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Windmills in The Netherlands

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Abstract

In this article we provide a brief reconstruction of the development of wind mill technology in Europe focused on the Netherlands. Windmills can be found in many countries, but an exceptionally wide variety of windmills emerged in the Netherlands. That has to do with the Dutch Golden Age in the late 16th and 17th centuries when the Dutch Republic dominated world trade, created a vast colonial empire and operated the largest fleet of merchantmen of any nation. We discuss in particular the contributions of Cornelis Corneliszoon van Uitgeest. His inventions were influential. His work led to the so-called paltrok mill, a very successful saw mill. We also briefly discuss Simon Stevin's theoretical approach to windmills.

Keywords

Dutch Republic, Standard Mill, Tower Mill, Smock Mill, Paltrok Mill, Simon Stevin

1. Introduction

The development of life on earth proceeds according to the principle of variation and selection. Something similar happens in technology. Inventions are modified, the successful variants survive and are in turn modified again until a certain perfection is achieved. This is also what happened in the development of the traditional windmills until the moment when other machines took over their tasks.

It all started with the invention of the post mill. A post mill is a so-called ground winder. It was used as a grain mill. The post mill represents the beginning of two lines of development, a line of cap winders and a line of ground winders. In the line of cap winders the first descendant of the post mill is the tower mill. Descendants of the tower mill are in this line the round stone mill and the smock mills. The fact that they are cap winders imposes restrictions on the shape of the mill: they must have rotational symmetry. In this line of cap winders both inside and outside winders occur. In this line the mills are initially grain mills, but in the end many different industrial mills appear. In the line of ground winders, the first descendant of the post mill is the hollow post mill, a polder mill. An important descendant of the hollow post mill is the paltrok mill, a saw mill.

The Dutch used windmills extensively to drain lakes and thus obtain new land. Moreover in the 16th and 17th centuries the industrial windmills were one of the most important drivers of the Dutch economy. The number of mills per inhabitant was large. In their hey-day there may have been 9000 windmills at work in the Netherlands, roughly equal to the number of mills in England, a country with two and a half as many inhabitants (Wailes, 1948: p. 1).

2. Water Powered Mills

2.1. Vitruvius' Grain Mill

In antiquity, the water powered windmill for grinding grain was preceded by the animal-powered mill. Animal-powered mills are no longer in use in Europe, but there they were in full use from the Middle Ages until the 19th century.

Our starting point is a water-powered flour mill described by the Roman military engineer Vitruvius (circa 80-70 BCE - after circa 15 CE) in his *De Architectura*. A paddle wheel causes a horizontal axis to rotate. Two gears transfer that rotation to a vertical shaft to which the upper millstone of a grinding couple is attached.

In Book X, Chapter 5, sections 1 and 2 of *De Architectura* Vitruvius wrote: "Wheels are used in rivers in the same way as described above. Round the outside, paddles are fixed, and these, when they are acted on by the current of the river, move on and cause the wheel to turn. […] at one end of the axle a toothed drum is fixed. This is placed vertically on its edge and turns with the wheel. Adjoining this larger wheel there is a second toothed wheel placed horizontally by which it is gripped. Thus the teeth of the drum which is on the axle, by driving the teeth of the horizontal drum, cause the grindstones to revolve. In the machine a hopper is suspended and supplies the grain, and by the same revolution the flour is produced" (Vitruvius, 1931-1934: pp. 304-307). **Figure 1** shows a picture from Barbaro's 1567 century translation of Vitruvius *De Architectura* (Vitruvius, 2019).

2.2. Ramelli's Saw Mill

In the High Middle Ages (1000-1300 CE) in Europe mills of the kind described by Vitruvius became the ubiquitous productive power. Over time, people also looked at other applications of water power than grinding grain. For example, the idea of using water power to saw wood can be found already with Villard de Honnecourt. It returns with Francesco di Giorgio and later with Ramelli (Ramelli, 1976: pp. 340-341). See **Figure 2**.

In Ramelli's saw mill the paddle wheel drives a shaft with a crank which is connected to a frame holding one saw. The wood to be sawed is pulled forward by a rope that winds around a shaft on which there is a wheel toothed like a saw.

Figure 1. Vitruvius' hydraulic flour mill (source: http://glavmex.ru/).

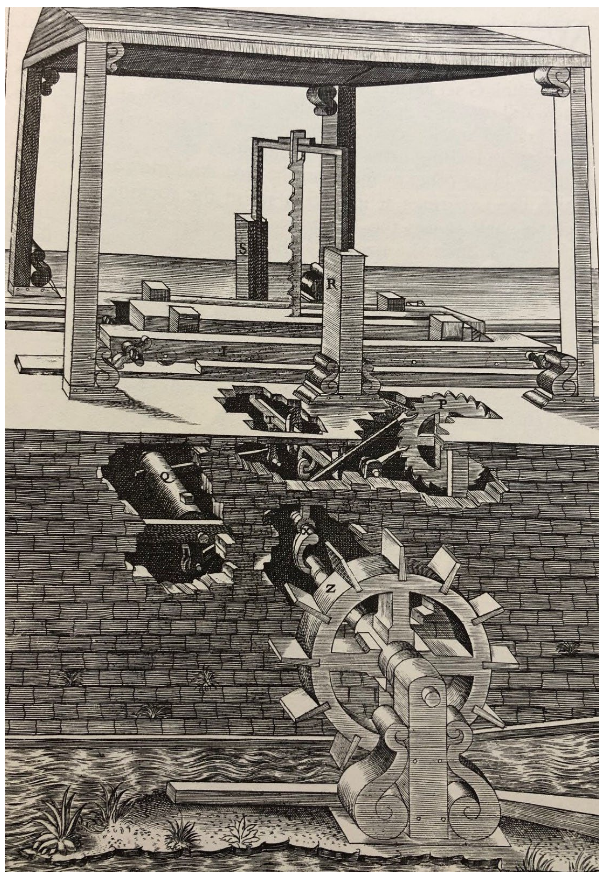


Figure 2. Ramelli's saw mill. Source: Ramelli, 1976: Plate 136.

