THE AUTOMATIC MECHANICAL HYDRAULIC ORGAN

OF

BĀNŪ MŪSĀ BEN SHĀKER

by

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Biographical Notes on Banū Mūsā ben Shāker [1]

The Banū Mūsā ibn Shāker were three brothers (Abu Dja'far Muhammad, Abu'l- Kāssim Ahmed and Al-Hassan) ibn Mūsā ibn Shāker- who lived in the third century A.H (ninth century CE). They made a name for themselves under the Abbasside rule as mathematicians, astronomers, technicians, and musicians. They even dabbled in politics. Their father Mūsā ibn Shāker was an astronomer and an astrologer working at the Caliph Al-Ma'mūn, who ruled from 813 to 833 CE. After the death of Mūsā ibn Shāker, his three young sons were looked after by Al- Ma'mūn and his court; the astronomer Yahyā bin Abi Mansūr[2] was appointed as their guardian, and was in charge of teaching them mathematics at the famous school "The House of Wisdom" (Bayt al-Hikma).

Thus, these three brothers joined the circle of scientists at a relatively early age. They were instrumental in introducing Greek Science to the Muslim world by providing precise translations of Greek texts, and at the same time produced original research that would result in the renaissance of scientific thought in the ninth and tenth centuries. The brothers, who were in possession of considerable fortunes and reputations, dedicated these resources to 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 encompass both translations and original contributions in the fields of geometry, astronomy, mechanic and music.

In the field of music a large body is attributed to them, although the manuscripts are now lost and their content is unknown. But we do know one of these manuscripts, the kitab al-urghanun [the

[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.

book of the organ], and, also, the description of the al-Ala allati tuzmiru bi-nafsiha [the instrument which plays by itself] which will be the subject of this study[3]

General features of the instrument Which Sounds by Itself

The instrument is a mechanical hydraulic organ that operates automatically by the action of the weight and water pressure. The air pushed by the hydraulic pump is compressed in a sphere to power a flute with nine holes. The holes are opened and closed by eight levers, the end of which make contact with the fixed raised pins arranged on the lateral surface of a revolving cylinder so as to produce a well-known melody.

Before embarking on this study, it is necessary to reconstruct a diagram of the complete instrument. Although the original diagram by Banū Mūsā is lost, the very detailed description in the surviving text is of great help in the reconstructing a diagram of the divice. [fig 1]

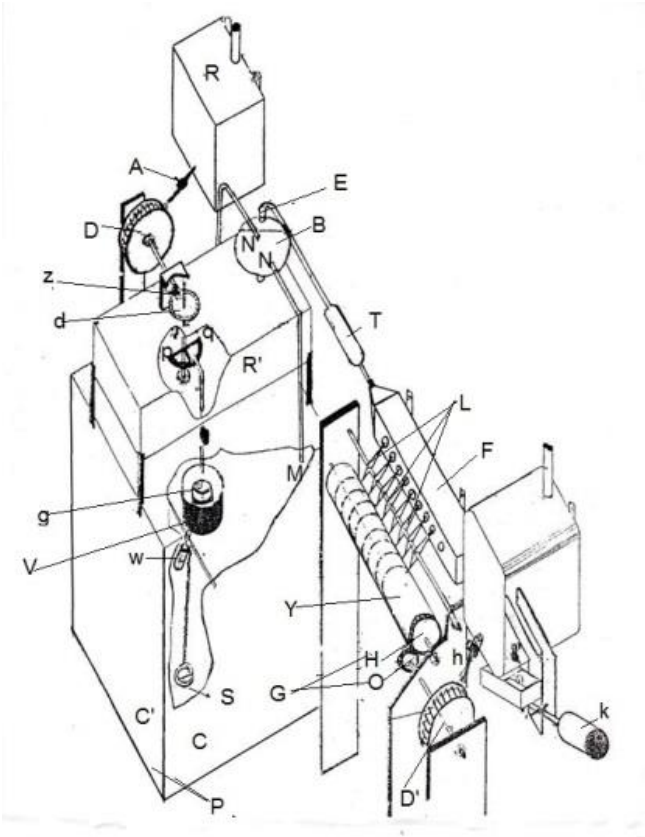


Fig – 1 - A profile view of the Banū Mūsā's instrument

This description divides the instrument into four independent parts, each containing several elements. Which are show in figure 1:

