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Animation by Computer.   A Tool for Understanding the Dynamical Behaviour of Ancient Machines.

Enter-the-Past! Obviously it is impossible to enter the past in real live. But under one assumption it is possible nevertheless: Let us assume, we are in the future, then the presence may become the past.
Every excavation should or will reveal a lot of finds and also many questions. Some of the most important questions about the excavated object are: How did it look like? How was the structure? How was it built? How was it used? Using the mentioned time transfer above , the arising problems of the fourth questions can be explained by the following example: An archaeologist excavates an complete car in the time 100 years later from now on. After cleaning the inside of the car he will see three strange pedals on the floor. Traces on the rubber surfaces show that they were used frequently. Since the technique for moving persons and objects has changed several times until now (e.g. controlling vehicles by joystick, bio-neural interfaces, transporting masses through energy-conversion and vice versa) the archaeologist from the year 2103 does not know the meaning of these pedals. Possibly he might suggest that both, the left and the middle pedal was used for moving direction (“left” and “right”) and the other one for the input of the desired velocity (“down”=fast, “up”=stop).
Today everyone with a driving licence, knows how to use these pedals, but in the future this knowledge might be lost. A transfer from generation to generation might no longer possible when the technique changes. Only in some old books written for driving schools or in museums one could get information about how to drive a car in former times.
Back to the presence. An old water wheel from the end of the 19. century (from the presence 100 years before) was excavated in 1997. This wheel was used as hoisting engine in the mining region Oberharz (northern Germany), where silver, lead and zinc were excavated from depths of several hundreds of meters for several centuries.
The construction of such wheels is well described and depicted (G. Agricola; 1556; Leupold, 1724; Delius, 1772) (Fig. 1).
Two types of wheels are known (Fig. 4):
1. The “Kunstrad” (Kunst= art, technique, Rad=wheel) delivers the energy for the “Kunst”, a system of two reciprocating rods which drive the pumps in the shaft to drain the pit. The rods are connected to the motion of the wheel shaft by a crank (Fig. 5)
2. The “Kehrrad” (reversible wheel) possesses two drums on its axle where two cable (or chains) are wound in different directions. The upper ends of the cables are led into the shaft. Their reciprocating movement allowes an almost balanced use of the wheel, similar to an elevator with counterweight.
The following will deal with construction and using of such reversible wheels. Driving such a “Kehrrad” requires a lot of experience, similar to the problem stopping a train in a station exactly at a predefined position. For the driver of the train there are a lot of unpredictable parameters which have influence on the dynamical behaviour of the train such as: load and velocity of the train, friction, wind, incline of the lane, temperature of the brakes, humidity and so on. It is not a trivial stopping at the desired point neither for a train nor for a “Kehrrad”.
The finds of the excavation revealed an “Kehrrad” (an overshot wheel, the water comes from the top). The construction is more sophisticated in respect to durability in contrary to the sketches of Agricola et al. . The shaft consists of a heavy oak block with cross section of 0.6 m x 0.6 m and length of about 8 m. At each of the ends there is a gudgeon made out of cast iron. The two cable drums consist of iron rims with wooden inlays for the

