An Historical Review and Upload of Juanelo Turriano's Mechanism in Toledo

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Abstract. This work introduces the figure of Juanelo Turriano, his works and historical legacy. The main work developed by Juanelo was the hydraulic mechanism, placed in the Spanish ancient city of Toledo. The purpose of this mechanism was to provide a clean water supply to the city. Taking advantage of the study of Juanelo's main work, an analysis about the evolution of the hydraulic mechanisms, which replaced Juanelo's, and the possibilities for future developments is carried out. This study analyze the implementation of a pumping group, fueled by the energy generated by a turbine, thus it uses the power generated by the water flow through the Tajo River. This update draw from the same principles and premise, it also have a similar purpose and gets a similar result tailored to the new hydraulic urban requirements. Despite of hosting a similar population, the present city of Toledo has increased enormously its water requirements.

Keywords: Turbine · Pump · Renewable energy

1 Introduction

There are several Spanish scientists, engineers and writers, who pointed out in different fields during the XVI and XVII centuries. Nonetheless there are few literature dedicated to highlight their work and remember their figures [1].

Spain has stood out throughout history as the cradle of illustrious artists and writers who have reached high positions in all fields of knowledge on many occasions. There have also been many great inventors and scientists who had no choice but to choose the path of "exile" or to reach the end of their lives in absolute poverty [2]. The biography of Juanelo Turriano is one of the many examples that tell about people who, despite their ingenuity, had the misfortune to develop their knowledge in a place where scientific progress was viewed with envy and even suspicion [1].

What is known about Juanelo's life refers almost entirely to the stage in which he worked in the service of Carlos V, repairing and building clocks and executing automatons [3] (Fig. 1).

Juanelo Turriano was born in Cremona, Lombardy (Italy), between the years 1500 and 1511. The date of his birth has not been settle but the latest studies tend to place

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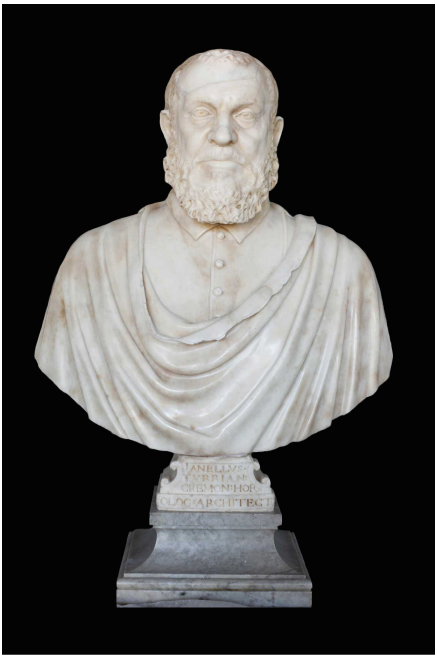

Fig. 1. "Bust of Juanelo Turriano", Pompeo y Leone Leoni, ca. 1565–1570. Museum of Santa Cruz (Toledo).

it closer to the beginning of the century [4]. Juanelo, who was born under the name of Giovanni Torresani, died in 1585. After the death of Carlos V, Juanelo continued in the service of his son, Felipe II, who asked him to build an artifact to raise the waters of the Tajo river to the Real Alcazar [3]. This mechanism is Juanelo's most known work.

From a humble family, his father Gherardo Torresani had two mills in operation on the Po River. Juanelo was not an illiterate, it could not be otherwise given his friendship with characters like Giorgio Fondulo, who, in addition to being a renowned physicist, doctor, philosopher, mathematician and astrologer, taught philosophy at the University of Pavia. The influence that Fondulo exerted on Juanelo was fundamental in his life by intervening in the early formation of the young inventor [5].

Juanelo arrived to Spain to serve the Emperor Carlos V in 1530. He worked as watchmaker for the Court [6]. His restoration of Giovanni Dondi's planetary clock and the construction of the famous "Cristalino" astronomical clock are remembered from this stage. He also stood out as engineer, mathematician and manufacturer of mechanisms, enjoying so much the favor of the monarch, that Juanelo accompanied the King in his retirement [5, 6].

