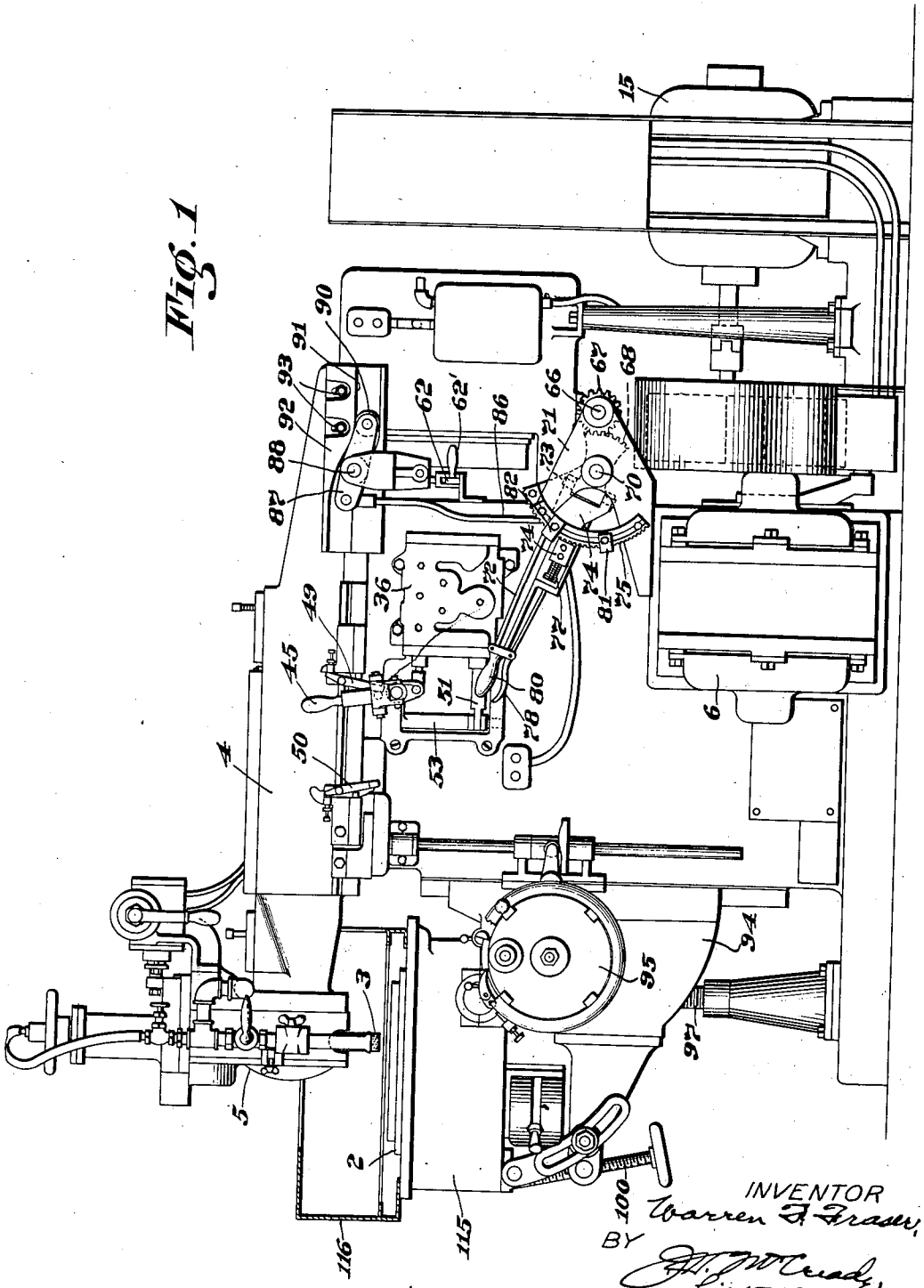
Oct. 29, 1935. W. F. FRASER 2,018,847

GRINDING MACHINE

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Fig. 1



INVENTOR
Warren F. Fraser,
BY
his ATTORNEY.

Oct. 29, 1935. W. F. FRASER 2,018,847

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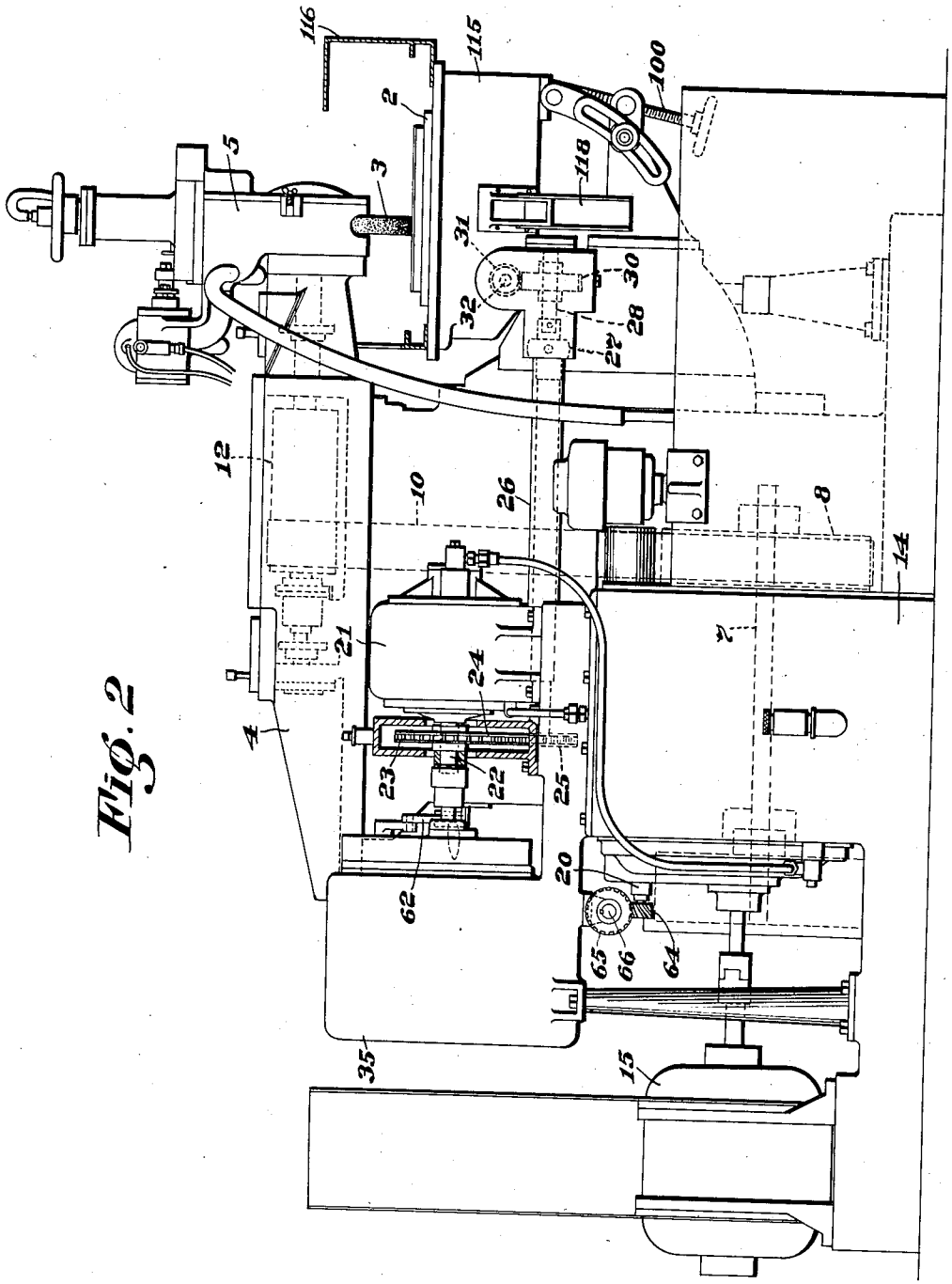


