June 20, 1967 A. J. WHITEHILL 3,326,086

MILLING MACHINE

Filed July 23, 1964 7 Sheets-Sheet 1

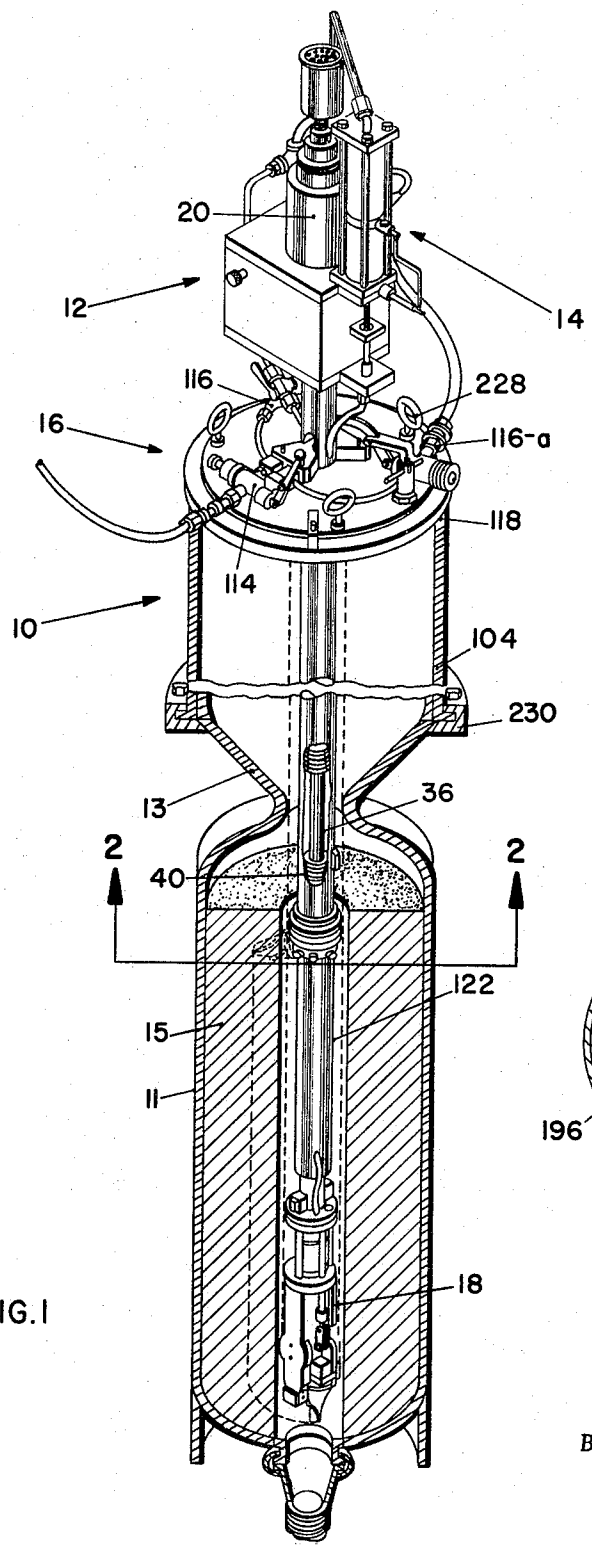


FIG. 1

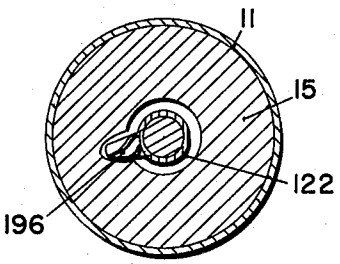


FIG. 2

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MILLING MACHINE

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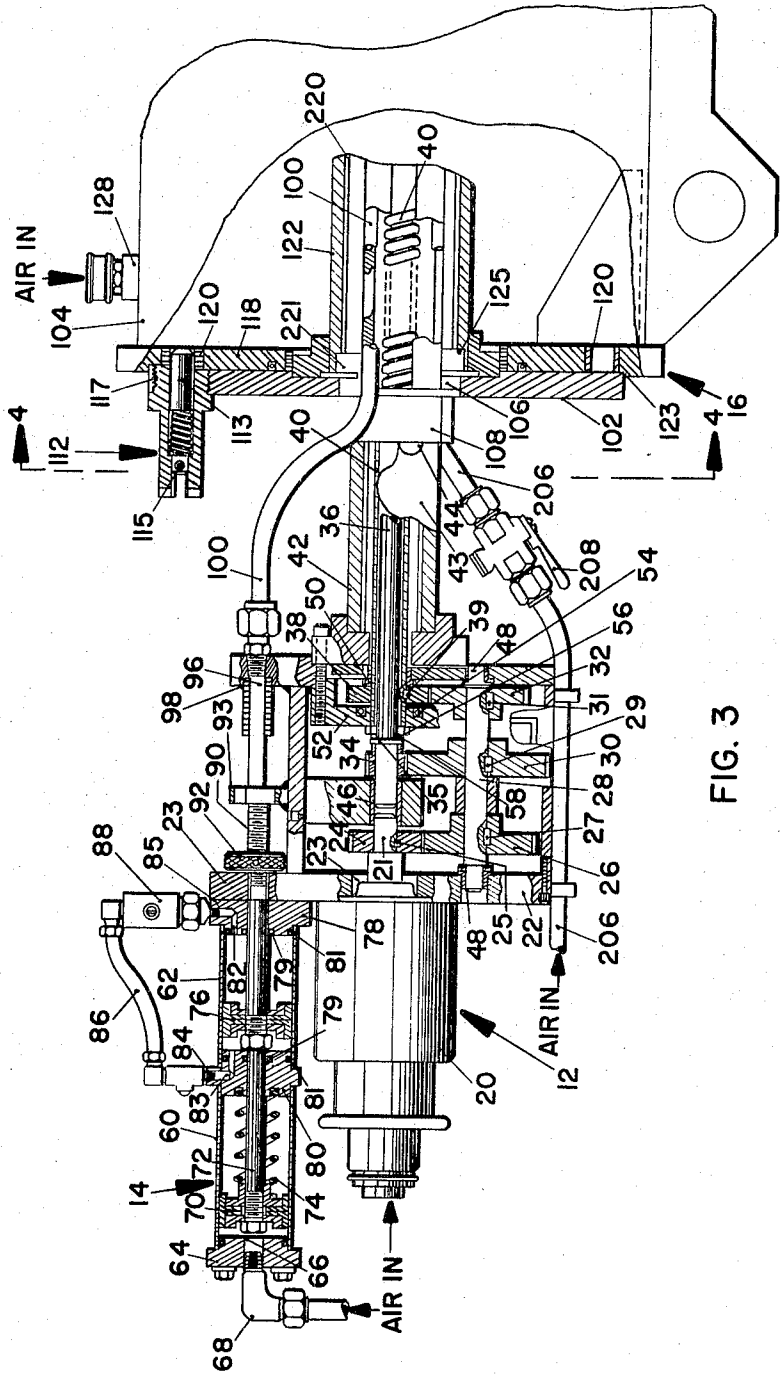