The toothed wheel is held in place by a forked iron. The wheel is pushed forward by another forked iron connected to a rocking shaft. The effect is that after each downward motion of the saw blade the toothed wheel moves one step forward and so does the wood to be sawed.

3. The First Windmills

Thousands of years BCE the Egyptians and the Sumerians used sails to move boats. The idea to use wind to power a machine is less old. Heron of Alexandria gave a description of a wind-powered organ. The first windmills to lift water or to grind grain seem to have appeared in Persia around 800 CE. On top of a mud-brick building vertical wooden sails are rigidly attached to vertical shaft. See Figure 3. The millstones are located inside the building.

Figure 3. Persian windmills. Courtesy of Mohammad Hossein Taghi.

At a certain moment similar windmills with a vertical shaft appear in China. See **Figure 4**. The sails are not rigidly fixed. The way the sails are attached is reminiscent of the way sails were used in shipping. The mills were used to drive chain-pumps.

The mills appear to have been used on a large scale in China. See **Figure 5**.

4. The First Windmills in Europe

4.1. The Post Mill

The horizontal-axis windmill was a development of the 12th century, first used in northern France, eastern England and Flanders. The first windmill of this type was the post mill. Kealy has argued that it was an English invention. He wrote: "English, rather than Continental technicians […] first tamed the whistling free air" (Kealy, 1987: p. 7).

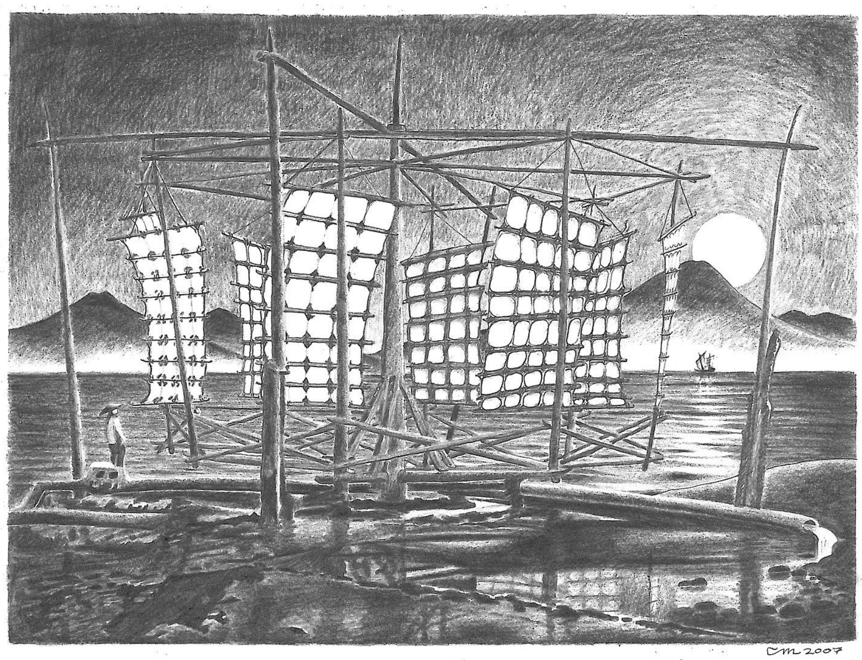


Figure 4. Chinese windmill.

Figure 5. The first European picture of Chinese horizontal windmills, from 1665. Source: Nieuhof, 1665.

What happened? See **Figure 6** and **Figure 7**. Probably someone considered a watermill powered by a vertical waterwheel as described by Vitruvius, in his or her mind replacing the waterwheel with a wheel with blades driven by the wind. This was in itself a spectacular idea. The oldest form of sail lining on the wings is square-rigged sail lining. Just like on old square-rigged sailing ships an equal amount of sail is carried on either side of the wing. There is undoubtedly an

Figure 6. Post mills in 1912 in Siberia (Source: Wikipedia).

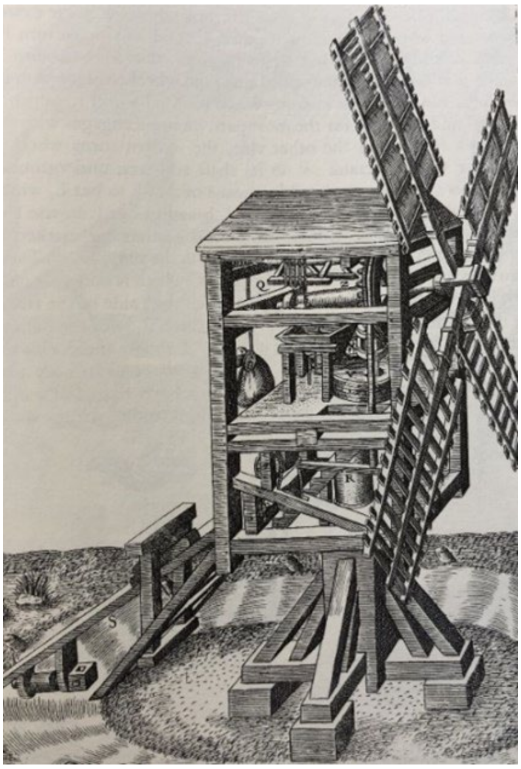


Figure 7. A post mill. Source: Ramelli, 1976: Plate 133.

influence here from experience with sailing ships. In order to catch the wind and give driving power sails must have the correct angle of weather, resembling that of a propeller, to catch the wind and give driving power. In the more modern wings with a sail on one side of the wing this usually is 5 degrees at the tip and about 25 degrees at the heel, measured from the plane of rotation.

Moreover, in Western Europe the wind direction varies considerably. The second novelty of the post mill is that it solves this problem. In order to set the windmill to the wind, the whole mill was made rotatable. The image of three post mills in Siberia (see **Figure 6**) suggests that one experimented with the number of wings and also—see the mill on the right—with the position of the drive shaft. The mill on the right suggests that one also looked at how the mill functioned when the drive shaft was placed at the bottom, analogous to the situation in Vitruvius' mill. The post mills were grain mills.

