THE AUTOMATIC MECHANICAL HYDRAULIC ORGAN
OF
BĀNŪ MŪSĀ BEN SHĀKER

by
Dr . Mona Sanjakdar Chaarani

Biographical Notes on Banū Mūsā ben Shāker [1]

The Banū Mūsā Ben Shāker were three brothers (Abu Dja'far Muhammad, Abu'l- Kāssim Ahmed and Al-Hassan) ben Mūsā ben Shāker who lived in the third century A.H (ninth century A.D). They made a name for themselves under the Abbasside rule as mathematicians, astronomers, technicians, and musicians. They even dabbled in politics. Their father Mūsā Ben Shāker was an astronomer and an astrologer working at the Califate court of Al-Ma'mūn who ruled from 813 till 833 A.D. After the death of Mūsā Ben Shāker, Al- Ma'mūn took it upon himself to raise his three sons and appointing the astronomer Yahyā Ben Abi Mansūr[2] as their guardian, in charge of teaching them mathematics at his famous school "The House of Wisdom".

Thus, these three brothers joined the circle of scientists at a relatively early age and were instrumental in introducing Greek Science to the Muslim world by providing precise translations and at the same time produced original research that would result in the renaissance of scientific thought in the ninth and tenth centuries. These brothers, now in possession of important fortunes and swathed in glory, would consecrate their important resources for the acquisition of Greek manuscripts, sending agents to the Roman provinces and entrusting them with the task of locating these treasures in the libraries and buying them from the Greeks.

The works of the Banū Mūsā

The works of Banū Mūsā comprise a series of translations and original contributions in the fields of geometry, astronomy, mechanic and music.

In music we attribute to them

- A large volume of music (Missing until now, which content is unknown)

- The Manuscript of the Instrument which Sounds by Itself, which is the subject of this present study[3]

1 Martijn Theodoor Houtsma et al (eds.) The Encyclopaedia of Islam – [E.J. Brill's First Encyclopaedia of Islam] , 9 vols. E.J.Brill, Leiden , 1913-1936, vol.7, pp.640-641

2 Abu Ali Yahyā ibn Abi Mansūr al Munajjim (Aleppo 830) , Persian astronomer at the court of the Abbasid caliph al- Ma'mūn.

General features of the instrument Which Sounds by Itself

it is a musical instrument that operates automatically by the action of the weight and pressure of water. The air pushed by the hydraulic pump is compressed in a compressing bag to power a flute with nine holes. The latter are opened and closed through eight levers, which extremities are pinched by the fixed pins and distributed according to a well determined melody on the lateral surface of a musical cylinder.

Before embarking on this study, a complete diagram of the instrument is necessary. Although the original diagram by Banū Mūsā is lost, the detailed description in the text is of great help in the reconstruction of the diagram. [Fig . 1]