FIG. 3

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MILLING MACHINE

Filed July 23, 1964 7 Sheets-Sheet 3

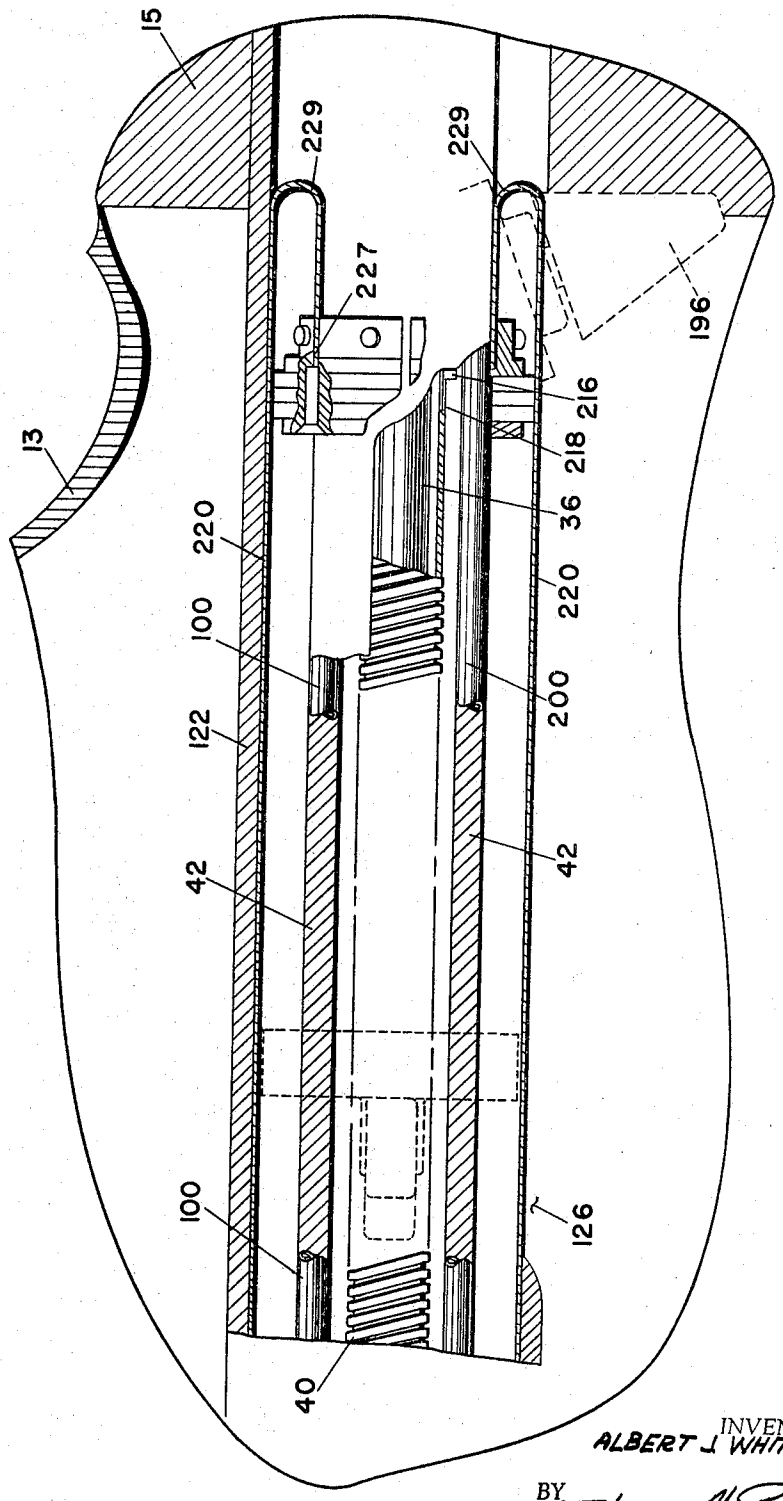


FIG. 3-a

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MILLING MACHINE

Filed July 23, 1964 7 Sheets-Sheet 4

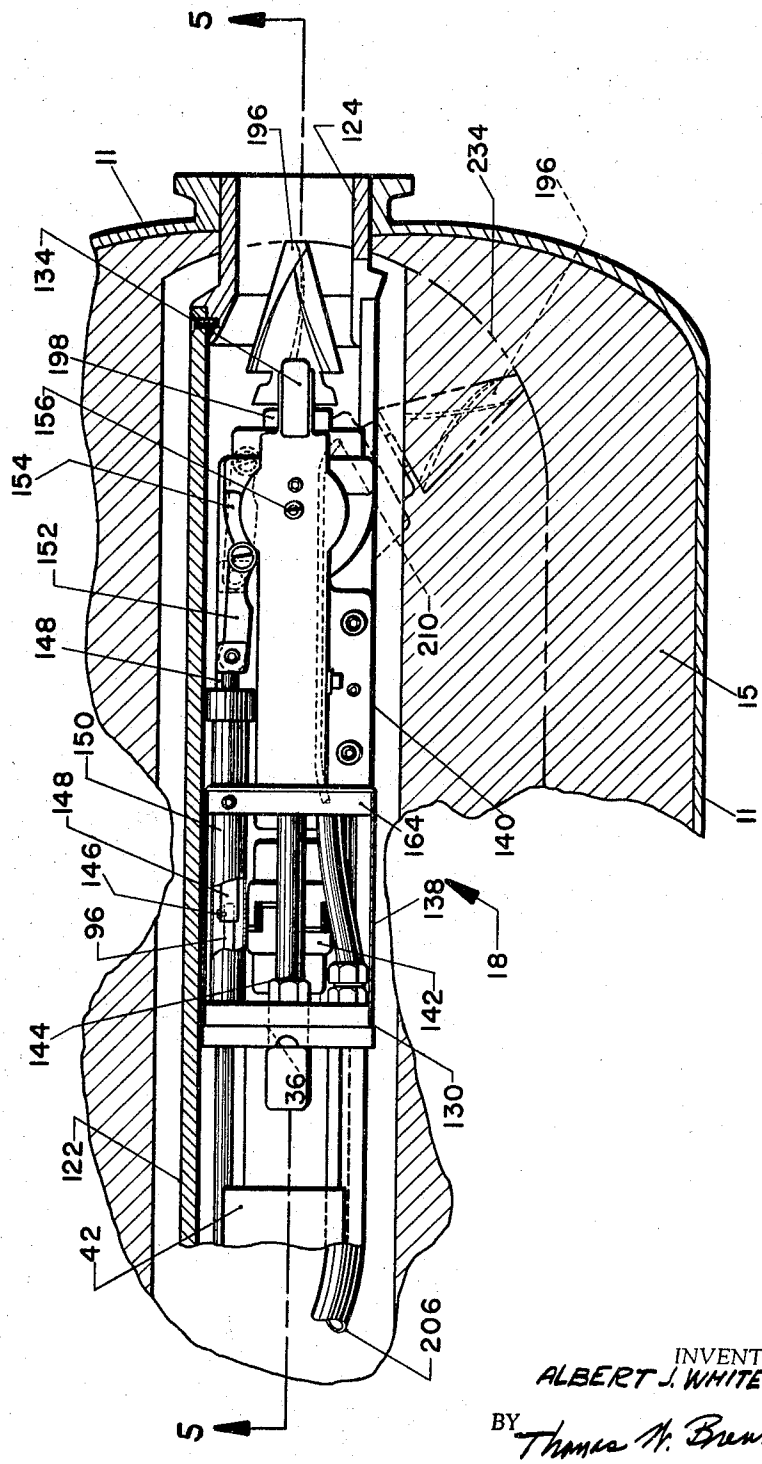


FIG. 3-b

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MILLING MACHINE

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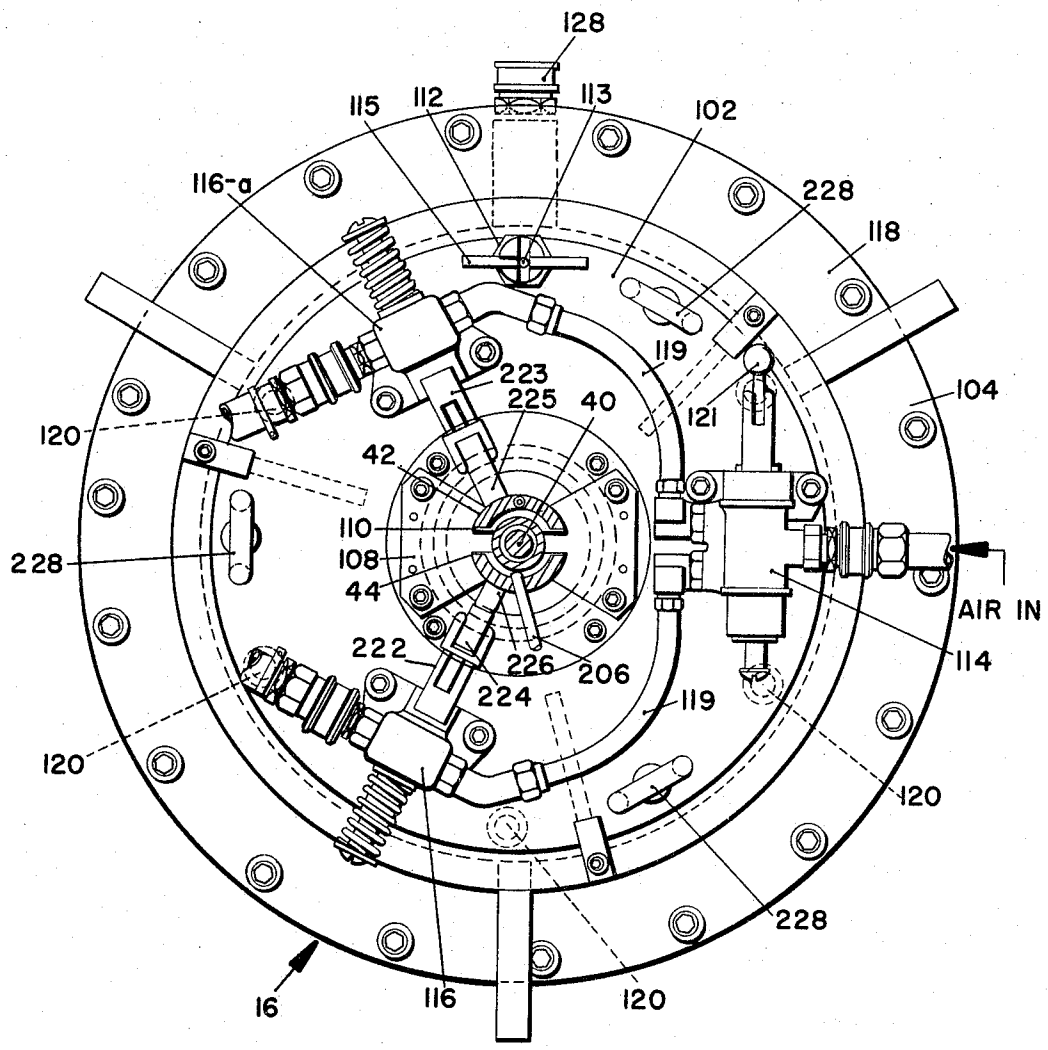


FIG. 4

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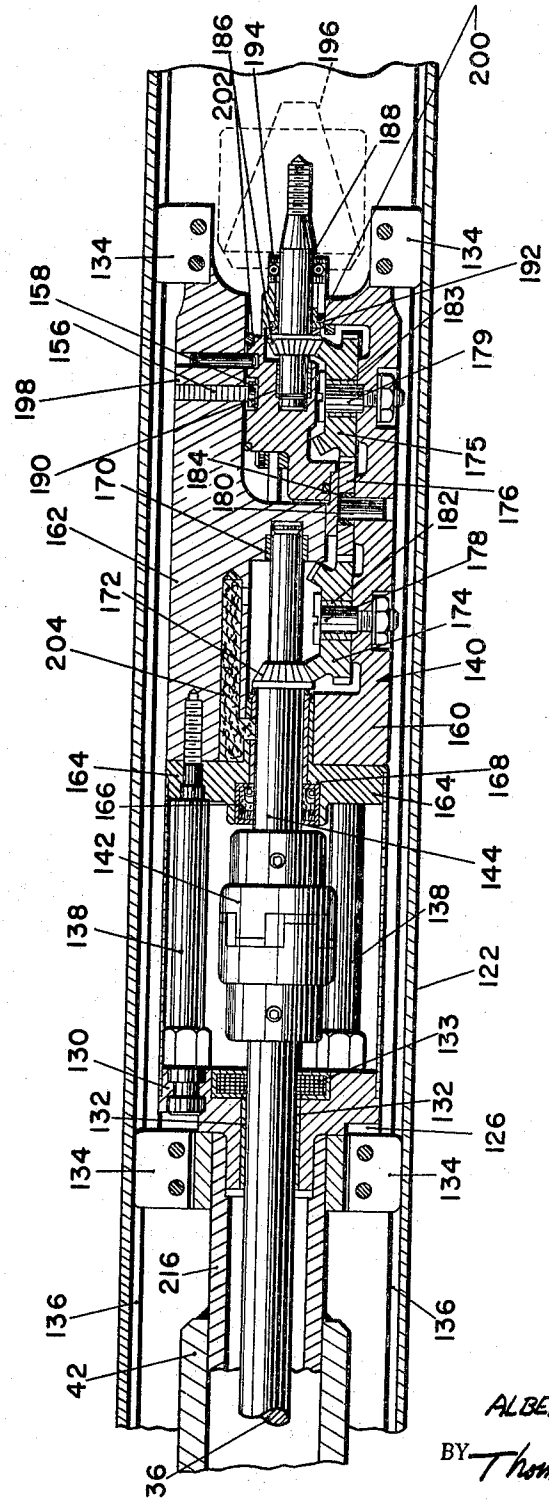


FIG. 5

