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Komazaki et al.

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(45) **Date of Patent: Jan. 2, 2007**

(54) **PNEUMATICALLY OPERATED FASTENER DRIVING TOOL**

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F01L 25/04 (2006.01)

(52) **U.S. Cl.** **91/304**; 91/461; 60/413

(58) **Field of Classification Search** 60/413; 91/304, 308, 456, 461

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,713,165 A * 7/1955 Campbell et al. 91/457
3,200,716 A * 8/1965 Le Sage 91/461
3,583,496 A * 6/1971 Fehrs 91/308
3,808,620 A * 5/1974 Rothfuss et al. 91/308
5,085,126 A 2/1992 Mukoyama
5,715,986 A * 2/1998 Sauer 227/130

FOREIGN PATENT DOCUMENTS

JP	54-023274	2/1979
JP	3-208569	9/1991
JP	32-08569	9/1991
JP	5-138548	6/1993
JP	51-38548	6/1993
JP	11-033930	2/1999

* cited by examiner

Primary Examiner—Igor Kershteyn
(74) *Attorney, Agent, or Firm*—Antonelli, Terry, Stout and Kraus, LLP.

(57) **ABSTRACT**

A pneumatically operated fastener driving tool capable of reducing a time period from operation timing of a trigger to downward movement of a driver blade for fastener driving, and reducing a time period from the release timing of the trigger to a timing at which respective components are returned to their initial positions for a subsequent nail driving. As components a main valve and a trigger valve is provided. The main valve is movable within a main valve chamber connected to a main valve control channel. The trigger valve selectively provides fluid communication between the accumulator and a main valve chamber through the main valve control channel and between the main valve chamber and the atmosphere through the main valve control channel. A ratio of cross-sectional area of the main valve control channel to an internal volume of the main valve chamber is defined to a specified ratio.

31 Claims, 16 Drawing Sheets

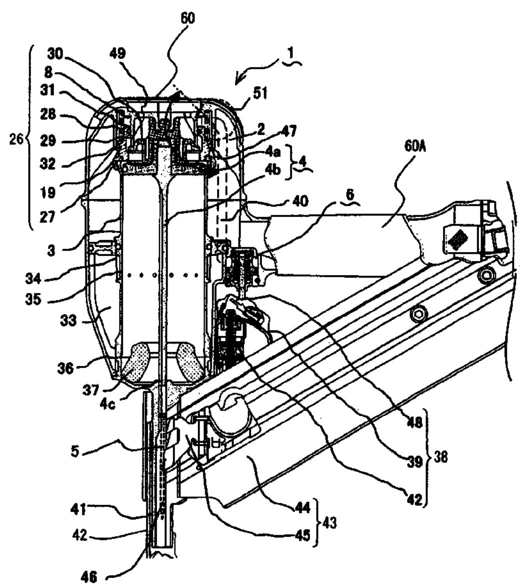

FIG. 1

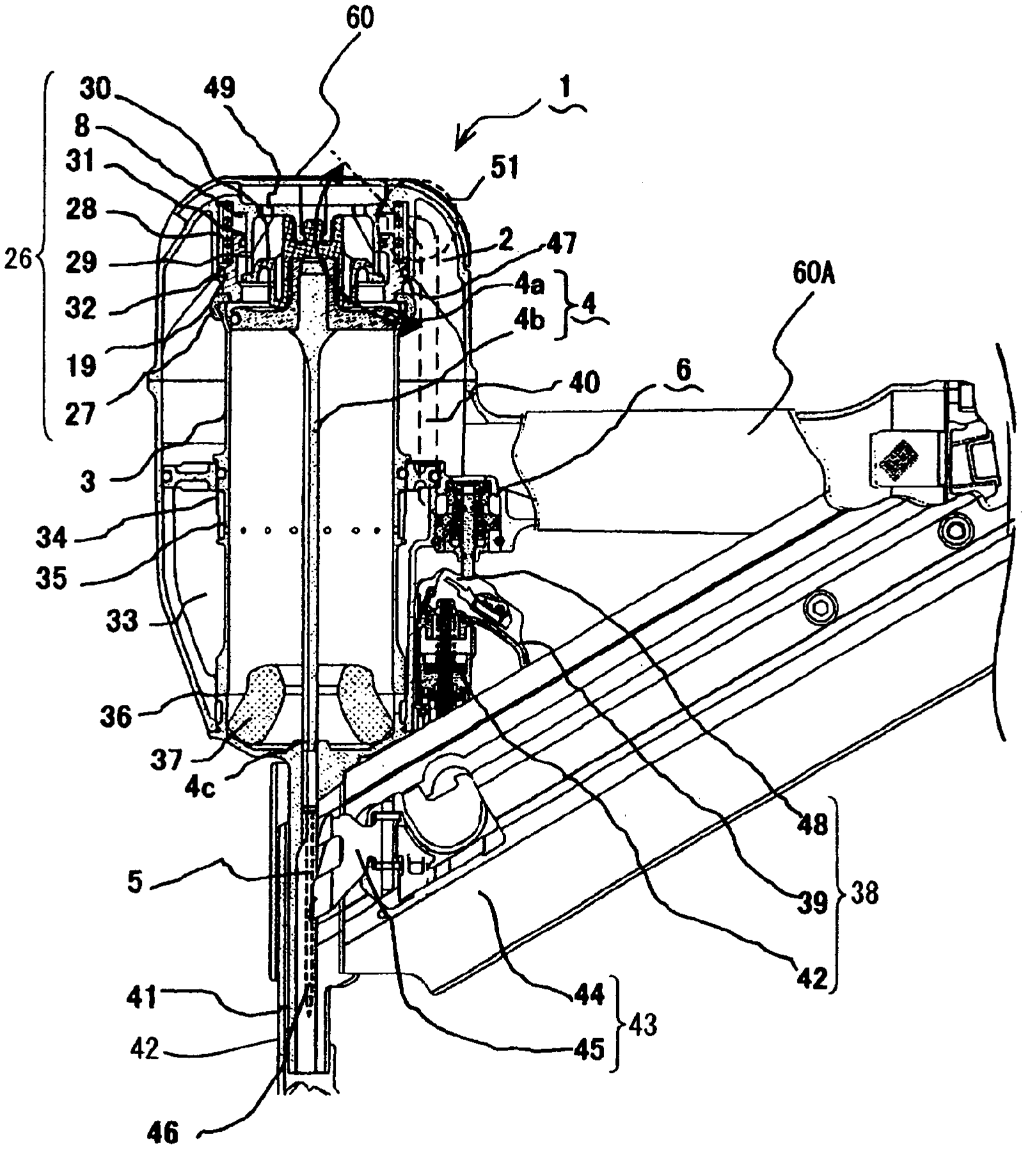
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FIG. 2

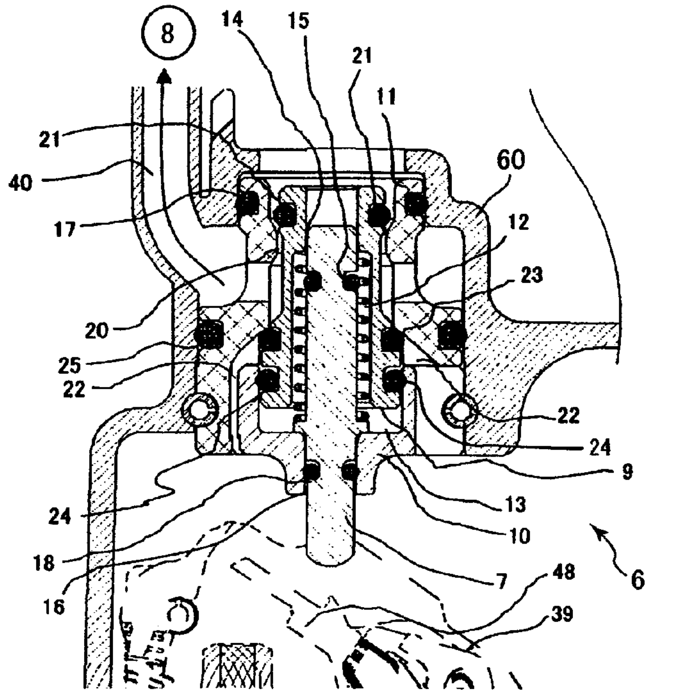
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FIG. 3

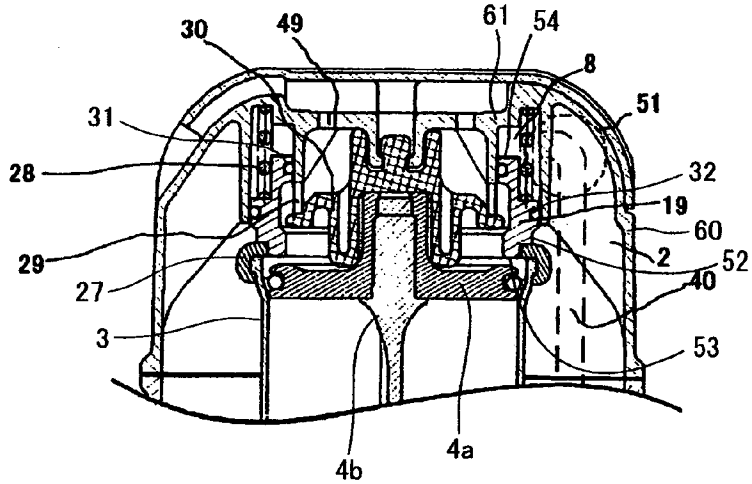
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FIG. 4

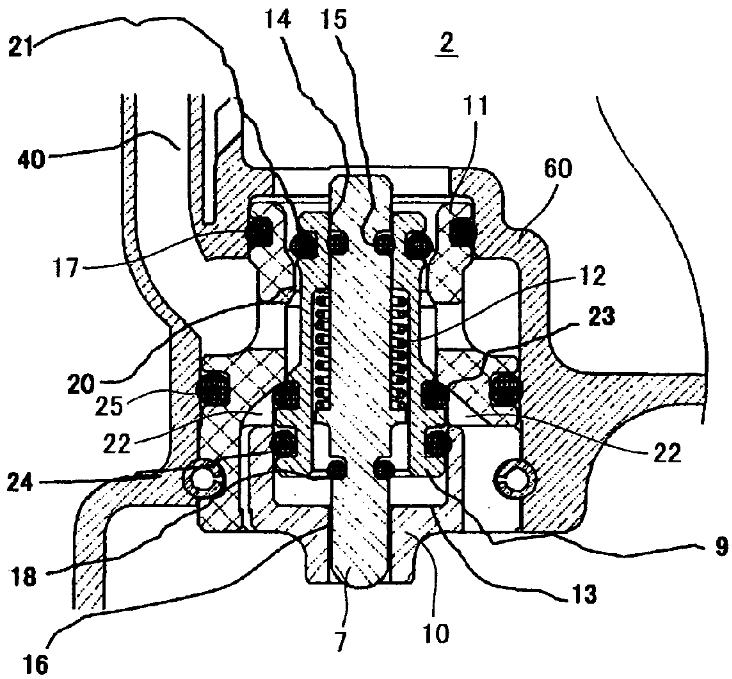
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FIG. 5

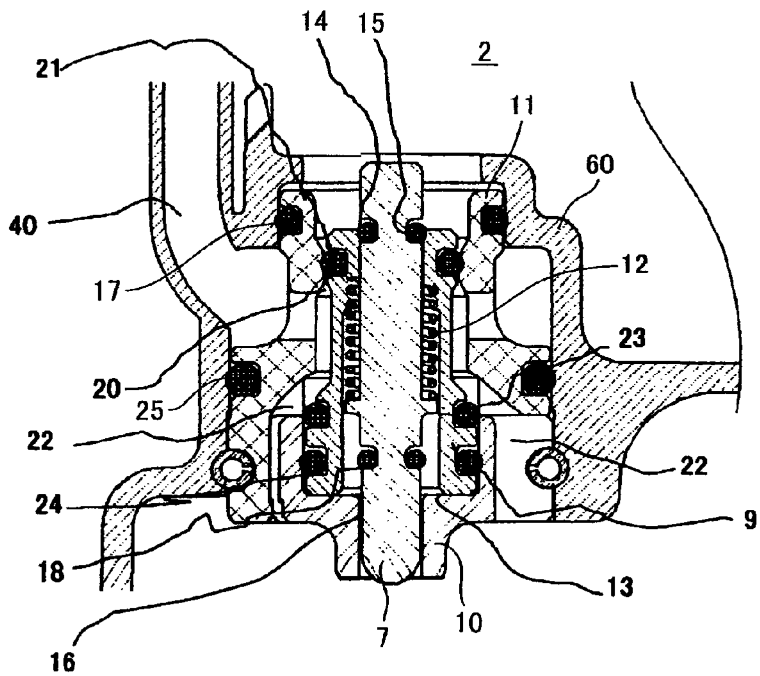
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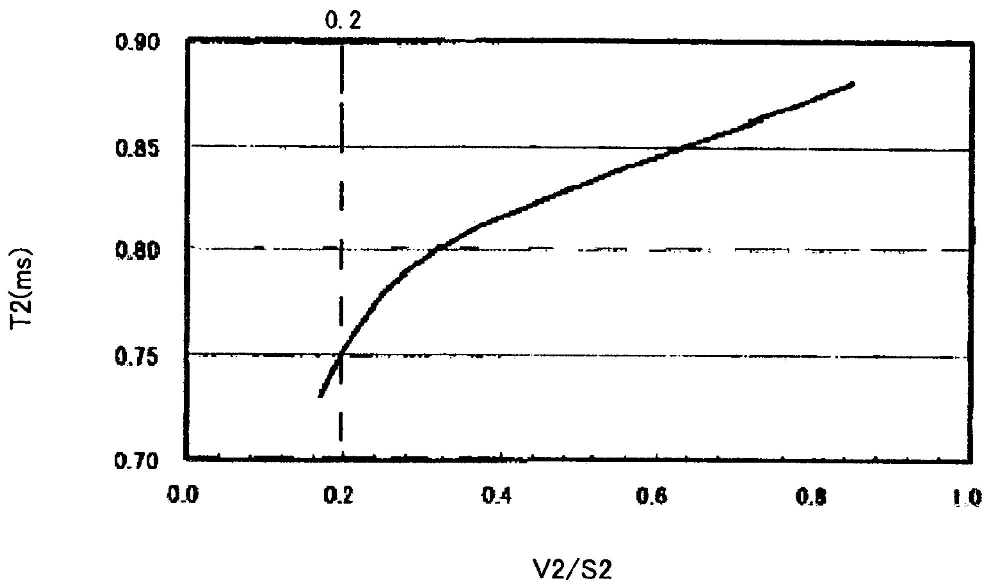
FIG. 6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0.90
0.85
0.80
0.75
0.70
T2(ms)
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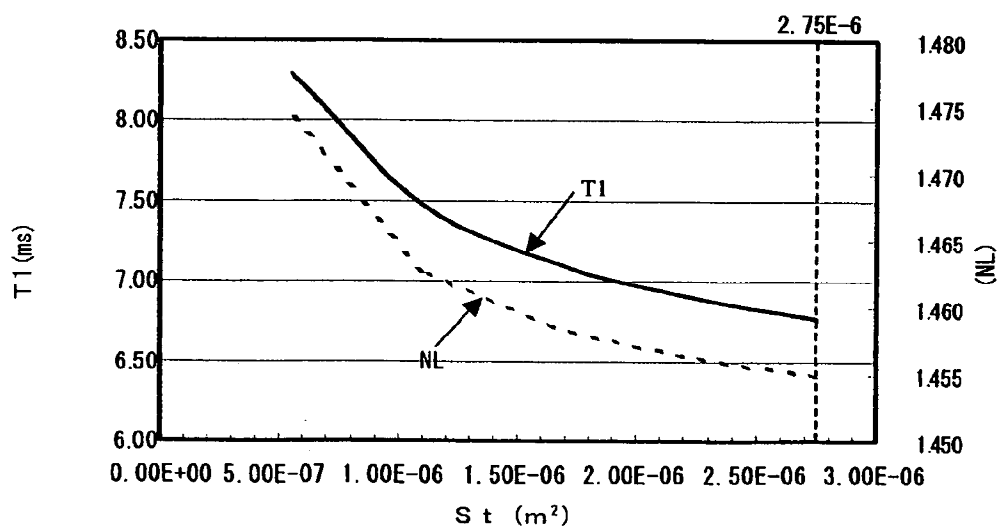
0.6
0.8
1.0
V2/S2

FIG. 7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7.50
7.00
6.50
6.00
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1.465
1.460
1.455
1.450
(NL)
T1
NL
0.00E+00
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1.00E-06
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3.00E-06
St (m²)

FIG. 8

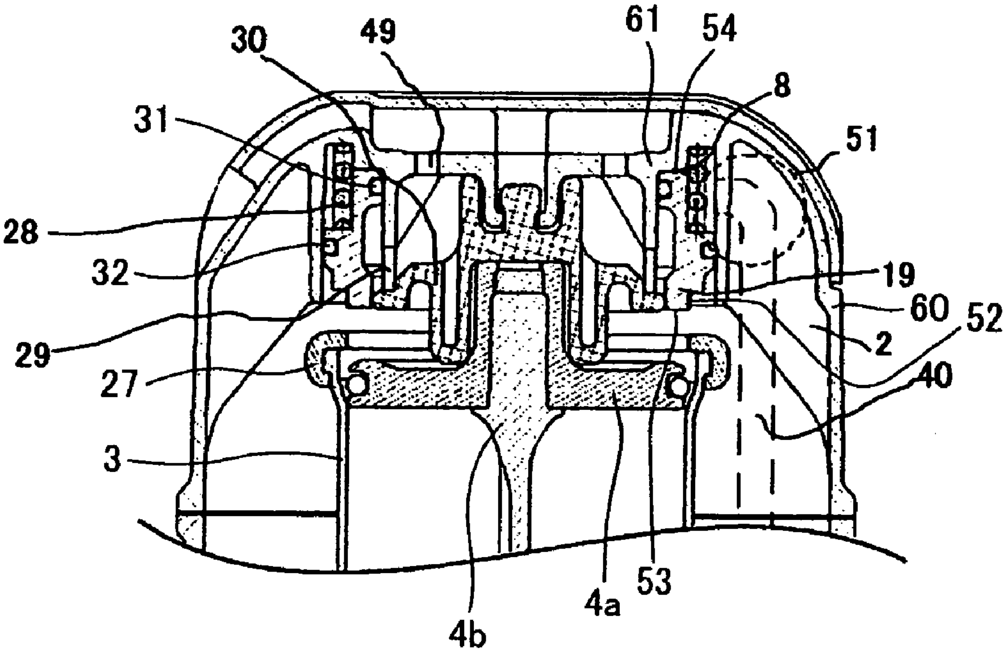
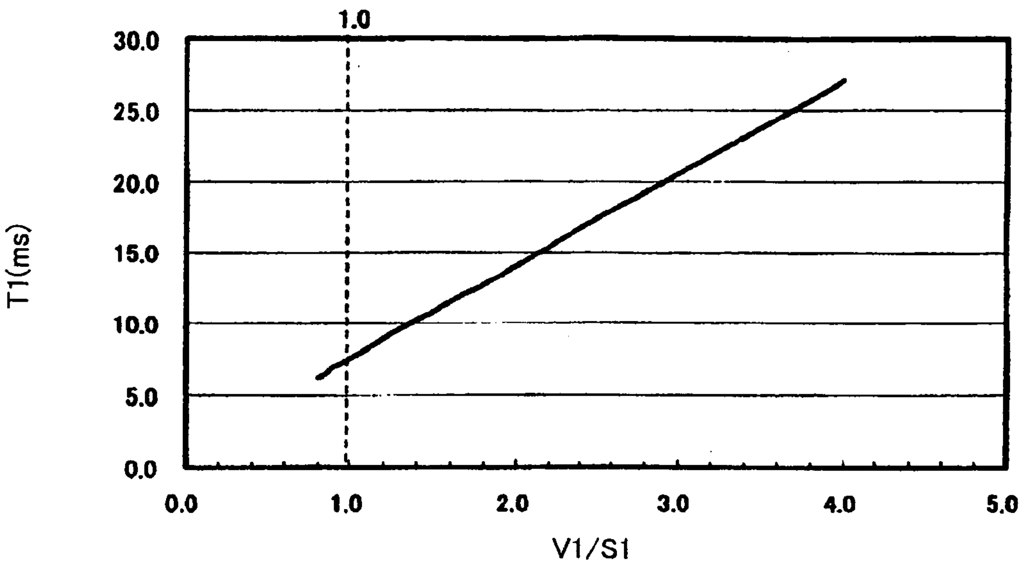