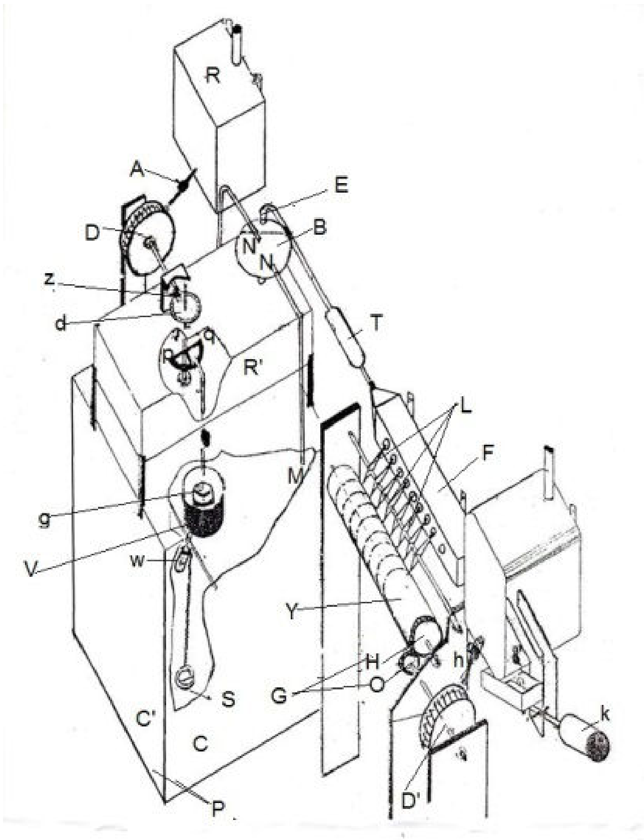


Fig. 1 - A profile view of the Banū Mūsā instrument

3 Photocopies of this manuscript can be found at the Oriental Library of the Jesuites in Beirut - Lebanon and the Library of the American University of Beirut - Lebanon

This description divides the instrument into four independent parts, each containing several elements. If you look at the first figure you will see:

1- On the left, towards the upper portion of the figure, the system of gears, which when activated by the hydraulic wheel (D), allows the alternate flow of water into the two compartments (C) and (C') of the pump (P) .

2 – A large reservoir with two compartments (This is the principal body of the apparatus of the air pump (P) which is located beneath this gear system.)

3 -The compressor (B) is located a little above and towards the middle, and acts as the blower, which continuously receives air from this first pump of the instrument and sends it into the flute (F) through a neck (T) fixed to its upper extremity.

4- This is the revolving cylinder with pins (Y), located at the right lower side of the diagram. A gear system (G) activated by a hydraulic wheel turns the cylinder in a uniform circular motion. The speed of rotation is regulated by the stream of water from the faucet (h). A regulating system is in place to either increase or decrease the speed of rotation.

Detailed Description of the Banū Mūsā instrument

Granted the difficulties readers would face in the comprehension of a textual translation of an Arabic text belonging to the ninth century, we present below a simplified description of this organ and it's mode of operation with a plan of its assembly that will render the text easier to comprehend:

I – Description

The apparatus is divided into four distinct parts made of multiple elements

1 – *The Main Body of the Apparatus*

It is made of a large reservoir divided into two compartments, which resemble a pump with two ventricles or chambers.

Each compartment consists of the following elements:

a) – A lever composed of a rigid bar, mobile around an axis fixed to the wall of the reservoir. A small basin (V) and a counter weight (W), fixed to the two ends of the bar, are in equilibrium when the small basin is empty. [Fig. 2]

b) A valve (S) located at the bottom of each compartment, connected to small basin (V) via a chain, which makes the valve open and close automatically. [Fig. 3]

c) An exhaust pipe (MN), welded at point M to the upper of the body (C) of the pump, carries the air to the compressed air bag. Another pipe (mn) welded at (n) returns to the interior of the body (C) to create an atmospheric pressure to help speed the emptying of the water from the valve (S). [Fig. 3]

