A short history of the development of tapping equipment

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The casthouse floor has always been one of the most dangerous working places on a blast furnace or a ferro-alloy/non-ferrous furnace. Apart from working in an atmosphere including toxic gases, fumes, and dust, the workers have to perform hard and heavy manual work close to runners and ladles filled with hot liquid metal and slag.

Before the invention and installation of tapping equipment the tap-holes were opened and closed manually. Opening was done by means of steel bars and sledgehammers, whereas the tap-hole was closed by repeatedly ramming small amounts of clay or refractory material into the tap-hole, again with the help of long, heavy bars. In addition, on blast furnaces the blast had to be stopped, since it was impossible to close the tap-hole properly against the blast furnace pressure. This stoppage of the blast resulted in regular losses of production.

Around 1900 a major change in technology occurred. Samuel W. Vaughen, superintendent of the blast furnace department of the Cambria Iron company at Johnstown, Pennsylvania (USA), invented the first clay gun in 1895 (Wiley, 1896) (Figure 1).

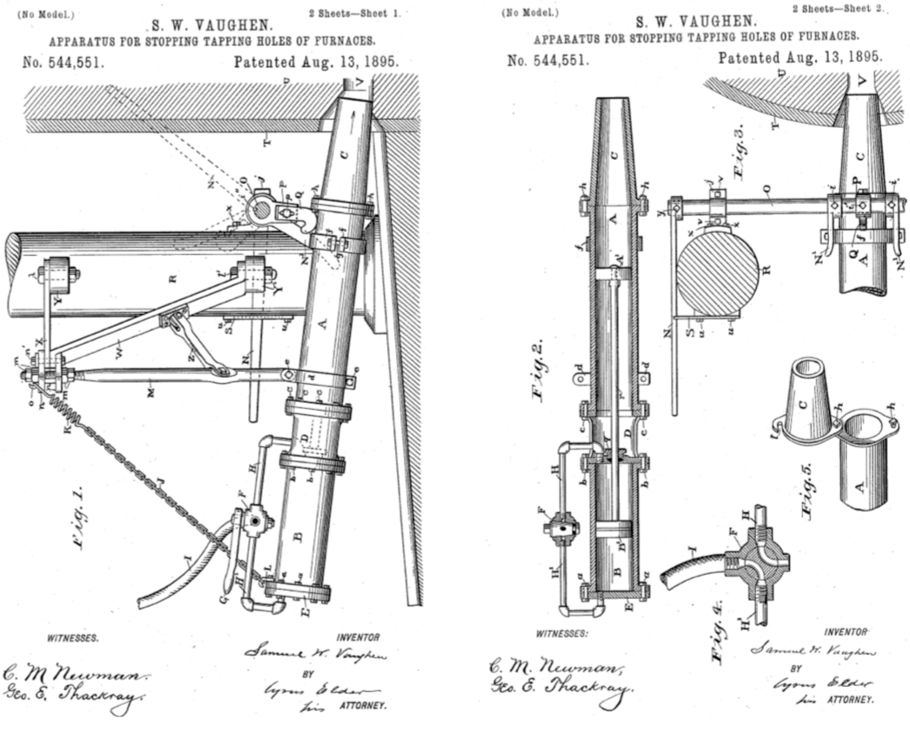


Figure 1. Apparatus for stopping tap holes by Samuel W. Vaughen (Vaughen, 1895)

His pneumatic clay gun, operated with steam, had a detachable nozzle that had to be swung open to load the clay. In addition, this design allowed an easy exchange of the nozzle, a part that was subject to great wear. The press-on force was realized by means of a fork-type clamping mechanism (Figure 2).

In 1901 the company Dango & Dienenthal, Siegen (Germany) acquired this patent and started introducing it to European customers. One clay gun of this type can still be seen at the museum furnace of Huta-Starrachowice, Poland.

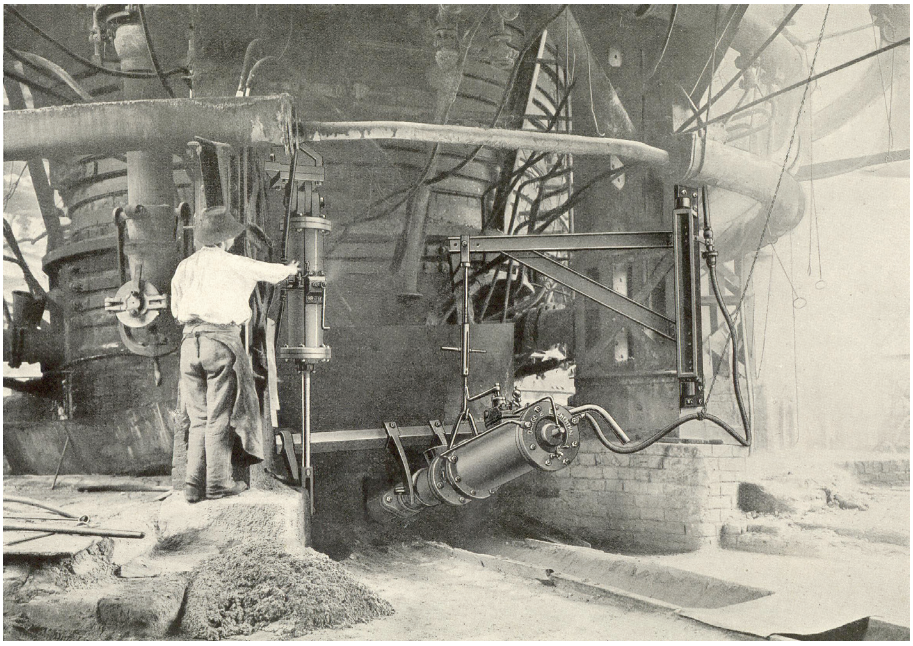


Figure 2. First clay gun built by Dango & Dienenthal (1901) (Dango & Dienenthal archives)

1901 brought another big change in tap-hole practices. In Kreuztal, a city close to Siegen (Germany), Dr Ernst Menne invented the oxygen lance (Figure 3). By blowing oxygen through a 1/8 inch pipe and igniting it, it was now possible to open the tap-holes very quickly compared to the pure manual methods. This lancing method is still used today, either when no tapping equipment is available or when the metal inclusions inside the tap hole make drilling impossible.