FIG. 9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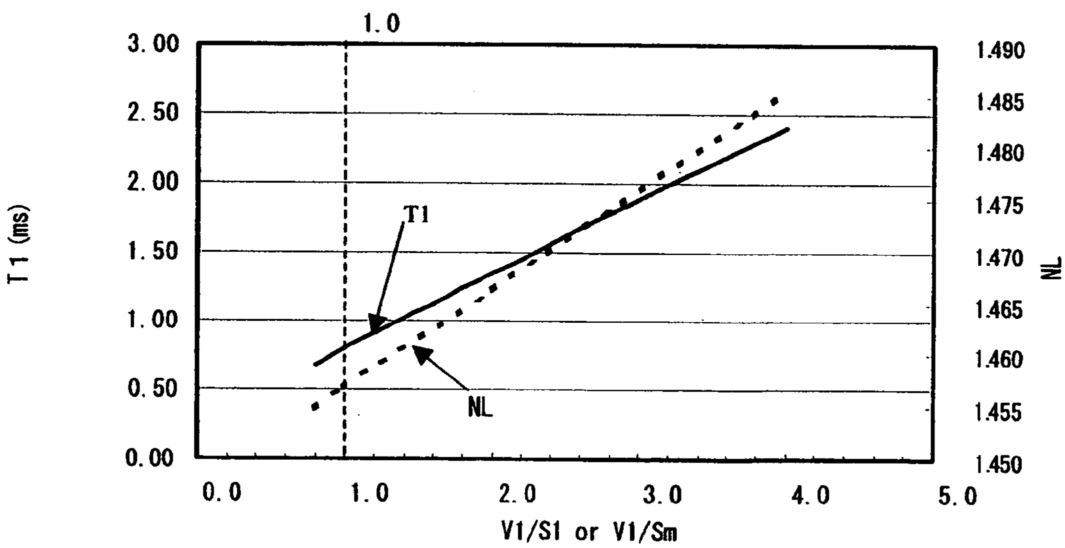
V1/S1

FIG. 10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1.470
1.465
1.460
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5.0
V1/S1 or V1/Sm

FIG. 11

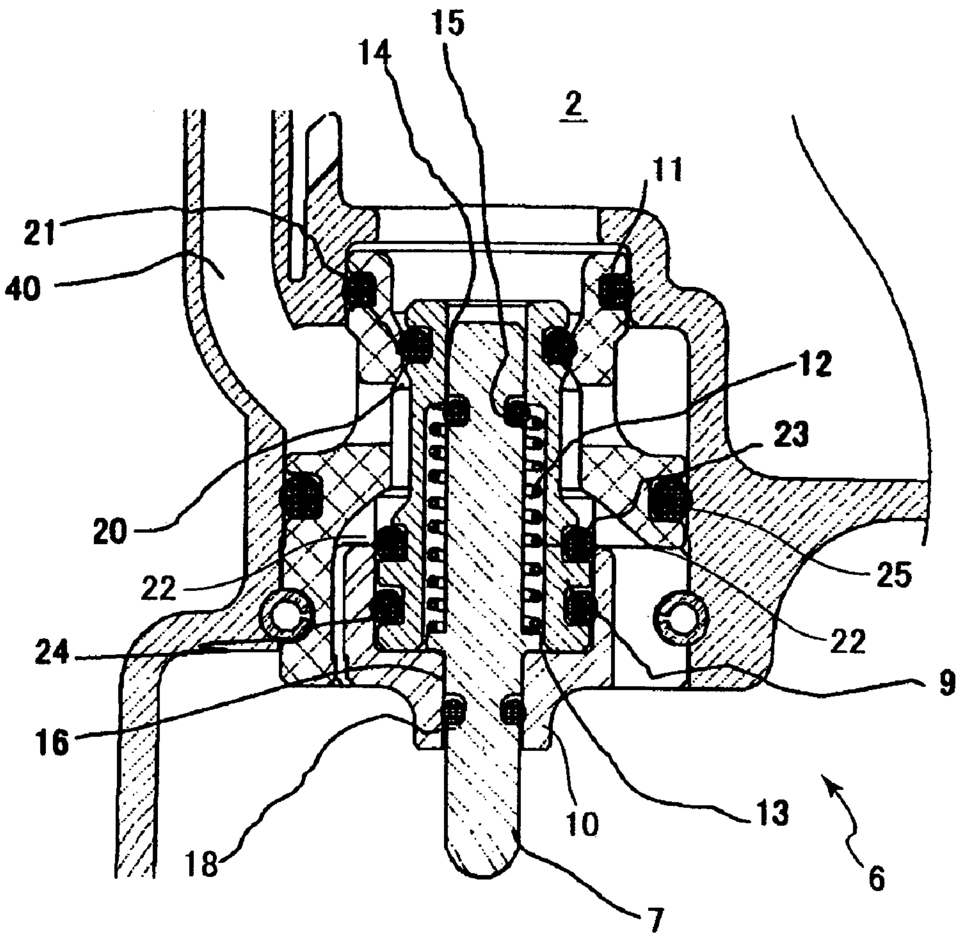

FIG. 12

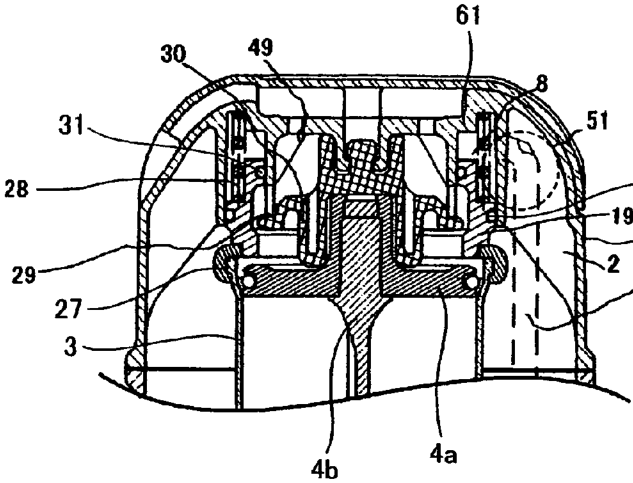
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FIG. 13

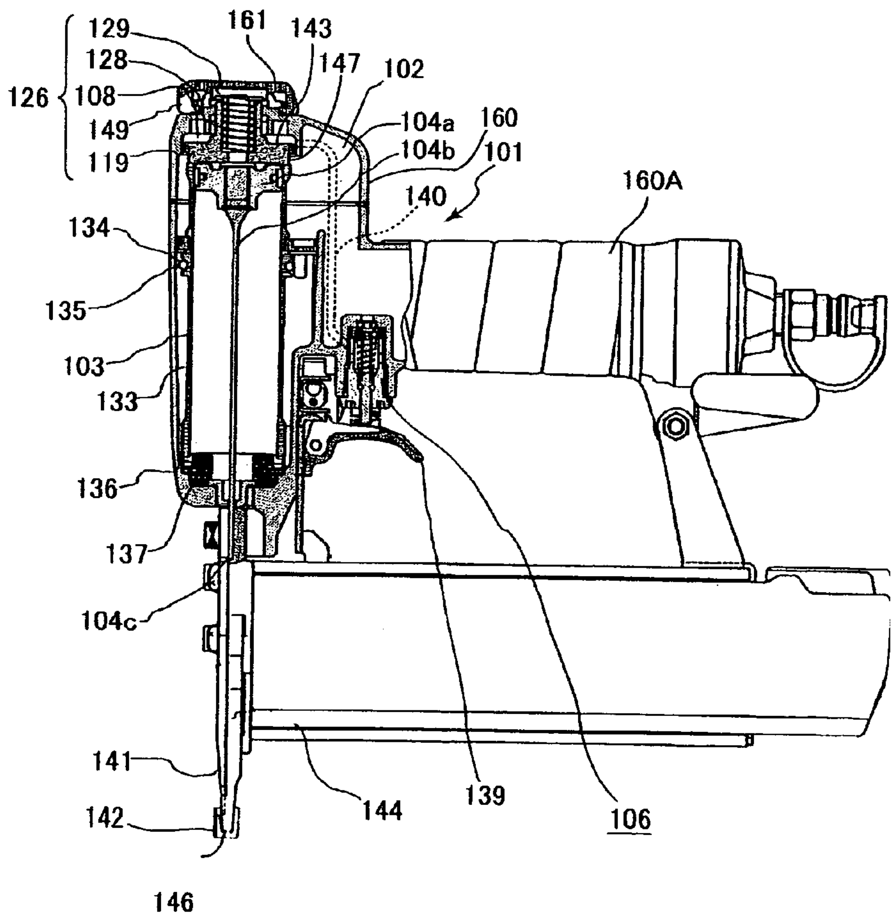
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FIG. 14

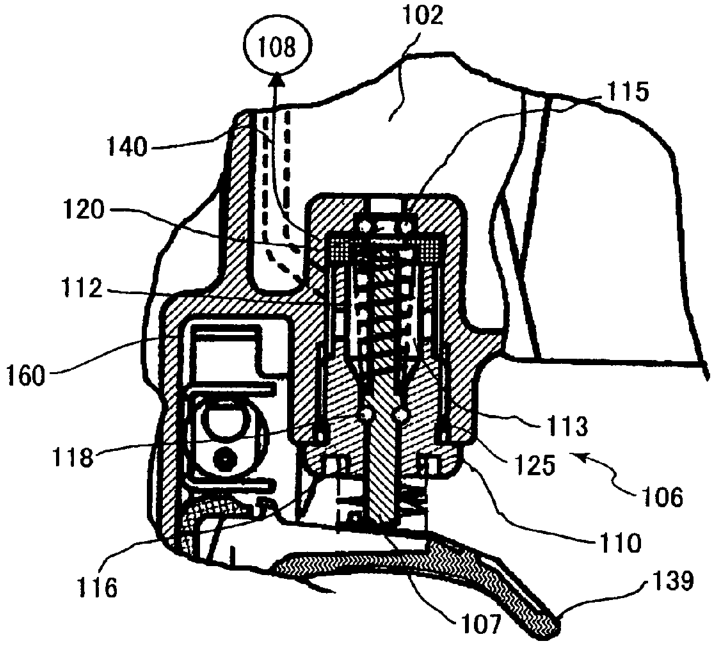
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FIG. 15

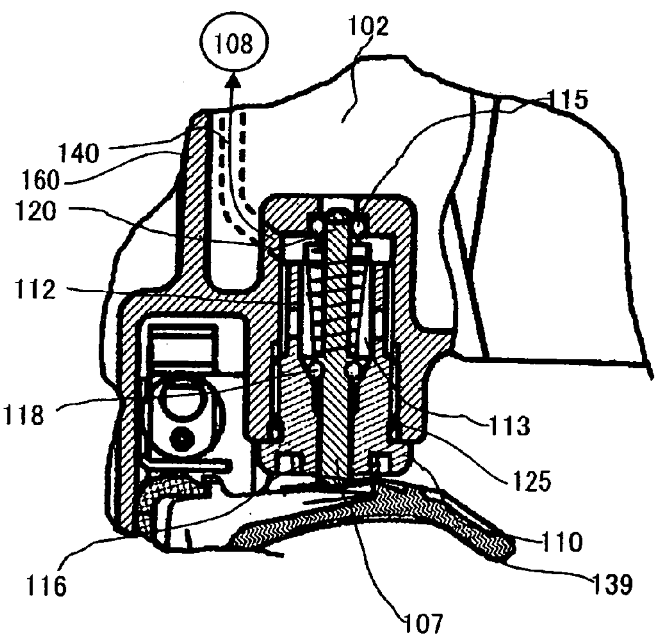
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FIG. 16

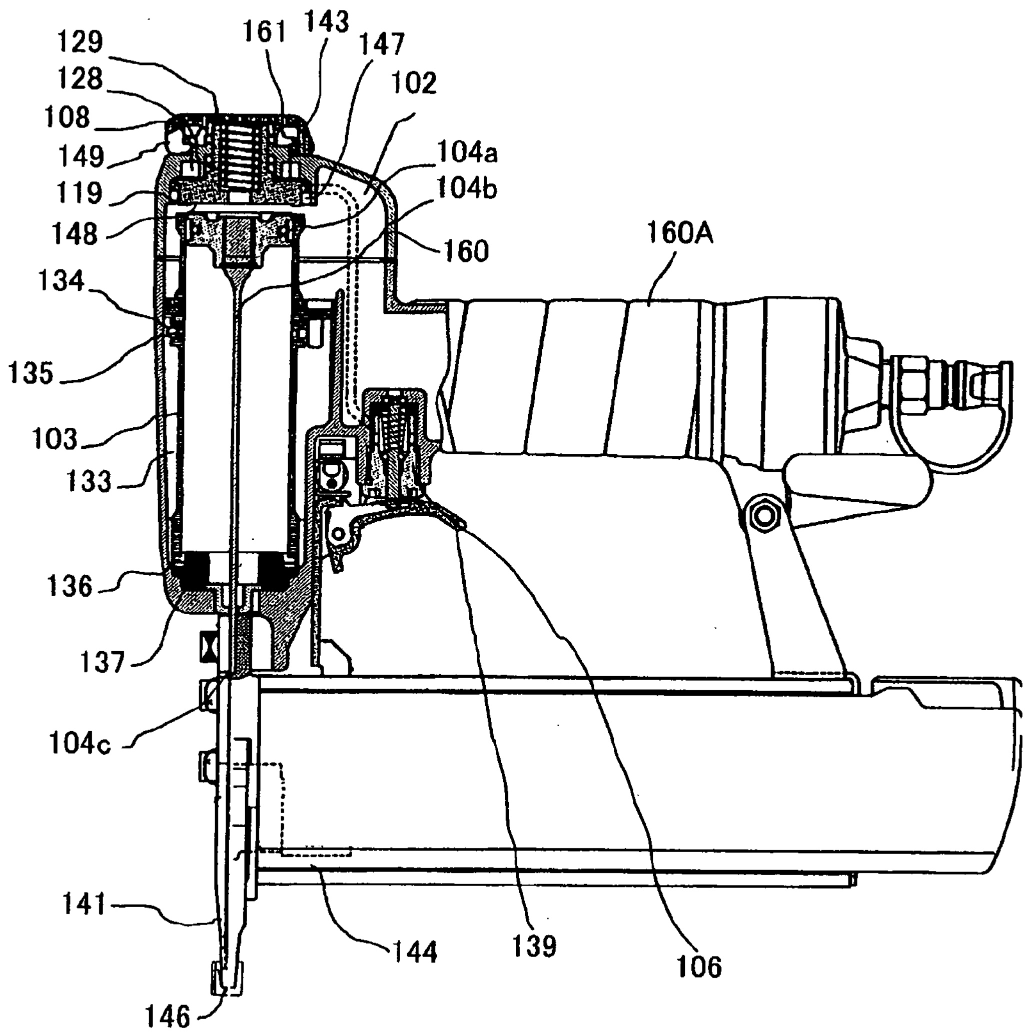

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FIG. 17

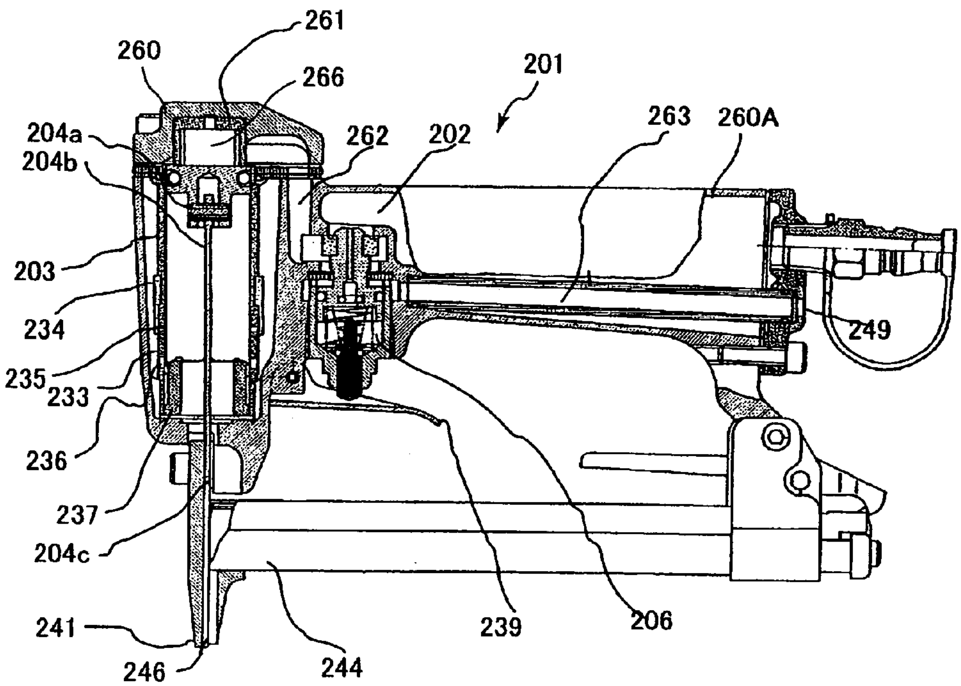
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FIG. 18

