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THE HYDRAULIC
RAM-BORING-APPARATUS

BY

W. WOLSKI
ENGINEER.

PRINTED AT THE OFFICES OF THE *SŁOWO POLSKIE*,
Lemberg (Galicia-Austria). Joseph Ziembiński, Manager. 1905.

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Hydraulic Boring in General.

In no other department of technics are the advantages of hydraulic transmission of force so numerous and important as in boring operations. Whoever takes the trouble to examine in detail what is so far known in the particular branches of boring, viz. deep-boring, shaft-boring, horizontal boring, and stone perforating, will be brought to the conclusion that here, in the technics of boring, the principle of hydraulic transmission of force will in the future play a most important and conspicuous rôle.

Deep-Boring.

The common feature of the systems of stroke-boring known hitherto is the manner of imparting to the chisel its motion by means of the poles to which it is attached. These poles, either tubular or massive, their upper ends fastened at the walking beam, perform their up and down movement together with the beam and chisel.

The principle of hydraulic boring, on the contrary, consists in giving to the chisel its movement not by means of the poles but by means of pressing-water forced through the poles and driving the chisel-motor, at the bottom of the bore-hole, then rising up after having been used in the motor, and thus rinsing the bore-hole.

The transposing and letting down of the chisel may be done either automatically or by hand, by means of the poles, at which the motor hangs together with the chisel. As a consequence of this new arrangement there results a series of far ranging advantages. As the enormous mass of the poles, exceeding (especially at somewhat greater depth) by many times the mass of the real striking parts (the chisel and the auger stem), does not take part in the quick up and down movement, nor in the concussion accompanying the blow, we gain:

1) Greater safety in working, since a system of quietly hanging poles is not subject to breaking, the worst inconvenience in deep boring.
2) Saving of the boring tools, for those violent shocks are rendered impossible which elsewhere make the iron poles brittle in a short time, loosen the bore-crane, etc. Nor can there happen any whetting through of the casing-tubes, which is so common with all the other stroke and rotatory systems.
3) Independence of depth, since the mechanical conditions of the chisel's motion remain the same, whether working at a depth of 10 or 1000 metres.
4) Greater economy in the transmission of force, since the working power, transferred to the bottom by the forcing water, is here expended exclusively on the move of the working parts, and the enormous waste of work connected with the motion of the poles, with the shocks and such like, is here precluded.
5) The rinsing of the bore-hole by the water used in the motor (the rinsing being thorough) results from itself, as a secondary advantage; whereas all the other systems require to that end a simultaneous working of both the steam engine and pump.
6) The possibility of an unlimited increase of the mechanical effect at the bottom — the factor which in the first line determines the progress of the boring. In the boring systems applied hitherto the number of the strokes of the chisel, as well as the force of a single blow, is restricted — by the greatness of the mass to be moved to and fro — to a certain point, practically not to be exceeded, which I should estimate at a total effect[1]) of about 450 *mkg/sec* (6 *HP*). Here, on the contrary, where the work is transmitted directly to the chisel at the very bottom itself, there is no such restriction. The number and the force of the blows may be multiplied

indefinitely by increasing the pressure and the quantity of the water. Thus e. g.:

5 l/sec with *20* atm. pressure give *1000 mkg/sec (13·3 HP)*
8 l/sec with *25* atm. pressure give *26·6 HP.*

7) Other practical advantages are: The poles remain hanging at the hauling rope during the boring operation, and need not be every time coupled to and uncoupled from the walking beam. The whole length of a pole (10—15 *m*) can be bored without intermission; this is of considerable importance, since every interruption in the rinsing causes at once the deposition of particles of mud suspended in the water, and requires their removal anew. Moreover there is simplification of the boring crane (the beam being superfluous), a lighter construction (because of the absence of shocks), quicker fitting up, and so on.

Shaft-Boring.

In the present state of the mining industry, it is usual to deepen the large shafts by hand work, with the employment of explosives. Where strong waterfeeders or quick sands render the manual labour impossible, and where the artificial frost-wall protecting the workmen cannot be built up (on account of warm or salt water springs), there boring appears to be the only means to sink the shaft.

The art of shaft boring has not undergone any essential modifications in the course of the last half century. Details have been changed in various ways, but the principle remains the same which it was fifty years ago, namely that of Kind and Chaudron's free-falling instrument, an exceedingly heavy block (up to 30 tons weight) provided with a number of blades underneath; this block succeeds in crushing the stone by being lifted and dropped by powerful poles some fifteen times per minute.

The comparatively very slow progress, the frequency of accidents, and, therefore, the high price of the meter induced Messrs. E. Frieh and R. Nöllenburg, of Nordhausen, to try an essentially different way (German Patent Nr. 158751, of April

15, 1903). Instead of the one huge falling block, they used a great number of single strikers *A*. (Fig. 12), which being fastened in a common, slowly rotating case, *G*, and properly driven on, perform the boring. The bottom is cleaned continually by rinsing. The rinsing water, conducted through the hollow poles, *H*, flows through the kettle-like case *G*, along the bottom, and rises up the walls of the shaft. The narrowness of the cross-section at this point, caused by the presence of the encasement *G*, necessitates a proportionate increase in the rapidity of the water flow, and thus intensifies the rinsing. The rapidity of the flow being above the case diminished, in consequence of the enlargement of the cross-section, the larger particles of the sediment accumulate in a sediment-box, *S*, fixed above the case.

The evident advantages of this new arrangement are these: a great safety of working, secured by the immobility of the poles; the possibility of increasing almost without limits the mechanical effect of the striking apparatus — thus the boring effect too — and besides, the application of efficacious rinsing, which hitherto in the other systems, where no immersed case is used, could not be of any effect, on account of the great cross-section and the exceedingly small velocity of the water. These advantages certainly suffice to justify the boldest expectations and hopes with regard to this new method of boring.

As to the driving of the striking apparatus, the patent admits of the use of electricity, gas, compressed air, and pressing-water, but a closer examination shows the hydraulic motion of the single borers to be the only really practicable one. This conclusion is based partly on self-evident arguments, partly on considerations which would require a somewhat lengthy discussion. But it will be sufficient to hint at the extraordinary advantage of the poles, the conduct of force, and the water conduct being united in one system of single pipes. In fact, the inventors too have chosen the hydraulic motive power for realising their idea.

Horizontal Boring.

The boring apparatus which serve to drive horizontal or inclined bore-holes of large diameter and relatively small depth (water and wind holes), or to bore whole galleries, may be very advantageously impelled by hydraulic power, as the water, which is nearly always present in the mine, can be used for it directly, and as the rinsing and the carrying out of the crushed stone may be left to the water used up in the motor.

Stone Perforating.

The principle of hydraulic motion can be applied with equal advantage to the boring of shallow (1—2 *m* deep) blast holes and to trenching.

Stone perforating machines are, as is well known, of ever growing importance in mining industry, in quarries, and tunnels; they gradually do away with the slow and costly hand labour. The machines are driven by steam (exceptionally), compressed air, electricity, and pressing-water. This last one was hitherto used only in rotating bore-machines (the Brandt, Jarolimek systems), which notwithstanding all their other advantages, are heavy and expensive, necessitate larger cross-sections of the galleries, water pressures of frightful elevation in the whole conduit, and (on account of the powerful pressure of the crown) a very strong fastening.

Hydraulic stroke apparatus seemed to be excluded— because of the hydraulic shock — and therefore the application of water pressure as motor power for stone perforating machines seemed exceedingly limited. Yet the use of water appears to be the most advantageous for this kind of boring. For tunnelling, water can usually be got from elevated springs, lakes and rivers, with a natural pressure of many atmospheres, so as to be directly applicable to the working of the boring machines. In the mining industry pressing-water is nearly always obtainable in any quantities; it may be taken from the rising pipe, and, the boring being done, it may be allowed to flow off to the sump. In this case the draining engine itself, as primary agent, does the boring, or trenching, and there is no need of special motor arrangements, such as electric centrales or air compressors. It must be remarked, too, that at all events water must be conducted to the fore-head, on account of the rinsing of the bore-holes, removing the crushed stone, keeping down the bore dust, etc. Here the water conduit and the conduit of force are one and the same, since the used up forcing water may itself perform the most efficacious rinsing of the bore holes. This is of special importance where the crushing of the stone is accompanied with a great deal of dust, which (especially when whirled up by the blast of atmospheric engines) has most disastrous effect on the lungs of the working men.*)

The pneumatic motion has the great drawback, as is well known, of a relatively insignificant efficiency (7—22% without taking into account the resistance of conduits).**)

The electric stroke-boring machines with crank-motion present very good efficiency, but hitherto they could not exceed — because of other causes — a certain limit of output (about 2 *HP*); besides it cannot be denied that the electric power in mines with abundant gases — especially in coal mines — is rather dangerous.

With hydraulic transmission of power all such evils and dis-advantages fall off.

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*) The extent of this calamity may be inferred from the fact that the Governments of some countries — in South Africa and elsewhere have lately announced a competition for the supply of a stone perforator, which would not bring up any dust, eventually for an arrangement for keeping it down. Probably, should such a machine be produced, its introduction would be obligatory.

**) See Dolezalek's „Tunnelbau“.

The Boring-Ram.

The advantages of hydraulic transmission of power are so evident that deep boring engineers have for many years endeavoured to invent a press water motor with striking action. The first Patents of this kind, so far as I know, bear the dates 1867 (Balzberg), and 1880 (Hoppe), and the last ten years have brought forth many other projects, none of which however proved workable.