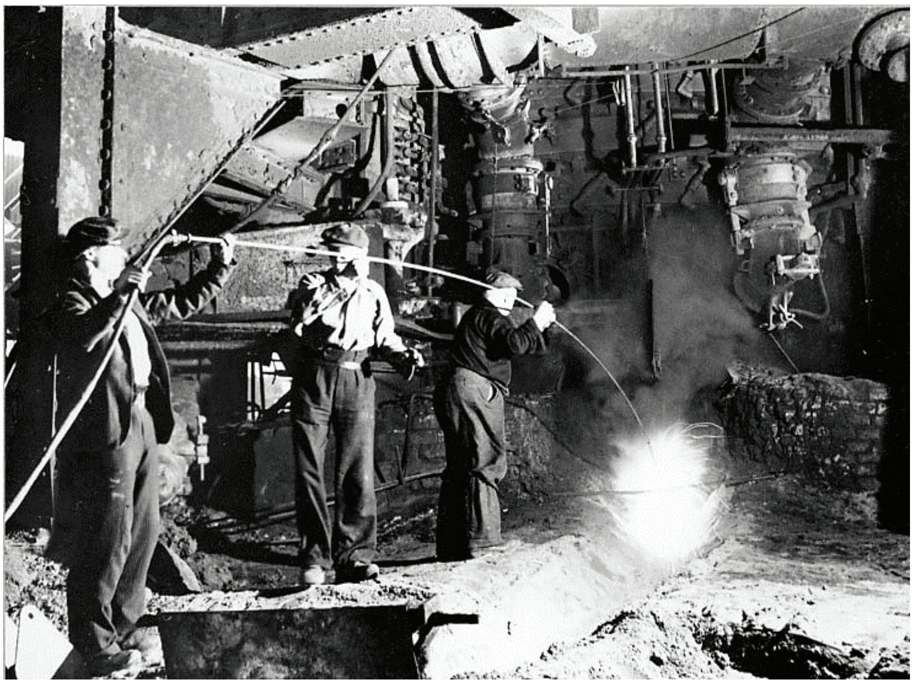


Figure 3. Lancing of a tap-hole at Workington Iron and Steel Company, UK (date unknown) (Baggley, n.d.)

Lancing remained the main method of opening tap-holes until the 1960s. However, this technology has many drawbacks with regard to workers' safety and tap-hole life. Therefore alternatives to lancing were sought and developed.

The first records of tap-hole drills can be found around 1921. Edgar E. Brosius from Pittsburgh, Pennsylvania and Joseph E. Judy from Keesport, Pennsylvania, suggested a method for drilling tap-holes open (Brosius, 1921; (Judy, 1921). Brosius even invented a combined drilling and lancing apparatus (Figure 4) in 1924.

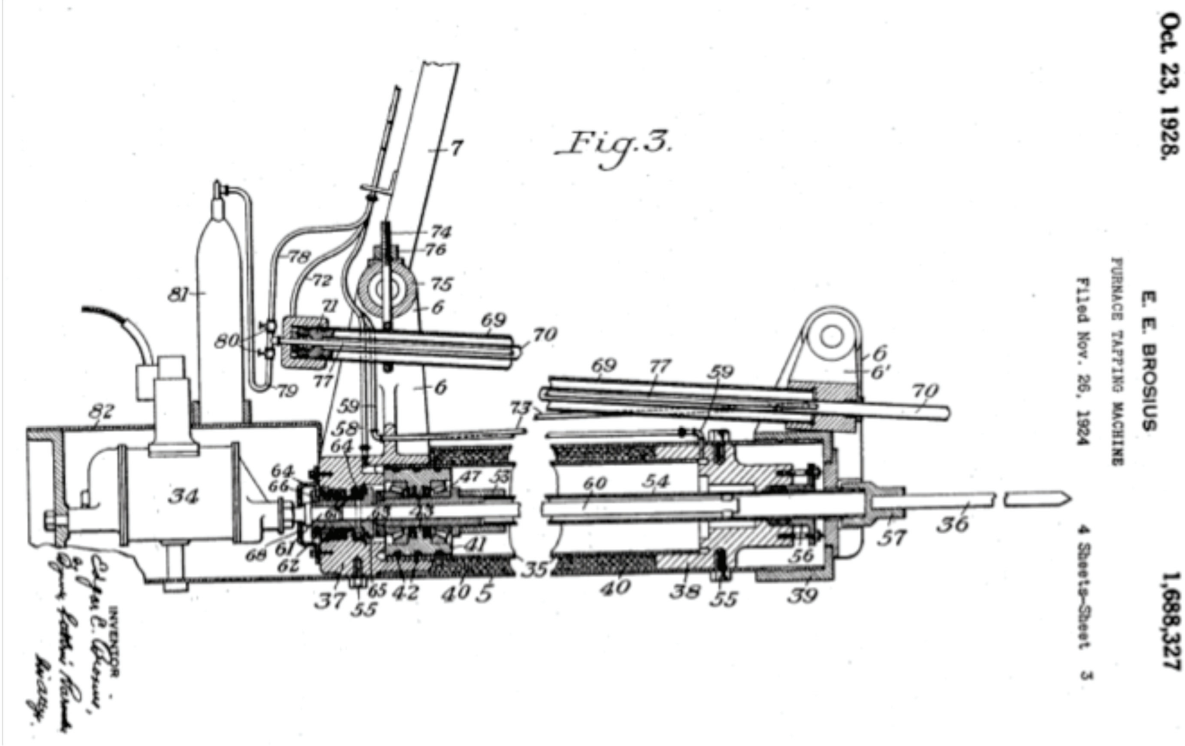


Figure 4. Drilling and lancing apparatus by E. E. Brosius (Brosius, 1924)

However, it seems that these machines did not work to the operators‘ satisfaction. On almost all casthouse pictures up to the early 1960s only lancing or crane-hung pneumatic hammers or mobile drill racks can be seen (Figure 5).