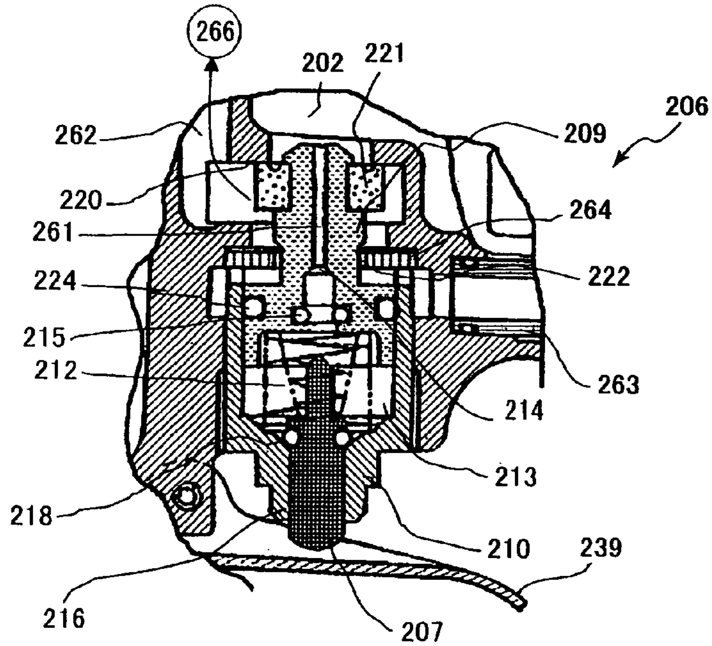
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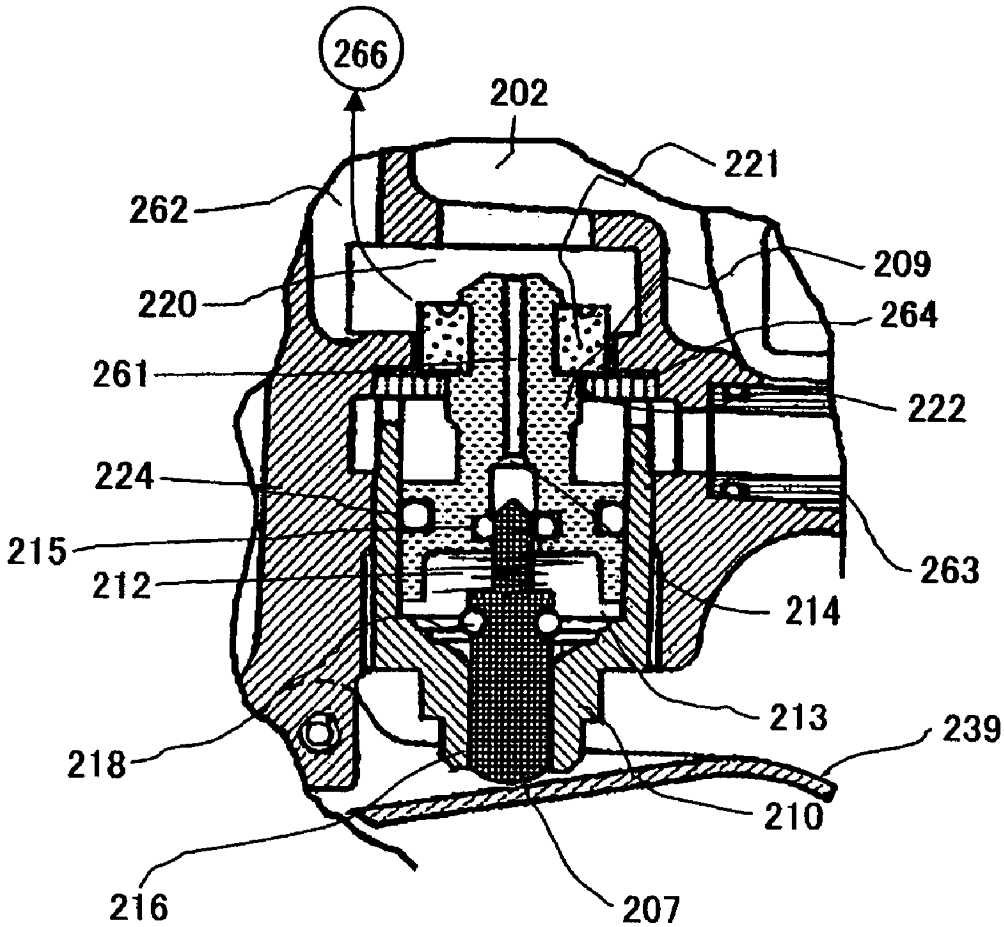
FIG. 19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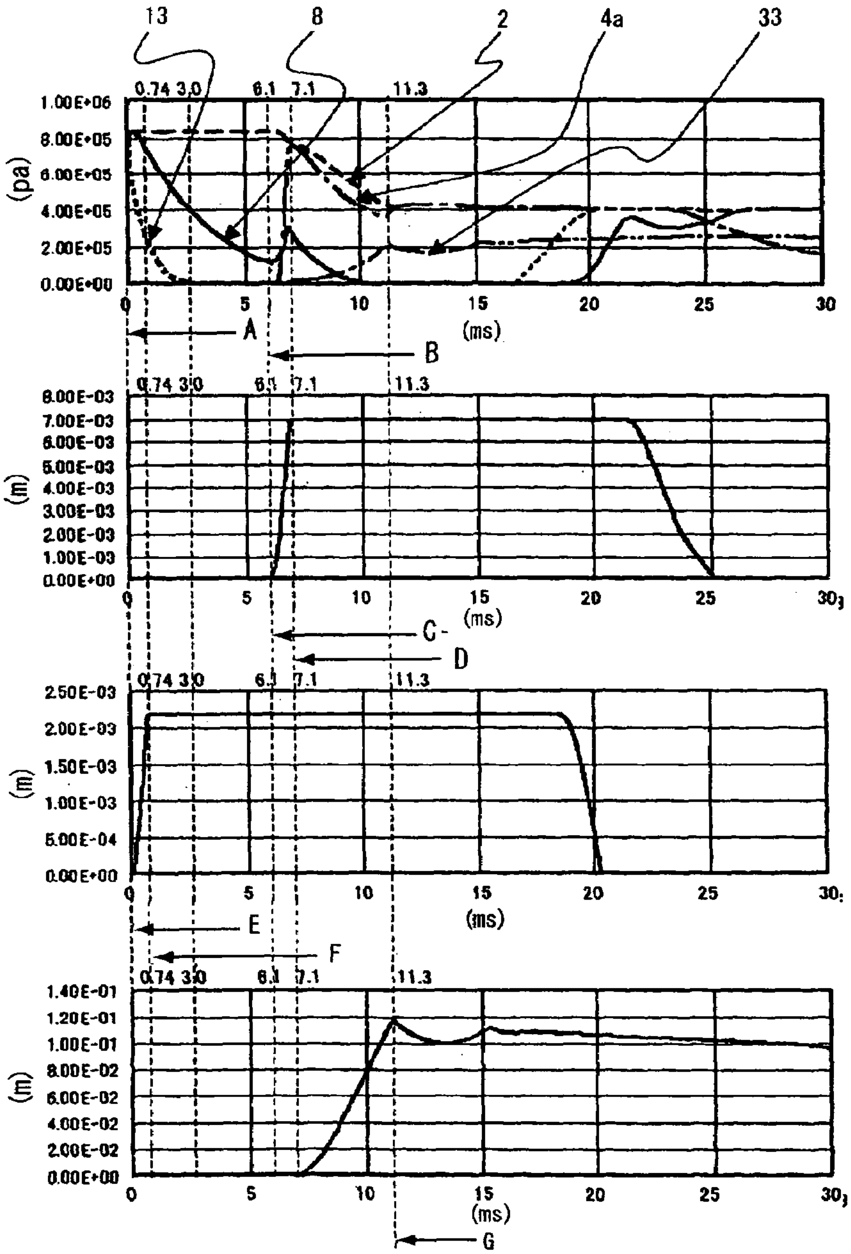


FIG. 20(a)

FIG. 20(b)

FIG. 20(c)

FIG. 20(d)

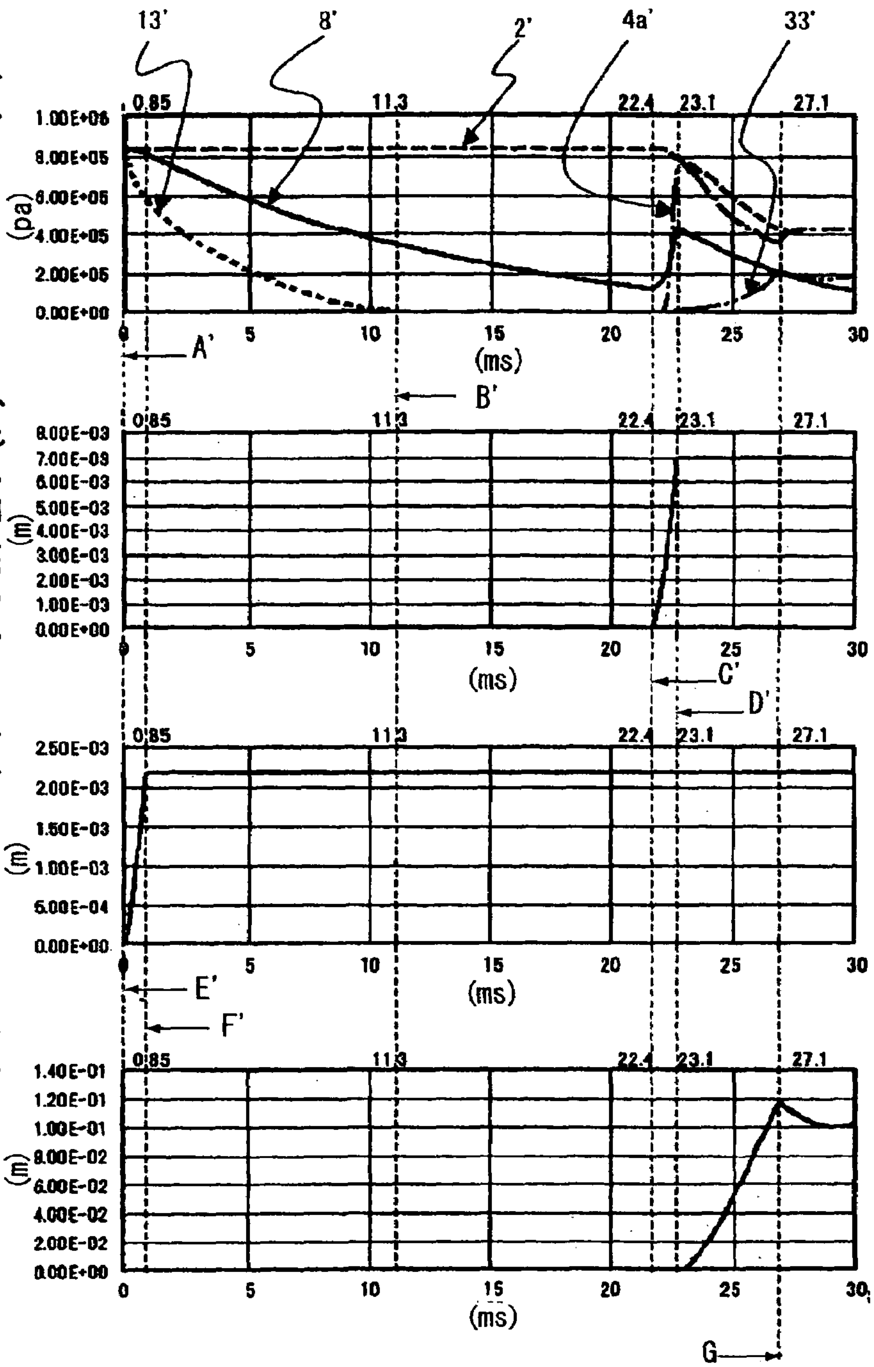


FIG. 21 (a)

FIG. 21 (b)

FIG. 21 (c)

FIG. 21 (d)

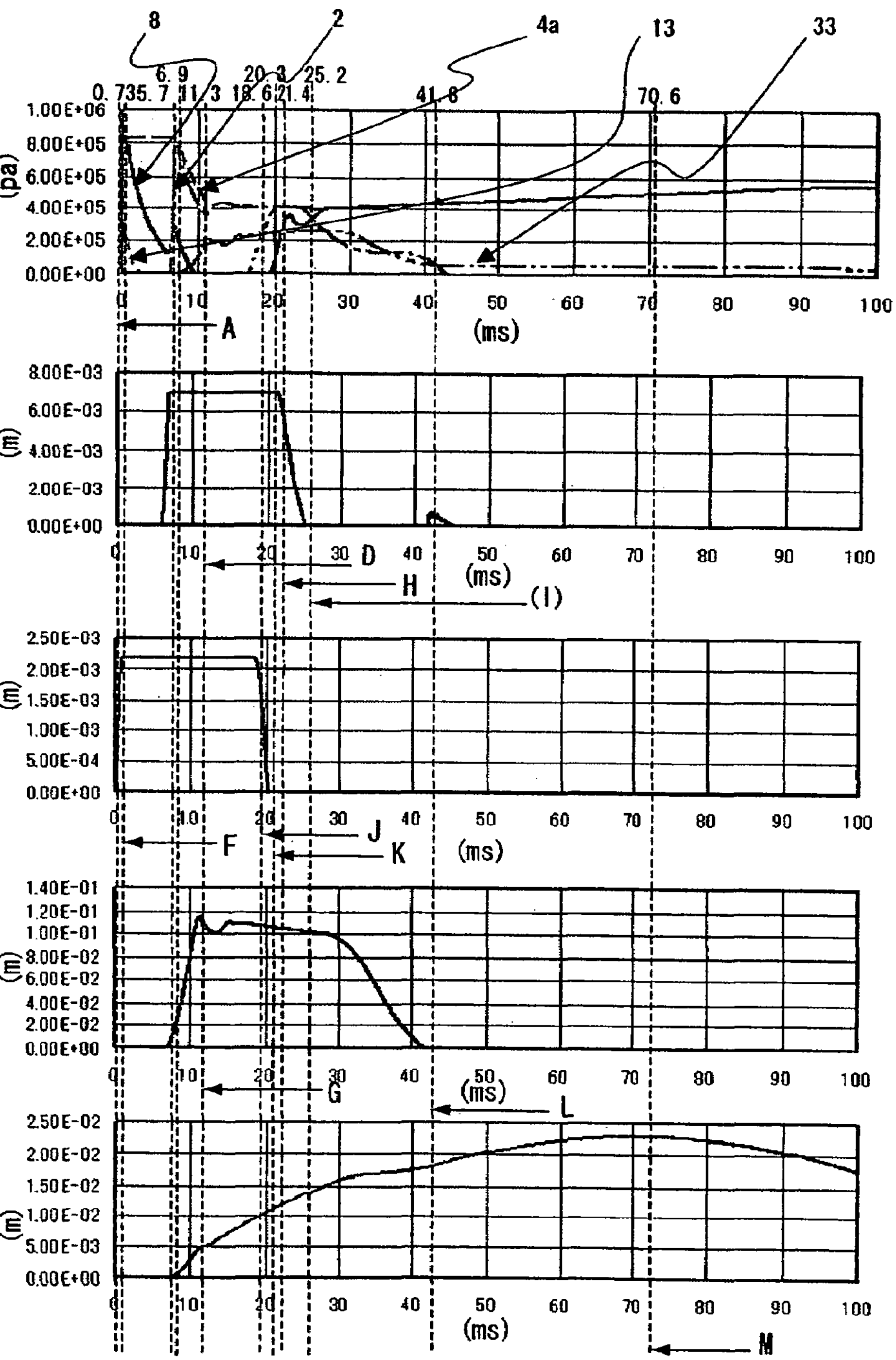
FIG. 22(a)

FIG. 22(b)

FIG. 22(c)

FIG. 22(d)

FIG. 22(e)



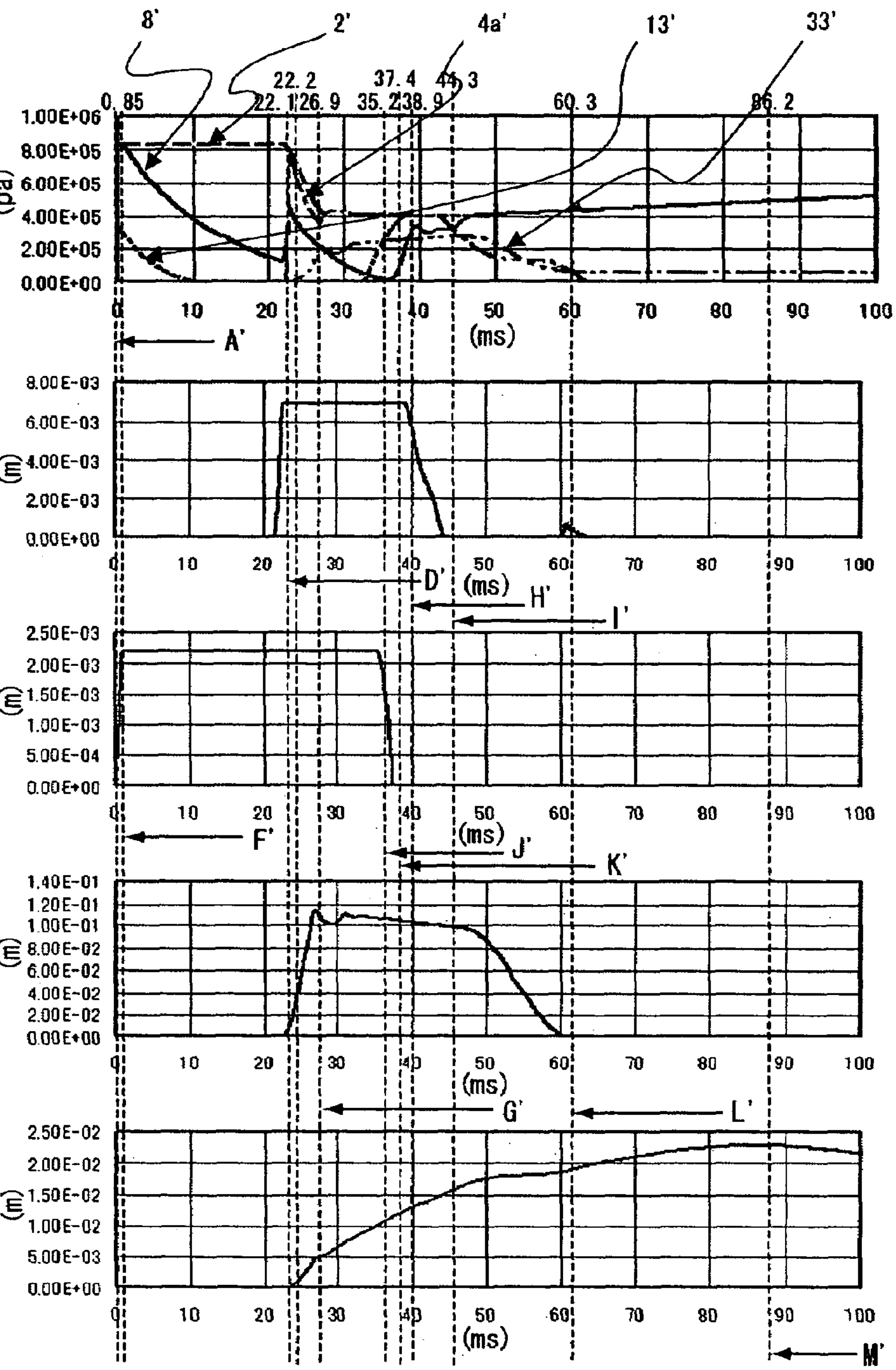


FIG. 23(a) FIG. 23(b) FIG. 23(c) FIG. 23(d) FIG. 23(e)

PNEUMATICALLY OPERATED FASTENER DRIVING TOOL

BACKGROUND OF THE INVENTION

The present invention relates to a fastener driving tool such as a nail gun driven by compressed air, and more particularly, to such fastener driving tool improving drive response and decreasing air consumption.

Heretofore, fastener driving tools such as nail guns have existed which drive fasteners such as nails or staples using compressed air as the power source. In such fastener driving tools, compressed air is supplied to a piston upper chamber defined by an inner surface of a cylinder and a piston for rapidly displacing the piston to perform nailing. Compressed air is supplied from an external source and temporarily stored in an accumulator formed within a frame of the nail gun. The accumulator and the piston upper chamber are connected by a channel, but one or more valves which are switched between open and shut-off positions are provided along this channel. These valves are designed to open or shut-off the channel by supplying or expelling compressed air in valve chambers constituted by the spaces each adjacent to each valve. Typically the structure is such that a first valve is activated as a result of external operation of a trigger or the like, and this operation allows a downstream passage to be communicated with or to be shut-off from the first valve. Thus, a downstream valve chamber is brought into communication with or shutting-off from the upstream passage, thereby sequentially activating or deactivating the downstream valves.

In addition, a time period starting from completion of the nail driving operation to restoration to an initial state for the next nailing operation is dependent upon the circulation speed of the compressed air in the fastener driving tool after the trigger is released, and the movement speed of the valves in proportion to this circulation speed. That is, the time period is dependent on the shut-off speed for shutting off the piston upper chamber in the cylinder from the accumulator by a valve caused by, after releasing the trigger or the like, circulation of the compressed air through the channel in the fastener driving tool as a result of the returning motion of a plunger which had been pressed by this trigger.

