

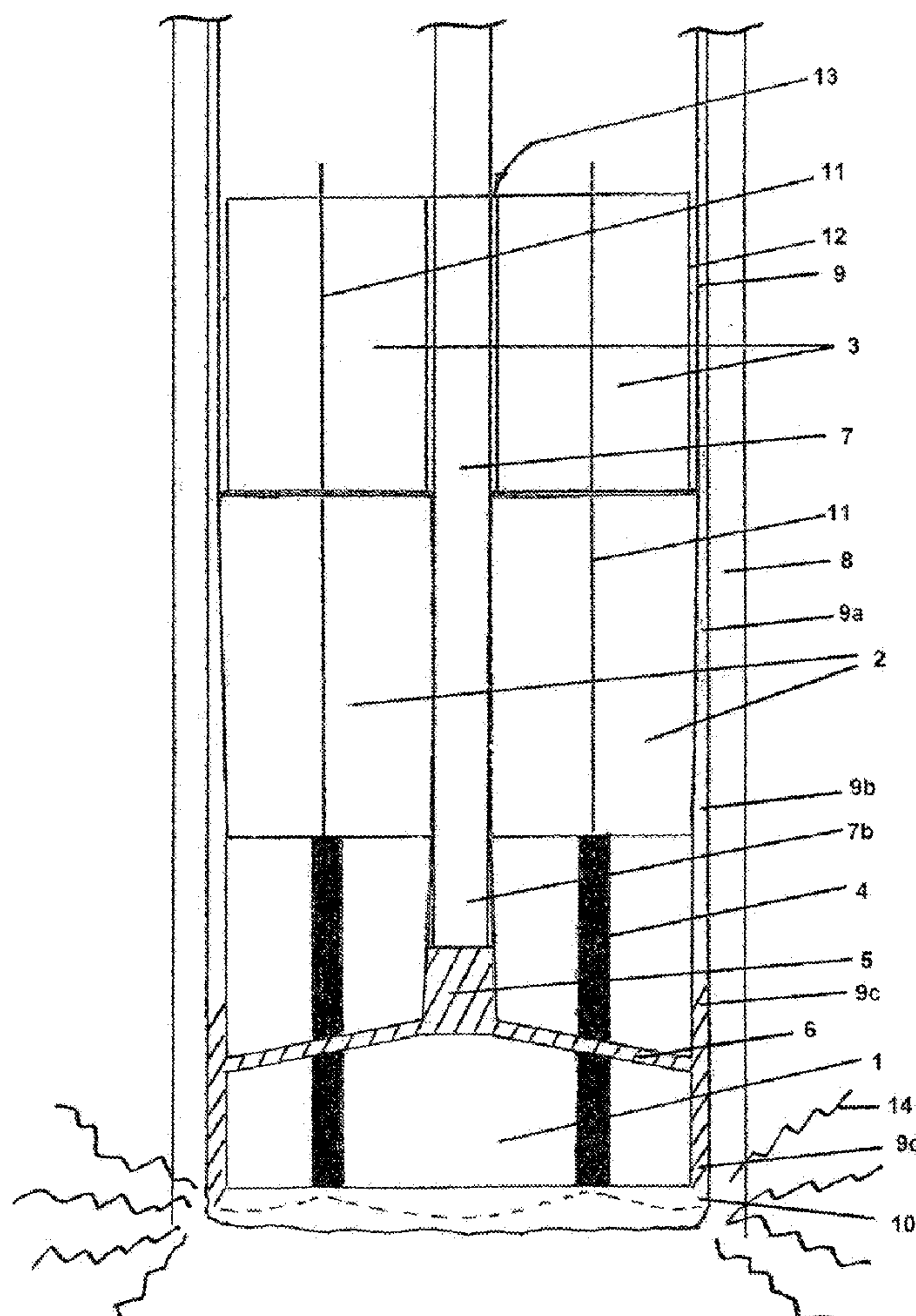
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(19) **United States**(12) **Patent Application Publication**
Foppe(10) **Pub. No.: US 2011/0220409 A1**(43) **Pub. Date: Sep. 15, 2011**(54) **METHOD AND DEVICE FOR FUSION
DRILLING**(76) Inventor: **Werner Foppe**, Geilenkirchen (DE)(21) Appl. No.: **13/122,500**(22) PCT Filed: **Sep. 29, 2009**(86) PCT No.: **PCT/EP09/06990**§ 371 (c)(1),
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E21B 7/15 (2006.01)(52) **U.S. Cl.** 175/16(57) **ABSTRACT**

The invention relates to a method for fusion drilling and to a fusion drilling device for producing dimensionally accurate bores, manholes rock and tunnels in the ground, particularly in rock. A drill hole bottom is molten by a melt and the overburden melt is pressed into the surroundings, particularly the surrounding rock which has cracked open under the effects of the temperature and pressure, and wherein during drilling, a drill hole lagging (9) is produced around piping formed by line elements (1, 2, 3). In a recess (5) of at least one lower line element (1) of the piping, said recess being particularly centric and open towards the top, metal (7) in a solid state of aggregation is fed from the top thereof, particularly through line elements (2, 3) arranged on the top thereof. The metal is molten in said recess (5) by feeding energy and is conducted through channels (6) extending from the recess (5) toward the outside and ending in the lateral surface of a line element (1) into the outer surroundings of the line element (1). A rock melt formed beneath the lowest line element (1) is pressed into the surrounding rock (14) and forms a metal lagging (9) surrounding the piping (1, 2, 3) by solidifying.