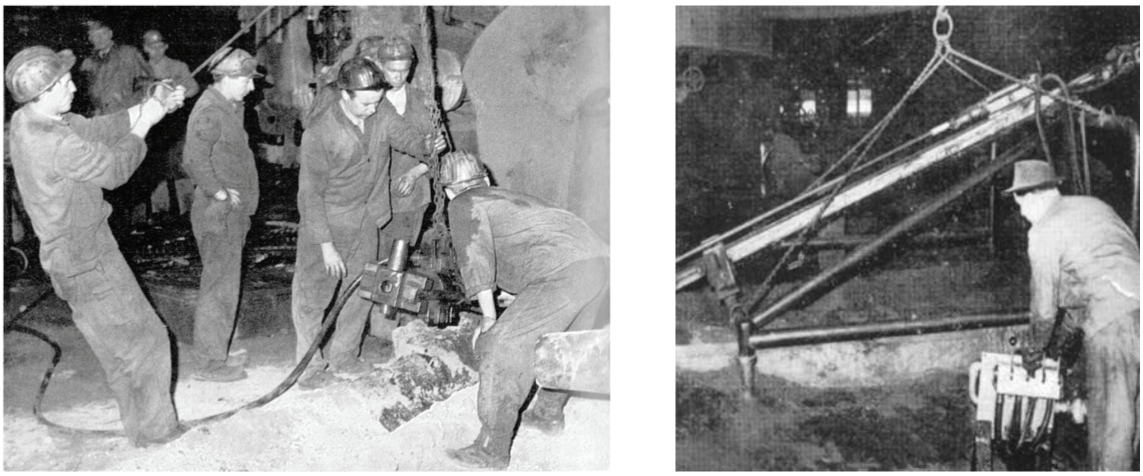


Figure 5. Opening technologies up to the early 1960s (right: Friedrichshütte Herdorf, date unknown; left: date and place unknown) (Koch, 1970)

Until the early 1960s most developments can be found on the clay gun side. It was again Edgar E. Brosius who invented a double-barreled clay gun, i.e. a clay gun with two independent clay barrels that used one common nozzle (Figure 6) (Brosius, 1933). His invention included some major changes. The biggest was the changeover from steamdriven cylinders to water hydraulics. He saw several drawbacks in using steam, like danger to workers from hot exhausts, condensing of water in long pipelines, and potential unavailability of steam due to many different consumers on the steam network. By adding one clay barrel on top of the other, the availability of the clay was increased: in case of mechanical failure of one plugging cylinder, the other was still operable. A very important advantage that was not addressed in the patent was that the design allowed keeping the same compact design while doubling the plugging volume by keeping the same working pressure of the pneumatic/hydraulic system.

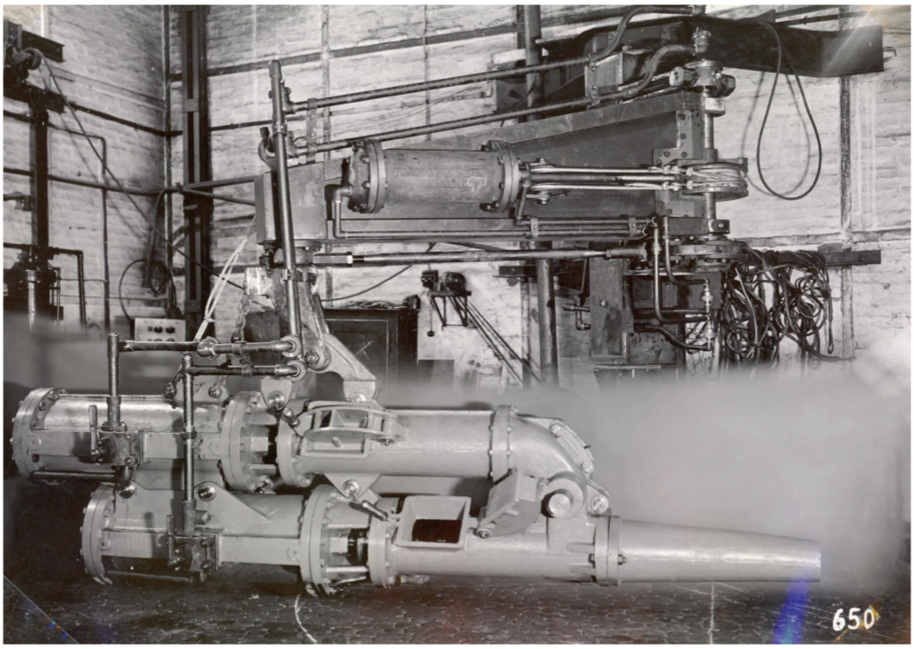


Figure 6. Clay gun with two clay barrels, manufactured by DDS (1928 and later)

This type of clay gun was also licensed in 1928 by Dango & Dienenthal, and was built many times until 1960. However, contrary to the original design, many installations were realized with pneumatic cylinders.

After World War II, double-barrelled clay guns were regularly built with electro-mechanical drives both for plugging and slewing (Figure 7). The idea of using an electric motor with some sort of gear to drive the plugging piston was also invented by Edgar E. Brosius during the early1930s (Brosius, 1932, 1934a). In most cases the slewing movement was performed by an electric rack and pinion drive. The last electro-mechanical clay gun was commissioned in 1981. Three machines are still in operation, one at DK Recycling in Duisburg (Germany), commissioned in 1961, and two at VoestAlpine Stahl in Linz (Austria), commissioned in 1960 and 1962. The latter two will be replaced in 2015/2016 by modern machines supplied by Tapping Measuring Technology (TMT) of Luxemburg/Siegen, a joint venture established by Dango & Dienenthal and Paul Wurth in 2003.

In 1954 the construction company Paul Wurth of Luxemburg finished the construction of their first blast furnace at Seraing (Belgium) for SA Métallurgique d'Espérance-Longdoz. For this project Paul Wurth built their first clay gun as well.