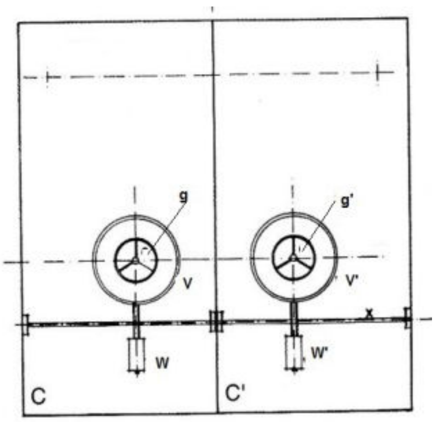


Fig. 2 - Levers- counter weight and small basin

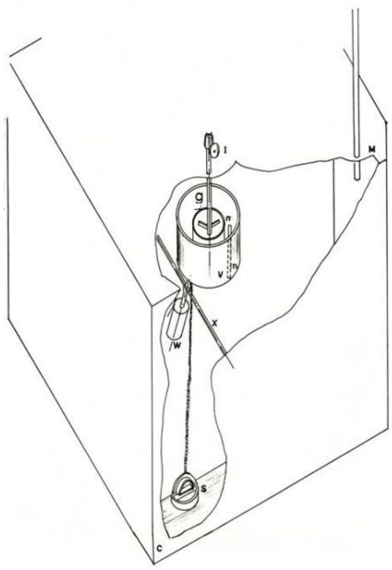


Fig. 3 - Valve, chain, and small basin

2 – *The Water Distributer*

It consists of a small reservoir (R’), which is always full of water, mounted on top of the main body or the large reservoir with compartments (C) and (C’). Two pipes UIJ and U’I’J’ reach up to about 2/3 of the vertical height of the small reservoir (R’) and bend again by about 1/3 of the height of the same reservoir. Each pipe is fitted with a valve holding a small rod (J) at the top end. Closer to the other end, a tap or faucet (I) regulates the flow of water, while the lower extremity of the pipe passes through the roof of the reservoir and has a vase attached to it, (g) , in which water is emptied. This vase (g) plunges into the small basin (V) when it is empty. At the base of the vase, (g), a nail is attached, which penetrates into the orifice of the empty small basin to remove the precipitate accumulated by the water. Inside the small reservoir (R'), which is always sealed hermetically, there is a half ring (pq) attached to a vertical axis (k). It rotates horizontally below the two valves (J) and (J'), pushing the two alternatively, to allow the alternate passage of water from the two tubes. [Fig. 4]

