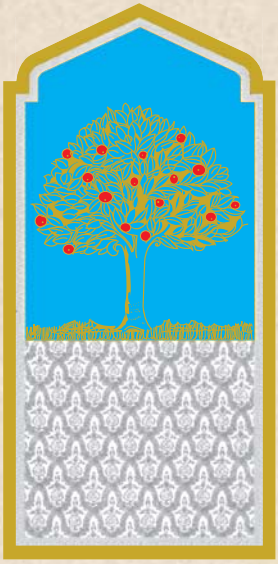

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THE TRUE INVENTOR OF SOME EARLY MECHANICAL ENGINEERING DEVICES AND MECHANISMS[1]

Waleed Fekry Faris[2]
Salah Elmoselhy[3]

Abstract

For centuries the inventions of automated crankshaft, camshaft, reciprocating double-action piston suction hydraulic pump with suction pipes, overshot curvaceous water turbines, and crank-connecting rod mechanism have been credited to Leonardo da Vinci (1452 – 1519) and Lester Allan Pelton (1829 – 1908). Recently, the concepts of these proven significant inventions in fluid mechanics and energy conversion systems have been found mentioned in the manuscripts of an inventor whose name is Abu-Aliz Al-Jazari (1136-1206). Leonardo da Vinci got these ideas from Al-Jazari's manuscripts and did not acknowledge Al-Jazari in his relevant manuscripts. In Lester Allan Pelton receives the credit for inventing the over-shot curvaceous water turbine whereas the over-shot curvaceous water turbine was described in Al-Jazari's manuscript which was made publicly available for reading many centuries before the time of Lester Allan Pelton. The concepts of these inventions which are described in Al-Jazari's manuscripts proves that his manuscripts were among the sources from which Leonardo da Vinci got these ideas and that Al-Jazari invented the over-shot curvaceous water turbine many centuries before Lester Allan Pelton are presented in this paper. It has been virtually proved that the true inventor of automated crankshaft, camshaft, reciprocating double-action piston suction hydraulic pump with suction pipes,

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overshot curvaceous water turbines, and crank-connecting rod mechanism is Abu-Aliz Al-Jazari.

Keywords: crankshaft; camshaft; reciprocating pump; water turbine; crank-connecting rod mechanism

1. Introduction

In the Greek mechanical engineering and technology tradition, studies were made on air, vacuum and balance principles by Archimedes (287-212 BCE), Ctesibios (3rd century BCE), Philon (2nd century BCE), and Heron (1st century CE). As a result of these studies, machines were developed[4] Many of the studies conducted by these inventors were translated into Arabic and their inventions were acknowledged in and greatly developed in the treatises of Banu Musa (9th century CE) and Al-Jazari (13th century)[5]. In the history of mechanical engineering and technology, there are inventors who deserve to be acknowledged for their inventions that contributed to the advancement of the state of knowledge in mechanical engineering and technology, yet they did not receive the recognition they deserve. Among those inventors is Abu-Aliz Al-Jazari (1136-1206)[6] who was an inventor and authored in 1206 a book entitled "The Book of Knowledge of Ingenious Mechanical Devices" that is considered a ground breaking work in the history of technology[7]. In his book,

[4] Sprague De Camp, L., *The Ancient Engineers*, (Garden City, N.Y.: Doubleday, 1963); Usher, Abbott Payson, *A History of Mechanical Inventions*, (Cambridge, Massachusetts: Harvard University Press, 1954). Second Edition: Dover Publications, 1988.

[5] Atilla Bir; Mustafa Kacar, "Pioneers of Automatic Control Systems," Research Report # 628, Foundation for Science, Technology, and Civilization (FSTC) Limited, December 2006; Banu Musa, *The Book of Ingenious Devices* (*Kitāb al-ḥiyal*), Translated by Hill, Donald, Routledge, Springer, 21–22, 1979.

[6] Al-Jazari, *The Book of Knowledge of Ingenious Mechanical Devices: Kitâb fî ma'rifat al-hiyal al-handasiyya*, English translation and introduction by Donald R.. Hill, Dordrecht: D. Reidel, Springer, 17-41, 1974; Al-Jazari, *A Compendium on the Theory and Practice of the Mechanical Arts (Al-Jami' bayna al-'ilm wa-'l-'amal al-nafi' fi sina'at al-hiyal)*, 1206, edited by Ahmad Y.Al-Hassan, University of Aleppo, 1979.

[7] Sarton, George, *Introduction to the History of Science*, (Baltimore: Williams and Wilkins, Co, Vol. II, 192), 632-633,

Al-Jazari acknowledged the contributions of his predecessors such as Archimedes, Banu Musa, Hibat Allah Bin Al-Husayn, and Al-Badi' Al-Astrulabi, and mentioned the list of improvements he had made on the work of his predecessors, and gave the list of the devices he invented that were completely new[8]. At his time there was a demand for devices that provide amusement and aesthetic pleasure, as well as meeting public and private needs, in the field of technology for computing of time and for agriculture, such as raising water for irrigation. Al-Jazari's devices, apart from being practical machines, incorporated techniques and components that were of significant impact in the development of machine technology[9].

Al-Jazari invented five machines for raising water from a river or well. It was in these machines that he introduced his most important ideas and concepts. The first two devices used animal power and an open channel with a scoop. The third machine of Al-Jazari featured his idea of the water turbine that is driven by the power of water and drives a devised gearing system to lift pots filled with water. In the fourth machine he devised the concept of using the crankshaft and connecting the rod system to lift the water. The fifth machine of Al-Jazari featured his invention of a reciprocating piston suction pump with suction pipes[10]. Creating vacuum for suction and the double-acting principle were technological advancements at his time, i.e., more than eight centuries ago[11].

The American historian of science, George Sarton[12], says

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[8] *Al-Hassani, Salim,* "The Machines of Al-Jazari and Taqi Al-Din," in *Proceedings of the 22nd Annual Conference on the History of Arabic Sciences*, (Aleppo University, Aleppo, 2001); Agius, Dionisius A.; Hitchcock, Richard, *The Arab Influence in Medieval Europe: (Folia Scholastica Mediterranea),* (Ithaca Press, 1994).

[9] *Al-Hassani, Salim,* "The Machines of Al-Jazar",; Glick, Thomas F., *Islamic And Christian Spain in The Early Middle Ages*, (Princeton: Princeton University Press, 1979); Cursetji Pavry, Jal Dastur, *Oriental Studies in Honour of Cursetji Erachji Pavry*, (London: Oxford University Press, 1933).

[10] *Al-Hassani, Salim,* "The Machines of Al-Jazari"; Aslam, Syed, "Muslim Scientists and Thinkers — Abu al Tz ibn Razaz al-Jazari," *The Muslim Observer*, 14 August, 2008.

[11] *Al-Hassani, Salim,* "The Machines of Al-Jazari",; Aslam, Syed, "Muslim Scientists and Thinkers…

[12] Sarton, George, *Introduction to the History of Science*, Baltimore, Vol. II,

about Al-Jazari's book: "This treatise is the most elaborate of its kind and may be considered the climax of this line of Muslim achievement". Many of the ideas employed in the construction of his devices were useful in the later development of mechanical engineering and technology such as static balancing of large pulley wheels, calibration of orifices, the use of wooden templates which are a kind of pattern, the use of paper models to establish designs, the lamination of timber to prevent warping, the grinding of the seats and plugs of valves together with emery powder to obtain a watertight fit, the casting of brass and copper in closed mould boxes with greensand, the use of tipping buckets that discharge their contents automatically, and the use of segmental gears[13]. The English historian and Chartered Engineer, Donald H. Hill, who was an authority in the history of mechanics and engineering, wrote as well about Al-Jazari's book: "Until modern times there is no other document, from any cultural area that provides a comparable wealth of instructions for the design, manufacture, and assembly of machines"[14]. Professor Gunalan Nadarajan, Associate Dean of Research and Graduate Studies in the College of Arts and Architecture at Penn State University, says about Al-Jazari's work: "Al-Jazari's work provides some interesting examples of untoward automation, which involves deliberate and elaborate programming for untoward rather than predictable behavior in automated devices. In addition, Al-Jazari's work is a catalyst for critical readings of and new directions in robotic arts"[15]. Professor Gunalan Nadarajan found

632-633, 1927.

[13] Hill, Donald Routledge, "Mechanical Engineering in the Medieval Near East", *Scientific American*, 64-69, May 1991; Hill, Donald R., *Arabic Mechanical Engineering: Survey of the Historical Sources*, Arabic Sciences and Philosophy, Cambridge University Press, Vol. 1, 167-186, 1991; Hill, Donald R., *Islamic Science and Engineering*, Edinburgh, Edinburgh University Press, 1993.

[14] Donald Routledge Hill, *Studies in Medieval Islamic Technology: From Philo to Al-Jazari From Alexandria to Diyar Bakr*, Edited by David A. King. Aldershot, Eng./ Brookfield, Vt.: Ashgate, Variorum Collected Studies Series, 231-232, 1998.

[15] *Al-Hassani, Salim*, "The Machines of Al-Jazari"; Nadarajan, Gunalan, *Media Art Histories*, Edited by Oliver Grau, Cambridge (Massachusetts), MIT Press, 163-178, 2007; Forbes, R. J., *Studies in Ancient Technology*, Volume 2, Leiden: E. J. Brill, 1965; Hayes, John R., *The Genius of Arab Civilization Source of Renaissance*, Oxford: Phaidon Press, 1976.

that Al-Jazari's technology in automation proposed automation as a means of control rather than a manner of submission[16].