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MILLING MACHINE

Filed July 23, 1964 7 Sheets-Sheet 7

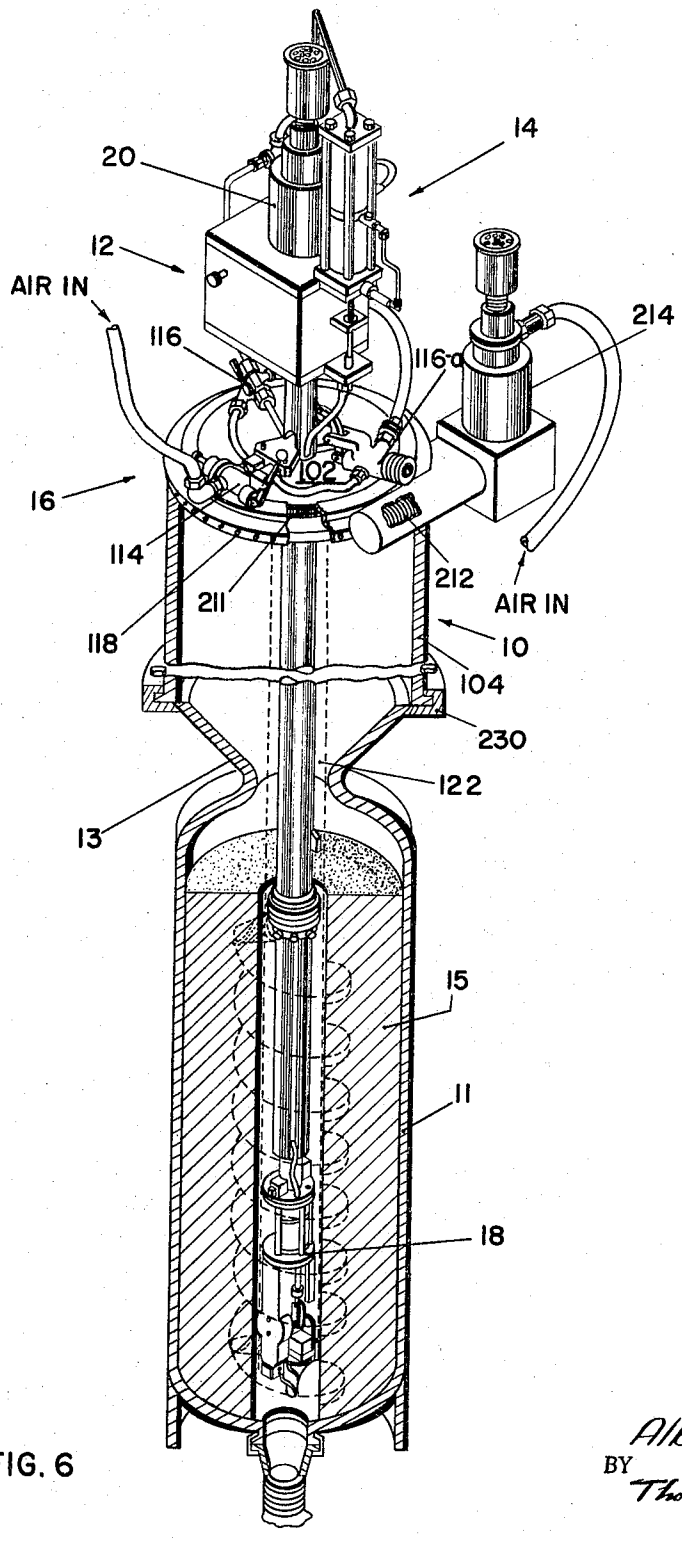


FIG. 6

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United States Patent Office 3,326,086
Patented June 20, 1967

3,326,086
MILLING MACHINE

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Filed July 23, 1964, Ser. No. 384,654
23 Claims. (Cl. 90—15)

This invention relates to an apparatus for forming internal cavities in solid combustible material containing casings, and in particular, to a machine which forms these cavities by internal milling thereof.