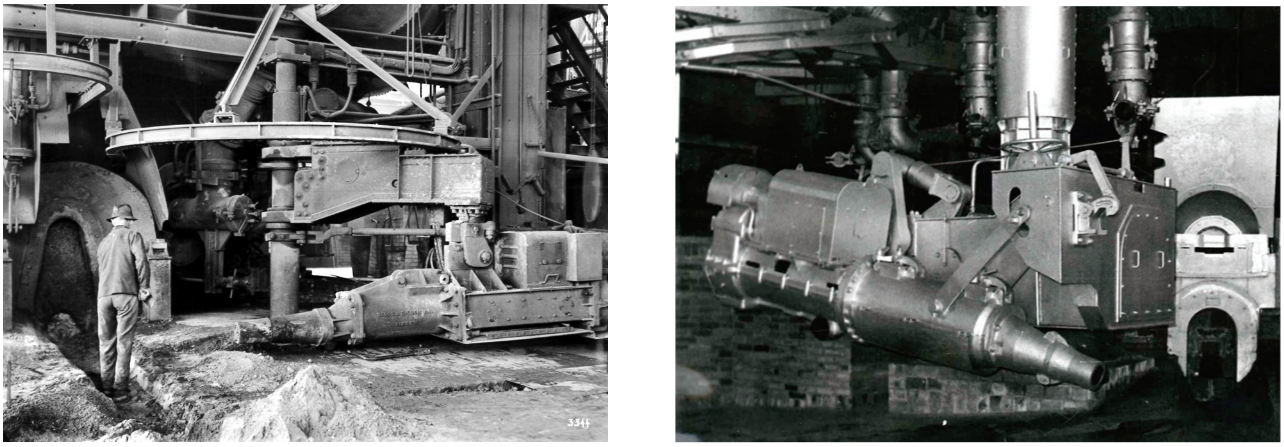


Figure 7. First generations of electromechanical clay guns (date and place unknown) left: Dango & Dienenthal, right: Paul Wurth (Dango & Dienenthal and Paul Wurth archives)

However, the electro-mechanical design had some drawbacks. The main aspect was that customers required higher plugging pressures due to improved (i.e. harder) plugging masses. In addition, teeth within the gears could break due to shocks, and the clay mass from the clay barrel entering the gear drives made frequent repairs necessary. The most efficient way to increase the clay guns' power was to apply hydraulics to drive the plugging cylinder (Figure 8), an idea that had already been promoted by (guess who?) Edgar E. Brosius in 1934 (Brosius, 1934b). Nevertheless, the problem with protruding clay from the barrel persisted. Clay on the hydraulic plugging cylinder's piston rod tended to destroy the seals, and the cylinder started leaking and had to be repaired. In order to overcome this problem, Dango & Dienenthal developed a plugging cylinder working with an inverse principle in 1962 (Figure 8). The piston rod stood still and the cylinder housing served as plugging piston. This design had a much longer lifetime compared with 'normal' plugging cylinders. The first clay gun with this design was commissioned 1964 at August-Thyssen-Huette, Duisburg (Germany).

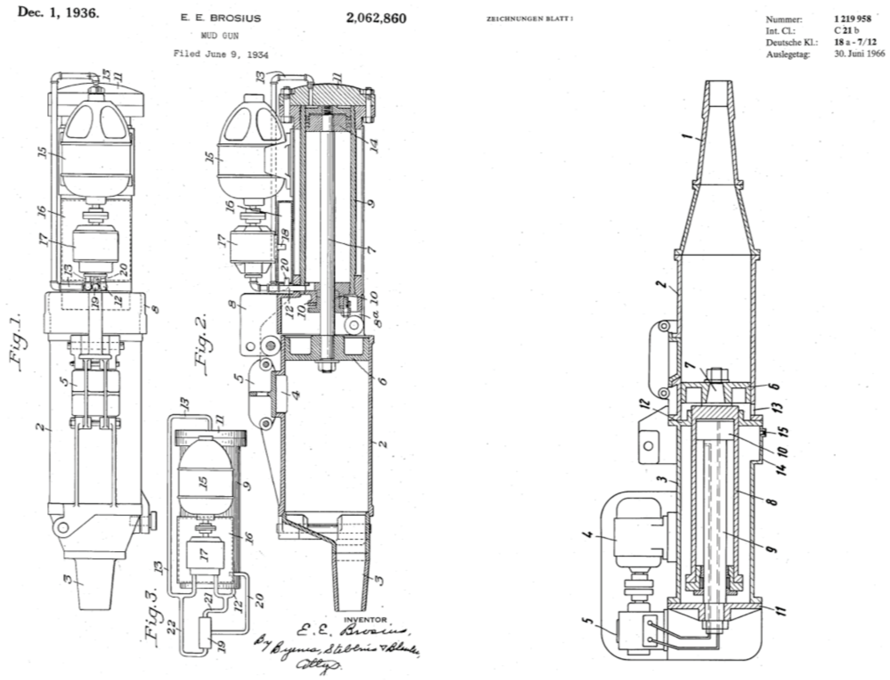


Figure 8. Brosius' hydraulic clay gun (Brosius, 1934b) and DDS's inverted plugging cylinder (1962) (Dienenthal,Ullrich, and Zimmermann, (1963)

Until the beginning of the 1970s the boom arrangements to swivel the clay gun towards the tap-hole consisted of several drives. In order to reach the working position at least two axes had to be actuated. In addition, the problem of how to follow a moving tap-hole in plugging direction was not sufficiently solved, although additional lateral travelling of the clay gun was known. Furthermore, the design was quite space-consuming, such that low tuyere platforms resulted in large swiveling areas.

In order to overcome all these problems, Paul Wurth (1971) invented a full hydraulic clay gun on a skewed pedestal that could reach the tap-hole in a single motion (Figure 9). By using a regulating rod, this design incorporated another advantage: the clay gun moved on an almost linear path around the working point. The slewing was actuated by a single cylinder that was connected directly to the boom, thereby giving easy access for maintenance purposes. The first installation of this design was commissioned at BFB of Arbed Belval in 1970. In principle, this fundamental design with modifications is still being built today by TMT.

