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[54] TUNNEL LINER JACKING SYSTEM AND METHOD

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[52] **U.S. Cl.**.....**61/43,** 61/85
[51] **Int. Cl.**.....**E01g 5/14**
[58] **Field of Search**.....61/45, 84, 85, 42, 43

[56] **References Cited**

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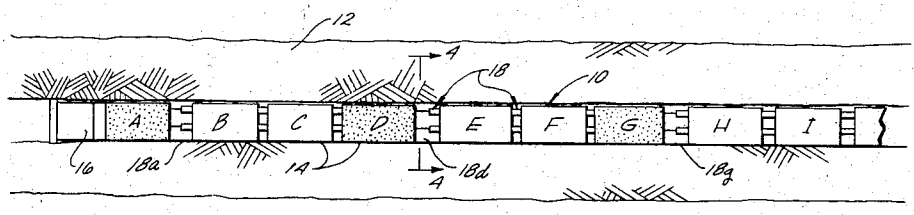
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Assistant Examiner—Philip C. Kannan
Attorney—Walter G. Maxwell

[57] **ABSTRACT**

A subterranean tunnel is formed by advancing a string of pipe sections behind a rotary boring head. Jacking stations between the respective pipe sections are remote-controlled from the tunnel portal to push the pipe sections forward. The pipe sections are advanced in an incremental jacking program operated by automatic controls. In the preferred jacking sequence, a first group of longitudinally spaced apart pipe sections is simultaneously advanced during the first phase of the sequence, while at least two adjacent jacking stations remain stationary between each adjacent pair of advanced pipe sections. After the first jacking phase, a second group of longitudinally spaced apart pipe sections is simultaneously moved forward against the previously advanced pipe sections of the first group. In a third jacking phase, a third group of longitudinally spaced apart pipe sections is simultaneously moved forward against the previously advanced pipe sections of the second group. The system preferably returns to the first jacking phase, followed by the second phase, the third phase, and so forth, although a fourth phase, or more, can be included in the jacking sequence before the system returns to the first phase. Thus, at least two adjacent pipe sections remain stationary behind each pipe section being advanced to act as a back-up for resisting the tendency of the pipe sections to back out of the tunnel instead of progressing forward.

