

[54] **APPARATUS AND METHOD FOR LARGE TUNNEL EXCAVATION IN SOFT AND INCOMPETENT ROCK OR GROUND**

3,667,808 6/1972 Tabor ..... 299/33  
3,693,731 9/1972 Armstrong et al. .... 175/11

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[57] **ABSTRACT**

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A tunneling machine for producing large tunnels in soft rock or wet, clayey, unconsolidated or bouldery earth by simultaneously detaching the tunnel core by thermal melting a boundary kerf into the tunnel face and forming a supporting excavation wall liner by deflecting the molten materials against the excavation walls to provide, when solidified, a continuous wall supporting liner, and detaching the tunnel face circumscribed by the kerf with powered mechanical earth detachment means and in which the heat required for melting the kerf and liner material is provided by a compact nuclear reactor.

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[52] U.S. Cl. .... **299/33; 175/11; 176/DIG. 3; 299/14**

[51] Int. Cl. .... **E21c 9/04**

[58] Field of Search ..... 299/33, 14; 175/11, 16; 61/45 R

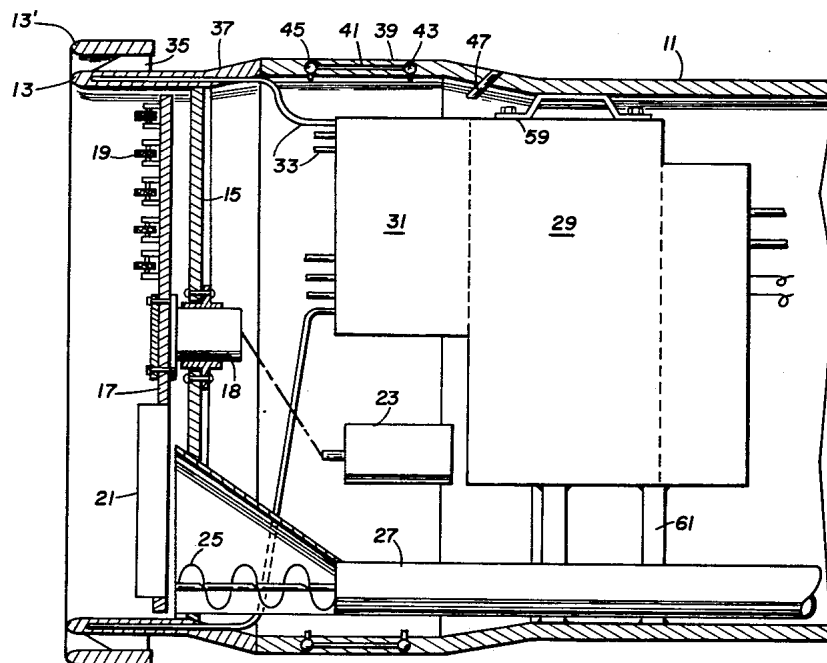
The invention described herein was made in the course of, or under a contract with the U. S. ATOMIC ENERGY COMMISSION.