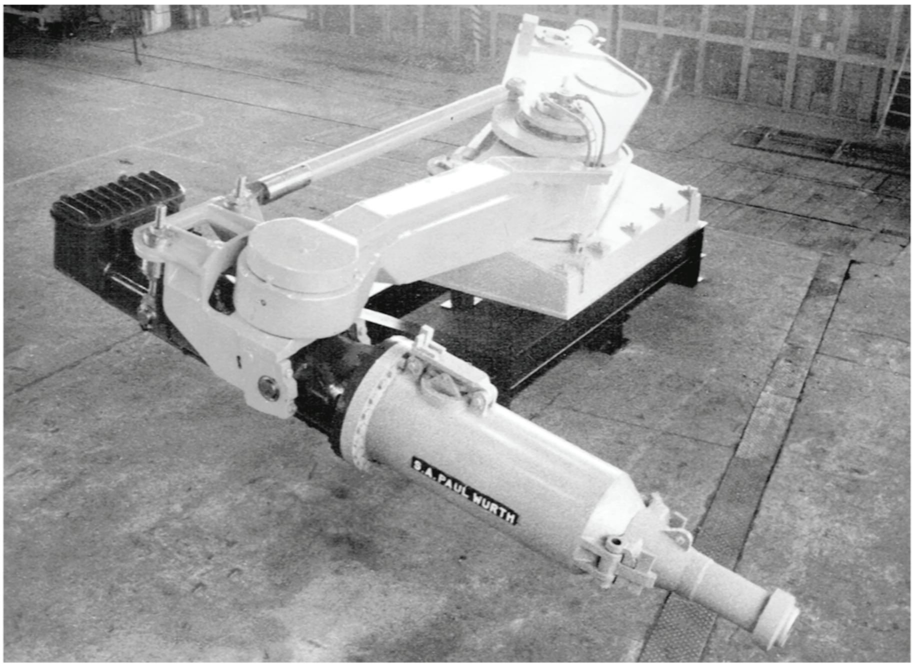


Figure 9. First clay gun, one-motion-type, built by Paul Wurth (1970)

Some years later, the second fundamental design of today's TMT clay guns was developed by Dango & Dienenthal (1978). The slewing mechanism (Figure 10) was designed such that all movable parts were placed inside the boom, thereby protecting them from dust and debris. Owing to the specific ratio of the levers, this mechanism produced an optimized torque with the maximum in the areas of the working point. In addition, this design allowed for larger slewing angles with only one cylinder.

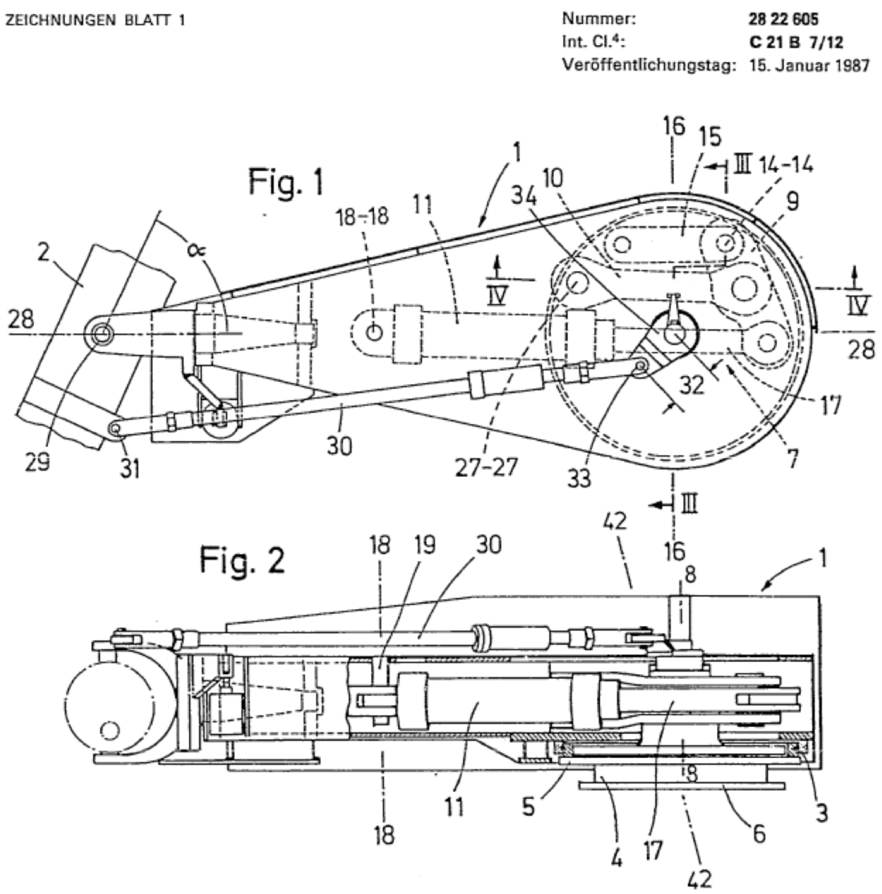


Figure 10. Closed swivel drive for clay guns with optimized torque (1978)

Further developments in the following years that improved clay gun operation were water-cooled clay guns in the mid-1990s. This development allowed heating of the plugging mass when the ambient temperature was low. But more importantly, with an effective cooling, whether only the barrel or additionally the front cone and nozzle, it was possible to delay hardening of the clay inside the gun. Today's high-performance clays cannot be handled without optimized temperature control of the gun.

In order to prolong tapping times, blast furnace operators tried to reduce the washout of the tap-hole channel by using harder and harder clay masses (Figure 11). Consequently, the market required more powerful machines. This led to the development of the world's most powerful clay gun in 1997, with a clay pressure of 350 bar. This design was built by Dango & Dienenthal for JFE Chiba's BF 6, and the machines are still in operation (Figure 12).