In a conventional fastener driving tools as disclosed in Japanese Patent Publication No.S58-50833, valve activation is performed sequentially from valves whose valve chamber volume is small to valves with large valve chamber in order to stabilize operation of the valves irrespective of the speed with which the trigger is pulled. Since with this structure the valves are sequentially activated by compressed air, a time period starting from pulling the trigger and/or pushing operation of a push lever against a workpiece to a start of the nailing driving motion is highly dependent upon the time required to sequentially activate the valves.

In order to reduce this time period and increase response, Japanese Patent Publication No. H7-112674 discloses a nail gun, in which a main valve is divided into first and second valves, so that kinetic energy of the first valve is utilized to improve the operating speed of the second valve.

With this structure in which the main valve is divided into two valves, only the time period from when the second valve begins to move until it moves to maximum displacement is reduced. The time period from both pulling the trigger and pushing the push lever onto the workpiece to the operation timing of the first valve is still not reduced. In addition, since only the time period from when the second valve begins to move until it moves to maximum displacement is reduced, it was only possible to reduce the time period from when the trigger is pulled until nailing is performed. Consequently, a time period from the completion timing of the nail driving operation to the start timing of the next nail driving operation cannot be reduced when continuous nailing is performed. That is, a response cannot be improved.

Laid-open Japanese Patent Application Kokai No. H11-33930 discloses a structure in which, an internal volume of a main valve chamber for accommodating therein a main valve is increased. With this arrangement, air damping behavior due to compression of the main valve chamber does not occur when the main valve rises and is contained in the main valve chamber.

With this structure in which the volume of the main valve chamber is increased, the amount of compressed air accumulated in the main valve chamber increases. For this reason, the time period for discharging the compressed air out of the main valve chamber is increased, which degrades the response.

Laid-open Japanese Patent Application Kokai No. H5-138548 discloses communication of a piston lower chamber with a trigger valve chamber. The movement speed of a valve piston and a main valve are increased as a result of the pressure which is generated from the movement of the piston.

With this structure in which the piston lower chamber and trigger valve chamber are connected, at the instant that the piston passes through the one-way valve disposed at an intermediate region of the cylinder, compressed air flows into the trigger valve chamber and closes the main valve. Therefore, the nailing force was reduced. Moreover, extremely complicated structure results.

Another conventional fastener driving tool has been proposed. The tool includes a trigger valve and main valve. A trigger valve exterior frame internally defines a trigger valve chamber. The trigger valve includes a plunger extending through the trigger valve exterior frame and the trigger valve chamber and slidably movable as a result of the movement of the trigger and the abutment of the push lever against the workpiece. The movement of the plunger selectively shuts off a fluid communication between the accumulator and the trigger valve chamber and between the trigger valve chamber and an atmosphere. However, the resultant arrangement cannot provide high response for discharging compressed air from the main valve.

Still another conventional fastener driving tool is proposed in which a main valve is not provided, but a trigger valve is additionally equipped with a valve piston. The valve piston is reciprocably slidably disposed in a trigger valve exterior frame, and has one side in the sliding direction facing the accumulator. The valve piston alternately opens and blocks a channel from the piston upper chamber connected to the trigger valve exterior frame to the accumulator and a channel from the piston upper chamber to the atmosphere. With this fastener driving tool, the displacement of the valve piston serves to select the air channel and control the nailing of the fastener. However, the speed of the displacement of the valve piston is low, and the delay in the displacement of this valve piston can cause other control to be delayed as well. Consequently, the problem arises that the time lag from when the operator begins the nailing operation until the fastener is actually driven becomes large, response becomes poor to lower workability. In addition, the problem arises that when many fasteners are to be driven in a short period of time, the aforementioned time lag makes continuous nailing difficult to perform.

In addition, with the conventional fastener driving tools, after nailing, in order to return the piston to the pre-nailing position, the piston upper chamber and the atmosphere are communicated with each other for releasing the compressed to the atmosphere, while the valve is closed for preventing the compressed air from flowing from the accumulator into the piston upper chamber.

However, during the period from when the valve begins to close until it is completely closed, the accumulator and the piston upper chamber are communicated with each other, and the piston upper chamber and the atmosphere are also communicated with each other. Accordingly, the compressed air in the accumulator would in some cases flow unnecessarily into the piston upper chamber and is expelled into the atmosphere. This causes an increase in air consumption, which consequently requires a high-performance compressor or the like to produce compressed air.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention is to provide a fastener driving tool improving the response and continuous shots or nailing performance in nailing work, yet reducing the consumption of compressed air.

This and other objects of the present invention will be attained by A fastener driving tool including a frame, a cylinder, a piston, a main valve, a main valve chamber section, a trigger valve, and a main valve control channel section. The frame defines therein an accumulator that accumulates a compressed air. The cylinder is disposed within the frame. The piston is reciprocally slidably disposed within the cylinder. A piston upper chamber is defined by an inner peripheral surface of the cylinder and an upper surface of the piston. The main valve alternately opens and blocks a fluid communication between the piston upper chamber and the accumulator. The main valve chamber section defines therein a main valve chamber in which the main valve is movably disposed. The main valve chamber provides a maximum internal volume. The trigger valve alternately opens and blocks a fluid communication from the accumulator to the main valve chamber, and a fluid communication from the main valve chamber to an atmosphere. The main valve control channel section defines therein a main valve control channel that provides a fluid connection between the main valve chamber and the trigger valve. A value obtained from dividing the maximum internal volume of the main valve chamber by a cross-sectional area of the main valve control channel being not more than 1.0.

In another aspect of the invention, there is provided a fastener driving tool including a frame, a cylinder, a piston, a trigger, and a trigger valve provided with a trigger valve exterior frame, a valve piston and a plunger. The frame defines therein an accumulator for accumulating a compressed air. The cylinder is disposed within the frame. The piston is reciprocally slidably disposed within the cylinder. A piston upper chamber is defined by the frame, an inner peripheral surface of the cylinder and an upper surface of the piston. The trigger functions as an operation input member. A trigger valve alternately opens and blocks a fluid communication between the piston upper chamber and the accumulator and a fluid communication between the piston upper chamber and an atmosphere. The trigger valve exterior frame is in fluid communication with the piston upper chamber and is formed with a through hole. The valve piston is reciprocably slidably disposed in the trigger valve exterior frame. The valve piston is movable between its top dead center where piston upper chamber is communicated with the atmosphere and its bottom dead center where the piston upper chamber is communicated with the accumulator. The valve piston has a first section exposed to the accumulator and formed with a trigger valve intake channel opened to the accumulator and a second section in sliding contact with the trigger valve exterior frame. A trigger valve chamber is defined by the second section and the trigger valve exterior frame and provides a maximum internal volume. The plunger is movable between its top dead center and its bottom dead center and has a first portion associated with the valve piston and a second portion associated with the through hole. A trigger valve control channel is formed between the second portion and the through hole and has a cross-sectional area. The trigger valve control channel is opened when the plunger is moved to its top dead center. A value obtained from dividing the maximum volume of the trigger valve chamber measured in m^3 by the cross-sectional area of the trigger valve control channel is not more than 0.20.

Further, in the fastener driving tool including the frame, the cylinder, the piston, the trigger, and the trigger valve provided with the trigger valve exterior frame, the valve piston and the plunger, the trigger valve intake channel has a cross-sectional area of not less than 2.75×10^{-6} m^2, and the trigger valve chamber has a maximum internal volume of 4.0×10^{-7} m^3.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings;

FIG. **1** is a cross-sectional view of the fastener driving tool according to the first embodiment of the present invention;

FIG. **2** is an enlarged cross-sectional view of a trigger valve in the fastener driving tool according to the first embodiment;

FIG. **3** is a partial cross-sectional view particularly showing a main valve in the fastener driving tool according to the first embodiment;

FIG. **4** is an enlarged cross-sectional view particularly showing the trigger valve in the fastener driving tool according to the first embodiment, with a plunger having been pushed upward;

FIG. **5** is an enlarged cross-sectional view particularly showing the trigger valve in the fastener driving tool according to the first embodiment, with the plunger having been pushed upward and a valve piston then having moved to its bottom dead center;

FIG. **6** is a graph showing the relationship between a valve piston displacement time (T**2**) and a ratio of volume (V**2**) of trigger valve chamber to a cross-sectional area (S**2**) of a trigger valve control channel in the fastener driving tool according to the first embodiment;

FIG. **7** is a graph showing the relationship between a time period (T**1**) until a main valve returns to its initial position after a plunger returns to its initial position and a cross-sectional area (St) of a trigger valve intake channel in the fastener driving tool according to the first embodiment;

FIG. **8** is a partial cross-sectional view particularly showing the main valve in the fastener driving tool according to the first embodiment, with the main valve having moved to the top dead center;

FIG. **9** is a graph showing the relationship between a main valve displacement time (T**1**) and a ratio of volume (V**1**) of main valve chamber to a cross-sectional area (S**1**) of a main valve control channel in the fastener driving tool according to the first embodiment;

FIG. **10** is a graph in which a solid line curves shows the relationship between the main valve displacement time (T**1**) and the ratio of volume (V**1**) of main valve chamber to the cross-sectional area (S**1**) of the main valve control channel, and a broken line curves shows the relationship between air consumption amount (NL) and the ratio (V**1**/S**1**) or (V**1**/Sm) in which "Sm" designates a main intake control channel according to the first embodiment;

FIG. **11** is an enlarged cross-sectional view particularly showing the trigger valve in the fastener driving tool according to the first embodiment, with the valve piston having moved to the bottom dead center and the plunger then having returned to its original position;

FIG. **12** is a partial cross-sectional view particularly showing a main valve according to a modification to the first embodiment;

FIG. **13** is a cross-sectional view of the fastener driving tool according to a second embodiment of the present invention;

FIG. **14** is an enlarged cross-sectional view particularly showing a trigger valve in the fastener driving tool according to the second embodiment;

FIG. **15** is an enlarged cross-sectional view particularly showing the trigger valve in the fastener driving tool according to the first embodiment, with a plunger having been pushed upward;

FIG. **16** is a cross-sectional view of the fastener driving tool according to the second embodiment, with a main valve having moved to the top dead center;

FIG. **17** is a cross-sectional view of a fastener driving tool according to a third embodiment of the present invention;

FIG. **18** is an enlarged cross-sectional view particularly showing a trigger valve in the fastener driving tool according to the third embodiment;

FIG. **19** is an enlarged cross-sectional view particularly showing the trigger valve in the fastener driving tool according to the third embodiment, with a plunger having been pushed upward;

FIG. **20**(*a*) is a graph showing the relationship between time and pressure in a trigger valve chamber **13**, a main valve chamber **8**, an accumulator **2**, a piston upper chamber **4***a*, and a return chamber **33** in a fastener driving tool according to the first embodiment;

FIG. **20**(*b*) is a graph showing the relationship between the time and a displacement of a main valve according to the first embodiment;

FIG. **20**(*c*) is a graph showing the relationship between the time and a displacement of a valve piston according to the first embodiment;

FIG. **20**(*d*) is a graph showing the relationship between the time and a displacement of a piston according to the first embodiment;

FIG. **21**(*a*) is a graph showing the relationship between time and pressure in a trigger valve chamber **13'**, a main valve chamber **8'**, an accumulator **2'**, a piston upper chamber **4***a'*, and a return chamber **33'** in a comparative fastener driving tool;

FIG. **21**(*b*) is a graph showing the relationship between the time and a displacement of a main valve according to the comparative fastener driving tool;

FIG. **21**(*c*) is a graph showing the relationship between the time and a displacement of a valve piston according to the comparative fastener driving tool;

FIG. **21**(*d*) is a graph showing the relationship between the time and a displacement of a piston according to the comparative fastener driving tool;

FIG. **22**(*a*) is a graph showing the relationship between time and pressure in a trigger valve chamber **13**, a main valve chamber **8**, an accumulator **2**, a piston upper chamber **4***a*, and a return chamber **33** in the fastener driving tool according to the first embodiment;

FIG. **22**(*b*) is a graph showing the relationship between the time and a displacement of a main valve according to the first embodiment;

FIG. **22**(*c*) is a graph showing the relationship between the time and a displacement of a valve piston according to the first embodiment;

FIG. **22**(*d*) is a graph showing the relationship between the time and a displacement of a piston according to the first embodiment;

FIG. **22**(*e*) is a graph showing the relationship between the time and a displacement of a tool itself according to the first embodiment;

FIG. **23**(*a*) is a graph showing the relationship between time and pressure in a trigger valve chamber **13'**, a main valve chamber **8'**, an accumulator **2'**, a piston upper chamber **4***a'*, and a return chamber **33'** in another comparative fastener driving tool;

FIG. **23**(*b*) is a graph showing the relationship between the time and a displacement of a main valve according to the comparative fastener driving tool;

FIG. **23**(*c*) is a graph showing the relationship between the time and a displacement of a valve piston according to the comparative fastener driving tool;

FIG. **23**(*d*) is a graph showing the relationship between the time and a displacement of a piston according to the comparative fastener driving tool; and

FIG. **23**(*e*) is a graph showing the relationship between the time and a displacement of a tool itself according to the comparative fastener driving tool.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A fastener driving tool according to a first embodiment of the present invention will be described with reference to FIGS. **1** through **11**. The fastener driving tool shown in FIG. **1** is a nail gun **1** which uses compressed air as the power source. The nail gun **1** includes a frame **60**, a handle **60**A disposed at one side of the frame **60**, and a nose **41** disposed at a lower end of the frame **60**. These frame **60**, handle **60**A and nose **41** are provided as an integral unit to form an outer frame. An accumulator **2** is formed within the handle **60**A and frame **60** for accumulating therein a compressed air delivered from a compressor (not shown) through an air hose (not shown). A cylinder **3** is provided within the frame **60**, and a piston **4***a* is reciprocally movably provided and slidably within the cylinder **3**. A driver blade **4***b* is provided integrally with the piston **4***a*, and has a free end **4***c* for abutting against the fastener **5** for driving.

A return chamber **33** which accumulates therein a compressed air to return the driver blade **4***b* to its upper dead center is provided around the lower outer peripheral surface of the cylinder **3**. A one-way valve **34** is provided in an axially intermediate portion of the cylinder **3**. An air channel **35** is formed in the cylinder **3** for allowing the compressed air to flow in only one direction, i.e., from inside the cylinder **3** to the return air chamber **33**, outside the cylinder **3**. In addition, an air channel **36** is formed at a lower portion of the cylinder **3** for providing continuous communication between the cylinder **3** and the return chamber **33**. In addition, a piston bumper **37** is provided at the bottom of the cylinder **3** for absorbing excess energy from the driver blade **4***b* after nailing the fastener **5**.

An operating portion **38** is provided at the base of the handle **60**A. This operating portion **38** includes a trigger **39** operated by the user, an arm plate **48** which is attached pivotally movably to the trigger **39**, and a push lever **42** which projects from the bottom of the nose **41** and extends to the vicinity of the arm plate **48**. The push lever **42** is movable along the nose **41** and is biased away from the frame **60**. In addition, a trigger valve **6** is provided at the base of the handle **60**A and in confrontation with the trigger **39**. As is well known in the art, the structure is such that, when both the trigger **39** is pulled and the push lever **42** is pressed against the workpiece, a plunger **7** on the trigger valve **6** is pushed upward, as shown in FIG. **2**, by a linking mechanism of the arm plate **48** and the trigger **39**.

A nail injection section **43** provided in conjunction with the nose **41** includes a magazine **44** and a feed mechanism **45**. The magazine **44** is loaded with fasteners **5** arrayed side by side. The feed mechanism **45** is adapted for successively feeding fasteners **5** loaded in the magazine **44** to an injection opening **46** at the nose **41**. The trigger valve **6** shown in FIG. **1** and FIG. **2** mainly includes an outer valve bush **10**, an inner valve bush **11**, a valve piston **9**, a plunger **7**, and a spring **12**. The outer valve bush **10** and inner valve bush **11** are fixed to the frame **60** to form a trigger valve exterior frame which constitutes an outer wall of the trigger valve. The valve piston **9** is provided reciprocably slidably within the outer valve bush **10** and inner valve bush **11**. The valve piston **9** and the outer valve bush **10** are formed with through holes, so that the plunger **7** is provided reciprocably slidably with respect to the through holes. The plunger **7** has a bottom end in contact with the arm plate **48**. The spring **12** is interposed between the valve piston **9** and the plunger **7** for biasing the valve piston **9** and the plunger **7** in opposite directions, i.e., for biasing the valve piston **9** upward while biasing the plunger **7** downward.

The trigger valve **6** is fluidly connected to a main valve control channel **40**, which is a cylindrical tube extending from a main valve chamber **8** described later. Specifically, the main valve control channel **40** is fluidly connected to a space between the outer valve bush **10** and inner valve bush **11**, and opens into the trigger valve **6**. This main valve control channel **40** is configured such that its cross-sectional area S**1** is 3.2×10^{-5} (m^2).

In addition, O-rings **17** and **25** are fitted on the inner valve bush **11**. The O-ring **17** is adapted for continually blocking fluid connection between the accumulator **2** and the main valve control channel **40**. The O-ring **25** is adapted for continually blocking fluid connection between the main valve control channel **40** and an atmosphere.

One side of the valve piston **9** in the sliding direction faces the accumulator **2**, and the inner valve bush **11** has an accumulator side and an atmospheric side. An outer diameter at an accumulator side of the valve piston **9** is smaller than an inner diameter of the accumulator side of the inner valve bush **11** to define therebeween a main valve intake channel **20**. Further, an outer diameter at an atmospheric side of the valve piston **9** is smaller than an inner diameter of the atmospheric side of the inner valve bush **11** to define therebetween an air channel **22**. Further, an O-ring **21** and an O-ring **23** are disposed at the accumulator side and atmospheric side of the valve piston **9**, respectively, for selectively blocking the respective channels **20** and **22**.

Consequently, the main valve intake channel **20** passes between the valve piston **9** and the inner valve bush **11** to provide fluid communication between the accumulator **2** and the main valve control channel **40** when the O-ring **21** is out of contact from the inner valve bush **11**. Further, the air channel **22** passes between the valve piston **9** and the inner valve bush **11** to provide fluid communication between the main valve control channel **40** and the atmosphere when the O-ring **22** is out of contact from the inner valve bush **11**. This air channel **22** is formed such that its cross-sectional area extending perpendicular to a flowing direction is larger than that of the main valve channel **40**. As a result, the flow resistance at the air channel **22** will be lower than that of the main valve channel **40**. The main valve intake channel **20** and air channel **22** are alternately opened and blocked due to the vertical sliding of the valve piston **9**. In addition, the main intake control channel **20** is formed such that its cross-sectional area Sm is 3.2×10^{-5} (m^2).

A trigger valve chamber **13** is defined by another side (lower side) of the valve piston **9** in the sliding direction and the outer valve bush **10**. This trigger valve chamber **13** has an internal volume variable due to the sliding movement of the valve piston **9**, and is formed such that a maximum internal volume V**2** defined when the valve piston **9** is at the top dead center is 4.0×10^{-7} (m^3). In addition, an O-ring **24** is fitted onto the valve piston **9** for continually blocking the fluid connection between the air channel **22** and the trigger valve chamber **13**.

The plunger **7** extends through the trigger valve chamber **13**, and a top end faces the accumulator **2**. The valve piston **9** has first and second sliding regions relative to the valve piston **9** and the outer valve bush **10**, and O-ring grooves are formed at the respective sliding regions for installing therein an O-ring **15** and an O-ring **18** for maintaining hermetic seal. An outer diameter of the first sliding region is smaller than an inner diameter of the valve piston **9** for defining therebetween a trigger valve intake channel **14**, and an outer diameter of the second sliding region is smaller than an inner diameter of the outer valve bush **10** for defining therebetween a trigger valve control channel **16**.