1- On the left, towards the upper part of the diagram, 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 tank with two compartments (This is the principal body of the apparatus of the air pump (P) which is located beneath this system of gears)

3 -The spherical air compressor (B) is located a little above and towards the middle of the diagram, is acts as the bellows and receives air continuously from the two compartments (C) and (C')through the pipes(MN) and (M'N')and send it to the flute (F) through a pipe (T) fixed to the end of the flute.

4- The revolving cylinder with pins (Y), is on the right 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 valve (h). A regulating system is in place to either increase or decrease the speed of rotation.

The Detailed Description of the Banū Mūsā instrument

Given the difficulties that the readers would probably have in understanding an exact translation of to the ninth century Arabic text, below is a simplified description of this organ and its mode of operation:

I – Description

1 – *The Main Body of the Apparatus*

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

Each compartment consists of the following elements:

a) – A lever composed of a movable bar, around an axle fixed to the wall of the tank. A small basin (V) and a counterweight (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 is 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 part of the body (C) of the pump, carries the air to the compression sphere. Another pipe (mn) welded at (n), returns to the interior of the body (C) to create atmospheric pressure to speed up the emptying of the water from the valve (S). [fig 3]

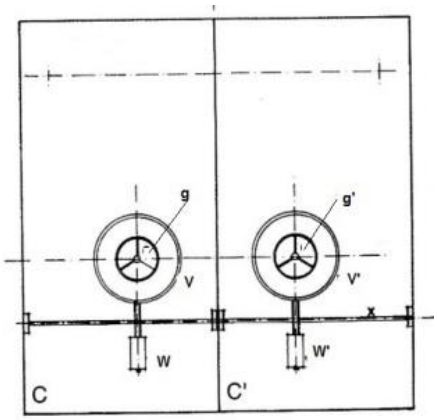


Fig – 2 - Levers- counter weight and small basin

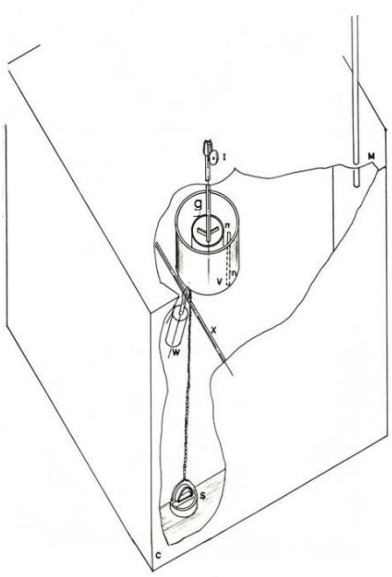


Fig 3 - Valve, chain, and small basin

2 – *The Water Distributor*

The water distributor consists of a small tank (R'), which is always full of water, that is mounted on top of the main body or the large tank with two compartments (C) and (C'). Two pipes UIJ and U'I'J', reach up to approximately two-third of the height of the small thank (R') and bend down by about one-third of the height of the same tank. 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 tank and has a vessel attached to it (g) in which water is emptied. This vessel (g) plunges into the small basin (V) when it is empty. At the base of the vessel (g) a nail is attached, which penetrates into the empty small basin to remove the precipitate accumulated by the water. Inside the small tank (R'), which is always sealed hermetically, there is a half ring (pq) attached to a vertical axle (k). The axle 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].

