The instant invention is broadly concerned with the field of earth excavation, and is more directly related to a pneumatic tooth for use, generally in conjunction with other such teeth, on the buckets of various excavating equipment such as tractor shovels, revolving shovels, trench hoes, etc.

The device of the instant invention is specifically intended to function in a manner so as to substantially increase the digging capacity and ability of an excavating bucket when placed on earth by any appreciable increase in the basic bulk and mass of the machine upon which the bucket is mounted. While it is appreciated that the broad idea of digging teeth is not in itself novel, the generally limited ability along with the enormous quantities of compressed air required, as well as the huge and costly equipment necessary to produce the tremendous quantities of compressed air, have resulted in devices which are clearly not economically feasible. Accordingly, it is a highly significant object of the instant invention to provide a pneumatic tooth for an earth excavator bucket which is capable of operating in all kinds of media with an extreme economy of air, this being of the utmost importance in a mobile excavating unit.

In eliminating the large waste of air characteristic of the more conventional types of pneumatic devices, it is intended that the instant invention utilize to the fullest degree practical the energy of expansion of compressed air while at the same time utilizing any unexploited energy of impact, this latter energy being generally available when the device faces a hard formation requiring several blows, without appreciable dissipation of energy, before shattering.

Inasmuch as the pneumatic tooth of the instant invention is to be applied to an excavation bucket intended for general use, it is intended that the device of the instant invention be operable in media presenting all degrees of resistance. However, inasmuch as the device will have little use in a relatively soft medium, it is also an object of the instant invention that the pneumatic tooth, in such circumstances, be inoperative in order to avoid unjustified wear and tear on the device, and to also conserve the supply of compressed air for those times when the device can do useful work.

Also, for facilitating the servicing of each of the teeth, it is significant that each tooth be self-contained and adapted for ready mounting on or removal from the operating lip of an excavating bucket. Such an arrangement is preferred rather than making the tooth an integral part of the bucket lip in that in addition to greater ease in the construction and inspection of the individual tooth, in actual operation a faulty tooth can be replaced without the necessity of removing the bucket from service.

These together with other objects and advantages which will become subsequently apparent reside in the details of construction and operation as more fully hereininafter described and claimed, reference being had to the accompanying drawings forming a part hereof, wherein like numerals refer to like parts throughout, and in which:

FIGURE 1 is a perspective view illustrating one form of excavation bucket having pneumatic teeth constructed in conformance with the instant invention and mounted thereon;

FIGURE 2 is an enlarged cross-sectional view taken substantially on a plane passing along line 2—2 in FIG.

URE 1 and further illustrating the mounting of one of the pneumatic teeth;

FIGURE 3 is a partial cross-sectional view taken substantially on a plane passing along line 3—3 in FIG.

URE 2;

FIGURE 4 is a longitudinal cross-sectional view of the pneumatic tooth comprising the present invention, the tooth being in its normal outward position;

FIGURE 5 is an enlarged cross-sectional view taken substantially on a plane passing along line 5—5 of FIG.

URE 4 illustrating the manner in which the spring steel locking rings are to be applied;

FIGURE 6 is an enlarged cross-sectional view taken substantially on a plane passing along line 6—6 in FIG.

URE 4 and illustrating the integral mounting pads;

FIGURE 7 is an enlarged group longitudinal cross-sectional view of the pneumatic tooth in its maximum inward position;

FIGURE 8 is an enlarged group longitudinal cross-sectional view of the pneumatic tooth with the plunger at the end of its forward stroke and beginning its return stroke, and the tooth point assembly in its extreme outward position;

FIGURE 9 is an enlarged partial cross-sectional view illustrating the engagement of the plunger with the tooth point assembly; and

FIGURE 10 is a partial longitudinal group sectional view of the device with the tooth point assembly partially out and the plunger nearing the end of the return stroke.

Referring now more specifically to the drawings, reference numeral 20 is used to generally designate the entire pneumatic tooth, this tooth being specifically intended for mounting on and use with an earth excavator bucket, one type of which has been designated by reference numeral 22 in FIG. 1. Each of the teeth 22 includes a hollow cylindrical body 24 having laterally projecting integral mounting pads 26 thereon, these teeth 20 being fixedly though releasably clamped to the lip portion of the bucket by means of suitable cap screws 28 located on opposite sides of the teeth 20, these pneumatic teeth 20 if so desired, alternating with fixed teeth 30. In such an arrangement, the pneumatic teeth 20 function to loosen or break apart formations with the fixed teeth 30 gathering up the material so formed.

Referring specifically to FIGURE 2, it will be noted that a suitable base connector and nipple assembly 32 is provided in conjunction with each pneumatic tooth 20 whereby the pneumatic tooth 20 can be pulled out or inserted with the air connection being automatically broken or established, suitable controls of course being provided for regulating and completely shutting off the air supply. Both ends of the cylindrical body 24 are provided with series of internal rectangular grooves 32 matching similar external grooves 34 within both the cylinder head 36 and the front end cap 38, the matching grooves 32 and 34 receiving therein preformed spring steel locking rings 40 inserted into the grooves through suitable external openings 42 in the cylindrical body 24 so as to provide secure yet replaceable locking means maintaining the body 24, cylinder head 36, and front end cap in their respective positions.