Recreation and 3D-model animation of some of Al-Jazari's devices, such as the reciprocating pump with a water wheel as the drive source, were successfully made recently by the Foundation for Science, Technology, and Civilization (FSTC) Limited in the UK and the Department of Mechanical Engineering at the University of Manchester[17]. Those recreated devices, as well as their animated models, proved to be efficient machines rather than toys as erroneously assumed by some historians[18]. In addition, the "castle" water clock was reconstructed in the Science Museum, London, for the 1976 World of Islam Festival, and it worked perfectly, exactly in accordance with Al-Jazari's intention[19]. Moreover, the Frankfurt Institute of the History of Arabic and Islamic Sciences, under the direction of Fuat Sezgin, has reconstructed recently small models of a few of Al-Jazari's devices[20].

In this present paper, early mechanical engineering devices and mechanisms in Al-Jazari's manuscript are reviewed. Comparative evaluation of Al-Jazari's work and other later inventors' work is presented. Proofs that Al-Jazari's concepts were systematically copied by other inventors who came after Al-Jazari's death are provided.

2. Mechanical Engineering Devices and Mechanisms in Al-Jazari's Concepts

Considered the father of modern engineering, Al-Jazari invented about 50 inventions: the top of these were automated crank-shaft, camshaft, hydraulic reciprocating suction pump with suction pipes,

[16] Nadarajan, Gunalan, "Islamic Automation: A Reading of al-Jazari's The Book Of Knowledge Of Ingenious Mechanical Devices (1206)," *Proceedings of the First International Conference on the Media Arts, Sciences and Technologies (REFRESH)*, Banff New Media Institute, October 2005.

[17] *Al-Hassani, Salim,* "The Machines of Al-Jazari".

[18] Aiken, Jane Andrew, "Truth in Images: From the Technical Drawings of ibn al-Razaz al-Jazari, Campanus of Novarra and Giovanni de'Dondi to the Renaissance Studies," Vol. 25, 325-359, 1994.

[19] *Al-Hassani, Salim,* "The Machines of Al-Jazari".

[20] Ibid.

over-shot curvaceous water turbines, and crank-connecting rod mechanism[21]. While many of al-Jazari's inventions could now seem trivial, the most significant aspect of his machines were the mechanisms, components, ideas, methods, and design features which they showed and employed[22]. His "Book of Knowledge of Ingenious Mechanical Devices" written in 1206 shows he also refined the use of valves and pistons[23]. Al-Jazari invented five machines for raising water with cams on their axle used for the purpose of automatic control and Al-Jazari's automata and described them in 1206[24].

Al-Jazari was a practical engineer who was more interested in the craftsmanship necessary to construct the devices he invented than in describing the technology which lay behind them. His machines were usually built by trial and error rather than by theoretical calculation. Al-Jazari was a gifted craftsman himself and regarded himself as one person in a succession of craftsmen and engineers[25]. He indicates this by describing in scrupulous detail how each device in his book was constructed using the language of the craftsmen of that time[26]. He was concerned only with making innovative and ingenious designs and inventions and completed his book in 1206. Today, the original book written by Al-Jazari is kept at Ahmed III Library at Topkapi Palace under manuscript # MS A 3472[27]. Another hand-written copy of this book is kept at the library of Aya Sophia,

[21] Hassan, Ahmad Y.; Hill, Donald Routledge, *Islamic Technology: An Illustrated History*, Cambridge University Press, 57–59, 1986.

[22] Hill, Donald Routledge, "Mechanical Engineering", 64-69; Hill, Donald R., *Arabic Mechanical Engineering*, 167-186.

[23] Hassan, Ahmad Y.; Hill, Donald Routledge, *Islamic Technology'* 57–59; Hill, Donald R., *"A Treatise on Machines by Ibn Mu*'ad Abu 'Abdallah al-Jayyani. "*Journal for the History of Aarabic Science*, vol. 1, 33-44, 1978; Landels, J. G., *Engineering in the Ancient World*, London: Chatto and Windus, Second Edition, 1980.

[24] Hill, Donald Routledge, *A History of Engineering in Classical and Medieval Times*, Routledge, 224, 1996.

[25] Hayes, John R., *The Genius of Arab Civilization*, 177.

[26] Ibid.

[27] Atilla Bir; Mustafa Kacar, "Pioneers of Automatic Control Systems," Research Report # 628, Foundation for Science, Technology, and Civilization (FSTC) Limited, December 2006.

with 66 pages stolen[28]. A part of that copy of the book of Al-Jazari is conserved at the Bodleian Library in Oxford under manuscript # MS Graves 27[29]. That manuscript was completed in April 1206 by Muhammad ibn Yusuf ibn Uthman al-Haskafiat: the colophon indicates that Al-Jazari passed away in that year[30]. Since the language of science used in the Artuk palace in the 13th century was Arabic, the book was also written in Arabic, which is similar to how the language of science was used by Latin in Western cultures[31]. The book was translated into German in 1915 by two German Scholars Wiedemann and Hauser in a series of seven articles covering the book content[32]. The book was translated into English in 1974 by Donald Hill, and published by Springer Corporation[33]. The Metropolitan Museum in New York displays in the Islamic Arts section two pages from al-Jazari's original hand-written book complete with colorful pictures, one page shows the "Automatic Tool with Elephant and Bird" and the other shows the "Automatic Horseman and Musicians Tool," and a page of which is shown in Figure 1[34]. Moreover, the book was translated into Turkish in 2002 by Sevim Tekeli, Melek Dosay, and Yavuz Unat in Turkey and

[28] Hakki, Konyali Ibrahim, "Turkish Palaces Used Machines Eight Centuries Ago," *Black Amid Magazine*, Issue 5, 2-7, 1969.

[29] *Al-Hassani, Salim,* "The Machines of Al-Jazari".

[30] Al-Hassani, Salim, *800 Years Later: In Memory of Al-Jazari, A Genius Mechanical Engineer*, Foundation for Science, Technology, and Civilization (FSTC) Limited, January 2008; *Al-Hassani, Salim,* "The Machines of Al-Jazari".

[31] Akman, Toygar, *An 800 Years Old Ancestor: Today's Science of Robotics and al-Jazari*, Foundation for Science, Technology, and Civilization (FSTC) Limited, February 2008; Akman, Toygar, *Cybernetics: An Evolution in Science Computers and Reform in Law*, Banka Ve Tic. Hu. Aras. Enstitusu, Ankara, 11-15, 1972; Akman, Toygar, *Automation System and Data Banks*, Banka ve Tic. Huk. Arastirma Ens., Ankara, 153-158, 1975.

[32] Al-Hassani, Salim, *800 Years Later*; Al-Jazari, *Al-Jami'byan al—ʿilm wa 'l-ʿamal al-nafi' fi sina'at al-hiyal*. (*Compendium on the Theory and Practice of the Mechanical Arts*.) Edited by F. Sezgin, Frankfurt: Institut fur Geschichte der Arabish-Islamischen Wissenschaften, 2003; F. Sezgin, "Badi'Azzaman al-Jazari: Texts and Studies," *Natural Sciences in Islam*, Vol. 41, Frankfurt, Frankfurt: Institute fur Geschichte der Arabish-Islamischen Wissenschaften, 2001; *Al-Hassani, Salim,* "The Machines of Al-Jazari…

[33] Al-Jazari, *The Book of Knowledge*, 17-41.

[34] Akman, Toygar, *An 800 Years Old Ancestor*.

published by TTK, Ankara[35]. In addition, Al-Jazari's inventions were recognized in Turkish professional scientific magazines, such as on the cover page of "Science and Techniques" *Bilim ve Teknik* magazine in 1976, as shown in Figure 2[36]. Furthermore, the book was translated into Persian as late as the 19th century[37]. The Arabic edition of the book of Al-Jazari, edited by Ahmad Al-Hassan, was published by the University of Aleppo in 1979 and enumerates fifteen manuscripts of Al-Jazari's book[38].

Figure 1: Automatic Horseman and Musicians Tool, a leaf detached from Al-Jazari's book displayed in the Metropolitan Museum in New York, Islamic Arts section (Ink, colors, and gold on paper; H. 11 13/16 in. (30 cm), W. 7 3/4 in. (19.7 cm)[39] .

[35] Al-Jazari, *Al-Câmi Bayna'l-Ilm va'l-Amal an-Nafi Fî Sinaati'l-Hiyal*, (*The Book of Knowledge of Ingenious Mechanical Device*,) Edited and translated by Sevim Tekeli, Melek Dosay, and Yavuz Unat (in Turkish), TTK, Ankara, 2002.

[36] Akman, Toygar, "The First Turkish Scientist in Cybertenics: Eb-Ul-Iz", *Bilim ve Teknil*, Issue 103, 1-4, 1976.

[37] Al-Jazari, *The Book of Knowledge*, 17-41; Al-Hassani, Salim T. S.; Kiat, Colin Ong Pang, *Characterisation of the tradition of Islamic Technology*, Foundation for Science, Technology, and Civilization (FSTC) Limited, April 2008.

[38] Al-Jazari, *A Compendium on the Theory*.

[39] Akman, Toygar, *An 800 Years Old Ancestor*.

Figure 2: The cover of the magazine "Science and Techniques" (*Bilim ve Teknik*) published by TUBITAK (The Turkish Science and Technical Council) showing one of Al-Jazari's automated ablution machines[40]

In this section, automated crankshaft, camshaft, reciprocating piston suction pumps, over-shot curvaceous water turbines, and crank-connecting rod mechanism described in Al-Jazari's manuscripts are reviewed.