As is well known, the central cavity of a solid propellant charge in a casing of a rocket motor is provided as a means for insuring a maximum burning surface whereby increased quantities of missile propelling, i.e., thrust producing, gas can be obtained. In addition, this surface should be precisely formed and its dimensional characteristics known to insure predictability in performance from motor to motor and hence from missile to missile during any preselected time in its operative cycle. In achieving this, oftentimes rather intricate cavity cross sectional shapes become necessary. Providing means to produce these shapes requires much ingenuity on the part of motor designers.

In current practice, solid propellant charge internal surface configurations are formed by means of a mandrel of accurately fabricated outer surfaces corresponding to the cross sectional charge shape desired, centrally positioned within the empty motor case. Propellant in an uncured or slurried state is poured in the space between the motor case and the mandrel and permitted to cure, after which the mandrel is removed, leaving ignition surfaces in the charge cavity.

This procedure is usually satisfactory for the manufacture of rocket motors once the charge cross sectional burning surface configuration has been determined and the performance thereof established. However, solid propellant rocket motors under development require that a number of different configurations be evaluated to obtain the optimum design. This usually involves the fabrication of a corresponding number of costly mandrels to form the core and relatively long lead times for this fabrication must be provided for in the development program. In addition, large access openings for the insertion and withdrawal of these mandrels must also be provided in the motor case, thus making separable nozzle section motors practically mandatory. Modern day motor cases, however, are preferably unitary in construction, hence conventional mandrels are not usable in these motors.

The present invention, therefore, provides a unique and novel solution to these unresolved problems whereby a propellant charge of practically any internal geometric configuration can be made in any motor which has a nozzle opening, whether unitary or separable. This solution is accomplished by means of a remotely operated milling machine which has a cutter or end mill controllable with regard to cutting speed, feed rate, angular orientation and radial indexing with the workpiece.

It is therefore an object of the invention to provide a machine which, from a remote place, automatically forms a predetermined cross sectional propellant charge cavity in a rocket motor.

Another object of the invention is to provide a milling machine which can automatically, under remote control, mill out practically any cross sectional geometric shape in a rocket motor propellant charge to form accurately dimensioned burning surfaces therein.

Still another object of the invention is to provide a machine of the character described which is capable of

forming all practical geometric internal core configurations in solid propellant motor charges through the relatively restricted access ports of the motor nozzles.

A further object of the invention is to provide a machine tool for cutting solid propellant internal core configurations through restricted access ports which has an extensible end mill insertable into a circular cavity previously formed therein.

A still further object of the invention is to provide a machine having a milling type cutter for solid propellant cores wherein cutting speed, feed rate, and angular position thereof is controlled to perform its cutting operation efficiently and in such a way that the chips formed are of uniform size and dimension.

An additional object of the invention is to provide a machine tool of the character described wherein the end mill cutter is pivotable and adapted to be extended within the core workpiece by a remotely controlled power means.

These and other objects and advantages of the invention will become more apparent when examined in the light of the following specification and drawings in which:

FIGURE 1 is a sectional elevation of a rocket motor illustrating the machine tool of the invention installed thereon;

FIGURE 2 is a view taken on line 2—2 of FIG. 1;

FIGURE 3 is a sectional view of the upper or motor and gearing section of the machine tool of the invention with certain elements of the control system removed;

FIGURE 3*a* is a sectional view of the middle portion of the machine tool of the invention;

FIGURE 3*b* is a sectional view of the lower or cutter driving unit section of the machine tool of the invention;

FIGURE 4 is a sectional view of the upper portion of the invention showing control elements deleted from FIG. 3;

FIGURE 5 is a view taken on line 5—5 of FIG. 3*b* and;

FIGURE 6 is a sectional, perspective view of an alternative means for indexing the position of the cutter head for special cutting and milling tasks of the machine tool of the invention.

Referring to the drawings, and particularly to FIG. 1, the invention comprises, in general, a machine tool **10** comprising; a motor and gearing unit **12**; a damped cutter positioning mechanism **14**; a housing and rotational positioning unit **16**; and a cutter driving unit **18**.

In FIG. 3, motor and gear unit **12** of machine tool **10** comprises an air motor **20** having a shaft **21** extendible through perforation **23** of the top plate of gear housing **22** to the interior thereof. The gearing unit comprises a driving gear **24** mounted on shaft **21** by common, well known means such as a key **25**, which supplies the driving force of the gear unit or system contained within housing **22**. A countershaft **28**, lying parallel to shaft **21**, has mounted thereon a driven gear **26**, also attached by a key means **27**, which meshes with driving gear **24**. Also mounted on counter shaft **28** at the intermediate and end portions thereof are gears **30** and **32** respectively, held by key means **29** and **31**. Meshing with gear **30** is driven gear **34**, attached by pin **35** to a centrally located cutter drive shaft **36**. Shaft **36** is in axial alignment with shaft **21** of motor **20** and longitudinally extensible through machine tool **10** terminating at cutter driving unit **18** (FIG. 3*b*). Meshing with gear **32** is lead screw driving gear **38**, attached to a lead screw **40** by key means **39**. Lead screw **40** is an externally threaded, hollow tube located concentrically with respect to the cutter drive shaft **36** and co-extensively extendible therewith. The upper end of lead screw **40** is secured in gear housing **22** as will hereinafter be described.

Motor gearing unit **12** is mounted on a centrally positioned main support or pilot tube **42** which is concentric with respect to drive shaft **36** and lead screw **40**. Main support tube **42** is also extendible throughout machine tool **10** terminating at cutter driving unit **18**. The wall **43** of main support tube **42** is provided with two diametrically opposite lengthwise slots **44** and provides access to threaded lead screw **40**.

Interiorly of gear housing **22**, shaft **21** of motor **20** and the upper end of drive shaft **36** are journaled within centrally located sleeve bearing **46**. Countershaft **28** is mounted at its opposite ends in bushings **48**, one of which is retained in the top plate, the other in the bottom plate of gear housing **22**. The upper end of lead screw **40** projects through a perforation in the bottom plate of gear housing **22** for support thereof in bushing **50**, bearing housing **52** and ball bearing **54**. It is held securely thereat against the upper surface of bearing housing **52** by locknut **56**. Separating the upper faces of lead screw **40** and locknut **56** from gear **34** is a spacer **58**.

Cutter positioning mechanism **14** (FIG. 3) is mounted on a radial extension **23** of the top plate of gear housing **22**, parallel and adjacent to motor **20**. Mechanism **14** is preferably a dash pot device comprising a spring-loaded pneumatic cylinder **60** having a double-acting piston containing hydraulic cylinder **62** mounted in axial alignment therewith. Pneumatic cylinder **60** comprises an end cap **64** having a threaded perforation **66** for receiving a pipe connection **68**, a centrally disposed helical spring **74** surrounding a piston rod **72** connected to a piston **70** which is urged leftward in the drawing by spring **74**. Cylinder **62** comprises a piston **76**, and a cylinder base or end cap **78**. An intermediate spacer **80** which serves as a base for cylinder **60**, a spring seat for spring **74** and as an upper end cap for cylinder **62**, contains a central perforation therethrough for receiving that portion of piston rod **72** which extends through piston **76** from cylinder **62**. Piston rod **72** is further extendible through a central perforation in cylinder base **78** and a matching hole in the radial extension of the top plate of gear housing **22**. Hence, piston rod **72** is common to both cylinders **60** and **62** and is sealed in cylinder base **78** and in spacer **80** by means of a pair of O-rings **79**. Cylinder base **78** and spacer **80** are in turn sealed in cylinder **62** by means of a pair of O-rings **81** and contain fluid passages **82** and **83** respectively, having threaded openings **85** and **84** to which hydraulic line **86** including a flow control valve **88** is connected thereby establishing communication between the space in cylinder **62** on the lower or right side of piston **76** and the space on the upper or left side thereof. Valve **88** is a device well known to the art, commercially available, and of the type operable to provide a restricted or metered fluid flow in one direction and relatively unrestricted flow in the opposite direction. The end of rod **72** extending through radial extension **23** of the top plate of gear housing **22** is fitted with a threaded portion **90** for engagement with an adjusting nut **92**. The extreme end of rod **72** is engaged by a centrally perforated boss or stop **93** attached to the side wall of gear housing **22**, and is connected to the end of a flexible shaft or cable **96** extending from a short, upright tubing **98**, through a perforation in a side mounted radial extension of the bottom plate of gear housing **22** and a casing or tubing **100**. Cable or shaft **96** in casing **100** extends to and terminates at cutter driving unit **18** to be hereinafter described.