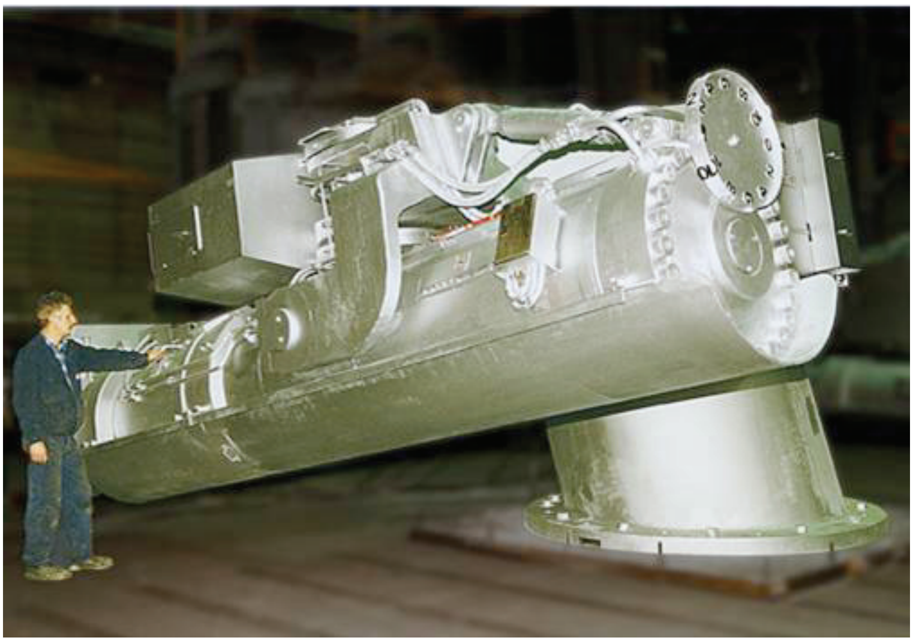


Figure 11. World's most powerful clay gun (350 bar clay pressure), built for JFE Chiba (Japan, 1997) (Dango & Dienenthal archives)

As can be seen in Figure 12, the high clay pressure with the inverse design led to a machine with a considerable space requirement. Nowadays, the best compromise between space restraints and maximum clay pressures are 200 bar plugging pressure/250 litres of clay volume for small and medium size blast furnaces and 250 bar/350–400 litres for large blast furnaces.

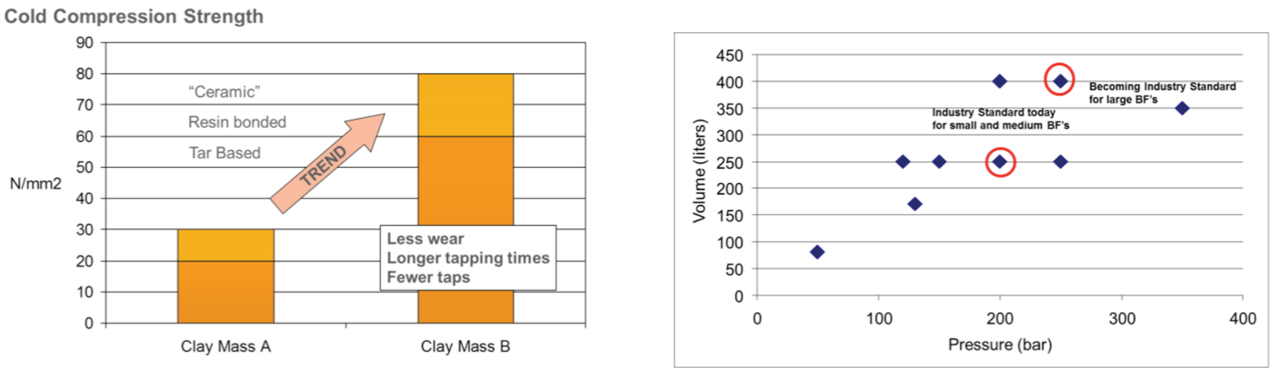


Figure 12. Developments in clay masses/industrial standard of clay gun sizes

Recent developments in clay guns have aimed at reducing capital and maintenance cost as well as optimizing hydraulic controls. Great efforts have been put in operational safety, especially with a focus on electrics and hydraulics. Modern machines nowadays comply completely with the EU machine directive.

A decent plug, which fills the entire tap-hole channel with clay, may be the most important consideration to allow for a safe and quick opening subsequently. Nevertheless, it is also important to be able to drill the plug open with a good repeatability in order to prolong the lifetime of the tap-hole channel or tap-hole block. Lancing has to be kept at a minimum.

During the 1950s the first stationary tap-hole drills were built. Chain feeds as used in mines were assembled together with simple tilting mechanisms (Figure 13, left). Tap-hole drills as we know them nowadays were developed by Walter Horn (Horn, 1958), who further developed his ideas together with Dango & Dienenthal (1959), leading to the first industrial installation at Westfalenhuette Dortmund (Germany) in 1960 (Figure 13, right). This design used a double chain feed, a system that was built in different variations until 1981. The main idea was to use a sturdy drill bar with an expensive drill bit to drill a major part of the tap-hole. The last portion was hammered through with a simple and therefore cheap bar. An additional feature of this design was that drilling at different angles was possible. In these early times the hammers and the drill bars were positioned on top of the chain feed.

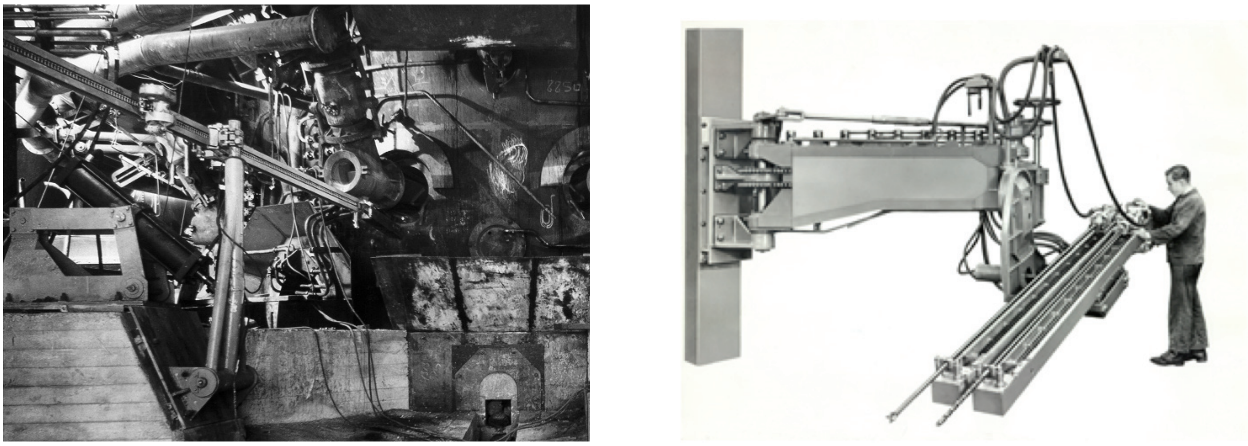


Figure 13. First stationary tap-hole drills (1950-1960) (Dango & Dienenthal and Paul Wurth archives)

In the middle of the 1960s two new features were introduced. Instead of pneumatic or electro-mechanic drives, hydraulic cylinders were used. In addition, the chain feed design changed such that hammers and drill bars were now positioned below the chain feed. This had the advantage that the chain feed support could move further away from the runner and from the heat. Since the beginning of the 1970s this became the standard arrangement.