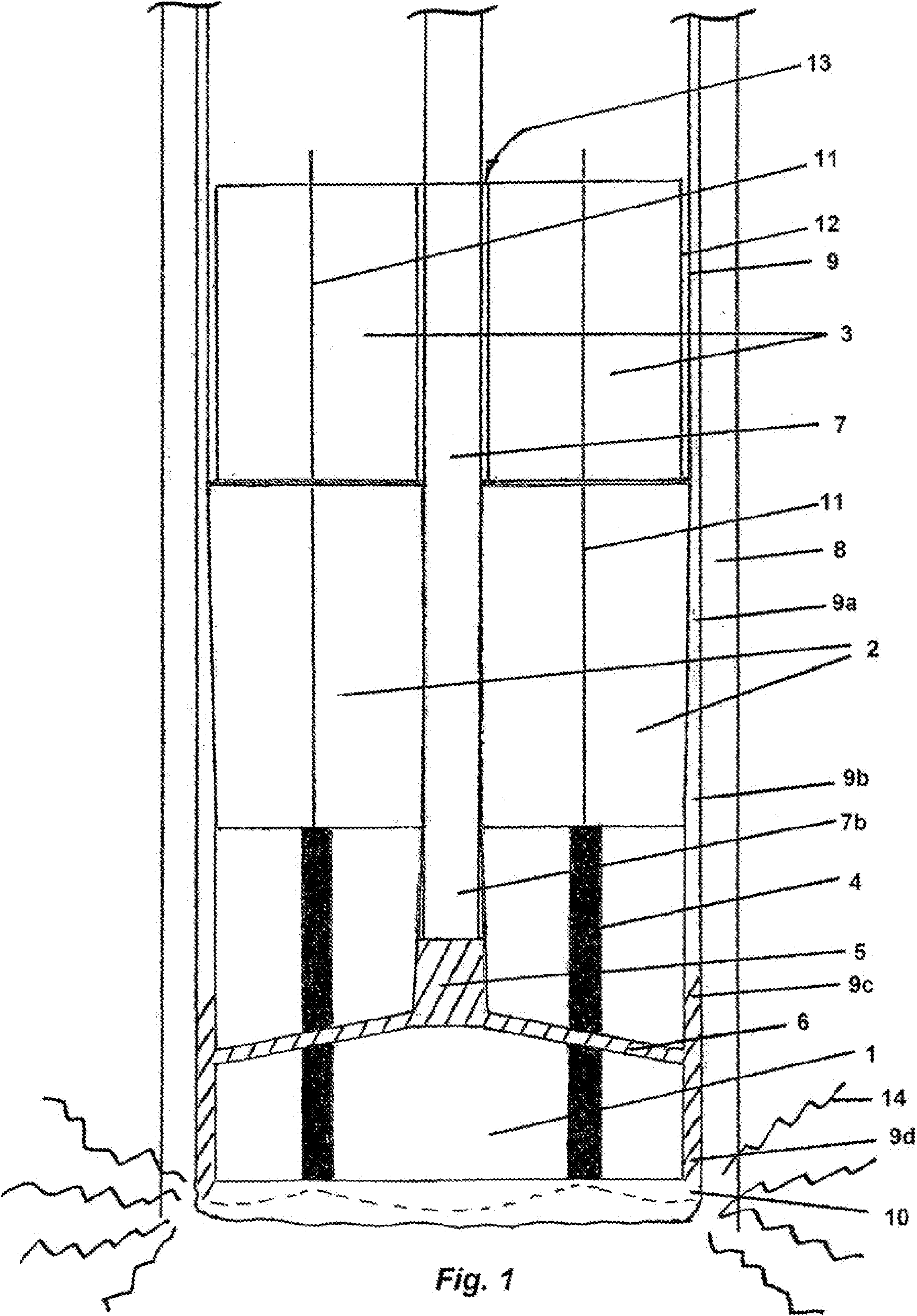


Fig. 1

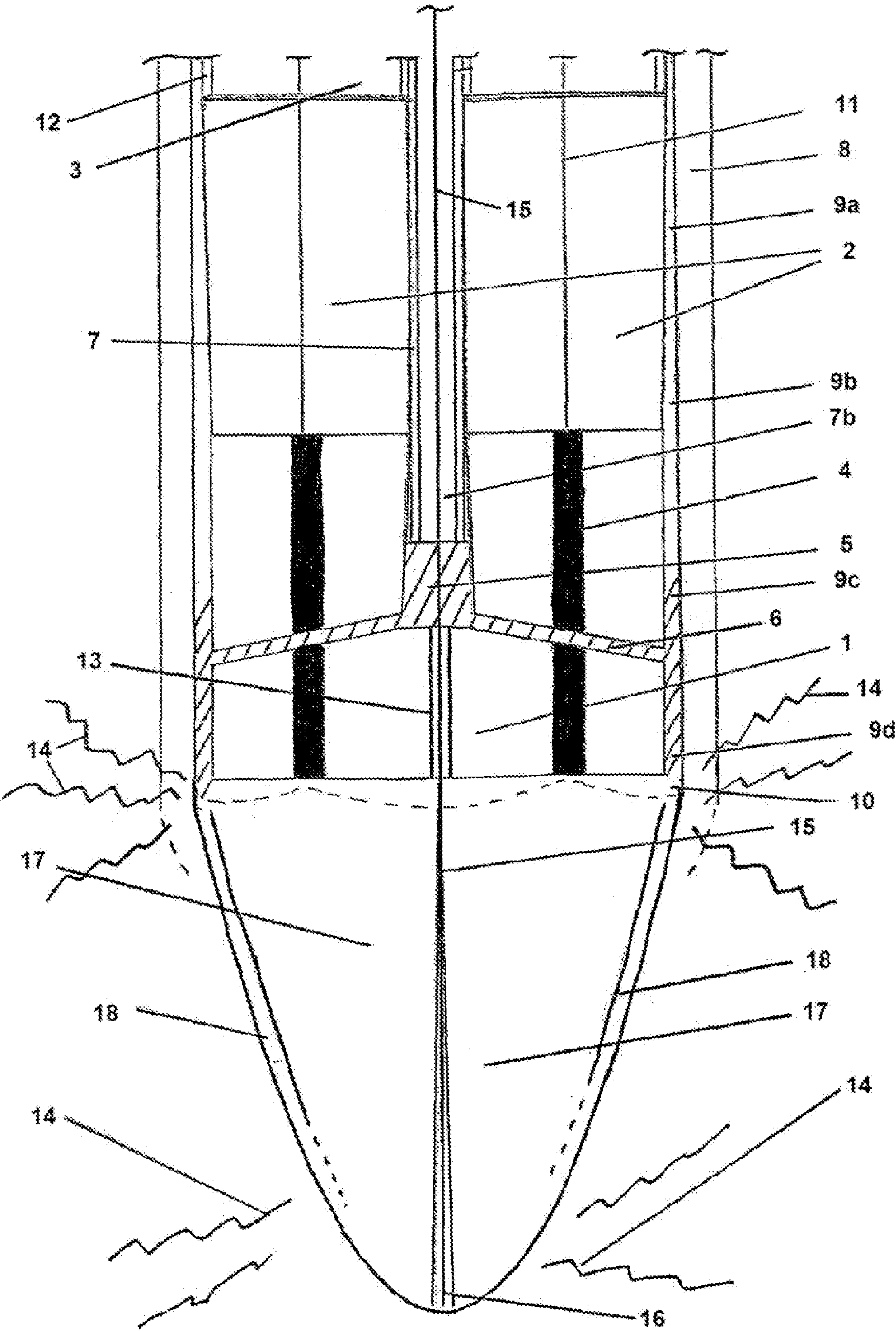


Fig. 2

METHOD AND DEVICE FOR FUSION DRILLING

[0001] The present invention relates to a method of and an apparatus for producing dimensionally accurate boreholes, manholes and tunnels in any kind of ground, for example rock, where a drill-hole floor is melted by a molten mass and the molten material of the floor is pressed into a region surrounding the drill hole, in particular the surrounding rock that has been cracked open by temperature and pressure, and where during drilling a drill-hole casing is formed by the solidifying molten mass around a well string formed by line elements.

[0002] Drilling methods for producing dimensionally accurate boreholes, manholes and tunnels where drilling is effected by a molten metal bath are known, for example from EP 1 157 187 [U.S. Pat. No. 6,591,210]. This document discloses how by means of molten metal as drilling medium, the rock of the ground is melted, how under the pressure of a graphite cylinder drilling apparatus, the molten rock is pressed as the result of lithofracking into the region surrounding the drill hole and how at the same time in a continuous fusion-drilling process, a metal drill-hole casing made of molten metal as drilling medium is cast around the graphite cylinders. The drilling apparatus is formed by a string of graphite cylinders extending from the surface to the drill target, the tubular graphite cylinders, the molten metal generated on the surface is conveyed from the surface down to the drill-hole floor.