[56] **References Cited**

**UNITED STATES PATENTS**

3,334,945 8/1967 Bartlett ..... 299/33  
3,396,806 8/1968 Benson ..... 175/11

**3 Claims, 5 Drawing Figures**



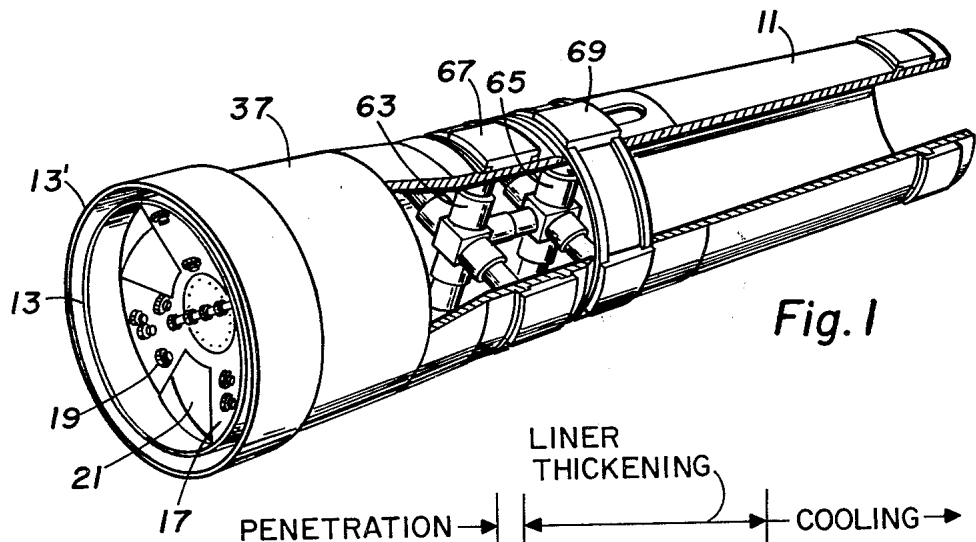
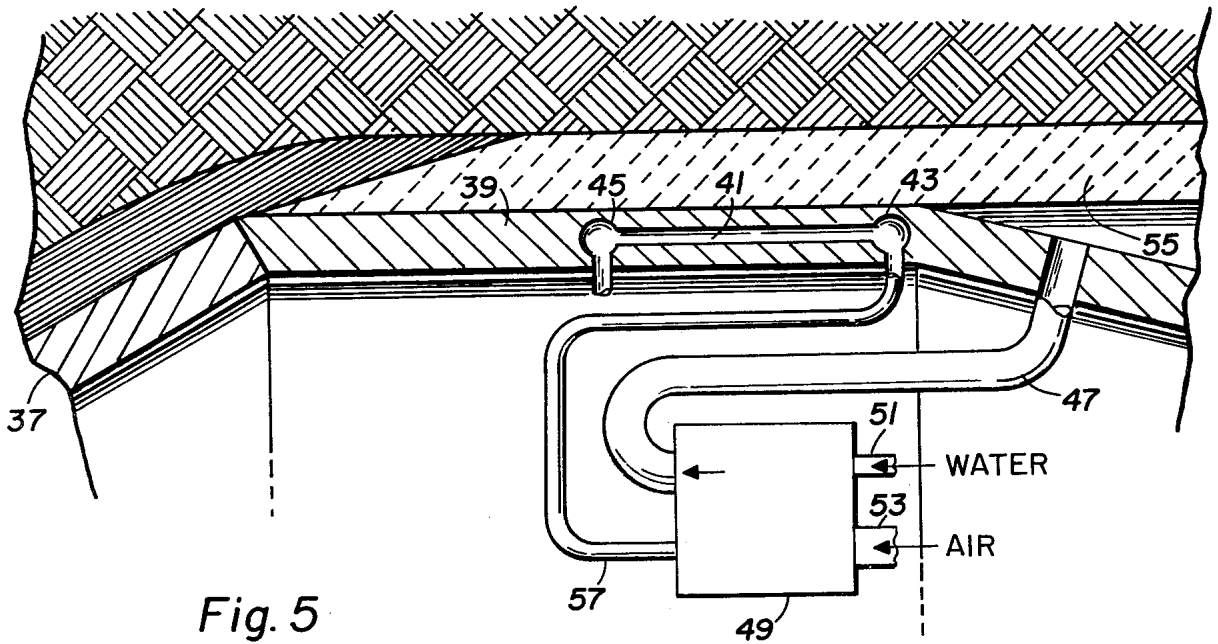


Fig. 4

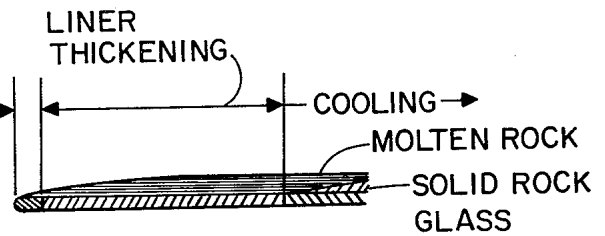
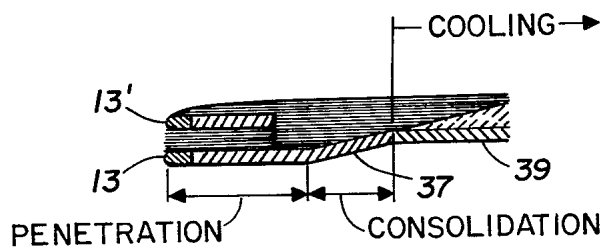