10 Claims, 6 Drawing Figures



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SHEET 1 OF 3

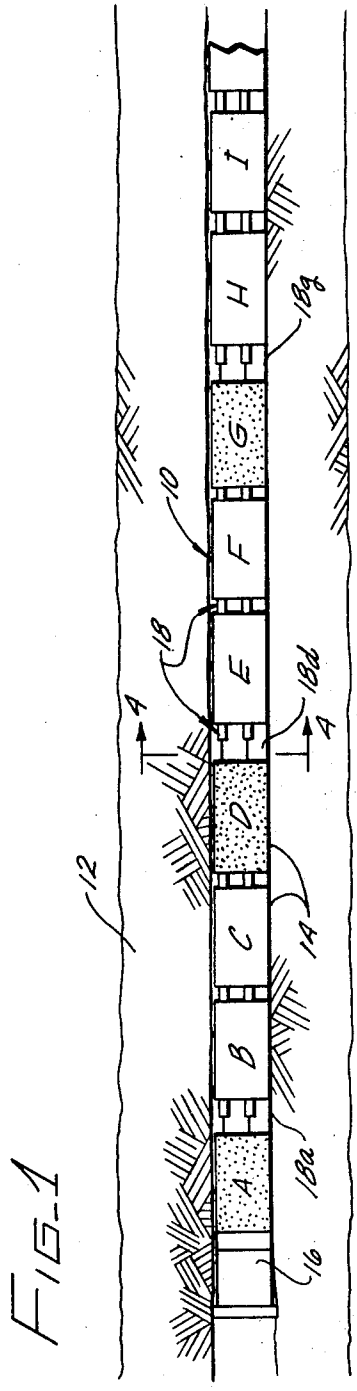


FIG. 1

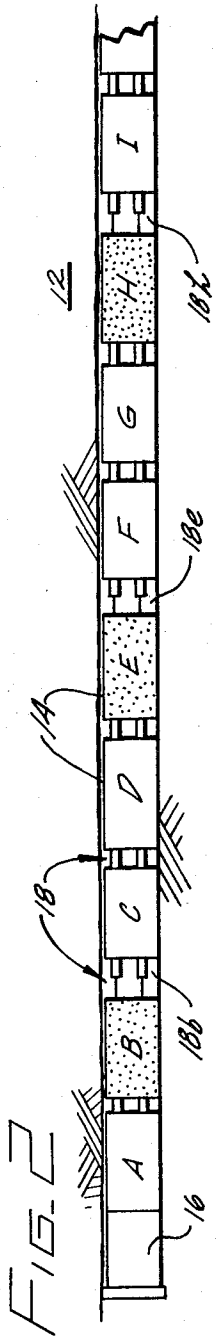


FIG. 2

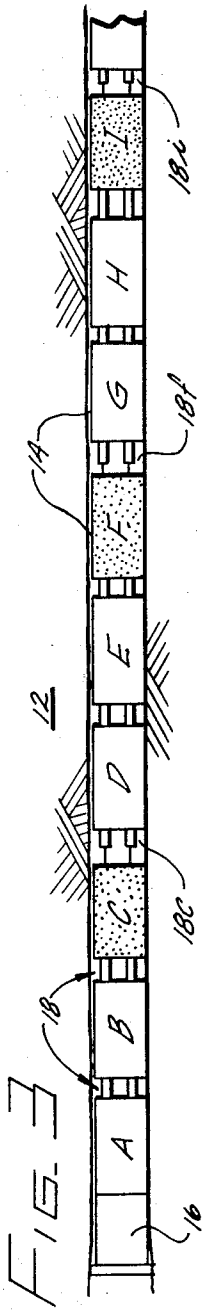


FIG. 3

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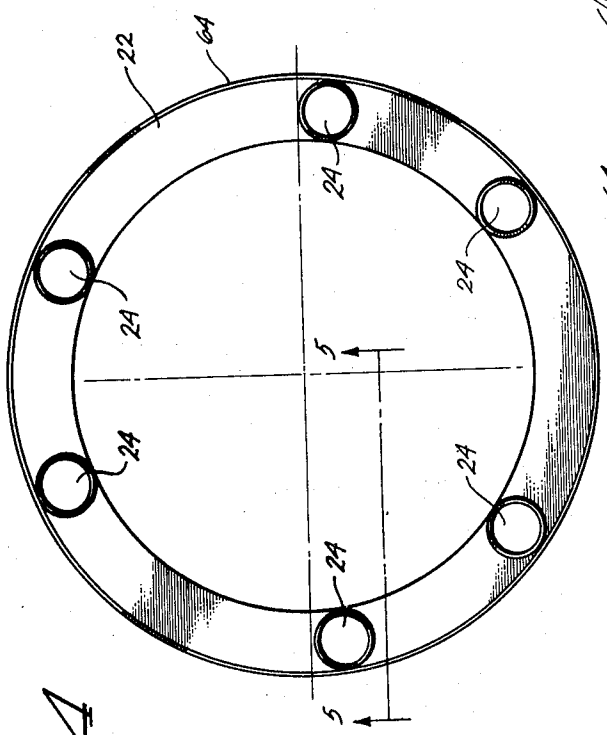