The tap-hole drill in Figure 14 was built for August-Thyssen-Huette, Duisburg (Germany), and was commissioned in 1966.

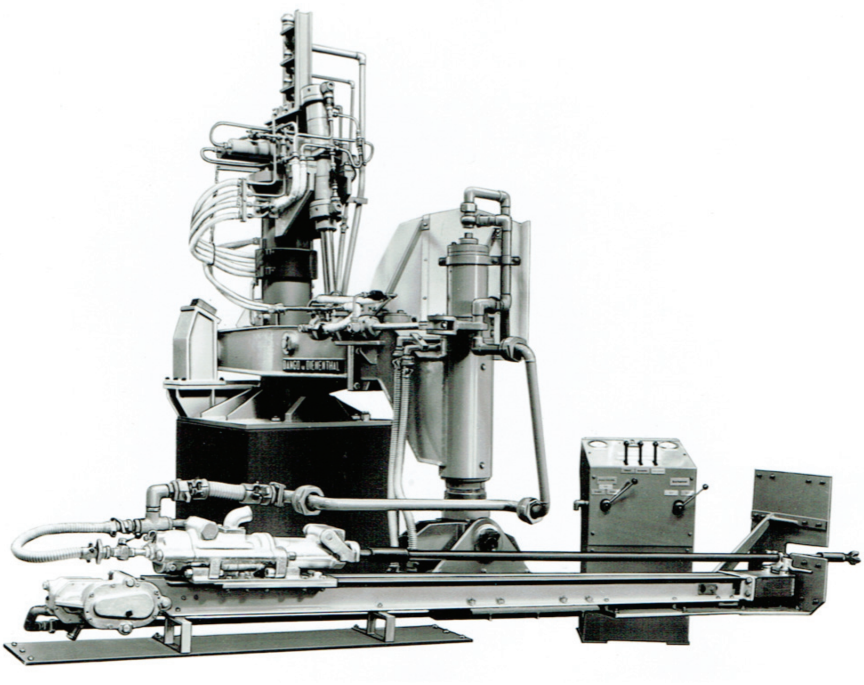


Figure 14. Full hydraulic tap-hole drill (except for hammer) for ATH (commissioned 1966) (Dango & Dienenthal archives)

When planning the casthouse, the engineers generally start with placing the clay gun. This leads to the fact that often, due to space restraints, the tap-hole drill has to occupy whatever space has been left. Many different layouts were therefore developed and patented, mainly by Dango & Dienenthal and Paul Wurth.

Of all different types, two have survived, the single-motion and the two-motion type.

In the single-motion type the swiveling movement is carried out by a single cylinder, whereas the swiveling axis is tilted. The first machines of this type were built in 1973 by Dango & Dienenthal for La Chiers (France) and in 1976 by Paul Wurth for Ensidesa Verina (Spain). However, the first tap-hole drill by Paul Wurth was commissioned in 1970 at Clabecq (Belgium). The design is unfortunately not known any more. The single-motion type design has maintenance advantages due to the minimum number of drives. In addition, it offers the most compact design. Before the founding of TMT in 2003, this design was mainly favoured by Paul Wurth.

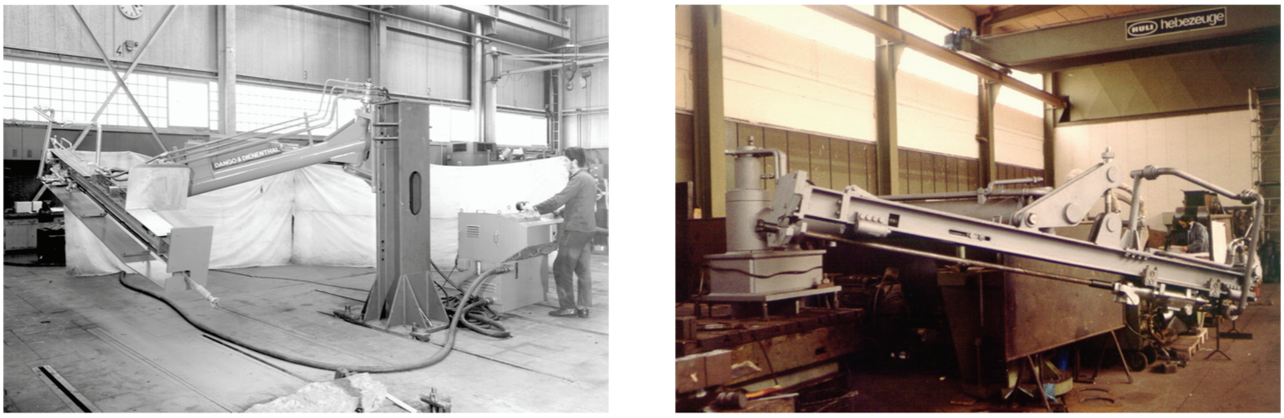


Figure 15. Early single-motion types (left: DDS; right: PW) (Dango & Dienenthal and Paul Wurth archives)

The dual-motion type of drill combines a horizontal swiveling action with lowering or tilting of the chain feed. Advantages of this design are a horizontal resting position, which is needed in case of automatic bar changers, and that the chain feed can be withdrawn out of the hot iron stream as soon as possible. In some installations, high lifting strokes of more than two metres can be realized, in order to create free space on the casthouse floor for better access to the clay gun. Until 2003 this design was mainly favoured by Dango & Dienenthal. Today, TMT is able to offer customers whatever suits the casthouse layout best, without having to consider in-house philosophies or competitor's patents.