Fig. 3



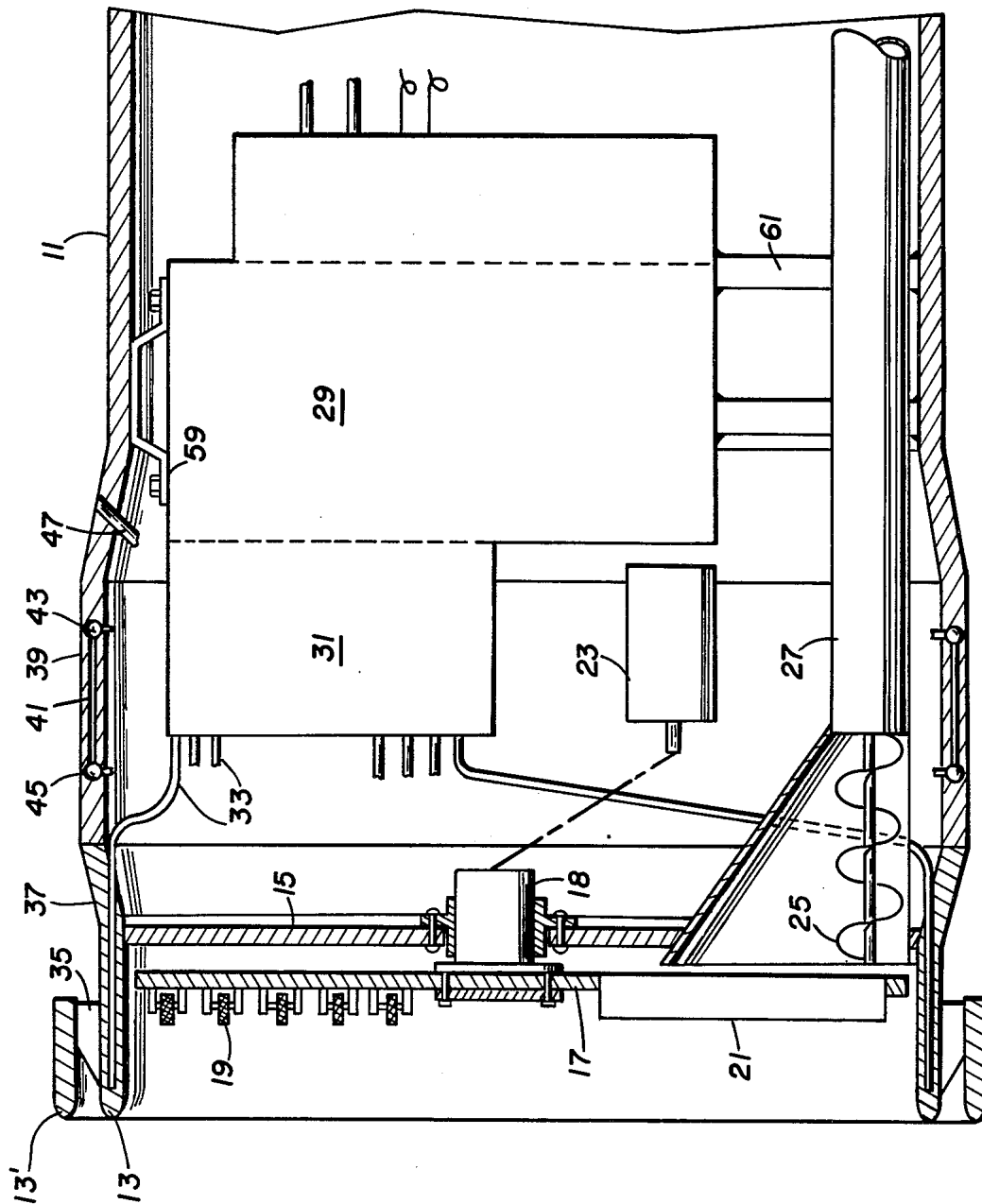


Fig. 2

## APPARATUS AND METHOD FOR LARGE TUNNEL EXCAVATION IN SOFT AND INCOMPETENT ROCK OR GROUND

### BACKGROUND OF THE INVENTION

The need for fast economical methods and machines for producing large tunnels and other excavations has considerably increased in importance with the increase in population, industrial congestion and environmental pollution. The production of large tunnels as needed, for example, for subway systems in and between cities, presents formidable tasks in excavating, removing the tunnel core and supporting the tunnel walls, particularly the roof, against collapse. Progress has been made in increasing the rate of large tunnel excavation by the use of mechanical boring machines such as the "MOLE". However, many problems are encountered in the use of such machines due to extreme variations in the earth through which the tunnel is being produced. For example, unstable ground with the associated risk of roof failure has not uncommonly buried the tunnel boring machine and stopped progress for weeks and even months. The ground may be unstable for a variety of conditions such as major fault zones, large water inflows, unconsolidated or running ground regions, squeezing plastic clay materials, and bouldery ground. The inaccessibility of the tunnel wall at the cutting face and alongside the prior art type tunnel boring machines prevents the installation of tunnel wall support where it is indispensable to prevent cave-in and possible burial of the machine and crew. In addition to the danger of cave-in, in the absence of preliminary wall support, the mechanical forces and vibration transmitted into incompetent surrounding earth by the tunneling machine causes excess detachment of tunnel wall material with attendant increased expense in the removal of the excess debris as well as increased expense due to thicker concrete liners being required to fill in the cavities caused by the above detachment of wall materials.

It is a primary objective of the present invention to provide a tunneling machine which simultaneously with removal of the tunnel face installs an initial supporting liner on the excavation walls.

Still another object is to provide a machine and method capable of an improved economical advance rate of excavation in loose, wet or unconsolidated earth by utilization of melt-consolidation techniques in which a tunnel defining kerf is melted into the tunnel face and the melt is simultaneously applied to the excavation bore to form an initial supporting liner.

Another object of the present invention is to provide a machine and method for tunneling which eliminates the excessive dust, ground shock and fumes incident to the use of the mechanical tunneling machine.

The above and other objectives and advantages afforded by the present invention will become apparent from reading the following description taken with the drawings made a part of this specification.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a horizontal isometric view, partly in section, of a preferred embodiment of the invention.