22
64
24
24
24
24
24
24
5
5

FIG. 4

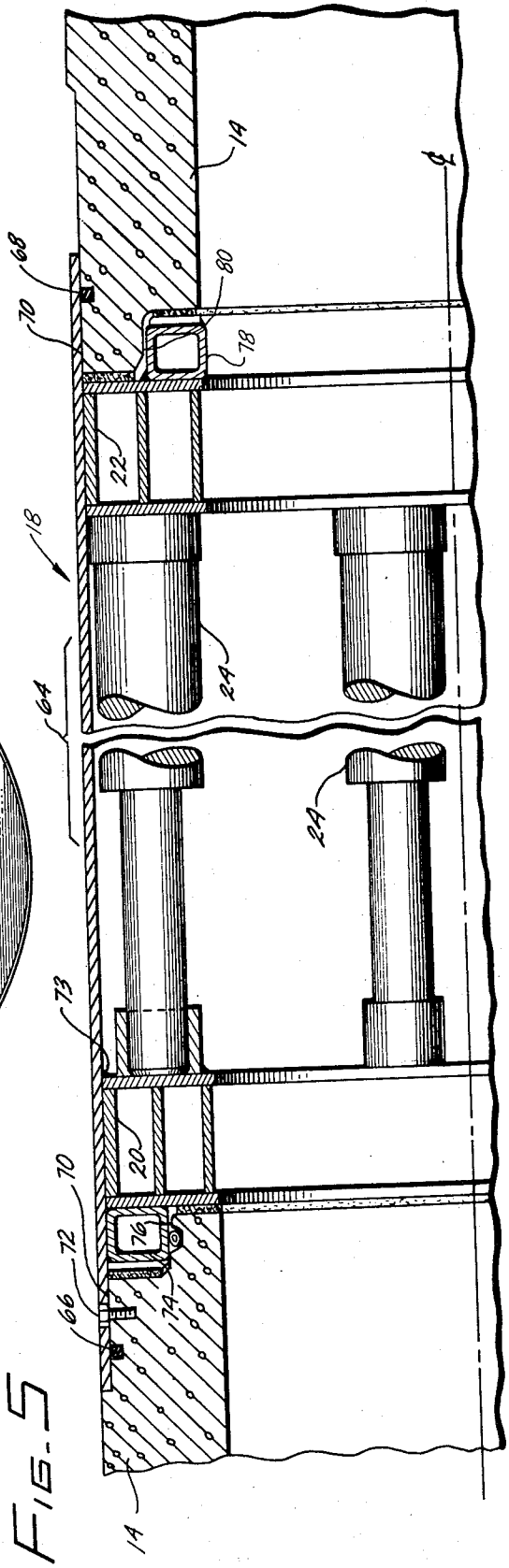
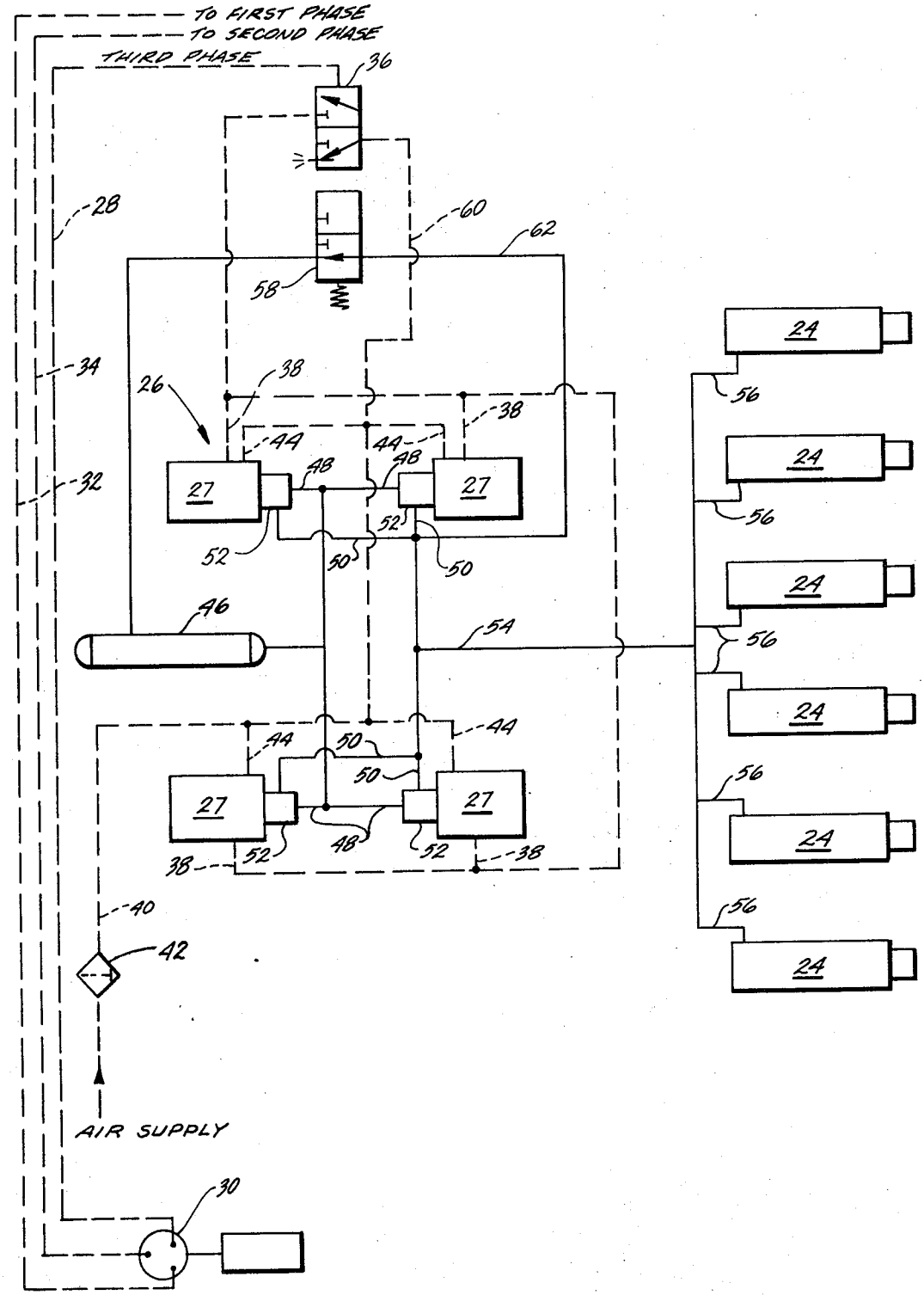

