIOUS DEVICES (KITAB AL-HIYAL)

Said about the Book:

Al-Qafti: “The best known work assigned to Banu Musa” [13].

Ibn Khallikan: “In ingenious devices they have an amazing and a rare book comprehending all novelties” [14].

Ahmed Al-Hassan: “Banu Musa made use, primarily, of the principles of the science of hydrostatics and aerostatics. No where in subsequent Arabic or Islamic writings do we find any thing similar to the devices included in Kitab al-Hiyal [18].

“The Banu Musa use of automatic valves, delayed action systems, and their application of the principles of automatic control, testify to genius, to brilliantly agile and creative mentality” [18].

Donald Hill: “In the two models 80 and 85, they used a mechanism similar to the modern crankshaft, thus outstripping by 500 years the first description of crankshaft in Europe” [18].

“They were the first people who used conical valves to a wide extent with different applications” [26].

The Book Designs (Models):

The book of ingenious devices (Kitab al-Hiyal) by Banu Musa includes 100 designs [27] classified as follows:

- 69 mechanical beakers, jugs, jars and bottles.
- 16 level control systems.
- 7 fountains.
- 4 automatic lamps.
- 2 well and river devices.

Total: 100

8. TRANSLATION OF KIYAB AL-HIYAL

- In 1918, Wiedemann and Hauser published a number of articles in German about Kitab Al-Hiyal of Banu Musa. They explained the operation of the designs 75-87 [28].
- In 1922, Hauser published a book in German about Kitab Al-Hiyal and explained the rest of their designs [29].
- In 1979, Donald Hill published an English translation for Kitab al-Hiyal including all the designs with complete explanation of their operation. He collected the basic principles used by Banu Musa in their designs [26].

9. LEVEL CONTROL SYSTEMS OF BANU MUSA

16 designs of the 100 designs of Kitab al-Hiyal are level control systems. Only two of those will be studied here.

DESIGN 78:

The level control system (design 78) is shown in Fig.1. It consists of the following parts:

Water reservoir (B), feeding pipe (C), conical valve (D), output vessel (E), tank (G), float (F), float stem (H), crankshaft (I), and a sealed frame (K).

The control system works as follows:

1. Water is poured from hole A into reservoir B where it flows through pipe C and conical vale D which is open (when there is no water in the system) to vessel E.
2. The float F and tank G are elements of a mechanical level transducer where the level in the output vessel E is measured by them.
3. The motion of the float indicating the water level in the output vessel is fed back to the conical valve D through a float stem G and a crankshaft I. The stem joined with the crankshaft using a ring (forming a revolute joint). The crankshaft is rigidly connected to the valve plug to drive it. The stem-crankshaft sub-mechanism transforms the translational motion of the float to an angular motion of the valve plug, them providing a feedback mechanical signal to the controlling valve. This is a unique technique never used before in the history of science and technology.