[0003] This known fusion-drilling apparatus is in particular composed of standardized high temperature- and pressure-resistant carbon or tubular graphite cylinders that, in the lower fusion-drilling zone, can be provided with electromagnetic or magnetohydrodynamic devices such as magnetic flanges, magnetic valves, magnetic pumps and holding magnets and can be equipped for the lift operation with magnetic devices for electromagnetic raising, lifting or pressurization.

[0004] According to this molten-metal drilling method it is known that the rock to be melted is melted by an electrically superheated molten metal as drilling medium. The metal is melted in a melting plant on the surface and fed via the drilling string formed of tubular graphite cylinders into the fusion-drilling zone. In this manner, most of the melting energy is generated on the surface in a melting plant so that only the amount of energy is to be fed in which is necessary and provided for superheating the molten metal by magnetic pumps or inductors as well as for holding magnets and magnetic valves that are to be used for generating and controlling the molten metal pressure.

[0005] The resulting reduced current flow into the melt zone by introducing the molten metal directly from the surface is partially offset again by the above-described power consumption of handling the molten metal so that the disadvantages of the electromagnetic and magnetohydrodynamic devices and their risk of technical failure can be greater than the advantages.

[0006] Also, it is considered to be costly to produce the molten metal in large quantities on the surface and to fill it or refill it into the installation and to keep it liquid over the entire length of the drill hole.

[0007] According to the latest state of the art, a vertical MagLev elevator (TOSHIBA) is known that, as a vertically operating high-speed elevator, does not need cables or safety

ropes and, for example by using Halbach magnets and high-performance permanent magnets, works according to the lift principle and is operated with a long stator motor. MagLev stands for “magnetic levitation” and is an abbreviation that is established among experts.

[0008] Also known are cableless and contactless superconducting magnets (IFW-Dresden), whose superconductivity is ensured by replaceable or refillable liquid nitrogen containers and provides high lift forces.

[0009] Furthermore, laser drilling is known (US-Gas Technology Institute) by means of which it was possible in trial drillings to drill ten times faster than with the rotary drilling technique and that corresponds to the fusion-drilling results of the hydrogen/oxygen fusion-drilling method of DE 2554101. However, up to now, no suitable drilling method for continuous or discontinuous drilling progress could be developed.

[0010] It is the object of the invention to improve the generic molten metal drilling method and apparatus and in particular to simplify the energy input needed for the melting process.

[0011] Furthermore, it is the object of the invention to provide a method and apparatus based on simple functional principles in which complicated and failure-prone devices such as holding magnets, magnetic flanges or magnetic valves and magnetic pumps as well as the power supply and control thereof can largely be eliminated and a metal casing of high and continuous casting quality with excellent behavior properties is ensured.

[0012] This object is solved according to the invention in that metal in a solid state is fed from above into a central and upwardly open chamber of at least one lower line element of the well string, in particular through line elements thereabove, the solid metal is melted in the chamber by fed-in energy into molten metal that is conducted through passages extending outward from the chamber and ending at the outer surface of the line element into the outer surroundings of the line element, and molten rock thus formed below the lowermost line element is pressed into the surrounding rock and a metal casing is formed surrounding the well string on solidification.

[0013] For optimizing the metal casing of the drill hole and for increasing the service life, the part of the pressure drill head below the opening of the passages for supplying the molten metal can be expanded in diameter at least by the metal wall thickness to be produced, which needs to be considered accordingly when preparing the pilot bore or “starter tunnel” and the steel pipe casing around it.

[0014] It is therefore the essential central idea of the invention to shift the production of the molten metal to the vicinity of the drill-hole floor and therefore to feed the molten metal no longer from the surface and over the entire length of the drill hole, but to generate the molten metal “on site” by melting solid metal and to utilize the molten metal and at least one line element having passages, which can be dedicated as “feeder”, for the direct build-up of the metal casing before the molten metal reaches the melt zone at the drill-hole floor. To this end, the mentioned line elements according to the invention are provided in which, among other processes described below, the melting process by energy input takes place.

[0015] In order to start the fusion-drilling process according to the invention in one embodiment, for example in a known manner, a pilot bore is made having a drill-hole floor that, for example is left open a few meters, in which pilot bore

a metal pipe is inserted as an initial drill-hole casing. Into this metal-pipe-lined drill hole (starter tunnel), at least one of the above-described line elements (feeder) having the passages and subsequently at least one line element for shaping (pulling element) the drill-hole casing formed by the solidified molten metal are driven.

[0016] It can be provided here that upstream of the line element having the passages, further line elements are inserted, in particular those that are consumed during fusion drilling due to wear, or a length for the line element having the passages is selected in such a manner that the expected wear below the passage openings is taken into account.

[0017] Subsequently, in the lower line element at the drill-hole floor or, in one embodiment, optionally, in the lowermost line element, a liquid melt can already be filled in, or the melting process in this line element is started by melting solid material. It is preferred here to use a magnetizable metal, in particular of good magnetic remanence such as iron or cobalt or nickel or alloys of the same, at least if in further possible embodiments, magnetic properties are of importance.

[0018] Then, under inherent pressure and/or gravitational force, the molten metal exiting through the passages of the line element comprising the passages fills the free space between the drill-hole floor and the drill-hole wall and bonds with the inserted metal pipe of the pilot bore to form a metal casing that builds up as the drilling progress advances. The molten metal that gets through the passages into the surrounding shell region of the line element flows downward in them and reaches the drill-hole floor where upon contact and by melting the rock, the actual fusion drilling is initiated and is maintained by further addition of energy.

[0019] Feeding energy to the molten rock and/or molten metal generated during fusion drilling can be carried out in one possible embodiment for example by an electric current that is conducted through lines from the surface to the lowermost line element and/or the one having the passages and to the melt zone, or is generated via at least one high-temperature reactor that is integrated in at least one of the lower line elements, in particular in or above the pulling elements, or, in another embodiment, can also be carried out by laser radiation that is directed from the surface centrally through all the line elements down to the drill-hole floor.

[0020] During melting, the molten rock is displaced into the region surrounding the drill hole that, below a certain depth, takes place by the weight force of the entire installation consisting of a plurality of line elements and, at the beginning of the drilling, can be supported for example hydraulically or electromagnetically. During melting of the drill hole floor, the lowermost and the adjacent line elements automatically sink downward by displacing the molten rock into the surroundings so that further line elements or different design can be continuously fed from the surface thereby forming a well string from a plurality of line elements, optionally with different functions.

[0021] Here, the individual line elements can be interconnected or can be connected when added to the string, in particular by means of a snap-on connection acting between in each case two line elements, in particular such a connection that can be released again, for example by a tensile force pulling the two line elements apart.

[0022] In contrast to the mentioned prior art, the molten metal of this invention fulfils the purpose of continuously producing a metal casing in the drill hole and no longer primarily the purpose of melting the drill-hole floor, but

serves specifically only as starting and displacing molten metal for the molten rock process that, after the starting phase, takes place by directly feeding an electric current therethrough and/or by laser light.