2.1. Automated Crankshaft in Al-Jazari's Manuscripts

A crank is an arm attached to a rotating shaft by which reciprocating motion is imparted to or received from the shaft. It is used to change circular motion into reciprocating motion or to change reciprocating motion into circular motion. The arm may be a bent portion of the shaft or a separate arm attached to it. Crank is the most important single mechanical device after the wheel [41]. The automated crank-shaft devised by Al-Jazari is a device which transformed rotary motion into linear motion and is central to much of the machinery in the modern world, such as the internal combustion engine and

[40] Akman, Toygar, "The First Turkish Scientist", 1-4.

[41] Gille, Bertrand, *A History of Technology and Invention, Progress Through the Ages*, Edited by Maurice Daumas, New York, Vol. I, 446-47, 1969.

automatic control systems. It is one of the most important mechanical inventions in the history of humankind and was created by Al-Jazari to raise water for irrigation[42]. In 1206, Al-Jazari invented an early automated crankshaft, which he incorporated with a crank-connecting rod mechanism in his twin-cylinder pump, transforming continuous rotary into linear reciprocating motion, as shown in Figure 3. Like the modern crankshaft described in Leonardo da Vinci's journals, Al-Jazari's mechanism consisted of a wheel setting several crank pins into motion, with the wheel's motion being circular and the pins moving back-and-forth in a straight line[43]. According to Donald H. Hill, the first known use of a crankshaft in a pump was in one of al-Jazari's raising water machines, Al-Jazari's *saqiya* chain pump[44]. A sort of crankshaft appeared in the mid-9th century in some of the hydraulic devices described by the Banu Musa brothers in their book entitled "Book of Ingenious Devices", but that has a very limited rotational capability and cannot perform the function of the crankshaft to the extent that key historians in the field of history of technology, such as Professor Lynn White, do not consider the device as a crankshaft at all[45]. According to Beeston the crank appeared in the 9th century in several of the hydraulic devices described by the Banu Musa brothers in their "Book of Ingenious Devices"; however,

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[42] Hassan, Ahmad Y.; Hill, Donald Routledge, *Islamic Technology* 57–59; Hill, D. R., *Islamic Science and Engineering*; Nasr, Seyyed Hossein, *Islamic Science: An Illustrated Study*, Photographs By Roland Michaud. London: The World of Islam Festival Trust, 1976.

[43] Sally Ganchy, Sarah Gancher, *Islam and Science, Medicine, and Technology*, The Rosen Publishing Group, 41, 2009; Donald Routledge Hill, *Studies in Medieval Islamic Technology*… 231-232.

[44] Donald Routledge Hill, "Engineering", in Roshdi Rashed, ed., *Encyclopedia of the History of Arabic Science*, Vol. 2, 751-795, Routledge, London and New York, 1996.

[45] Beeston, A. F. L.; Young, M. J. L.; Latham, J. D.; Serjeant, R. B., *The Cambridge History of Arabic Literature*, Cambridge University Press, 266, 270–271, 1990; Banu Musa, *The Book of Ingenious Devices*, 21–22; White, Lynn, Jr., *Medieval Religion and Technology: Collected Essays*, Berkeley, California, 1978; White, Lynn, Jr., *Medieval Technology and Social Change*, London, 1962; White, Lynn, Jr., "The Study of Medieval Technology, 1924-1974, Personal Reflections," *Technology and Culture*, Vol. 16, 519-30, 1975; White, Lynn, Jr. "Technology and Invention in the Middle Ages," *Speculum*, Vol. 15, 141-56, 1940.

these devices made only partial rotations and could not transmit much power[46].

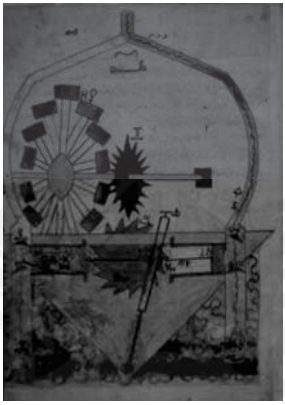

Figure 3: Al-Jazari's crank shaft, crank-connecting rod, and double-acting piston pump with suction pipes, (Ink, colors, and gold on paper; H. 11 13/16 in. (30 cm), W. 7 3/4 in. (19.7 cm), from the manuscript copy held in Topkapi Sarayi Library, Ahmet III collection, Manuscript # MS 3472[47]

Al-Jazari developed the earliest water supply system to be driven by gears and hydropower in his water raising chain pump, which was built in 13th century Damascus to supply water to its public facilities, such as hospital[48]. For receiving or communicating reciprocating motion, Al-Jazari devised a system of gears, as shown in Figure 4. In Figure 4, Al-Jazari demonstrated his devised water raising chain pump, also known as Al-Jazari's Third Water Raising Device, which features a crankshaft which transforms rotary motion into linear motion. The rotation is transmitted through the cogwheel (driven gear) and the lantern (driving pinion gear) via a pillar connected to the upper lantern and the cogwheel which turns the *sindi*-wheel which is a chain carrying a series of jars connected to ropes.

[46] Banu Musa, *The Book of Ingenious Devices*, 21–22; Beeston, A. F. L.; Young, M. J. L.; Latham, J. D.; Serjeant, R. B., *The Cambridge History of Arabic Literature*, Cambridge University Press, 266, 270–271, 1990; Al-Jazari, *A Compendium on the Theory…*

[47] Al-Jazari, *A Compendium on the Theory.*

[48] Turner, Howard R., *Science in Medieval Islam: An Illustrated Introduction*, University of Texas Press, 181, 1997.

Professor Lynn Townsend White, Jr. wrote: “Segmental gears first clearly appear in Al-Jazari, in the West they emerge in Giovanni de Dondi‘s astronomical clock finished in 1364, and only with the great engineer Francesco di Giorgio (1501) did they enter the general vocabulary of European machine design”[49]. The gears devised by Al-Jazari can transform vertical rotation into horizontal rotation. Al-Jazari through his water chain pump first introduced the concept of automation by automating the rotation of gearwheels by means of water flow[50]. The first description of a gearing system was first mentioned in the ‘Mechanics' (the oldest-known engineering textbook) written by Aristotle of Stagyra (384 - 322 BCE) and Straton of Lampsakos which dates to the Hellenistic era[51]. Yet, gearing had been rarely used because of the difficulty of making well-fitting gears[52].

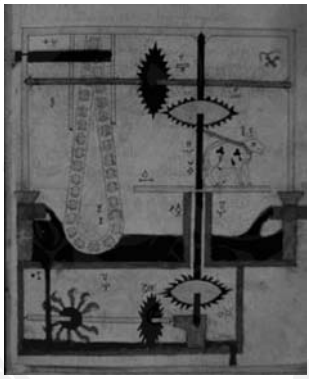

Figure 4: Gears devised by Al-Jazari for transforming vertical rotation into horizontal rotation in his raising water *saqiya* chain pump for raising water (Ink, colors, and gold on paper; H. 11 13/16 in. (30 cm), W. 7 3/4 in. (19.7 cm), from the manuscript copy held in Topkapi Sarayi Library, Ahmet III collection, Manuscript # MS 3472[53].

[49] White, Lynn, Jr., *Medieval Religion*; White, Lynn, Jr., *Medieval Technology*; White, Lynn, Jr., “The Study of Medieval Technology”, 519-30; White, Lynn, Jr. “Technology and Invention”, 141-56.

[50] Uzun Abdullah; Vatansever, Fahri, “Ismail Al Jazari Machines and New Technologies,” *Acta mechanica et automatica*, Vol.2, No. 3, 2008.

[51] *Al-Hassani, Salim*, “The Machines of Al-Jazari”.

[52] Ibid.

[53] Al-Jazari, *A Compendium on the Theory.*

Initially, it was thought that this device of Al-Jazari for raising water was simply an unrealistic idea of Al-Jazari, whereas the Third Water-Raising Device is a scaled down version of a utilitarian machine since a water raising machine that was built based on this design of Al-Jazari has been located on the River Yazid in Damascus, on a riverside path called the "Land of the Norias", as shown in Figure 5[54].

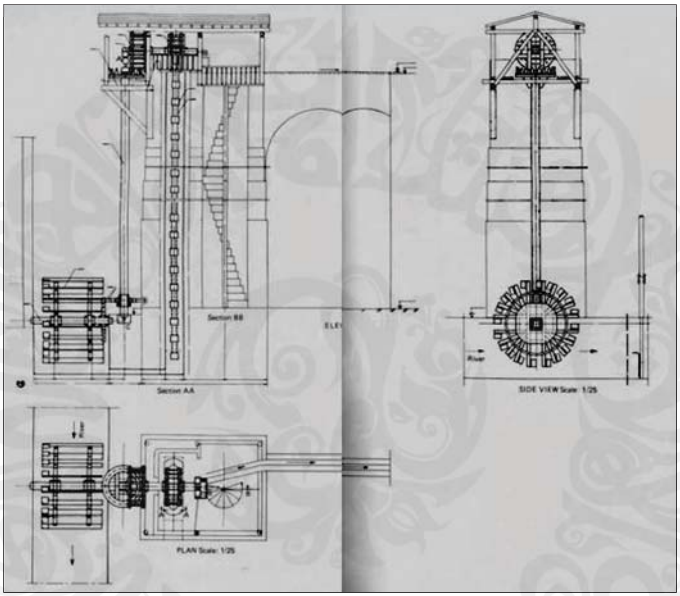

Figure 5: The water raising mechanism in the water raising device located on the River Yazid in Damascus[55]

Figure 5 shows clearly that Al-Jazari's water chain pump was implemented in the water raising device located on the River Yazid in Damascus.