The front end cap 38 is internally recessed, as at 44 so as to position a combination dirt and grease seal 46 around the front end of the tooth point 48. The larger internal chamber or cavity 50 is provided with a bronze bushing 52 slidably receiving a shouldered portion 54 on the tooth point 48. A plugged opening 56 is provided in communication with the cavity 50 for the introduction of lubricating grease with the shoulder portion 54 being provided at its outer periphery with longitudinal grooves 58 intersecting an annular groove 60 so as to enable the passage of the lubricating grease upon move-
ment of the tooth point 48, the shoulder 54 acting as a pump whereby grease trapped within the cavity 50 is transferred from one side to the other of the shoulder thus insuring a proper lubrication of the bushing 52.

On the inner side of the shoulder 54, the tooth point 48 extends inwardly and forms an internally threaded portion 62 into which, through an interference fit, a tooth holder 64 is securely fastened. This tooth holder 64 is also provided with a shouldered portion 66 which is adapted for axial sliding within a bronze bushing 68 which in turn, through a shrink press fit, lines the inner wall of the cylindrical body 24. This shouldered portion 66 is provided with an annular, longitudinal and radial lubricating grooves 70, as well as a suitable seal 72, such as for example a “quadrizing” seal.

Freely mounted between the shoulders 64 and 66 is a synthetic rubber doughnut 74 bonded at each end to washers 76 and 78, in their normal or unstressed state, occupy or extend through the space between the front end of the bushing 68 and the inner end of the front end cap 38, as illustrated in FIGURES 4 and 10. At the time of assembly, the cavity between the shouldered portion 66 and the washer 76 is partially filled with grease, this washer 76 having inner longitudinal passages 80 there-through whereby at a forward motion of the tooth holder 64 forces the grease first into the lubricating grooves 70 and then through the passages 80 into the sleeve-like cavity by virtue of the pressure. A suitable breather hole 82 being provided so as to insure against any build-up of positive or negative pressures.

The inward motion of the interlocked tooth point and tooth holder assembly is limited to the position shown in FIGURE 7 wherein the portion 62 of the tooth point 48 is abutted against the washer 76 which in turn is abutted against the forward end of the bushing 68, this position requiring a predetermined compression of the doughnut 74 from its natural form for reasons which shall be given later.

The maximum forward position of the tooth assembly is shown in FIGURE 8 where the doughnut 74 is compressed to a substantial degree by an excessive forward motion of the tooth assembly due to unused energy of impact which must be absorbed by the rubber doughnut 74. This may happen occasionally, depending on the particular surface formation, whereby a relatively hard material reacts sufficiently against the tooth point 48 to force the tooth assembly, including the tooth point 48 and tooth holder 64, inwardly of the full extent needed to open the air supply valve but where the medium backing the crust is taken away by the impact of the tooth point exerted onto it once the device has been actuated by the opening of the supply valve as shall be described presently. The rebound energy of the doughnut 74 will, however, immediately restore the tooth assembly to its normal position as shown in FIGURE 4. It is contemplated 66 durometer Nitrile Rubber be used for this doughnut which is capable of absorbing, occasionally up to 20 ft. lbs. of energy, without permanent deformation.

Referring now specifically to the cylinder head 36, it will be noted that such is provided with a stepped-down axial bore forming an annular shoulder 34 forming a seat for the septum 86 which, through gaskets 88 and 90, a threaded plug 92, and a lock nut 94, effectively divides the axial bore of the cylinder head 36 into two chambers 96 and 98. The rear chamber 98 housing a supply valve 100, of the poppet-type, backed up by a spring 102. The supply valve 100 is provided with an axially movable annular shouldering 104 axially movable within a corresponding axial bore 106 in the septum 86 where “quadrizing” seal 108 completes the separation between the chambers 96 and 98 in the cylinder head 36. The septum 86 is provided with an enlarged bore portion 110 and an annular groove 112 so as to form a shoulder 142 adapted to engage the shoulders 132 and 134 when the tooth assembly is pushed inwards as shown in FIGURES 7 and 10. The spring 136 is such that, in its range from its initial length (FIGURES 4 and 8) to full compression (when the two shoulders 132 and 134 abut against each other), its force is larger than the combined force of the spring 102 and that of the air pressure applied to the cross-sectional area of the valve seat 112 when the supply valve 100 is closed (FIGURES 4 and 8). Consequently, any inward motion of the tooth assembly, when the supply valve 100 is closed, can have no effect against the valve 100 until the two sleeves 132 and 134 are brought into abutment with each other. The proportioning of the various elements involved is such, however, that this abutment cannot take place until the rubber doughnut 74 has been compressed a predetermined amount, for example ½”. When this position has been reached, any further inward motion of the tooth assembly will serve to crack open valve 100 which then by equalization of pressures on both sides thereof, succumbs to the action of spring 136 and opens fully, for example, ⅞”, while the tooth assembly can proceed inwards approximately another ⅛” at which point it is stopped by the extension 62 meeting the washer 76. The position of the various elements at this stage is shown in FIGURE 7. It is well to note now that, once the supply valve 100 has been opened, it will be kept at rest in this position as long as any outward motion of the tooth assembly does not exceed the point where the sleeve 134, which also would move outwards under the action of spring 136. Communication between the two chambers is established by provided between the enlarged bore portion 110 and an annular groove 114 in the cylinder head by means of radial apertures 116 with bores 118 and 120 forming, in conjunction with the apertures 116 and annular groove 114, a complete communication between the rear and front chambers 98 and 96. The open ends of the bores 118 and 120 are closed by the use of suitable brazed-in plugs 122. The threaded plug 92 is provided with a central tapped hole 124 permitting the pneumatic device to a source of compressed air.