The difficulty of constructing a powerful hydraulic motor for quickly succeeding blows lies — not to mention the narrow dimensions of the bore-hole, the presence of sand in the water, and the arduous conditions of working, which exclude complicated constructions — in the nature of the force-transmitting medium, being heavy and almost incompressible. Every stoppage and every change in the direction of motion is necessarily followed by a more or less heavy shock of the water in the pipes and in the motor, and this phenomenon, increasing in force with the rapidity of the motion, limits both the rapidity (therefore also the force) of the chisel stroke and the number of strokes which are possible with an ordinary hydraulic motor, to about 150, at most 200 per minute.

Ram Principle.

Now I believe to have supplied in my own boring ram*) an effective as well as a simple solution of the problem of hydraulic boring, making it possible to deliver with any desirable force 600,

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*) Wolski Patent: Austria: 4010, Germany 135322. France: 303465, Engl.: 15017, U. S. Amer.: 699273 etc.

1000, and more blows per minute. Since it is impossible to do away with the hydraulic shock, I have turned it to use. The boring ram is founded on the same principle as the familiar hydraulic ram used for raising water: the impact of a column of water stopped suddenly in its motion by instantaneous closing up of a valve which was open before. Thus the pressure exercised by the pump does not act directly upon the chisel, but serves only to accelerate the motion of the column of water, which does not strike until the proper moment arrives, and then transmits its kinetic energy by elastic impact to the chisel.

Fig. 1 represents the schematic arrangement of the apparatus. The forcing-water flows through the conduit pipe *D*, and the air-vessel *B* into the stroke tube *U*. At the end of this tube the conduit branches out. One of the outlets is closed by an automatic valve *W*, kept open by the spring *f*, the second by the piston and the buffer-spring *Z*, the third by the piston *O*, which serves at the same time as stem for the chisel *S* screwed on to it. A powerful spring *F* tends to keep uplifted stem and chisel.

Now, when a stream of water is sent by the pump through the tubular poles, at first it will rush out freely through the open valve *W*. But when the stream has attained a certain velocity, it will exercise such a pressure on the valve-plate from above, that the elastic resistance of the spring will be overcome and the plate will be thrown with great vehemence on its seat. This is the moment, when the hydraulic shock (or jar) takes place: the column of water in the tube *U* having been in motion and now stopped suddenly, strikes the piston *O* and throws it with great violence against the bottom of the bore-hole. At the same time the buffer *Z* is compressed by the sudden increase of pressure. But when the kinetic energy of the column of water is exhausted by the work done, the reaction follows. The buffer *Z*, again expanding, throws back the column of water in *U*, whereby the pressure of the pump (resp. of the air contained in the air-vessel) is neutralized for a moment in its effect on the valve. Of this moment the spring takes advantage to tear off the valve-plate from its seat. Thus the outlet is opened again for the water, and the column *U* repeats the accelerated downward motion. At the same time the chisel, after having delivered the blow at the bottom, is raised by the spring F until the moment when the next water-shock drives it down.

In reality the buffer Z appears to be superfluous, for the specific elasticity of the water acts in its stead: the shutting of the valve causes a temporary compression of the column of water, by the increase of pressure accompanying the hydraulic shock, and afterwards, by its expanding again, a subsequent rebounding from the valve. The instantaneous rarefaction taking place between the two masses thrown apart (chisel and column of water) effects every time the re-opening of the valve.

The boring-ram is certainly a very simple — probably the most simple possible form of hydraulic pressure engine, specially adapted for a rapid striking motion. One valve-plate, one piston, and two springs are the only moveable parts. For smaller dimensions, instead of the valve-plate and valve-spring, there may be put a single elastic steel-lamina (like the tongue of a reed-pipe), forming a further simplification of the construction.

The ram-principle also solves very simply the difficulty of construction arising from the narrow width of the deep bore-holes. For, as the effective pressure moving the piston is not the pressure caused by the pump, but the five to ten times greater pressure of the water-shock (see the next chapt.), the surface of the piston can be taken 5—10 times smaller.

A piston of 20 cm^2 surface (50 *mm* diameter) gives an effective pressure of as much as 2000—4000 *kgs*.

In the boring systems employed so far, a huge mass (500—1500 *kgs*) strikes with small velocity against the bottom. Here, on the contrary, the effect is accomplished by small masses (30—70 *kgs*), but high velocities (exceeding 4 *m*).*) Corresponding to the great forces and small masses, the transmission and discharge of energy goes on extremely rapidly, shot-like, and the number of strokes is such as never — not even approximately — could otherwise be attained.

The opening and closing of the steering valve works instantaneously and almost without any gradient of pressure,

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*) About the difference resulting therefrom in the action of the edge in hard stone, see my paper „*Über die Bohrstange*“, „*Glückauf*“ (Essen), 1901, Nr. 10.

in contrast to any mechanical steering. Thus is prevented and excluded all the waste, otherwise inevitable, of energy, connected with the steering — a waste which is rather considerable.

The motor can be used with any muddy, sandy, or salty water, unavoidable in rinse-borings.

There is yet another circumstance proving often advantageous: since the steering valve when inactive remains open, we can pass at any moment from boring to only rinsing (see beneath the chapter on pressure and quantity of water); for the same reason the poles when hoisted are empty.

The violence of the water-shock and, in consequence, of the blow delivered by the chisel, may be regulated at will:

1) by suitably adjusting the valve;

2) by changing the length of the stroke-tube.

The Water-Shock.

The laws of the water-shock have been expounded and theoretically explained for the first time, as far as I know, in my paper published in the periodical issued by the Lemberg Polytechnical Society*) (1900). It will be necessary to repeat here briefly the chief results of my theory which, I may mention, have been proved by direct measurement to closely agree both as regards quality and quantity.

Water is known to be an elastic liquid, diminishing in volume under the pressure of one atmosphere by $\frac{48}{1.000.000}$ or we may say roundly by $\frac{1}{20.000}$ **).

The column of water contained in a tube can be considered as a row of uniformly distributed elastic particles of matter. If such a row, moving with the velocity u, is stopped suddenly by a fixed obstacle, there arises first at the striking end, then gradually spreads out to farther distant parts of the column, a compression and a corresponding pressure. This pressure depends only on

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*) „Czasopismo techniczne“, 1900, Nr. 25.

**) The elasticity of the walls of the tubing has the effect to increase its apparent elasticity, but under working conditions not more than by some millionths.

the velocity of the striking column c, but is quite independent of its length[2]. The value in atmospheres is:

$$A = 14{\cdot}4\ c \qquad \text{I.}$$

If the obstacle is not fixed but receding with the velocity v, the pressure arising from the water-shock will be only

$$A = 14{\cdot}4\ (c-v) \qquad \text{II.}$$

The compression proceeds as an elastic wave, from the pottom towards the end, with the velocity of sound in water:

$$V = 1443\ m/sec \qquad \text{III.}$$

At the moment when the elastic wave has run through the whole length of the column of water, there follows its reflexion at the free end, that is at the surface separating the denser from the less dense medium. The pressure originated by the water-shock and propagated from the obstacle to this other end of the column, is converted here into an equivalent velocity in these latter particles, and, by and by, in a gradually increasing part of the column, causing it to move backwards. Using the terminology of acoustics we should say: the reflected wave, returning as a wave of rarefaction, neutralises by interference, gradually, the former compression, until the pressure in the whole column is annulled and transformed into the equivalent velocity. Then the reflected column moves away from the fixed obstacle with the same velocity which it had before, while approaching towards it, and there arises a rarefaction at the bottom equal to the previous compression.*)

The pressure produced by the water-shock on the obstacle continued for such a time as was taken by the elastic wave to proceed through the whole length L of the column and to return. Thus the duration of the water-shock is:

$$T = \frac{1}{722}\ L \text{ (in seconds)} \qquad \text{IV.}$$

Fig 5 shows graphically the course of the phenomenon; it represents a column of water 7·22 m long in intervals of $\frac{1}{1000}$

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*) The rarefaction cannot reach any higher value, of course, than the surrounding pressure: at the surface: 1 *atm*, at a depth of 500 *m*: 51 *atm*, and so on. If the rarefaction is greater, there must arise a real vacuum, whilst the column is torn away from the obstacle.

sec. to begin with the moment of collision with the fixed obstacle. Its velocity of striking has been assumed to be $c = 12\ m$ per second. The upper row represents (according to the indicated scale) the stresses arising in the respective parts of the column, at every moment of the „shock“, the positive values (pressures) on the left side, the negative ones on the right. The lower row indicates (by reference to another scale) the velocities of the single particles of water, the positive values (downward) to the left, the negative (upward motion) to the right.

The column of water, as is evident from the diagram, does not lose anything of its kinetic energy by the collision with a fixed obstacle, it only changes the direction of motion,

$$c' = -c \qquad \text{V.}$$

which is self-evident, as the impact is elastic, and no exterior work has been done.

It is otherwise when the obstacle recedes during the collision with the (constant) velocity v. Then the pressure (as has been mentioned above) is only $A = 14{\cdot}4\ (c-v)$, and the final velocity, after rebounding (the same for any elastic collision)

$$c' = -c + 2\,v \qquad \text{VI.}$$

The quantity of work transmitted during the collision from the column to the receding obstacle will be (Q being the cross-section in cm^2):

$$E = 14{\cdot}4\ Q\ (c-v)\ v \qquad \text{VII.}$$

This transmission of energy is most efficacious, if the expression $(c-v)\ v$ reaches its maximum, i. e. if

$$v = {}^1/_2\ c \qquad \text{VIII.}$$

then the velocity of rebounding is

$$c' = 0 \qquad \text{IX.}$$

that is to say: the column of water, the collision ended, has transmitted its whole energy to the receding obstacle (e. g. a piston) and stands still.

Fig. 4 shows this phenomenon graphically.