[0023] Exclusively at the beginning of the method, with no molten rock present yet, the molten metal serves also for first melting rock. However, subsequently the molten rock cushion is maintained by direct energy supply, for example of the above-described kind, and the continuously generated molten metal is used for producing the casing by guiding the molten metal via the passages first into the shell region immediately surrounding the line element (feeder) having the passages before it arrives in the fusion-drilling zone and preferably in such a manner that for building up the metal drill-hole casing, no mixing with molten rock can take place.

[0024] It can principally also be provided that the melt zone in which the solid metal is melted is in a line element different from the one with the passages through which the molten metal is conducted toward the outside. Preferably, melt zone and passages are combined in one line element.

[0025] In a preferred embodiment of the invention the solid metal is fed in a controlled manner into the melt zone, for example as a metal rod that, in particular, can be put together element by element, wherein it can further be provided that the unused part can be pulled out after reaching the drill target.

[0026] In case of laser heating, the continuous feed can be carried out through the line elements by a metal pipe (hollow string) through which the laser beam is guided from the surface to the drill-hole floor. The continuously supplied material thus surrounds the laser beam that melts the metal in the lower line elements and, at the same time, displaces in particular under high light pressure the molten metal via the passages that are in at least one of the lower line elements so as to form the metal casing. Here, a central bore through the lower line elements (graphite elements) can be kept free from molten metal by the laser beam.

[0027] If in case of the two embodiments, the metal is not fed from the surface as a continuous rod but in rod sections, the continuous feed can be done with a line element that receives and holds a metal rod segment and moves downward in the lined drill hole. In so doing, the line element abuts as further element on the last one and, in particular, connects with it or the line element is lifted off again. It can also be provided that a metal rod section is transferred from line element to line element until the one is reached in which the melting takes place.

[0028] Specifically to allow the continuous feeding and/or sliding or moving of line elements in the well string according to the invention in a possible embodiment at least one line element is inserted that follows the one in which the melting takes place and by means of which the solidified metal casing can be given the desired shape.

[0029] The shaping can be, for example a deforming process and/or a surface finishing process. In order to be able to perform both types of shaping, such an element can be configured, for example as so-called pulling element that due to its outer shape generates the final form and surface quality of the metal casing when moving (pulling) through the solidified but still formable metal casing. For this purpose, the element can have, for example a shape that tapers conically downward with otherwise circular cross-section. Elliptical cross-sections can also be used. In particular, the basic shape of the pulling element is adapted to the basic shape of the line

elements arranged therebelow that likewise can be circularly or otherwise formed. It is precisely the advantage of the method according to the invention to be principally able to produce drill holes of any cross-sectional shape.

[0030] In a preferred embodiment of the invention, the fusion-drilling apparatus can have at least three types of line elements that divide a drilling string formed from the line elements into a hot part, a pulling and/or cooling part and a cold part. The line elements of the hot part can be formed as tubular graphite cylinders. At least the at least one lower, optionally lowermost element having the passages is a line element of this type. Upstream and downstream of such a line element, further elements of this type can be arranged.

[0031] The line elements of the pulling and/or a cooling part can be made of a particularly high-strength metal construction, and are between the hot and the cold part and used for shaping, in particular expanding and surface-finishing, the metal drill-hole casing. At least one line element of this type is provided. Here, the metal construction can enclose a core of graphite.

[0032] The line elements of the cold part can be made of a particularly pressure-resistant metal that is used in particular for pressure generation and/or for infeed control and energy devices as well as solid metal that is guided through the line elements to a line element at the drill-hole floor in which line element the solid metal is melted.

[0033] Accordingly, in this embodiment, the invention provides a method and an installation having three functional sections:

[0034] 1. The “hot part” consisting of tubular graphite cylinders,

[0035] 2. The “pulling and/or cooling part” serving for densification, dimensional accuracy and surface finishing of the metal casing, and

[0036] 3. The upper “cold part” that is responsible for the pressure generation, infeed of the metal rod or metal well string for molten metal supply or conveying it in the well bore.

[0037] In contrast to known fusion-drilling methods of the above-described kind, the elements, in particular hollow cylinder elements of the “cold part” and the pulling and/or cooling part of the drilling apparatus, consist of high-pressure resistant materials or high-temperature resistant metal alloys and not of pure carbon hollow cylinders. However, they may have a carbon core.

[0038] According to the invention, in one variant of use it is also possible to keep the length of the fusion-drilling apparatus, thus the entire well string, as short as possible because a continuous pipe from the surface down to the drill-hole floor is no longer required for the melt transport.

[0039] For the transport (assembly/disassembly) of the individual line elements to the already existing well string, an elevator system can be used.

[0040] Such an elevator system, if necessary, can be obtained by introducing elevator system elements in/on the metal-lined drill hole wall. Particularly preferred is an elevator system according to the MagLev technology where the line elements interact through magnetic interaction directly with the metallic drill-hole casing or with the elevator system elements retrofitted therein and drive downward at least in a controlled manner and preferably allow elevator operation in both vertical directions.

[0041] It is possible here to use an elevator in MagLev technology in an adapted form that is currently being tested by the company Toshiba and that uses the metal casing directly or indirectly as rail.

[0042] Accordingly, a line element can be used as MagLev elevator with high running speed so as to assemble and disassemble or feed the extension elements for the fusion-drilling apparatus and/or the metal rod or the metal well string to be fed in. Such a MagLev elevator does not necessarily have to form a line element but can form a principally independent element that is movable within the well bore.

[0043] Problems of the known fusion-drilling apparatus are also solved according to the invention in that most of the above-described electromagnetic or magnetohydrodynamic units can be eliminated and here, the molten metal loss occurring during the continuous build-up of the metal drill-hole casing is not put together and fed in directly as melt, but is put together and fed in via the hollow drill string in pieces, for example in the form of rod or pipe sections, preferably by an elevator system, for example MagLev elevator, so as to form a metal rod or metal well string (in the case of melting energy transmission by laser).

[0044] The metal fusion-drilling apparatus according to the invention can be built and operated, for example in different versions.

[0045] The line elements of the well string in the known version can form one unit from the drill hole start to the drill hole target, only the lower “hot part” consisting of carbon and ending with a pulling part made of carbide, and the specific shape of the pulling elements creating the shape of the metal drill-hole casing and thus the shape of the drill hole.

[0046] The “cold part” of the drill string serves in particular for generating the necessary pressure by means of its dead weight, for supplying and controlling the drilling progress speed and has to ensure that the pressure drill head does not touch the rock face. To ensure that a melt cushion is always maintained between the drill-hole floor and the pressure drill head, the “cold part” of the drill hole string is retained mechanically by hanging it on the hook or, according to the invention, by lift elements installed in the drill string modules or by self-advancing, synchronously clocked electromagnetic slide shoes on the drill-string modules.

[0047] It can be provided to carry out a synchronous stepping of the electromagnets, in particular with an optimal frequency that makes the drill string act like a vibratory pile driver and optimizes the drilling progress in the fusion-drilling zone and pulling region.