When the supply valve 100 is seated against the valve seat 112 by the force of the spring 102 and the compressed air, as shown in FIGURES 4 and 8, no communication exists between the two chambers 96 and 98 in the cylinder head 36 and hence the device is rendered inoperative. A poppet type valve has been chosen, in preference to a sliding port type, because, besides being capable of providing an effective seal against a continuous air leakage while the device is not in use, it has the property of requiring a large force in order to open it, and a much lesser force to keep it open. In fact, in order to open the valve 100, a force is required which is capable of overcoming not only the light resistance of the spring 102, but also the force resulting from the air pressure applied to the area of the valve seat 112. Once the valve 100 has been opened, however, the force exerted by the air pressure is reduced proportionately to the cross-sectional area of the stem 104. The importance of this shall be explained presently.

To control the supply valve 100, a floating rod 126 has been provided, this rod 126 having a cross-sectional diameter larger than that of the valve stem 104. This floating rod 126 extends into a suitable cavity 128 specifically provided in the tooth assembly consisting of the tooth point 48 and tooth holder 64. Toward its forward end, the rod 126 is provided with a reduced diameter extension 130 receiving two shouldered sleeves 132 and 134 holding the compression spring 136 therebetween. The assembly of the rod 126 is completed by a riveted-on ferrule 138. The tooth assembly cavity 128 is stepped down to a smaller diameter cavity 140 so as to form a shoulder 142 adapted to engage the shoulders 132 and 134 when the tooth assembly is pushed inwards as shown in FIGURES 7 and 10. The spring 136 is such that, in its range from its initial length (FIGURES 4 and 8) to full compression (when the two sleeves 132 and 134 abut against each other), its force is larger than the combined force of the spring 102 and that of the air pressure applied to the cross-sectional area of the valve seat 112 when the supply valve 100 is closed (FIGURES 4 and 8). Consequently, any inward motion of the tooth assembly, when the supply valve 100 is closed, can have no effect against the valve 100 until the two sleeves 132 and 134 are brought into abutment with each other. The proportioning of the various elements involved is such, however, that this abutment cannot take place until the rubber doughnut 74 has been compressed a predetermined amount, for example ½”. When this position has been reached, any further inward motion of the tooth assembly will serve to crack open valve 100 which then by equalization of pressures on both sides thereof, succumbs to the action of spring 136 and opens fully, for example, ⅞”, while the tooth assembly can proceed inwards approximately another ⅛” at which point it is stopped by the extension 62 meeting the washer 76. The position of the various elements at this stage is shown in FIGURE 7. It is well to note now that, once the supply valve 100 has been opened, it will be kept at rest in this position as long as any outward motion of the tooth assembly does not exceed the point where the sleeve 134, which also would move outwards under the action of spring 136. Communication between the two chambers is established by provided between the enlarged bore portion 110 and an annular groove 114 in the cylinder head by means of radial apertures 116 with bores 118 and 120 forming, in conjunction with the apertures 116 and annular groove 114, a complete communication between the rear and front chambers 98 and 96. The open ends of the bores 118 and 120 are closed by the use of suitable brazed-in plugs 122. The threaded plug 92 is provided with a central tapped hole 124 permitting the pneumatic device to a source of compressed air.
assembly from any active contact with the sleeve 134. It is then that the combined forces of spring 102 and the compressed air acting upon the cross-sectional area of stem 104 will push forward the rod 126 and its assembled parts to follow the outward motion of the tooth assembly until the valve 160 is closed and the relative position of the parts involved is again as shown in FIGURES 4 and 8.

Thus, it will be appreciated that in order to open the supply valve 100, the tooth point 48 must be pushed inward with a force capable not only of overcoming the full force which keeps the valve 160 closed, but also of compressing spring 144 (to be referred to later) and the rubber doughnut 74, the total of which is a substantial force capable of being engendered only by the reaction of a very compact media. Also, the opening of this supply valve 100 can take place only at the very inward limit of this travel. From then on, the tooth assembly can move in and out, up to, for example, 1/36" outward penetration, without affecting the position of the valve 100. The valve will begin to move only to follow any further outward motion of the tooth assembly by the outer diameter slightly smaller than the inner diameter of the recess 170 provided to house it, but not by any further inward motion of the tooth assembly after which any further outward motion of the tooth assembly will cause it to lose all contact with the sleeve 134. Once this has taken place, that is once the valve 106 has been closed, the tooth assembly must travel inwards to within 1/36" of its maximum inward position before the valve 100 can be opened again, and the reaction of the medium opposing the tooth point 48 must be such as to engage the full force required to open the valve 100, to compress the spring 144 and to deform the rubber doughnut 74 as described supra. In normal operation, however, once the medium of suitable resistance has been encountered, such as to open the valve 100, this medium is also capable of absorbing the energy of impact to which the tooth assembly is subjected within the limits of its normal penetration, and, consequently, the supply valve 100, once opened, will remain at rest in this position, or at worst, will be subjected to limited axial movements. At this point, it should be recognized that if the application of the device were to be limited to hard media, the doughnut 74 could be eliminated and the device simplified.

To provide for the hammer blows against the inner face of the tooth holder 64, a plunger 146 is provided. This plunger 146 is adapted to float axially through a closed passage in the holder and will follow the inward movement of the holder 64 when the holder is rotated forward by a supply of compressed air being admitted and metered against the rear face of the plunger 146 as will be described presently. The return spring 144 is intended to return the plunger 146 to its original position, note FIGURE 4, after the blow against the tooth holder 64 has been imparted, note FIGURE 9. The cylinder chamber between the front end of the plunger 146 and the inner end of the tooth holder 64 is always open to the atmosphere through openings 148 and 156. Openings 148 and 156 are provided at both sides of the cylinder for convenience when mounting the device 20 into the appropriate recesses in the lip of a bucket 22. The unused opening 150 is to be suitably plugged as at 154 with the outer ends of the openings 148 being permanently sealed by the brass stop plug 156. In order to protect the pneumatic tooth 20 from dirt and dust, the perforated nipple 152 and the opening 150 is to be filled with a section of plastic window screening 158 rolled several times over itself, or with other non-rusting air filtering material, the rear end of the perforated nipple 152 then being closed by a suitable pipe plug 160.