Referring now to the lower portion of FIG. 3, the upper portion of FIG. 3*b* and FIG. 4, there is illustrated a housing and rotational unit **16** of machine tool **10** comprising a rotatable plate **102** mounted on a substantially cylindrical hollow housing **104** which is adaptable for attachment to the aft end of a solid propellant rocket motor casing **11** (see also FIG. 1) and has provision for air supply thereto through air connection **128**. Plate **102** has a central perforation **106** through which main support tube **42** is insertable. Attached to the top surface of plate **102** at perforation **106** is a lead screw nut **108**. Lead screw nut **108** is a separable, preferably two piece, construction each piece being in the general form of a 60 degree sector formed with a projection **110** the inner end of which is threaded (FIG. 4). Projections **110** extend through slots **44** in main support tube **42** and engage with the external thread of lead screw **40**.

Located on plate **102** near the outer periphery thereof is spring-loaded index pin assembly **112** comprising a slidable pin **113** and a pin handle **115**. Pin assembly **112** engages plate **102** by means of hole **117** therein. Also located on plate **102** (FIG. 4) are a four-way hydraulic or air control valve **114** and a pair of shut-off valves **116** and **116–*a*** spaced thereon approximately 120 degrees apart. Valves **116** and **116–*a*** are connected by tubing **119** to four-way valve **114** and motor **20** through a multiple outlet fitting (not shown) and appropriate connective air hose. Four-way valve **114** is connected to an air supply as indicated and as shown in FIG. 4 is operable by hand through handle or positioning crank **121**. Operation of valve **114** by remotely controlled power means (not shown) for instance, electric motors, hydraulic or air powered actuators and the like is also contemplated or within the purview of the invention. In fact, depending upon the composition of the material being worked by the invention, remote operation of valve **114** is preferred.

Plate **102** is rotationally slidably mounted on top plate **118** of housing **104** and has a central perforation **106**. Plate **118** is also centrally perforated to receive a cylindrical housing **122** and its top flange. At the outer periphery of plate **118** are a plurality of equally spaced holes **120** which register with index pin **112** as plate **102** is rotated relative thereto. The top surface of plate **118** also contains an annular recess **123** to receive plate **102** thereby insuring concentricity therewith. Cylindrical housing **122** passes through plate **118** perforation and extends from the underside of plate **102** throughout the length of machine tool **10** and terminates in an adapter **124** at the forward or igniter port of rocket motor casing **11**. The wall of cylindrical housing **122** contains a longitudinal slot **126** (FIG. 3*a*) extending from adapter **124** upwardly for a distance somewhat exceeding the length of motor casing **11**.

Referring now to FIG. 3*b* and FIG. 5, there is illustrated in detail cutter driving unit **18** and its means of attachment to the end of main support or pilot tube **42**. Cutter driving unit **18** preferably comprises; a bearing housing **130** (FIG. 5) containing a sleeve bearing **132** and a seal **133** for support of cutter drive shaft **36**; cutter driving rear unit guides **134**, attached to bearing housing **130** slidable on tracks **136** attached to the inner wall of cylindrical housing **122**; a plurality of connecting rods **138** secured to a cutter driving unit gear housing **140** (FIG. 3*b*); a coupling **142** located between bearing housing **130** and gear housing **140**; and a drive pinion shaft **144** connected to the end of cutter drive shaft **36**.

In FIG. 3*b*, guide tubing **100** containing flexible shaft **96** terminates in bearing housing **130** being attached thereto. Flexible shaft **96** is connected to a guide rod **148** by set screw **146** within the central bore of a guide housing **150**. Guide tubing **100** is arranged along its entire length within narrow slots in the wall of main support tube **42** (see also FIG. 4). Guide rod **148** arranged within guide housing **140** emerges therefrom adjacent gear housing **140** where it is piovtally attached to an actuating link **152**. Link **152** has its opposite end pivotally attached to the cutter assembly **154** which is connected to the forward end of gear housing **140** for pivoting or turning about the axis of a pin **156** retaining a thrust bearing **158** (FIG. 5).

Gear housing **140** preferably comprises a separable, two-piece cylinder containing a plurality of longitudinal holes, a bottom plate **160**, an upper section **162** and an end plate **164**. End plate **164** has a central perforation locating a seal **166** surrounding pinion shaft **144** (FIG.

5). Pinion shaft 144 extends longitudinally into the interior of upper section 162 through a hole therein and is mounted in bearings 168 and 170. Pinion shaft 144 includes an integral bevel gear 172 situated between bearings 168 and 170.

Mounted on bottom plate 160 is a gear train comprising a pair of combination bevel spur gears 174 and 175 and an idler spur gear 176 located therebetween meshing with the spur portions of gears 174 and 175. Gears 174, 175 and 176 are mounted on small shafts 178, 179 and 180 in bearings 182, 183, and 184 respectively, the shafts being secured to bottom plate 160. The interior of upper section 162 is fabricated to permit sufficient clearance for full rotation of gears therein. The bevel gear portion of gear 174 meshes with bevel gear 172 of pinion shaft 144 as shown. The bevel gear portion of gear 175 meshes with the bevel gear 186 integrally formed with the cutter shaft 188. Cutter shaft 188 is contained within cutter rotating body 154 and is mounted in bearings 190 and 192 located on either side of bevel gear 186. Surrounding cutter shaft 188 at its exit from cutter rotating body 154 is seal 194 housed therein. Attached to the exposed end of cutter shaft 188 is a fluted end mill or cutter 196, having an external geometry proportioned to prepare the desired cross sectional shape of the propellant charge 15. Bottom plate 160 and upper section 162 both contain a longitudinally extending, bifurcated projection to which are attached forward guides 134 identical in construction to rear guides 134 previously described. Cutter rotating body 154 is sealed against bottom plate 160 and upper section 162 by means of O-rings 200 and 202. The interior parts of gear housing 140, i.e., pinion shaft 144 and bearing 168, are lubricated by means of commercially available oil packing 204 contained in an elongated cavity lying parallel to pinion shaft 144. Communication with this interior cavity in the upper section 162 and the surface of pinion shaft 144 is established by means of a hole in the wall of bearing 168.

Referring again to FIGS. 3, 3*a* and 3*b*, an air supply line 206 is connected to an air supply through valve 208 and extends through the length of main support tube 42, being retained in a slot in the wall thereof by means similar to previously described guide tubing 100, and terminates at upper section 162 of gear housing 140. In gear housing 140, line 206 communicates with an internal, longitudinal passage indicated by dotted line in upper section 162 (FIG. 3*b*) which terminates at a port (not shown) provided thereat and indicated by numeral 210 on the side of upper section 162 near cutter rotating body 154.

FIG. 6 is illustrative of an additional means for rotating plate 102 relative to plate 118 and thereby constitutes a further embodiment of the invention. In this embodiment, plate 102 contains peripheral gear teeth and forms a worm wheel 211. In mesh with worm wheel 211 of modified plate 102 is a worm gear 212 on the drive shaft of an auxiliary air motor 214. Motor 214 is mounted on a radial extension of stationary plate 118 in a manner similar to cylinder 62 of mechanism 14 on air motor 20 plate extension 23.