14
68
80
70
78
22
18
64
24
24
24
73
20
70
72
76
66
74
14

FIG. 5

FIG. 6


TO FIRST PHASE
TO SECOND PHASE
THIRD PHASE
36
28
60
62
58
34
26
38
44
48
27
32
52
50
46
54
24
56
40
42
AIR SUPPLY
30

TUNNEL LINER JACKING SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

This invention relates to the installation of underground tunnels, and more particularly to a remote-controlled system and method of lining an underground tunnel by sequentially advancing a string of pipe sections behind a rotary boring head.

Underground tunnels for water lines, sewer lines, utility lines and the like generally are constructed by forcing tunnel lines through the ground, using a rotary boring head to excavate material at the heading of the underground formation as work proceeds. It is common to construct the tunnel from a series of coaxially aligned pipe sections. The tunnel is installed by jacking the pipe sections forward, and adding new pipe sections as boring progresses.

The usual method of jacking pipe sections is the "single station" jacking arrangement in which jacking proceeds from a large excavated hole or "portal" at the entrance of the tunnel. Hydraulic jacks at the portal push the string of pipe sections forward. When the tunnel has been jacked forward a sufficient distance, the jacks are retracted, a new pipe section is placed behind the last pipe section, and jacking is resumed. Jacking progresses in this manner until the friction build-up in the system makes it impractical or impossible to continue jacking the tunnel forward through the formation. A new portal is then constructed at the opposite end of the tunnel, and jacking is continued in the same manner until the tunnel is completed.

A major disadvantage of the single station jacking method is that jacking only can be carried out for a relatively short distance in formations of average hardness. Thus, several portals must be constructed to install a relatively long underground tunnel, which becomes a problem when buildings and the like are located above the desired site for a new portal. Moreover, a substantial cost is involved in continuously constructing new portals and moving workmen and equipment to the new portals.

SUMMARY OF THE INVENTION

This invention provides a remote-controlled system and method of jacking tunnel liner sections in such a way that a relatively long underground tunnel can be constructed from a single portal.

Briefly, this invention contemplates an underground tunnel formed by a string of end-to-end pipe sections, with a separate jacking station preferably between each adjacent pair of pipe sections. Jacking is carried out by automatic controllers which simultaneously advance a first group of the pipe sections, followed by simultaneous advancement of a second group of different pipe sections, and so forth, the jacking being carried out in phases until all pipe sections in the string make one forward advancement. The jacking sequence is then continuously repeated to advance the string of pipe sections in steps until the end of the tunnel is reached, except for interruptions needed to add new pipe sections and jacking stations at the portal.