In the case of our boring-ram, which interests us most, the obstacle is neither fixed nor receding with constant velocity: the velocity of the piston will be variable. The column v of water collides with the inert mass of the chisel, rising under the influence of the spring. In consequence of the impact the velocity of the piston changes gradually during the time of the water-shock: at first it is negative, goes down to zero in a certain time, and finally assumes increasing positive values.

Fig. 6 shows the kind of motion resulting from the theoretical equations[3]), if we suppose:

striking velocity of water $c = 12\ m$
initial velocity of receding chisel $v_0 = -6$
cross-section of column of water and of piston $Q = 10\ cm^2$
weight of chisel $= 10\ kgs.$

We see: the mass of the chisel, rising upwards, is stopped gradually by the water shock till it reaches the point H of maximal elevation ($y = 0{\cdot}80\ cm$), and of momentary repose ($v = 0$) after the interval $= 0{\cdot}00285\ sec.$ From this moment there begins the accelerated downward motion. But in proportion as the velocity v increases, there must diminish the pressure exercised by the column of water on the piston, and accordingly the acceleration of the mass. The velocity v of the piston approaches asymptotically the velocity c without ever reaching or surpassing it. This is represented in the time-way diagram (Fig. 6 I.) by the inclined asymptote, in the time-velocity graph (Fig. 6 II.) by the horizontal asymptote drawn in the distance $v = c$.

The third diagram (Fig. 6 III.) shows the kinetic energy of the mass:

$$E = {}^1\!/_2\, m\, v^2 \qquad \text{X.}$$

at every moment of the shock, from which the quantity of work transmitted from the column of water to the piston can be inferred. The kinetic energy increases slowly at first, quicker and quicker afterwards. The increase is most considerable for $v = {}^1\!/_2\, c$ (point W), where the curve has a point of inflexion. From this point its inclination towards the axis of abscissae diminishes gradually, the kinetic energy increases less rapidly, finally approaches asymptotically a certain limit, corresponding to the velocity $v = c$ (horizontal asymptote).

Fig. 5 represents the distribution of pressure and rarefaction (upper row), and of velocities (lower row) in a column having struck against an inert mass, in intervals of $\frac{1}{1000}$ sec. The length of the column is assumed to *7·2 m*, the mass of the chisel *7·2 kgs.**)

It is easy to prove by calculation as well as by the above diagrams,**) the sum of kinetic and potential energy contained in the chisel and in the whole column of water to be always the same before, during, and after the collision — which is an obvious conclusion from the fact of conservation of energy for elastic impact.

Fig. 8 shows the complete diagram of motion of the chisel resulting from the above considerations: After having delivered the blow (point S), the chisel is raised by the spring (harmonic motion, sinusoidal curve). At the point O, the valve being shut, there begins the watershock, which causes reversion of the motion and ends at the point K. The following part of the curve KS^2, which is performed by the chisel contrary to the elastic force, is a part of a sinusoide again; at the point S^3 follows the second chisel-stroke, and the play begins afresh.

Fig. 9 shows (in natural dimensions) the facsimile of a diagram taken directly from the boring instrument. The greater inclination of the curve immediately after the blow is to be explained by the rebounding of the edge, having struck in this case against a block of hard steel. On stone, even of the hardest sort, the rebound is scarcely perceptible.

Adjustment of the Valve.

As has been mentioned, the force of the chisel-blows can be regulated at will, chiefly by the adjustment of the valve, for the velocity of the water at the moment of shutting the valve is

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*) See beneath the relation between mass of chisel and length of column.

**) Pressure and velocity of the particles of water are equivalents. The sign is of no import, for the sum of the energy depends on the value of the velocity, but is independent of its direction, and likewise independent of the sense of elastic deformation (compression or rarefaction).

identical with the stroke-velocity of the column, and this determines the pressure acting on the piston. The valve shuts itself, when the spring tending to hold it open against the stream of water is overpowered by its pressure. This takes place in this way: the valve-plate, little distant from its seat, causes a narrowing of the cross-section, forcing the water to pass it with great rapidity. To this increase of velocity there corresponds a difference of pressure at both sides of the valve-plate, pressing it downwards, which, increasing with the square of velocity of streaming, bears down the spring and finishes by overpowering it.

The rule governing this action is the following[4]): Let us call „normal distance" the distance of the valve-plate from its seat when the spring is unloaded. With the water turned on, the distance must diminish gradually, as the water accelerates its motion, until the deformation has reached *1/3* of the normal distance. At this moment (when the distance of the plate has been reduced to *1/3* of its normal distance), the stable equiibrium turns into instability, and the valve is shut suddenly. Now, the velocity of water causing the shutting depends on two factors: the strength of the spring (viz. the ratio of resistance and deformation) and the normal distance of the valve-plate. Thus there results the force of the blow to be influenced by the strength of the spring in proportion to its first power, and by the normal distance in proportion to its third power.[5])

If the play of the valve-plate is limited by an upper stop, the spring sustaining thus some initial deformation, this, is of no influence at all on the force of the blow, provided this initial deformation is less than *1/3* of the normal distance.

A yet deeper position of the upper stop diminishes the force of the blow and causes unnecessary throttling of the current in its rush.

Length of Striking-Column.

The second factor determining the force of the water-shock is the length of the striking-column, since this defines the duration of the pressure, acting on the piston. It is not the whole length of the poles, of course, which comes into account, but only the distance between the apparatus and the air-vessel. For the air-vessel, being a flexible, elastic part yielding to pressure, forms an interruption in the column of water of homogeneous elasticity, and causes thus a reflexion of the waves of compression in the same way, as (in acoustics) the open end of a pipe causes reflexion of the sound-waves.

Now the question is: what length of the striking-column is the most advantageous. If the tube is very short, the water-shock is interrupted so quickly as to transmit but a very small part of the kinetic energy of the water to the chisel. A very long tube, on the contrary, causes, by protracting extremely the duration of the water-shock, a gradual approximation of the velocity of the mass to the velocity c of the striking-column, and a very insignificant transmission of work to the piston, in the latter stage of the shock. The one and the other extreme case must be considered unfavourable.

The length of the stroke-tube has to be chosen in such a way, as to effect the transport of the greatest possible part of the energy contained in the column of water to the mass of the chisel, and this is the case, if the striking mass is equal to the stricken mass of the chisel[6]). There is no need, of course, of an absolute exactness, approximate equality of both masses is sufficient to warrant favourable conditions of transmission of work.

As the diagrams (Fig. 5 and Fig. 6 III.) show, the column of water gives off $2/3$ of its initial energy to the chisel, if the most favourable ratio of masses is chosen, but keeps the rest of energy in form of velocity or deformation and uses most of it for its own rebounding after the collision.

If the cross-section of the piston is not equal to the cross-section of the column of water, but a times larger, than the water-shock goes on in the same way as with equal cross-sections, but with a mass of the chisel a^2 times smaller than in reality.[7]) Then the length of the striking-column must be shortened in the same proportion.

If we wish, on the contrary, to increase β times the cross-section of the striking-column with given chisel and piston, than its length too must be enlarged. Then the mass of the column will be larger β^2 times, its velocity β times smaller, the kinetic energy at the moment of the shock is unchanged. The only difference in effect is this: the water-shock will act on the piston with a β times smaller pressure, but this pressure will last β times longer.

Quantity of Water and Working-Pressure.

The quantity of water wanted for the working of the boring-ram is much less than the quantity wanted at the start. For the latter quantity corresponds to the maximal instantaneous velocity of streaming — which is sufficient to cause the closing of the valve — whilst the apparatus, when working, uses only the mean quantity of water, resulting on average from the three periods: of start, shock, and rebound.

Now, theoretic calculation and direct observation agree in showing this mean quantity of water used to be only from 1/3 to 1/2 of the maximal quantity.

Therefrom results a certain peculiarity of the boring-ram — and a very advantageous one it is: at first a great amount of water (double or threefold) can be sent through the apparatus without starting its boring action, the water flowing through the open valve without hindrance and almost without pressure, and serving only to rinse the bore-hole. But when the quantity of water reaches the limit required for the closing of the valve, then the apparatus starts suddenly, the pressure in the air-vessel increases, and the stream of water diminishes to 1/2 to 1/3 of its original quantity. Thus, whenever wanted, there can be used a very efficacious rinsing, instead of boring, which in deep-boring has proved often advantageous.

The working-pressure of the pump determines the time wanted for imparting to the column of water the necessary velocity for each shutting of the valve. Therefore the number of strokes per second depends on the pressure supplied by the pump. This pressure varying, the number of strokes varies also, but not the force of each single blow, nor the quantity of water; these are determined by the adjustment of the valve.

The product of the quantity of water and of the pressure is the measure of the total work done.

As the above considerations show, we have at our disposal with this apparatus all the mechanical elements, which determine the motion of the chisel, viz. the force, number, and length of its strokes. Therefore we can accommodate it with the greatest ease to every condition of working.

Losses and Efficiency.

Partial losses of work can be caused by:

1. leakage,
2. resistance of conduit, and
3. friction of piston.

Leakage in the conduit-poles can be found out easily, and just as easily avoided. A carefully worked conical thread, greased with tallow or tar, secures in this respect almost absolute safety. At all events, the amount of the losses arising from this cause, being determined by the proportion of the quantity of leakage to the whole quantity of water, is quite insignificant.