The post mill reached the Netherlands in the 13th century. The body of the mill that houses the machinery is mounted on a big vertical post around which it can be turned. The vertical post is kept steady by supporting beams. Post mills have an arm projecting from them on the side opposite the sails. The arm, combined with a ladder, serves to rotate the mill into the wind by hand.

Edward Kealy wrote: "The post-mill was a daring construction. Harmonizing its various parts was an authentic test of the genius of the carpenters and millwrights" (Kealy, 1987: p. 18). The big wheel on the windshaft inside the mill is in English called the "brake wheel", because it is also used to brake the mill. Just like in the later mills, the brake in the early standard mills may have consisted of a band brake of wood that could be tightened in some way.

4.2. The Tower Mill

At a certain moment, in the 14th century or before, another brilliant mind must have realized that the transmission from the horizontal or slightly inclined windshaft to the main upright shaft makes it possible to disconnect the cap, with the windshaft fixed in it, from the rest of the mill. We can then rotate the cap without losing the connection of the gearing. This requires that the bottom of the cap and the top of the rest of the mill are coinciding circles with the central shaft in their center. The cap with the horizontal windshaft and the wings is very heavy and if we prevent horizontal movement, the cap may lie loose. To turn the cap we need rollers of some sort. The led to the first offspring of the post mill: the *tower mill*.

This has consequences for the shape of the mill. Because the bottom of the cap has become circular and the sail cross should be able to move around the building, it is very natural to make the building circular or give it the shape of a regular hexagon or octagon. Because the windshaft is slightly tilted, the mill can be wider at the bottom. That provides extra space. Another advantage of the tilted windshaft is that the miller can more easily climb the wings.

Because the whole body can be rotated the post mill is a so-called *ground winder*. The tower mill, however, is a *cap winder*. Allegedly in all early tower mills the winding mechanism was inside the cap (Stokhuyzen et al., 2017: p. 72).

Such a cap winder with the winding mechanism inside is called an *inside winder*. There usually is an internal windlass with spokes.

Inside winders have the disadvantage that the miller has to climb into the tower to set the mill to the wind. If the wind direction turns further, he will only notice it later and he will have to climb to the top of the tower again.

So allegedly for a long time the tower mills were inside winders. In the 16th century tower mills that are *outside winders* appeared. Outside a *tail pole* is connected to the cap and by means of a series of small posts or eye-bolts around the mill and a winch the tail pole and with it the cap can be turned. Yet, the idea of the tail pole is so simple, that we feel we cannot exclude that outside winder tower mills existed already in the 15th century.

The tower mills were also grain mills. See **Figure 8** for a 16th century tower mill. It is an outside winder.

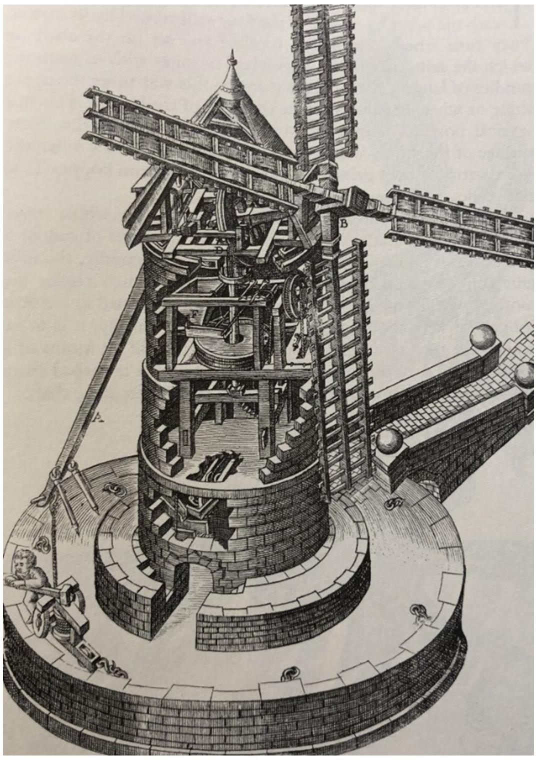


Figure 8. Picture of a tower mill. Source: Ramelli, 1976: Plate 132.

5. Developments in the Netherlands in the 15th Century: Polder Mills

The Hollow Post Mill

At the end of the 14th century there were two types of mill in the Netherlands: the post mill, which was a ground winder, and the tower mill, which was a cap winder. In the 15th century a new ground winder, the hollow post mill, and new cap winders, the round conical stone mill and the smock mill, appeared.

At a certain moment it occurred to someone that the post of the post mill could be made hollow and the rotation of the wings could be transferred to a main upright central shaft rotating inside the post. By means of gearing the rotation of this shaft could then be transferred to a fixed horizontal axis in the base of the mill. In precisely the same way, but now reversed, in which in the tower mill the cap can move with respect to the body of the mill, the body of the mill can rotate with respect to this fixed horizontal axis. This idea led around 1450 (Bonke et al., 2004: p. 87) in the Netherlands to the so-called hollow post mill. In this way we can set the sails to the wind and let the mill drive a paddle wheel in order to help drain a polder.

In the Netherlands, the hollow post mills are called wipmolen and they were mostly used for drainage. See **Figure 9**.