Fig. 2

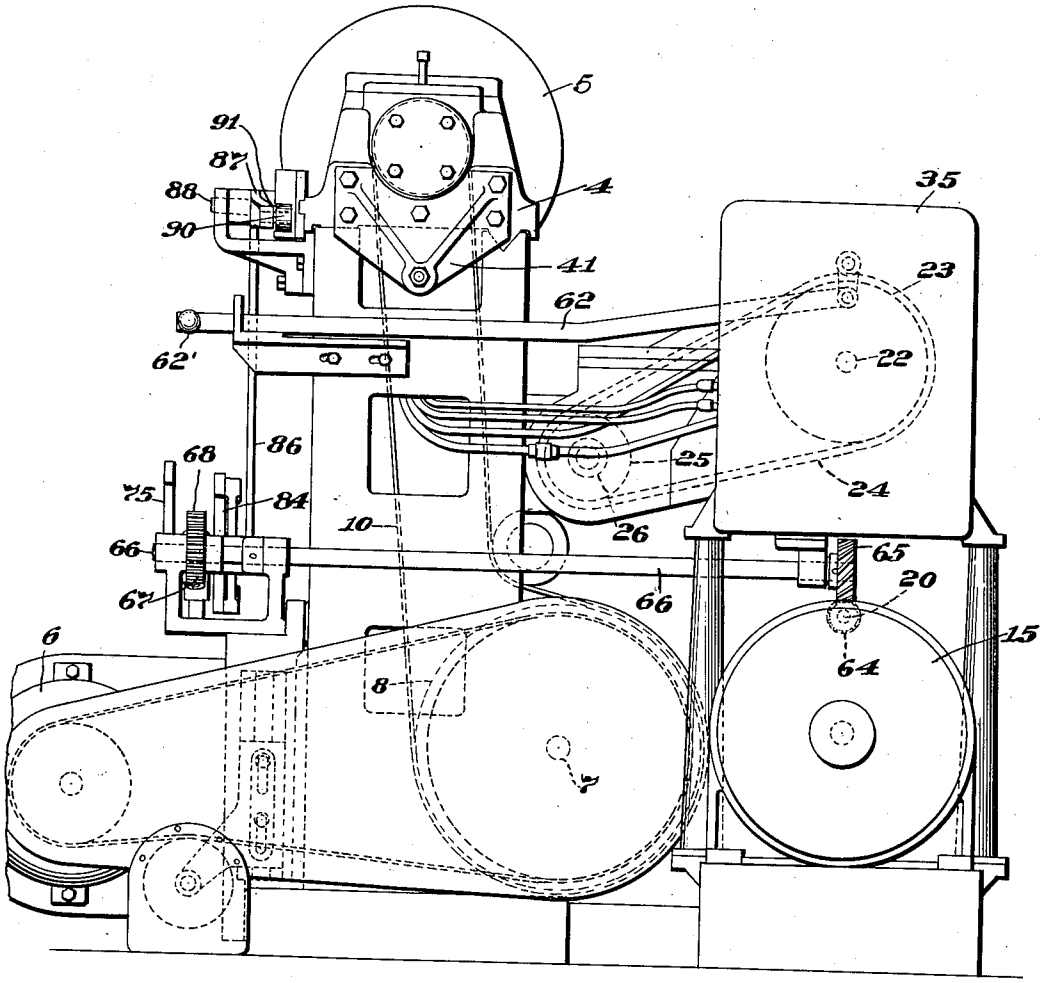
INVENTOR
Warren F. Fraser,
BY J. H. McCready,
his ATTORNEY.

Oct. 29, 1935. W. F. FRASER 2,018,847

GRINDING MACHINE

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Fig. 3



INVENTOR
Warren F. Fraser
BY
J. H. McCready
his ATTORNEY.

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GRINDING MACHINE

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Fig. 4

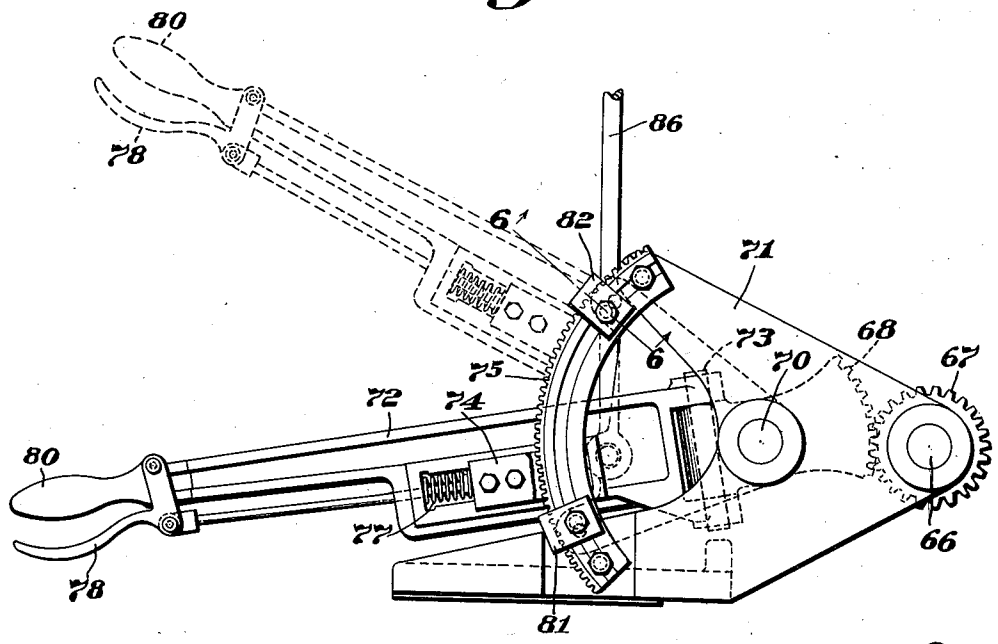


Fig. 5

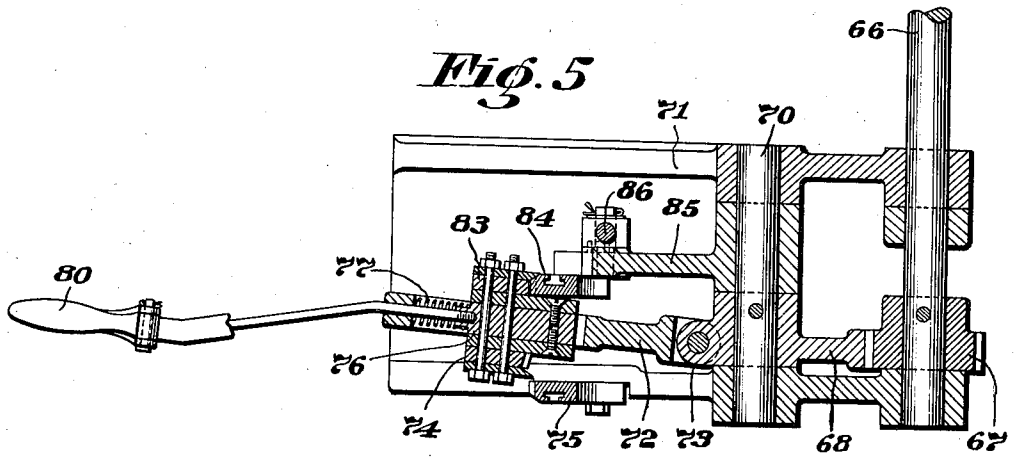
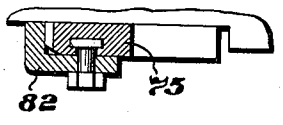