To control the admission of compressed air into the chamber behind the plunger 46, that is between the cylinder head 36 and the plunger 146, a sliding port inlet valve 162 is provided. A spring 164 tends to maintain this valve 162 in the forward or closed position, note FIGURES 8 and 10, and a retaining ring 166 is used as a stop against any further forward motion of the valve 162 beyond the limits as shown in FIGURES 4 and 8.

The inlet valve 162 is provided with an extension 168 which holds, within a suitable recess 170, a floating ground washer 172, a retaining ring 174 being utilized. The floating washer 172 has its outer diameter slightly smaller than the inner diameter of the recess 170 provided to house it, but not by any further inward motion of the valve 162 beyond the limits as shown in FIGURES 4 and 8. To control the admission of compressed air into the chamber behind the plunger 146, a sliding port inlet valve 162 is provided. A spring 164 tends to maintain this valve 162 in the forward or closed position, note FIGURES 8 and 10, and a retaining ring 166 is used as a stop against any further forward motion of the valve 162 beyond the limits as shown in FIGURES 4 and 8.

The inlet valve 162 is provided with an extension 168 which holds, within a suitable recess 170, a floating ground washer 172, a retaining ring 174 being utilized. The floating washer 172 has its outer diameter slightly smaller than the inner diameter of the recess 170 provided to house it, but not by any further inward motion of the valve 162 beyond the limits as shown in FIGURES 4 and 8.

The inner diameter of the floating washer 172 is such that it provides a close tolerance sliding fit over the outer diameter of the straight portion of the rear end of a sleeve 178 when this sleeve is engaged with the floating washer 172 as shown in FIGURES 7, 8, and 9. The tapered tip 180 of the sleeve 178 is tapered down to such a diameter that, as the sleeve 178 is about to engage the floating washer 172, the washer 172 will be engaged without interference due to lack of concentricity, and it will be automatically centered around the sleeve 178 in the tapered tip 180 during the continued rearward motion of the sleeve 178.

The sleeve 178 is actually an exhaust valve held by, and cooperating with, the plunger 146. An O-ring 182, bonded in place within a recessed groove against a shoulder 184 on the sleeve 178, provides the valve seal when it serves as the beveled entrance 186 of the recess 188 within the plunger 146. The rear face of the shoulder 184 serves as a stop against any further unwanted rearward motion of the sleeve 178 in relation to the plunger 146 when this rear face engages the perforated disc 190 maintained in position within the plunger 146 by a retaining ring 192, note FIGURE 8.

The forward portion 194 of the sleeve 178, immediately adjacent the shoulder 184, is adapted for a close tolerance sliding fit within the recess 188 in the plunger 146, this forward portion 194 being provided with three longitudinally extending flutes 196 positioned at 120° from each other and terminating, at one end thereof, in an annular groove 198, this groove 198 being so positioned and so dimensioned so as to, irrespective of the relative position of the sleeve 178 and plunger 146, be always in communication with the air passages through a matching perforation 200 suitably located in the plunger 146. Forward of the fluted portion 194, the sleeve 178 is stepped down so as to receive and cooperate with a spring 202, this stepped down portion 204 extending beyond the forward end of the plunger 146 essentially as shown.

The sleeve 178 includes a passage extending axially therethrough, this passage 206 being of such a diameter as to provide a close tolerance sliding fit over the rod 126 which is thereby held centrally located within the device while at the same time being free to float axially. The rod 126 is provided, for a predetermined length, with three longitudinal flutes 208 located at 120° from each other, the purpose of these flutes 208 to become apparent subsequently. The sleeve 178, which as noted before serves as an exhaust valve, is maintained open by the spring 202 as shown in FIGURE 8, and is closed and maintained closed by a predetermined air pressure behind the plunger 146, such as for example at least 10 p.s.i., the spring 202 being so calibrated that a pressure of 10 p.s.i. applied to the effective area of the sleeve 178 will overcome it.

When the plunger 146, in its forward motion with the exhaust valve closed, is about to reach the rear face of the tooth holder 64, the protruding end of the sleeve 178
is first engaged by a floating washer 210 which is held in place by a suitable recess 212 provided within the rearward end of the tooth holder 64. This floating washer 210 is backed by a rubber bumper 214 and another washer 216, a filler ring 218 and retaining ring 220 holding these elements in position. The bumper 214 and washer 216 are of a size so as to fit snugly within the inside diameter of the recess 212 within the tooth holder 64 with their inside diameters being such so as to provide ample clearance around the rod 126. The washer 210 has an outside diameter smaller than the inside diameter of the recess 212 while its inner diameter is adapted for sliding fit around the rod 126. The longitudinal clearances between these washers being such that the washer 210 is free to float in a cross-sectional plane. Accordingly, the washer 210 is self-centering around the rod 126 so as to allow for any lack of concentricity. The inner periphery of the washer 210 is provided with three scalloped openings 222 serving as vents for free air breathing to and from the longitudinal cavity 128 within the tooth assembly.