In the preferred jacking sequence, a first group of longitudinally spaced apart pipe sections is simultaneously advanced, while at least two adjacent pipe sections remain stationary between each adjacent pair of pipe sections in the first group. In the next jacking phase, a second group of different spaced apart pipe sections is simultaneously advanced toward respective pipe sections in the first group. The third jacking phase is then carried out by simultaneously advancing a third group of pipe sections, each of which is different from the pipe sections in the first and second groups. The pipe sections in the third group are advanced toward respective pipe sections in the second group. The system then preferably returns to the first jacking phase, followed by the second jacking phase, the third jacking phase, and so forth, although a fourth phase, or more, can be added to the tunnel if soil conditions permit.

This invention facilitates the construction of relatively long underground tunnels, because each pipe section has its own respective jacking station downstream of the portal. Thus, friction build-up along the exterior of the tunnel liner system does not limit the length of the tunnel as it does when a single jacking station is located at the portal. The installation of the underground tunnel can be controlled automatically from the single portal area, which avoids the need for constructing a large number of portals and continuously moving men and equipment to complete a long tunnel.

The simultaneous jacking of groups of pipe sections in phases allows the unadvanced group of pipe sections during each phase to act as a back-up for the advanced pipe sections, thereby resisting the tendency of the pipe sections to back out of the tunnel instead of progressing forward.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will be more fully understood by referring to the following detailed description and the accompanying drawings in which:

FIG. 1 is a schematic elevation view showing a string of tunnel liner sections in the first phase of a preferred jacking sequence;

FIG. 2 is a schematic elevation view showing the string of tunnel liner sections of FIG. 1 in the second phase of the jacking sequence;

FIG. 3 is a schematic elevation view showing the string of pipe liner sections of FIG. 1 in the third phase of the jacking sequence;

FIG. 4 is a sectional elevation view of a typical jacking station taken on line 4—4 of FIG. 1;

FIG. 5 is a fragmentary sectional elevation view taken on line 5—5 of FIG. 4; and

FIG. 6 is a schematic diagram of the air-hydraulic control system for a typical jacking station.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, an underground tunnel 10 is installed in a formation 12 by advancing a series of concrete pipe sections 14 behind a rotary boring head 16. As boring of the tunnel proceeds, additional pipe sections are added to the string of pipe at the tunnel portal until the tunnel is completed. Boring is intermittently stopped while the new pipe sections are added.

The string of pipe sections is jacked forward by longitudinally spaced apart jacking stations 18 located between each adjacent pair of pipe sections. As shown best in FIGS. 4 and 5, each jacking station 18 comprises a forward jacking ring 20 secured to the trailing

end of each pipe section **14**, and a rear jacking ring **22** secured to the forward end of the respective pipe section behind the forward jacking ring. Each jacking station also includes several circumferentially spaced apart hydraulic rams **24** extending between adjacent pairs of forward and rear jacking rings. Boring is intermittently interrupted to add new jacking stations to the string of pipe sections at the portal. The construction of the jacking sections will be described in greater detail below.

The pipe sections are advanced by an automatic jacking program in which a given jacking sequence is initiated to advance a certain group of pipe sections each time the boring head advances a predetermined distance. FIGS. **1** through **3** show a preferred jacking sequence which is carried out in three phases of operation. Underground tunnel **10** is lined with the string of pipe sections **14**, the latter being designated by the letters A through I. The jacking stations corresponding to pipe sections A through I are designated **18***a* through **18***i*, respectively. FIG. **1** shows phase one of the jacking sequence, in which jacking stations **18***a*, **18***d*, and **18***g* are operated (by extending hydraulic rams **24**) to advance the pipe sections A, D, and G. Preceding the first phase, pipe sections C, F, and I had been moved forward against pipe sections B, E, and H, respectively, as shown in FIG. **3**.

Following phase one, the jacking sequence shifts to phase two in which pipe sections B, E, and H are moved forward by extending the rams at jacking stations **18***b*, **18***e*, and **18***h*, respectively. The system is then ready for phase three in which pipe sections C, F, and I are moved forward by extending the rams at jacking stations **18***c*, **18***f*, and **18***i*, respectively. The system is then ready for a new cycle of operation beginning with phase one.