Fig. 6

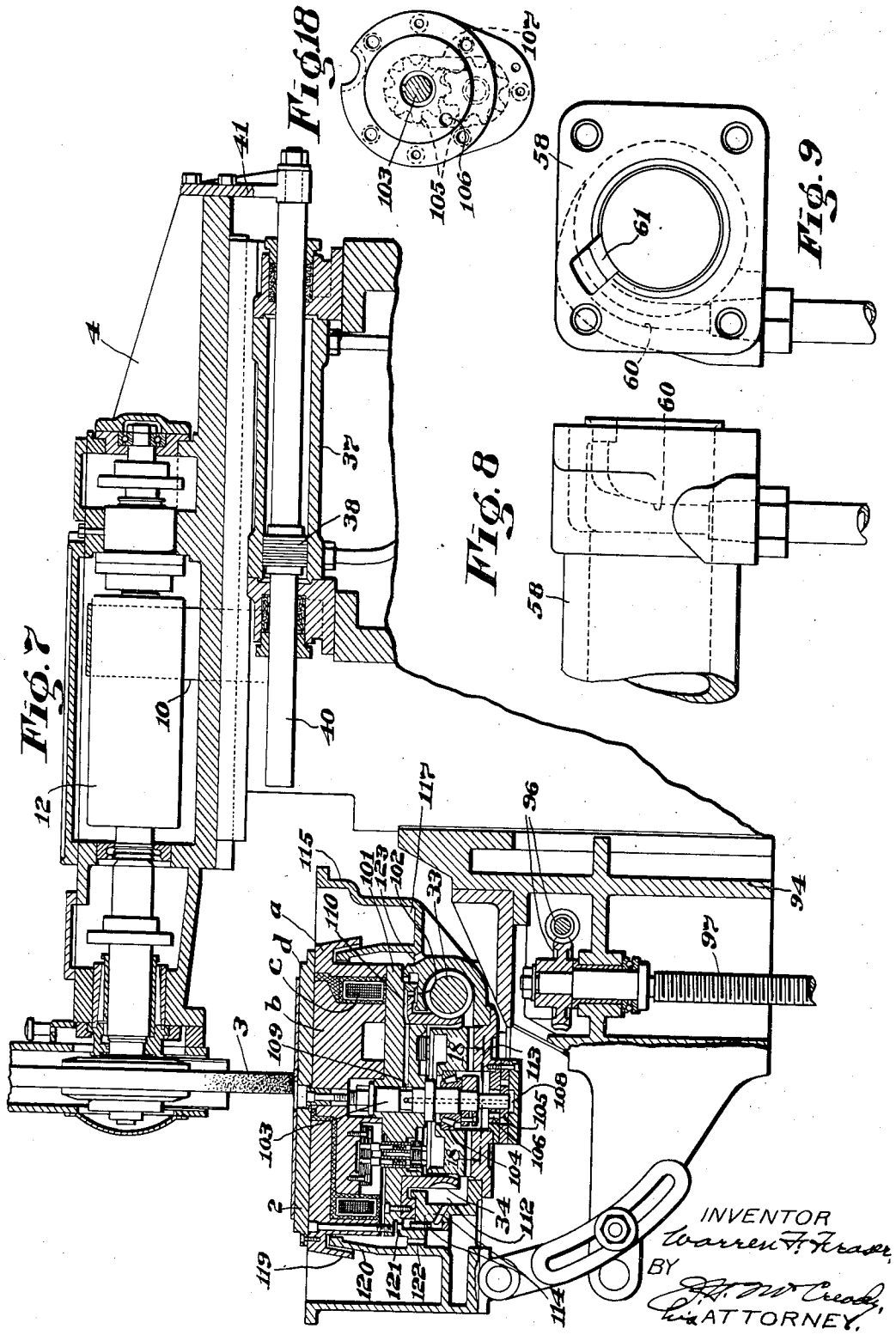


INVENTOR
Warren F. Fraser,
BY
J. F. McCready,
ATTORNEY.

Oct. 29, 1935. W. F. FRASER 2,018,847

GRINDING MACHINE

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Fig. 10

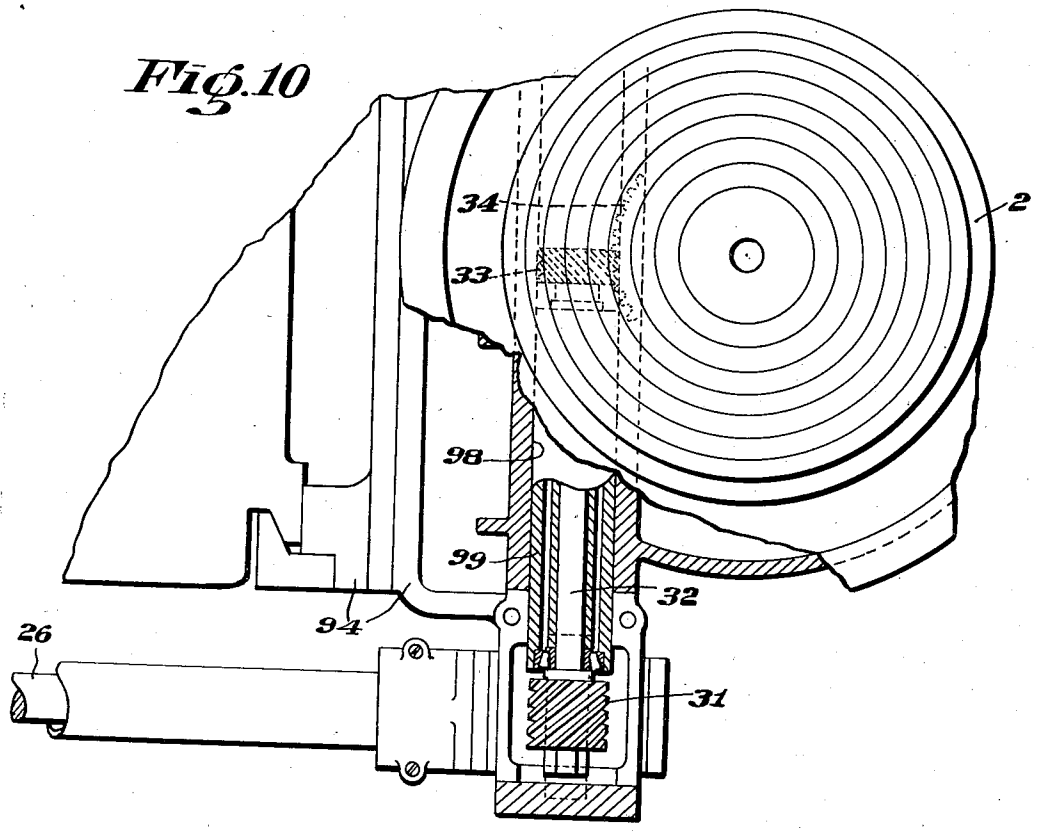
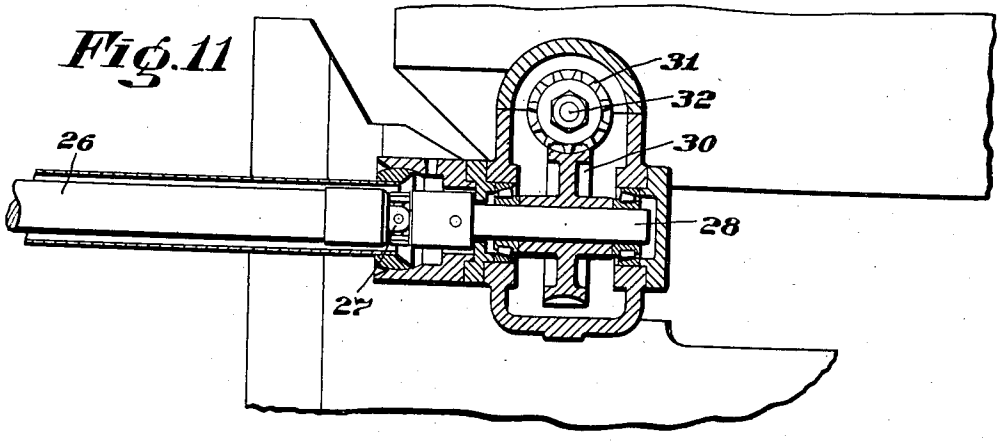