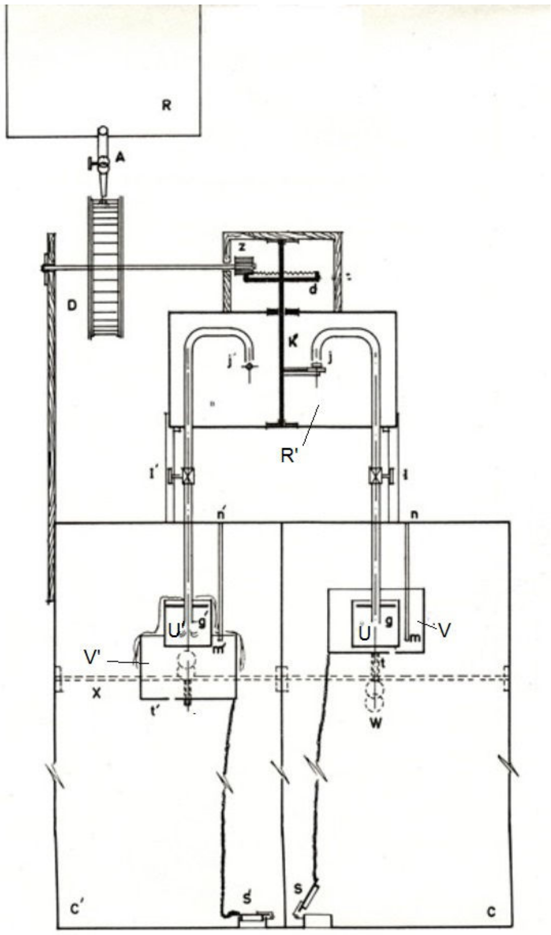


Fig. 4 - The Water Distributer

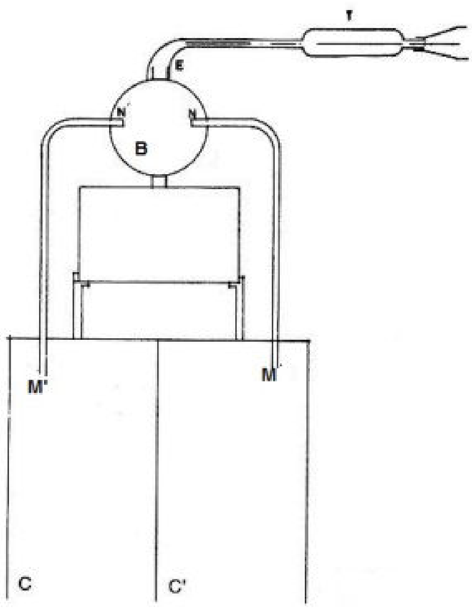


Fig. 5 - Compressing Bag

The vertical axis (k) rotates through a gear system composed of a wheel, (d), with teeth geared to a pinion (z). This pinion (z) is rotated by a horizontal axis attached to the hydraulic wheel (D). This wheel is set into motion by a stream of water that comes through the top (A), attached to the reservoir (R). [Fig. 4]

3 – *Compressing Bag*

The two pipes (MN) and (M'N') bend into the interior of a compressing bag (B) and each one is fitted at its bent end with a valve, which closes by its own weight in the absence of air pressure. Air enters into it continuously through one of the two tubes and is compressed in the bag. This bag is fitted with a neck (T) attached to an elbow (E), where the air is compressed, and then pushed back through the flute to produce musical tunes. [Fig. 5]

4 – *The Flute and Its Revolving Cylinder*

A sonorous tube pierced with nine holes, provided with a whistle comprises the flute. Eight levers,(L) moving around a horizontal axis, open and close, according to the melody the eight holes of the flute, whereas the ninth hole remains always open. One end of each rod has a valve which closes the mouth of one hole at the required moment, while the other rests on the composing cylinder. [Fig. 6]

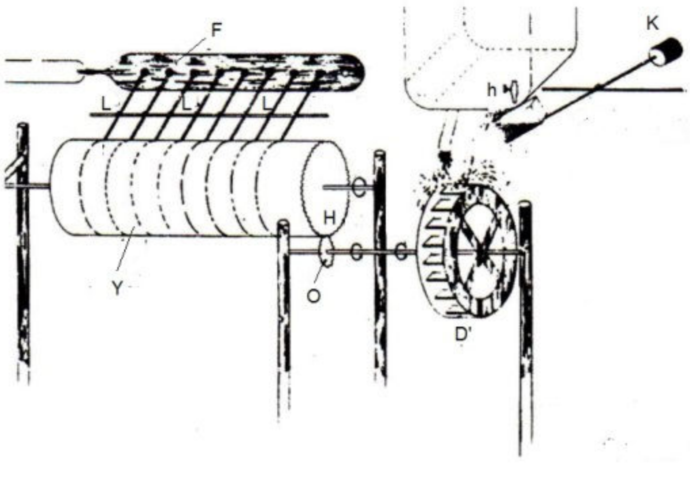


Fig . 6 - Revolving Cylinder

The Revolving Cylinder

On the lateral surface of a large cylinder (Y), moving around a horizontal axis, are fixed (following circles parallel to the rods) thick pins, with lengths proportional to the notes of the melody. This cylinder is rotated by a gear-system formed by two dented discs, (O) and (H). The disc (O) is rotated by a stream of water that puts in motion a large hydraulic wheel (D') attached to its axis. The speed of rotation of this wheel changes according to whether the stream of water comes from the tap (h), only, or from tap (h) and the reservoir balanced by the counter weight (K). [Fig. 6]