In the three-phase pipe jacking sequence described above, each pipe section being advanced is backed up by two stationary adjacent pipe sections. The weight of the two stationary pipe sections is sufficient to resist the tendency of the pipe sections to back out of the tunnel, instead of progressing forward as desired, when the pipe section immediately in front of them is being moved forward.

The advancement produced by the hydraulic rams during any one phase of operation necessarily proceeds at 3 times the average rate of the boring head.

Jacking arrangements other than the three-phase jacking sequence described in FIGS. **1** through **3** may be used. For example, a four-phase arrangement may be used. Such a system has the advantage of providing a back-up of three end-to-end pipe sections, instead of two, for each pipe section being advanced. This arrangement could be necessary if boring takes place in a very hard formation. However, the tunnel liner system travels slower in a four-phase system than in a three-phase system, assuming that the jacking rate for each jacking station is the same. The travel of the pipe line in a four-phase system, however, could be adjusted to be the same as that of the three-phase system, but the four-phase system then would require the jacking rate for each phase to be 4 times the rate of travel of the boring head.

The jacking stations are spaced along the pipe line at intervals determined by a preliminary soil study. For example, if the soil study indicates that the friction developed by the formation is relatively low, the jacking stations need not be placed between each adjacent pair of pipe sections, but could be spaced between groups of pipe sections.

The system for automatically controlling operation of the jacking stations is best understood by referring to FIG. **6**. Hydraulic rams **24** are hydraulically coupled to a pressure manifold **26** in such a manner that each ram receives the same pressure, so that all rams at any jacking station provide essentially the same forward thrust. The pressure manifold in FIG. **6** is shown for the third phase of operation, in which the rams at stations **18***c*, **18***f*, and **18***i* are actuated simultaneously. Operation of the rams preferably is controlled by an air-hydraulic control system. However, movement of the tunnel liner sections could be provided by alternate means, such as an electrical control system for operating electric pumps, without departing from the scope of the invention.

The air-hydraulic system of FIG. **6** shows, by way of example, the operation of a single jacking station for phase three of the tunnel liner movement. All other jacking stations have identical arrangements for actuating their respective hydraulic rams.

Power to hydraulic rams **24** supplied by a set of hydraulic pumps or intensifiers **27** adapted to operate on signal from an air signal line **28** controlled by a rotary variable speed air distributor valve **30**. Valve **30** is timed to admit air through line **28** at the beginning of the jacking sequence for phase three. Valve **30** also admits air through other air lines **32** and **34** at selected time intervals corresponding to the beginning of the jacking sequence for phases one and two, respectively.

The signal through line **28** opens an air pilot valve **36** which admits air through respective control lines **38** to operate solenoid valves (not shown) in each of the intensifiers to admit compressed air from a high pressure line **40** to the intensifiers. The high pressure air in line **40** flows from a compressor (not shown) at ground level through an air filter **42** and through separate high pressure lines **44** extending from the main high pressure line **40** to the respective intensifiers.

The high pressure air flowing to the intensifiers allows the intensifiers to draw in hydraulic fluid from a reservoir **46** through respective hydraulic lines **48**. The hydraulic fluid is pumped by the intensifiers through separate lines **50**, controlled by respective one-way check valves **52**, through a high pressure hydraulic line **54** which delivers the high pressure fluid to separate lines **56** connected to the hydraulic rams. The rams, upon receiving the hydraulic fluid, extend forward to push their respective pipe sections forward.

Jacking during this phase of operation is stopped when the hydraulic rams reach their full extension, thus stalling the intensifiers until the air distributor valve **30** progresses to the next phase condition, at which time air pilot valve **36** closes and opens a by-pass valve **58**. At this time the intensifiers are depressurized by exhausting the air in them to the atmosphere through an air exhaust line **60** extending from the intensifiers to air pilot valve **36**. At the same time, the hydraulic fluid in the rams is recycled through a return line **62**, through the open by-pass valve **58**, to hydraulic reservoir **46**. The by-pass valve remains open until the jacking sta-

tion again receives a control signal from air distributor valve **30**, at which time the by-pass valve is closed and the air pilot valve is opened for the next jacking sequence.