When the protruding end of the sleeve 178 meets the washer 210, the exhaust valve is forcibly opened thereby overcoming the remaining air pressure behind the plunger 146 at the end of its forward stroke, the exhaust valve remaining open until a pressure of at least 10 p.s.i. is re-established behind the plunger 146 during the return stroke of the latter.

Referring again to the cylinder head 36, it will be noted that the rubber washer 88, forming a seal for the forward end of the septum 86, extends radially inward beyond the surfaces to be sealed so as to form a bumper and a seal against the rearward rounded lip 224 of the inlet valve 162 when the inlet valve 162 is fully opened by air pressure shown in FIGURE 7. To provide a seal between the cylinder head 36 and the cylindrical body 24, a rubber washer 226 has been provided, this washer 226 being pressed between the forward end of the cylinder head 36 and the rear lip of the bushing 68. The washer 226, as will be appreciated from the drawings, extends radially inward beyond the limits of the surfaces to be sealed for the purpose of providing a bumper for the rear end of the plunger 146 when the plunger 146 comes to rest against it at the end of a return stroke while the air supply valve 100 has been closed and when, at the same time, the return stroke of the plunger 146 is reflected solely through the energy of the return spring 144.

The bottom of the inner cavity of extension 168 on inlet valve 162 is also provided with a rubber bumper 228 which comes into action against the suitably beveled rear lip of sleeve 178 when the supply valve 100 has been closed and the inlet valve 162 is opened and kept open only by the action of the return spring 144, note FIGURE 4.

Referring now to the general operation of the pneumatic tooth comprising the instant invention, attention is first directed to FIGURE 4 wherein the device 20 has been illustrated in an at rest position. Since the tooth point 48 is not being pressed against a reacting medium, the return spring 144 keeps the tooth point 48 in its normal outward position with the shoulders of extension 66 of the tooth holder 64 resting against the washer 76, the return spring 144 at the same time keeping the plunger 146 in its most rearward position resting against the bumper 226. The exhaust valve or sleeve 178 is kept in the closed position while its extreme rear beveled lip 180 holds the inlet valve 162 open by pressing against the bumper 228. It will of course be appreciated that until the spring 144, when the latter is fully extended as shown in FIGURE 4, will substantially exceed the sum total of the weight of the plunger 146 and of the inlet valve 162 along with the force exerted by the fully compressed spring 164. In this position, the rear straight extension of the valve or sleeve 178 is well inside the extension 168 of the inlet valve 162 and, in cooperation with the washer 172, forming an effective partition between the air chambers behind and ahead of the inlet valve 162. This partition needs merely to function as an effective obstruction, rather than a seal, against the passage of air from the forward chamber into the rear chamber. Also, it will be appreciated that the relative position of the sleeve 178 and rod 126 keeps the air trapped in the rear chamber of the inlet valve 162 at atmospheric pressure through the flutes 208 within the rod 126, these flutes 208 being open at both ends in this position.

When the pneumatic tooth is pushed forward against a medium of sufficient resistance, the tooth assembly, including the tooth point 48 and tooth holder 64, is forced inward until the doughnut 74 is compressed and the supply valve 100 is opened, note FIGURE 7. The inrush of compressed air in the chamber ahead of the inlet valve 162 forces the latter to open more fully, also with reference to FIGURE 7, where the rounded lip 224 of the inlet valve 162 comes to rest against the bumper seal 88, the plunger 146 at the same time being started in its forward stroke.

With continuing reference to FIGURE 7, the plunger 146 has been illustrated therein as in a position where the rubber washer 88, forming a seal for the forward end of the sleeve 178 is about to completely cover the flutes 208 in the rod 126, and at the same time, the straight portion of the rear extension of the sleeve 178 is about to lose its engagement with the washer 172. Any further forward motion of the plunger 146 will have then the effect of closing the communication between the rear chamber of the inlet valve 162 with the atmosphere by completely covering the forward ends of the flutes 208 in the rod 126, and that of opening a communication between the two chambers behind and ahead of the inlet valve 162, thereby establishing an equilibrium of pressure between the two chambers and thus allowing spring 164 to push the inlet valve 162 forward until it is stopped by the retaining ring 166, this being shown in FIGURE 8. Accordingly, the air inlet behind the plunger 146 is thereby closed as soon as the plunger 146 has traveled forward for a predetermined distance from its initial position, as shown in FIGURE 4, to a position which is only slightly more forward than the one shown in FIGURE 7.

The compressed air so trapped behind the plunger 146 is now allowed to expand and to dissipate its energy by further accelerating the plunger 146 in its forward motion. The return spring 144 has been designed to effect the forward motion and beginning its return stroke after having hit the rear face of the tooth holder 64, note FIGURE 4. The mass of the plunger 146 and that of the tooth assembly being so chosen that the plunger 146 be lighter than the tooth assembly, by example, the plunger weighing 3.6 lbs. and the tooth assembly weighing 4.6 lbs., thus, the plunger 146 can never move any further forward than the position at which it hits the inner face of the tooth holder 64. Before the impact of the plunger 146 against the tooth assembly has had an opportunity to occur, it will be recognized that the exhaust valve 178 has been opened in order that any remaining air pressure behind the plunger 146 may be released to the atmosphere and atmospheric pressure be restored behind the plunger 146.