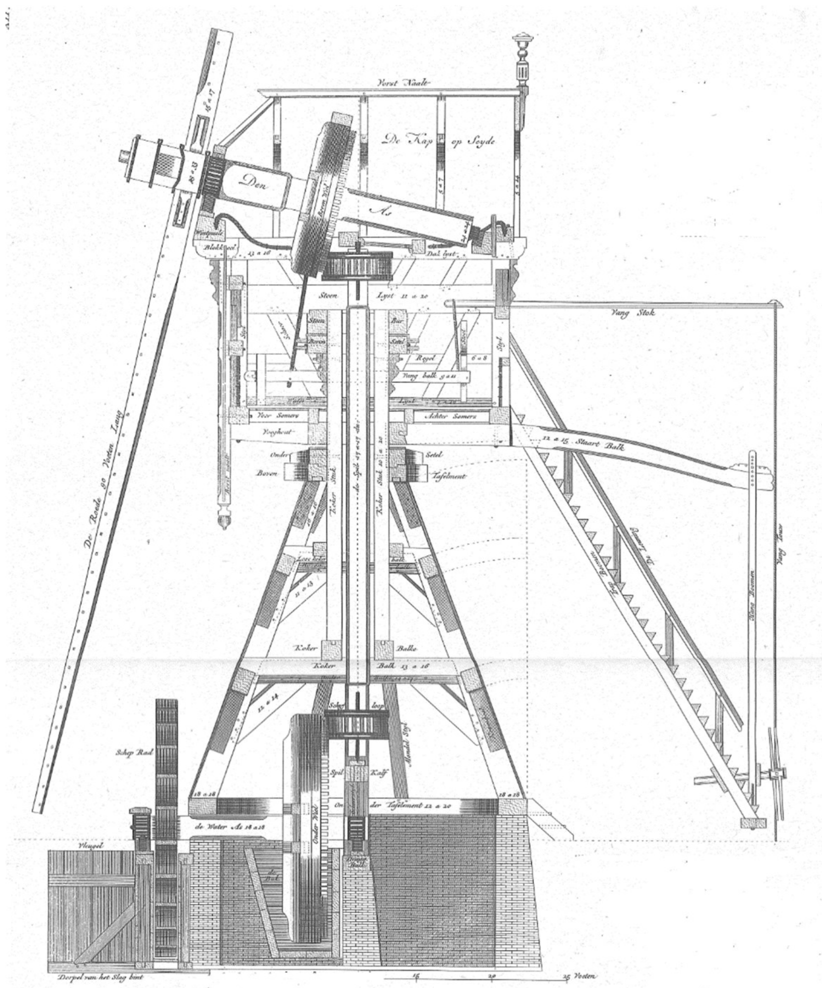


Figure 9. A hollow post mill. Source: Van Natrus, 1734.

Numerous lakes in the Netherlands were drained from the 15th century to the 17th century. For example, between 1564 and 1632 eight lakes, together covering 27,000 hectares, were drained with hundreds of mills (Bonke et al., 2004: p. 92). This hardly happened in the 18th century. In the 19th century, on the other hand, some remaining large lakes were drained, such as the huge Haarlemmermeer. In the 19th century steam engines were used, but earlier the hollow post mill and a successor of the tower mill, the wooden Dutch polder mill was used. We will discuss the Dutch polder mill below. Such mills are called in English smock mills. The mill apparently got its English name from its resemblance to smocks worn by farmers in the past.

The disadvantage of the stone tower mill was that it was heavy. In the Netherlands, polygonal wooden cap winder polder mills, the smock mills, were developed out of the tower mill in the 15th century. Hundreds of them were built. They were originally used for the draining of polders. Before the 17th century they all used a paddle wheel. See Figure 10.

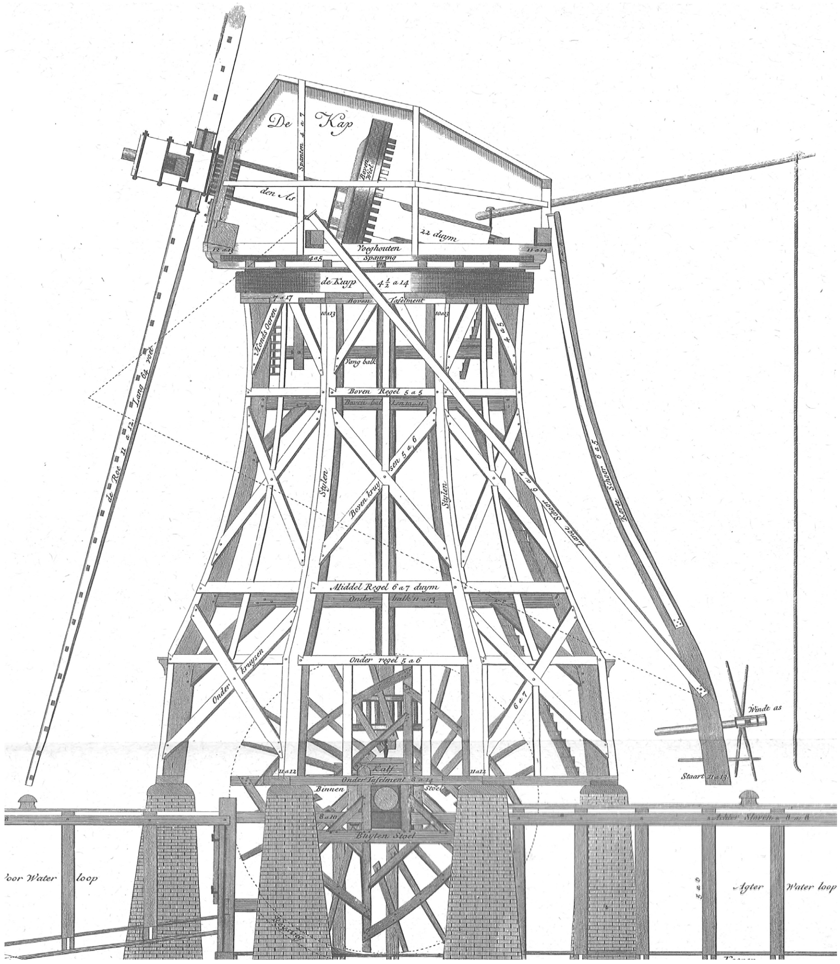


Figure 10. Octogonal smock mill with paddle wheel. Source: Van Natrus, 1734.

6. Developments in the 16th and Early 17th Centuries

6.1. Inventions

We saw above that in the 16th century outside winders appeared: tower mills but also Dutch polder mills. At the end of the 16th century, the economy of the Netherlands flourished. This is the time when mill technology was refined.