cables.
In Fig. 2 the construction of the buckets can be seen. Three wooden boards build the container for the water. The outer (lower) are mounted “elbow like”. The inner board, the soal, has been removed, but the wooden rims can show the arrangement.
Since the beginning of the last period of ore mining in the Oberharz in the middle of the 16. century the miners had build a large number of artificial ponds with hundreds of kilometers of drains collecting, storing, transporting and distributing the rain water. This system is preserved till today as cultural heritage and is called “Oberharzer Wasserregal”.
As the miners produced a large amount of dump material, which they put down in the direct near of the shaft, the waterwheel had to be protected against this dump by a large ring wall made out of stones. During the long operating time of the mine and the less space in that valley the height of the wall had to be increased for several times to protect the wheel continuously. After closing the shaft in the beginning of the 20. century the inner of the wall including the remains of the water wheel were filled with dump material, which was now excavated in 1997. Wet conditions in the lower part and heavy metals in the water preserved the wooden remains from decay so that they now can still be presented. In an exposition of the Oberharzer Bergwerksmuseum, located in the whim of the former Ottiliae-Shaft a reconstruction of the wheel (scale 1:1) is presented. Most of the finds could be integrated into the construction. (Fig. 6)
Helpful for the analysis of the finds and their use in former times are drawings and models which are preserved and presented in that museum. A mine named “Dorothea” at Clausthal was visited by a number of famous persons in the past, e.g. Wolfgang von Goethe and James Watt. A precise model of that “Dorothea” mine from 1820 and a perfect drawing from the middle of the 19. century still exists. Both describe the technique in a perfect manner and beyond the model can show and explain the mechanics of several parts of the machines and their construction.
Some of these important parts are three wooden levers, with which the driver could control the movement of the machine (two of them can be seen at Agricolas picture too). They were used similar to that proposed for the car before mentioned: “left”, “right” and “stop”. The first two levers control the function of the two water taps above both halfs of the wheel. Each of them can put water on the wheel so that it will move in the one or the other direction. The third lever can serve the tongs of the brake, which will touch either the rim of the wheel (drawing) or an additional wheel (model) from the outside.
The most important rule of the miners in the Oberharz was to save water during its application on water wheels. Less consumption meant longer use of the stored water in the ponds. In dry periods the miners could not work in the mines, because they were unable to pump the groundwater out of the shafts.
It was the goal to lead the water into the buckets and let it remain there on its way down as long as possible. Splashing or dropping down led to losses in energy transfer.
As the effective volume in a bucket decreases, because the bucket during its going down is turned respectively to the centre of gravity, more than half of the water is lost after half of the way (Fig. 3). In consequence of this reason one should fill the buckets not by 100% but only by 20% or 25%. This water will stay about 75% of the way down in the buckets so that the energy efficiency may reach 75% at best conditions.
The driver of the engine stands in the near of the shaft and can watch the work at the landing stage, where the load of the cable is moved into and out of the shaft. A hammer is connected to a long line down to the bottom of the shaft, it is used as signalling system. In almost all mines the driver has no visual contact to its engine.

During the moving of the ore drums the driver can read their actual depth at an mechanical instrument like a clock. The hands of the instrument are coupled by a gear to the shaft of the water wheel. In order to transfer the rotation of the shaft to the instrument a pair of two reciprocating rods are used which were connected on both ends by two cranks on each axle respectively. The cranks are oriented in such manner that during the highest velocity of one the other has its turning back point. This device which showes (to show = "weisen", tool = "Werkzeug") the driver the depth is called "Weis-Zeug".

Fortunately there is an ancient film (16 mm) which was produced in 1923. The film shows some scenes from the environment of the driver and its techniques.

In the near of the excavated wheel (80 m) there was another water wheel which worked in the years about 1800. Its construction is slightly different. (see application) Instead of one shaft with wheel and cable drums side by side there are two axles one upon another one for the wheel and the other for the drums. Both axles are coupled by two systems of two rods respectively. Each rod is connected to a crank at both ends similar to that Weis-Zeug mentioned above. The advantage of this construction is to have shorter axles and less space necessary for the wheel. The disadvantage is a more complex construction with more wear.

To study the dynamical behaviour of such system an internet application was created using JAVA. (www.pe.tu-clausthal.de/AGBalck/kehrrad/kehr_app-d.html)

This program takes into consideration:

the masses of the cables in the shaft depend on their length hanging,

the mass of a long cable is comparable to the mass of a fully filled ore drum,

the diameter of the cable drums decreased, while the cable is unrolled,

the wheel has a moment of inertia,

high velocity will produce noticeable centrifugal power in the water buckets,

the buckets are not elbow-like, they are simplified.

For purpose of training the program can run in a special mode without ore drums.

The switches are:

opening the taps (left, right)	L, R	brake (open, close)	AUF, ZU
ore drums, full or empty	VOLL, LEER	cable with /without load	TONNEN

Some surprising observations can be done:

A full ore drum can drive the wheel without water.