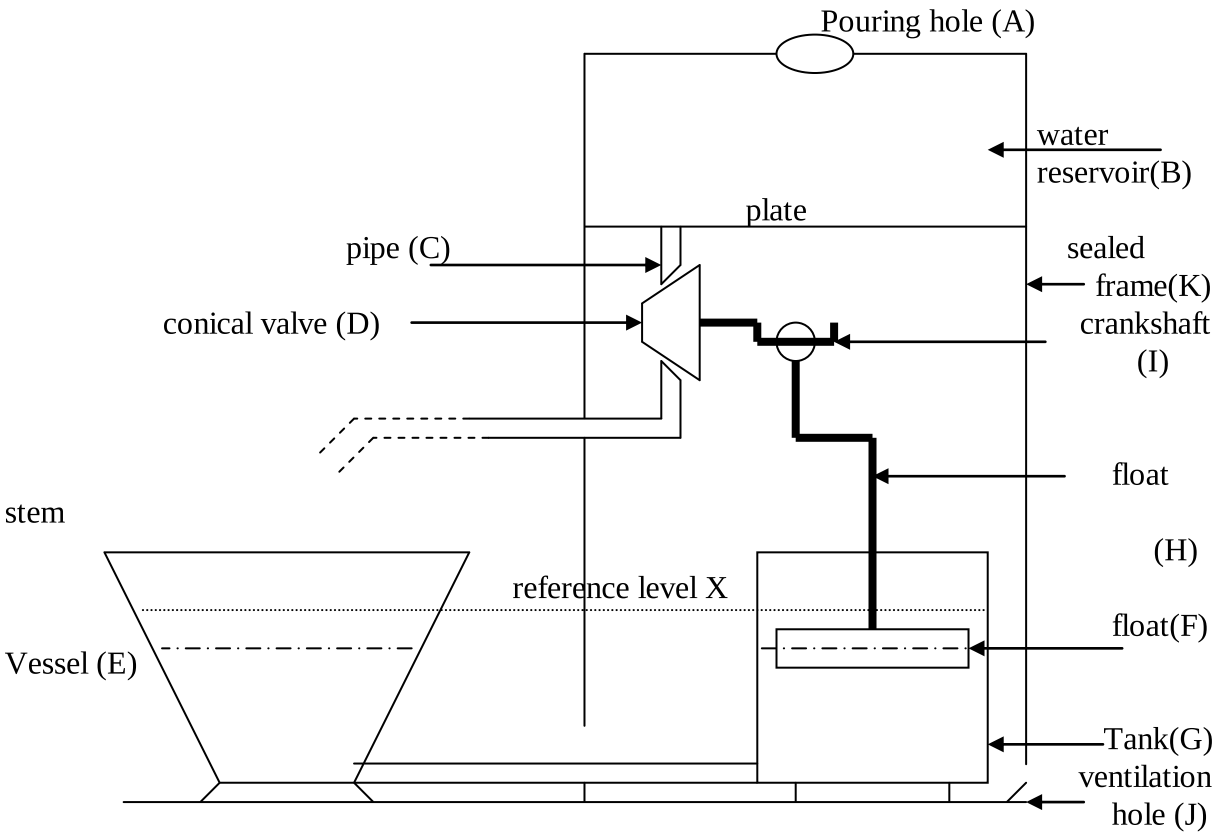

Fig.1 Banu Musa design 78.

4. Water is poured from hole A into reservoir B where it flows through pipe C and conical vale D which is open (when there is no water in the system) to vessel E.

5. The float F and tank G are elements of a mechanical level transducer where the level in the output vessel E is measured by them.

6. The motion of the float indicating the water level in the output vessel is fed back to the conical valve D through a float stem G and a crankshaft I. The stem joined with the crankshaft using a ring (forming a revolute joint). The crankshaft is rigidly connected to the valve plug to drive it. The stem-crankshaft sub-mechanism transforms the translational motion of the float to an angular motion of the valve plug , them providing a feedback mechanical signal to the controlling valve. This is a unique technique never used before in the history of science and technology.

7. When the float reaches a preset level X (reference level), the conical valve closes completely and the water level remains constant at X.

8. Upon suction from vessel E by any means (continuously or intermittently), the float and the stem drop down, thus turning the crankshaft in opposite direction, and hence opens the conical valve allowing water to flow to the output vessel again.

9. The small hole in the bottom of the sealed frame allows ventilating the internal environment of the frame and hence the possibility of the feedback operation to take place.

Banu Musa mentioned in their book that this design is for use in bathrooms, in mosques and near rivers [27]. This simply means that their control systems were full-scale applied systems and not for toys or specially designed for the entertainment of the rulers!.

DESIGN 76:

This is another level control system with an operation technique different from that of design 78. Fig.2 shows design 76 of Banu Musa.