There are two types of gears in a mill: cog wheels and pinions. Cog wheels have wooden teeth and pinions consist of two round discs between which bars are placed. The wheels are masterpieces of artisan craftsmanship. They are often made of oak wood. The cogs and bars are made of a harder type of wood. The cogs of two interlocking wheels must be made of different kinds of wood, otherwise rapid wear will occur. Practice shows this, allegedly. With two meshing wheels, the number of meshing cogs or bars of the smaller wheel may not be a divisor of the number of cogs of the other wheel. This prevents the same cogs or bars from always interfering with each other which would cause local wear (Stokhuyzen et al., 2017: pp. 97-98). Beeswax is used as a lubricant.

Two very important technical innovations were the asymmetrical wings with a wind board and the curved surface of the wing, the sail twist (Bonke et al., 2004: p. 93).

At the time there were many trade secrets in the millwork industry that were only passed on orally. Some were based on experience acquired over centuries, others were new.

In the Netherlands only a few names are known of men who made innovative inventions in mill construction. One of them was Symon Hulsebosch. At the time the Archimedean screw pump was known. It consisted of a helical surface that was fixed inside a pipe. By tilting the pipe and turning it water could be lifted. However, when the pump is used, the weight of the helical surface, the pipe and the water must be supported. If such a pump is enlarged too much, it will weigh too much, bend and break. In 1634 Symon Hulsebosch realized that the helical surface did not have to be fixed in the pipe. It is sufficient to place that surface at an angle in a semi-circular gutter. This seems to be an originally Dutch invention. In this form the screw pump appeared to function better than the paddle wheel. In many mills the paddle wheel was replaced by a screw pump, but not in all of them (Stokhuyzen et al., 2017: pp. 111-113).

6.2. More Inventions

Before the Industrial Revolution wood dominated the economy. It was used as a construction material for buildings, ships, vehicles, furniture etc. Only after the Industrial Revolution it was replaced by iron and later by plastics.

When the Dutch economy gained momentum at the end of the 16th century the need for wood increased dramatically. Shipbuilding required large quantities of wood. A lot of it came from Germany in the form of large rafts that travelled down the Rhine River. The wood was initially sawn by hand with a maximum trunk length of 4 meters. The supply was not a problem. The processing was. It is therefore understandable that there was experimentation with sawmills. The difficulty was not so much in the idea of a sawmill but much more in building a well-functioning mill.

In this context Cornelis Corneliszoon van Uitgeest (Circa 1550 - Circa 1607) played a crucial role. Corneliszoon possibly was hardly literate. In any case, he had a rather awkward drawing style. See **Figure 11** for a drawing accompanying the patent for a wind-powered sawmill (left) on December 15, 1593, that was granted to Cornelis Corneliszoon van Uitgeest by the States of Holland, the highest administrative body in Holland.

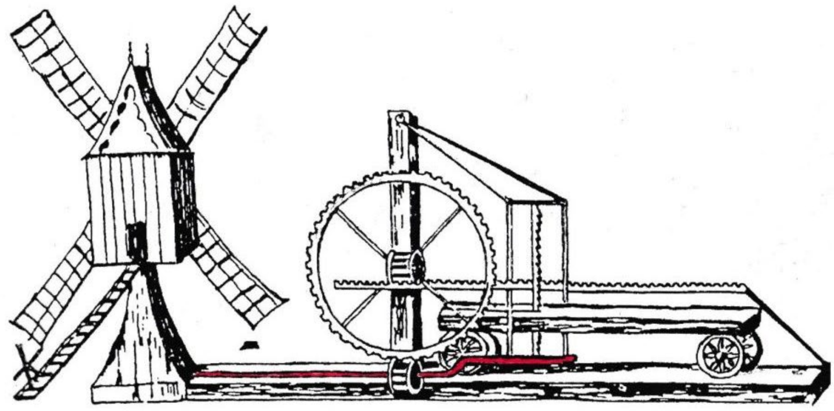


Figure 11. Drawing accompanying Corneliszoon's 1593 patent. Source: Bonke et al., 2004.

The drawing shows a hollow post mill that drives a long horizontal crankshaft. At the end the crank moves a saw blade up and down. There is also a pinion on the shaft that drives a large wheel, which has a pinion on its axle that moves a rack so that the tree trunk to be sawn is pulled towards the saw. The use of an iron rack instead of a rope, as in the Ramelli sawmill, to move the wood to be sawn forward was a good idea.

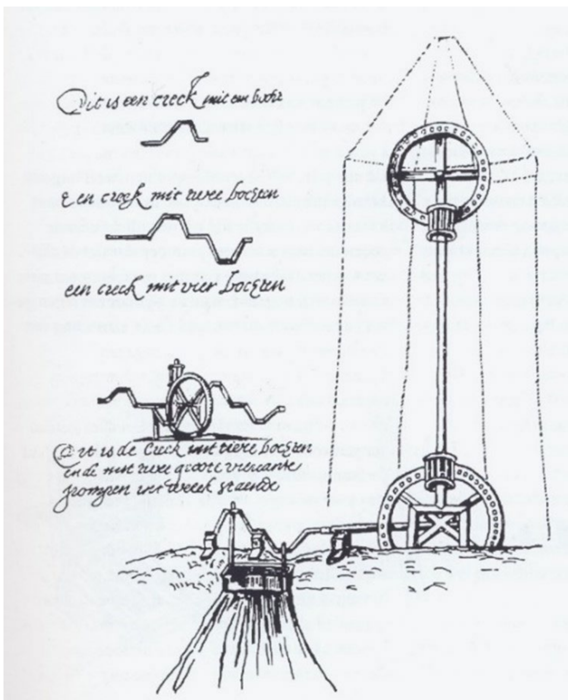


Figure 12. Drawing accompanying Corneliszoon's patent of December 6, 1597. Source: Bonke et al., 2004.