2.2. Camshaft in Al-Jazari's Manuscripts

The camshaft, a shaft to which cams are attached, was first introduced in 1206 by Al-Jazari, who employed them in his automata

[54] Hill, Donald Routledge, *A History of Engineering*, 224.
[55] Ibid.

and water-raising machines. The cam and camshaft later appeared in European mechanisms from the 14th century[56]. In 1206, Al-Jazari incorporated this invention into his twin-cylinder pump. Al-Jazari invented machines for raising water with cams on their axle in the 12th century and described them in 1206. It was in these water-raising machines that he introduced his most important ideas through the design of their components[57]. The automata device and camshaft of Al-Jazari were included in his boat robot as well as in his programmable castle clock where he devised four robotic musicians who automatically play music when they are moved by levers operated by a hidden camshaft attached to a water wheel, as shown in Figure 6[58]. Al-Jazari was the first as well to introduce the idea of four-stroke cylinder system to transform energy to raise water, as shown in Figures 7 (a) and 7 (b)[59]. That brilliant technological idea of a four-stroke cylinder and camshaft system to transform energy to raise water which is key in internal combustion engines and steam engines is described in Al-Jazari's manuscript and celebrated at the Metropoletan Museum of Art, New York[60]. In addition, the international weekly journal of science *Nature*, celebrated as well that brilliant technological idea of the four-stroke cylinder and camshaft system to transform energy to raise water by publishing a photo of Al-Jazari's manuscript that devised that technological idea on the front page of *Nature* in April 2006, as shown in Figure 8[61].

[56] Georges Ifrah, *The Universal History of Computing: From the Abacus to the Quantum Computer*, 171, Translated by E.F. Harding, John Wiley & Sons, Inc., 2001.

[57] Al-Jazari, *The Book of Knowledge*, 17-41; Hill, Donald Routledge, *A History of Engineering*, 224.

[58] Al-Hassani, Salim, *800 Years Later*; *Al-Hassani, Salim,* "The Machines of Al-Jazari.

[59] Uzun Abdullah; Vatansever, Fahri, "Ismail Al Jazari Machines".

[60] Abu Dhabi Education Council, *Robotics and the Islamic World – Al-Jazari*, Abu Dhabi Education Council, World Robot Olympiad, 2010.

[61] Ibid.; Ball, Philip, "Science in culture: The zenith of Islamic science," *Nature*, Vol. 440, No. 997, 20 April 2006.

Figure 6: Al-Jazari's boat robot (Ink, colors, and gold on paper; H. 11 13/16 in. (30 cm), W. 7 3/4 in. (19.7 cm), from the manuscript copy held in Topkapi Sarayi Library, Ahmet III collection, Manuscript # MS 3472[62]

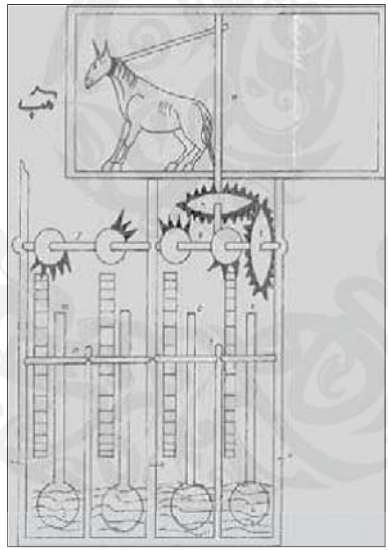

Figure 7 (a): The four-stroke cylinder and camshaft system to transform energy to raise water[63]

[62] Al-Jazari, *A Compendium on the Theory.*
[63] Uzun Abdullah; Vatansever, Fahri, "Ismail Al Jazari Machines".

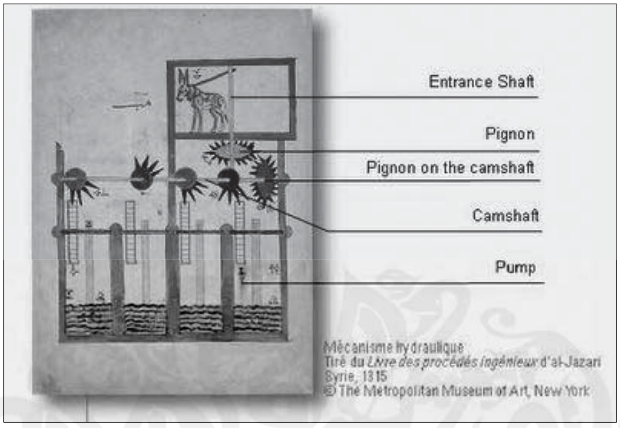

Figure 7 (b): The four-stroke cylinder and camshaft system to transform energy to raise water, Al-Jazari's manuscript on display at the Metropoletan Museum of Art, New York[64]

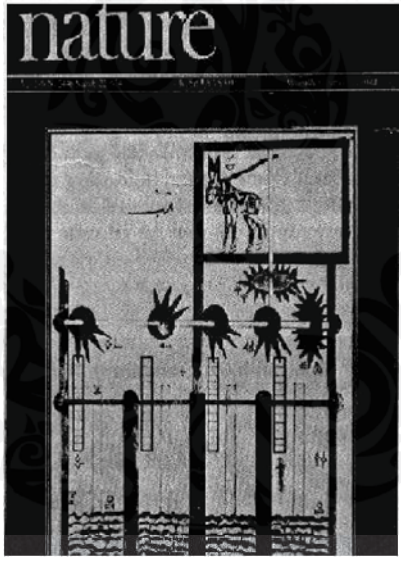

Figure 8: Al-Jazari's manuscript features the technological idea of the four-stroke cylinder and camshaft system to transform energy to raise water on the front page of the *Nature* journal in April 2006[65]

[64] Ibid.

[65] Ibid.; Ball, Philip, "Science in culture: The zenith of Islamic science," *Nature*,

George Ifrah, the well-known historian in the field of history of technology, stated about Al-Jazari's camshaft: "Al-Jazari in his works gives a description of true sequential automata, driven notably by a camshaft, which transforms the circular motion of a sort of crankshaft into an alternating motion of a distributor: such automata thus marks a break with the Greco-Roman concept of the simple device endowed with automatic movements. This is a significant milestone in the sequential programming of machines where he views it as having achieved a greater level of control over the movements".

2.3. Reciprocating Piston Suction Pump with Suction Pipes in Al-Jazari's Manuscripts

Al-Jazari also invented the double acting piston pump with suction pipes, as shown in Figure 3. Al-Jazari described in 1206 the first suction pipes, first suction pump, first double-action pump, and first valve-based system, and the first crankshaft-connecting rod mechanism, when he invented the twin-cylinder reciprocating piston pump[66]. His reciprocating pump has three features: (1) It features pistons based on the double-acting principle; (2) It is the first pump known to have suction pipes; (3) It incorporates an effective means of converting rotary into reciprocating motion through the crank-connecting-rod mechanism[67]. Figure 3, shows Al-Jazari's double-acting piston pump with suction pipes. In Figure 3, the gear on the upper shaft drives the gear on the lower level which in turn is connected to a connecting rod that oscillates to the right and to the left to operate two horizontally positioned pistons that slide into two copper cylinders each of which is connected to a valve-operated suction and delivery pipes. The delivery pipes are joined above the centre of the machine to form a single outlet into the irrigation system[68].

An animation presented this reciprocating water raising pump in Figure 9 that depicts a virtual model of this pump. The details of

Vol. 440, No. 997, 20 April 2006.

[66] Hill, Donald Routledge, "Mechanical Engineering", 64-69.

[67] Hassan, Ahmad Y.; Hill, Donald Routledge, *Islamic Technology*, 57–59.

[68] *Al-Hassani, Salim*, "The Machines of Al-Jazari".

this devised pump were obtained from his manuscript. Figure 9 shows two suction pistons in synchronous motion driven by a wheel that is driven by a water stream[69]. The virtual modelling investigation was an in-depth research and discussion aimed at the reconstruction of Al-Jazari's reciprocating water raising pump and at mimicking its operation. Geometrical and mechanical details were obtained from the original Arabic manuscripts and from English translations. Mathematical modeling of the pump in terms of kinetic, motion and energy characteristics was coded in MATHCAD to predict the various positions of the parts and the motion of the water. When all the equations were encoded into MATHCAD, the solution provided the relationship between the geometrical and mechanical parameters and graphs were plotted to assist in the assessment of the efficiency of the machine. Additional analysis was conducted on the strength requirement of the components. From the forces and torques, stresses were calculated which are compared to the failure strengths and buckling capacity of the components. The mathematical analysis and the virtual model confirmed the viability and efficiency of the original design as described by Al-Jazari[70].

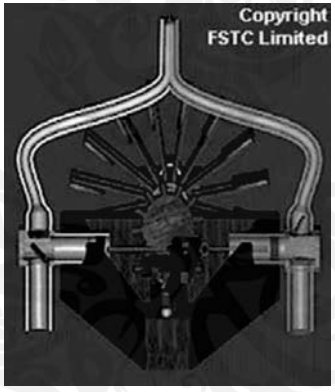

Figure 9: An animated virtual model of Al-Jazari's reciprocating water raising pump[71]

[69] Al-Hassani, Salim, *Al-Jazari: The Mechanical Genius*, Foundation for Science, Technology, and Civilization (FSTC) Limited, February 2001; *Al-Hassani, Salim,* "The Machines of Al-Jazari".

[70] *Al-Hassani, Salim,* "The Machines of Al-Jazari".