Much more important is every leakage in or below the striking-column, above all in the apparatus itself. For the pressures arising there from the shock are incomparably greater (100—300 *atm*) than the pressure of the pump (10—25 *atm*). Such enormous pressures, changing 10—15 times per second from positive into negative values, render the tightening more difficult. Besides, a leakage causes there not only considerable loss of efficiency, but may foul the working of the apparatus altogether, as the rebounding of the column of water, which is indispensable to open the valve, may be lost on account of the leakage. This will be understood by comparison with an elastic rod, a walking stick, which shows reboundig from a stone pavement, but not from soft earth, where it wastes its kinetic energy by sinking a little way into the earth. As the calculation shows, leakage through a cross-section of several hundredths of the cross-section of the tube is sufficient to waste the whole kinetic energy of the column of water, in driving the water through the narrow slit. Under such conditions, there is no regular rebounding, the apparatus stops, with its valve shut*).

Fortunately, there is no difficulty in securing the tightness in the two places where, first of all, leakage could occur, at the valve and the piston, if their form is correct, and the materials are properly selected.

---

*) In order to start it again we have only to stop for a moment the pressure of the pump.

A piston provided with leather-packing, or tightening-rings, is absolutely tight. For a valve, a thin, elastic steel plate, with seat of hardened steel, has proved most appropriate.

The frictional resistance of the water in the conduit increases, as is well known, in proportion to the length of the poles, and to the square of the quantity of water driven through them. The diameter of the tube has an influence on the resistance in inverse proportion to the fifth power:

$$A_1 = 2{\cdot}1 \ L \ \frac{W^2}{d^5} \qquad \text{XI.}$$

(A in *atmospheres*, L in *m*, W in *l/sec*, d in *cm*)

If the pump operates with A *atm.* pressure, the loss of effect caused by the frictional resistance of the poles, relatively to the whole work, is

$$\frac{E_1}{E} = \frac{A_1}{A} \qquad \text{XII.}$$

Hence the necessity to employ as wide pole-pipes as possible If we take for instance: $W = 4$ *l/sec*, d $7 =$ *cm*, there results a los of 0·2 *atm.* for every 100 *m.* of poles. For a working-pressure of 20 *atm.* and a depth of 600 *m* this means 6% waste of work.

Another loss arises from the resistance of the water in the stroke-tube and in the narrow cross-section of the valve. But these resistances are not constant, they vary with the varying velocity of the column of water. The pressure wanted at the start, for shutting the valve for the first time (maximal resistance of stroke-tube and valve) may be designed by A_2. Then the mean loss of effect arising from this cause is, fairly approximately: 8)

$$\frac{E_2}{E} = {}^1/_2 \ \frac{A_2}{A} \qquad \text{XIII.}$$

We may diminish it as much as possible:

1. by adjusting the valve in such a way as to get strong shocks rather by taking a greater normal distance, than by using a too strong valve-spring;

2. by chosing a somewhat wider and correspondingly*) longer stroke-tube.

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*) See the relation between cross-section and length of the stroke-tube in the chapter on length of the striking-column.

As the length of the tube has a directly proportionate increasing effect on the resistance, the cross-section a diminishing effect proportional to the power $2^1/_2$, the loss of effect diminishes in proportion of the $1^1/_2$ power of cross-section (third power of diameter).

Supposing, for instance, the diameter of the tube d $= 40$ *mm* ($Q = 12{\cdot}5$ cm^2), $L = 20$ *m*, $w_2 = 10$ *l/sec*; the maximal resistance opposing the current will be 4 *atm.* in the stroke tube, 0·5 *atm,* in the valve, together: $A_2 = 4{\cdot}5$ *atm.* This amounts to 11% of the whole work, for a working pressure of 20 *atm.*

The friction of the piston in the cylinder cannot be calculated exactly; it will depend on the sort of packing used, and on the presence of sand in the water. I should estimate this resistance for leather-packing at 10%, less for tightening-rings, least of all for a long, transversely grooved piston, if grinded in accurately.

Thus, under the above supposed conditions, the total loss would amount to 27% of the work done by the pump, the efficiency to 73%*).

The labour spent every time in straining the spring F is not wasted. The spring, when expanding again, returns this labour in the form of velocity added to the rebounding mass. It helps thus, after the collision, the column of water to rebound towards the air-vessel, and causes a corresponding reduction of the quantity of forcing-water.

In order to prevent any misunderstanding, I may be allowed to draw attention to the fundamental difference between the hydraulic shock, being the principle of the construction of the boring-ram, and the shock of water which must be avoided — e. g. in constructing water-wheels — on account of its causing loss of efficiency. There we have an open jet of water, dispersing itself by the impact, scattering in all directions, and wasting its energy. Here we have a column of water, locked in tightly, which, just as any other elastic body, does not lose anything of its energy by collision.

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*) According to Eytelwein's experiments, the hydraulic ram used for raising water works with an efficiency of 70—90%.

Deep-Boring Ram.

In designing a deep boring apparatus by aid of the principle of the hydraulic ram, its construction had to be accommodated to the given conditions of space (the narrow dimensions of the bore-hole, with length unlimited). The water had to flow out in the centre, as near as possible to the bottom, the chisel must be easy to change, the whole apparatus must be solid, simple and easy to take to pieces.

These requirements are fulfilled by the construction shown in Fig. 10. The valve-seat has the shape of a steel cylinder with a central bore and a row of parallel holes around it. These holes are, all together, shut (resp. opened) by a thin, elastic, steel-plate-ring, the valve-plate, playing above them. The valve-spring works in a cylindric, widened groove of the valve-seat. Its effect can be strengthened or weakened at will by putting under it thin steel-plate rings of various thickness. A short central tube serves as guide for the valve-plate, and two displaceable check-nuts on it form its upper stop.

When the valve is open, the water flows through the row of holes, trough the mantle-tube, and the bore-shoe to the chisel, rinses the chisel and the bottom, and rises in the bore-hole as rinsing water. When the valve is shut, the pressure of the water-shock spreads itself through the valve-guiding-tube into the working-cylinder, a tube of chilled steel, in which the piston is playing.

The chisel (constructed in this case as an excentric step-chisel) is joined to the long piston-rod, at which it is suspended, by a ball and socket-joint, to prevent it from shaking. Its cylindrical part is guided exactly by four ledges in the interior of the cast-steel bore-shoe. Its flat part plays in a slit of the bore-shoe; thus the motion of transposing is communicated from the poles to the chisel.

The strong back-lifting-springs resist on the bore-shoe and press with their upper part (by means of a short bit of tube) against the piston. It is sufficient therefore to screw off the bore-shoe, if we wish to draw out, examine and change any of the parts connected with the chisel (also the piston with its leather-packing).

The screw-joints are conical, with scarcely any exception, resting thus full and tight, notwithstanding the natural wear, and safe against accidental slackening. The stroke-tube with thick walls composed of parts with conical screw-joints, has a total length of 10 to 20 metres.

The form of the air-vessel which has proved the best is shown in Fig. 11. The wall of the tube is perforated by a great many tiny holes, like a sieve, over which an india-rubber hose is put, fastened, by tying-up, at both ends. The whole is covered by a steel-tube, closing hermetically at both ends, as a solid mantle. In the space between the mantle and the hose air is pressed in by means of a small valve to a certain pressure. During the boring work, the hydraulic pressure (hydraulic pressure plus pressure of pump) from one side, the pressure of the enclosed air from the other side, act against each other, and the india rubber, now expanding, now contracting, forms the elastic separation between the air-space and the water-space.

But the boring-ram is also very well adapted for getting bore-cores. If we wish to draw, from a given depth samples of stone in the shape of short pieces of core, we need only to replace the chisel by a striking-crown, a short steel-tube, at its lower end provided with a crown of hardened teeth. The rapid, short strokes and the accurate guiding of the crown between the ledges of the bore-shoe facilitate the forming of good cores, which, after the boring being stopped, wedge in the crown with mud and can be drawn out.

This simple procedure, no doubt, has a considerable value, as giving information, from time to time, about the ground just bored-through, but is unsuitable for continaul core-boring. In order to compass this too, Mr. E. Frieh, the engineer already mentioned before, remodelled the apparatus by placing the striking part, the crown, on the outside, while guiding it on the fixed, central core-tube, many metres long. This construction allowed to bore through a way of any length, and to get cores not inferior to those which are supplied in diamond-boring.

Shaft-Boring Ram.

The hydraulic motion, as has been told above, is especially appropriated for working the group-arrangement of shaft-boring apparatus. Now since the boring-ram is the only hitherto known hydraulic striking-apparatus to the purpose, this has been adopted for the construction of the new shaft-boring apparatus.

Fig 12. represents schematically such an apparatus in the form exhibited at the Liege Exhibition by the German Deep-boring Company of Nordhausen.

The bore-hole, of 1·70 m width, is commanded by six chisels. The instruments which work on the periphery are inclined somewhat towards the outside, thus neutralizing the detrimental consequences of the wear and tear of the border-chisels, and, on the contrary, giving to the apparatus the tendency of boring out a shaft of rather exaggerated width. If we place the border apparatus on hinges, as shown in the Fig. 12, we obtain a very effective enlargement of the walls in order to sink the shaft timbering.

Every chisel has its own back-lifting spring and its own piston. But the air-vessel, the striking-tube and the valve are common to all instruments. The common hydraulic shock is distributed by channels to all working cylinders.

The greater the dimensions of the shaft to be bored, the greater must be the number of the single instruments used. They must be distributed in such a way, of course, as to give approximately equal shares of stone, to be bored out, to every edge.

The same principle, of a number of chisels worked by a common hydraulic shock, can be applied to the construction of a very effective shaft widening-borer with laterally acting edges.