It is certain that Cornelis Corneliszoon was already thinking of several saw blades. See **Figure 12** with the drawing from his patent of December 6, 1597. On the left the drawing shows shafts with multiple bends with which several saw blades can be driven. The drawing on the right is also interesting. It is not a hollow post mill but looks more like a cap winder.

After a number of further improvements by others, Corneliszoon's patents led to two kinds of very successful saw mills: a ground winder, the so-called paltrok mill, and the cap-winder sawing mill. In general the sail cross of the cap winder sawing mills is bigger, so that they can saw heavier wood. Below we will have a closer look at the paltrok mill. There used to be hundreds of such sawmills in the Netherlands. There are only 5 left.

6.3. The Paltrok Mill

The name was chosen because the shape of the mill resembles the shape of the garment called "paltrok". See **Figure 16(a)** and **Figure 16(b)**. The paltrok mill is specially designed for sawing wood. The brake wheel of the mill drives a crankshaft with three bends at angles of 120 degrees. In general the left and right bends drive saw frames, while the middle one drives an empty pump frame for stability. See **Figure 13** and **Figure 14**.

The mill house is supported by a short central wooden post around which the entire mill house revolves. For further support, a rim bearing is mounted on a brick base, on which the mill housing rotates with numerous rollers. Like the hollow post mill the paltrok mill is also a groundwinder.

The paltrok mill was extremely successful. John Reynolds called it the "earliest type of a wind driven saw mill, introduced in Holland" (Reynolds, 1970: p. 187).

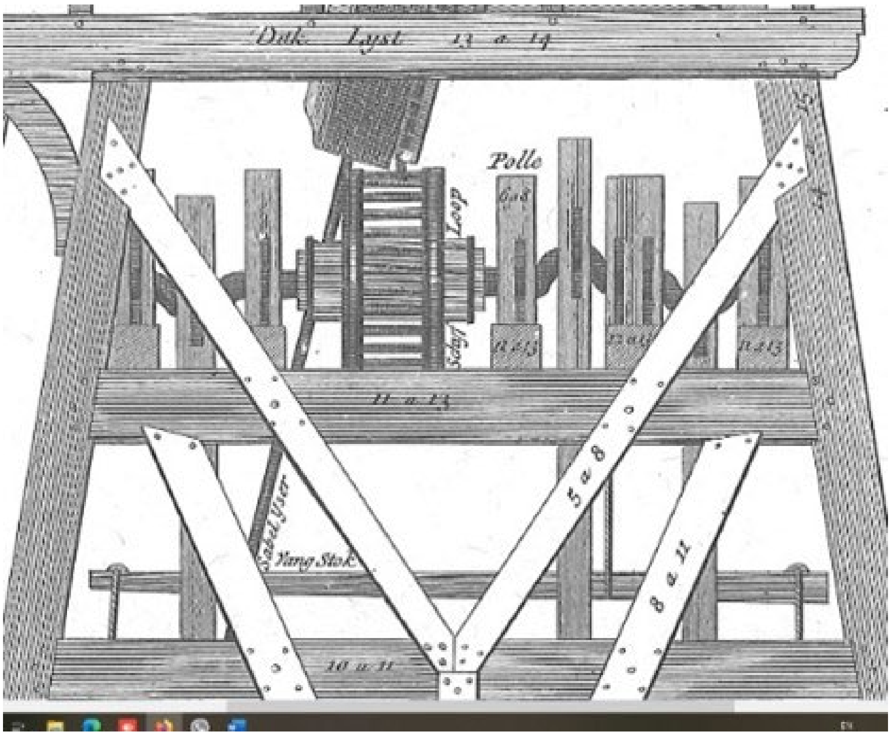


Figure 13. Paltrok mill close up of the crankshaft. Source: Van Natrus, 1734.