Consequently, the trigger valve intake channel **14** passes between the plunger **7** and the valve piston **9** for providing fluid communication from the accumulator **2** to the trigger valve chamber **13** when the O-ring **15** is out of contact from the valve piston **9**. Further, the trigger valve control channel **16** passes between the plunger **7** and the outer valve bush **10** to provide fluid communication from the trigger valve chamber **13** to the atmosphere when the O-ring **18** is out of contact from the outer valve bush **10**. The trigger valve intake channel **14** and trigger valve control channel **16** are alternately opened and blocked in accordance with the sliding motion of the plunger **7**.

The trigger valve intake channel **14** is formed such that its cross-sectional area St is 2.75×10^{-6} (m^2). Further, the trigger valve control channel **16** is formed such that its cross-sectional area S**2** is 1.98×10^{-6} (m^2). As a result, the value obtained from dividing the volume of the trigger valve chamber **13** by the cross-sectional area of the trigger valve control channel **16** is V**2**/S**2**=0.2.

The structure of the trigger valve **6** is such that, when the valve piston **9** is positioned toward the top dead center (for example FIG. **2**), the main valve intake channel **20** is opened so that the accumulator **2** and the main valve control channel **40** are communicated with each other, while air channel **22** is closed by the O-ring **23** so that fluid communication between the main valve control channel **40** and the atmosphere is blocked. In addition, when the valve piston **9** is positioned toward the bottom dead center (for example FIG. **5**), the main valve intake channel **20** is closed by the O-ring **21**, so that fluid communication between the main valve control channel **40** and the accumulator **2** is blocked, while air channel **22** is opened so that and the main valve control channel **40** and the atmosphere are communicated with each other.

When the plunger **7** is positioned toward the top dead center (FIG. **5**), the trigger valve control channel **16** is opened so that the trigger valve chamber **13** is communicated with the atmosphere, while the trigger valve intake channel **14** is closed by the O-ring **15** so that fluid communication between the accumulator **2** and the trigger valve chamber **13** is blocked. In addition, when the plunger **7** is positioned toward the bottom dead center (FIG. **2**), the trigger valve control channel **16** is closed by the O-ring **18**, so that fluid communication between the trigger valve chamber **13** and the atmosphere is blocked, while the trigger valve intake channel **14** is opened so that the accumulator **2** and the trigger valve chamber **13** are communicated with each other.

A main valve section **26** is provided immediately above and around the outer peripheral surface of the cylinder **3** as shown in FIGS. **1** and **3**. The main valve section **26** generally includes a main valve **19**, a main valve rubber **27**, a main valve spring **28**, and an exhaust rubber **30**. The main valve rubber **27** is fitted to the top end of the cylinder **3**. The main valve spring **28** is adapted for biasing the main valve **19** toward its bottom dead center. The exhaust rubber **30** is placed above the cylinder **3**. An air discharge passage **29** is formed above the cylinder **3** for discharging the compressed air in the piston upper chamber above the piston **4***a*. The exhaust rubber **30** is adapted for shutting off the air discharge passage **29** when the main valve **19** is coming into contact with the exhaust rubber **30**. In addition, the upper end of the frame **60** is formed with an exhaust hole **49** to which the air passage **29** is connected. Thus, the compressed air in the piston upper chamber can be discharged to the atmosphere.

A main valve sectioning region **61** is provided as an upper part of the frame **60**. The main valve sectioning region **61** provides a main valve chamber **8** in which the main valve **19** is vertically slidably movably provided. The main valve chamber **8** is in communication with the main valve control channel **40**.

The main valve **19** has top and middle portions provided with O-rings **31** and **32**, respectively. The O-ring **31** is adapted for continually blocking fluid communication between the main valve chamber **8** and the air channel **29**, and the O-ring **32** is adapted for continually blocking fluid communication between the main valve chamber **8** and the accumulator **2**. Thus, the main valve chamber **8** is hermetically maintained by these O-rings **31** and **32**.

The main valve chamber **8** has an internal volume variable in accordance with the vertical movement of the main valve **19**, but has a maximum volume V**1** of 2.56×10^{-5} (m^3). As a result, the value obtained from dividing the volume V**1** of the main valve chamber **8** by the cross-sectional area S**1** of the main valve control channel **40** is $V1/S1=0.8\leqq1.0$. Likewise, the value obtained from dividing the volume V**1** of the main valve chamber **8** by the cross-sectional area Sm of the main valve intake channel **20** is $V1/Sm=0.8\leqq1.0$. In addition, the main valve control channel **40** has a curving portion as shown at the location enclosed by a circle in FIG. **3**. The curving portion is formed into a gentle arc shape.

When the main valve **19** is positioned toward the top dead center, the main valve **19** comes into contact with the exhaust rubber **30** to shut off the air exhaust passage **29**, so that fluid communication between the piston upper chamber of the cylinder **3** and the atmosphere is blocked, while the piston upper chamber of the cylinder **3** and the accumulator **2** are communicated with each other. On the other hand, when the main valve **19** is positioned toward the bottom dead center, the main valve **19** comes into contact with the main valve rubber **27** for blocking fluid communication between the piston upper chamber of the cylinder **3** and the accumulator **2**, while the main valve **19** separates from the exhaust rubber **30** for opening the air exhaust passage **29**, so that the piston upper chamber of the cylinder **3** is communicated with the atmosphere.

The nail driving operation will be described. FIG. **1** to FIG. **3** show state in which compressed air from the compressor (not shown) is accumulated in the accumulator **2** through the hose (not shown). In this state, as shown in FIG. **2**, the plunger **7** is positioned at the bottom dead center, since the pressure within the accumulator **2** acts on the upper surface of plunger **7**, and since biasing force of the spring **12** is imparted on the plunger **7**. Since the plunger **7** is positioned at the bottom dead center, the trigger valve intake channel **14** is open to provide fluid communication between the accumulator **2** and the trigger valve chamber **13**. At the same time, the trigger valve control channel **16** is closed by the O-ring **18**, so the fluid connection between the trigger valve chamber **13** and the atmosphere is blocked. As a result, a part of the compressed air in the accumulator **2** flows through the trigger valve intake channel **14** and into the trigger valve chamber **13**, and air in the trigger valve chamber **13** has the same pressure as in the accumulator **2**.

In this case, because of the biasing force of the spring **12** and the difference in pressure receiving areas of the valve piston **9**, the valve piston **9** is positioned at its top dead center. Therefore, the main valve intake channel **20** is open to communicate the accumulator **2** with the main valve control channel **40**. At the same time, the air channel **22** is closed by the O-ring **23**, so the connection between the main valve control channel **40** and the atmosphere is blocked. As a result, a portion of the compressed air in the accumulator **2** flows into the main valve control channel **40**, and air accumulates in the main valve chamber **8** at the same pressure as in the accumulator **2**.

Since the part of the compressed air in the accumulator **2** flows into the main valve chamber **8**, the main valve **19** is positioned at the bottom dead center as shown in FIG. **3** as a result of downward pressing load arising from the difference in pressure receiving areas between the lower peripheral surface **52** and the upper end surface **54** of the main valve **19**, along with the biasing force of the main valve spring **28**.

Since the main valve **19** is positioned at the bottom dead center, the main valve **19** comes into contact with the main valve rubber **27** while separating from the exhaust rubber **30** to open the air discharge passage **29**. As a result, the piston upper chamber of the cylinder **3** is brought into communication with the atmosphere. Thus, the piston upper chamber assumes the atmospheric pressure. In addition, the fluid connection between the piston upper chamber of the cylinder **3** and the accumulator **2** is blocked. Thus, compressed air in the accumulator **2** does not flow into the piston upper chamber. As a result, the piston **4***a* is maintained at its top dead center position.

FIG. **4** shows the state where the plunger **7** is pushed up to the top dead center by pulling the trigger **39** and pressing the push lever **42** against the workpiece. Since the plunger **7** is positioned at the top dead center, the O-ring **18** loses its sealing effect, and the trigger valve control channel **16** will be opened. As a result, the trigger valve chamber **13** and the atmosphere are communicated with each other, so the inside of the trigger valve chamber **13** assumes the atmospheric pressure. In addition, the trigger valve intake channel **14** is closed by the O-ring **15** for blocking fluid communication between the accumulator **2** and the trigger valve chamber **13**. Thus, compressed air does not any more flow from the accumulator **2** into the trigger valve chamber **13**.

Since the trigger valve chamber **13** assumes the atmospheric pressure, a difference arises between the pressure imparted to the valve piston **9** at its accumulator side and the pressure imparted to the valve piston **9** in the trigger valve chamber **13**. Because of the pressure difference, the valve piston **9** moves to the bottom dead center as shown in FIG. **5**.

The value obtained from dividing the maximum volume V**2** of the trigger valve chamber **13** by the cross-sectional area S2 of the trigger valve control channel **16** is V2/S2=0.2. This value is set smaller than that in conventional fastener driving tools. This is a design concept obtained as a result of recognition of the principle in a tube flow that there is a proportional relationship between the mass rate of flow and the cross-sectional area of the tube. More specifically, it is based on the discovery that, with fastener driving tools which have valve chambers, the time period required for the pressure in these valve chambers to drop to a specific pressure due to the discharge of air decreases in accordance with an increase in the cross-sectional area of the channels used to discharge air with respect to the volume of these valve chambers.

FIG. **6** shows the relationship between V**2**/S**2** and the time period T**2** from when the pressure inside the trigger valve chamber **13** begins to drop until the valve piston **9** moves to maximum displacement. The smaller V**2**/S**2** is made, the smaller T**2** becomes as well. For the value in this first embodiment, V**2**/S**2**=0.2, T**2** is approximately 0.75 ms. Consequently, the time period required for the pressure in the trigger valve chamber **13** to drop to a specific pressure decreases, and accordingly, time period from when the plunger **7** is pressed until the valve piston **9** moves to maximum displacement can be reduced. As a result, the amount of time from when the trigger **39** and the push lever **42** are operated until the nailing motion occurs due to the displacement of the trigger valve can be further reduced. Incidentally, by making V**2**/S**2**=0.15, T**2** can be made smaller, and by making V**2**/S**2**=0.10, T**2** can be made smaller still, and the amount of time until the nailing motion occurs can be shortened.

Thus, by setting the maximum volume V**2** of the trigger valve chamber **13** and the cross-sectional area S**2** of the trigger valve control channel **16** to the aforementioned values, discharge of the compressed air from the trigger valve chamber **13** can be promptly performed, and the time period until the trigger valve chamber **13** assumes the atmospheric pressure can be reduced. Furthermore, since the discharge of air from the trigger valve chamber **13** can be improved when the valve piston **9** is moved to the bottom dead center, a so-called air damper in which the pressure in the trigger valve chamber **13** impedes the movement of the valve piston **9** is not readily formed. Accordingly, the valve piston **9** can be moved immediately from the top dead center to the bottom dead center without being interrupted by the air damper. Incidentally, even though the valve piston **9** is biased toward the top dead center by the spring **12**, the valve piston **9** is movable to the bottom dead center by the pressure difference since the biasing force of the spring **12** is set beforehand to be weaker than the force caused by the pressure difference.

As shown in FIG. **5**, since the valve piston **9** is positioned at the bottom dead center, the main valve intake channel **20** is closed by the O-ring **21** to block fluid communication from the accumulator **2** to the main valve control channel **40**. In addition, the O-ring **23** loses its sealing effect to open the air channel **22**, so that the main valve control channel **40** is brought into communication with the atmosphere. As a result, the main valve control channel **40** and the main valve chamber **8** assume atmospheric pressure.

When the main valve chamber **8** assumes generally the atmospheric pressure, the main valve **19** then moves to the top dead center as shown in FIG. **8** as a result of the upward pressure arising from the difference in pressure receiving areas at the lower outer peripheral surface **52** and at the upper end surface **54** of the main valve **19**. When the main valve **19** begins to move toward the top dead center, the accumulator **2** and the piston upper chamber in the cylinder **3** are brought into fluid communication with each other. Thus, because of the pressure imparted to the lower outer peripheral surface **52** as well as to the lower end surface **53** of the main valve **19**, the main valve **19** moves rapidly toward the top dead center, and comes into contact with the exhaust rubber **30** to close the air discharge passage **29** whereupon the piston upper chamber is shut off from the atmosphere. In this case, the accumulator **2** is also shut off from the atmosphere.

By the movement of the main valve **19** toward its upper dead center, the fluid in the main valve chamber **8** is discharged into the main valve control channel **40**. As described above, the value obtained from dividing the maximum volume V**1** of the main valve chamber **8** by the cross-sectional area S**1** of the main valve control channel **40** is V**1**/S**1**=0.8. This value is set smaller than that in the conventional fastener driving tools. This is a design concept which, just as with the design concept described above, was also obtained as a result of recognition of the flow principle that, with fastener driving tools which have valve chambers, the time period required for the pressure in these valve chambers to drop to a specific pressure due to the discharge of air decreases in accordance with an increase in cross-sectional area of the channels used to discharge air with respect to the volume of these valve chambers.

FIG. **9** shows the relationship between V**1**/S**1** and the time period T**1** from when the pressure in the main valve chamber **8** begins to drop until the main valve **19** moves to maximum displacement. The smaller V**1**/S**1** is made, the smaller T**1** becomes as well. For the value in this first embodiment, V**1**/S**1**=0.8 at which T**1** is approximately 7.0 ms. Consequently, the time period required for the pressure in the main valve chamber **8** to drop to a specific pressure decreases. Accordingly, the time period from when the plunger **7** is pressed as a result of the trigger **39** and the push lever **42** being operated until the main valve **19** moves to maximum displacement can be reduced. As a result, the time period from when the trigger **39** and the push lever **42** are operated until the nailing motion occurs because of the displacement of the main valve **19** can be reduced. Incidentally, if V**1**/S**1** is set to 1.0, T**1** becomes 7.5 ms, which is sufficiently small. If V**1**/S**1** is set to 0.6, T**1** can be made even smaller, about 5.0 ms. Thus, time period until the nailing motion occurs can be further shortened.

In the first embodiment, a bending section is provided in the main valve control channel **40**. However, the bending section does not cause significant flow path resistance, since the bending section is configured into an gentle arcuate shape. Consequently, there is no obstruction in the flow of air in the main valve control channel **40**. Furthermore, as described above, the air in the main valve chamber **8** passes from the main valve control channel **40** through air channel **22** of the trigger valve **6** and is discharged into the atmosphere. In this case, since cross-sectional area of the air channel **22** is larger than that of the main valve control channel **40** in terms of air flowing passage, the air channel **22** does not prevent the air from flowing from the main valve chamber **8** into the atmosphere. Consequently, the time period from when the trigger **39** and the push lever are operated until the nailing motion occurs can be shortened.

Thus, by setting the maximum volume of the main valve chamber **8** and the cross-sectional area of the main valve control channel **40** to the aforementioned values, the compressed air in the main valve chamber **8** will escape more quickly, so that the time period until the main valve chamber **8** assumes the atmospheric pressure can be reduced. Furthermore, a so-called air damper in the main valve chamber **8** is not readily formed because of the improvement on the shape of the main valve control channel **40** and improvement on passing of air through the air channel **22**. Accordingly, the escape of air from the main valve chamber **8** can be improved even when the main valve **19** rises to the top dead center. Consequently, the main valve **19** can be moved immediately from the bottom dead center to the top dead center.

By the movement of the main valve **19** from its bottom dead center to the top dead center, the compressed air rapidly flows from the accumulator **2** into the piston upper chamber, thereby rapidly moving the piston **4***a* toward its bottom dead center. Thus, the fastener **5** is driven by the tip end **4***c* of the driver blade **4***b* connected to the piston **4***a*. The air in the underside of the piston **4***a* in the cylinder **3** flows through air channel **36** into the return air chamber **33**. Further, a portion of the compressed air in the piston upper chamber also flows through the air channel **35** into the return air chamber **33**, after the piston **4***a* is moved past the air channel **35**.

FIG. **11** shows the state where the plunger **7** has just returned to the bottom dead center after release of the trigger **39** or after the pressing of the push lever **42** against the workpiece is stopped. The plunger **7** has moved to the bottom dead center because of the pressure applied to the upper end face of the plunger **7** from the accumulator **2** and the biasing force of the spring **12**.

By the movement of the plunger **7** to the bottom dead center, the trigger valve control channel **16** is closed by the O-ring **18**, while the O-ring **15** loses its sealing effect. Thus, the compressed air in the accumulator **2** flows through the trigger valve intake channel **14** into the trigger valve chamber **13**.

In this case, as described above, the cross-sectional area St of the trigger valve intake channel **14** is set to 2.75×10^{-6} (m^2), which is relatively larger than that of the conventional tool. This is due to a design concept obtained as a result of recognition of the tube flow principle that there is a proportional relationship between the mass rate of flow and the cross-sectional area of the tube. More specifically, it is based on the discovery that, with fastener driving tools having valve chambers, the time period required for the pressure in these valve chambers to be increased to a specific pressure due to introduction of the compressed air thereinto is reduced in accordance with an increase in the cross-sectional area of the channels used for the introduction of the compressed air with respect to the volume of these valve chambers.

FIG. **7** shows the relationship (solid line curve) between the cross-sectional area (St) of the trigger valve intake channel **14**, and the time period T**1** until the main valve returns to the initial position. FIG. **7** also shows the relationship (broken line curve) between the cross-sectional area (St) and air consumption volume NL. As the cross-sectional area St decreases, the main valve return time period can be reduced and the air consumption volume can be decreased. These curves T1 and NL appear as convex functions toward the lower direction. Therefore, the reducing or decreasing effects are not greatly exhibited at the greater range of the cross-sectional area. Taking the phenomena into consideration, the specific value was determined experimentally to be 2.75×10^{-6} (m^2). As a result, the time period required for the pressure in the trigger valve chamber **13** to rise to a specific pressure due to the inflow of compressed air is reduced. Thus, the time period from when the pressing force on the plunger **7** ceases until the valve piston **9** returns to the pre-nailing position can be shortened.

By the introduction of the compressed air into the trigger valve chamber **13**, the valve piston **9** is moved to its top dead center. Thus, the O-ring **23** blocks fluid communication between the air channel **22** and the main valve control channel **40**, while the O-ring **21** loses its sealing effect so that the accumulator **2** is fluidly connected to the main valve chamber **8** via the main valve intake channel **20** and the main valve control channel **40**. Thus, compressed air flows from the accumulator **2** into the main valve chamber **8**.

As described above, the value obtained from dividing the maximum volume V**1** of the main valve chamber **8** by the cross-sectional area S**1** of the main valve control channel **40** is V**1**/S**1**=0.8. This value is set smaller than that of the conventional fastener driving tools. As with the design concept for the trigger valve intake channel **14**, this value is determined based on the design concept that, with fastener driving tools having valve chambers, the time period required for the pressure in these valve chambers to be increased to a specific pressure by the introduction of the compressed air thereinto is reduced in accordance with an increase in the cross-sectional area of the channels used for the introduction of the compressed air with respect to the volume of these valve chambers.

FIG. **10** shows the relationship between V**1**/S**1**, and the time period T**1** until the main valve **19** returns to the initial position (lower dead position). FIG. **10** also shows the relationship between V**1**/S**1** and the air consumption volume NL. The lower V**1**/S**1** becomes, the lower T**1** becomes as well. For the value in this first embodiment, V**1**/S**1** is set to 0.8 at which T**1** is approximately 7.0 ms. Consequently, the time period required for the pressure in the main valve chamber **8** to rise to a specific pressure by the introduction of compressed air thereinto can be reduced. Thus, the time period from when the valve piston **9** begins to return to the pre-nailing position (toward the top dead center) until the main valve **19** closes the main valve rubber **27** can be reduced. As a result, the time period to the restoration timing for the subsequent nail driving operation after the actual nail driving operation can be reduced. More specifically, the time period from when the trigger **39** and the push lever **42** are operated until the main valve reaches its bottom dead center as a result of the movement of the valve piston **9** to the pre-nailing position can be reduced. Further, since the time period for the main valve **19** to be closed is reduced, the amount of compressed air flowing from the accumulator **2** to the piston upper chamber can be reduced during movement of the main valve **19** toward its bottom dead center. Incidentally, even if V**1**/S**1** is set to 1.0, T**1** will be approximately 7.5 ms, which is sufficiently small in comparison to the conventional examples. If V**1**/S**1** is set to 0.6, T**1** can be made even smaller, approximately 5.5 ms. Consequently, the time period, following nailing, for the return to the pre-nailing state can be further reduced, while the amount of compressed air which flows from the accumulator **2** to the piston upper chamber can be further decreased.