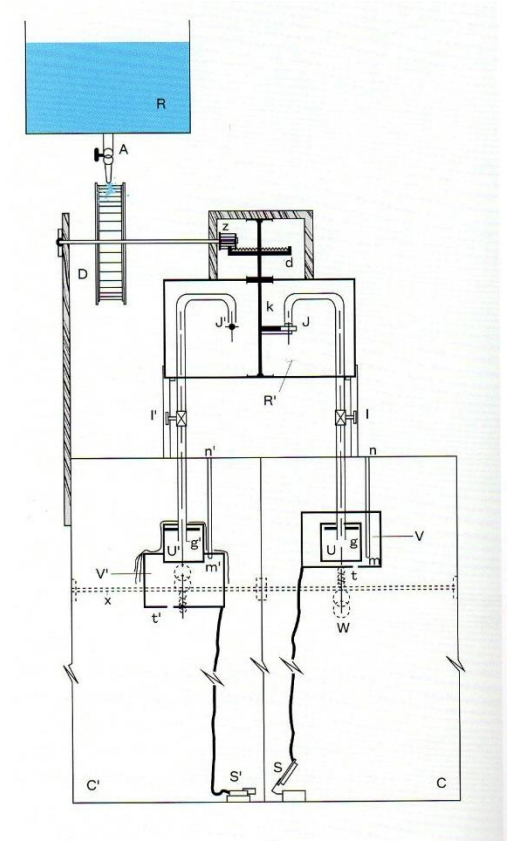


Fig – 4 - The Water Distributor

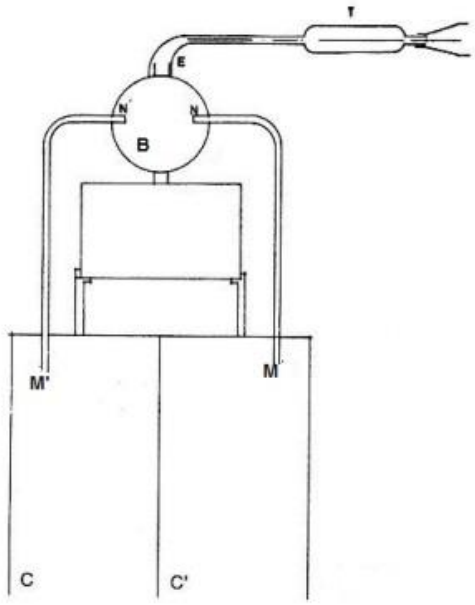


Fig – 5- the Air Compressing Sphere

The vertical axle (k) rotates through a gear system composed of a wheel (d) with cogs teeth geared to a pinion (z). This pinion (z) is rotated by a horizontal axle 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 tank (R).[fig 4]

3 – *The Air Compressing Sphere*

The two pipes (MN) and (M'N') bend into the interior of a compressing sphere (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 sphere. This sphere is fitted with a pipe (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 axle, open and close the eight holes of the flute according to the melody, whereas the ninth hole always remains 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 musical cylinder. [fig 6]

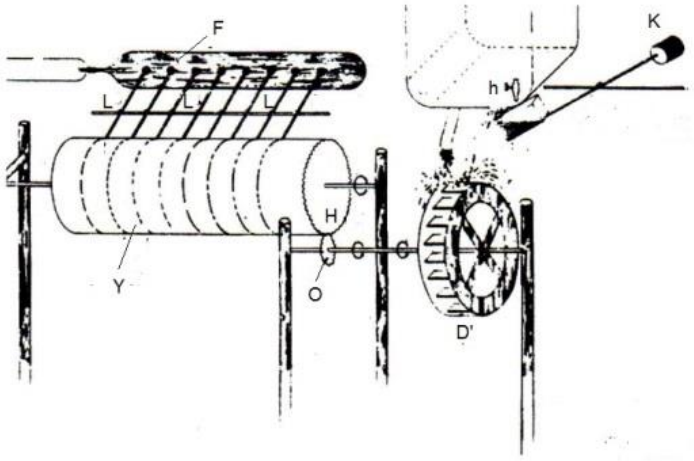


Fig – 6 – The Revolving Cylinder

5 - The Revolving Cylinder

On the lateral surface of a large cylinder (Y), moving around a horizontal axle, thick pins are fixed (following circles parallel to the rods), 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 sets in motion a large hydraulic wheel (D') attached to its axle. The speed of rotation of this wheel changes according to whether the stream of water comes only from the tap (h), or from tap (h) and the tank balanced by the counterweight (K). [fig 6]