[71] Al-Hassani, Salim, *Al-Jazari: The Mechanical Genius*.; *Al-Hassani, Salim,* "The

The uniqueness of Al-Jazari's gearing system was such that it not only caused the motion to be transferred, but also changed the motion direction from vertical to horizontal[72]. The devised gear system by Al Jazari was found the first functional gear system which practically transferred the rough movement of water flow to a smooth horizontal motion used to operate a reciprocating suction pump. The horizontal gear was the main gear to operate the central device in Al Jazari's water system known as the hydraulic suction pump, which was first introduced by Al Jazari[73].

This main gear rotates when the water wheel starts to rotate. The challenge was to change the horizontal rotational movement to a back and forth movement, a linear motion. Al Jazari had introduced an interesting solution consisting of a small knob placed on the main horizontal gear to operate the arm of the pump, so that when the main gear rotated, it led to a piston-like movement of the suction pump, pumping water out from the water stream into a pipe which was then channelled to the respective areas of Diyarbakir, as shown in Figure 10[74]. Al Jazari accomplished three things: (1) he had succeeded in inventing a gear which channelled water power from a water wheel to operate other devices, (2) by using an unprecedented unique combination of gears he was able to change the direction of the motion from vertical to horizontal, (3) by connecting the main gear to a suction pump, he was able to create a piston-like dual motion movement[75]. The valve system incorporated in Al-Jazari's reciprocating suction piston pump is shown in Figure 11.

Machines of Al-Jazari".

[72] Universiti Kebangsaan Malaysia (UKM), *Al Jazari, the Islamic Engineer Inventor built man's earliest water supply system*, Universiti Kebangsaan Malaysia (UKM) News Official Portal, 21 June 2010.

[73] Ibid.

[74] Ibid.

[75] Ibid.

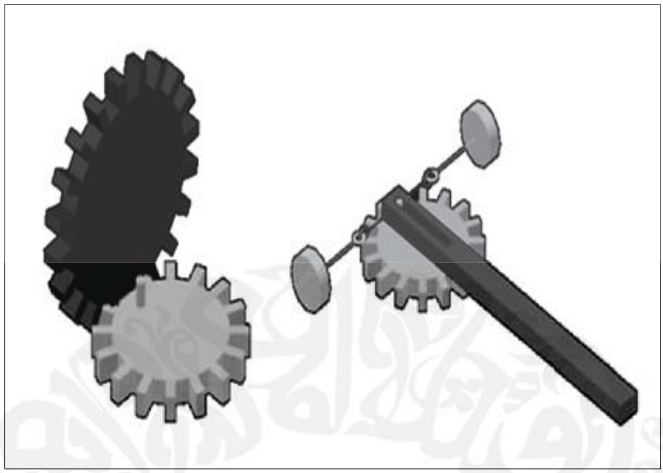

Figure 10: Main gear in Al-Jazari's reciprocating suction piston pump[76]

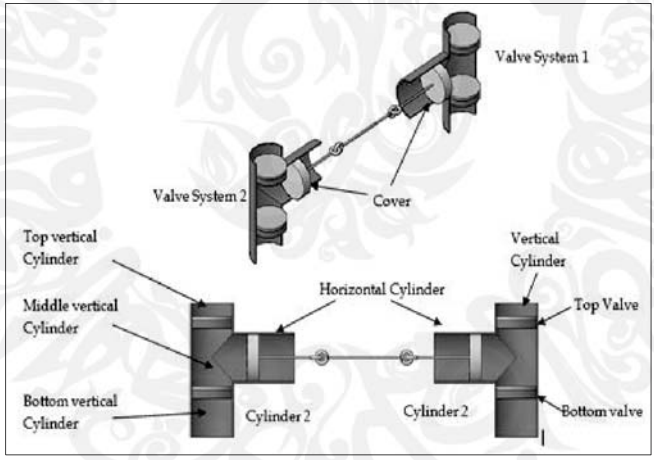

Figure 11: The valve system incorporated in Al-Jazari's reciprocating suction piston pump[77]

This water-raising machine had a direct significance for the development of modern engineering. Al-Jazari's suction piston pump could lift 13.6 metres of water with the help of delivery pipes. This

[76] Ibid.
[77] Ibid.

was more advanced than the suction pumps that appeared in 15th-century Europe, which lacked delivery pipes[78]. Al-Jazari's devised the water supply system using water as the power to distribute water to selected areas with Al Jazari's machine, consisting of a water wheel, an advanced pump system, a gear mechanism, and a piping network built to channel water to selected areas that pumped water from the water source located down at the bottom of a hill to public facilities, such as hospitals in the city in which he lived which was situated at the top of a hill[79]. In addition, that devised water supply system was used as well for agricultural irrigation purposes[80]. Al Jazari's *reciprocating suction piston pump efficiently* used the water stream to power a turbine which, in turn, by a combination of gears, creates a reciprocating motion to operate the suction pump[81].

2.4. Over-shot Curvaceous Water Turbines in Al-Jazari's Manuscripts

Designing a water raising device requires addressing the following factors: the nature of the source of water, the required height of the lift, the type of constructional materials available, and the quantity of water required. Al-Jazari's devised mechanisms for raising water addressed these factors and were either of higher efficiency of the available traditional technologies at that time or of special characteristic, such as the Scoop-Wheel (i.e. over-shot curvaceous water turbine) and the *Sindi*-Wheel (i.e. water-driven pot-garland)[82]. Al-Jazari's over-shot curvaceous water turbine consisted of curvaceous scoops being fixed to the ends of spokes that radiated from a solid disc and are struck by the force of water that was poured from above into the scoops, as shown in Figure 12[83].

[78] Hill, Donald Routledge, *A History of Engineering*, 224.
[79] *Al-Hassani, Salim*, "The Machines of Al-Jazari".
[80] Ibid.
[81] Universiti Kebangsaan Malaysia (UKM), *Al Jazari, the Islamic Engineer.*
[82] Donald Routledge Hill, *Studies in Medieval Islamic Technology*, 231-232.
[83] Ibid.

Figure 12: A 3D graphic of Al-Jazari's Overshot Scoop-Wheel[84]

Al-Jazari's over-shot curvaceous water turbine was intended for taking energy from water and transmitting it to other mechanisms. It was more commonly employed in the reverse sense, which imparted the motion into water. Al-Jazari's concept of the over-shot curvaceous water turbine was similar to a primitive Pelton wheel, which was credited to Lester Allan Pelton (1829 – 1908), as shown in Figure 13, which depended on a high head of water for its effectiveness, since there was no utilisation of pressure energy[85]. One important consideration was that the water had to be directed accurately into the scoops, which had to have a properly designed profile to obtain a maximum change in momentum of the jet flow. Al-Jazari needed to carefully calibrate the water jet flow accurately on the scoop so that the over-shot curvaceous water turbine would power the invention as desired[86]. In addition, he devised a curvaceous shape of the scoop so that the loss of energy in the form of spray and turbulence became minimal which had been proved true recently in John Smeaton's experiments on the impact between a stream of water and a flat plate[87].

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[84] *Al-Hassani, Salim,* "The Machines of Al-Jazari".

[85] Ibid.; Smith, Norman, *Man And Water: A History of Hydro-Technology*, London: Peter Davies, 155-156, 1976; Reynolds, Terry S., *Stronger Than a Hundred Men: A History of the Vertical Water Wheel*, The John's Hopkins University Press, 47-122, 1983; Newton, K., Steeds, W., and Garrett, T.K., *The Motor Vehicle*, The Butterworth Group, 1972, 396.

[86] Al-Jazari, *The Book of Knowledge*, 17-41.

[87] *Al-Hassani, Salim,* "The Machines of Al-Jazari"; Smith, Norman, *Man And Water,* 155-156; Reynolds, Terry S., *Stronger Than a Hundred Men,* 47-122.

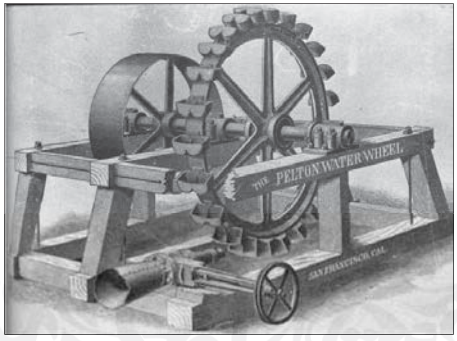

Figure 13: A primitive Pelton wheel[88]

John Smeaton of England did an experiment (made public in 1759) on the efficiency of actual water wheels driven by weight of water alone; namely the Undershot and Overshot Wheels, as shown in Figures 14 and 15. The main result of that experiment was that Overshot Wheels were about twice as efficient as Undershot Wheels; in more specific terms the ratio was 66% efficient against 30%, respectively[89].

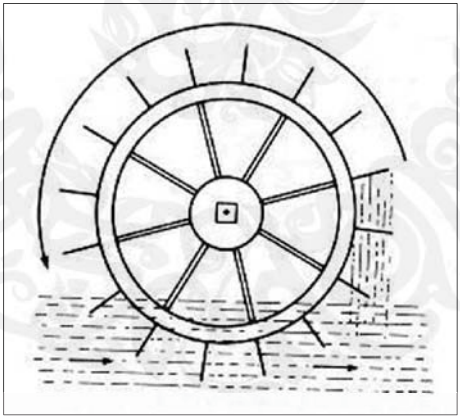

Figure 14: The Undershot Wheel is turned by the pressure of moving water on the paddles of the lower parts of the wheel[90]

[88] *Al-Hassani, Salim,* "The Machines of Al-Jazari".
[89] Smith, Norman, *Man And Water,* 155-156.
[90] *Al-Hassani, Salim,* "The Machines of Al-Jazari".