After the death of the emperor, his son, Felipe II did not want to run the kingdom without his service and appointed him as Senior Mathematician, participating at this time in the reform of the current calendar, while he was "lent" to the service of Pope Gregorio XIII. During his stay in Spain. Juanelo's contributions to the Empire's heritage were numerous: construction of the Tibi reservoir dam in Alicante, the highest in the world for almost 300 years; he designs the bells, during the construction of San Lorenzo del Escorial, manufactured by his friend Juan de Herrera; he also builds mills, various automatons [7, 8].

It was in 1565 when Turriano settled permanently in Toledo. By then, the city was no longer the imperial capital, since it has been a few years since Felipe II established his Court in Madrid. In the years in which it has been, Toledo has lived through a period of splendor and demographic expansion, although it has not solved its problem of water supply that it drags [6, 9].

This task had already been tried before, the people in charge of the first attempt were two German officers whose attempt finally failed in 1526, and two Flemish engineers suffered the same fate who also tried to satisfy this demand. These previous rulings caused harsh and demanding clauses to be imposed on Juanelo. He would not receive any part of the payment until the water reached the Alcázar. The amount of water destined for the Real Alcazar was one seventh of the total to be raised. After 4 years, the work was finished, but Juanelo's success was not recognized and he did not get paid the agreed amount of money. By the side of the city of Toledo did not pay because the water reached the Alcazar in and from there it was distributed to the city and by the side of the king, because he had not been compromised to pay for it.

Frustrated and in a difficult economic situation, Turriano proposed to the city the construction of a second device. This time Juanelo would have been the one who retained the rights to the exploitation. The work was completed in 1581 and, this time, it seems, Turriano did get paid. Although his ordeal was not over. Juanelo could not cope with the subsequent costs of maintaining the mill and had to end up giving control of it to the city.

After numerous requests, only his daughter received partial compensation after Juanelo's death [3, 6].

2 Background and Its Context

2.1 The Need of Water

Advances in technology and architecture have always been essential to the formation and durability of empires throughout history, and water supply has also played an important role. During the XVI and XVII centuries, the Spanish crown became a major political and economic power in the world, so great that "the sun never set" under King Felipe II reign [9].

Water is and has always been a fundamental element in the development of any society. There is concrete news from more than 4000 years ago by which various peoples worried about finding good quality and abundant water. The existence of pipelines and deposits in Jerusalem with more than 3000 years old is known [10]. Relevants hydraulic devices were designed along the history from Antiquity (by Ctresibius, Heron, Vitruvius

etc.), in the Middle Ages (Villard de Honnecourt etc.), in the Renaissance (Francesco di Giorgio, Sangallo etc.) and in the following centuries (Branca, Ramelli, Puccini, Ozanam etc.) [11, 12].

This is why the settlement of the first people of Toledo is understood to have occurred in the vicinity of the riverbed, settling on the nearby hills, having to go down to the water constantly. The clarification of the water was carried out by decantation in cisterns or reservoirs [13].

In Roman times, civilization and improvements in the life of population arrived to the peninsula. Roman Empire governors resolved the supply problem by building a dam in Alcantarilla, in the municipality of Mazarambroz [14] as shown in Fig. 2: Alcantarilla's dam engraving by Santiago Palomares. s. XVIII as well as a stone conduit with aquarium towers to bridge the unevenness. The dam was 500 m long and had a maximum height of 21 m [7].