[0048] In one version, the line elements can be assembled and disassembled by an elevator, preferably with a MagLev elevator as feed conveyor, and required supply material can be transported by such an elevator if the length of the drill string does not fill the entire drill hole from the bottom to the top but is limited to a length at which the dead weight is sufficient for displacing the drill hole melt and generating pressure for the pulling elements.

[0049] In the simplest manner, the individual line elements of the “cold part” are inactive. The sliding properties with respect to the drill-hole casing or the fed in metal rod in the central bore of the line elements is provided by built-in carbon rings or other sliding elements made of graphite. Thus, contact of the line element with the outer metal casing or the inner metal rod takes place only via graphite elements having excellent sliding properties.

[0050] In another version, the individual line elements of the “cold part” as a whole act as a magnetic slide having spacing and holding functions with respect to the metal drill hole wall and the fed-in metal rod or metal well string by guiding the latter preferably in a contactless manner.

[0051] In yet another version, each line element, at least the ones of the “cold part”, can act as a MagLev elevator and can assemble and disassemble itself and/or can levitate, hold, press and lift as a whole drill string.

[0052] The metal rod or a metal well string, for example can also be fed in according to one of the last two versions in a contactless manner inside the drill-string elements or can be decelerated by induction loops or by an air cushion building up or, for example according to the mentioned simple version, can be continuously fed in a sliding manner under low friction by carbon rings or carbon spacers up the tubular graphite cylinder string of the hot part and, while doing this, can be melted on site, on the one hand, by heat transfer from the solidified but still glowing hot region of the drill-hole casing and also by targeted electrical heating or laser heating in the “melt zone” upstream of the passages of the lower line element.

[0053] According to the invention, in a vertical configuration, the total weight of the metal rod or metal well string acts on a relatively small string cross-section in relation to the length, thereby generating an enormous pressure in the molten metal to compress the superheated molten rock, the upwardly acting reaction pressure on the drilling apparatus cross-section being absorbed in the functional sections of the “hot part” and pulling and cooling parts by the weight of the drilling apparatus elements and their friction in the pressure sealed zone of solidifying molten metal in the outer region of the fusion-drilling apparatus or of the expanding and not completely melted metal rod in the hollow cylinder region of the elements, and the drilling apparatus can therefore be kept relatively short and does not have to extend to the surface for feeding in the molten metal.

[0054] Holding magnets for building up the metal drill-hole casing as required in the prior art are no longer required according to the invention by providing the mentioned passages, in particular preferably at least three transverse passages that are installed as “feeders” at the end of the “melt zone” in at least one of the lower line elements (at the drill-hole floor). The transverse passages serve as molten metal feeders and, at the beginning of the fusion-drilling process, fill the free spaces around the lower graphite cylinder elements completely with molten metal up to the drill-hole floor so as to build up the metal drill-hole casing.

[0055] In a preferred embodiment, when using a laser as melting energy source, the inner hollow space of the line elements having the transverse passages for feeding the molten metal into the surroundings narrows from the transverse passages downward, in particular to the size of the laser beam cross-section. The tapering results in a reduced cross-section that corresponds to the cross-section of the laser beam or is slightly larger so that the laser beam can exit downwardly in the direction of the drill-hole floor through the lower line element and optionally through line elements arranged therebelow that also have such a bore. The rock fusion-drilling method using direct heating by an electric current does not have this central bore. In this embodiment, the line element having the passages and optionally further line elements arranged therebelow are closed at the bottom and the molten metal can exit only through the transverse passages.

[0056] Preferably, the molten metal is fed at optimal pressure casting temperature via the transverse passages to the line element at the drill-hole floor for building up the metal drill-hole casing and is protected against direct radiation of the hotter molten rock in the fusion-drilling zone by the “melt cushion” around the lower graphite cylinder “drill head”, i.e. by the lowermost line element made of graphite.

[0057] Thus, according to the invention, the solidification time is reduced and therefore also the length of the “hot part” of the drill string.

[0058] In a possible embodiment the lowermost line element, in particular the one that forms the actual “drill head”, tapers upward, for example conically. This shape causes an automatic downward force on this line element due to the pressure that is exerted on this element by the region surrounding the drill hole. A shaping line element, in particular a so-called pulling element, arranged above the line element, can change a metal casing that has adapted to the shape of such a lowermost line element for example in such a manner that the metal casing has a constant cross-section axially.

[0059] It is a further object of the invention to make magnet pumps (magnetic flanges) for re-superheating the molten metal in the melt zone unnecessary. In the known molten metal drilling method it is the task of the molten metal as superheated drilling medium to melt the rock; thus, the molten metal is dramatically hotter than the molten rock.

[0060] In the present method according to the invention, the molten metal is used only as starting molten metal for fusion drilling and subsequently, the resulting molten rock is directly heated by an electric current flowing therethrough or by laser radiation and not by superheating the molten metal by the above-described devices such as magnet pumps thereby removing the rock. In fact, the molten metal, for example molten iron is used substantially only as starting molten metal and for forming the metal drill-hole casing or as displacing and protection melt so as to start directly heating the molten rock by an electric current by means of resistance heating because rock as a good insulator becomes a current conductor only in the liquid phase.

[0061] Thus, the molten rock is dramatically hotter than the molten metal. As a result of the high temperature difference between the two melts, the viscosity and surface tension of the molten rock is lower than the one of the molten metal.

[0062] According to the invention, the high surface tension of the cooler molten metal, its higher viscosity same and the density contrast are used to displace the hotter and lighter molten rock into fractures of the region surrounding the drill hole that are made by the thermal pressure of the hot molten rock abutting directly against the rock due to the LithoFrac effect. In this manner, a mixing of molten metal and molten rock is prevented from the beginning.

[0063] The power supply for directly melting the rock by superheating the molten rock by means of current flow therethrough can take place in a possible embodiment via at least one electrode that ends in the lower surface of the lowermost line element, preferred via at least three graphite electrodes integrated and insulated in the graphite well string.

[0064] In case of a plurality of electrodes, the same can have a uniform angular arrangement, for example in case of three electrodes, in each case at an angle of 120 degrees with respect to each other and positioned such that each of them extend in a centered manner.

[0065] If only one electrode is used, the heating can take place, for example by a current flow between the electrode

and the metal casing. If preferably three or more electrodes are used, a current flow between the same and/or the metal casing can be achieved. Here, the electrodes can be powered out-of-phase and can generate a rotating field.

[0066] These electrodes can preferably perform at the same time the task of a fully automatic control according to the (ERT) Electrical Resistance Tomography (Lawrence Livermore National Laboratory) by a computer program and/or, according to the three-phase current principle, can control the melts between graphite cylinder and drill-hole floor by rotating and pivoting the melts like a “melt drilling head” for an exact rock removal.

[0067] Each electrode can have in one embodiment an electrical line running to the surface. An electrode can be supplied with an electric current directly from a reactor carried along in a lower line element, for example one of the cold part. A current flow can take place between three electrodes via the molten metal in a phase-shifted manner and with different strength, so that the metallic drill-hole casing serves as return conductor.