Stone-Perforator

For the purpose of stone-perforating the ram must be changed in its construction in several respects (Fig. 14). Above all provision must be made for an automatic transposing of the chisel. It is best to arrange for lateral outflow of water. The hydraulic shock can be originated outside of the boring instrument itself, and can be transmitted to it by means of link-tubes. This arrangement is specially advantageous, where (as in tunneling) several chisels, mounted up on one boring-car, are attacking one common front wall (Fig. 15). In this case the air-vessel, the stroke-tube and the valve are fixed on the boring-car, and the hydraulic shock, produced by them, common to all instruments, is transmitted to the single pistons. Thus the construction of the single instruments is extremely simplified, their attendance facilitated.

The stroke-tube can be stretched out straight, or can be folded or rolled together, just as the given space permits.

The back-drawing of the chisel here is obtained by the action of the spring, or by suitable rubber straps.

On the whole, the construction admits of great variety. So e. g. the column may serve at the same time as air chamber, in which case the water-stroke is directed to the apparatus by a link-tube (Fig. 16). This arrangement is to be specially recommended, where several apparatus operate upon one column. In the case of single apparatus the simplest arrangement is to connect the moveable air-chamber with the apparatus by a straight or a folded stroke-tube (Fig. 17).

The advantages offered by the boring-ram in comparison with other machines, not to mention the advantages of hydraulic transmission of force in general (page 7), consist chiefly in an efficiency surpassing much the efficiency attainable with pneumatic boring-machines, and, in connexion with it, a greater boring-effect.

The hitherto used boring-machines give not more than 3—5 strokes per second and don't bore any more in hard ground (e. g. granitic gneiss) than 150 cm^3 per minute. Any considerable increase of the effect seems to be excluded in practice, because an increase of the dimensions (width of cylinder and length of stroke) would involve disproportional increase of the machine, and the use of higher air-pressures (above 6 *atm*), is prevented by a substantial decrease of the efficiency.

With our instrument, on the contrary, the normal number of strokes is 10—20 per second, and (as I have shown) the effect of every blow can be increased enormously by adjustment of valve and length of striking-tube.

The high pressure arising from the water shock (about 200 *atm*). allows the application of small piston cross-sections and diminishes the dimensions and the weight of the machine.

The smallness of the stroke, too, is advantageous in working. For the lateral wear of the edges is proportional to the length of way made. Here this way is very small in comparison with the work done. Therefore it is possible to use tallies of more strokes, changing of borers will be less often needed, less time will be spent on the replacing.

If we chose a straight form for the striking-column, and direct so as to coincide nearly with the direction of movement of the borer, the machine will undergo scarcely any reaction, since the force of the shock is transmitted immediately from the column of water to the striking-piston, the apparatus serving only a a casing and guide for both masses. This particularity of the boring-ram, together with its small weight, facilitates its fastening and allows the use of light propping columns. It seems possible even to work with advantage the smaller types of thiss boring-machine without special fixing.

Mathematical Appendix.

1) The two chief factors of the effect: number and length of strokes restrict one another mutually. But as the force of the blow is proportional to the length of stroke, the number of strokes being inversely proportional only to the square root of the length, there results a higher total effect for a greater length of stroke. (See my paper „On length of the stroke", Österr. Zeitschr. f. Berg. und Hüttenwesen. 1895, Nr. 48). In Canadian borings the boring-weight amounts at the utmost to 900 *kgs.*, the length of the stroke to 60 *cm.*, the number of strokes to 50 per minute; in borings with stiff poles: boring-weight 1500 *kgs.*, length of stroke 15 *cm*, number of strokes 120 per minute. If taking into account the buoyancy of the boring-weight and other resistances against the free fall, we get in both cases little more than 5 *HP* as realisable total work at the bottom.

2) Imagine the column of water divided into an infinite number of elements of mass, denoting by

λ the distance of two elementar cross sections
μ the mass of one element
Q the cross-section of the column in cm^2
M_1 the mass of the current meter

Then we have (supposing approximately $g = 10$):

1) $$M_1 = 0{\cdot}01\ Q$$

and

2) $$\mu = 0{\cdot}01\ Q\ \lambda$$

Besides, let us denote by

c the velocity of the striking-column
A the pressure arising from the shock, in atm.
Δl respectively $\Delta\lambda$ the elongation of the primary lengths l and λ corresponding to this stress
ε the kinetic energy of an element in the moment of the shock
a the work wanted for diminishing, contrary to the elastic force, the primary distance of two neighbouring cross-sections by $\Delta\lambda$.

If the elastic column strikes suddenly in its motion against a fixed obstacle, the foremost element will be stopped when its own kinetic energy ε is spent on the elastic resistance. From this moment it is a fixed obstacle for the next element, this for the next one, and so on. Thus the compression propagates itself on more and more distant elements, while the first ones remain compressed.

The value of the compression can be found easily by considering that α and ε are equivalents.

$$3) \qquad \varepsilon = \frac{1}{2} \mu c^2 = 0{\cdot}005 \; Q \lambda c^2$$

and

$$4) \qquad \alpha = \frac{1}{2} Q \; A . \Delta\lambda = 0.000024 \; Q \lambda A^2$$

By equalizing $\varepsilon = \alpha$ we get

$$\text{I)} \qquad A = 14{\cdot}43 \; c$$

If the obstacle is receding with the velocity v, the relative velocity $c - v$ only will originate pressure

$$\text{II)} \qquad A = 14{\cdot}43 \; (c - v)$$

The velocity of propagation of the elastic wave through the column of water results from the following consideration:

Consider an element which at first had the distance l from the colliding end. It will move with unchanged velocity c till it is reached by the wave of compression. The time t wanted for the wave, propagating itself with the velocity V, for reaching this point, is

$$5) \qquad t = \frac{l}{V}$$

But in the same time the element has wandered through the way Δl with the velocity c

$$6) \qquad t = \frac{\Delta l}{c}$$

By equalising 5) and 6) and considering

$$7) \qquad \frac{\Delta l}{l} = 0{\cdot}00048 \; A$$

we get

$$V = 1443 \; m/sec$$

[3] Let us denote by

m the mass of the chisel and stem,

v_0 the initial velocity of this mass, immediately before the collision (in m/sec),

v the (variable) velocity of the mass in consecutive phases of the collision (in m/sec),

y the (variable) distance (way) of the mass from the point where the first collision took place (in m),

t the time passed since the beginning of the collision (in sec),

Q the cross-section of the column of water and of the piston (in cm^2).

The downward acceleration of the mass under the (variable) pressure A of the hydraulic shock, exercised on the piston, will be:

$$8)\qquad \frac{dv}{dt} = \frac{AQ}{m} = 14{\cdot}43\,\frac{Q}{m}\,(c-v)$$

whence, by integration:

$$9)\qquad v = c - (c - v_0)\,.\,e^{-14{\cdot}43\,\frac{Q}{m}\,t}$$

Now, since

$$10)\qquad v = \frac{dy}{dt}$$

we get by a second integration y as a function of t; thus results the equation defining the motion of the mass:

$$11)\quad y = ct - 0{\cdot}0693\,\frac{m}{Q}\,(c - v_0)\left(1 - e^{-14{\cdot}43\,\frac{Q}{m}\,t}\right)$$

4) Let us denote by:

p the surface of the valve plate (in cm^2)
o its circumference (in cm)
x_0 the normal distance of the valve-plate from its seat (distance with unloaded valve-spring) (in cm)
x the variable value of this distance, with gradually compressed spring
a the (variable) excess of pressure reigning above the valve (in atm)
y the pressure of the water on the valve-plate (in kg)
z the resistance of the spring reacting against the water pressure (in kg)
w the (variable) quantity of water flowing through in the given moment (in l/sec)
u the (variable) velocity of the water in the narrowest valve-cross-section (in m/sec)

The cross-section of the water-way narrowed by the valve is (in cm^2)

$$12)\qquad q = o\,x$$

The velocity of streaming at this „rapid“ is

$$13)\qquad u = 10\,\frac{w}{ox}$$

For imparting this velocity to the water there is needed an excess of downward pressure, which amounts, according to well known laws of hydrodynamics, to:

$$14)\qquad a = \frac{1}{10}\frac{u^2}{2g} = \frac{1}{2}\frac{w^2}{o^2}\frac{1}{x^2}$$

(The insignificant velocity of the water above the narrow cross-section is neglected, for simplicity's sake).

To the excess of pressure a there corresponds a force acting on the valve-plate

$$15)\qquad y = \frac{1}{2}\frac{p}{o^2}\, w^2\, \frac{1}{x^2}$$

This equation defines the relation between the respective distance of the valve-plate and the corresponding pressures of the water on it. It is represented graphically (Fig. 7) as a set of similar curves M_{10}, M_{15}, M_{20} a. s. o. for the different values of the parameter (w = *10 l/sec, 15 l/sec, 20 l/sec* a. s. o.).

Against the hydraulic pressure there opposes the valve-spring, the resistance of which z, being proportional to the displacement, appears as an inclined straight line on the diagram. In the initial position of the valve-plate ($x = x_0$) the spring does not exercise any pressure. Its resistance z increases in proportion to its compression to smaller values of x; the constant ratio, between resistance and displacement

$$16)\qquad \frac{z}{x - x_0} = tg\ a$$

indicates the strength of the spring.

Hydraulic pressure and spring are in equilibrium, if

$$17)\qquad z = y$$

which takes place in the points of intersection between the curve M and the straight line N. The equilibrium is stable or unstable, according to: an approximation of the valve-plate to its seat causing greater increase of the hydraulic pressure or of the resistance of the spring, in other words: corresponding to a greater inclination of the curve M or the straight line N in the point of intersection. In the first case (point A, $x = x_1$) the equilibrium is stable, the valve-plate keeps its distance x_1 from its seat, in midst of the streaming water. In the second case (point C, $x = x_3$) the water-pressure increases so quickly as to get the superiority in the case of the least transgression of the position $x = x_3$, and as to shut suddenly the valve-plate.