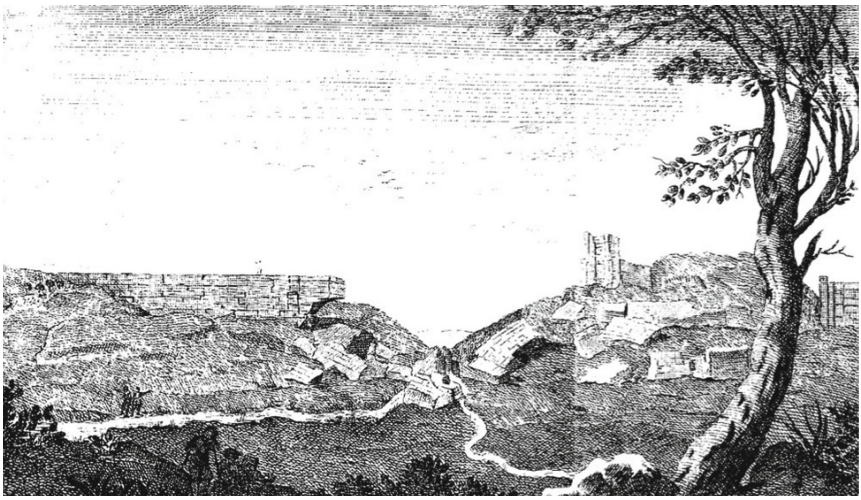

Fig. 2. Alcantarilla's dam engraving by Santiago Palomares. s. XVIII

2.2 Juanelo's Mechanism

The Juanelo's mechanism, Fig. 3, carried 1.17 m^3/h in 1569 [8]. The population of Toledo back to this year was around 53,700 people [15]. Which means that each person consumed 0.52 L per day, this would currently be an extremely small amount of water, insufficient for current water-demanding activities. Nowadays, the average consumption per habitant entails an increase of more than the 33000% in water consumption.

2.3 Further Mechanisms After Juanelo's

The construction of the mechanism in Toledo caused a great sensation, not only within Spain, where most of the great writers of the Golden Age mention it in their works, but

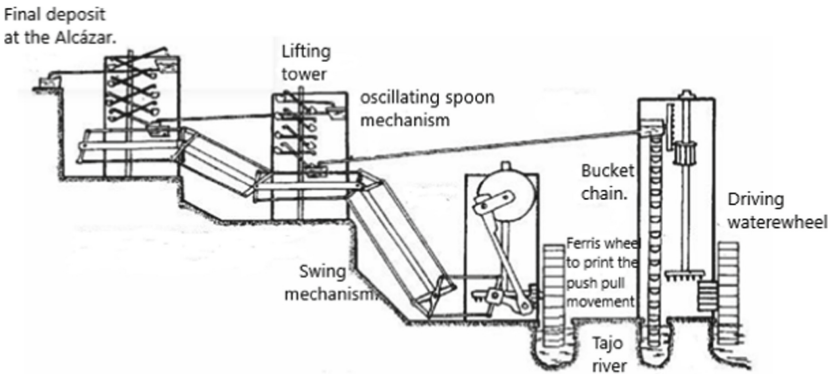

Fig. 3. Juanelo's water lifting mechanism [16].

also outside, being visited by such relevant figures as D. Juan de Austria [7, 16]. Until then nothing similar had been done in the world, since the highest elevation previously made was that of Augsburg; a tower of less than forty meters and that in view of descriptions of the time used Archimedean screws to raise the water level. Despite the success and renown he gained, Turriano would die at his home in Toledo after having been forced to hand over his artifice to the city by not being able to take charge of its maintenance [8, 16].

The machines, however, continued operating until 1639, although each time they gave less performance. By then, due to lack of maintenance and parts theft, the two machines were already in a very bad state. That year, the first was dismantled and the second was left standing as a symbol of the city. Without the artifices of Juanelo, the situation returned to normal and the water rose again to the city on the back of his donkeys. With the passage of time, little was left of the second. The looting ended up reducing it to ruins as well.

Despite the passing of the years and the physical disappearance of the machinery, the admiration for the artifice has not been lost, and the answer to the question of how the Artifice of Juanelo worked still remains a matter of controversy. Several have tried to find an explanation and several proposed models, but it is not an easy task, as no plan or drawing of the device has been preserved. The only thing they have been able to count on, those who have tried, has been the descriptions made by travelers and writers of the time.