Fig. 11



INVENTOR
Warren F. Fraser,
BY
Geo. W. Creade,
his ATTORNEY.

Oct. 29, 1935. W. F. FRASER 2,018,847

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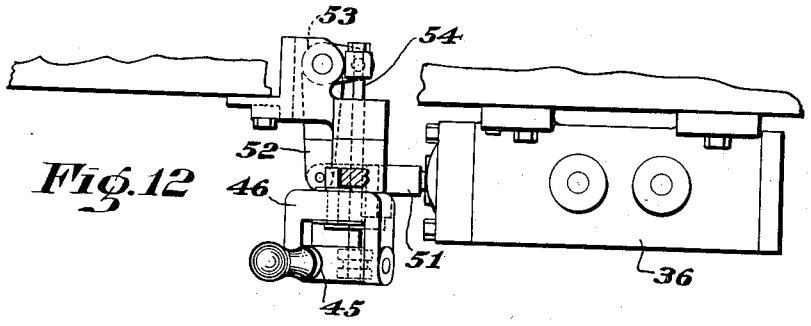


Fig. 12

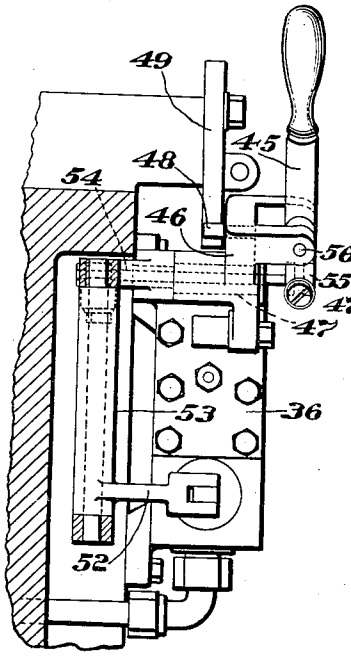


Fig. 14

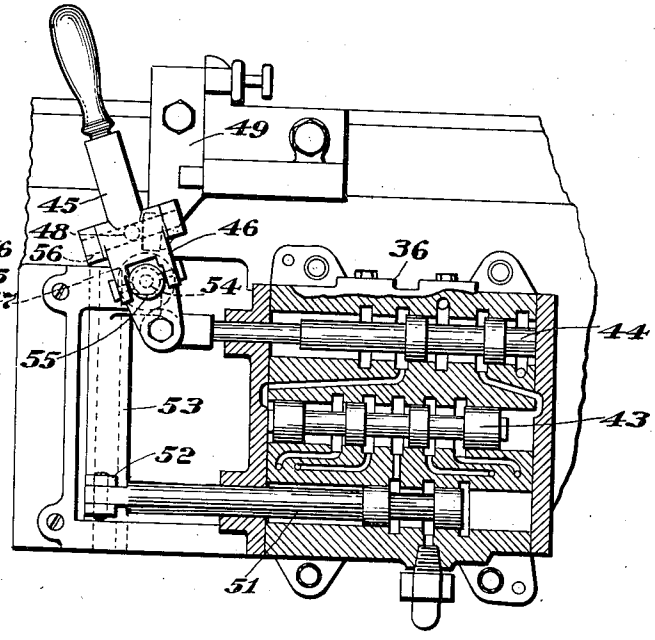


Fig. 13

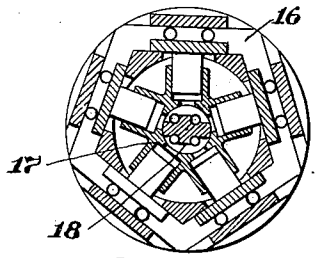


Fig. 15

INVENTOR
Warren F. Fraser
BY
W. F. McCready
ATTORNEY.

Oct. 29, 1935. W. F. FRASER 2,018,847

GRINDING MACHINE

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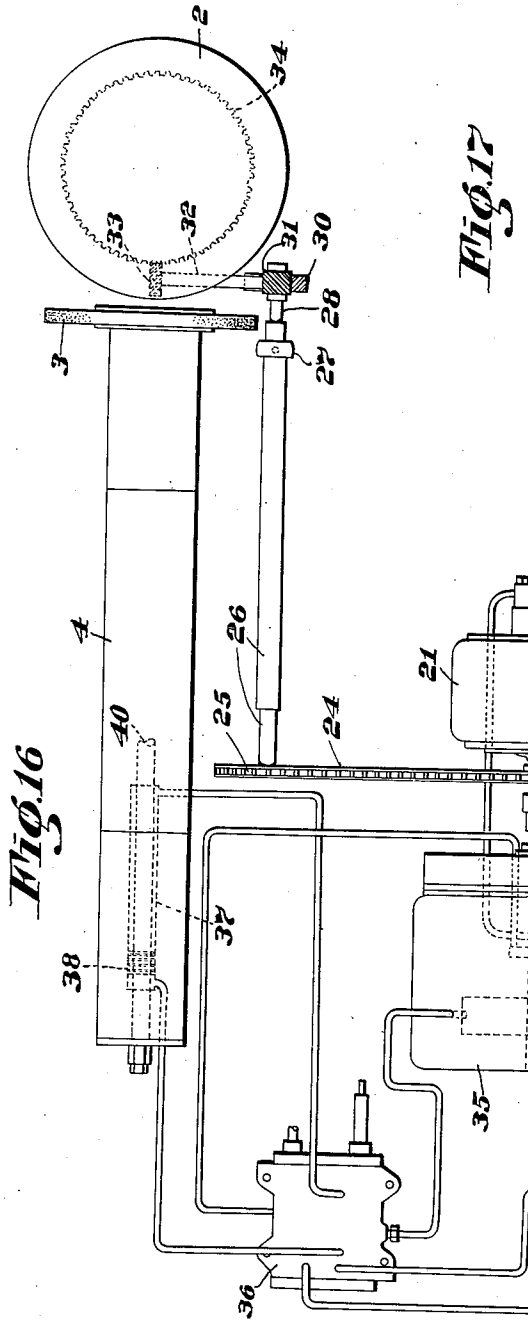


Fig. 16

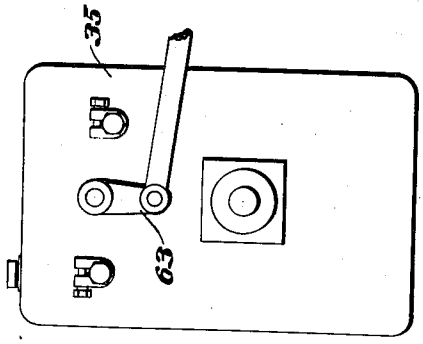


Fig. 17

INVENTOR
Warren F. Fraser,
BY J. H. McCreath,
his ATTORNEY.