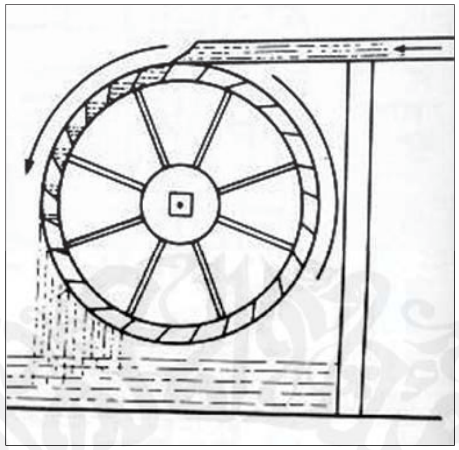

Figure 15: The Overshot Wheel is turned by the pressure of water pouring from above into the bucket-like compartments onto its rim[91]

The mechanism devised by Al-Jazari to raise water to a higher head is the *Sindi* Wheel, i.e., water-driven pot-garland, which was driven by Al-Jazari's devised over-shot curvaceous water turbine, as shown in Figure 16. The raising water process was such that the pots were filled with water at the bottom of their travel and discharged at the top into a head tank and subsequently to the designated areas through the aqueducts. The first description of the pot-garland was first mentioned in Roman times in terms of an animal-driven pot-garland, from about the start of the Christian era[92]. Yet, what Al-Jazari innovatively proposed was a water-driven pot-garland[93].

2.5. Crank-Connecting Rod Mechanism in Al-Jazari's Manuscripts

A crank-connecting rod is a rod attached to the end of the crank by a pivot. The end of the crank-connecting rod attached to the crank moves in a circular motion, while the other end is usually constrained to move in a reciprocating linear sliding motion. The invention of the

[91] Ibid.
[92] Hassan, Ahmad Y.; Hill, Donald Routledge, *Islamic Technology*, 57–59.
[93] Ibid.

crank-connecting rod system is considered by historians of technology to be the most important mechanical device of the early fifteenth century in Europe[94]. The connecting rod was also invented by al-Jazari and was used in a crank and connecting rod system in two of his water-raising machines: the crank-driven *saqiya* chain pump and the double-action reciprocating piston suction pump[95]. His water pump also employed the first known crank-slider mechanism[96]. Figure 3 shows that the gear on the upper shaft drives the gear on the lower level which in turn connects to a connecting rod that swings to the right and to the left. In 1206, Al-Jazari invented an early crankshaft which he connected with a crank-connecting rod mechanism in his twin-cylinder pump[97]. He used the crankshaft with a connecting rod in two of his water-raising machines: the crank-driven *saqiya* chain pump and the double-action reciprocating piston suction pump.

> Donald H. Hill, commenting on Al-Jazari's inventions, stated: "Al-Jazari went on to describe the first suction pipes, the first suction pump, the first double-action pump, and made early uses of valves and a crankshaft-connecting rod mechanism, when he invented a twin-cylinder reciprocating piston suction pump"[98]. The fully developed crank-connecting rod system was devised in two of al-Jazari's water raising machines in 1206 which is about three centuries prior to Francesco di Giorgio Martini[99]. In al-Jazari's fourth machine for raising water, as shown in Figure 17, the

[94] Gille, Bertrand, *A History of Technology*, 446-47.

[95] Hill, Donald Routledge, "Mechanical Engineering", 64-69; *Al-Hassani, Salim*, "The Machines of Al-Jazari".

[96] Beeston, A. F. L.; Young, M. J. L.; Latham, J. D.; Serjeant, R. B., *The Cambridge History*, 270–271; Lotfi Romdhane & Saïd Zeghloul, "Al-Jazari (1136–1206), History of Mechanism and Machine Science," *Springer*, 2010.

[97] Ganchy, Sally; Gancher, Sarah, *Islam and Science, Medicine, and Technology*, The Rosen Publishing Group, 41, 2009.

[98] Hill, Donald Routledge, "Mechanical Engineering"; Hill, Donald Routledge, *A History of Engineering*, 224.

[99] Al-Jazari, *The Book of Knowledge*, 17-41; Al-Jazari, *A Compendium on the Theory*.

drawing bar of an animal rotates a vertical axle which in turn drives a gear wheel, meshing at right angles with a second wheel mounted on a horizontal axle which has a crank fitted to it. The free end of the crank enters a connecting rod under the channel of a flume-beam swapping the scoop, which is in a pool[100]. Thus, as the animal walks in a circle the horizontal axle is turned by the gears and the end of the crank slides in the hinged connecting rod causing it to oscillate around its hinge and thus causing the scoop to rise and fall. Figure 18 shows a line drawing of the mechanism devised in this machine[101].

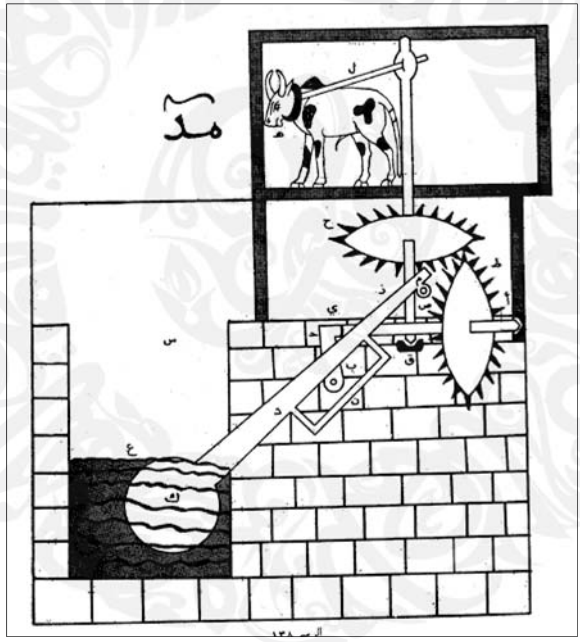

Figure 17: Al-Jazari's fourth machine for raising water[102]

[100] Ibid.

[101] Hill, Donald R., *Islamic Science and Engineering*.

[102] Al-Jazari, *The Book of Knowledge*, 17-41; Al-Jazari, *A Compendium on the Theory*.

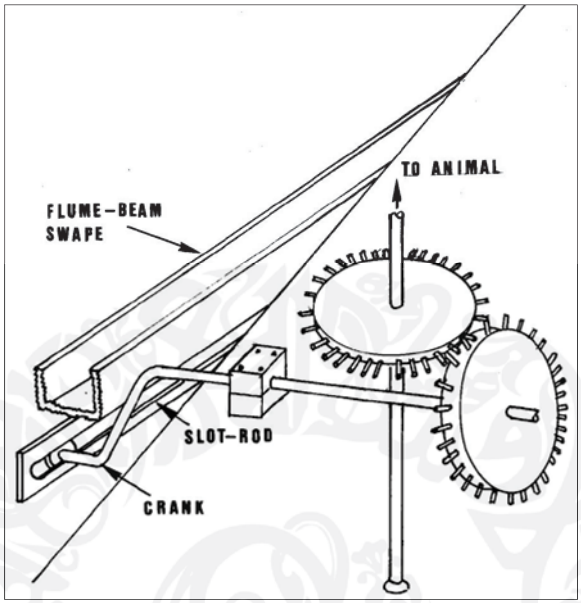

Figure 18: Line drawing of the mechanism of Al-Jazari's fourth machine for raising water[103]

The other pump in which the crank-connecting rod system was used is Al-Jazari's piston suction pump (his fifth water raising machine), which is depicted in Figure 3[104]. Al-Jazari's piston suction pump incorporated an efficient means of converting rotary into reciprocating motion through the crank-connecting-rod mechanism[105]. Having reviewed these five key inventions in mechanical engineering and technology devised by Al-Jazari, let us now have a look at a comparative evaluation of his work and other later inventors' work.

[103] Hill, Donald R., *Islamic Science and Engineering*.

[104] Al-Hassan, Ahmad Y., *Taqi al-Din and Arabic Mechanical Engineering*, Institute for the History of Arabic Science, University of Aleppo, 38-42, 1976.

[105] Hassan, Ahmad Y.; Hill, Donald Routledge, *Islamic Technology*, 57–59.

3. Comparative Evaluation of Al-Jazari's Work and Other Later Inventors' Work

Science and technology flourished during the time of Al-Jazari, which is called by many historians, the Golden Islamic Age, which was a period of unrivalled intellectual activity, whereby Muslim scholars made important and original contributions in all fields, namely literature, science and technology. This blossoming was the result of the increasing quality of material life in Muslim cities, such as Diabakir, and the faith in Islam as the driving force. Crusades invaded those Muslim cities shortly after that, that is, in the thirteenth century, resulting in the stealing of many of the treasures of knowledge in science and technology that were made in those Muslim cities and taken away to Europe[106].

The importance and originality of the book of Al-Jazari is due to its being the first book to feature automatic control studies in the history of mechanical engineering and technology and the first to feature automated cranks 300 years before Western engineers, such as Francesco di Giorgio Martini and Leonardo Da Vinci[107], achieved this much later[108]. He used in his book some kind of symbols for understanding his drawings like the use of electronic circuits[109]. There are several manuscripts of Al-Jazari's book in Oxford, Leiden, Paris, Dublin and İstanbul[110]. Al-Jazari, through his water chain pump, first introduced the concept of automation by automating the rotation of gear wheels by means of water flow[111]. The automata device and camshaft of Al-Jazari were included in his boat robot, as well as in his programmable castle clock, where he devised four robotic musicians who automatically play music when moved by

[106] Terzioglu, Arslan, "Attempts of Flight, Automatic Machines, Submarines and Rocket Technology in Turkish History," Research Report # 634, Foundation for Science, Technology, and Civilization (FSTC) Limited, January 2007.