In FIGS. 3*a* and 3*b* and 5 at the lower end of lead screw 40 is a sleeve 216 concentric with respect to cutter drive shaft 36 and located within main support tube 42. Sleeve 216 extends from the lower end (FIG. 3*a*) of lead screw 40 to bearing housing 130 (FIG. 5) to which it is attached. At its upper end, sleeve 216 contains a bearing 218 (FIG. 3*a*) which supports cutter drive shaft 36. It is attached by welding or like means to main support or pilot tube 42 immediately above bearing housing 130 near the lower end of slot 126 (FIGS. 3*a* and 5).

Attached to the inner periphery of cylindrical housing 122 beginning at the uppermost portion thereof in a recess 125 is one end of a cylindrical boot, dust cover, tube or protective shroud 220 comprising a ring 221 (FIG. 3). The other end of tube 220 is secured to the outer periphery of main support or pilot tube 42 at the middle portion thereof by means of lower boot ring 227. Shroud 220 is arranged with a slack loop 229 between points of attachment (FIG. 3*a*).

In FIG. 4 valves 116 and 116*a* each comprise an actuating arm 222 (and 223) which extends radially inwardly therefrom and includes a roller 224 (and 225). Roller 225 of valve 116*a* bears against the outer, upper portion of the wall of main support tube 42. Valve 116 roller 224 in the illustration shown, is contacted by radial projection, lobe or stop 226 located on the outer, upper portion of the wall of support tube 42. Stop 226, being attached to main support or pilot tube 42, travels therewith and contacts roller 224 of valve 116 when tube 42 (and hence cutter 196) is at its uppermost position, as will be explained in the description of the operation of the invention which follows. Finally, eye bolts 228 are positioned on plate 102, preferably in equiangular spacing around the periphery thereof as illustrated.

As will be noted, all moving parts except fluted cutter or end mill 196 are completely sealed to preclude fouling thereof with propellant dust or chips resulting from operation of milling machine 10 to be later described. Thus, cutter driving unit 18 is a completely sealed, oil-filled unit supported in housing 122 on tracks 136 by means of front and rear guides 134. Guides 134 are made of low-friction, spark resistant material such as any of the fluorocarbon plastics and the like. Shaft 36 is sealed within main support or pilot tube 42 by means of seal 133 and the moving parts contained within the upper portion of cylindrical housing 122 are sealed from the lower propellant contacting portions by means of boot or shroud 220.

Operation

In operation of the invention, reference is made to FIG. 1 wherein machine tool 10 is shown installed on previously prepared, vertically mounted solid propellant rocket motor 11 with slotted, longitudinally extending cylindrical housing 122 inserted through nozzle 13 thereof until it is seated in the head end igniter port of motor 11 by means of adapter 124 attached to the lower end thereof. Machine tool 10 is secured to rocket motor 11 by split collar 230 which is fastened in clamping engagement to the aft end of nozzle 13 and the lower base plate of housing 104. Rocket motor 11 contains a solid propellant charge 15 having a central, cylindrical perforation of a diameter slightly in excess of housing 122 outside diameter.

Air from main air supply (indicated in FIGS. 3 and 4) enters four-way valve 114 and is distributed therefrom to valves 116 and 116*a* as previously described. Valves 116 and 116*a* are connected to cutter positioning mechanism 14, valve 208 and air motor 20 by means of a distributor fitting (not shown). Valve 116 controls the rotation of motor 20 for "forward" operation of machine tool 10 as will be hereinafter explained. Valve 116*a* is connected directly to motor 20 and controls its rotation for "reverse" operation of machine tool 10 as will also be hereinafter explained. Air is also supplied to fitting 128 on the side of housing 104.

At the start of operation, machine tool 10 is rotated into position relative to rocket motor 11 (plate 102 being rotated relative to plate 118) and index pin 112 is engaged in the selected matching hole 120 in plate 118. Machine tool 10 is fully extended with fluted cutter or end mill 196 proximate to adapter 124 and in axial alignment with cylindrical housing 122 (see FIGS. 1 and 3*b*).

Four-way valve 114 is operated by means of handle 121 (or remotely by power means not shown—FIG. 4) and air pressure from the main air supply is applied to the "forward" valve 116 through its supply line 119 thereby permitting air pressure to be applied to air motor 20 and simultaneously to cutter positioning mechanism 14. At this time, supply valve 208 is opened to permit air to enter the lower part of supply line 206. Thus, the

system's air operated devices are all put in readiness for operation.

In the following description it should be borne in mind that the separately described events occur simultaneously, hence air is supplied to air cylinder **60** of cutter positioning mechanism **14** through connection **68** displacing piston **70** longitudinally therewithin, compressing spring **74** and forcing piston rod **72** toward the right in FIG. 3. The motion of piston rod **72** causes piston **76** of hydraulic cylinder **62** to be correspondingly displaced thus forcing hydraulic fluid contained in cylinder **62** into passage **82** in the base of cylinder **62**. Hydraulic oil then enters line **86** and oil passage **83** in spacer **80** arriving at the left side of piston **76**. Thus by metering oil flow as described, the action of air pressure in cylinder **60** is cushioned and the motion of rod **72** downward (or to the right in FIG. 3) forces flexible shaft **96** attached thereto to be displaced longitudinally within guide tubing **100** at a predetermined rate of speed.

Movement of flexible shaft **96** in cutter driving unit **18** in turn causes guide rod **148** within guide housing **150** (FIG. 3*b*) to be extended and give motion to actuating link **152**. Motion of actuating link **152** results in pivotal rotation of cutter assembly **154** about pin **156** thereby rotating fluted cutter or end mill **196** into propellant charge **15** along the arc described by broken line **234** at the bottom portion thereof. Degree of travel of end mill **196** along arc **234** is limited by special adjustment nut **92** on threaded portion **90** of shaft **72** abutting against travel stop **93** (see FIG. 3). Therefore, the angular displacement, and corresponding thereto, the depth of cut made by end mill **196** is controlled to an accuracy dependent only upon the fineness of threads **90** on shaft **72**.

Air supplied to air motor **20** causes rotation thereof in a manner well known to those users of such devices, and "forward" operation is easily achieved by valve **116** operation above-mentioned. In response to rotation of air motor **20** gear **24**, in gear housing **22** rotates and drivingly engages gear **26**, thereby rotating countershaft **28** containing it. Gear **30**, also mounted on countershaft **28** in turn drives gear **34** and causes rotation of cutter drive shaft **36** thereby. Cutter drive shaft **36** causes pinion gear shaft **144** to rotate by means of coupling **142** attached thereto (see FIG. 5). In gear housing **140** (FIGS. 3*b* and 5) bevel gear **172**, integrally connected to pinion shaft **144**, is provided for driving the gear train comprising the pair of combination bevel-spur gears **174** and idler gear **176** whereby bevel gear **186** and cutter shaft **188** are rotated, and by connection thereto, cutter **196**. Cutter **196** rotates about its longitudinal axis and a star point in propellant charge **15** begins to be formed.

Simultaneously, gear **32** (FIG. 3), also mounted on countershaft **28**, drives gear **38**, and by attachment, lead screw **40**, causing rotation thereof. Lead screw **40** rotates in lead screw nut **108** which is fixed to plate **102** thereby causing longitudinal displacement of lead screw **40** main support or pilot tube **42**, air motor **20** and end mill **196** upwardly. In other words, the upward movement of lead screw **40** results in cutter driving unit **18** together with fluted cutter **196**, main support tube **42**, motor and gearing unit **16**, and cutter positioning mechanism **14** being moved upwardly relative to rocket motor **11** and housing **104**.

In essence, the application of air through actuation of four-way valve **114** causes cutter **196** to be positioned by rotation through an arc into solid propellant charge **14** and to be drawn upwardly therethrough, cutting a valley or star point therein. FIG. 2 is illustrative of a configuration in the initial stages of production.

Gears **34** and **38** in gear housing **22** are selected such that solid propellant chips produced by cutter **196** are of reasonable size to facilitate removal. The rotational speed of the cutter **196** and the rotational speed of lead screw **40** have a constant relation to each other, and with constant speed and feed, the chip size produced by cutter **196** is always the same, regardless of the rotational speed of motor **20**.