[0068] After the drill hole target of a deep drilling is reached, at least the elements of the “cold part” and the “pulling and/or cooling part” of the drilling apparatus including the unused metal rod or metal well string are automatically disassembled or disassembled with the aid of an elevator, in particular an elevator according to the MagLev principle.

[0069] The wellbore-forming line elements, in particular graphite cylinders of the “hot part” of the drilling apparatus including the inner metal core can remain in the lower part of the well bore because during the solidifying process, the well bore metal casing slightly shrinks on in the upper part and thus can possibly not be recovered.

[0070] This slight shrinking process can be taken into account in that the tubular graphite cylinder string expands conically and in a corresponding manner downward which additionally strengthens the pressure closure to the high-tension melt region. For cost reasons and in other respects, the length of the “hot part” is preferably to be reduced to a necessary minimum since the length of the “hot part” also determines the length of the pilot bore. Thus, the pilot bore is preferably to be carried out deep enough that all line elements of the hot part can be inserted therein so as to start the melting process.

[0071] Preferably, the pilot bore including a metal pipe casing has such a depth prior to the start of the fusion-drilling process that the pilot bore, in addition to the entire “hot part” and the “pulling and cooling part”, can also receive a sufficient number of elevator elements, in particular Maglev elements, for holding and pressing, in particular if the dead weight of the “hot part” and the “pulling and/or cooling part” is not sufficient. Here, the weight of all the above-described elements plus the generated pressure force of the elevator elements, in particular Maglev elements, have to generate a pressure that is high enough that the line elements formed as pulling elements can fulfill their work of expanding, densifying and smoothing the metal drill-hole casing to an exact dimension and displacing the generated molten rock into the rock surrounding the drill hole.

[0072] The “pulling elements” serve have the task to expand, densify and smooth the solidified but still red-hot metal drill-hole casing above the at least one line element in which the melting takes place, in particular at the upper end of the tubular graphite cylinder string, to a predefined dimension

so that in the cold state, the casing meets the requirements of an elevator system, in particular MagLev elevator, for a problem-free use.

[0073] The pulling elements can be formed at least slightly conically and the surface of the same can be provided with a coating, for example with zircon so that when the fusion-drilling apparatus advances, the metal drill-hole casing that still can be formed under high pressure receives its final shape. For this purpose, densification means, lubricants or means for surface treatment can be used that are new or known from the prior art and that optimize and complete the densification and expansion process.

[0074] Cooling elements are not necessarily needed. It has to be considered if the efforts for coolant supply and heat dissipation pay off. The cooling can come into effect without any problems via the inner surfaces of the pulling elements or via line elements that are separately supplied for the purpose of cooling so as to improve the quality of the metal drill-hole casing and to accelerate the cooling process. The cooling can be carried out via commercially available cooling techniques in which the generated high temperature heat is used for cooling, for example via steam jet cooling systems integrated in drill-string modules, via thermocouples for cooling or can be carried out according to the invention via an SC (super-critical) water cooling unit that, same as the electricity supply in the TubeCoil system, moves up corresponding to the drilling progress via a self-advancing magnetic holding system on the metal casing of the well bore if the drill string does not run through the entire drill hole from top to bottom.

[0075] The SCW cooling unit comprises a closed two-part high-pressure pipe system that is continuously fed in a heat insulated manner in the TubeCoil system via the self-advancing magnetic holding system. Since the viscosity of the SCW is almost zero and thus hardly generates any friction in the pipe, despite volume increase, the SCW flows through a pipe with the same diameter approximately as fast as the cold pressure water. The SC water passes on the surface for energy recovery through a heat exchanger and is used, for example, for power production with an efficiency of 50% by expanding it via a SC high-temperature and high-pressure turbine.

[0076] The self-advancing magnetic holding system, in particular with adequately equipped line element, comprises electromagnets and is used according to the invention such that it centrally controls all electromagnets that are switched in short intervals to “hold”/“release” so that they “glide” under the force of gravity at the pace of the drilling progress along the drill-string elements. After reaching the drill target and disassembly of the drill string elements, the magnetic holding system is also disassembled via the elevator system, in particular the MagLev elevator, in the same manner as it was previously assembled from the surface.

[0077] Since two opposing supply systems with their self-advancing magnetic holding systems require space in the well bore, adequate chambers in the region of the supply elements are to be provided in the “cold part” of the drilling apparatus to be fed in or the shape of the well bore is to be selected such that the latter is supplemented by adequate free spaces that, in case of the fusion-drilling method, is possible as desired by suitably shaping the graphite cylinders that form the well. For example, a well having a square base would have sufficient space in the four corners for supply elements and would also provide space in the four corners for a potentially required elevator system, in particular, if necessary, a long stator system for the Maglev elevator.

[0078] In addition to the power supply via a cable, there is also the possibility of supplying energy for melting via effective lasers that are available on the market and are under development. The use of lasers as a source of melting energy requires a perfectly straight drill hole from the surface to the drill-hole floor so that from the surface downward, the laser beam can be enclosed via the hollow line elements. For feeding in the metal rod this would mean that it would have to be tubular.

[0079] During the addition of the well-string elements to the hollow well string at the surface by an automatic machine, in one possible embodiment, at least two laser beams with mirror system can be provided so that in case of an interruption of a laser beam during the insertion of the elements, the second laser beam is available so that during the insertion, the elements cannot be damaged by the laser beam and the light pressure on the high-pressure molten metal cannot be briefly interrupted. The content of the “melt cushion” between drill-hole floor and “drill string head” would otherwise rush into the free space of the graphite elements and the drill string head would then abut against the rock and would be destroyed under the high inherent pressure. In order to prevent this preferably even during a failure of the lasers, in this embodiment, a plurality of magnetic valves in the graphite hollow element string can be used for safety reasons.

[0080] When using the laser as a source of melting energy, the arrangement of the fusion-drilling apparatus can be substantially maintained. Only the line elements beginning at or below the melt zone would have to be provided with a continuous central bore. The laser beam would be focused such that it would fill the central bore in the lower drill string so as to be applied directly onto the drill-hole floor to create extremely hot molten rock. This way, a high melt pressure would build up and the light pressure of the laser would prevent the molten metal from rushing up into the central bore through which also the laser beam passes.

[0081] The directional correction and automatic control can be carried out as mentioned above via ERT and three-phase current electrodes.

[0082] The figures each show one illustrated embodiment of the invention, namely:

[0083] FIG. 1 shows melting with an electric current,

[0084] FIG. 2 shows melting with a laser beam.

[0085] FIG. 1 shows a drilling apparatus comprising a lower, here lowermost line element 1 made of graphite and having an internal chamber that serves as melt zone 5 so as to melt there, for example by current flow, solid metal fed in from above. Here, the metal is fed as a rod 7 through the line elements arranged thereabove. Here, the lowermost line element 1 forms the hot part of the drilling apparatus. It is possible that a plurality of such hot line elements are provided; however, in this case without melt zones.