The forces impelling the plunger 146 in its return stroke are twofold, the force exerted by the return spring 144 and the suddenly applied force of rebound resulting from the impact between the plunger 146 and the tooth holder 64. The force of the spring 144 will be the same, independently of circumstances. However, the force of rebound will depend upon the amount of energy of which the tooth assembly has been able to dissipate by the amount and speed of its penetration into the medium opposing its forward motion. In the case of full dissipation of this energy, in which case the tooth assembly can reach, at the end of its forward motion, a position as shown in FIGURES 8 and 10, the rebound energy of impact is practically nil, it being possibly as low as
1.5% of the total energy of impact due to the relative masses of the plunger and tooth assembly. But, when the medium is such that repeated blows are required, involving very little dissipation of energy, before it yields, then practically all of the energy of impact is transferred back to the plunger as energy of rebound. Hence the plunger 146 can return with speeds varying from a minimum to a maximum, depending upon the magnitude of the energy of rebound available, which is added to the always available energy of the return spring 144.

As pointed out previously, the exhaust valve spring 282 is so calibrated as to be overcome by an air pressure of 10 p.s.i. acting against the effective area of the valve 178. The exhaust opening 200 in the plunger 146 is so calibrated that, at the travel speed which the plunger 146 acquires under the accelerating force of the return spring 144 alone, the amount of air which is allowed to pass through it to the atmosphere, from the chamber in the rear of the plunger 146, is such that by the time the plunger 146 is about in the position shown in FIGURE 10, a pressure of 10 p.s.i. will have developed behind the plunger 146 and thus behind the valve 178. The regulating and adjusting coefficients, and the known coefficients of air flow through sharp-edged orifices, will be a sufficient basis for establishing the size of this opening 200. In these circumstances, that is in the absence of any substantial energy of rebound, the exhaust valve 178 will close at a point where this valve is about to engage, or has just engaged, the inlet valve 162 through the gasket 228. Any further rearward motion of the plunger 146 from this position serves to create an air cushion between the cylinder head 36 and the rear face of the plunger 146, the build-up of this air cushion also assisting in opening the inlet valve 162 in order to admit a new supply of compressed air and start a new cycle.

Incidentally, it should be noted that the mass of the exhaust valve or sleeve 178 should be as light as possible, aluminum preferably being used. The reason for this is that in the event the valve 178 should hit the inlet valve 162 through the bumper 228 before the valve 178 is closed, its energy of impact should never be great enough so as to cause the inlet valve 162 to open before the exhaust valve 178 has been closed. Hence, it is important to establish a satisfactory relationship between the masses of the inlet valve 162 and of the exhaust valve 178, along with a suitable rating of the inlet valve spring 164.

Once the size of the exhaust opening 200 has been determined in accordance with the above, it follows that if the medium to be penetrated is such that the energy of the impact imparted by the plunger 146 upon the tooth assembly 151 is not sufficient to cause the plunger 146 to pass a definite amount of air in a given time under a given pressure, it follows that, with a greater speed of the plunger 146, in order for the same amount of air to be transferred from the chamber behind the plunger 146 to the atmosphere in a shorter period of time, a greater pressure would be required, this greater pressure, however closing the exhaust valve 178 before the plunger 146 reaches the position shown in FIGURE 10. The more unused energy is imparted to the plunger 146 in its return stroke the greater becomes the speed of this return stroke and the sooner the exhaust valve 178 be closed. Accordingly, the air cushion behind the plunger 146 will be proportionate to the amount of the unused energy, and this unused energy is exploited in recompressing the air so trapped behind the plunger 146 so that when the plunger 146 has finally reached the position shown in FIGURE 10, the flutes 200 in the valve 126 and about 10 p.s.i. will be exposed to the atmosphere and the inlet valve 162 opened, and when the valve 162 has finally been opened, only such an amount of compressed air will be admitted from the supply to the chamber behind the plunger 146 as required to re-establish full supply pressure in the chamber.

Accordingly, it will be appreciated that the economy of compressed air which this device realizes is obtained first by admitting only a predetermined amount of compressed air behind the plunger 146 and by exploiting the adiabatic energy of expansion of said air for the remainder, and greater part, of the forward stroke of the plunger, and second, by exploiting the occasional unused energy of impact, as it occurs in rock work, and partially recompressing the air trapped behind the plunger 146 by causing a premature closing of the exhaust valve 178 so as to require, for the next cycle, only a differential amount of compressed air sufficient to restore the equilibrium of pressure with the supply.

As an example, with a 3" outside diameter of cylinder, and a 2¼" plunger diameter, a plunger weight of 3.6 lbs., and a minimum plunger travel of 3", this device is capable of delivering 50 ft. lbs. blows at the rate of about five blows per second, using an average of 3 to 5 c.f. of free air per minute, compressed to 8 atmospheres (about 100 p.s.i.), depending on the medium of the plunger.

It should be noted also that since a good part of the energy imparted to the plunger 146 is generated by expansion of the compressed air, a noticeable cooling effect takes place within the cylinder during the forward stroke of the plunger. Accordingly, the air reservoir used to store the compressed air should be as small as practically possible, this reservoir together with the main supply lines leading from it to the device being suitably insulated against excessive heat losses so that the compressed air, when admitted into the device, has most of its heat of compression, and consequently, after expanding inside the cylinder, is exhausted at about ambient temperature, or slightly below.

In addition, for the lubrication of the supply valve, inlet valve, plunger, exhaust valve, and cylinder bushing, it is considered sufficient to insert on the main supply line an oiler, as usually practiced, making sure that a good grade of non-foaming hydraulic oil be used.

From the foregoing, it will be appreciated that a device has been defined incorporating many unique and patentably significant features among which are the following:

The use of a controlled volume of compressed air for the forward stroke of the plunger, this controlled volume of air being approximately one-quarter of the total volume available after the plunger has completed its forward stroke with the remaining three-quarters of the volume allowing practical exploitation of the adiabatic expansion of the compressed air. The return stroke of the plunger is obtained exclusively through a return spring and through the energy of rebound when available.