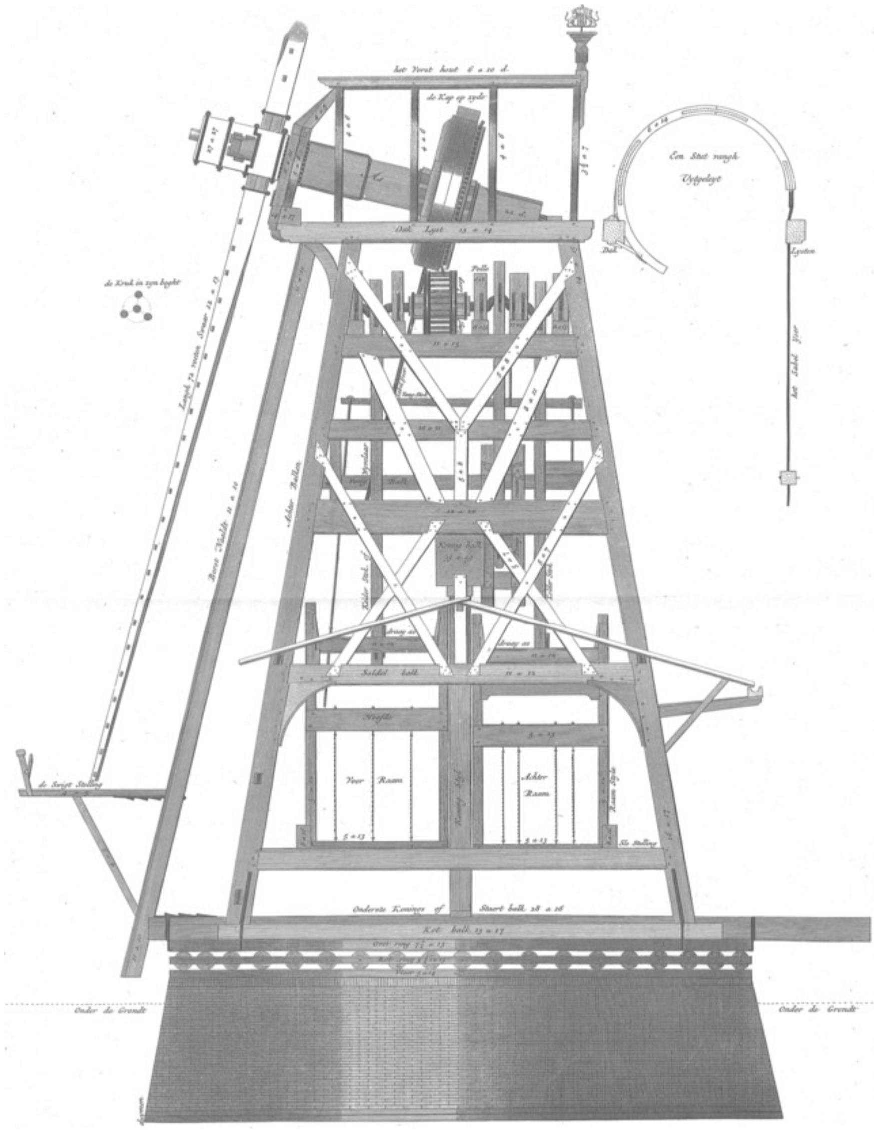


Figure 14. Side cross-section of paltrok mill. Source: Van Natrus, 1734.

6.4. The Paltrok Mill "De Otter" in Amsterdam

One of the 5 paltrok mills left in the Netherlands is the paltrok mill called "De Otter" in Amsterdam. It was built in 1631. See **Figure 15**, **Figure 16(a)** and **Figure 16(b)**.

The tree trunks that have been in the water for a sufficient time are pulled into the mill and sawn with the saw frames. See **Figure 18**. Because the trunks protrude to the left and right of the mill due to their length, roofs have been placed on both sides of the hull. And the space below the roofs is shielded on the side of the wings from the wind with wooden walls. This works well because the mill always faces the wind when it is operating. It also gives the paltrok mill its very characteristic shape, which led to its name. The Dutch word "rok" means "skirt".

To operate the sails, one walks from the sawing floor to a short reefing stage located at the front. To turn the cap of a tower mill and the other cap winders,

Figure 15. Picture from circa 1900. De Otter is the mill in the center. The other mills have all disappeared. Source: https://www.allemolens.nl/.

(a) (b)

Figure 16. (a) Rear of De Otter in 2024; (b) Front of De Otter with reefing stage.

(a) (b)

Figure 17. (a) Windlass to set paltrok mill De Otter to the wind; (b) The rollers.

Figure 18. One of the saw frames of De Otter.

rollers were used where the cap and body of the mill meet. This system is also used in the paltrok mill. Because the paltrok mill is a ground winder, the rollers are now located below between the body of the mill and the brick base. See **Figure 17(a)** and **Figure 17(b)**.

6.5. Explosion of Industrial Mills

In the Dutch province Zuid-Holland the paddle wheel managed to maintain itself in the hollow post mills and the smock polder mills. Originally the smock mills were all inside winders but after the 16th century in this part of the country the outside winders took over. In the province Noord-Holland one switched to screw pumps. In this part of the country inside winders continued to dominate. In the 17th century there was a real explosion of industrial mills: husking mills (for husking barley or rice), oil mills, sawmills, paper mills, drill mills (for drilling gun and cannon barrels), cocoa mills, mustard mills, bark mills (they ground oak bark for the tannery), felting mills (for felting woolen cloth), snuff mills (made snuff).

Many industrial mills were located in the Zaan region north of Amsterdam, which is one of the oldest industrial areas in Europe.

An oil mill is all about pressing oil from seeds. Edge runners were used for this. These are heavy stone wheels that roll on their side over a lying stone. Also here Cornelis Corneliszoon contributed to the development. See **Figure 19** and **Figure 20**.

7. Simon Stevin

The mill builders who were involved in the construction of the polder mills and the industrial mills in the 16th, 17th and 18th centuries were craftsmen whose knowledge and skills were passed on from generation to generation without any

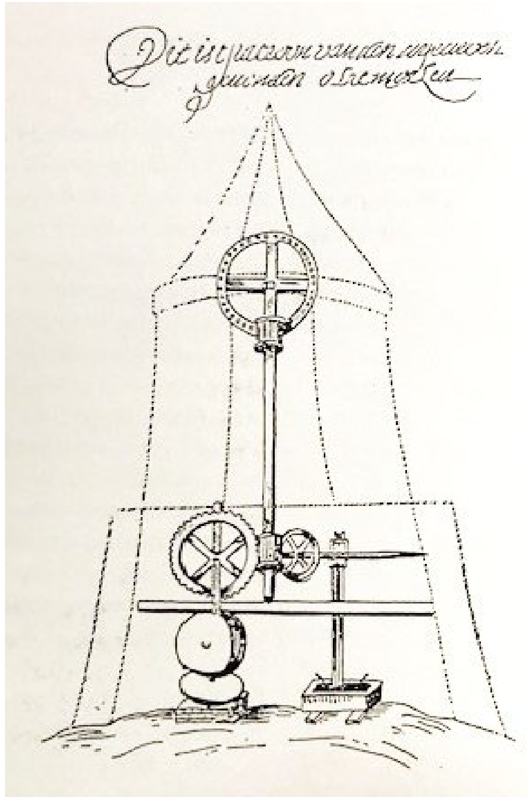


Figure 19. Drawing for patent H 23/1597 for an oil mill with edge stones granted to Cornelis Corneliszoon (Source: Bonke et al., 2004).