[0086] From this melt zone, passages 6 run substantially radially outward and here slightly downward toward the outer surface of the line element 1, where the molten metal can exit and solidify. This way, it displaces molten rock into the surrounding rock that has fractures 14. An electric current fed in through lines and applied to electrodes 4 so as to melt the rock or maintain it molten.

[0087] Here, the central chamber of the lowermost element 1 is conically tapered upward so that the metal rod 7 forms a pressure closure at the upper end of the lowermost element for the melt.

[0088] A line element 2 immediately above the lowermost element 1 forms a pulling element that is conically tapered from top to bottom and, during the progressing drilling operation, forms and smooths a metal casing 9b that is already solidified but can still be shaped. Here too, only one of the elements is shown by way of example. It is also possible that several elements one behind the other successively carry out different shaping operations.

[0089] A line element 3 arranged thereabove has a smaller circumference and a larger inner chamber so that the metal rod 7 is freely movable in it. The element 3 has a uniform spacing from the metal casing 9 and can be configured as an elevator, for example as a magnetic slider or MagLev elevator.

[0090] FIG. 2 shows an embodiment with the same elements but here the lowermost line element 1 has a bore 13 that is open downward and through which a laser beam 15 can pass to impinge directly on the drill-hole floor and melt same. In the course of this, the laser beam 15 penetrates the melt zone 5 filled with molten metal. There, metal in the form of the rod 7 fed in from above, is melted and is directed to the outer circumference of the line element 1. Here, the laser beam is guided inside a tubular metal rod 7. Here too, as in FIG. 1, only one line element of the respective part of the drilling apparatus (hot part, pulling and/or cooling part, cold part) is shown by way of example.

REFERENCE LIST FIG. 1

- [0091] 1. Tubular graphite well-string element with “pressure drill head”
- [0092] 2. Pulling and/or cooling element
- [0093] 3. Magnetic (slider) element
- [0094] 4. Electrodes (preferably at least three)
- [0095] 5. Melting chamber (melt zone)
- [0096] 6. Lower/lowermost line element having passages for supplying the molten metal
- [0097] 7. Fed-in metal rod for building up the metal drill-hole casing
- [0098] 8. Molten rock drill-hole casing from solidified molten rock
- [0099] 9. Metal casting drill-hole casing (densified, tempered and smoothed)
- [0100] 9a At the end of the pulling process (metallic state)
- [0101] 9b At the beginning of the pulling process (solidified but still red-hot)
- [0102] 9c Molten metal in the process of solidification
- [0103] 9d Molten metal liquid but with high viscosity and surface tension
- [0104] 10 Molten metal displaces molten rock
- [0105] 11 Power supply
- [0106] 12 Air gap for MagLev element and MagLev elevator
- [0107] 13 Air gap for metal rod to be fed in
- [0108] 14 Fractures of the Thermo- and Litho-Frac system

REFERENCE LIST FIG. 2

- [0109] 1 Graphite cylinder string with central bore for laser beam
- [0110] 2 Pulling & cooling element part
- [0111] 3 Magnetic (slider) element part
- [0112] 4 Graphite electrodes
- [0113] 5 Melting chamber (melt zone)

- [0114] 6 Lower/lowermost line element having passages for supplying the molten metal, metal rod for building up the metal drill-hole casing
- [0115] 7 Molten rock drill-hole casing from solidified molten rock
- [0116] 9 Metal casting drill-hole casing (densified, tempered and smoothed)
- [0117] 9a At the end of the pulling process (metallic state)
- [0118] 9b At the beginning of the pulling process (solidified but still red-hot)
- [0119] 9c Casting melt in the process of solidification
- [0120] 9d Casting melt liquid but with high viscosity and surface tension
- [0121] 10 Molten metal displaces molten rock
- [0122] 11 Power supply
- [0123] 12 Air gap for MagLev element and MagLev elevator
- [0124] 13 Central bore in the graphite cylinder for the laser beam
- [0125] 14 Fracture system by Thermo- & Litho-Frac for molten rock compression
- [0126] 15 Laser beam
- [0127] 16 Release of molten rock by laser (maximum melt temperature)
- [0128] 17 Reduced temperature region (melt cone)
- [0129] 18 Outer melt zone region
- [0130] 19 Slightly conically expanded melt chamber
- [0131] 20 metal rod with opening for laser beam

1. In a fusion-drilling method for producing dimensionally accurate boreholes, manholes and tunnels in rock, where a drill-hole floor is melted by a molten metal mass and the molten material of the floor is pressed into the surrounding rock that has been cracked open by temperature and pressure, and where during drilling a drill-hole casing is formed around a well string of line elements by solidifying molten metal, the steps of:

feeding from above metal in a solid state into a central and upwardly open chamber of at least one lower line element of the well string through line elements thereabove, and

melting the solid metal in the chamber by fed in energy into molten metal that is conducted through passages extending outward from the chamber and ending at the outer surface of the line element into the outer surroundings of the line element, and molten rock thus formed below the lowermost line element is pressed into the surrounding rock and a metal casing is formed surrounding the well string on solidification.

2. The method according to claim 1, wherein the molten rock generated below the lowermost line element, in particular by the molten metal, is superheated by direct energy supply to a greater extent than the molten metal and thus a continuous melting of the rock takes place.

3. The method according to claim 1, wherein energy is supplied to the molten rock or molten metal by an electric current that is conducted through lines from the surface to the lowermost line element or the line element having the passages, or is generated by means of at least one reactor that is integrated into one of the line elements, or takes place by laser radiation that is guided from the surface to pass centrally through all line elements down to the drill-hole floor.

4. The method according to claim 1, wherein for generating an initial molten rock, a molten metal generated in the line

element having the passages is fed through the passages and along the outer surface of the line element to the drill-hole floor.

5. The method according to claim 1, wherein for starting a fusion-drilling process first a pilot bore with a drill-hole floor is generated into which a metal pipe is inserted as initial drill-hole casing, wherein into the metal pipe at least one line element having the passages and at least one line element for shaping the metallic drill-hole casing are inserted, and the molten metal exiting through the passages, in particular under inherent pressure, fills a free space between drill-hole floor and drill hole wall and bonds with the metal pipe of the pilot bore to form a metal casing that builds up continuously as drilling progresses.

6. The method according to claim 5, wherein upstream of the line element having the passages at least one further line element is inserted into the pilot bore so as to obtain a desired length of the well string below the passage openings or that the line element having the passages has a desired length below the passage openings, the desired length being determined by the intended drilling depth and the wear of the line element expected for the drilling depth.

7. The method according to claim 1, wherein the infeed of the metal when heating with an electric current is carried out by a solid metal rod fed in through the line elements or, when heating with laser, through the line elements as a tubular metal rod through which the laser beam is guided.

8. The method according to claim 1, wherein the molten rock is heated to a higher temperature than the molten metal so that due to the higher surface tension, the higher density and higher viscosity of the cooler molten metal with respect to the hotter molten rock, a mixing of molten metal and molten rock is prevented and during the drilling progress, on the one hand, a metal drill-hole casing is continuously build up from a single casting and, on the other, the less viscous molten rock is displaced by the high surface tension and the density contrast of the molten metal into the surrounding rock cracked open by temperature and pressure, in particular without metal getting lost in the surrounding rock.