An exhaust valve calibrated to close at a relatively low pressure and an exhaust port within the plunger which is so calibrated as to allow the build-up of this low pressure behind the plunger during its return stroke so as to close the exhaust valve when the plunger has completely passed a definite amount of air in a given time under a given pressure, it follows that, with a greater speed of the plunger 146, in order for the same amount of air to be transferred from the chamber behind the plunger 146 to the atmosphere in a shorter period of time, a greater pressure would be required, this greater pressure however closing the exhaust valve 178 before the plunger 146 reaches the position shown in FIGURE 10. The more unused energy is imparted to the plunger 146 in its return stroke the greater becomes the speed of this return stroke and the sooner the exhaust valve 178 be closed. Accordingly, the air cushion behind the plunger 146 will be proportionate to the amount of the unused energy, and this unused energy is exploited in recompressing the air so trapped behind the plunger 146 so that when the plunger 146 has finally reached the position shown in FIGURE 10, the flutes 200 in the valve 126 and about 10 p.s.i. will be exposed to the atmosphere and the inlet valve 162 opened, and when the valve 162 has finally been opened, only such an amount of compressed air will be admitted from the supply to the chamber behind the plunger 146 as required to re-establish full supply pressure in the chamber.

Accordingly, it will be appreciated that the economy of compressed air which this device realizes is obtained first by admitting only a predetermined amount of compressed air behind the plunger 146 and by exploiting the adiabatic energy of expansion of said air for the remainder, and greater part, of the forward stroke of the plunger, and second, by exploiting the occasional unused energy of impact, as it occurs in rock work, and partially recompressing the air trapped behind the plunger 146 by causing a premature closing of the exhaust valve 178 so as to require, for the next cycle, only a differential amount of compressed air sufficient to restore the equilibrium of pressure with the supply.

As an example, with a 3" outside diameter of cylinder, and a 2¼" plunger diameter, a plunger weight of 3.6 lbs., and a minimum plunger travel of 3", this device is capable of delivering 50 ft. lbs. blows at the rate of about five blows per second, using an average of 3 to 5 c.f. of free air per minute, compressed to 8 atmospheres (about 100 p.s.i.), depending on the medium of the plunger.

It should be noted also that since a good part of the energy imparted to the plunger 146 is generated by expansion of the compressed air, a noticeable cooling effect takes place within the cylinder during the forward stroke of the plunger. Accordingly, the air reservoir used to store the compressed air should be as small as practically possible, this reservoir together with the main supply lines leading from it to the device being suitably insulated against excessive heat losses so that the compressed air, when admitted into the device, has most of its heat of compression, and consequently, after expanding inside the cylinder, is exhausted at about ambient temperature, or slightly below.

In addition, for the lubrication of the supply valve, inlet valve, plunger, exhaust valve, and cylinder bushing, it is considered sufficient to insert on the main supply line an oiler, as usually practiced, making sure that a good grade of non-foaming hydraulic oil be used.

From the foregoing, it will be appreciated that a device has been defined incorporating many unique and patentably significant features among which are the following:

The use of a controlled volume of compressed air for the forward stroke of the plunger, this controlled volume of air being approximately one-quarter of the total volume available after the plunger has completed its forward stroke with the remaining three-quarters of the volume allowing practical exploitation of the adiabatic expansion of the compressed air. The return stroke of the plunger is obtained exclusively through a return spring and through the energy of rebound when available.

An exhaust valve calibrated to close at a relatively low pressure and an exhaust port within the plunger which is so calibrated as to allow the build-up of this low pressure behind the plunger during its return stroke so as to close the exhaust valve when the plunger has completed approximately three-fourths of its return travel when actuated by the return spring only, that is, in the absence of any rebound energy. With higher return speeds, as caused by the existence of rebound energy, the exhaust valve will naturally close at an earlier stage of the return stroke, with the consequent formation of an air cushion behind the plunger which is proportionate to the amount of rebound (or unrecovered) energy. An air inlet valve controlling the admission of the controlled volume of compressed air behind the plunger, this inlet valve being spring closed and opened by compressed air through its cooperation with an extension of the exhaust valve whereby the air line opening behind the inlet valve is allowed to attain full cylinder pressure when it has to close, or is separated from the cylinder chamber and opened to atmospheric pressure when it has to open.
this latter being accomplished also in cooperation with special flutes built into a floating axial stem, the main purpose of which however is to control the main supply valve as will be described subsequently.

A main supply valve which controls the operation of the device, and which is adapted to open, through the action of the floating axial stem mentioned supra, when the latter passes inward by the inward motion of the tooth resulting from the pushing of the device against a medium of sufficient resistance. This resistance is determined by the force required to open the poppet type supply valve plus the force required to compress the main return spring, plus the force required to compress a rubber shock absorber during the very last part of the inward motion of the tooth point, the design of the elements just described being such that, through the action of a spring engagement between the tooth point and floating stem, the supply valve can open only during the last eighth of an inch of the inward travel of the tooth point, however, it is to be kept open and in a fixed position until the tooth point is about to complete its forward motion under the impact of the plunger if the medium opposing the tooth point is such as to allow this forward motion.

A rubber shock absorber adapted to absorb any unused energy of the tooth point when the latter is about to complete its forward motion. This shock absorber functions only as such when the medium opposing the tooth point, while presenting a sufficiently hard crest to enable the tooth point to move all the way inward so as to open the supply valve, does not have a sufficiently hard core behind this crest and thereby is incapable of absorbing the energy of the hammer blow it receives. If the device is used only against very hard material, the rubber shock absorber is superfluous.