Each jacking station is provided with a pipe joint shown best in FIG. **5**. The pipe joint includes a joint sleeve or wrapper plate **64** which surrounds the area between the ends of adjacent pipe sections. The wrapper plates have the same outside diameter as the pipe sections, so that the exterior of the tunnel liner system is continuous for its entire length to minimize friction. Seals **66** and **68** at the front and back, respectively, of the wrapper plate prevent mud, water, or soil from entering the tunnel during jacking operations.

A separate recess **70** is formed at the front and rear of each pipe section **14**. The front and rear portions of the wrapper plate are fitted in the recessed portions of their corresponding pipe sections. The front portion of the wrapper plate is rigidly secured to the rear portion of its corresponding pipe section by circumferentially spaced apart anchors **72**. The rear edge of forward anchor ring **20** is welded to the wrapper plate at **73** to provide additional means for firmly securing the wrapper plate to the forward jack ring. During forward movement of the hydraulic jacks, the end portion of each wrapper plate slides forwardly along the recessed portion **70** of its corresponding rear pipe section.

A separate annular anchor ring **74** is secured to the front edge of each forward jacking ring **20**. Anchor ring **74** is anchored, by suitable means, in a recess **76** formed in the outer surface of the pipe section adjacent the forward jacking ring to firmly secure the forward jacking ring to the pipe section. A separate annular anchor ring **78** is secured to the rear edge of each rear jacking ring **22**. Anchor ring **78** is anchored, by suitable means, in a recess **80** formed in the interior wall of the pipe section behind the rear jacking ring so as to hold the jacking ring in the front end of the rear pipe section. The anchor rings **74** and **78** firmly resist both inward and outward lateral movement of the jacking rings relative to the pipe sections.

When the tunnel is completed, the jacking rings and rams are removed, welds **73** being gouged out by suitable means, and the wrapper plate at each jacking section is left as part of the tunnel liner.

Thus, a remote-controlled system has been described for jacking pipe sections or other similar prefabricated tunnel liner sections into an underground tunnel where environmental conditions, or the length and diameter of the tunnel may preclude use of the normal single station jacking arrangement. The system disclosed permits horizontal boring of relatively long tunnels from a single portal. The wrapper plates and seals at the jacking stations permit installation of a tunnel liner below the water table while maintaining a dry tunnel. It also permits safe penetration of hazardous caving or flowing soils without exposure of operating personnel to injury from caves, falling rocks, or flooding. Since the system normally does not require an operator in the tunnel, it provides means for constructing relatively small diameter tunnels (48 inches or less) over a long distance. Since the operations are automatically controlled, a further advantage results from reduced manpower requirements.

I claim:

1. Apparatus for installing a subterranean tunnel, the apparatus comprising a string of coaxially aligned tunnel liner sections; jacking means coupled with certain tunnel liner sections and adapted to be actuated to advance said tunnel liner sections; and means for advancing different groups of the tunnel liner sections simultaneously in phases, the advancing means including first actuating means coupled with a first group of the jacking means, second actuating means coupled with a second group of the jacking means, each of the jacking means in the second group being different from those in the first group, means for selectively operating the first actuating means to actuate the first group of jacking means and thereby simultaneously advance a first group of tunnel liner sections associated with the first group of jacking means, and means for selectively operating the second actuating means in timed relation with operation of the first actuating means to actuate the second group of jacking means and thereby simultaneously advance a second group of tunnel liner sections associated with the second group of jacking means after advancement of the first group of tunnel liner sections.

2. Apparatus according to claim 1 in which the advancing means are arranged so that the tunnel liner sections in each group of advanced sections are spaced apart from one another in the string, there being at least two tunnel liner sections between each adjacent pair of sections in the same group.