The most important developments in tap-hole drills have always been on the hammer side. Different (harder) clay masses and different drilling philosophies called for different types of hammers. Drilling strategies included drilling by pure hammering, by pure rotation, a combination of both (conventional drilling), variations in hammering frequency and impact energy, or soaking bar technology.

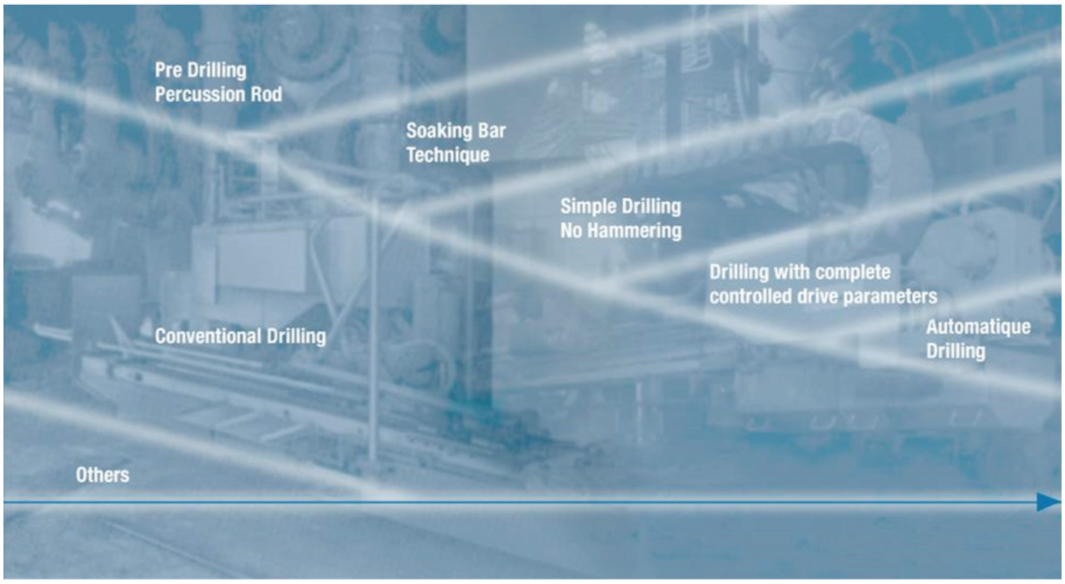
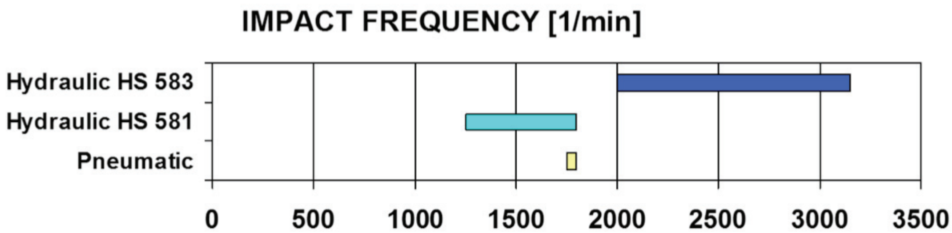


Figure 16. Development of drilling strategies over time

As explained previously, pre-drilling and finanally opening with a percussion rod started around 1960. The first installations that were able to support opening tap-holes with soaking bars were installed mid-1970s. PaulWurth even built special soaking bar machines capable of opening a tap-hole within 6 seconds (Figure 17). The first machine of this type was installed at Thyssen's Schwelgern number two blast furnace in 1993.

Figure 17. Soaking bar machine capable of pulling a soaking bar with 20 tons pulling force at Schwelgern BF2 (commissioned 1993) (Paul Wurth archives)

Another big step was the introduction of full hydraulic hammers instead of pneumatically operated hammers. Hydraulic hammers now offered more impact energy and could be controlled over a much wider range of parameters. In addition, the performance of pneumatic hammers was, and still is, very sensitive towards drops in the pressure supply (Figure 18).



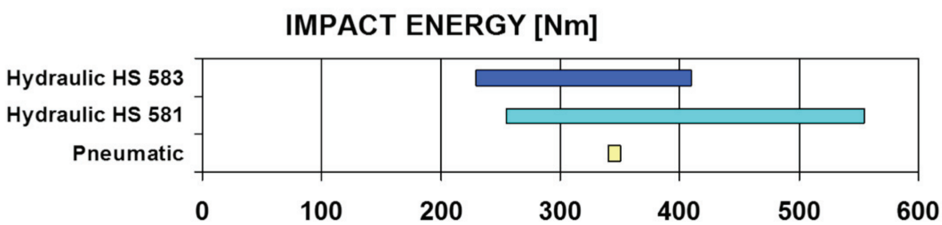


Figure 18. Performance comparison of hydraulic and pneumatic BF hammers

Nevertheless, operators have always striven to open the tap-hole as gently as possible, i.e. without subjecting the refractory to too much stress and shock. This requirement lead to the development of high-frequency hydraulic hammers in 2005. The performance characteristics of the high-frequency, short-stroke hammer (TMT type HS 583), the low-frequency, long-stroke hammer (TMT type HS 581), and the pneumatic hammer (TMT type HM 761) can be seen Figure 17.

Other developments for tap-hole drills are similar as for clay guns, like reduction in capital and maintenance costs as well as the optimizing of hydraulic controls. Modern machines (Figure 19) comply completely with the EU machine directive, with great attention to operational safety, especially with a focus on electrics and hydraulics.

Figure 19. Modern tap-hole equipment by TMT (TMT archives)

This paper has described the development in tapping technology over the last 120 years. Whereas earlier developments focused on the mechanical aspects of equipment designs, recent efforts have focused on electric and hydraulic controls. Future developments will have to continue to strive for longer tap-hole lifetimes by allowing for harder tap-hole clays and by reducing the influence of the hammer's impact energy on the hearth refractory.

Alternatives to drilling and plugging have proven unfeasible up to today. The 'tapping valve' for blast furnaces or submerged arc furnaces is still a metallurgist's dream. Ideas like stopping or regulating the metal flow by magnetic currents (Morgenstern, 2009) have not worked out on an industrial scale.

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