Air simultaneously supplied to air line **206** through valve **208** enters gear housing **104** in a stream directed at cutter **196** from a port provided therein (not shown). In this manner propellant chips formed by cutter **196** are carried to the opening in adapter **124** and collected in a collecting device (not shown) outside motor casing **11**. Air is also supplied to connection **128** on housing **104** to insure that the interior of housing **104** and the central cavity of rocket motor charge **15** are subjected to a continuous air purge during the cutting operation. In this manner, all propellant dust and chips are directed away from the moving parts of the machine and toward the opening in adapter **124**.

Upon completion of a valley or star point in charge **15**, lead screw **40** is at its upward stop or limit and cutter **196** has traversed its predetermined full length. At this instant, projection or stop **226** on the lower end of the outer wall of main support tube **42**, strikes roller **224** of valve **116** and moves actuating arm **222** to shut off the air supply to motor **20** venting its pressure. Motor **20** becomes inoperative and halts the rotation of cutter **196** and lead screw **40**. Piston **70** in air cylinder **60** returns to its original position under urging of spring **74** along with piston rod **72**. Flexible shaft **96** and cutter rotating body **154** then return to their axially aligned position prior to charge **15** cutting operation above-described. Return of cutter **196** to its original position is effected quite rapidly since flow of hydraulic oil through flow valve **88** is un-restricted in the return direction hence, little or no resistance to motion is offered to piston **76**.

Four-way valve **114** is now operated by means of actuating arm **121** to open or activate "reversing" valve **116***a* thereby reversing the direction of air motor **20**. Lead screw **40** is thus caused to rotate oppositely and the cutter position mechanism **18** is returned to the bottom (or right hand end) of rocket motor **11** charge **15**. At the limit of lead screw **40** downward travel a second stop or block **226**, attached to the upper end of the outer wall of main support tube **42**, strikes roller **224** on actuating arm **222** of "reversing" valve **116** closing it, and shutting off the air supply to motor **20** thereby stopping the entire mechanism.

Index pin **112** is then withdrawn from hole **120** and machine tool **10** rotated on plate **118** to the next selected index position. Index pin **112** is engaged in its new matching hole **120** and the operational sequence previously described is repeated. This procedure is followed until the desired charge configuration has been completely cut in solid propellant charge **15**.

As an alternative to the rotational indexing of machine tool **10** and cutter **196** by manual means, FIG. 6 illustrates a worm wheel and gear arrangement to accomplish this operation. Secondary air motor **214** is operated by supplying air pressure thereto rotating worm **212** which, in turn, causes worm wheel **211** (integral with plate **102**) to rotate thereby automatically indexing machine tool **10** and cutter **196** with respect to the charge **15** after rotating cutter rotating body **154** into position, as above described. This arrangement not only allows for incremental positioning, as with the index pin **112** in plates **102** and **118**, but in addition permits cutter **196** to be rotated about its own shaft **188** and simultaneously about the longitudinal axis of machine tool **10**. Therefore, by means of the embodiment herein described, many additional propellant charge core configurations for example, spirals, cork screws and unsymmetrical perforations, become possible.

It should also be stated with regard to the shape and design of fluted cutter **196** that it can be changed in innumerable ways to effect almost any cutting requirement under many and varied operations and cutting tasks. However, in solid propellant milling, the milling cutter

should desirably be designed with chip breakers to provide chips of limited and uniform size for easy removal and minimum danger.

Having, therefore, described the invention in a preferred and a second embodiment, it should be understood that it is not limited thereto, but may be used in other ways and made in many additional embodiments without departure from the spirit and scope thereof except as defined by the subtended claims.

What is claimed is:

1. A machine for forming internal cavities in solid combustible material containing casings, said cavities having relatively complex configurations in cross section comprising, a primary power source, a cutter shaft rotatably driven by said power source adapted to pass through a central, longitudinal perforation in said combustible material, means for supporting said cutter shaft adapted to be longitudinally restrained in an opening in one end of said casing, a main housing comprising at least one flange for mounting said housing on said casing, a top plate contacting said housing comprising means for radially positioning said cutter shaft in said combustible material perforation, a stationary lead screw nut mounted on said top plate, an end mill rotatable about its longitudinal axis and pivotally attached to one end of said cutter shaft for rotation thereby and for turning relative thereto, remote power means for turning said end mill into said combustible material for milling an arcuate passage therein, control means mounted on said machine for selectively changing the direction of rotation of said cutter shaft, and a rotatable lead screw driven by said power source operative with said stationary nut to raise said end mill through said material for milling a longitudinal passage therein.

2. A machine for forming complex configurations in cylindrical, preformed internal cavities in solid combustible material charge containing casings such as the propellant charge of a solid propellant rocket motor comprising, a power driven motor and a gear box in power communication therewith, an extended cutter shaft attached to said gear box and axially rotated thereby, a cutter driving assembly coupled to the other end of said cutter shaft comprising a coupling and a gear train, an end mill attached to said gear train for rotation thereby comprising fluted cutting edges for milling said solid combustible material charge, means surrounding said cutter shaft for guiding said shaft into said internal, preformed cylindrical cavity in said charge, a cylindrical housing surrounding said guide means for supporting said cutter shaft and driving assembly and adapted to be contained at one end in an opening in said casing containing said combustible material charge, remote power means for pivotally rotating said cutter driving assembly with respect to the combustible material charge comprising, a spring loaded, powered piston and piston rod assembly and a flexible extended shaft attached to said rod and to said cutter driving assembly for pivoting said cutter driving assembly and said fluted cutter into said charge to mill an arcuate passage therein, a centrally positioned lead screw connected to said gear box for rotation thereby, a hollow, main housing surrounding the upper portions of said cylindrical housing, said guide means, said cutter drive shaft, and said lead screw comprising an upper and a lower flange, said lower flange adaptable for mounting said housing on one end of said casing, a top plate rotationally, slidably engaged with said upper flange comprising means for radially indexing the position of said cutter drive shaft and said fluted cutter with respect to the solid material charge, means centrally positioned and fixed to said top plate comprising threaded portions for engagement with said lead screw, said lead screw rotatable in said threaded portions of said centrally positioned threaded means for raising and lowering said machine through said charge to mill successive, longitudinal passages therein in response to the milling action of said rotating fluted cutter, and means mounted to said machine for changing the rotational direction of said machine motor, transmission gear box and lead screw.

3. A machine for milling the longitudinal internal cavity in a solid propellant charge of a rocket motor from a preformed central, cylindrical perforation therein, said cavity having a relatively complex cross-sectional configuration comprising, a reversible air driven motor and gear box therefor, a cutter shaft drivingly engaged to said gear box, a lead screw concentric with said cutter shaft drivingly engaged to said gear box of a length substantially the same as said charge cavity, a centrally positioned support tube surrounding said lead screw fixedly attached to said gear box and extendible therefrom, a longitudinal, cylindrical housing surrounding said lead screw support tube, a main, hollow housing surrounding a portion of said cylindrical housing comprising upper and lower flanges, said lower flange adaptable for mounting said machine to the aft end of said rocket motor, said upper flange comprising a central perforation for receiving said cylindrical housing an inner flange means fixedly attached thereto, a top plate slidably rotatable over said upper flange comprising radial indexing means thereon, a cutter driving assembly coupled to said cutter shaft at its lower end, a cutter mounted to said driving assembly for rotation thereby about its lengthwise axis, means mounted on said machine for positioning said cutter assembly and cutter comprising a powered piston and rod, a flexible shaft attached to one end of said rod extendible to said cutter driving assembly for rotating said cutter about a transverse axis of said rocket motor charge, means mounted on said top plate for selectively controlling the direction of rotation of said air motor and said cutter drive shaft comprising, a four-way control valve and a pair of shut-off valves connected thereto, stop means on said support tube adapted to operate one of said shut-off valves for shutting off the air supply thereto and venting said air motor systems, means on said four-way valve for directing air to the other of said shut-off valves for rotating said motor in the opposite direction thereby returning said cutter to the bottom of said motor charge upon finishing a cutting operation, and a stationary lead screw nut fixedly mounted on said top plate threadably engaged to said lead screw whereby said cutter shaft, cutter driving assembly, air motor and gear box, support tube and cutter are raised and lowered throughout the length of said propellant charge in response to rotation of said lead screw by said gear box driven by said motor.