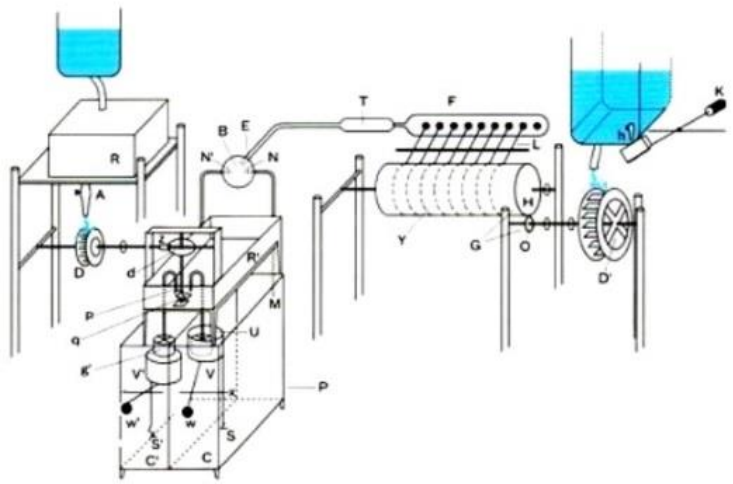


Fig - 7 -

II – The Operation of the Instrument

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

The stream of water, flowing from the tap (A), of the tank (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 cogs [gear wheel] (d). The latter activates the rotation of a half-ring (pq) set up on its vertical axle (k). At each turn, this half-ring located inside the small tank (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 vessel (g) is filled and the water is emptied into the small basin (V). Once the small basin is filled it 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 to 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 sequence is repeated constantly. In this manner, air arrives continuously in the compression sphere (B). This compressed air is driven back to the flute, which emits musical sounds according to the melody programmed 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 vessel (g) and the small basin (V) no longer receive any water. The small basin (V) 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 counterweight, which is heavier and pulls at the chain to open the valve (S). Now the compartment (C) empties. In order for the water to discharge rapidly, a pipe (mn), open at both ends, has been placed on the upper surface of the body (C).

For the instrument to function properly it is necessary 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 sphere (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 which method consists in using a large wooden cylinder, and coating its surface with black wax. It is fixed to a gear system (not show here), which allows it to turn in a uniform circular motion around its main axle. Eight movable levers mobile around a horizontal axle parallel to that of the revolving cylinder. Each lever is attached to one finger of the flute player by means of a fine but robust string (with zero elasticity). The other pointed end of the lever rests on the lateral surface of the cylinder. [fig 8]

The cylinder is set in motion and we the flutist to play a melody. Immediately clear markings begin to be drawn in the wax. The length of the engraved markings are measured, the corresponding pins customized, and fixed on the revolving cylinder while respecting the order and the distance that separates each pin.

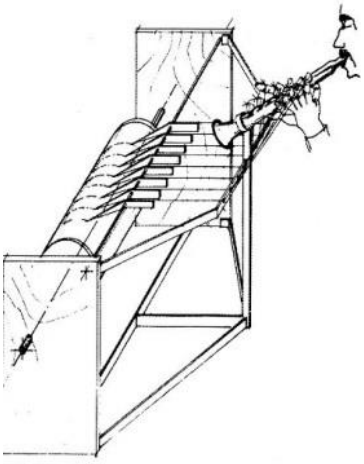


Fig – 8 – Distribution of Pins on the Cylinder

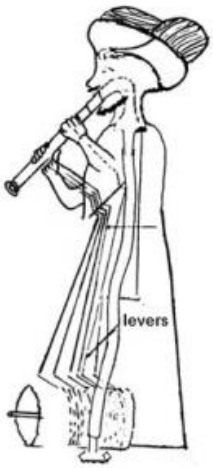


Fig – 9 – The Automaton

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 humanoid automaton. [fig 9]

They mention the following: « If we want to create the humanoid flutist, we simply have to incorporate the whole device in the body of the statue, fix the flute in its mouth and disguise the levers as 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 mechanism, so that only the flutist who is playing can be seen ».

The Banū Mūsā then explain the operating mechanism of the humanoid automaton 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 compared the musical notes of the mechanical flute to that of a real oud

Conclusion

A technical and analytical critical study of the manuscript described above demonstrates that the Banū Mūsā's "Instruments Which play by Itself" is an Automatic Mechanical Hydraulic Organ.