3. Apparatus for installing a subterranean tunnel comprising a string of tunnel liner sections aligned end-to-end; a separate jacking station between each adjacent pair of tunnel liner sections, each jacking station including jacking means adapted to be actuated to advance a respective tunnel liner section; means for selectively actuating a first set of the jacking means to simultaneously advance a first group of longitudinally spaced apart tunnel liner sections while maintaining at least two unactuated jacking stations between each adjacent pair of advanced tunnel liner sections; means for selectively actuating a second set of the jacking means in timed relation with actuation of the first set to simultaneously advance a second group of longitudinally spaced apart tunnel liner sections after advancement of the first group while maintaining at least two unactuated jacking stations between each adjacent pair of advanced tunnel liner sections in the second group, each tunnel liner section in the second group being different from those tunnel liner sections in the first group; and means for selectively actuating a third set of jacking means in timed relation with actuation of the second set for simultaneously advancing a third group of spaced apart tunnel liner sections after advancement of the second group while maintaining at least two unactuated jacking stations between each adjacent pair of advanced tunnel liner sections in the third group, each tunnel liner section in the third group being different from those liner sections in the first or second group.

4. Apparatus according to claim 3 in which each jacking station comprises a first jacking ring secured to an end of one tunnel liner section, a second jacking ring secured to the end of a neighboring tunnel liner section and spaced from the first jacking ring, hydraulic actuator means extending between the adjacent first and second jacking rings, and a circumferential shield car-

ried by the tunnel liner section to which the first jacking ring is secured and adapted to cover the second jacking ring during the complete advancement of the hydraulic actuator means to seal the space between the jacking rings against entry of foreign matter.

5. A method of advancing a string of coaxially aligned tunnel liner sections to form a subterranean tunnel, the method comprising simultaneously advancing a first group of the tunnel liner sections, and simultaneously advancing a second group of the tunnel liner sections, all of which are different from any of those in the first group, after advancement of the tunnel liner sections in the first group.

6. The method according to claim 5 including advancing the first group of tunnel liner sections so that at least two unadvanced tunnel liner sections are between each adjacent pair of tunnel liner sections in the first group, and advancing the second group of tunnel liner sections so that at least two unadvanced pipe liner sections are between each adjacent pair of tunnel liner sections in the second group.

7. The method according to claim 6 in which any tunnel liner sections not included in the first and second groups consist of at least a third group of tunnel liner sections, and including advancing the tunnel liner sections in the third group so that at least two unadvanced pipe liner sections are between each adjacent pair of tunnel liner sections in the third group.

8. Apparatus according to claim 1 in which each jacking means comprises a first jacking ring secured to an end of one tunnel liner section, a second jacking ring secured to the end of a neighboring tunnel liner section and spaced from the first jacking ring, hydraulic actuator means extending between the adjacent first and second jacking rings, and a circumferential shield carried by the tunnel liner section to which the first jacking ring is secured and adapted to cover the second jacking ring during the complete advancement of the hydraulic means to seal the space between the jacking rings against entry of foreign matter.

9. Apparatus according to claim 1 in which each jacking means comprises a set of radially spaced apart, longitudinally extendable and contractable hydraulic rams disposed between adjacent tunnel liner sections; and in which the first actuating means is operable to extend each set of hydraulic rams associated with the first group of jacking means, and in which the second actuating means is operative to extend each set of hydraulic rams associated with the second group of jacking means, each set of hydraulic rams in the first group being adapted to automatically retract due to subsequent extension of the sets of hydraulic rams in the second group.

10. Apparatus according to claim 3 in which:

a. each jacking means comprises a set of radially spaced apart, longitudinally extendable and contractable hydraulic rams disposed between adjacent tunnel liner sections,

b. the actuating means associated with the first set of jacking means are operative to extend the sets of hydraulic rams associated with the first set of jacking means,

c. the actuating means associated with the second set of jacking means are operative to extend the sets of hydraulic rams associated with the second set of jacking means,

d. the actuating means associated with the third set of jacking means are operative to extend the sets of hydraulic rams associated with the third set of jacking means,

e. each set of previously extended hydraulic rams associated with the first group of tunnel liner sections is adapted to retract due to subsequent advancement of the second group of tunnel liner sections, and

f. each set of previously extended hydraulic rams associated with the second group of tunnel liner sections is adapted to retract due to subsequent advancement of the third group of tunnel liner sections.

* * * * *