3 Mechanism Update

The current average consumption per habitant in the city of Toledo is 132 L [17] per day, which represents a flow of 440 m^3/h. According to the capacity of the available commercial pumps, for a 50 m^3/h water flow and its characteristic curve, as shown in the Fig. 4, thus, to replace the mechanism and make it renewable today, it would be necessary to install 9 commercial pumps, model CS 50-250A from Speroni Company, with 22.5 kW power each. This group makes a total consumption of 202.5 kW of installed

power. For the installation to be renewable, a 500 kW turbine would be installed with a 70% efficiency, which would generate a total amount of 350 kW [18].

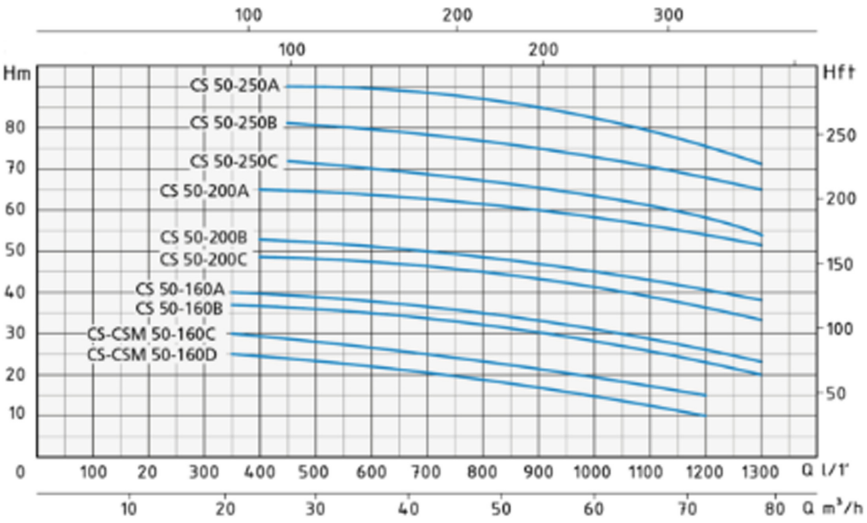

Fig. 4. H/Q Curve for the selected pump [19]

The flow that would have to pass through the turbine to generate that power would be 2 m^3/s, this corresponds to 4% of the river flow at the point where the turbine would be placed [20]. To achieve this flow, a quadrangular channel 1 m wide by 1 m high would be built. At the entrance of this channel, a gate would be placed to regulate the inflow through said channel. It is also necessary to place a grid to prevent fish and weeds from entering it. Keep in mind that maintenance would have to be carried out every so often to clean the dirt that may remain on the grill. Once it passes through the turbine, part of that water is pumped and a part of it returns to the river.

The work that would have to be carried out would be similar to the one that can be seen in the Fig. 5: Model for hydroelectric generation in a river, which is a scale model made for a civil work that is being carried out in the town of Pastores (Guatemala).

The objective of the turbine in both locations would be similar, which is to generate enough energy so that a pump can be powered. This machine would be in charge of pumping the water from the Tajo River to the city of Toledo. In the case of Guatemala, it would be the Guacalate River as it passes through Pastores. In this case, it must be taken into account that in the region where this turbine is to be installed, the majority of the population is in a situation of extreme poverty.

The estimated cost of the installation to be placed in the Tajo River would be of 2670 € per pump, 10,000 € for the turbine and 50,000 € for civil works. Which adds up to a total amount of 84,000 €.

Fig. 5. Model for hydroelectric generation in a river

4 Conclusions

The technological advances developed by Juanelo Turriano represented a great revolution in his time, despite the remaining documentation from that time, the complexity of the mechanisms developed continues to pose many unknowns. In particular, the mechanism developed for the city of Toledo is of great application today. However, social needs for water supply have changed over time. Therefore, an update of its mechanism is proposed based on available technologies and current needs.

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