[107] Uzun Abdullah; Vatansever, Fahri, "Ismail Al Jazari Machines".

[108] Uzun, Abdullah, *Cizreli Eb-Ul-Iz ve Otomasyon Sistemleri*, UMTS, Gazi Universitesi, Ankara, Turkey, 2003.

[109] Uzun Abdullah; Vatansever, Fahri, "Ismail Al Jazari Machines and New Technologies," *Acta mechanica et automatica*, Vol.2, No. 3, 2008; Uzun, Abdullah, *Cizreli Eb-Ul-Iz.*

[110] Ibid.

[111] Uzun Abdullah; Vatansever, Fahri, "Ismail Al Jazari Machines".

levers operated by a hidden camshaft attached to a water wheel, as shown in Figure 6[112]. Al-Jazari was also the first to introduce the idea of the four-stroke cylinder system to transform energy to raise water, as shown in Figures 7 (a) and 7 (b)[113].

It has been proved that Al-Jazari developed the earliest water supply system to be driven by gears and hydropower in his water raising chain pump, which was built in 13th century Damascus to supply water to its public facilities, such as hospitals[114]. It has been proved that the connecting rod was also invented by Al-Jazari, and was used in a crank and connecting rod system in two of his water-raising machines: the crank-driven *saqiya* chain pump and the double-action reciprocating piston suction pump[115]. It has been proven that Al-Jazari in the beginning of the 13th century described the first suction pipes, first suction pump, first double-action pump, and first valve-based system, and first crankshaft-connecting rod mechanism, when he invented the twin-cylinder reciprocating piston pump, as stated by Donald H. Hill[116].

It has been proven as well that Al-Jazari's concept of the over-shot curvaceous water turbine is similar to a primitive Pelton wheel, which is credited to Lester Allan Pelton (1829 – 1908), which depended on a high head of water for its effectiveness, since there was no utilisation of pressure energy[117]. This proves that Abu-Aliz Al-Jazari invented the over-shot curvaceous water turbine many centuries before Lester Allan Pelton.

The brilliant technological idea of the four-stroke cylinder and the camshaft system to transform energy to raise water which is key in internal combustion engines and steam engines is described in Al-Jazari's manuscript and celebrated at the Metropolitan Museum of

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[112] Al-Hassani, Salim, *800 Years Later.*; *Al-Hassani, Salim,* "The Machines of Al-Jazari".

[113] Uzun Abdullah; Vatansever, Fahri, "Ismail Al Jazari Machines".

[114] Turner, Howard R., *Science in Medieval Islam: An Illustrated Introduction*, University of Texas Press, 181, 1997.

[115] Hill, Donald Routledge, "Mechanical Engineering", 64-69; *Al-Hassani, Salim,* "The Machines of Al-Jazari".

[116] Hill, Donald Routledge, "Mechanical Engineering", 64-69.

[117] *Al-Hassani, Salim,* "The Machines of Al-Jazari"; Smith, Norman, *Man And Water,* 155-156.; Reynolds, Terry S., *Stronger Than a Hundred Men,* 47-122.

Art, New York[118]. In addition, the international weekly journal of science, *Nature*, celebrated that brilliant technological idea of four-stroke cylinder and camshaft system to transform energy to raise water by publishing a photo of Al-Jazari's manuscript that devised that technological idea on its front page in April 2006, as shown in Figure 8[119]. The World Intellectual Property Organization (WIPO) magazine celebrated Al-Jazari's inventions and his book in September 2010[120]. The WIPO magazine called Al-Jazari: 'The mechanical genius of inventors' and 'The pioneer of some 50 mechanical devices, including water clocks, the use of a crankshaft in machines, a double-action pump that could raise water to a height of 12 meters and lamination of timber to reduce warping'[121]. In addition, Al-Jazari's inventions were recognized in Turkish professional and scientific magazines such as on the cover page of 'Science and Techniques' *Bilim ve Teknik* magazine in 1976, as shown in Figure 2[122]. Furthermore, the book was translated from Arabic into Persian, English, German and Turkish.

Donald H. Hill, who was an authority in the history of mechanics and engineering, wrote about Al-Jazari's book: "His book is an absolute wealth of Islamic mechanical engineering"[123]. Commenting on the value of this book, Donald H. Hill wrote: "This work reached a high peak in mechanical technology"[124]. Donald H. Hill also wrote about Al-Jazari: "Al-Jazari added several mechanical and hydraulic devices. The impact of these inventions can be seen in the later designing of steam engines and internal combustion engines, paving the way for automatic control and other modern machinery. The impact of Al-Jazari's inventions is still felt in modern contemporary mechanical engineering"[125]. Donald H. Hill stated about Al-Jazari's crankshaft: "This attention to and ability to harness

[118] Abu Dhabi Education Council, *Robotics and the Islamic World.*
[119] Ibid.; Ball, Philip, "Science in culture".
[120] World Intellectual Property Organization (WIPO), "Uncovering A Thousand Years".
[121] Ibid.
[122] Akman, Toygar, "The First Turkish Scientist", 1-4.
[123] Al-Jazari, *The Book of Knowledge,* 17-41.
[124] Ibid.
[125] Donald Routledge Hill, *Studies in Medieval Islamic Technology,* 231-232.

minute variations required the use of several innovative mechanisms including the crankshaft, which might be the first recorded use of this historically significant technology."[126]. In addition, Donald H. Hill added: "Cranks may have first been documented by Al-Jazari - 300 years before Western Engineers achieved this, such as Francesco di Giorgio Martini and Leonardo Da Vinci"[127].

The historian in the history of technology Professor Lynn White Jr. wrote about the book of Al-Jazari saying: "Segmental gears first clearly appear in Al-Jazari, in the West they emerge in Giovanni de Dondi's astronomical clock finished in 1364, and only with the great Sienese engineer Francesco di Giorgio (1501) did they enter the general vocabulary of European machine design"[128]. George Ifrah, the well-known historian in the field of history of technology, stated about Al-Jazari's camshaft: "Al-Jazari in his works gives a description of true sequential automata, driven notably by a camshaft, which transforms the circular motion of a sort of crankshaft into an alternating motion of a distributor: such automata thus marks a break with the Greco-Roman concept of the simple device endowed with automatic movements. This, he argues, is a significant milestone in the sequential programming of machines, where he views it as having achieved a greater level of control achieved over the movements."[129]. Mark E. Rosheim summarizes the advances in automation made by Arab engineers, especially Al-Jazari, as follows: "Unlike the Greek designs, these Arab examples reveal an interest in manipulating the environment for human comfort. Thus, the greatest contribution the Arabs made, besides preserving, disseminating and building on the work of the Greeks, was the concept of practical application. This was the key element that was missing in Greek robotic science."[130].

In his essay on Al-Jazari's inventions, Professor Gunalan Nadarajan, Associate Dean of Research and Graduate Studies in the

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[126] Ibid.

[127] Hill, Donald R., *Islamic Science*; Al-Hassan, Ahmad Y., *Taqi al-Din and Arabic Mechanical*, 38-42.

[128] White, Lynn, Jr., *Medieval Religion*; White, Lynn, Jr., *Medieval Technology*; White, Lynn, Jr., "The Study of Medieval Technology, 519-30; White, Lynn, Jr. "Technology and Invention", 141-56.

[129] Georges Ifrah, *The Universal History of Computing*, 171.

[130] Donald Routledge Hill, "Engineering", 751-795.

College of Arts and Architecture at Penn State University, drew on the work of Al-Jazari. He specifically reviewed Al-Jazari's "Book of Knowledge of Ingenious Devices" as a means to develop an alternative history for robotic arts. He argued that the various machines developed and conceptualized by Al-Jazari reflect not only an alternative perspective on automation, which were radically different from those developed in the West, but also present a range of new possibilities for contemporary explorations in robotics art[131]. The essay written by Prof. Gunalan Nadarajan presented Al-Jazari's "Book of Knowledge of Ingenious Mechanical Devices" as a significant contribution to the history of robotics and automation[132].

Studies made during the past fifty years demonstrate that the scientists and engineers of the classical age of Islamic civilisation made substantial contributions to developments in engineering and that some of their accomplishments were passed on to the Europeans through Spain and Italy and the Crusades[133]. The display of two complete and original pages from Al-Jazari's hand-written book at the Metropolitan Museum in New York implies that these two pages were from the 66 stolen pages from Al-Jazari's hand-written book[134]. Commenting on how Al-Jazari's inventions were transmitted into Europe, Donald H. Hill wrote: "The most likely route was Spain. Such fine technology could have followed the same route as the astrolabe (itself part of this fine technology.) Apart from Spain, there were other possible lands of transfer: Sicily, Southern France, Italy, Byzantium and Syria during the Crusades"[135].

It is known that Leonardo da Vinci was under the influence of Islamic scholars like Al-Hazen. In addition, it is known that a hand-written copy of the technical work of Ahmed bin Musa, the Islamic engineer who was one of the references in the book of

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131 *Al-Hassani, Salim,* "The Machines of Al-Jazari".

132 Ibid.

133 Ibid.; Ludlow, C.G.; Bahrani, A.S., *Mechanical Engineering during the Early Islamic Period, Institution of Mechanical Engineers, The Chartered Mechanical Engineer*, 79-83, 1978.

134 Hakki, Konyali Ibrahim, "Turkish Palaces Used Machines Eight Centuries Ago," *Black Amid Magazine*, Issue 5, 2-7, 1969; Akman, Toygar, *An 800 Years Old Ancestor*.