In addition, the value obtained from dividing the maximum volume **V1** of the main valve chamber **8** by the cross-sectional area Sm of the main valve intake channel **20** is likewise set to **V1**/**S1**=0.8. The main valve intake channel **20** and the main valve control channel **40** become a contiguous inflow passage directing to the main valve chamber **8**. In this connection, the main valve intake channel **20** should provide a performance at least equal to that of the main valve control channel **40**. As a result, **V1**/Sm was also set to 1.0 or less. In addition, **V1**/**S1** and **V1**/Sm need not be the same value provided that they are both 1.0 or less. Incidentally, there is the curved area at the main valve control channel **40**. However, the curved area does not lead to a significant flow resistance because of the gentle arcuate shape in the curved area. Thus, there is no obstruction in the flow of air to be directed into the main valve chamber **8**.

As a result, the compressed air can instantaneously flow into the main valve chamber **8** so that a downward pressing force arises because of the difference in pressure receiving areas among the lower outer peripheral surface **52**, the lower end surface **53**, and the top end surface **54** of the main valve **19**. In this first embodiment, by setting both **V1**/**S1** and **V1**/Sm to 0.8, the time period required for the main valve **19** to move to the bottom dead center, that is, to return the main valve **19** to its pre-nailing position can be reduced to approximately 3.8 ms. This returning movement is also due to the pressing force arising from the compressed air flowing into the main valve chamber **8** and the biasing force of the main valve spring **28**.

Upon movement of the main valve **19** to its bottom dead center, the main valve **19** is coming into contact with the main valve rubber **27** to shut off fluid connection between the accumulator **2** and the piston upper chamber. Further, immediately before the main valve **19** reaches its bottom dead center, the main valve **19** is separated from the exhaust rubber **30** for providing fluid communication from the piston upper chamber with the atmosphere. As a result of the structural relationships, the main valve **19** is separated from the exhaust rubber **30** prior to the complete return of the main valve **19** to the bottom dead center. In this instance, since the accumulator **2** and the piston upper chamber are not yet completely blocked from each other, the accumulator **2** is connected to the atmosphere through the piston upper chamber and the air discharge passage **29**, so that the compressed air is discharged unnecessarily into the atmosphere. However, by setting VI/S1 and **V1**/Sm to 1.0 or less, and also setting the cross-sectional area St of the trigger valve intake channel **14** to 2.75×0^{-6} (m^2), the time period for the main valve **19** to move to the bottom dead center can be shortened, so that the unwanted consumption of the compressed air due to leakage of compressed air from the accumulator **2** to the atmosphere can be reduced as is apparent from FIG. **10**.

Then, underside of the piston **4***a* is then pressed by the compressed air accumulated in the return air chamber **33**, and the piston **4***a* rapidly moves to its top dead center. The air in the piston upper chamber is released from the exhaust hole **49** to the atmosphere through the air discharge passage **29**, and the fastener driving tool **1** returns to the initial state shown in FIG. **1**.

FIG. **12** shows a modification to the main valve control channel **40**. In the first embodiment shown in FIG. **3**, the bending portion (enclosed by the circle **51**) of the main valve control channel **40**, is configured into the gentle arcuate shape. In the modification shown in FIG. **12**, the bending portion can include at least two bent areas. In the latter case, the bending angle is preferably not less than 100°. With this arrangement, air can be smoothly flowed into the main valve chamber **8**, and the air in the main valve chamber **8** can be smoothly discharged therefrom, without excessive channel resistance. As an another modification, the cross-sectional area of the trigger valve intake channel **14** can be made large such as 3.00×10^{-6} (m^2) or 3.25×10^{-6} (m^2). In so doing, the unit rate of flow of the compressed air entering the trigger valve chamber **13** increases, so that the time period required for the pressure increase in the trigger valve chamber **13** can be shortened.

Next, a fastener driving tool according to a second embodiment of the present invention will be described with reference to FIG. **13** to FIG. **16**. The overall structure of the fastener driving tool **101** shown in FIG. **13** is substantially the same as the first embodiment except that the valve piston **9** in the first embodiment is not provided. Consequently, a detailed description will be omitted. In FIGS. **13** through **16**, like parts and components are designated by reference numerals added with **100** to the reference numerals shown in FIGS. **1** through **11**.

A nail gun **101** includes a frame **160**, a handle **160**A, a nose **141** having an injection opening **146**, an accumulator **102**, a cylinder **103**, a piston **104***a*, a driver blade **104***b* and its tip end **104***c*, a return air chamber **133**, one way valve **134**, air channels **135**, **136**, a piston bumper **137**, a trigger **139**, a trigger valve **106** including a plunger **107**, a push lever **142**, a magazine **144**, and a main valve **126**.

The trigger valve **106** shown in FIGS. **13** and **14** mainly includes a valve bush **110**, a plunger **107**, and a spring **112**. The valve bush **110** formed with a through hole is fixed to the frame **160** to form a trigger valve exterior frame which constitutes an outer wall of the trigger valve **106**. The plunger **107** is provided reciprocably slidably with respect to the through hole of the valve bush **110**. The plunger **9** has a bottom end in contact with the trigger **139**. The spring **112** is interposed between the frame **160** and the plunger **107** for biasing the plunger **107** downward.

The trigger valve **106** is fluidly connected to a cylindrical main valve control channel **140** extending from a main valve chamber **108**. Specifically, the main valve control channel **140** is configured such that its cross-sectional area **S1** is 3.2×10^{-5} (m^2).

In addition, an O-rings **125** is fitted on the valve bush **110** for continually blocking fluid connection between the main valve control channel **140** and an atmosphere. A trigger valve chamber **113** is defined by the frame **160** and the valve bush **110** secured to the frame **160**.

The plunger **107** extends through the trigger valve chamber **113**, and has an upper portion extending through a through-hole formed in the frame **160**. An annular space is defined between the through-hole and the plunger **107** for serving as a main valve intake channel **120**. The main valve intake channel **120** has a cross-sectional area Sm of 3.2×10^{-5} (m^2). The cross-section extends in a direction perpendicular to the flowing direction. An O-ring **115** is fitted at the through-hole of the frame **160** for shutting off the main valve intake channel **120** when the plunger **107** is moved to its top dead center.

The plunger **107** has a lower section associated with the through hole of the valve bush **110**. The lower section has an outer diameter slightly smaller than an inner diameter of the through hole of the valve bush **110** for defining an air channel **116** therebetween. This air channel **116** has a cross-sectional area of at least 3.2×0^{-5} (m^2). An O-ring **118** is fitted onto the lower section of the valve bush **110** for closing the air channel **116** when the plunger **107** is moved to the bottom dead center. The main valve intake channel **120** and air channel **116** are alternately blocked in accordance with the sliding motion of the plunger **107**.

The main valve **126** is provided at an upper end and around an outer peripheral surface of the cylinder **103** as shown in FIG. **13**. The main valve **126** includes a main valve **119** and a main valve spring **128** for biasing the main valve **119** toward its bottom dead center. An discharge passage **129** is formed above the main valve **119**, and an exhaust port **149** in communication with the discharge passage **129** is formed at an upper portion of the frame **160**.

A main valve sectioning region **161** is provided as a part of the frame **160** for defining a main valve chamber **108** in which the main valve **119** is vertically movably disposed. The main valve chamber **108** is in communication with the main valve control channel **140**.

The main valve chamber **108** is hermetically provided by O-rings (not shown). The main valve chamber **8** has an internal volume variable in accordance with the vertical movement of the main valve **119**, but has a maximum volume **V1** of 2.56×10^{-5} (m^3). As a result, the value obtained from dividing the volume **V1** by the cross-sectional area **S1** of the main valve control channel **40** is $V1/S1=0.8\leqq1.0$. Likewise, the value obtained from dividing the volume **V1** by the cross-sectional area Sm of the main valve intake channel **120** is $V1/Sm=0.8\leqq1.0$. In addition, the main valve control channel **140** has a curving portion. The curving portion is formed into a gentle arcuate shape.

The nail driving operation will be described. FIGS. **13** and **14** show a state in which compressed air from the compressor (not shown) is accumulated in the accumulator **102** through the hose (not shown). In this state, as shown in FIG. **14**, the plunger **107** is positioned at its bottom dead center by the biasing force of the spring **112**. Since the plunger **107** is positioned at the bottom dead center, the main valve intake channel **120** is open to provide fluid communication between the accumulator **102** and the trigger valve chamber **113**. At the same time, the air channel **116** is closed by the O-ring **118**, so the fluid connection between the trigger valve chamber **113** and the atmosphere is blocked.

As shown in FIG. **14**, since the trigger valve chamber **113** is in communication with the main valve control channel **140**, a portion of the compressed air in an accumulator **102** also flows into the main valve control channel **140**. Therefore, compressed air is accumulated in the main valve chamber **108** at the same pressure as in the accumulator **102**.

Since the part of the compressed air in the accumulator **102** flows into the main valve chamber **108**, the main valve **119** is positioned at its bottom dead center as shown in FIG. **13** as a result of downward pressing load arising from the difference in pressure receiving areas between a lower peripheral surface **142** and an upper end surface **143** of the main valve **119**, along with the biasing force of the main valve spring **128**.

Since the main valve **119** is positioned at the bottom dead center, the main valve **119** comes into contact with an upper end of the cylinder **103** to block fluid communication between the accumulator **102** and the piston upper space in the cylinder **103**. In this case, the main valve **110** is separated from the frame **160** to open the air discharge passage **129**. As a result, the piston upper chamber of the cylinder **103** is brought into communication with the atmosphere through the air discharge passage **129**. Thus, the piston upper chamber assumes the atmospheric pressure. In addition, since the fluid connection between the piston upper chamber and the accumulator **102** is blocked, compressed air in the accumulator **102** does not flow into the piston upper chamber. As a result, the piston **104***a* is maintained at its top dead center position.

FIGS. **15** and **16** show the state where the plunger **107** is pushed up to the top dead center by pulling the trigger **139** and pressing the push lever **142** against the workpiece. Since the upper portion of the plunger **107** extends through the O-ring **115**, the fluid connection between the trigger valve chamber **113** and the accumulator **102** is blocked. In addition, the O-ring **118** loses its sealing effect to open the trigger valve control channel **116**. As a result, the trigger valve chamber **113** and the atmosphere are fluidly connected to each other, so the inside of the trigger valve chamber **113** assumes the atmospheric pressure. The cross-sectional area of the air channel **116** is greater than that of the main valve channel **140**. Thus, the channel resistance in air channel **116** is smaller than that in the main valve channel **140**. The main valve control channel **140** connected to the trigger valve chamber **113** is also connected to the atmosphere, and in addition, the main valve chamber **108** connected to the main valve control channel **140** is also connected to the atmosphere and assumes the atmosphere pressure.

When the main valve chamber **108** assumes roughly the atmospheric pressure, the main valve **119** moves to its top dead center as shown in FIG. **16** because compressed air pressure is applied to the lower outer peripheral surface **147** of the main valve **119** whereas the atmospheric pressure is applied to the upper end face **143** of the main valve. When the main valve **119** begins to move toward the top dead center, the accumulator **102** and a piston upper chamber in the cylinder **103** are brought into communication with each other, so that compressed air pressure is also applied to the lower end face **148** of the main valve **119**. Thus, the main valve **119** moves rapidly toward the top dead center. As a result, the top end face of the main valve **119** comes into contact with the frame **160** to close the exhaust hole **149**, so that fluid communication between the piston upper chamber and the atmosphere is blocked.

In the second embodiment, similar to the first embodiment, the value obtained from dividing the maximum volume **V1** of the main valve chamber **108** by the cross-sectional area **S1** of the main valve control channel **140** is $V1/S1=0.8$. This is a design concept which, just as with the design concept in the first embodiment, was obtained as a result of recognition of the flow principle that, with fastener driving tools having valve chambers, the time period required for the pressure in these valve chambers to drop to a specific pressure due to the discharge of air can be reduced in accordance with an increase in cross-sectional area of the channels used to discharge air with respect to the volume of these valve chambers.

The relationship between **V1**/**S1** and the time period **T1** from when the pressure in the main valve chamber **108** begins to drop until the main valve **119** moves to maximum displacement is basically the same as that shown in FIG. **9**. For the value in this second embodiment, if **V1**/**S1** is 0.8, **T1** is approximately 7.0 ms. Further, even if **V1**/**S1** is set to 1.0, **T1** will be approximately 7.5 ms, which is sufficiently small in comparison with the conventional tools. With a fastener driving tool which is at least equipped with the main valve **119**, the time period required for the pressure in the main valve chamber **108** to drop to a specific pressure due to the discharge of air can be reduced. Accordingly, the time period from when the trigger **139** and the push lever **142** are operated until the nailing motion occurs because of the displacement of the main valve **119** can be reduced. Incidentally, if V**1**/S**1** is set to 0.6, T**1** can be made even smaller, about 5.0 ms. Thus, time period until the nailing motion occurs can be further shortened. These values for T**1** are sufficiently smaller than those in conventional fastener driving tools.

The air in the main valve chamber **108** passes through the main valve control channel **140** and through the air channel **116** of the trigger valve **106** and is discharged into the atmosphere. In this case, since cross-sectional area of the air channel **116** is larger than that of the main valve control channel **140**, the air channel **116** does not prevent the air from flowing from the main valve chamber **108** into the atmosphere. Consequently, the time period from when the trigger **139** and the push lever are operated until the main valve **119** is moved to the top dead center can be shortened.

Thus, by setting the maximum volume of the main valve chamber **108** and the cross-sectional area of the main valve control channel **140** to the aforementioned values, the compressed air in the main valve chamber **108** can be discharged quickly, so that the time period until the main valve chamber **108** assumes the atmospheric pressure can be reduced. Furthermore, a so-called air damper in the main valve chamber **108** is not readily formed because of the improvement on the shape of the main valve control channel **140** and improvement on passing of air through the air channel **116**. Accordingly, the discharge of air from the main valve chamber **108** can be improved even when the main valve **119** rises to the top dead center. Consequently, the main valve **119** can be moved immediately from the bottom dead center to the top dead center.

By the movement of the main valve **119** from its bottom dead center to the top dead center, the compressed air rapidly flows from the accumulator **102** into the piston upper chamber, thereby rapidly moving the piston **104***a* toward its bottom dead center. Thus, the fastener is driven by the tip end **104***c* of the driver blade **104***b* connected to the piston **104***a*. The air in the underside of the piston **104***a* in the cylinder **103** flows through air channel **136** into the return air chamber **133**. Further, a portion of the compressed air in the piston upper chamber also flows through the air channel **135** into the return air chamber **133**, after the piston **104***a* is moved past the air channel **135**.

When the trigger **139** is returned or the pressing of the push lever **142** against the workpiece is stopped, the plunger **107** moves to the bottom dead center because of the pressure applied to the plunger **107** from the accumulator **102** and the biasing force of the spring **112** (FIG. **14**).

By the movement of the plunger **107** to the bottom dead center, the air channel **116** is closed by the O-ring **118**, while the O-ring **115** loses its sealing effect. Thus, the compressed air in the accumulator **102** flows through the main valve intake channel **120** into the trigger valve chamber **113**. In this case, because the trigger valve chamber **113** is in communication with the main valve control channel **140**, the main valve chamber **108** is communicated with the accumulator **102** through the main valve intake channel **120**. Thus compressed air is introduced into the main valve chamber **108**.

As described above, the value obtained from dividing the maximum volume V**1** of the main valve chamber **108** by the cross-sectional area S**1** of the main valve control channel **140** is V**1**/S**1**=0.8. This value is set smaller than that of the conventional fastener driving tools. As with the design concept for the trigger valve intake channel **14**, this value is determined based on the design concept that, with fastener driving tools having valve chambers, the time period required for the pressure in these valve chambers to be increased to a specific pressure by the introduction of the compressed air thereinto is reduced in accordance with an increase in the cross-sectional area of the channels used for the introduction of the compressed air with respect to the volume of these valve chambers.

The graph shown in FIG. **10** is also available in the second embodiment. The lower V**1**/S**1** becomes, the lower T**1** becomes as well. Since V**1**/S**1** is set to 0.8, T**1** is approximately 7.0 ms. Consequently, the time period required for the pressure in the main valve chamber **108** to rise to a specific pressure by the introduction of compressed air thereinto can be reduced. Thus, the time period from when the main valve **119** begins to return to the pre-nailing position (toward the bottom dead center) until the main valve **119** closes the top end of the cylinder **103** can be reduced. As a result, the time period from when the trigger **139** and the push lever **142** are operated until the main valve **119** reaches its bottom dead center (until the pre-nailing state for the subsequent nail driving operation) can be reduced. Further, since the time period for the main valve **119** to be closed is reduced, the amount of compressed air flowing from the accumulator **102** to the piston upper chamber can be reduced during movement of the main valve **119** toward its bottom dead center. Incidentally, even if V**1**/S**1** is set to 1.0, T**1** will be approximately 7.5 ms, which is sufficiently small in comparison to the conventional tools. If V**1**/S**1** is set to 0.6, T**1** can be made even smaller, approximately 5.5 ms. Consequently, the time period, following nailing, for the return to the pre-nailing state can be further reduced, while the amount of compressed air which flows from the accumulator **102** to the piston upper chamber can be further decreased.

In addition, the value obtained from dividing the maximum volume V**1** of the main valve chamber **108** by the cross-sectional area Sm of the main valve intake channel **120** is likewise set to V**1**/S**1**=0.8. The main valve intake channel **120** and the main valve control channel **140** become a contiguous inflow passage directing to the main valve chamber **108**. In this connection, the main valve intake channel **120** should provide a performance at least equal to that of the main valve control channel **140**. As a result, V**1**/Sm was also set to 1.0 or less. In addition, V**1**/S**1** and V**1**/Sm need not be the same value provided that they are both 1.0 or less. Incidentally, there is the curved area at the main valve control channel **140**. However, the curved area does not lead to a significant flow resistance because of the gentle arcuate shape in the curved area. Thus, there is no obstruction in the flow of air to be directed into the main valve chamber **108**.

As a result, the compressed air can instantaneously flow into the main valve chamber **108** so that a downward pressing force is imparted on the main valve **108** because of the difference in pressure receiving areas between the lower outer peripheral surface **147** and the top end surface **143** of the main valve **119**. In the second embodiment, by setting both V**1**/S**1** and V**1**/Sm to 0.8, the time period required for the main valve **119** to move to the bottom dead center, that is, to return the main valve **119** to its pre-nailing position can be reduced to approximately 3.8 ms. This returning movement is also due to the pressing force arising from the compressed air flowing into the main valve chamber **108** and the biasing force of the main valve spring **128**.

Upon movement of the main valve **119** to its bottom dead center, the main valve **119** is coming into contact with the upper end of the cylinder **103** to shut off fluid connection between the accumulator **102** and the piston upper chamber.

Further, immediately before the main valve **119** reaches its bottom dead center, the main valve **119** is separated from the frame **160** for providing fluid communication from the piston upper chamber with the atmosphere. As a result of the structural relationships, the main valve **119** is separated from the frame **160** prior to the complete return of the main valve **119** to the bottom dead center. In this instance, since the accumulator **102** and the piston upper chamber are not yet completely blocked from each other, the accumulator **102** is connected to the atmosphere through the piston upper chamber and the air discharge passage **129**, so that the compressed air is discharged unnecessarily into the atmosphere. However, by setting V**1**/S**1** and V**1**/Sm to 1.0 or less, the time period for the main valve **119** to move to the bottom dead center can be shortened, so that the unwanted consumption of the compressed air due to leakage of compressed air from the accumulator **102** to the atmosphere can be reduced as is also apparent from FIG. **10**.