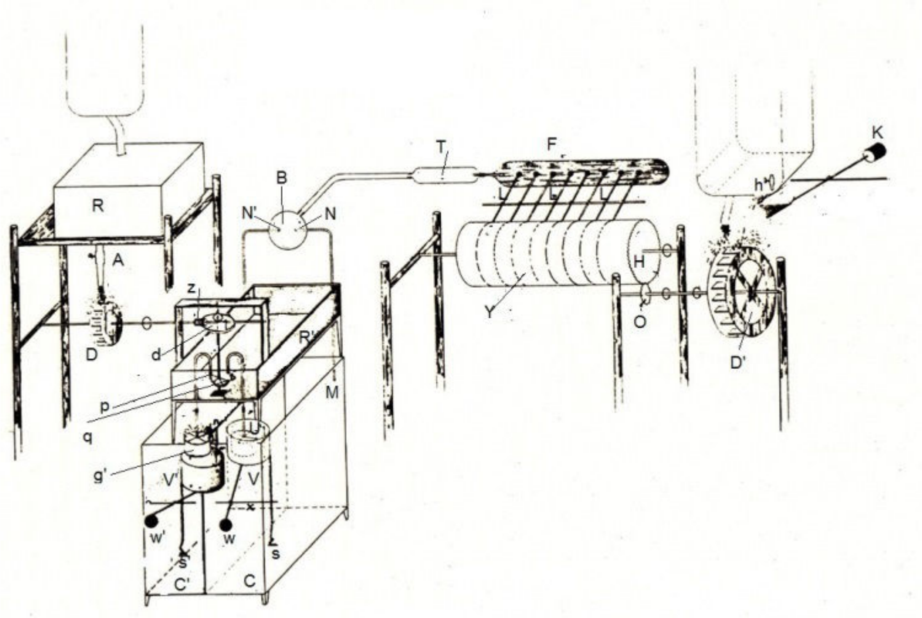


Fig. 7 - Assembly Diagram of the instrument

II – The Operation of the Banū Mūsā Instrument

To understand the operation of this instrument, it is important to follow the explanations provided while examining point by point the assembly diagram shown in figure 7.

The stream of water, flowing from the faucet (A), of the reservoir (R), activates the hydraulic wheel (D) in a rotating movement that is either fast or slow depending on the flow of water. When this wheel rotates, it activates the gear system, made up of the pinion (z) and the disc with teeth (d). The latter activates the rotation of a half-ring (pq) set up on its vertical axis (k). At each turn, this half-ring located inside the small reservoir (R’), opens and closes alternately the two valves (J) and (J’) allowing water to pass through either of the two conduits. If, for example, water flows through the pipe (JIU), the vase (g) is filled and the water is emptied into the small basin (V). The latter, once filled oscillates and closes the valve (S) at the bottom of the compartment (C). Thus the accumulating water forces the air into the pipe (MN), closed at (N) by a valve, which opens due the pressure of the air. Meanwhile the half-ring (pq) concludes a half-turn, leaves the valve (J) to open the one found at (J’), and this phenomenon is repeated constantly. In this manner, air arrives constantly in the compression bag (B). This compressed air is driven back to the flute, which emits musical sounds according to the recorded melody on its revolving cylinder. [Fig. 7]

Mechanism of the Automatic Backflow of the Air

As soon as the half-ring leaves the valve (J), the latter closes the pipe hermetically due to its own weight. The vase (g) and the small basin (V) no longer receive any water. The latter starts discharging the water through the small hole (t), Once empty the equilibrium of the lever which holds the small basin (V) is disturbed. Thus the small basin (V) rises under the action of the counter-weight, which is heavier and pulls at the chain to open the valve (S). Now the compartment (C) empties. In order for the rapid discharge of the water, a pipe (mn) has been placed on the upper surface of the body (C), open at both ends.

It is necessary for the proper functioning of the instrument that compartment (C') should fill while the compartment (C) empties , and vice versa. Thus in order for the water to accumulate in the compartment (C'), the air escapes through the pipe (M'N') and passes into the compression bag (B).