Patented Oct. 29, 1935 2,018,847

UNITED STATES PATENT OFFICE

2,018,847

GRINDING MACHINE

Warren F. Fraser, Westboro, Mass.

Application July 6, 1932, Serial No. 621,053

18 Claims. (Cl. 51—51)

This invention relates to grinding machines and is more especially concerned with that type of machine known as rotary surface grinders.

A machine of the latter type usually comprises a rotary chuck or support on which the work to be ground is held and revolved, a grinding wheel or equivalent abrading element, mounted for traversing movement across the surface of the work supported on said chuck, and suitable driving mechanisms for said chuck and wheel. A considerable proportion of the work to be ground in such machines consists of disks, collars and similar articles, which may or may not have tapered surfaces. In grinding them they are centered one at a time on the chuck, and the wheel is traversed across each piece and in contact with it while both the work and the wheel are revolved rapidly. Assuming the traversing speed to be uniform and the speed of revolution of the grinding wheel and chuck to remain constant, it will be evident that as the grinding wheel approaches the axis about which the work revolves, the ratio between said traversing speed and the surface speed of rotation of the work will increase as the axis of rotation is approached, and will decrease as the grinding wheel recedes from said axis.

It will readily be appreciated that there is a certain optimum speed or rate of revolution of the grinding wheel which may vary with the composition of the wheel, the character of the work, and various grinding conditions, but which should be maintained, or at least approximated, in any grinding operation. In addition, it is also desirable that equal areas on the work should be acted upon by the wheel, or presented to the operation of the wheel, in equal successive intervals of time. With the usual arrangement, such as that above described, where the traversing speed of the wheel head in feet per minute and the revolutions of the work per minute remain constant, the second condition above described obviously cannot be obtained in grinding work having any great radial dimension. In other words, if the speeds are so related as to produce the desired action of the wheel on the work when operating on the outer margin of a disk or collar, it will not have the desired action on those parts closely adjacent to the axis of revolution of the chuck due to the slower surface speed of these portions of the work. Frequently the longer contact of the wheel on those areas close to said axis results in heating the work sufficiently to discolor it or "burn" it. When the work is made of hardened steel it sometimes is injured at points adjacent to the inner margins while the outer marginal surfaces are properly ground.

These difficulties have long been recognized. For the purpose of overcoming them and maintaining the proper operating conditions between the work and the grinding wheel throughout the traverse of the latter, it has been proposed to accelerate both the rotary speed of the chuck or work support and the traversing speed of the wheel as the axis of rotation of the work is approached and to decelerate said speeds as the wheel recedes from said axis. Driving mechanisms for the grinding wheel and the chuck designed to produce these results have been used heretofore. So far as I have been able to learn, however, all of these mechanisms heretofore proposed have depended upon friction drives and they have not been satisfactory, except for limited conditions, for this reason. In other words, while such mechanisms can be used where the grinding conditions are easy, they are not capable of producing the desired results under heavy loads or more severe operating conditions.

The present invention deals with this problem and aims to devise a thoroughly practical and satisfactory solution for it.

The nature of the invention will be readily understood from the following description when read in connection with the accompanying drawings, and the novel features will be particularly pointed out in the appended claims.

In the drawings,

Figure 1 is a side elevation of a rotary surface grinder embodying features of this invention;

Fig. 2 is a view of the opposite side of the machine shown in Fig. 1, certain of the parts being shown in section;

Fig. 3 is a rear elevation of the machine shown in Figs. 1 and 2;

Fig. 4 is a side view of one of the control mechanisms included in the machine shown in Fig. 1;

Fig. 5 is a sectional view of the mechanism shown in Fig. 4;

Fig. 6 is a detailed sectional view approximately on the line 6—6, Fig. 4;

Fig. 7 is a vertical, sectional view through the wheel head and chuck of the machine shown in Fig. 1;

Figs. 8 and 9 are side and end views, respectively, of one of the cylinder heads shown in Fig. 7;

Fig. 10 is a plan view of the chuck, illustrating in section certain of the driving mechanism therefor;

Fig. 11 is an end view, partly in section, of the mechanism shown in Fig. 10;

Fig. 12 is a plan view of the reverse valve which forms an element of the machine shown in Fig. 1;

Fig. 13 is a front elevation, partly in section, of said reverse valve;

Fig. 14 is an end view of the reverse valve;

Fig. 15 is a diagrammatic view illustrating features of organization of the variable displacement pump used in the machine;

Fig. 16 is a diagrammatic view of the driving mechanism for the work support and the wheel head;

Fig. 17 is an end view of one of the pumps; and

Fig. 18 is a plan view, partly in section, taken on the line 18—18 of Fig. 7.

Referring first to Figs. 1, 2 and 3, the machine there shown comprises a rotary work support 2 which, in the particular machine illustrated, consists of a magnetic chuck, and a grinding wheel 3 which is supported on and carried by a wheel head 4. The chuck is mounted to revolve about a vertical axis, while the wheel revolves on a horizontal axis, the wheel head being supported to reciprocate in a horizontal plane in order to produce the desired traversing movement of the wheel relatively to the work. In its general organization this machine is similar to that illustrated in Patent No. 1,579,056, and reference may be made to said patent for many of the details of construction.

A considerable part of the wheel 3 is enclosed in a casing 5 which supports various accessories including the connection for conducting water for wet grinding, or coolants of various kinds, to the wheel. In the particular machine shown the wheel is driven from an electric motor 6, Figs. 1 and 3, which is belted to a counter shaft 7 at the opposite side of the machine, and this shaft carries a pulley 8 that is connected by the belt 10 with the barrel pulley 12, Figs. 2 and 7, secured fast on the wheel spindle.

The driving mechanism for the work support or chuck 2 comprises a variable displacement rotary pump, indicated at 14 in Figs. 2 and 16, this pump being directly connected with and driven by an electric motor 15. While any suitable type of variable delivery pump can be used for this purpose, I have obtained particularly satisfactory results with the type of pump indicated diagrammatically in Fig. 15. This pump includes an outer rotor 16 carrying a series of radially disposed pistons which work in a corresponding series of similarly disposed cylinders carried by a central hub 17. Both the rotor and the hub or cylinder barrel revolve on a normally stationary stub shaft 18 having a pair of inlet ports at its upper side and a pair of outlet or discharge ports on the lower side thereof. This stub shaft 18 is carried by an arm which is secured fast on a rock shaft that forms the controlling element of the pump, since by rocking the latter shaft it may be caused to throw the stub shaft 18 to the right or left of the position shown in Fig. 15 where it will be off center. When held in such an eccentric position the pistons will reciprocate in the cylinders as the rotor 16 revolves, thus drawing oil or other liquid into the upper cylinders (provided the rotor is revolving in a counter clockwise direction, Fig. 15, and the shaft 18 is offset toward the right) and discharging the oil from the lower cylinders. The rate of delivery at a given speed can be varied by adjusting the distance by which the shaft 18 is moved away from the center of the rotor. This type of pump is readily obtainable on the market. The rock shaft for controlling the pump 14 and adjusting its delivery is shown in Figs. 2 and 3 at 20.