Designation of this instrument as a hydraulic organ came after it was compared with the hydraulic instrument of Ctesibios (third century BCE in Alexandria) and its operating system. The Banū Mūsā replaced Ctesibius's tubes, which each produced one distinct note with a single flute with nine holes, which was capable of producing nine distinct notes.

The pointed musical cylinder, the basic element of the mechanical musical instrument that is found in the Banū Mūsā's device, led to designation of the instrument as a mechanical hydraulic organ, and ``automatic`` describes its operation, on the basis of water pressure and its own weight activating a system of levers.

The manuscript described in this article evidences the true genius of the Banū Mūsā who were the authors of three ground-breaking inventions, namely mechanical music, graphic recording, and musical humanoid automata.

Berlin University of the Arts: Reconstruction of the Banū Mūsā's Music Automaton According to Their Description

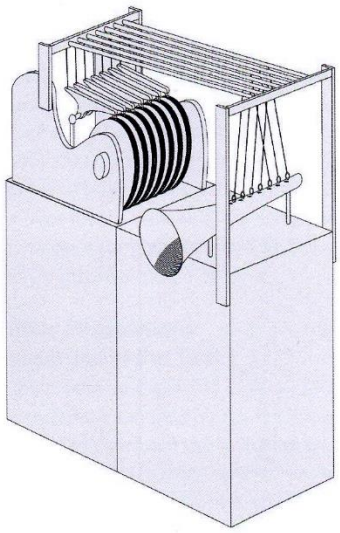
The first illustration shows the "programmer" **[Fig. 1]**, the machine used to transcribe the melody played on the sorna onto the cylinder. Rings hung next to the flute holes connect each finger of the player with a lever via taut threads. When the sorna is played, the finger movements are recorded as notes and rhythms on the rotating cylinder teeth, like on programmable computer chips.

The markings on the individual cylinder "chips" are milled to create indentations. These chips are then inserted into the "player" **[Fig. 2]** and the indentations trigger the identical lever movements to those that originally played the sorna.

The cylinder chips rotate constantly in the player, driven by a motor. The animation shows how the cylinder was originally turned by a water wheel mechanism. A compressor ensuring constant air pressure is located inside the pedestal. Constant air supply for playing the flute was created via a hydraulic and pneumatic mechanism in the Banū Mūsā's automaton. An animation showing this mechanism was made for the exhibition and can be viewed here. **[Figs. 4–6]** The air from the compressor is inputted into the sorna through a valve and the levers play the melody on the sorna that is programmed on the cylinders.

Micro-archaeological reconstruction team:

Programming and precision engineering:	Liang Zhipeng and Petja Ivanova
Animation:	Olivia von Pilgrim
Production:	Stefanie Rau
Supervisor:	Alberto de Campo



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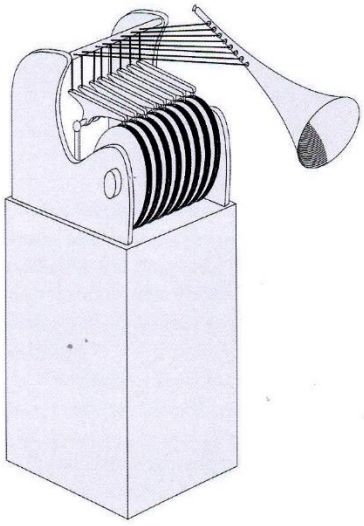