Then, underside of the piston **104***a* is then pressed by the compressed air accumulated in the return air chamber **133**, and the piston **104***a* rapidly moves to its top dead center. The air in the piston upper chamber is released from the exhaust hole **149** to the atmosphere through the air discharge passage **129**, and the fastener driving tool **1** returns to the initial state shown in FIG. **13**.

In the second embodiment, the bending portion of the main valve control channel **140** is configured into the gentle arcuate shape. As a modification, the bending portion can include at least two bent areas. In the latter case, the bending angle is preferably not less than 100°. With this arrangement, air can be smoothly flowed into the main valve chamber **108**, and the air in the main valve chamber **108** can be smoothly discharged therefrom, without excessive channel resistance. With this arrangement, can be reduced the first time period from operation timing of the trigger **139** and the push lever **142** to the actual driving operation, and the second time period from release timing of the plunger **107** to the timing at which the main valve **119** has returned to its pre-driving position.

A fastener driving tool according to a third embodiment of the present invention will next be described with reference to FIGS. **17** through **19**. The overall structure of the fastener driving tool **201** is substantially the same as the first embodiment except that the main valve section **26** in the first embodiment is not provided. In FIGS. **17** through **19**, like parts and components are designated by reference numerals added with **200** to the reference numerals shown in FIGS. **1** through **11**.

A nail gun **201** includes a frame **260**, a handle **260**A, a nose **241** having an injection opening **246**, an accumulator **202**, a cylinder **203**, a piston **204***a*, a driver blade **204***b* and its tip end **204***c*, a return air chamber **233**, one way valve **234**, air channels **235**, **236**, a piston bumper **237**, a trigger **239**, a trigger valve **206** including a plunger **207**, and a magazine **244**.

A piston upper chamber **266** is defined by the piston **204***a*, the cylinder **203**, and the frame **260**. The piston upper chamber **266** extends into an upper section of the frame **260**. Further, an air channel **262** extends from the piston upper chamber **266** to the trigger valve **206**.

The trigger valve **206** shown in FIGS. **17** and **18** mainly includes a valve bush **210**, a valve piston **209**, the plunger **207**, and a spring **212**. The valve bush **210** formed with a through hole is fixed to the frame **260** to form a trigger valve exterior frame which constitutes an outer wall of the trigger valve **206**. The valve piston **209** is reciprocally slidably disposed in the valve bush **210**. The plunger **207** is provided reciprocably slidably with respect to the through hole of the valve bush **210**. The plunger **207** has a bottom end in contact with the trigger **239**. The spring **212** is interposed between the valve piston **209** and the plunger **207** for biasing the valve piston **209** and the plunger **207** in opposite directions, that is, the valve piston **209** is biased upward, and the plunger **207** is biased downward.

An air channel **262** having a circular cross-section is formed within the frame **260** and extends from the piston upper chamber **266**. The air channel **262** is connected to the trigger valve **206**. In addition, an exhaust pipe **263** is provided in the handle **206**A and has one end serving as an exhaust hole **249** opened at an end face of the handle **260**A. The exhaust pipe **263** is connected to the trigger valve **206** at a position below the location at which the air channel **262** is connected to the trigger valve **206**. Further, in the trigger valve **206**, a valve plate **264** formed with a hole is disposed at a position between the connecting position between the air channel **262** and the trigger valve **206** and the connecting position between the exhaust pipe **263** and the trigger valve **206**. The valve piston **209** extends through the hole of the valve plate **264**. Further, a space is defined between the hole of the valve plate **264** and the valve piston **209**. The space serves as an air channel **222**.

Another air channel **220** is formed at the part of the frame **260**, the part serving as a part of the trigger valve **206**. The air channel **220** is adapted to provide a communication between the accumulator **202** and the trigger valve **206**.

One end of the valve piston **209** in the sliding direction faces the accumulator **202**. A valve piston rubber **221** is fitted in the vicinity of the opening of air channel **262** and at the upper end portion (a small diameter section) of the valve piston **209**. The valve piston rubber **221** is adapted to come into -contact with the frame **260** near the periphery of air channel **220** when the valve piston **209** is at its top dead center (FIG. **18**), and come into contact with an area near the periphery of the center hole of the valve plate **264** when the valve piston **209** is at its bottom dead center (FIG. **19**). The air channel **222** provides fluid communication between the piston upper chamber **266** and the air channel **262** when the valve piston rubber **221** is released from the valve plate **264** in accordance with the movement of the valve piston **209** to its upper dead center.

The valve piston **209** has a large diameter section provided with an O-ring **224** in sliding contact with the valve bush **210**. The O-ring **224** provides sealing at the boundary between the valve piston **209** and the large diameter section.

A trigger valve chamber **213** is defined by one end (lower end) of the large diameter section of the valve piston **209** and the valve bush **210**. The trigger valve chamber **213** has an internal volume variable due to the sliding movement of the valve piston **209**, and is formed such that a maximum internal volume V**2** defined when the valve piston **209** is at the top dead center is 4.0×10^{-7} (m^3). The O-ring **224** is adapted for blocking the fluid connection between the air channel **222** and the trigger valve chamber **213**.

The plunger **207** extends into the trigger valve chamber **213**, and a top end faces the accumulator **2**. The small diameter section of the valve piston **209** is formed with a central bore **261** in communication with the accumulator **202**, and the large diameter section of the valve piston **209** is formed with a stepped bore in communication with the central bore **261**. An O-ring **215** is assembled at the stepped bore.

The plunger **207** has a small diameter section in association with the stepped bore. The outer diameter of the small diameter section of the plunger **207** is smaller than an inner diameter of the stepped bore. The small diameter section of plunger **207** is slidingly engagable with the O-ring **215** (FIG. **19**) when the plunger **207** is moved to its top dead center. A trigger valve intake channel **214** is defined by the central bore **261**.

The plunger **207** has a large diameter section provided with an O-ring **218** and in association with the through hole of the valve bush **210**. An outer diameter of the large diameter section of the plunger **207** is smaller than an inner diameter of the through hole of the valve bush **210** to thus define a trigger valve control channel **216**.

Consequently, the trigger valve intake channel **214** provides fluid communication between the accumulator **202** and the trigger valve chamber **213** when the small diameter section of the plunger **207** is disengaged from the O-ring **215**. Further, the trigger valve control channel **216** provides fluid communication from the trigger valve chamber **213** to the atmosphere when the O-ring **218** is out of contact from the valve bush **210**. The trigger valve intake channel **214** and trigger valve control channel **216** are alternately opened and blocked in accordance with the sliding motion of the plunger **207**.

The trigger valve intake channel **214** is formed such that its cross-sectional area St is 2.75×10^{-6} (m^2). Further, the trigger valve control channel **216** is formed such that its cross-sectional area S**2** is 1.98×10^{-6} (m^2). As a result, the value obtained from dividing the maximum volume of the trigger valve chamber **213** by the cross-sectional area of the trigger valve control channel **216** is V**2**/S**2**=0.2.

The structure of the trigger valve **206** is such that, when the valve piston **209** is positioned at the top dead center (FIG. **18**), the valve piston rubber **221** is in abutment with the frame **260** near the air channel **220**. Since the air channel **220** is closed by the valve piston rubber **221**, the communication between the accumulator **202** and the piston upper chamber **266** through the air channels **262** and **220** is blocked. Further, the air channel **222** is opened to allow fluid communication between the piston upper chamber **266** and the exhaust pipe **263** through the air channels **262**, **220**,**222**. On the other hand, when the valve piston **209** is positioned at the bottom dead center (FIG. **19**), the valve piston rubber **221** is seated on the valve plate **264** to close the air channel **222**. Thus, fluid communication between the piston upper chamber **266** and the exhaust pipe **263** is shut off. Further, the air channel **220** is opened to provide fluid communication between the accumulator **202** and the piston upper chamber **266** through the air channels **262** and **220**.

When the plunger **207** is positioned at the top dead center (FIG. **19**), the trigger valve control channel **216** is opened so that the trigger valve chamber **213** is communicated with the atmosphere, while the trigger valve intake channel **214** is closed by the O-ring **215** so that fluid communication between the accumulator **202** and the trigger valve chamber **213** is blocked. On the other hand, when the plunger **207** is positioned at its bottom dead center (FIG. **18**), the trigger valve control channel **216** is closed by the O-ring **218**, so that fluid communication between the trigger valve chamber **213** and the atmosphere is blocked, while the trigger valve intake channel **214** is opened so that the accumulator **202** and the trigger valve chamber **213** are communicated with each other.

The nail driving operation will be described. FIGS. **17** and **18** show a state in which compressed air from the compressor (not shown) is accumulated in the accumulator **202** through the hose (not shown). In this state, as shown in FIG. **18**, the plunger **207** is positioned at its bottom dead center by the biasing force of the spring **212**. Since the plunger **207** is positioned at the bottom dead center, the main valve intake channel **214** is open to provide fluid communication between the accumulator **202** and the trigger valve chamber **213**. At the same time, the trigger valve control channel **216** is closed by the O-ring **218**, so the fluid connection between the trigger valve chamber **213** and the atmosphere is blocked.

In this case, because of the biasing force of the spring **212** and the difference in pressure receiving areas between the lower end area and the upper end area of the valve piston **210**, the valve piston **209** is positioned at its top dead center. Therefore, air channel **220** is closed by the valve piston rubber **221** to shut off communication between the accumulator **202** and the air channel **262**. At the same time, since the air channel **222** is opened by the valve piston rubber **221**, the air channel **262** and the exhaust pipe **263** are fluidly connected to each other. Thus, the piston upper chamber **266** assumes the atmospheric pressure, and the piston **204*a*** is positioned at its top dead center as shown in FIG. **17**.

FIG. **19** shows the state where the plunger **207** is pushed up to the top dead center by pulling the trigger **239**. In this state, the O-ring **218** loses its sealing effect to open the trigger valve control channel **216**. As a result, the trigger valve chamber **213** and the atmosphere are fluidly connected to each other, so the trigger valve chamber **213** assumes the atmospheric pressure. Further, since the trigger valve intake channel **214** is closed by the O-ring **215**, fluid communication between the accumulator **202** and the trigger valve chamber **213** is blocked.

Since the pressure in the trigger valve chamber **213** becomes atmospheric pressure, pressure difference is provided between the accumulator side and the trigger valve chamber side of the valve piston **209**. Thus, the valve piston **209** is moved to its bottom dead center.

The relationship between V**2**/S**2** and the time period T**2** from when the pressure in the trigger valve chamber **213** begins to drop until the valve piston **209** moves to maximum displacement is basically the same as that shown in FIG. **6**. In the third embodiment, if V**2**/S**2** is 0.2, the time period for the valve piston **209** to move from its top dead center to its bottom dead center is approximately 0.75 ms. With a fastener driving tool which is at least equipped with the valve piston **209**, by making the cross-sectional area of the trigger valve used to discharge the air larger with respect to the volume of the trigger valve **213**, the time period required for the pressure in the trigger valve chamber **213** to drop to a specific pressure because of the discharge of air can be decreased. Accordingly, the time period from when the plunger **207** is pressed until the valve piston **209** moves to maximum displacement can be shortened. As a result, the time period from when the trigger **239** is operated until the nailing motion occurs due to the displacement of the valve piston **209** can be shortened. Incidentally, if V**2**/S**2** is set to 0.15, T**2** can be made even smaller, and if V**2**/S**2** is set to 0.10, T**2** can be made smaller still. These values for T**2** are sufficiently smaller than those in conventional fastener driving tools.

Thus, by setting the maximum volume V**2** of the trigger valve chamber **213** and the cross-sectional area S**2** of the trigger valve control channel **216** to the aforementioned values, discharge of the compressed air from the trigger valve chamber **213** can be promptly performed, and the time period until the trigger valve chamber **213** assumes the atmospheric pressure can be reduced. Furthermore, since the discharge of air from the trigger valve chamber **213** can be improved when the valve piston **209** is moved to the bottom dead center, a so-called air damper in which the pressure in the trigger valve chamber **213** impedes the movement of the valve piston **209** is not readily formed. Accordingly, the valve piston **209** can be moved immediately from the top dead center to the bottom dead center without being interrupted by the air damper. Incidentally, even though the valve piston **209** is biased toward the top dead center by the spring **212**, the valve piston **209** is movable to the bottom dead center against the biasing force because of the pressure difference since the biasing force of the spring **212** is set beforehand to be weaker than the force caused by the pressure difference.

As shown in FIG. **19**, when the valve piston **209** reaches its bottom dead center, the air channel **222** is closed by the valve piston rubber **221** to block fluid communication between the air channel **262** and the exhaust pipe **263**. At the same time, the air channel **220** is opened by the valve piston rubber **221**, so that the accumulator **202** and air channel **262** are fluidly connected to each other. Thus, air flows from the accumulator **202** into the piston upper chamber **266**, and the piston upper chamber **266** provides the pressure level the same as that in the accumulator **202**. In this instance, since the pressure in the piston upper chamber **266** becomes greater than the pressure in the piston lower chamber in the cylinder **203**, the piston **204***a* moves rapidly to its bottom dead point. Thus, the fastener is driven by the tip end **204***c* of the driver blade **204***b*. The air in the underside of the piston **204***a* in the cylinder **203** flows through an air channel **236** into the return air chamber **233**. Further, a portion of the compressed air in the piston upper chamber **266** flows through the air channel **235** into the return air chamber **233**, after the piston **204***a* is moved past the air channel **235**.

When the trigger **239** is returned, the plunger **207** moves to its bottom dead center because of the pressure applied from the accumulator **202** and the biasing force of the spring **212**. In this case, as described above, the cross-sectional area St of the trigger valve intake channel **214** is set to 2.75×10^{-6} (m^2), which is relatively larger than that of the conventional tool. This is due to a design concept in that the mass rate of flow is proportional to the cross-sectional area of the tube. That is, it is based on the discovery that, with fastener driving tools having valve chambers, the time period required for the pressure in these valve chambers to be increased to a specific pressure due to introduction of the compressed air thereinto is reduced in accordance with an increase in the cross-sectional area of the channels used for the introduction of the compressed air with respect to the volume of these valve chambers.

At this point, since the cross-sectional area St of the trigger valve intake channel **214** is set to 2.75×10^{-6} (m^2), the pressure in the trigger valve chamber **213** instantaneously rises. As a result, the time period required for the pressure in the trigger valve chamber **213** to rise to a specific pressure due to the flow of compressed air can be decreased. Thus, the time period from when the pressing force on the plunger **207** ceases until the valve piston **209** returns to the pre-nailing position can be shortened. The valve piston rubber **221** provided on the valve piston **209** comes into contact with the frame **260** at the top dead center of the valve piston **209**, and comes into contact with the valve plate **264** at the bottom dead center of the valve piston **209**. Therefore, a fluid connection between the piston upper chamber **266** and the accumulator **202**, and a fluid connection between the piston upper chamber **266** and the exhaust pipe **263** is alternately provided.

However, in more detailed aspect, during the movement of the valve piston **209** from its bottom dead center to its top dead center, the valve piston rubber **264** is out of contact from the frame **260** and from the valve plate **264**. Accordingly, the connection between the piston upper chamber **266** and the accumulator **202** and the connection between the piston upper chamber **266** and the atmosphere can be simultaneously formed. As a result, the accumulator **202** and the atmosphere are connected, and the compressed air in the accumulator **202** is discharged into the atmosphere even during the movement of the valve piston **209** from its bottom dead center to its top dead center, which results in a waste of compressed air. However, since the valve piston **209** in the third embodiment can move from the bottom dead center to the top dead center more quickly than with the conventional tools, the amount of wasted compressed air which is unnecessarily discharged can be reduced.

At that point, the air channel **220** is closed by the valve piston rubber **221** to block communication between the accumulator **202** and the air channel **262**. Thus, the flow of air from the accumulator **202** to the piston upper chamber **266** stops. In addition, air channel **222** is opened, so that air channel **262** and the exhaust pipe **263** are fluidly connected to each other. As a result, the air which has been accumulated in the piston upper chamber **266** is discharged to the atmosphere through the air channel **262**, **222**, exhaust pipe **263** and the exhaust hole **249**. Thus, the piston upper chamber **266** assumes the atmospheric pressure.

Consequently, the piston **204***a* moves rapidly to the top dead point because the bottom of the piston **204***a* is imparted with a pressing force by the compressed air accumulated in the return air chamber **233**, and the fastener driving tool **201** returns to the state shown in FIG. **17**. Incidentally, the cross-sectional area of the trigger valve intake channel **214** can be made larger such as 3.00×10^{-6} (m^2) or 3.25×10^{-6} (m^2). With this arrangement, the unit rate of flow of the compressed air entering the trigger valve chamber **213** increases, so that the time period required for the pressure increase in the trigger valve chamber **213** can be shortened.

Characteristic in nailing motion of the fastener driving tool according to the first embodiment will be described chronologically in comparison with a comparative fastener driving tool. In the graph shown in FIG. **20**, the characteristics of the process of driving a nail into wood are shown for the fastener driving tool **1** involved in the first embodiment, and in the graph shown in FIG. **21**, the characteristics of the process of driving a nail into wood with a fastener driving tool are shown for the comparative fastener driving tool.

In these graphs, the x-axis represents time, and y-axis in FIG. **20**(*a*) represents pressure in the trigger valve chamber **13**, the main valve chamber **8**, the accumulator **2**, the piston **4***a* upper chamber, and the return chamber **33** in the fastener driving tool according to the first embodiment. Further, Y-axes in FIGS. **20**(*b*) through **20**(*d*) represent a displacement of the main valve **19**, a displacement of the valve piston **9**, and a displacement of the piston **4***a* according to the first embodiment. Here, the origin of the x-axis (0 ms) represents the time at which the plunger **7** is pressed and the pressure in the trigger valve chamber **13** begins to drop. The same is true with respect to FIGS. **21**(*a*) through (*d*) for the comparative fastener driving tool.

The dimensions in the comparative fastener driving tool involved in the nailing process were: maximum main valve chamber volume $V1'=2.56\times10^{-5}$ (m^3); main valve control channel cross-sectional area $S1'=0.8\times10^{-5}$ (m^2); $V1'/S1'=3.2$; maximum trigger valve chamber volume $V2'=4.0\times10^{-7}$ (m^3); trigger valve control channel cross-sectional area $S2'=0.465\times10^{-6}$ (m^2); $V2'/S2'=0.86$. The dimensions in the fastener driving tool involved in the first embodiment were:

maximum main valve chamber **8** volume $V1=2.56\times10^{-5}$ (m^3); main valve control channel **40** cross-sectional area $S1=3.2\times10^{-5}$ (m^2); $V1/S1=0.8$; maximum trigger valve chamber **13** volume $V2=4.0\times10^{-7}$ (m^3); trigger valve control channel **16** cross-sectional area $S2=1.98\times10^{-6}$ (m^2); $V2/S2=0.2$.

In FIGS. **20** and **21**, A and A' represent the timing at which pressure drop in the trigger valve chamber **13** is started, B and B' represent the timing at which the pressure in the trigger valve chamber **13** becomes atmospheric pressure, C and C' represents the timing at which the movement of the main valve **19** toward its upper dead center is started, D and D' represent the timing at which the main valve **19** reaches its top dead center, E and E' represent the timing at which the movement of the valve piston **9** toward its bottom dead center is started, F and F' represent the timing that the valve piston **9** reaches its bottom dead center, and G and G' represent the timing at which the piston **4***a* reaches its bottom dead center.