This pump 14 is utilized both to drive the chuck 2 and also to reciprocate the wheel head 4. Referring to Figs. 2 and 16, it will be observed that a rotary hydraulic motor 21 is connected with the pump 14 to be driven by the pump. This motor may be of the same general type as the pump 14, or of some other convenient form. It includes a power delivery shaft 22 on which is mounted a sprocket wheel 23, this wheel being connected by a chain 24 to another sprocket wheel 25, Figs. 2, 3 and 16, which is secured fast on a telescoping shaft 26 that lies horizontally beside the machine frame. At its forward end this shaft is connected through a universal joint 27 with a short shaft 28 carrying a spiral gear 30 which meshes with and drives another gear 31 on a shaft 32 extending at right angles to the telescoping shaft 26 and lying between the axis of the chuck 2 and the machine frame, as better shown in Fig. 10. A worm gear 33 on the end of this shaft meshes with and drives the chuck gear 34. These connections thus operate to rotate the chuck 2 positively at a speed determined by the delivery of the pump 14.

The mechanism for reciprocating the wheel head includes a variable displacement pump 35, Figs. 2 and 16, directly coupled to the shaft 22 of the hydraulic motor 21 and connected through suitable piping and through a reversing valve mechanism 36 with a cylinder 37 mounted just below and parallel to the wheel head, as shown in Fig. 7. The reverse valve is operated automatically by connections with the wheel head to deliver oil, or other liquid supplied under pressure by the pump 35, alternately to the opposite ends of the cylinder 37. Working in this cylinder is a piston 38 carried by a piston rod 40 which is secured rigidly to the wheel head 4 by a bracket 41, Figs. 3 and 7. Consequently, the wheel head is compelled to move in unison with the piston 38.

The reversing valve mechanism 36 is similar to those heretofore used with reciprocating hydraulically driven apparatus and therefore need not be described in detail. It is best shown in Figs. 1, 12, 13 and 14, the illustration in Fig. 13, however, being somewhat diagrammatic. This construction and its connections with the cylinder 37 will be readily understood from the drawings, particularly in connection with Fig. 16. The reverse valve includes a high pressure valve 43 which directly controls the flow of oil from the pump 35 to the cylinder 37, and a pilot valve or low pressure valve 44 which controls the operation of the valve 43. The pilot valve is mounted on a reciprocating rod which is connected to the lower end of a control lever 45 carried by a rocking bracket 46 which is mounted to oscillate on the hollow shaft 47. Projecting from the back of said bracket is a pin 48 arranged to be engaged by either of two dogs 49 and 50 which are carried by, but are adjustable longitudinally of, the wheel head 4, these dogs corresponding in general character and function to those shown in Patent No. 1,579,056 previously referred to.

The arrangement is such that when the wheel head 4 moves forward or toward the left, Fig. 1, the dog 49 will engage the pin 48 as the wheel head approaches the forward limit of its stroke, and throw the control lever 45 into the position shown in Fig. 13. This will move the pilot valve 44 into such a position as to effect a reversal of the movement of the piston 38 and the wheel

head 4. As the wheel head approaches the rearward limit of its stroke the other dog 50 will engage said pin 48 and tip the lever in the opposite direction, thus shifting the pilot valve 44 into such a position that the movement of the piston will again be reversed, these operations continuing so long as the operator desires. The length of stroke of the wheel head can be varied by manually adjusting the dogs 49 and 50 toward or from each other, and the positions of reversal can also be predetermined by properly adjusting the dogs on the wheel head.

This reversing valve also includes a starting and stopping valve 51 which is connected with the lever 45 to be controlled thereby. For this purpose one end of the valve 51 is pivoted to an arm 52, Fig. 14, which is secured fast on an upright rocking sleeve 53, the upper end of this sleeve carrying an arm which is secured to one end of a rod 54 mounted to slide through the rock shaft 47 on which the bracket 46 swings. The opposite end of this rod has a circumferentially grooved collar 55 secured rigidly to it into which project two diametrically opposed pins or screw ends secured in the lower end of the lever 45. This lever, in addition to swinging on the shaft 47, is pivoted at 56 on the bracket 46. Consequently, by swinging this lever on said pivot it will operate through the connections just described to slide the valve 51 into either its starting or stopping position. In other words, this valve controls the fluid supply line between the reversing valve 36 and the pump 35.

It may here be pointed out that the pipe lines for conducting fluid from the reverse valve to the cylinder are tapped into cylinder ends which are provided with ducts that open into the cylinder behind the outer limits of the range of movement of the piston 38. One of these cylinder ends is shown at 58 in Figs. 8 and 9 and one of the ducts above mentioned is illustrated at 60, the end of this duct being shown at 61 in Fig. 9. With this arrangement there is no danger of the piston sticking at either end of its range of movement.

From the foregoing description it will be seen that both the rotative movement of the chuck 2 and the traversing movement of the wheel 3 are produced positively by the hydraulic driving mechanisms above described and the connections operated by them. Since both the driving mechanisms for the chuck and the wheel head are operated from the same shaft 22 which, in turn, is positively driven by the motor 21, it is practically impossible for the speed relationship between them to change unless some part breaks. That is, the connections between the shaft 22 and the chuck 2 are entirely mechanical and are of such a nature as to be positive in operation, and the connections between said shaft and the wheel head 4, while depending upon the pressure and movement of liquids, such as oil, water, or the like, are, nevertheless, positive because of the fact that these liquids are substantially incompressible. A definite speed relationship thus can be maintained positively and continuously between the traversing movement of the wheel head and the rotary motion of the chuck. By adjusting the speed control shaft 20 of the main variable delivery pump 14 to increase its liquid displacement or delivery, the speeds of both the wheel head 4 and chuck 2 can be increased or decreased, as desired, and such control can be effected substantially instantaneously. Provision is made for effecting this speed change automatically in each movement of the wheel head, as will presently be described. In addition, the ratio or speed relationship between the rotary motion of the chuck and the traversing movement of the wheel and wheel head can be adjusted by using, at 35, a pump of the variable displacement or variable delivery type similar to the pump 14. This is the preferred arrangement, the pump 35 being equipped with adjusting mechanisms so that its rate of delivery can be set manually to any desired value. The controlling shaft for this pump has a link 62, Figs. 1, 2 and 3, connected to it and extending across the back of the machine to the side on which most of the other control devices are placed, a handle 62' being secured to this end of the link so that by moving this handle backward or forward the delivery of the motor 35 can be changed as desired. Since the speed of the motor shaft 22 can be controlled by adjustment of the control shaft 20 for the main pump 14, and the ratio between the speeds of the chuck 2 and wheel head 4 can be adjusted in the manner just described, practically any operation condition, as to speed, can be obtained within the limits of operation of the apparatus.

For the purpose of automatically accelerating the rotation of the chuck and the traversing movement of the wheel head as the wheel approaches the axis of rotation of the chuck and decelerating said movements as the wheel recedes from said axis, the shaft 20 is connected through intermeshing spiral gears 64 and 65, Fig. 2, with a horizontal shaft 66 which extends across the back of the machine frame as best shown in Fig. 3. At the control side of the machine a pinion 67, Figs. 1, 4 and 5, is secured on the shaft 66 and meshes with a sector 68 which is pinned to a rock shaft 70 mounted in a supporting bracket 71. A control lever 72 is pivoted at 73 on the sector 68 to swing at right angles to the swinging movement of the sector, and it carries a toothed retaining dog 74 adapted to engage the teeth of a stationary segment 75 which is secured fast on the bracket 71. This dog is carried by a bracket 76 slidably mounted in the lever 72 and normally pressed forward by a strong coiled spring 77, but it can be withdrawn or retracted by its connections with a hand piece 78 located immediately beside the handle 80 of said lever.