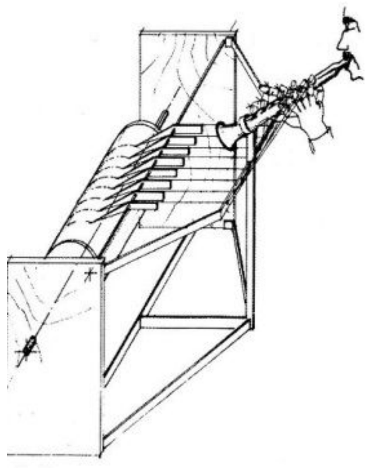
III Other Propositions Presented in the Text

1 - Distribution of Pins on the Revolving Cylinder

To distribute the pins on the revolving cylinder the Banū Mūsā outlined the following method:

This method consists in using a large wooden cylinder, and coating its surface with black wax. We fix to it a gear system (not represented here) which allows it to turn in a uniform circular motion around its main axis. We also add eight levers mobile around a horizontal axis parallel to that of the revolving cylinder. Each lever is attached to one finger of the flutist by means of a fine but robust string (with zero elasticity). The other pointed extremity of the lever rests on the lateral surface of the cylinder. [Fig. 8]

The cylinder is put into motion and we ask the flutist to play a melody. We notice immediately clear traces being drawn into the wax. We then measure the length of the engraved traces, customize the corresponding pins, and fix it on the revolving cylinder while respecting the order and the distance that separates each one.



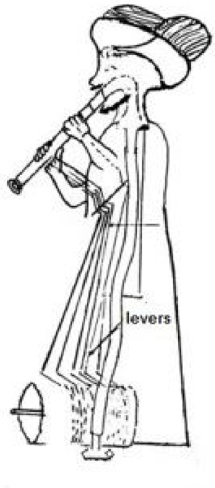


Fig. 8 – Distribution of Pins on the Cylinder

Fig. 9 – The Automaton

2 – *The Automaton*

In this part of the text, the Banū Mūsā explains the mechanism of an automated flutist, the embryonic stadium of the first musical android. [Fig. 9]

They mention the following: « If we want to create the android flutist, we just have to incorporate the whole instrument in the body of the statue, fix the flute in its mouth and disguise the levers into fingers and adapt it to his arms. Furthermore, we have to bend back these levers inside the body of the statue so that they reach the pins fixed on the revolving cylinder. Finally we put in place the air conduits in the body of the statue and direct them towards the mouth of the flute. We can also hide the entire instrument, where only the flutist who is playing can be seen ».

The Banū Mūsā then explain the operating mechanism of the android as follows: « When we activate the instrument with the flow of water necessary for the movement of all the elements, the air is continuously pushed to the mouth of the flute. The flutist then plays the melody recorded on the revolving cylinder through the movement of levers (the fingers). When the fingers of the flutist close all eight holes of the flute, we hear the note produced by the ninth hole, which is always open. Then the other notes of the music scale follow, played by the movement of the levers activated by the pins of the revolving cylinder. This way, the statue plays the entire melody recorded on the cylinder while moving its fingers on the flute like a real flutist. »

Finally, the Banū Mūsā were able to compare the musical notes of the mechanical flute to that of a real lute. (Oud)

Conclusion

A technical and analytical critical study of the manuscript just described allows us to show that the Banū Mūsā Instruments that Sounds by Itself is an Automatic Mechanical Hydraulic Organ.

The designation of this instrument as a hydraulic organ was chosen after its comparison with the hydraulic instrument of Ctesibios (third century B.C. in Alexandria) and its operating system. The Banū Mūsā replaced the tubes of Ctesibios where each produces one note by the flute with nine holes, capable of producing nine distinct notes.

The pointed musical cylinder, the basic element of the mechanical musical instrument, found in the Banū Mūsā instrument, led us to name the instrument a mechanical hydraulic organ, whereas the automatic operation of the instrument, through water pressure and its own weight activating a system of levers added the automatic aspect of the instrument. Therefore, the Banū Mūsā instrument is indeed an Automatic Mechanical Hydraulic Organ.

The manuscript described in this article showed the true genius of, Banū Mūsā who invented three major scientific breakthroughs, namely mechanical music, graphic recording, and musical androids.