4. An apparatus for forming the internal burning surfaces in the solid propellant charge of a rocket motor, said charge preformed with a central, longitudinal cylindrical perforation therein comprising, a hollow, main housing assembly comprising upper and lower flanges, said lower flange adapted for attaching said apparatus to the aft end of said rocket motor and having a central hole therein, said upper flange comprising a centrally perforated plate, said plate containing a plurality of peripheral holes and a peripheral recess, a cylindrical housing having a slotted lower portion comprising an elongated tube insertable in said central holes in said upper and lower main housing flanges, said tube extendible therethrough into said rocket motor charge preformed perforation and terminating in the head end of said rocket motor casing, a top plate on said tube housing adapted to contact said main housing upper flange plate in said peripheral recess thereof, pin means on said top plate adapted to engage said flange plate peripheral holes for radially indexing said tube housing within said charge perforation, a power supply and transmission means, a separable, stationary thread containing lead screw nut attached to the top surface of said top plate and positioned with its threaded portions extendible into said central perforation of said top plate,

an elongated pilot tube having a pair of diametrically opposite slots running along a substantial portion of said tube length fixedly attached within said tube housing in co-extension therewith, a hollow lead screw within said pilot tube threadably engaged with the threaded portions of said lead screw nut, a rotating cutter shaft drivingly connected to said power transmission means extendibly positioned within said hollow lead screw, a support sleeve attached to said pilot tube lower end concentrically mounted therewithin and over said cutter shaft extendible from the lower end of said lead screw to a point below said pilot tube, a bearing housing and bearing means supportably connected to said cutter shaft at the lower end thereof, a cutter driving assembly, a plurality of connecting rods attached to said bearing housing and to said driving assembly, a coupling connecting said cutter shaft to said driving assembly, a first pinion shaft attached to said coupling, a mitre gear train drivingly engaged to said pinion on said first pinion shaft, a second pinion shaft having its pinion drivingly engaged to said gear train, bearing means for supporting said first and second pinion shafts, a cylindrical gear housing for containing said pinion shafts, bearings, and gear train comprising an upper section and a bottom plate having bifurcated end projections, forward guide means mounted on said end projections, a pair of guide tracks mounted on the interior walls of said cylindrical tube housing for slidably engaging said guide means, rear guide means attached to said sleeve slidably contacting said tracks in said tube housing, an actuating arm attached to said cutter driving assembly for rotatably actuating said assembly into said propellant charge about a line perpendicular to the long axis of said rocket motor, a fluted cutter mounted on said second pinion shaft for rotation thereby, a cutter positioning mechanism mounted on said apparatus at a place remote from said cutter driving assembly and cutter comprising, a two-chambered power cylinder containing an elongated rod having a threaded end, an air operated, spring loaded first piston on said rod in one of said chambers, a spacer having a fluid passageway formed therein and adapted to permit said rod to pass therethrough, a second piston mounted on said rod and axially aligned with said first piston in the other chamber of said cylinder, a base plate in said second chamber having a fluid passageway therein, fluid conveying means including fluid restrictor means for establishing fluid flow communication between both sides of said second piston, means in said base plate of said cylinder for sealingly passing said rod to the exterior of said cylinder, said threaded portion of said rod exteriorly projecting from said cylinder, an adjusting nut threadably engaged to said rod threaded portion for establishing the travel limits of said rod, a flexible shaft attached to said rod end, a housing for said flexible shaft, said housing and shaft extendible to said cutter driving assembly within said cylindrical housing of said apparatus, pivot means for attaching said flexible shaft to said actuating arm on said cutter driving assembly, means on said power cylinder for passage of air into said first chamber thereof for linearly displacing said first and second pistons in a direction to cause a compressive load on said spring, a damping fluid contained in second chamber, said fluid displaceable through said fluid conveying means and restrictor means by said second piston, said flexible shaft undergoing a corresponding linear motion to rotate said cutter driving assembly by said actuating arm on said pivot means about said line perpendicular to said long axis of said motor and said cutter is rotated through said cylindrical housing slot into said propellant charge for milling an arcuate passage therein, and control means mounted on said top plate for controlling the rotation of said power supply and transmission means, said cutter shaft and cutter comprising, a four-way pneumatic control valve and a pair of pneumatic shut-off valves connected thereto, stop means on said pilot tube ends each adapted to operatively contact one of said shut-off valves for shutting off said power supply, means on said four-way valve for reversibly operating said power supply, power transmission means and lead screw to raise and lower said machine and cutter through said propellant whereby milled longitudinal passages are formed therein.

5. The machine of claim 1 wherein the means for radially positioning said cutter shaft and end mill comprises an indexing pin peripherally mounted on said plate and said main housing contacted by said plate comprises means for receiving said indexing pin.

6. The machine of claim 1 wherein the means for radially positioning said cutter shaft and end mill comprises a worm wheel attached to said top plate and a worm gear for rotating said wheel, said gear driven by a power source mounted on said machine.

7. The machine tool of claim 1 wherein said primary power source is a reversible air motor coupled to said cutter shaft through a speed reduction gear transmission.

8. The machine of claim 1 wherein the control means is a four-way pneumatic selector valve connected to a pair of shut-off valves for directionally controlling the rotation of said primary power source.

9. The machine of claim 1 wherein the end mill comprises fluted cutter blades for forming small, uniformly sized chips and particles.

10. The machine of claim 1 wherein an air stream is provided at the end mill during milling to remove particles and chips resulting from milling said combustible material.

11. The machine of claim 2 wherein the radial indexing means comprises a worm wheel mounted on said top plate peripheral edge, a worm gear in engagement therewith and an auxiliary reversible air motor for rotating said worm gear.

12. The machine of claim 2 wherein an air blast is directed at the fluted end mill where it contacts the milled combustible material to effect removal of particles and chips resulting from said milling operation.

13. The machine of claim 2 wherein the means for changing the rotational direction thereof comprises a four-way pneumatic valve and a pair of pneumatic shut-off valves, said four-way valve operable to selectively supply working fluid to said shut-off valves to determine the rotational direction of said machine.

14. The machine of claim 2 wherein the power driven motor is a reversible air motor.

15. The milling machine of claim 3 wherein means is provided to direct an air stream at the cutter where it contacts the solid propellant in said charge for removal of cut particles and chips from said cutter edges.

16. The milling machine of claim 3 wherein the cutter comprises fluted edges so that the resulting propellant chips and particles are of small and uniform size for easy removal.

17. The milling machine of claim 3 wherein the indexing means comprises a worm wheel on said top plate, a worm gear in engagement therewith, and means for driving said worm and said wheel thereby.

18. The apparatus of claim 4 wherein the top plate consists of a worm wheel, said worm wheel adapted to engage with a worm gear driven by an auxiliary reversible power supply means for radially indexing said tube housing, cutter shaft and fluted cutter with respect to said preformed central solid propellant cavity.

19. The apparatus of claim 4 wherein said power supply is a reversible air motor.

20. The apparatus of claim 4 wherein the cutter driving assembly is provided with an internal passage therethrough for delivering an air stream to said solid propellant surface where said surface is contacted by said fluted cutter, said air stream directed thereat so as to remove propellant particles and chips from said cutter fluted edge.

21. Apparatus for cutting cavities in the inner periphery of a charge formed of a solid combustible material

having a perforation, said apparatus comprising, in combination, elongated drive means having a cutting means driven thereby and pivotally connected thereto for swinging from a first position in which the cutting means is axially aligned with the drive means to a second position in which the cutting means is disposed radially, and back to the first position, said drive means adapted for insertion in a perforation in a solid combustible material charge with said cutting means in axially aligned position in which condition the transverse dimensions thereof are less than those of the perforation, said cutting means in the radially disposed position extending beyond the periphery of the perforation, and means for swinging said cutting means while being driven and for moving the drive means longitudinally for cutting a cavity in the periphery of the perforation.

22. The apparatus of claim **21** wherein the cutting means is rotatable about its longitudinal axis and its form and speed are correlated to the speed of the means for moving the drive means longitudinally for cutting uniform chips and particles of the combustible material.

23. The apparatus of claim **21**, wherein means are provided for removal of the cuttings resulting from operation of the cutting means.

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