With this arrangement the operator can adjust the control shaft 20 of the main pump 14 at will and consequently, set the speeds of the wheel head 4 and chuck 2 at the desired value. These speeds will be maintained as so adjusted until some further change is made in the adjusting mechanism. Adjustable stops 81 and 82 may be provided on the sector 75 to assist the operator in making the desired speed adjustments.

The adjustment just described is made manually, but the block 76 also carries a second toothed dog 83, similar to the dog 74, and arranged to engage teeth on another segment 84 which is secured rigidly to an arm 85 mounted to rock on the shaft 70. This arm is connected by an upright rod 86 with one end of a lever 87, Fig. 1, which is fulcrumed on a stationary bracket 88 and carries, at its opposite end, a roll 90 running in a cam path 91 in a cam block 92 which is adjustably secured by screws 93—93 to the wheel head 4. Consequently, when the control lever 72 is locked to the segment 84, as shown in Fig. 5, and the machine is in operation, the connections just described will rock the shaft 66, and consequently the control shaft 20 of the main pump 14, into various positions as the wheel head moves for-

ward or backward, these positions being determined by the adjustment of the parts and the shape of the cam path 91. For present purposes this path is so developed that as the wheel head moves forward the traversing speed of the head and the rotary speed of the chuck 2 are gradually increased as the axis of rotation of the chuck is approached, and said speeds are gradually decreased as the wheel recedes from said axis. The adjustment can readily be made such that equal areas of the work will be presented to the operation of the wheel in equal successive intervals of time, notwithstanding the fact that the distance between the operating point of the wheel and the center of rotation of the work is constantly changing. Furthermore, this relationship can be maintained while the ratio between the traversing speed of the wheel head and the rotary speed of the chuck are kept constant, as above described. In addition, since the movements of both the wheel head and the chuck are produced positively, the desired speed relationship is positively maintained notwithstanding variations in the resistance to these movements offered by the work.

The work support or chuck is mounted on a slide or bracket 94, Figs. 1 and 7, which is vertically adjustable in ways formed on the machine frame, and mechanism is provided for adjusting the slide or bracket 94 either automatically or manually, as may be desired, such mechanism being common in machines of this general type. A part of the automatic adjusting mechanism is shown at 95 in Fig. 1. Both this adjusting mechanism and the hand mechanism operate through a worm gear connection 96 which rotates the vertical screw 97.

The chuck may also be adjusted angularly to accommodate tapered work. To this end the bracket 94 is provided with a knee section which is bored horizontally, as shown at 98, Fig. 10, to receive a sleeve 99 in which the shaft 32 and the bearings therefor are supported. This sleeve or bushing forms a pivot on which the entire chuck assembly can be swung into various angular positions by means of an adjusting screw 100, Fig. 1, such adjustment taking place around the axis of the sleeve 99 and shaft 32.

The invention further involves novel features of chuck construction. Referring to Fig. 7 it will be observed that the magnetic chuck including the shell *a*, the core *b*, winding *c*, and the face plate *d* are all secured together and are supported on a chuck plate or table 101 to the lower side of which the worm gear 34 is securely bolted. The weight of these parts and the load carried by them is borne by a horizontal annular bearing or track 102 upon which rests an annular rim projecting downwardly from the flange of the worm gear 34, this rim being grooved at suitable points to facilitate the flow of lubricant. Secured rigidly to the chuck is a central spindle 103 running in a tapered roller bearing 104 which serves both to hold the chuck in a centered position while it revolves and also to prevent the chuck from being lifted.

Also included in the chuck structure is a self-contained lubricating system which supplies oil or other lubricant to the bearing surfaces above mentioned and also to the worm gear 34. It comprises a gear pump of a common type, indicated in general at 105, the driving gear being secured on the lower end of the chuck spindle 103. The oil inlet aperture to this pump is indicated in Figs. 7 and 18 at 106 while the discharge aperture or outlet is shown in the latter figure at 107, this aperture leading directly into the chamber 108, Fig. 7, below the end of the chuck spindle 103. An oil hole or duct is drilled axially in this spindle and conducts the oil under pressure from the chamber 108 to an annular chamber 109 located above the middle of the spindle and surrounding said spindle. From this chamber oil flows through several radial holes, one of which is shown at 110, Fig. 7, to points immediately above the track 102. Vertical holes are drilled through the flange of the worm gear 34 at these points and conduct the oil or other lubricant directly on to the friction surface of the annular bearing 102. Most of this oil overflows the inner raised ledge of said bearing 102 and runs into an oil chamber 112 surrounding the worm gear 34. From this chamber oil is conducted through several ducts back into the central chamber 113 which communicates directly with the pump inlet port 106. Any oil discharged radially outwardly from the track 102 is returned to the chamber 112 by means of ducts 114. A sufficient quantity of oil preferably is maintained continuously in the chamber 112 so that the toothed surfaces of the gear 34, and consequently the driving surfaces of the worm 33, are continuously bathed in oil. The axis of the worm 33 is located in the same horizontal plane with the bearing 104 so that the thrust of the worm is taken by the bearing, and because of this arrangement the maintenance of the oil level as just described keeps the roller bearing substantially flooded with oil.

This arrangement, therefore, not only provides an exceptionally sturdy and dependable bearing construction which contributes to accuracy in grinding, but it also reduces wear to a minimum because of the continuous circulation of lubricant maintained across the bearing surfaces. The fact that the lubricating system is self-contained in the chuck structure is of advantage also in avoiding the use of flexible connections which would be required if the lubricant were supplied from an external source.

All of the chuck structure is laterally enclosed in the casing 115. In wet grinding an extension or hood 116, Figs. 1 and 2, is supported on the casing. The water or coolants supplied to the grinding wheel or the work flow off the work and the top of the chuck and over an apron 119, Fig. 7, into the chamber 117 in the casing from which they are discharged through the spout 118, Fig. 2. Entrance of these liquids to the chuck structure is prevented by an outer baffle 120 which is surrounded by the apron 119 and by an inner baffle 121 that surrounds the lower margin of the chuck plate 101 and the upper margin of the worm gear flange. Any liquid which finds its way into the space between these baffles is discharged through ducts 122 and 123.

The operation of the machine has been described so completely in connection with the description of the structure, that any further statement as to operation is believed to be unnecessary other than perhaps to point out that in order to stop the reciprocating movement of the wheel head 4 and the rotary motion of the chuck, it is simply necessary to rock the shaft 66 into such a position that the cylinder block or hub 17 of the main variable delivery pump 14 is returned to a position where it is co-axial with the rotor 16. In this position delivery of liquid from this pump is stopped and consequently, both the traversing movement of the wheel head and the rotary movement of the chuck will be

stopped and these parts will be held stationary. In addition, the starting and stopping of the wheel head may be effected while the chuck continues to rotate by operating the valve 51 of the reverse valve 36, as above described.

While I have herein shown and described a preferred embodiment of my invention, it will be evident that the invention may be embodied in other forms without departing from the spirit or scope thereof. For example, in the machine shown the wheel head is traversed while the work support remains stationary except for its rotary movement. For structural and manufacturing reasons this arrangement is preferred, but from a functional standpoint it obviously is immaterial whether the chuck or the wheel head is traversed, one being the equivalent of the other. Similarly, other fluids may be used in the place of that above mentioned where the same functional results are produced by it.