FIG. 2 is a vertical cross sectional and diagrammatic view of the forward part of a tunneling machine in accordance with the present invention.

FIG. 3 is a vertical cross section of a preferred form of kerf melting penetrator taken on plane 3—3 of FIG. 1.

FIG. 4 is a vertical cross-sectional diagrammatic view of an alternative kerf melting penetrator.

FIG. 5 is a diametric fragmentary cross section of the machine hull showing cooling details.

### DESCRIPTION OF THE PRIOR ART

The utilization of the concept of melting earth materials to dig a hole or small tunnel is taught in the prior art. For example, U.S. Pat. No. 3,357,505 issued to Armstrong et al., 1967, discloses an electrically heated earth drill. U.S. Pat. No. 3,396,806 issued to Benson, 1968, discloses a unitized machine for thermal earth drilling utilizing a nuclear reactor for supplying the melting energy requirements. This patent also suggests that the bore could be melted to a larger diameter than required for the finished hole so that space would be available to apply melt material as a hole casing. U.S. Pat. No. 3,693,731 issued to Armstrong et al., 1972, also discloses a nuclear reactor powered earth boring machine and melt material is used as structural hole lining material. This patent, like others that disclose machines for drilling tunnels by melting the earth, describes a solid front machine which melts the entire tunnel cross section.

### SUMMARY OF THE INVENTION

The tunneling machine of the present invention is particularly adapted to excavate large tunnels, that is tunnels having a cross sectional dimension of 2 to 12 metres or larger. The melting of the entire face of large tunnels would involve an inordinate amount of thermal energy. The most economical method is for the machine to thermally melt just enough material to detach the core and to provide enough melt for a tunnel support lining of adequate strength. Except in hard rock, the core is most economically disposed of by mechanical fracturing.

Briefly stated, the tunneling machine of the present invention is a self-propelled vehicle carrying on and projecting forward of, its front face a peripheral segmented heated ring, hereinafter called "kerf melting penetrator", for melting a kerf in the earth and for consolidating the melt outward into the excavation walls. Rearward of the kerf melting penetrator is a heat dissipating peripheral surface for supporting and solidifying the melt so that there is formed a rigid rock-glass tunnel wall initial supporting liner. A mechanical cutter and pulverizer is rotatably supported in the front end of the machine hull. The heat supply for the melting penetrator is a compact nuclear reactor of the type developed for space propulsion as shown in U.S. Pat. No. 3,693,731 referred to supra. Such a reactor is capable of energy output of many megawatts.

### DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1 and 2 of the drawing, the tunneling machine of the present invention includes a structural shell or hull 11 in and on which the machine parts are assembled. Peripheral segmented kerf melting penetrator 13,13' is mounted on the front end of the machine. Kerf penetrator 13,13' is shaped to melt a kerf in the earth which outlines the cross-sectional shape of the tunnel. The kerf penetrator may be a single seg-

mented heated elongated band such as shown in FIG. 4 or also could be a pair of such bands supported in spaced telescoped relationship as shown in FIG. 3. The melting function of two spacially separated plates is enhanced as a result of the hot region generated therebetween. Other similar configurations of kerf melting surfaces are possible.

The selection of either the single band kerf melting penetrator shown in FIG. 4 or the spaced band penetrator 13,13' shown in FIG. 3 depends on the integrity of the earth through which the tunnel is being bored. The single band penetrator is adequate for working in unified hard rock where a thick tunnel wall supporting liner is not needed. The double band penetrator is advantageous in unconsolidated earth where economical melting of a larger quantity of earth enables the formation of a thick excavation wall supporting liner.

Hull closure plate 15 is affixed to the front end of hull 11. A rotary cutter plate 17 is rotatably supported on plate 15 by shaft 18 on the axis of the hull. Rotary cutter plate 17 supports on its surface rotary supported rock cutters 19 and earth and debris sweep blades 21. Electric motor 23 is coupled through an appropriate gear reducer to rotary cutter plate shaft 18. Debris which has been cut away from the tunnel face is swept to the rear of cutter plate 17 to be engaged by auger 25. Auger 25 and transport tube 27 is illustrious of state-of-the-art devices to transport the debris rearwardly through the tunneling machine for delivery to other state-of-the-art transport mechanisms.

The heat source for kerf penetrators 13,13' is nuclear reactor 29 shown in FIG. 2. The nuclear reactor is of the compact type such as developed for space propulsion. In a manner similar to that shown in the referenced patent, the heat energy generated in the reactor is transferred to rock melting penetrators 13,13' by a liquid metal heat exchanger 31 and heat pipes 33.

The nuclear reactor power requirements for any desired size nuclear system tunneling machine are determined in accordance with well known heat transfer and nuclear reactor design data. The melting temperature of earth and rock of various chemical compositions lies between 1,420° and 1,470°K. The ambient temperature of the rock is assumed to be about 290°K. To assure the fluidity of the melt necessary to form the tunnel liner, the melt is heated to an average temperature of 1,570°K. An adequate glass liner thickness to provide safe interim support in unconsolidated earth is 4% of the finished tunnel diameter. Typical values of the heat of fusion in joules per kilogram of rock is  $418 \times 10^3$  and specific heat is 1,000 joules per kilogram-kelvin. From this data and allowing about 40% for extraneous heat losses not available for earth melting and with a selected boring advance rate of 1.5 metres per hour, a reactor capability in the range of 25 MW is more than adequate for a tunnel of 7.3 metre diameter. The energy requirements for any selected size tunnel is readily extrapolated.

The double penetrator 13,13' shown in FIG. 3 has a number of advantages over the single type penetrator of FIG. 4 for boring in unconsolidated earth in that heat is utilized with better efficiency in producing the more copious melt needed for a thick liner. The reason for the greater efficiency is that heat flow can be maximized in the annular space between the penetrator elements which minimizes the heat losses to the surrounding earth. The outer penetrator can be coupled by heat

pipes to heat exchanger 31 but is preferably heat coupled to inner penetrator 13 by a liquid metal heat transfer coupling strut 35. The outer penetrator melts a relatively shallow layer of earth whereas the heat concentrated between the penetrators provides the greater volume of melt. The melt is troweled outwardly against the excavation wall by an outwardly flaring skirt on consolidation band 37. The melt is supported and solidified in sliding contact with liner forming band 39.

As shown in FIGS. 2 and 5, liner forming band 39 is attached to hull 11 but is provided with water cooled heat exchanger passages 41 connected between water inlet manifold 43 and water outlet manifold 45. In order to minimize thermal shock to the solidifying glass and make use of well-known counterflow heat exchanger principles, the inlet cooler water enters the rear ends of the coolant passages. The hot exit water collected from manifold 45 is returned to a point of useful extraction, e.g., the generation of auxiliary electric power, of the collected heat and is recirculated. The molten rock is cooled to solidification by heat flowing radially outward into the surrounding rock and by inward flow into the water cooled liner-forming band 39. The glass or lava is solidified and cooled through a range of from about 1,570°K to about 900°K adjacent band 39. The liner is further cooled by forced air circulation through air ducts 47 and between the hull and the liner. The coolant system, liquid for the liner forming band and forced air for the in situ liner is desirably integrated as shown in FIG. 5. Heat exchanger 49 is supplied with cold water through port 51. Coolant air which has picked up heat from the liner by flow between the hull and the liner, as well as tunnel air in the vicinity of hull 11 is forced into the heat exchanger through port 53. Inside the heat exchanger the warm air is cooled and transferred through duct 47 to cool liner 55. The coolant water is circulated out of the heat exchanger at port 57 and is piped to the inlet manifold in liner forming band 39.