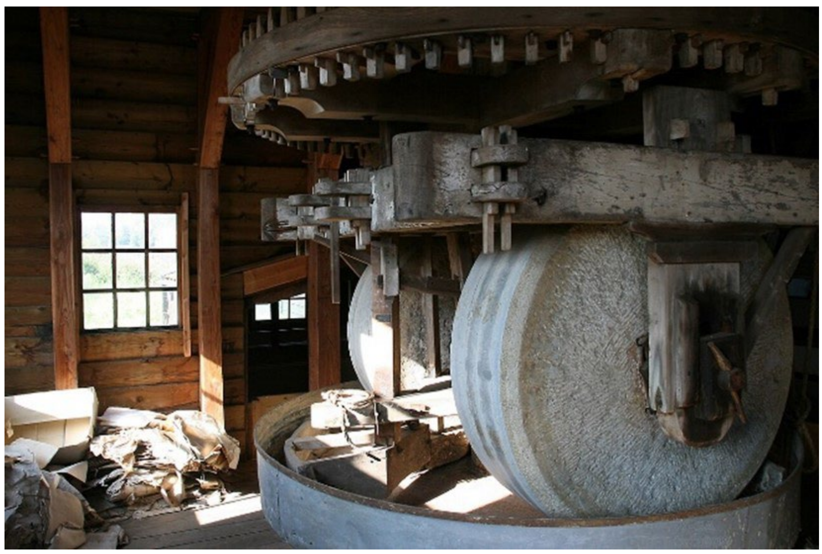


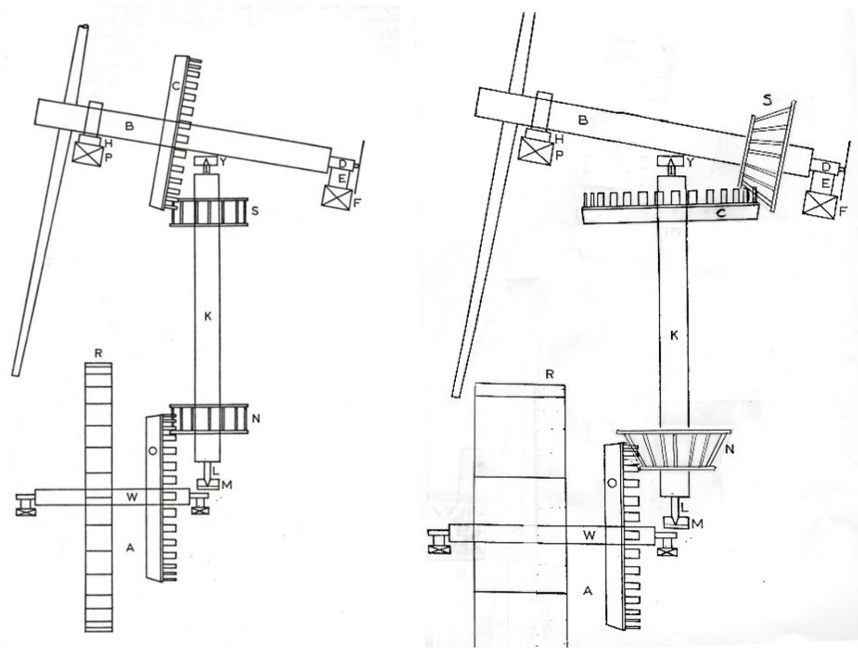
Figure 20. Edge stones in the paper mill De Schoolmeester (Source: Wikipedia).

written record. In this context, Simon Stevin (1548-1620) is a remarkable figure (Koetsier, 2010). Stevin was born in Brugge in Flanders, probably in 1548. Before he left Flanders in 1581 and settled in Holland he worked as a clerk and bookkeeper in Brugge and Antwerp. On the one hand, Stevin was a scholar who made among other things fundamental contributions to statics and hydrostatics. On the other hand, he was actively involved in the design and construction of mills.

Consider the gears in a Dutch polder mill. See Figure 21(a). The gear train consists of the brake wheel C, the pinions S and N, and the wheel O. Let N_C, N_S, N_N and N_O be the number of teeth of these wheels. Stevin related the force F_S exerted by the wind on the wings to the opposing force F_P exerted by the water on the paddle wheel as follows

$$F_S = \frac{N_C}{N_S}\frac{N_N}{N_O}F_P.$$

I call this the Fundamental Relation. It is correct assuming that the forces F_S and F_P act in respectively the planes of the sails and the paddle wheel, respectively, at equal distances from the axes. Because he knows what force is exerted by water on a vertical wall, he can estimate F_P for a given mill and, with the formula, also F_S. Stevin first measured and counted the fundamental geometrical parameters of several existing and functioning windmills. Then he used his original hydrostatic results to determine F_P for those windmills. And finally he applied the Fundamental Relation to calculate F_S for those windmills.



(a) (b)

Figure 21. (a) The gear train of a Dutch polder mill; (b) Stevin's new design.

See Figure 21(b). The basic new element of Stevin's new design is a much bigger paddle wheel. As a result, the resistance of the water that must be conquered is consequently much higher. By means of his hydrostatics Stevin calculated F_P for his new design and used his model to calculate the dimensions of the gear wheels such that the force that the wind can apparently yield on the basis of his earlier calculations is enough to resist the pressure of the water on the paddle wheel. One of the consequences of the new design is that while in the traditional mill the transmission from the upper axis to the central axis speeds up the velocity of rotation and the transmission from the central axis to the lower axis slows it down again, in the new mill the big force needed to move the water makes it necessary to use both transmissions to slow down the rate of rotation. In the traditional design the gear wheels on the central axis are both pinions and the two other gear wheels, on respectively the upper shaft and the paddle-wheel shaft, are crown wheels. The need to slow down the rate of rotation immediately made it necessary to put the upper pinion on the upper axis and the upper crown wheel on the central axis: the wheels S and C change places. In the new design the forces that the teeth of the gear wheels exert on each other are bigger than in the case of the traditional mills.

Stevin built several mills. Some functioned satisfactorily, but with his new design he seems not to have been successful. However, his theoretical approach to the windmill was completely unique.

8. Concluding Remarks

Mills of which the sails and the brake can be operated from the ground are ground-sail mills. Almost all types of windmills can be lifted in order to catch more wind or create more space inside. This led, for example, to the so-called stage mills because a stage is installed on the mill from which the sails can be operated.

The round conical stone stage mills in Schiedam in the Netherlands are the highest in the world. Six of them still exist.

In the 18th century, the power and influence of the Dutch Republic declined. The country was exhausted by its wars with the French and the British and its colonial empire was eclipsed by that of England.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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