By pressing the plunger **7**, the pressure in the trigger valve chamber **13** drops and, in conjunction with this pressure change, the valve piston **9** begins to be displaced from the top dead center. At that point, since $V2/S2=0.2$ in the first embodiment has been set smaller than the value $V2'/S2'=0.86$ in the comparative tool, so the compressed air in the trigger valve chamber **13** can be instantaneously discharged through the trigger valve control channel **16** into the atmosphere. As a result, only 3.0 ms was required for the pressure drop to the atmosphere in the trigger valve chamber **13**, whereas 11.3 ms was required for the pressure drop in the comparative tool (see B and B'). Further, only 0.74 ms was required for moving the valve piston **9** to its bottom dead center in the first embodiment whereas 0.85 ms was required for the movement in the comparative tool (see F and F').

Because of the displacement of the valve piston **9** toward its bottom dead center, the O-ring **23** loses its sealing effect, so that the air channel **22** and the main valve control channel **40** are fluidly connected to each other and the pressure in the main valve chamber **8** begins to drop. At that point, since $V1/S1=0.8$ in the first embodiment is smaller than $V1'/S1'=3.2$ in the comparative tool, the compressed air in the main valve chamber **8** can be instantaneously discharged through the main valve control channel **40** and the air channel **22** into the atmosphere. As a result, 22.4 ms was required for the pressure drop in the conventional main valve chamber to the minimum value for starting movement of the main valve from its bottom dead center. On the other hand, only 6.1 ms was required for the pressure drop in the main valve chamber **13** to the minimum value for starting movement of the main valve **19** from its bottom dead center (see C and C'). During this period, the pressure in the main valve chamber **8** rises temporarily due to the displacement of the main valve **19**. However, since the cross-sectional area of the air channel **22** was set to be smaller than the cross-sectional area of the main valve control channel **40**, excessive back-pressure is not applied to the main valve chamber **8**. Then, the main valve **19** in the first embodiment reaches the top dead point after 7.1 ms (see D).

By the movement of the main valve **19** toward its top dead center, the compressed air flows from the accumulator **2** to the piston upper chamber, so that the piston upper chamber becomes highly pressurized. Due to the pressure difference between the upper chamber and lower chamber of the piston **4***a*, the piston **4***a* drops to the bottom dead center for driving the fastener **5**. As a result of this, the process from when the worker pulls the trigger **39** until the fastener **5** is driven is completed. In the first embodiment, the process only requires 11.3 ms, whereas the comparative tool requires 27.1 ms (see F and F'). This difference clearly represents an improvement on the nailing response.

In addition, as a result of experimentation using a variety of fastener driving tools and investigating what degree of improvement in the response was sufficient for the effect to be perceived, it was found that if nailing occurred within 12 ms after the trigger is pulled and the push lever was pressed against the workpiece, the response was perceived to be good, the work became easy to perform, and it became easy to drive fasteners in a continuous manner. Moreover, it was found that as this amount of time grew longer, the response gradually grew worse, and in the vicinity of the 27.1 ms of the conventional tool, the work became difficult to perform and it became difficult to drive fasteners in a continuous manner. From this perspective as well, the response was improved, and the work performance was improved as well based on the fastener driving tool **1** in the first embodiment.

Next, an entire one-shot process starting from the pushing timing of the plunger **7** to the recovery timing to the initial state for starting the next nail driving operation will be described with reference to FIGS. **22**(*a*) through **23**(*e*). These graphs are particularly useful for the explanation of the process of returning to the initial state.

In these graphs, the x-axis represents time, and y-axis in FIG. **22**(*a*) represents pressure in the trigger valve chamber **13**, the main valve chamber **8**, the accumulator **2**, the piston **4***a* upper chamber, and the return chamber **33** in the fastener driving tool according to the first embodiment. Further, Y-axes in FIGS. **22**(*b*) through **22**(*d*) represent a displacement of the main valve **19**, a displacement of the valve piston **9**, a displacement of the piston **4***a*, and a displacement of a tool itself according to the first embodiment. Here, the origin of the x axis (0 ms) represents the time at which the plunger **7** is pressed and the pressure in the trigger valve chamber **13** begins to drop. The same is true with respect to FIGS. **23**(*a*) through (*e*) for another comparative fastener driving tool.

The dimensions in the comparative fastener driving tool involved were: maximum main valve chamber volume $V1'=2.621\times10^{-5}$ (m^3); main valve control channel cross-sectional area $S1'=1.963\times10^{-5}$ (m^2); $V1'/S1'=1.335$; main valve intake channel cross-sectional area $Sm'=0.41\times10^{-5}$ (m^2); $V1'/Sm'=6.5$; trigger valve intake channel cross-sectional area $St'=1.78\times10^{-6}$ (m^2). The dimensions in the fastener driving tool involved in the first embodiment were: maximum main valve chamber **8** volume $V1=2.56\times10^{-5}$ (m^3); main valve control channel **40** cross-sectional area $S1=3.2\times10^{-5}$ (m^2); $V1/S1=0.8$; main valve intake channel **20** cross-sectional area $Sm=3.2\times10^{5}$ (m^2); $V1/Sm=0.8$; trigger valve intake channel cross-sectional area $St=2.75\times10^{-6}$ (m^2).

In FIGS. **22**(*a*) through **23**(*e*), A through G and A' through G' are the same as those shown in FIGS. **20**(*a*) through **21**(*d*). H and H' represent the timing at which the returning motion of the main valve is started. I and I' represent the timing at which the main valve is returned to its initial position. J and J' represent the timing at which the returning motion of the valve piston is started. K and K' represent the timing at which the valve piston is returned to its initial position. L and L' represent the timing at which the piston is returned to its initial position. M and M' represent the timing at which the entire tool is displaced by a maximum amount.

In the first embodiment, 6.9 ms was required for starting nail driving by starting the movement of the piston **4***a* whereas the comparative tool required 22.2 ms for the starting (see FIGS. **22**(*d*) and **23**(*d*). In reaction to the movement of the piston, the tool body itself begins to move upward. Subsequently the piston **4***a* reaches the bottom dead center, and nailing was completed after 11.3 ms in the first embodiment, as opposed to after 26.9 ms in the comparative tool. The upward displacement of both the fastener driving tool **1** and the comparative tool at this point was 5 mm. Further, in the first embodiment, the upward displacement of the tool itself reached 10 mm at 18.6 ms, whereas in the comparative tool, the upward displacement of the tool itself reached 10 mm at 35.1 ms (see FIGS. **22**(*e*) and **23**(*e*)).

At this point, the relative position between the push lever **42** and the nose **41** was restored to the initial position, and the plunger **7** which has been biased upward by the push lever **42** is returned to its initial position. In the first embodiment, the valve piston **9** began to move due to the pressure of the accumulator **2** and the pressing force of the spring **12** at 18.6 ms, and the valve piston **9** was returned to the initial position at 20.3 ms. On the other hand, in the comparative tool, the valve piston began to move at 35.2 ms, and returned to the initial position at 37.4 ms (See FIGS. **22**(*c*) and **23**(*c*)).

By the movement of the valve piston **9**, the compressed air in the accumulator **2** flows into the main valve chamber **8** through the main valve intake channel **20** and the main valve control channel **40**. As a result in the first embodiment, the main valve **19** began to move at 21.4 ms, whereas in the comparative tool, the main valve **19'** began to move at 38.9 ms (see H and H'). In addition, in the first embodiment, the main valve **19** was returned to the initial position at its bottom dead center at 25.2 ms, whereas in the comparative tool, the main valve **19'** was returned to the initial position at its bottom dead center at 44.3 ms (see I and I'). Simultaneously, the compressed air filled in the piston upper chamber is released to the atmosphere through air channel **29** and the exhaust hole **49**, and the tool was returned to the initial state.

As described above, in the first embodiment, the time period from the moment when either the pulling of the trigger **39** is released or the pressing of the push lever **42** against the workpiece is released (18.6 ms) until the main valve is closed (25.2 ms) was 25.2 ms−18.6 ms=6.6 ms. On the other hand, in the comparative tool, the time period was 44.3 ms−35.2 ms=9.1 ms.

In addition, experimentations were conducted using a variety of fastener driving tools for investigating how much the time period needed to be shortened in order for a sufficient improvement on response to be perceived, the time period being from the moment when either the pressing of the trigger **39** was released or the pressing of the push lever **42** against the workpiece is released until the main valve is closed. As a result of experiments, it was found that if the time period is within 7 ms, the response was perceived to be extremely good facilitating driving work and continuous driving.

Therefore, since the first embodiment requires the time period of within 7 ms, the transition to the next nailing operation can proceed rapidly to improve the response. In addition, because of the prompt closure of the main valve, unnecessary air consumption can be avoided.

While the invention has been described in detail and with reference to specific embodiments thereof, it would be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A fastener driving tool comprising:

a frame defining therein an accumulator that accumulates a compressed air;

a cylinder disposed within the frame;

a piston reciprocally slidably disposed within the cylinder, a piston upper chamber being defined by an inner peripheral surface of the cylinder and an upper surface of the piston;

a main valve which alternately opens and blocks a fluid communication between the piston upper chamber and the accumulator;

a main valve chamber section defining therein a main valve chamber in which the main valve is movably disposed, the main valve chamber providing a maximum internal volume;

a trigger valve which alternately opens and blocks a fluid communication from the accumulator to the main valve chamber, and a fluid communication from the main valve chamber to an atmosphere; and

a main valve control channel section defining therein a main valve control channel that provides a fluid connection between the main valve chamber and the trigger valve, the main valve control channel having a cross-sectional area, a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve control channel measured in m^2 being not more than 1.0.

2. The fastener driving tool as claimed in claim **1**, further comprising:

a push lever in pressure contact with a workpiece; and

a trigger functioning as an operation input member; and

wherein the main valve is reciprocably movably provided in the main valve chamber for alternately providing a fluid communication between the piston upper chamber and the accumulator and between the piston upper chamber and the atmosphere; and

wherein the trigger valve comprises:

a trigger valve exterior frame to which the main valve control channel is fluidly connected;

a valve piston reciprocally slidably disposed within the trigger valve exterior frame and having one end exposed to the accumulator and another end, the valve piston being movable between a top dead center and a bottom dead center, a main valve intake channel being defined between the valve piston and the trigger valve exterior frame for providing fluid connection between the accumulator and the main valve control channel when the valve piston is moved to the upper dead center, and an air discharge channel being defined between the valve piston and the trigger valve exterior frame for providing fluid connection between the main valve control channel and the atmosphere when the valve piston is moved to the bottom dead center, a main valve intake channel and the air discharge channel being alternately opened; and

a plunger movable in an axial direction thereof between its top dead center and its bottom dead center and extending through the valve piston and the trigger valve exterior frame, a trigger valve chamber being defined by the trigger valve exterior frame, the another end of the valve piston and the plunger, the air discharge channel having a cross-sectional area not less than the cross-sectional area of the main valve control channel.

3. The fastener driving tool as claimed in claim **2**, wherein the main valve intake channel has a cross-sectional area, a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve intake channel measured in m^2 being not more than 1.0.

4. The fastener driving tool as claimed in claim **2**, wherein the plunger has a first section exposed to the accumulator and extending through the valve piston, and a second section extending through the trigger valve exterior frame, a trigger valve intake channel being defined between the first section and the valve piston for providing a fluid connection between the accumulator and the trigger valve chamber when the plunger is moved to its bottom dead center, and a trigger valve control channel being defined between the second section and the trigger valve exterior frame for providing a fluid connection between the trigger valve chamber and the atmosphere when the plunger is moved to its top dead center, the trigger valve intake channel and the trigger valve control channel being alternately opened.

5. The fastener driving tool as claimed in claim **4**, wherein the trigger valve intake channel has a cross-sectional area of not less than 3.00×10^{-6} m^2.

6. The fastener driving tool as claimed in claim **4**, wherein the trigger valve intake channel has a cross-sectional area of not less than 3.25×10^{-6} m^2.

7. The fastener driving tool as claimed in claim **4**, wherein the trigger valve intake channel has a cross-sectional area of not less than 2.75×10^{-6} m^2.

8. The fastener driving tool as claimed in claim **2**, wherein a ratio obtained from dividing a maximum volume of the trigger valve chamber measured in m^3 by the cross-sectional area of the trigger valve control channel measured in m^2 is not more than 0.20.

9. The fastener driving tool as claimed in claim **8**, wherein a ratio obtained from dividing the maximum volume of the trigger valve chamber measured in m^3 by the cross-sectional area of the trigger valve control channel measured in m^2 is not more than 0.15.

10. The fastener driving tool as claimed in claim **9**, wherein a ratio obtained from dividing the maximum volume of the trigger valve chamber measured in m^3 by the cross-sectional area of the trigger valve control channel measured in m^2 is not more than 0.10.

11. The fastener driving tool as claimed in claim **2**, wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve control channel measured in m^2 is not more than 0.8, and

wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by a cross-sectional area of the main valve intake channel measured in m^2 is not more than 0.8.

12. The fastener driving tool as claimed in claim **2**, wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve control channel measured in m^2 is not more than 0.6, and

wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve intake channel measured in m^2 is not more than 0.6.

13. The fastener driving tool as claimed in claim **2**, wherein the main valve control channel has a curving portion along its path, the curving portion being composed of one of a continuous arcuate portion and discontinuous two bending portions.

14. The fastener driving tool as claimed in claim **13**, wherein the two bending portions provide bending angles of not less than 100°.

15. The fastener driving tool as claimed in claim **2**, wherein a ratio obtained from dividing the maximum volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve control channel measured in m^2 is not more than 0.8.

16. The fastener driving tool as claimed in claim **2**, wherein a ratio obtained from dividing the maximum volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve control channel measured in m^2 is not more than 0.6.

17. The fastener driving tool as claimed in claim **1**, further comprising:

a push lever in pressure contact with a workpiece; and

a trigger functioning as an operation input member; and

wherein the main valve is reciprocably movably provided in the main valve chamber for alternately providing a fluid communication between the piston upper chamber and the accumulator and between the piston upper chamber and the atmosphere; and

wherein the trigger valve comprises:

a trigger valve frame to which the main valve control channel is fluidly connected, the trigger valve frame having a first through hole serving as a main valve intake channel and exposed to the accumulator and a second through hole; and

a plunger movable in an axial direction thereof between its top dead center and its bottom dead center relative to the trigger valve frame, the plunger having a first section closing the first through hole when the plunger is moved to its upper dead center for closing the main valve intake channel to shut off fluid communication between the accumulator and the main valve control channel and opening the main valve intake channel to provide communication between the accumulator and the main valve control channel, the plunger also having a second section extending through the second trough hole, an air discharge channel being defined between the second through hole and the second section, the air discharge channel being opened when the plunger is moved to its top dead center to provide fluid communication between the main valve control channel and the atmosphere and being closed when the plunger is moved to its bottom dead center, the main valve intake channel and the air discharge channel being alternately opened by the movement of the plunger.

18. The fastener driving tool as claimed in claim **17**, wherein the main valve intake channel has a cross-sectional area, a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve intake channel measured in m^2 being not more than 1.0.

19. The fastener driving tool as claimed in claim **18**, wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve control channel measured in m^2 is not more than 0.8, and

wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve intake channel measured in m^2 is not more than 0.8.

20. The fastener driving tool as claimed in claim **18**, wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve control channel measured in m^2 is not more than 0.6, and

wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve intake channel measured in m^2 is not more than 0.6.

21. The fastener driving tool as claimed in claim **17**, wherein the main valve control channel has a curving portion along its path, the curving portion being composed of one of a continuous arcuate portion and discontinuous two bending portions.

22. The fastener driving tool as claimed in claim **21**, wherein the two bending portions provide bending angles of not less than 100°.

23. The fastener driving tool as claimed in claim **17**, wherein the air discharge channel has a cross-sectional area equal to or greater than that of the main valve control channel.

24. The fastener driving tool as claimed in claim **17**, wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve control channel measured in m^2 is not more than 0.8.

25. The fastener driving tool as claimed in claim **17**, wherein a ratio obtained from dividing the maximum internal volume of the main valve chamber measured in m^3 by the cross-sectional area of the main valve control channel measured in m^2 is not more than 0.6.

26. A fastener driving tool comprising:

a frame defining therein an accumulator for accumulating a compressed air;

a cylinder disposed within the frame;

a piston reciprocally slidably disposed within the cylinder, a piston upper chamber being defined by the frame, an inner peripheral surface of the cylinder and an upper surface of the piston;

a trigger functioning as an operation input member;

a trigger valve alternately opening and blocking a fluid communication between the piston upper chamber and the accumulator and a fluid communication between the piston upper chamber and an atmosphere, the trigger valve comprising:

a trigger valve exterior frame in fluid communication with the piston upper chamber and formed with a through hole;

a valve piston reciprocably slidably disposed in the trigger valve exterior frame, the valve piston being movable between its top dead center where piston upper chamber is communicated with the atmosphere and its bottom dead center where the piston upper chamber is communicated with the accumulator, the valve piston having a first section exposed to the accumulator and formed with a trigger valve intake channel opened to the accumulator and a second section in sliding contact with the trigger valve exterior frame, a trigger valve chamber being defined by the second section and the trigger valve exterior frame, and providing a maximum internal volume; and

a plunger movable between its top dead center and its bottom dead center and having a first portion associated with the valve piston and a second portion associated with the through hole, a trigger valve control channel being formed between the second portion and the through hole and having a cross-sectional area, the trigger valve control channel being opened when the plunger is moved to its top dead center, a ratio obtained from dividing the maximum volume of the trigger valve chamber measured in m^3 by the cross-sectional area of the trigger valve control channel measured in m^2 being not more than 0.20.

27. The fastener driving tool as claimed in claim **26**, wherein the ratio obtained from dividing the maximum volume of the trigger valve chamber measured in m^3 by the cross-sectional area of the trigger valve control channel measured in m^2 is not more than 0.15.

28. The fastener driving tool as claimed in claim **26**, wherein the ratio obtained from dividing the maximum volume of the trigger valve chamber measured in m^3 by the cross-sectional area of the trigger valve control channel measured in m^2 is not more than 0.1.

29. A fastener driving tool comprising:

a frame defining therein an accumulator for accumulating a compressed air;

a cylinder disposed within the frame;

a piston reciprocally slidably disposed within the cylinder, a piston upper chamber being defined by the frame, an inner peripheral surface of the cylinder and an upper surface of the piston;

a trigger functioning as an operation input member;

a trigger valve alternately opening and blocking a fluid communication between the piston upper chamber and the accumulator and a fluid communication between the piston upper chamber and an atmosphere, the trigger valve comprising:

a trigger valve exterior frame in fluid communication with the piston upper chamber and formed with a through hole;

a valve piston reciprocably slidably disposed in the trigger valve exterior frame, the valve piston being movable between its top dead center where piston upper chamber is communicated with the atmosphere and its bottom dead center where the piston upper chamber is communicated with the accumulator, the valve piston having a first section exposed to the accumulator and formed with a trigger valve intake channel opened to the accumulator and a second section in sliding contact with the trigger valve exterior frame, a trigger valve chamber being defined by the second section and the trigger valve exterior frame and providing a maximum internal volume; and

a plunger movable between its top dead center and its bottom dead center and having a first portion associated with the valve piston and a second portion associated with the through hole, a trigger valve control channel being formed between the second portion and the through hole and having a cross-sectional area, the trigger valve control channel being opened when the plunger is moved to its top dead center, the trigger valve intake channel having a cross-sectional area of not less than 2.75×10^{-6} m^2, and the trigger valve chamber having a maximum internal volume of 4.0×10^{-7} m^3.

30. The fastener driving tool as claimed in claim **29**, wherein the trigger valve intake channel has the cross-sectional area of not less than 3.00×10^{-6} m^2.

31. The fastener driving tool as claimed in claim **29**, wherein the trigger valve intake channel has the cross-sectional area of not less than 3.25×10^{-6} m^2.

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