The point of contact B forms the transition from the first to the second kind of equilibrium. The abscissa x_2 of this point is equal for all curves M, as can be proved by equation 15); it has the value

$$x_2 = {}^2/_3\, x_0$$

For if we put

$$\frac{dy}{dx} = -tg\ \alpha \tag{18)}$$

the coordinates of the point of contact will be

$$x_2 = \sqrt[3]{\frac{p}{o^2} w^2 \frac{1}{tg\alpha}} \tag{19)}$$

$$y_2 = \frac{1}{2}\ tg\alpha\ x_2 \tag{20)}$$

The tangent drawn through this point under the angle α intersects the axis of abscissae in the distance

$$x_0 = x_2 + \frac{y_2}{tg\alpha} \tag{21)}$$

whence follows:

$$x_2 = {}^2/_3\ x_0 \tag{22)}$$

5) The kinetic energy of the shock is determined by the velocity c_2 which the column of water had, immediately before the shutting of the valve. This velocity results from the quantity of water w_2, corresponding to the curve M being just touched by the straight line N

$$c_2 = 10 \frac{w_2}{Q} \tag{23)}$$

In the given case (Fig. 7) we have, for instance: $w_2 = 25$ *l/sec.*

When the normal distance x_0 is given, the cross-section of the water way, ($q_2 = {}^2/_3\ o\ x_0$) just before the shutting of the valve, as well as the corresponding strain of the spring, ($d_2 = {}^1/_3\ x_0$) are always equal and independent of the strength of the spring. A stronger spring will need a greater excess of hydraulic pressure for the same strain, though, and this will imply a velocity of water increased in proportion to the square-root of the pressure. Thus the kinetic energy of the blow will be proportional to the strength of the spring.

With a certain spring, on the contrary, the normal distance affects the force of the blow in proportion to its third power. For with increasing x_0 the crosssection as well as the velocity of water is increasing, (this last one in quadratic proportion); therefore the quantity of water w_2 will increase in proportion of the $1^1/_2$ power, the kinetic energy in proportion of the cube of x_0.

6) The most convenient length of the striking-tube can be determined in a graphical way by the diagram of work (Fig. 6 III). The abscissae, representing the time of duration of the shock, are proportional to the length of the tube and also to the energy contained in the column of water, while the ordinates determine the work transmitted to the chisel. Thus the ratio of the ordinate to the absciss is an indication how much of the kinetic energy of the water has been used for doing work. The greater

the value of this ratio, the better. Circumstances are most favourable in the point K, where the tangent drawn through O is touching the curve. In this moment the hydraulic shock should end Accurate construction and measurement show the most favourable conditions for transmission of work to be realised if the mass of the water is equal to the mass of the chisel.

7) This results from the following consideration:
If Q_1 is a-times greater than Q, the pressure of the hydraulic shock, acting in every moment on the piston, and the acceleration of the mass too, is a-times greater. But as the movement of a greater piston corresponds to an a-times greater movement of water in the striking-tube, there results such a course of the hydraulic-shock as if Q were equal to Q_1 but the mass of the chisel a^2-times smaller.

8) With higher degree of exactitude:

$$\frac{E_2}{E} = 1 - \frac{A_2}{A} \frac{1}{\text{lognat}\,\frac{A}{A-A_2}}$$

VII

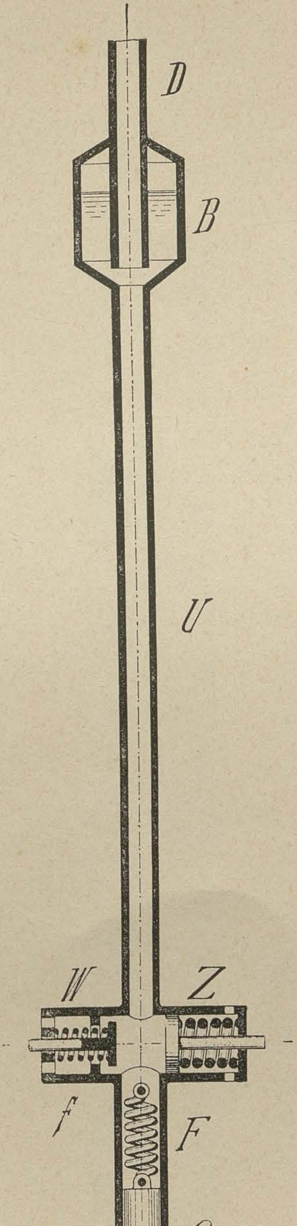


Fig. 1.

IX

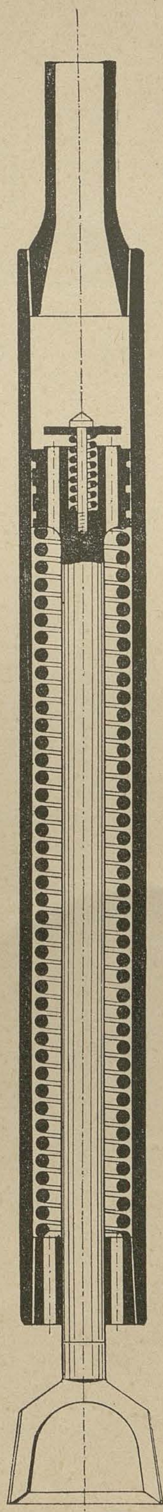


Fig. 2.

XI

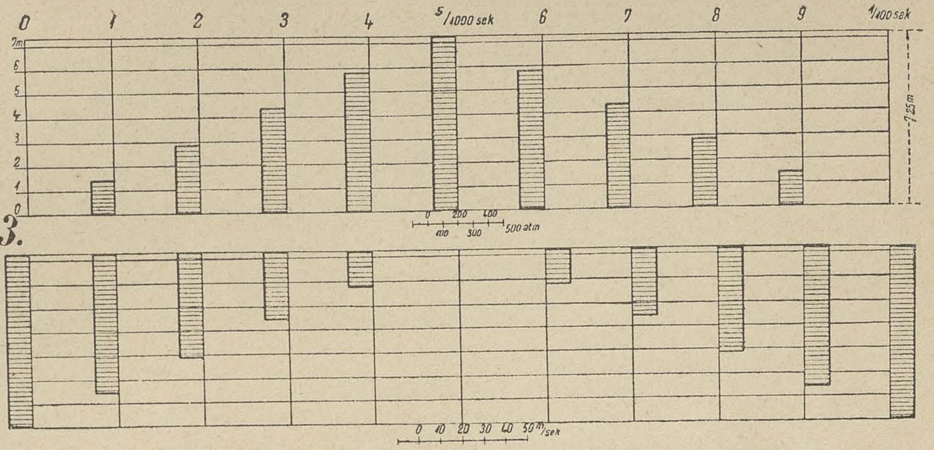


Fig. 3.

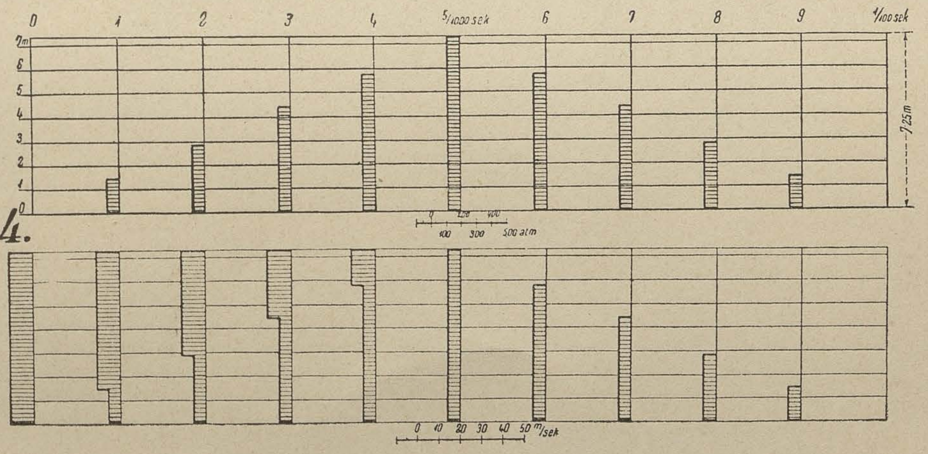


Fig. 4.