Using water from the opposite tap to stop the wheel will not work effectively.

All buckets fully filled with water will override the brake.

References:

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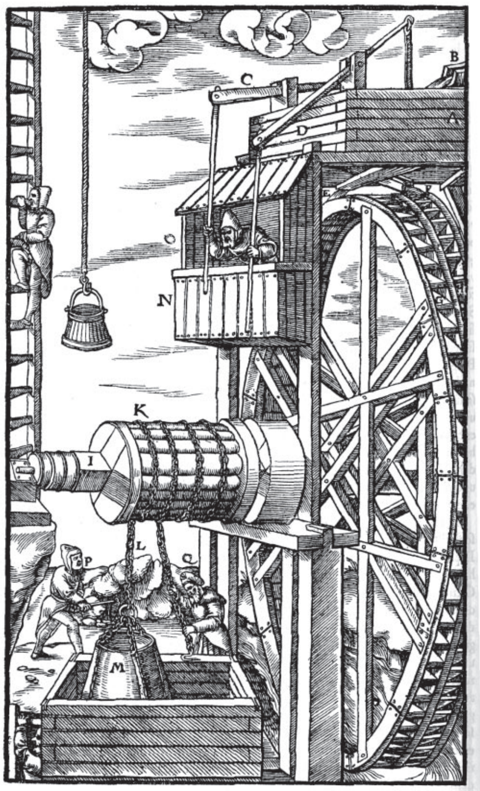
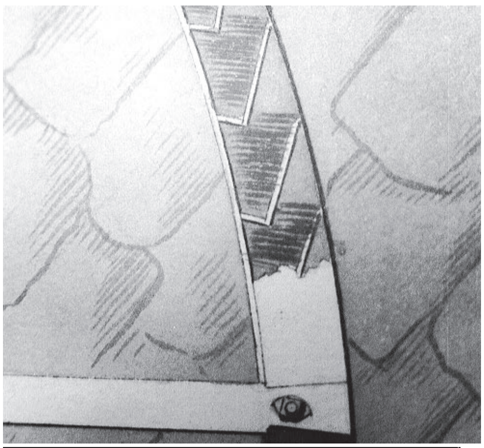
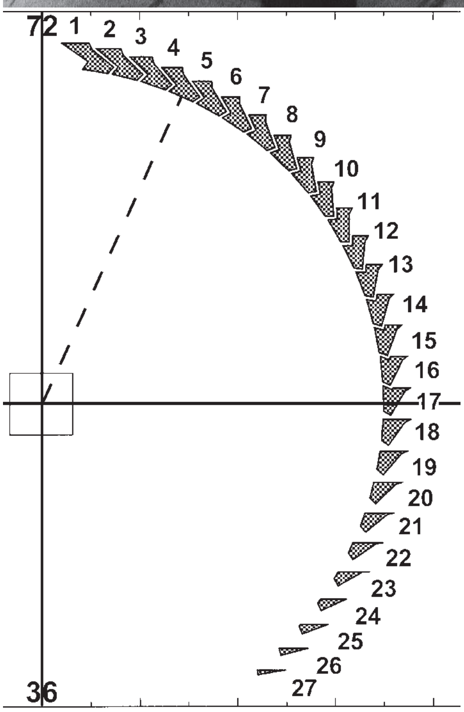
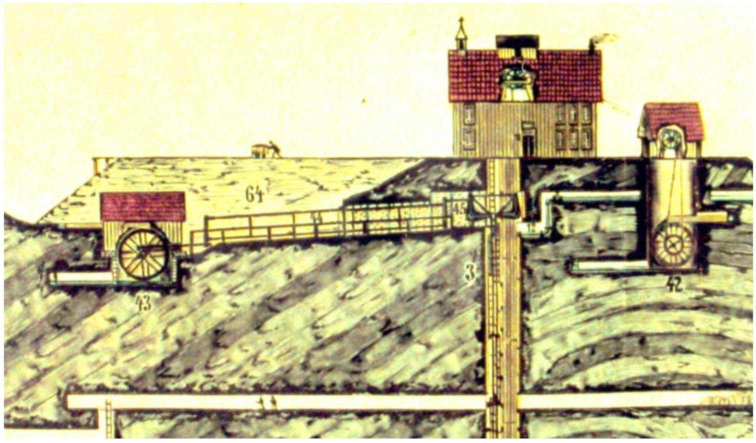
Leupold, J. 1725, Theatrum Machinarum Generale