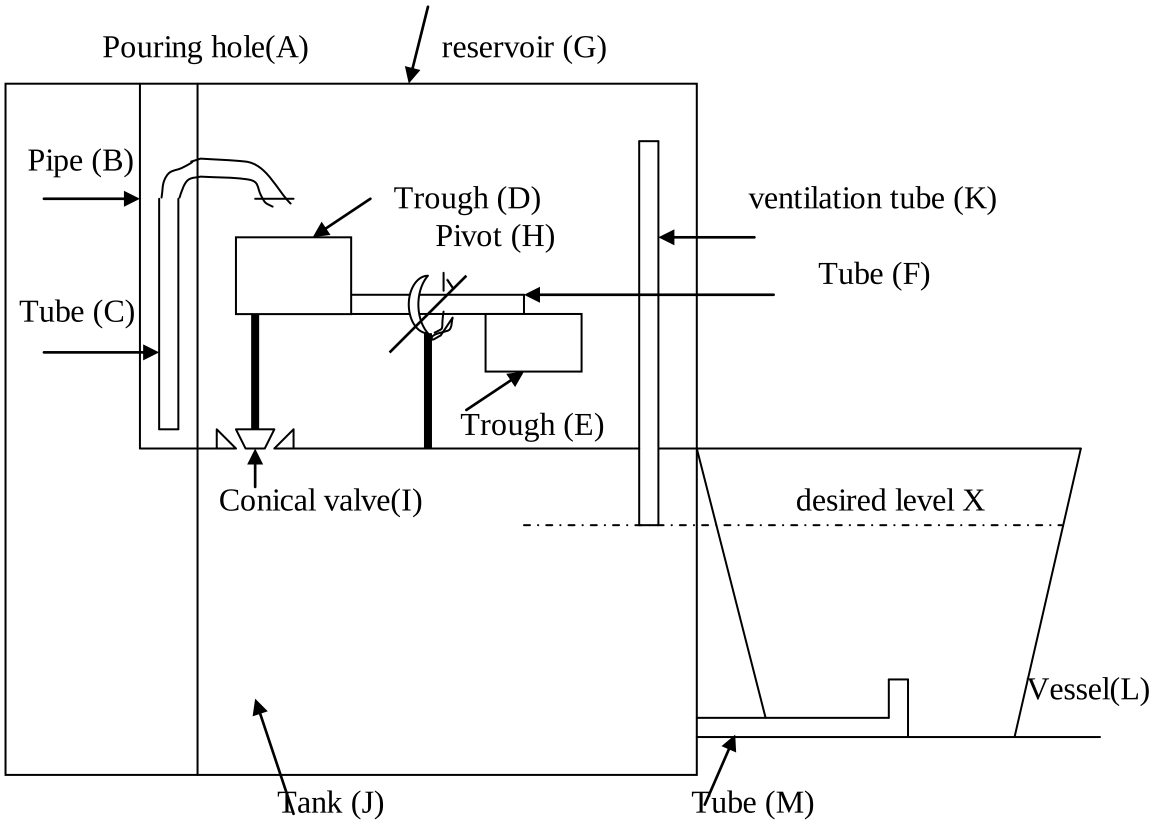

Fig.2 Banu Musa design 76.

The level control system (design 76) consists of:
Reservoir (G), tank (J), output vessel (L), feeding tubes (F) and (M), two troughs (D) and (E), siphon consisting of two concentric elements ,pipe (B) and tube (C), pivot (H) for tube (F), ventilation tube (K) and a conical valve (I).

This control system works as follows:

1. Liquid is poured from hole A into pipe B, then through tube C to trough D and trough E through the pivoted tube F. Then the liquid flows to the top reservoir G.
2. Because trough D is bigger than trough E, and the pivot H is at mid-span of tube F, the conical valve I will be always closing during the filling operation. This allows the flow to be stored entirely in reservoir G only.
3. The relative positioning of the two troughs at the end of the pivoted tube F guarantees that when liquid pouring stops, only trough E will be full of liquid, and hence it will be heavier than trough D. This means that the lever (tube F) will move in the clockwise direction, allowing the conical valve to open. Now, liquid flows from the top reservoir G to the sealed tank J. The ventilation tube K allows this process to take place.

4. In the same time the liquid flows from tank J to the output vessel L until the liquid level reaches level X defined by the ventilation tube K (desired level). Then, there will be no ventilation for tank J and the flow rate to both tank J and vessel L stops.

5. Upon suction from vessel L, the level drops than the desired level X and tank J ventilation takes place through tube K allowing liquid to flow through the conical valve until level X is reached.

6. During filling the top reservoir G, it is ventilated through tubes K and M. During control of liquid level in the output vessel, tank J is ventilated through tube K and the siphon tube C and pipe B.

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