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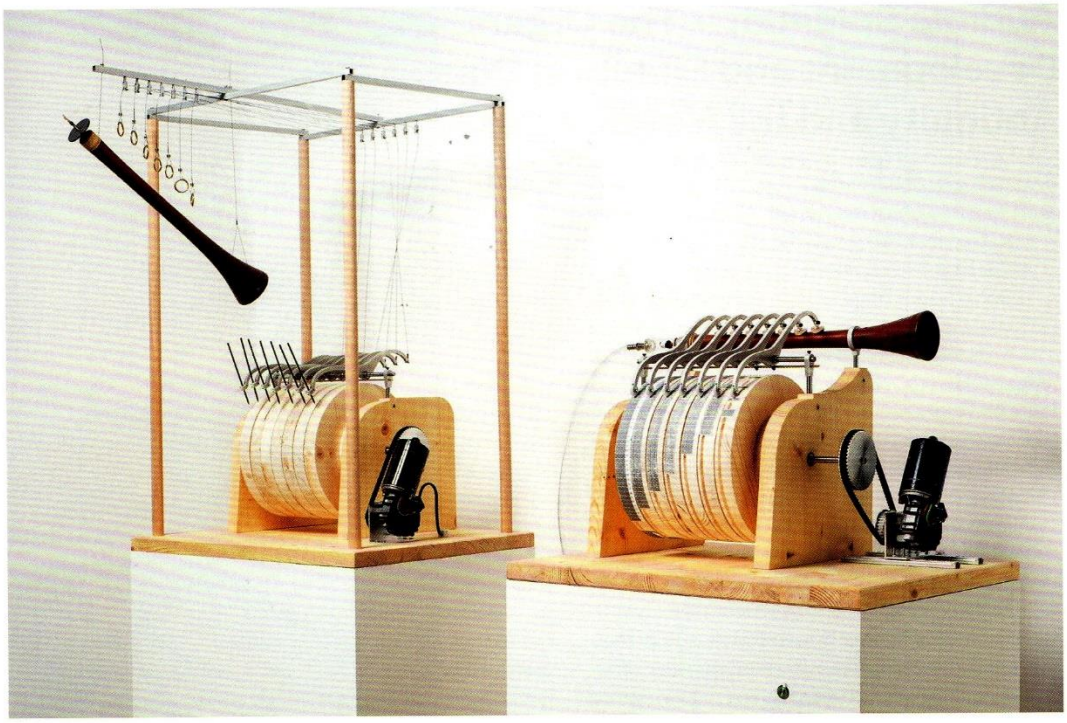
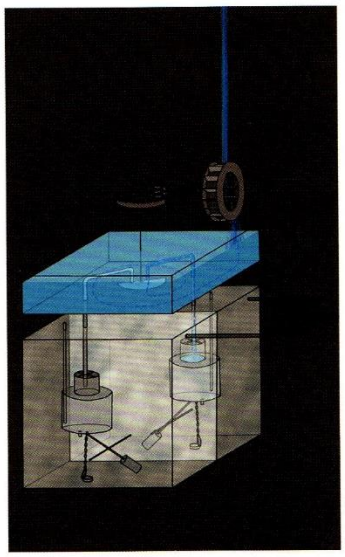


Figure 3
Reconstruction of the Banū Mūsā's music automaton according to their description, exhibition view *Allah's Automata*, ZKM | Karlsruhe 2015



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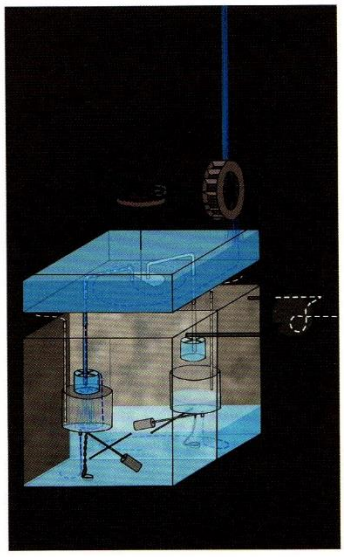

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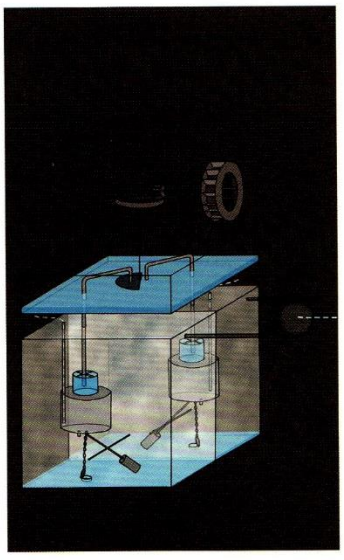

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