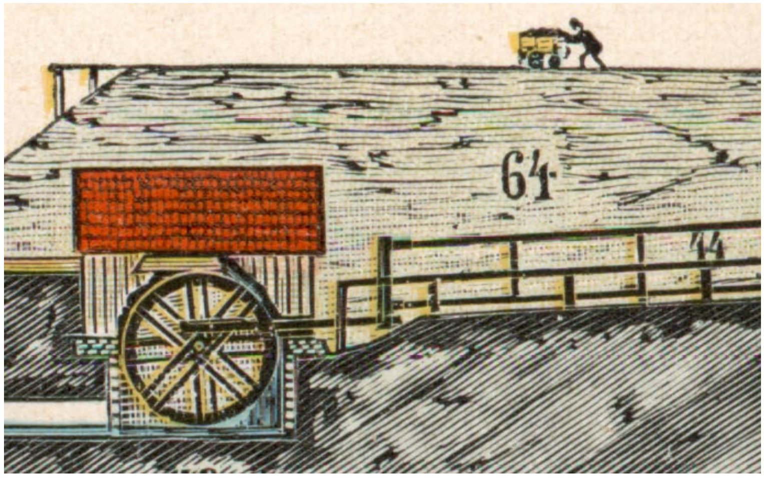
Delius, C. H., 1772, Anleitung in der Bergbaukunst











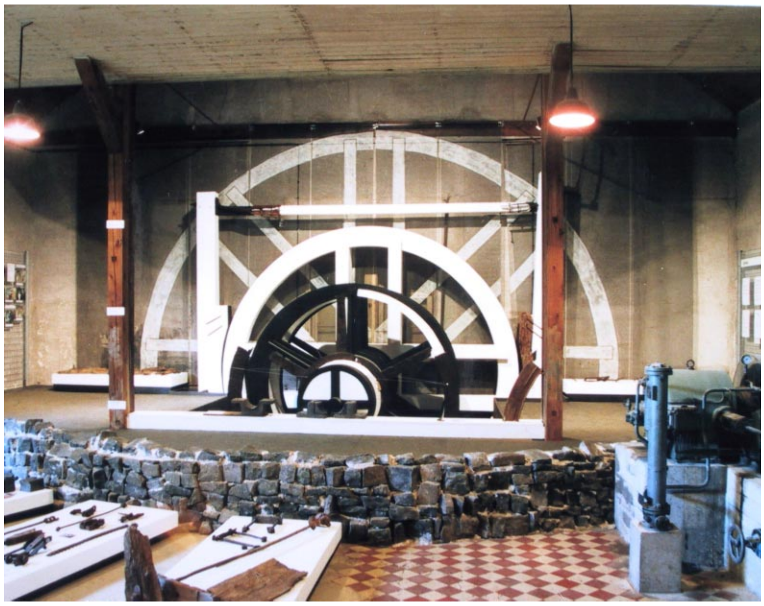


Fig. 1 (l. top): Reversible water wheel (G. Agricola, 1556)
Fig. 2 (l. middle): Elbow-like buckets (A. Polle, 1848)
Fig. 3 (l. bottom): The effective content of the buckets decreases due to the motion of the wheel (FB)
Fig. 4 (r. t.): Two wheels are necessary, pumping water (l.) and transport of material, hoisting engine (r.) (Beyersdorf 1908)
Fig. 5 (r. m.): A crank converts the rotational motion of the wheel to a reciprocating movement of the rods (as Fig. 4)
Fib. 6 (r. b.): Remains of the excavated wheel, exposition (FB)