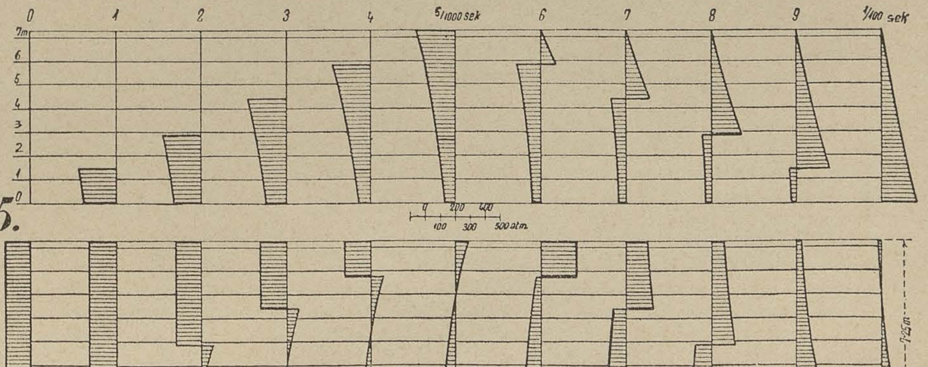
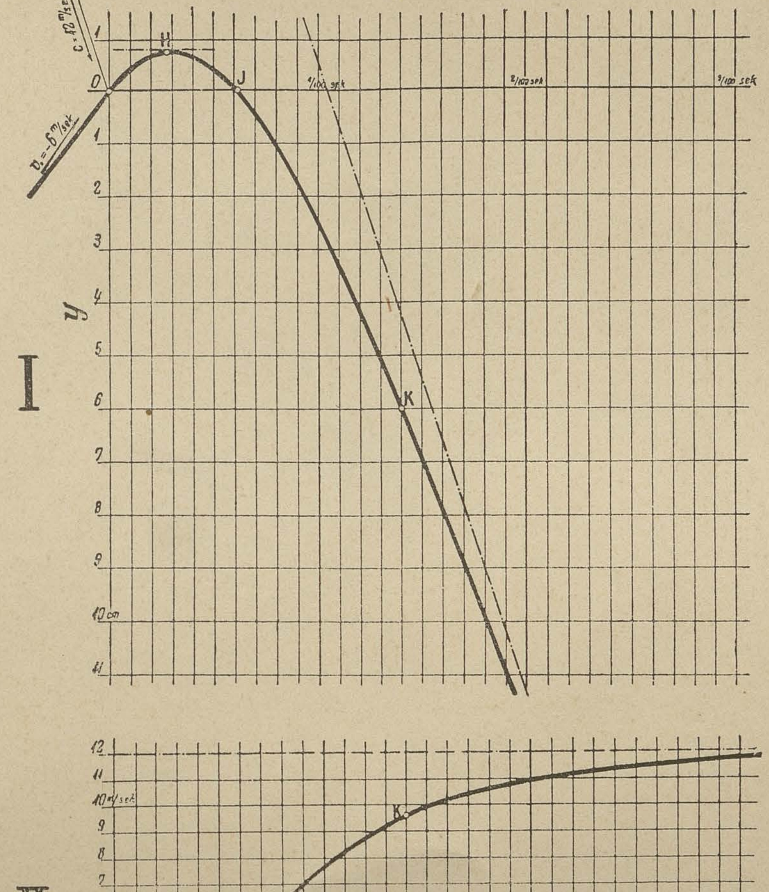


Fig. 5.

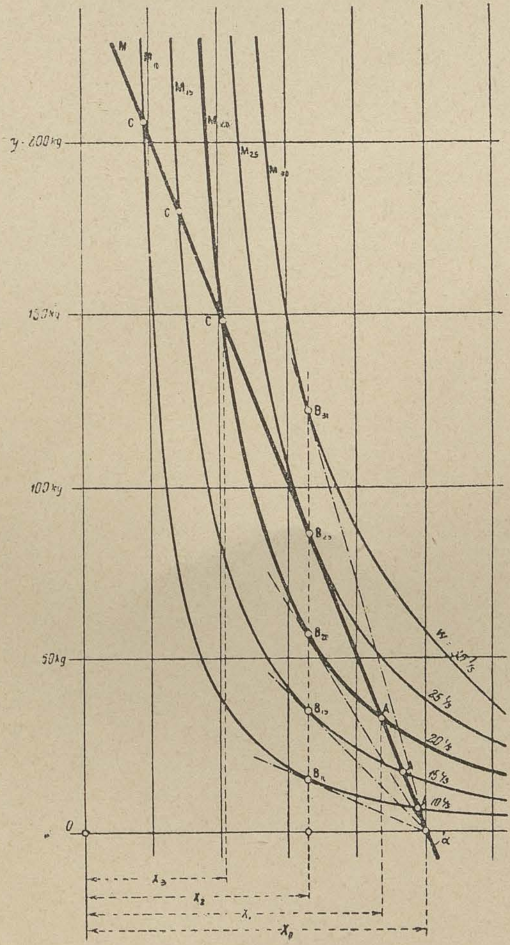
XIII

Fig. 6.


I
$c = 12\ ^m/_{sek}$
$v_0 = -6\ ^m/_{sek}$
H
0
J
K
1/100 sek
2/100 sek
3/100 sek
y
1
0
1
2
3
4
5
6
7
8
9
10 cm
11
II
v =
12
11
10 m/sek
9
8
7
6
5
4
3
2
1
0
H
W
K
1/100 sek
2/100 sek
3/100 sek
III
E =
70
60
50 mkg
40
30
20
10
0
Q
H
W
K
1/100 sek
2/100 sek
3/100 sek

XV

Fig. 7.


M
M10
M15
M20
M25
M30
C
C
C
y · 200 kg
150 kg
100 kg
50 kg
0
B31
B25
B21
B15
B11
A
α
W = 30 m/s
25 m/s
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10 m/s
X3
X2
X1
X0

XVI

XVII

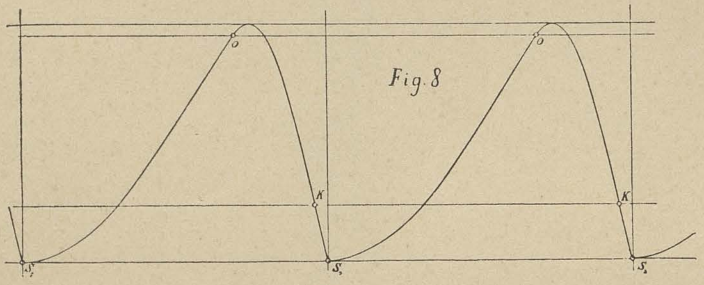

Fig. 8

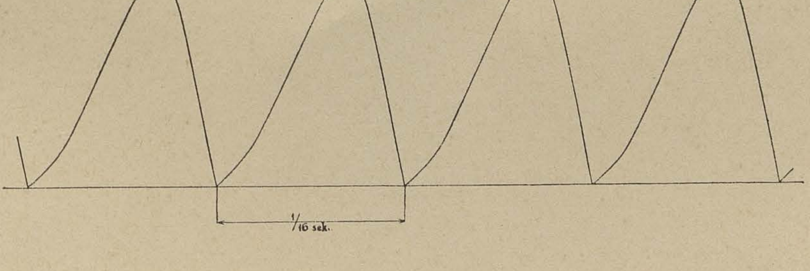

Fig. 9

XIX

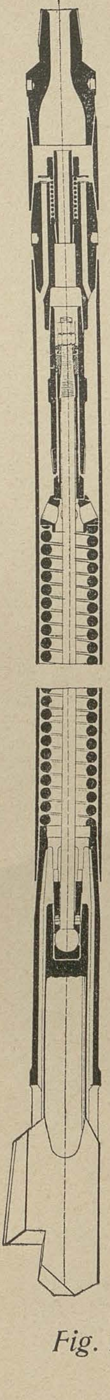

Fig. 10.

XX

XXI

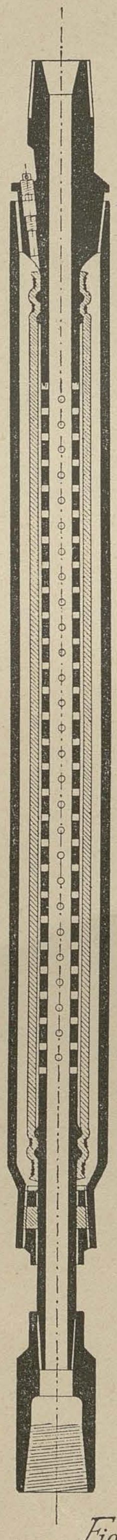

Fig. 11.

XXII

XXIII

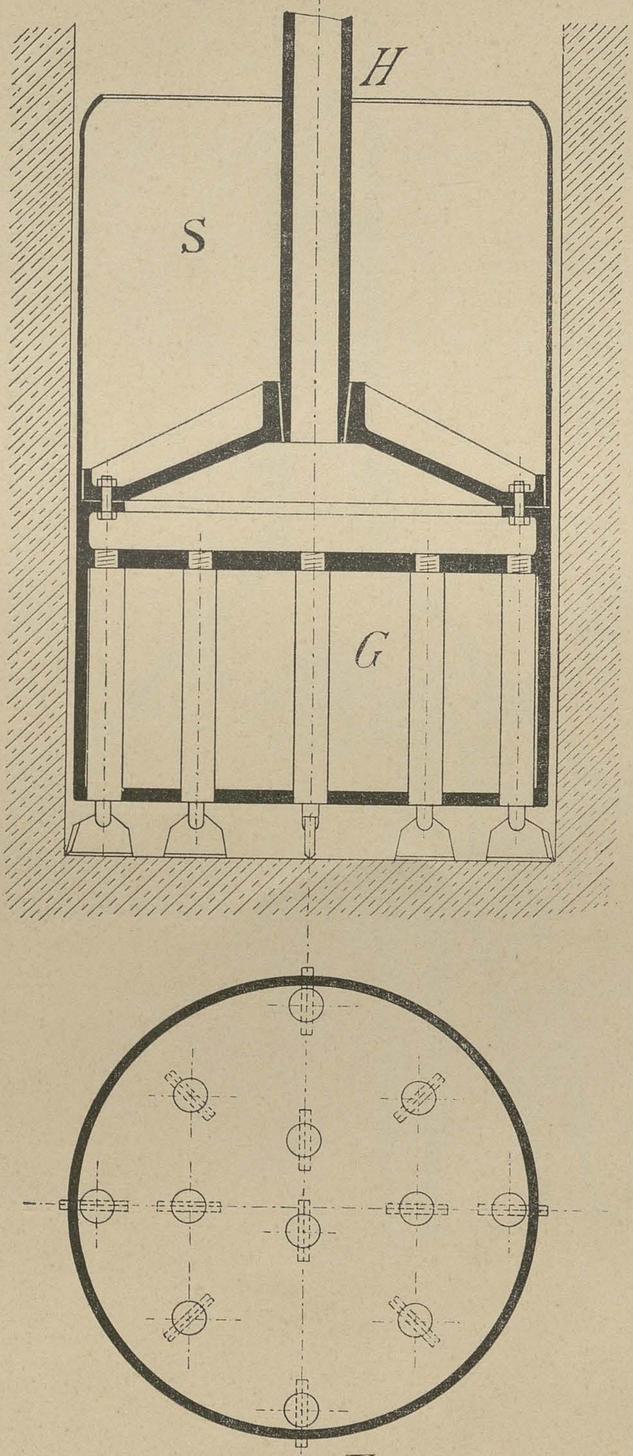

Fig. 12.