Referring again to FIG. 2, nuclear reactor 29 is supported in hull 11 by any suitable means such as brackets 59 and stanchions 61.

Crawler mechanism for propelling the tunneling machine is shown in FIG. 1 and is similar to state-of-the-art MOLE-type machines. Two sets of radially arranged hydraulic wall gripping ram arrays are used. The most forward set consists of 63 and 65. The aft set is identical and not illustrated. Array 65 is slidably supported in hull 11 for axial reciprocation. Ram array 63 is provided with radially extensible liner gripping pads 67 and is supported in the hull with restraint against movement in the direction of elongation of the hull. Ram array 65 is provided with tunnel wall gripping pads 69. Propulsion ram 71 is supported in an axial position in associated relation with ram arrays 63 and 65 to controllably reciprocate ram array 69 or, when 69 is stationary due to the gripping pad actions, the remaining machine is reciprocated. Operation of the propulsion and gripping mechanisms either for forward or backward motion and for machine axial orientation is self obvious. Selective extension of the ram array pistons permits controllable guidance of the machine.

Utility services such as electricity, cooling water, debris removal, etc. are connected to the tunneling machine from an earth surface terminal by conduits, cables, slurry transport mechanisms, etc.

Although the illustrative embodiment of the kerf melting and tunnel face removal machine has been described as cylindrical, there is an advantage inherent in this type of tunneling which is that it need not be cylindrical, but can be any shape most economical with respect to the desired cross section of the tunnel being bored. Other face fragmenting mechanisms can be used for noncylindrical configurations. Such types are already available in currently used tunneling machines.

What we claim is:

1. An earth tunneling machine comprising an elongated structural hull having a forward portion and a rearward portion, a closure plate affixed to the front end of the forward portion at right angles to the longitudinal axis of the hull, a peripheral segmented earth kerf melting penetrator of elongated plates affixed in adjacent relationship at the front end of the hull, a nuclear reactor supported in the hull, a plurality of heat pipes each thermally coupled at one end to the nuclear reactor core and at least one of such heat pipes being coupled at the other end to each of the earth kerf melting penetrator plates and adapted to maintain the kerf melting penetrator plates at a temperature above the melting temperature of earth materials, a rotary rock and earth cutting plate rotatably supported on the axis of the closure plate, motor means supported in the hull and coupled to the cutting plate for rotating the same, means for transporting the earth debris loosened by the cutter plate away from the cutter plate, said kerf melting penetrator having an outwardly flared skirt on the rearward portion thereof whereby melted earth is trowelled outward against and into the tunnel walls, a pe-

ripheral band portion at the front end of the hull constituting a tunnel liner forming band, liquid coolant means for thermally cooling the tunnel liner forming band, whereby said tunnel liner forming band supports the molten earth against the tunnel walls while simultaneously solidifying said molten earth into a tunnel wall initial supporting liner.

2. The earth tunneling machine of claim 1 in which the earth melting penetrator comprises an outer cylindrical heated segmental array having an inner diameter not less than the diameter of the forward portion of the hull; and an inner cylindrical heated segmental array having an outer diameter less than the inner diameter of the outer array by an amount predetermined by the selected thickness of the tunnel wall supporting glass liner, whereby an efficiently heated melt zone is provided between the arrays, the working edges of the two arrays lying substantially on a radial cross-sectional plane forward of the machine hull, the inner array being extended rearwardly of the rear end of the first array by an outwardly flared skirt portion terminating on and being affixed to the front end of the hull tunnel liner forming band, and means for heating both arrays to above the melting temperature of the earth.

3. The earth tunneling machine of claim 2 in which said hull rearward portion is reduced in cross section commencing at the rear end of the tunnel liner forming band, means for passing cooled air through the space provided by the reduced hull cross section and the tunnel wall initial supporting liner.

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