9. The method according to claim 1, wherein the transmission of the melting energy into the melts, or a manipulation of the melts for generating a rotating or pivotable melt, in particular for forming a wear-free melting drill head, or the control of the entire installation by "Electrical Resistance Tomography" is carried out by means of three graphite electrodes integrated and insulated in a lower line element, which graphite electrodes, by means of phase shift and lo different load application during energizing, effect the rotational or pivoting movement of the melts, wherein in particular the ERT program detects the molten metal distribution upstream of the fusion-drilling apparatus and makes it visible on the monitor and allows a fully automatic control of the fusion-drilling method.

10. The method according to claim 1, wherein three types of line elements are used that divide a drilling string formed from the line elements into a hot part, a pulling or cooling part and a cold part, the line elements of the hot part being formed as tubular graphite cylinders, the line elements of the pulling or cooling part being formed from a particularly high-strength metal and being between the hot and the cold part and used for shaping, in particular expanding and finishing the metal drill-hole casing, and the line elements of the cold part being of a particularly pressure-resistant metal construction and used in particular for generating pressure or infeeding

control and energy devices as well as solid metal that is conveyed through the line elements to the lower line element, in particular the line element at a lower end of the drill hole where the solid metal is melted.

11. The method according to claim **1**, wherein assembly and disassembly of the line elements of the drilling string, provided that the line elements themselves are not equipped as an elevator system, in particular a Maglev system, are carried out by an elevator, in particular a Maglev elevator, by means of which in particular also the supply of solid metal, in particular as metal rod elements for the well bore metal casing, is carried out, in particular if the drilling string does not run from bottom to top through the drill hole.

12. The method according to claim **1**, wherein heat is extracted from the metal drill-hole casing via an SC water cooling system, and a power supply is cooled by steam jet chillers.

13. The method according to claim **1**, wherein supply lines, in particular lines if the power supply or cooling lines or supply elements or line elements extend along the metal-cased drill hole wall by an electromagnetic step system.

14. A fusion-drilling apparatus for producing fusion drill holes in rock, by means of which the drill-hole floor can be melted and by means of which a drill-hole casing made of metal can be formed, comprising a well string of line elements, wherein a lowermost line element of the well string, has a central upwardly open chamber into which metal as a solid rod, is fed from above through the line elements thereabove, wherein the solid material in the chamber can be melted by feeding energy and the line element has passages that extend from the chamber toward the outside and open out in the outer surface of the line element so that melted metal can be conducted through the passages into the outer surroundings of the line element.

15. The apparatus according to claim **14**, wherein the apparatus comprises a feeding element that is configured as elevator, in particular MagLev elevator, or as sliding element, and by means of which makeup supply material, in particular solid metal or supply material or line elements can be moved or assembled in the longitudinal extension of the metal-lined drill hole.

16. The apparatus according to any one of the preceding claims **14**, wherein the apparatus comprises three types of line elements that divide a drilling string formed from the line elements into a hot part, a pulling or cooling part and a cold part, one line element of the hot part being formed as tubular graphite cylinder, one line element of the pulling or cooling part being formed from a particularly high-strength metal and being between the hot and the cold part and used for shaping, in particular expanding and finishing the metal drill-hole casing, and one line element of the cold part being formed from particularly pressure-resistant composite material and comprising in particular control and transport devices and being used for generating pressure or for feeding in solid metal through the line elements to the lower line element, in particular the line element at a lower end of the drill hole, in which line element the solid metal can be melted.

17. The apparatus according to claim **16**, wherein one line element of the cold part is inactive and has sliding properties with respect to the drill-hole casing or a fed-in metal rod, which properties are imparted by carbon spacers as sliding elements that are arranged in the surface of the outer or shell of the line element.

18. The apparatus according to claim **16**, wherein one line element of the cold part is active and is configured in particular as controlled elevator, in particular magnetic slider having spacing and holding functions with respect to the metal drill hole wall and by means of which a metal rod can be fed toward the drill-hole floor or can be retrieved.

19. The apparatus according to claim **14**, wherein at least one line element is configured as an elevator, in particular Maglev elevator and uses the drill hole metal casing as reaction rail or sliding rail for the vertical, in particular contactless transport.

20. The apparatus according to claim **14**, wherein feeding the electric cable and feeding the cooling water line, in particular in the TubeCoil system, is carried out electromagnetically by a self-actuating stepping system that is carried on the drill hole wall by magnetic adhesion or is integrated in the drilling string if the drilling string runs continuously through the drill hole.

21. The apparatus according to claim **14**, wherein on its outside, the at least one line element of the pulling part expands conically upward and this line element, in particular under the pressure of the line elements arranged thereabove, compacts or expands or smooths the already solidified but still glowing hot, forgeable metal casting casing, in particular in such a manner that in the cold state, the latter provides sufficient space for an air gap of the Maglev elevator.

22. The apparatus according to claim **21**, wherein one line element of the pulling part consists of at least one particularly high-strength metal alloy and has a reinforcement layer of zircon.

23. The apparatus according to claim **14**, wherein a total length of the line elements strung together is smaller than the spacing between drill-hole floor and the surface and is in particular selected such that a weight of the line elements is achieved that is necessary to press the generated molten rock into the surroundings of the drill hole and to densify the metal casting casing to a desired dimension to expand it or to provide it with a smoothed, in particular mirror-smooth surface.

24. The apparatus according to claim **14**, wherein for building up the metal drill-hole casing, the fed in metal rod is fitted received in the a cylindrical passage of at least one of the line elements of the hot part, in particular the ones made of graphite, and can be melted in particular electrically or with laser light in a melt zone upstream of or in a line element having passages, a central bore of the line element expanding conically downward, in particular to the extent as it is required by the material expansion due to temperature increase so that by the weight of the metal rod, a required compressive pressure can be generated in the melt.

25. The apparatus according to claim **14**, wherein the melt energy supply is carried out per laser beam through a hollow metal rod that feeds in metal and extends into the melt zone of a line element having passages and further down to the drill-hole floor.

26. The apparatus according to claim **14**, wherein in an embodiment for melting by an electric current, a line element having the passages, in particular a graphite line element, is closed downward and in an embodiment for melting by laser beam, has a passage opening downward for the laser beam.

27. The apparatus according to claim **14**, wherein a lowermost line element, in particular a line element having the passages, comprises at least one electrode, preferably three electrodes, which in particular extend axially in the line element and are arranged at a uniform angular spacing and end in

the bottom face of the line element facing the drill-hole floor and can generate a current flow in the melt.

28. The apparatus according to claim **14**, wherein the laser beam with its high energy penetrates to the rock of the drill hole floor and with the radiation pressure of the laser, the necessary compression pressure can be generated at the same time in the melt.

29. The apparatus according to claim **14**, wherein magnetohydrodynamic valves or check valves are mounted in the

line elements of the pulling part so as to prevent the molten metal from rushing up into the metal well string in the event that the laser beam is interrupted or fails.

30. The apparatus according to claim **14**, wherein the lowermost line element that in particular forms the actual drilling head, is formed tapered upward, in particular conically tapered.

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