The foregoing is considered as illustrative only of the principles of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation shown and described, and accordingly all suitable modifications and equivalents may be resorted to, falling within the scope of the invention as claimed.

What is claimed as new is as follows:

1. A pneumatic tooth for an earth excavator comprising an elongated cylindrical body, a tooth assembly slidably mounted within the forward end portion of the body and axially extensible and retractable relative thereto, an impact receiving surface on the inner end of said tooth assembly, a plunger means freely floating within said body and selectively engageable with said impact receiving surface, biasing means engaging said plunger means and said tooth assembly and resiliently urging said members apart, means communicating the chamber formed between the plunger means and tooth assembly with the atmosphere, an expansion chamber rearward of said plunger means, means for conveying compressed air into said expansion chamber, a supply valve for selectively allowing passage of the compressed air into the expansion chamber, a floating rod means having one end thereof engaged with the supply valve and means operatively connecting the other end with the tooth assembly in a manner so as to allow for a predetermined reciprocating movement of the tooth assembly relative to the body and rod means, said rod means being operative so as to open supply valve upon retraction of said tooth assembly beyond a predetermined point, means effecting the closing of said supply valve upon the extension of the tooth assembly beyond a predetermined point subsequent to the opening of the supply valve whereby reciprocation of the tooth assembly is allowed between the two predetermined points without effecting a closing of the supply valve, a control means controlling the introduction of compressed air into the expansion chamber, said control valve being operative in response to movement of the plunger means so as to open upon the approach of the plunger means to its rearmost or retracted position and to close upon the movement of the plunger means forward beyond a predetermined point along its path of travel toward the tooth assembly impact receiving surface, and an exhaust valve selectively communicating the expansion chamber with the atmosphere, said exhaust valve remaining closed through the major portion of the forward travel of the plunger means, the exhaust valve closing during the retraction of the plunger at a point variable in response to the speed of retraction so as to produce an air cushion within the expansion chamber.

2. The device of claim 1 wherein said tooth assembly includes a shock absorbing means cushioning excessive forward movement of the tooth assembly and providing a predetermined resistance to the retraction of the tooth assembly.

3. The device of claim 1 wherein the means operatively connecting the other end of the rod means with the tooth assembly comprises an abutment member slidably received on said rod means adjacent said other end, a second abutment member on said rod means rearward of said first abutment member, said second abutment member being fixed against rearward movement of said rod means, means resiliently biasing said first abutment member toward said other end and away from said second abutment member, and means on said tooth assembly engageable against said first abutment member upon a retraction of said tooth assembly in a manner so as to move the first abutment member rearward against the biasing means into engagement with the second abutment member and subsequently move the rod means rearwardly to open said supply valve.

4. The device of claim 1 wherein said rod means extends generally coaxially within said body, said plunger means including an axial passage therethrough slidably receiving said rod means, at least one flute in said rod means along that portion thereof received through the plunger means, said flute communicating the expansion chamber rearward of the plunger means with the chamber forward of the plunger means between the plunger means and the tooth assembly, said exhaust valve comprising a sleeve received over a portion of the fluted section of the rod means and slideably thereon for selectively precluding communication between the flute and the chamber forward of the plunger means.

5. In a pneumatic tool, an elongated hollow body, a tooth assembly slidably mounted in the forward end portion of the body and axially extensible and retractable relative thereto, an impact receiving surface on the inner end of said tooth assembly, plunger means freely floating within said body and selectively engageable with said impact receiving surface, biasing means engaging said plunger means and said tooth assembly and resiliently urging said members apart, means communicating the chamber formed between the plunger means and tooth assembly with the atmosphere, an expansion chamber rearward of said plunger means, means for conveying compressed air into said expansion chamber, a supply valve for selectively allowing passage of the compressed air into the expansion chamber, a floating rod means having one end thereof engaged with the supply valve and means operatively connecting the other end with the tooth assembly in a manner so as to allow for a predetermined reciprocating movement of the tooth assembly relative to the body and control means, said control means being operative so as to open supply valve upon the continued retraction of the tooth assembly beyond a predetermined point reached by an initial retraction of said tooth assembly, and means effecting the closing of said supply valve upon the extension of the tooth assembly beyond a predetermined point subsequent to the opening of the supply valve whereby reciprocation of the tooth assembly is allowed between the two predetermined points without effecting a closing of the supply valve.
6. The device of claim 5 including control valve means controlling the introduction of compressed air into the expansion chamber, said control valve means being operative in response to movement of the plunger means so as to open upon the approach of the plunger means to its rearmost or retracted position and to close and trap compressed air within the expansion chamber upon movement of the plunger means forward and beyond a predetermined point along its path of travel toward the tooth assembly impact receiving surface, and exhaust valve means selectively communicating the expansion chamber with the atmosphere.

7. In a pneumatic tool, an elongated hollow body, a tooth assembly slidably mounted within the forward end portion of the body and axially extensible and retractible relative thereto, an impact receiving surface on the inner end of said tooth assembly, plunger means slidable within said body and selectively engageable with said impact receiving surface, an expansion chamber rearward of said plunger means, means for conveying compressed air into said expansion chamber, supply valve means for selectively allowing passage of the compressed air into the expansion chamber, means operatively connecting the tooth assembly with the supply valve means for controlling the opening and closing of said supply valve means on movement of the tooth assembly beyond predetermined points, and control valve means operative in response to a forward movement of said plunger means for sealing said expansion chamber and trapping compressed air therein for a subsequent expansion thereof and a corresponding forward driving of said plunger means.

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