XXIV

XXV

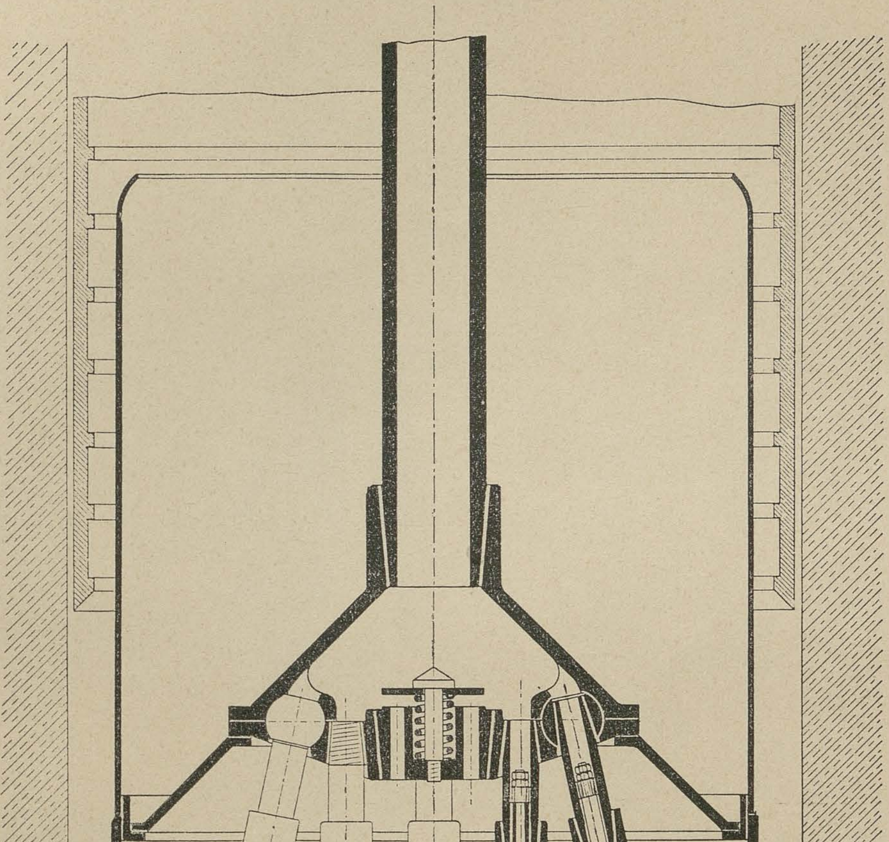

Fig. 13.

XXVI

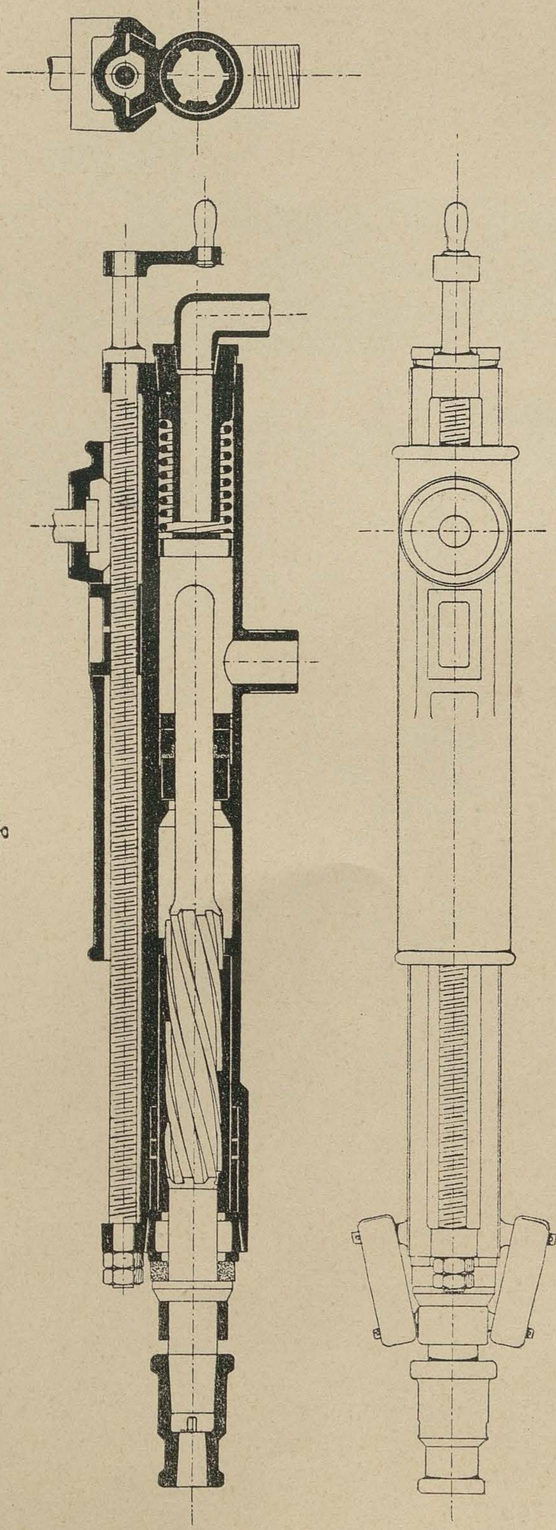

Fig. 14.

XXVIII

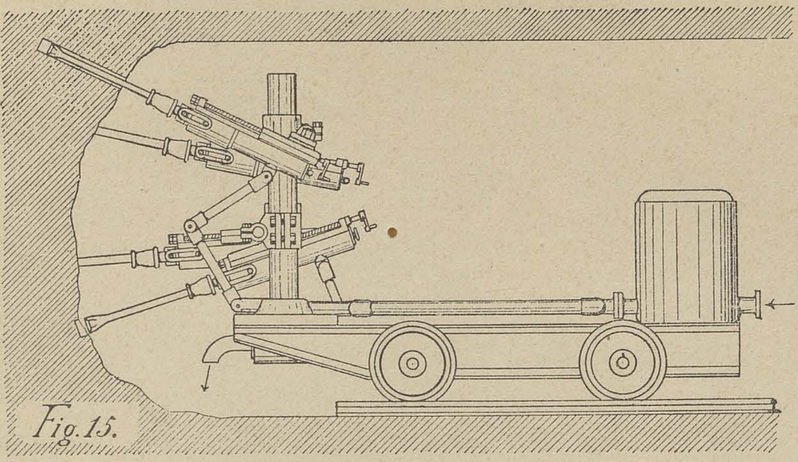

Fig. 15.

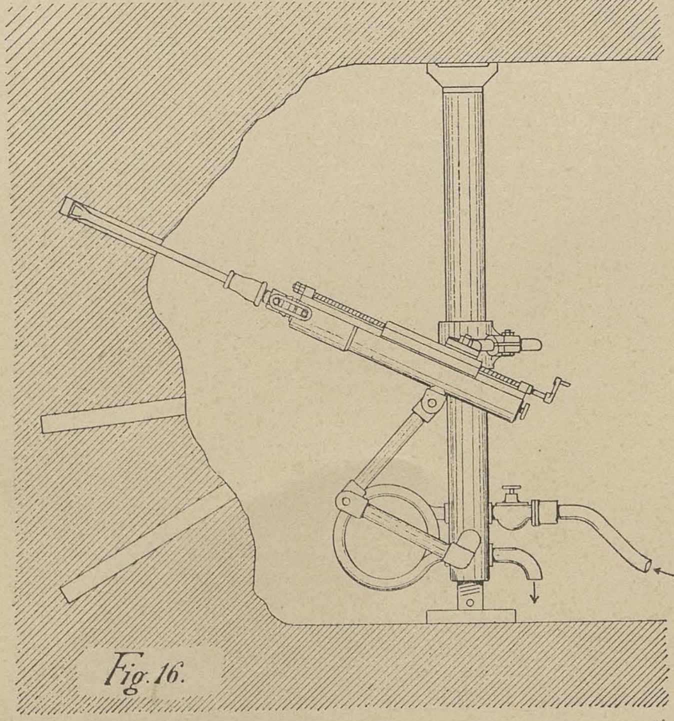

Fig. 16.

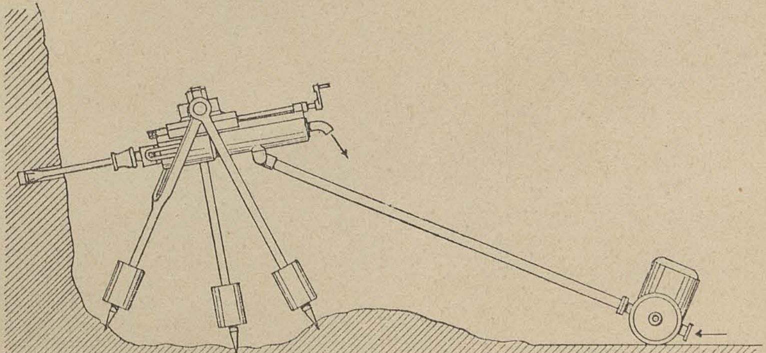

Fig. 17.

XXX

XXXI

XXXII