135 Al-Jazari, *The Book of Knowledge*, 17-41.

Al-Jazari for authoring the book that was entitled "The Book of Ingenious Devices" and was acknowledged in the book of Al-Jazari for his book and inventions, is still in the Vatican Library[136]. It is noteworthy that Leonardo Da Vinci's approach to science was an observational one, i.e., he tried to understand a phenomenon by describing and depicting it in utmost detail and did not emphasize experiments or theoretical explanation. Since he lacked formal education in Latin and mathematics, contemporary scholars mostly ignored Leonardo, the scientist[137]. Yet, his artistic work, recorded in notebooks 13,000 pages of notes and drawings[138]. In addition, Leonardo Da Vinci's journals appear to have been intended for publication because many of the sheets have a form and order that would facilitate this[139]. Those Leonardo Da Vinci journals include a vast number of claimed inventions, both practical and impractical, such as musical instruments, hydraulic pumps, reversible crank mechanisms, finned mortar shells, and a steam cannon[140].

The belief that it was Leonardo da Vinci, who was the first to develop and to use hydraulics and mechanical gears, is questionable since it has been found recently that Leonardo was influenced by Al Jazari's writings because there is evidence of interactions between Leonardo da Vinci and the Ottoman Empire where Al Jazari had lived[141]. In 1502, Leonardo produced a drawing of a single span 720 foot (220 m) bridge as part of a project for the Ottoman Sultan Beyazid II of Istanbul. This fact alone proved that there were communications between Leonardo and the descendants of Al Jazari's employer, Sultan Artuq in Turkey during the Ottoman period. Yet Leonardo's sketch was rejected because it was too impractical to implement [142].

Although it was Al-Jazari who devised the first automatic

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[136] Banu Musa, *The Book of Ingenious Devices*, 21–22; Terzioglu, Arslan, "Attempts of Flight".

[137] Arasse, Daniel, *Leonardo da Vinci*, Konecky, William S. Associates, Inc., 1998.

[138] Ibid.

[139] Ibid.

[140] Arasse, Daniel, *Leonardo da Vinci*, Konecky, William S. Associates, Inc., 1998. Bortolon, Liana, *The Life and Times of Leonardo*, London: Paul Hamlyn, 1967.

[141] Universiti Kebangsaan Malaysia (UKM), *Al Jazari, the Islamic Engineer*.

[142] Ibid.

machines and programmable humanoid robot, the person who received credit for this innovation is Leonardo Da Vinci approximately two centuries after Al-Jazari. Yet, recent investigations about who deserves that credit were made in 2007 and concluded with documentary evidence that Al-Jazari was the first to devise automatic machines and programmable humanoid robot[143]. Unlike Leornado Da Vinci whose greatness is measured in sketches that he made in his notes, Al Jazari successfully created a working and functional mechanical system operated by the devices he invented with great precision and accuracy[144]. Two centuries after the death of Al-Jazari, crankshafts were described in Europe in the 15th century by Konrad Kyeser, who died in 1405 and by Leonardo da Vinci (1452–1519) and in the 16th century by Cornelis Corneliszoon van Uitgeest in 1592[145]. Cornelis Corneliszoon van Uitgeest's wind-powered sawmill used a crankshaft to convert a windmill's circular motion into a back-and-forward motion, thus powering the saw. Corneliszoon was granted a patent for his crankshaft in 1597[146].

Hand operated cranks were known for centuries in Han China before the time of Al-Jazari, but the incorporation of a crank-connecting rod system in a machine was unknown before that date of accomplishing the book of Al-Jazari as stated by Donald H. Hill[147]. After more than two centuries of Al-Jazari's death, Leonardo da Vinci, who died in 1519, incorporated a crank and rod in his designs and Ramelli also used the crank-connecting rod in a pump in his book of 1588[148].

One of the proofs that many of Al-Jazari's ideas mentioned in his manuscripts, a copy of which was stolen, were used long after his death by European scientists is that the physician Guido da Vigevano from the land of Vatican (1280−1349), planning for a new crusade,

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[143] *Al-Hassani, Salim*, "The Machines of Al-Jazari"; Abu Dhabi Education Council, *Robotics and the Islamic World.*

[144] Universiti Kebangsaan Malaysia (UKM), *Al Jazari, the Islamic Engineer.*

[145] White, Lynn, Jr., *Medieval Technology.*

[146] Ibid.

[147] Hayes, John R., *The Genius of Arab Civilization.*; Gille, Bertrand, *A History of Technology*.

[148] Gnudi, Martha Teach; Ferguson, Eugene S., *The Various and Ingenious Machines of Agostino Ramelli*, Dover, N.Y., 579. 1994.

made illustrations for a paddle boat and war carriages that were propelled by cranks and gear wheels[149]. Another proof that many of these ideas mentioned in Al-Jazari's manuscripts were used long after his death by European scientists is that from September 1513 to 1516, Leonardo Da Vinci spent much of his time living in the Belvedere in the Vatican in Rome[150]. According to *Encyclopædia Britannic*a, the Italian inventor Leonardo da Vinci may have been influenced by the automata of Al-Jazari[151]. The following table of comparison summarizes the ideas similarity.

Table 1: Comparison of Ideas Similarity Described by Al-Jazari and his Successors

Idea/Inventor	**Al-Jazari**	**Leonardo da Vinci**	**Lester Allan Pelton**	**Guido da Vigevano**	**Francesco di Giorgio Martini**	**Cornelis Corneliszoon van Uitgeest**	**Ramelli**
Automated Crankshaft	V	V		V	V	V	V
Camshaft	V	V					
Reciprocating Piston Suction Pumps	V	V					
Over-shot Curvaceous Water Turbines	V		V				
Crank-Connecting Rod Mechanism	V	V			V		V

4. Conclusion

It has been proven that probably Al-Jazari was the first to invent the automated crankshaft, camshaft, reciprocating double-action piston

[149] White, Lynn, Jr., *Medieval Technology.*

[150] Della Chiesa, Angela Ottino, *The Complete Paintings of Leonardo da Vinci*, The Library of Congress Classification 'ND 623.L55 O89,' 83, 1967.

[151] "Al-Jazari," Encyclopædia Britannica, 2009. (In http://www.britannica.com/EBchecked/topic/301961/al-Jazari).

suction hydraulic pump with suction pipes, overshot curvaceous water turbines, and crank-connecting rod mechanism which are key inventions in fluid mechanics, hydraulic systems, and energy transmission. Proofs from investigating refereed publications have been provided to prove that Leonardo da Vinci, to whom the credit of inventing the automated crankshaft, camshaft, reciprocating hydraulic pump, and crank-connecting rod mechanism goes, got the ideas of these inventions from Al-Jazari's manuscripts, more than two centuries after the death of Al-Jazari. Yet, Leonardo da Vinci did not acknowledge Al-Jazari in his notes and journals that were ready for publication before the death of Leonardo Da Vinci. It has been proven as well through investigating refereed publications that Al-Jazari invented the overshot curvaceous water turbines many centuries before Lester Allan Pelton, to whom the credit of inventing the overshot curvaceous water turbines goes. Therefore, this study concludes that the true inventor of the automated the crankshaft, camshaft, the reciprocating double-action piston suction hydraulic pump with suction pipes, the overshot curvaceous water turbines, and the crank-connecting rod mechanism was Abu-Aliz Al-Jazari.

TRANSLITERATION TABLE

CONSONANTS

Ar=Arabic, Pr=Persian, OT=Ottoman Turkish, Ur=Urdu

	Ar	Pr	OT	UR		Ar	Pr	OT	UR		Ar	Pr	OT	UR
ء	’	’	’	’	ز	z	z	z	z	گ	–	g	g	g
ب	b	b	b	b	ڑ	–	–	–	ṛ	ل	l	l	l	l
پ	–	p	p	p	ژ	–	zh	j	zh	م	m	m	m	m
ت	t	t	t	t	س	s	s	s	s	ن	n	n	n	n
ٹ	–	–	–	ṭ	ش	sh	sh	ş	sh	ہ	h	h	h[1]	h[1]
ث	th	th	th	th	ص	ṣ	ṣ	ṣ	ṣ	و	w	v/u	v	v/u
ج	j	j	c	j	ض	ḍ	ẓ	ż	ż	ی	y	y	y	y
چ	–	ch	çh	ch	ط	ṭ	ṭ	ṭ	ṭ	ة	-ah			-a[2]
ح	ḥ	ḥ	ḥ	ḥ	ظ	ẓ	ẓ	ẓ	ẓ	ال	al[3]			
خ	kh	kh	kh	kh	ع	‘	‘	‘	‘					
د	d	d	d	d	غ	gh	gh	ğ	gh					
ڈ	–	–	–	d	ف	f	f	f	f					
ذ	dh	dh	dh	dh	ق	q	q	k	q					
ر	r	r	r	r	ك	k	k/g	k/ñ	k					

[1] – when not final
[2] – at in construct state
[3] – (article) al - or 1-

VOWELS

		Arabic and Persian	Urdu	Ottoman Turkish
Long	ا	ā	ā	ā
	آ	Ā	Ā	–
	و	ū	ū	ū
	ي	ī	ī	ī
Doubled	ي	iyy (final form ī)	iy (final form ī)	iyy (final form ī)
	و	uww (final form ū) uvv (for Persian)	uv	uvv
Diphthongs	و	au or aw	au	ev
	ى	ai or ay	ay	ey
Short	ـَ	a	a	a or e
	ـُ	u	u	u or ü o or ö
	ـِ	i	i	i

URDU ASPIRATED SOUNDS

For aspirated sounds not used in Arabic, Persian, and Turkish add h after the letter and underline both the letters e.g. جھ jh گھ gh

For Ottoman Turkish, modern Turkish orthography may be used.

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Contents

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