Having thus described my invention, what I desire to claim as new is:

1. In a grinding machine, the combination of a rotary work support, a rotary grinding wheel mounted for traversing movement in contact with the work on said support toward and from the axis of revolution of said work support, hydraulic means rotating said work support, additional hydraulic means for reciprocating said wheel, and mechanism for operating through both of said means to simultaneously accelerate the rotary movement of said support and the traversing movement of said wheel as the wheel approaches the axis of revolution of said support and to decelerate said movements simultaneously as the wheel recedes from said axis, to present substantially equal areas of said work to the action of said wheel in equal successive intervals of time notwithstanding changes in the radial position of the wheel on the work.

2. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement, a rotary support for holding and revolving the work while it is operated upon by said wheel, hydraulic mechanism for revolving said work support, additional hydraulic mechanism for reciprocating said wheel across the surface of the work toward and from the axis of rotation of said work support, means for changing automatically the speeds of operation of said work support and wheel as the wheel moves radially of the work, while maintaining the ratio between the traversing movement of said wheel and the rotating movement of said work support substantially constant, and manually adjustable means for changing said ratio.

3. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement, a rotary support for holding and revolving the work while it is operated upon by said wheel, hydraulic driving mechanism for revolving said support, additional hydraulic mechanism for producing said traversing movement of the wheel on the work toward and from the axis of rotation of said work support, and means adjustable to vary the speed at which said wheel and support will be driven while maintaining a substantially constant ratio between the traversing speed of said wheel and the rotary speed of said support.

4. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement a rotary support for holding and revolving the work while it is operated upon by said wheel, hydraulic driving mechanism for revolving said chuck, hydraulically operated connections between said mechanism and said wheel for reciprocating the wheel in a definite speed relationship to the rotation of said chuck, said connections being adjustable to change said speed relationship, and means for adjusting the speed of said hydraulic mechanism.

5. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement, a rotary support for holding and revolving the work while it is operated upon by said wheel, hydraulic mechanism for positively reciprocating said wheel to move it toward and from the axis of rotation of said work support, hydraulic mechanism for positively revolving said support, and means for simultaneously accelerating the traversing movement of said wheel and the rotation of said support as the wheel approaches said axis and decelerating said movements as the wheel recedes from said axis to present approximately equal areas of work to the action of said wheel in successive equal intervals of time.

6. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement, a rotary support for holding and revolving the work while it is operated upon by said wheel, a hydraulic pump, mechanism operated by said pump for reciprocating said wheel toward and from the axis of revolution of said work support, a hydraulic motor for driving said pump, and driving connections between said motor and said work support for revolving said work support.

7. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement, a rotary support for holding and revolving the work while it is operated upon by said wheel, a variable displacement hydraulic pump, hydraulic mechanism operated by said pump for reciprocating said wheel toward and from the axis of revolution of said work support, a hydraulic motor for driving said pump, and driving connections between said motor and said work support for revolving said work support.

8. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement, a rotary support for holding and revolving the work while it is operated upon by said wheel, a variable displacement hydraulic pump, a cylinder, a piston working in said cylinder, connections between said pump and said cylinder including a reversing valve mechanism for causing the fluid displaced by said pump to reciprocate said piston positively in said cylinder, connections between said piston and said wheel for giving said wheel its traversing movement, a hydraulic motor for driving said pump, and connections between said motor and said work support for driving said work support.

9. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement, a rotary support for holding and revolving the work while it is operated upon by said wheel, driving mechanism for revolving said work support, said mechanism including a driven shaft, a hydraulic pump driven by said shaft, a cylinder,

a piston mounted to reciprocate in said cylinder, connections between said pump and said cylinder for supplying liquid to the cylinder from the pump, said connections including a reversing valve mechanism, and connections between said piston and said wheel for causing the piston to reciprocate said wheel toward and from the axis of revolution of said work support.

10. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement, a rotary support for holding and revolving the work while it is operated upon by said wheel, a main variable displacement pump, a hydraulic motor operated by said pump, driving connections between said motor and said work support for revolving the work support, and hydraulic mechanism driven by said motor for reciprocating said wheel toward and from the axis of rotation of said work support.

11. In a grinding machine, the combination of a rotary grinding wheel, means for supporting said wheel for reciprocating traversing movement, a rotary support for holding and revolving the work while it is operated upon by said wheel, a main variable displacement pump, a hydraulic motor operated by said pump, driving connections between said motor and said work support for revolving the work support, a second variable displacement pump driven by said motor, a cylinder, a piston mounted to reciprocate in said cylinder, connections between said second pump and said cylinder for supplying liquid under pressure to the cylinder, said connections including a reversing valve mechanism whereby said piston is hydraulically reciprocated in said cylinder, connections between said piston and said wheel for reciprocating said wheel toward and from the axis of revolution of said work support, and connections between said wheel and said reversing valve mechanism for causing the traversing movement of said wheel to control the action of said reversing valve mechanism.

12. In a grinding machine, the combination of a rotary grinding wheel, a reciprocating wheel head in which said wheel is mounted, a rotary support for holding and revolving the work while it is operated upon by said wheel, hydraulic driving mechanism for revolving said work support and reciprocating said wheel head, and means for adjusting the speed at which said wheel will be traversed and said support revolved to accelerate said speeds as the wheel moves toward the axis of rotation of the work and to decelerate said speeds as the wheel moves away from said axis, said adjusting means including a cam carried by said wheel head and connections from said cam to said hydraulic mechanism arranged to be operated by said cam.

13. In a grinding machine, the combination of a rotary grinding wheel, a reciprocating wheel head in which said wheel is mounted, a rotary support for holding and revolving the work while it is operated upon by said wheel, hydraulic driving mechanism for revolving said work support and reciprocating said wheel head, and means for adjusting the speed at which said wheel will be traversed and said support revolved to accelerate said speeds as the wheel moves toward the axis of rotation of the work and to decelerate said speeds as the wheel moves away from said axis, said adjusting means including a power driven cam and connections between said cam and said hydraulic mechanism arranged to be operated by the cam.

14. In a grinding machine, the combination of a rotary grinding wheel, a reciprocating wheel head in which said wheel is mounted, a rotary support for holding and revolving the work while it is operated upon by said wheel, hydraulic driving means for revolving said work support and for reciprocating said wheel head in a definite speed relationship to the rotation of said work support, and means for adjusting said speed relationship.

15. In a grinding machine, the combination of a rotary grinding wheel, a reciprocating wheel head in which said wheel is mounted, a rotary support for holding and revolving the work while it is operated upon by said wheel, hydraulic driving means for revolving said work support, additional hydraulic means for reciprocating said wheel head in a definite speed relationship to the rotation of said work support, and means operating in timed relationship to the reciprocating movement of said wheel head for governing the operation of both of said hydraulic means and thereby governing the speeds of said work support and said wheel head to accelerate and decelerate said speeds synchronously as the radial distance of said wheel from the axis of rotation of said work support varies.

16. In a grinding machine, the combination of a rotary work support, a rotary grinding wheel mounted for traversing movement in contact with the work on said support toward and from the axis of revolution of said work support, hydraulic driving means for positively rotating said work support, additional hydraulic means for reciprocating said wheel, and mechanism for automatically adjusting the speeds of both of said means to maintain substantially constant the area of the work presented to said wheel in equal intervals of time as the wheel moves radially toward and from the axis of said work support.

17. In a grinding machine, the combination of a rotary grinding wheel, a reciprocating wheel head in which said wheel is mounted, a rotary support for holding and revolving the work while it is operated upon by said wheel, hydraulic means for revolving said work support, additional hydraulic means for reciprocating said wheel head in a definite speed relationship to the rotation of said work support, and means for varying the speed of one of said hydraulic means to adjust said speed relationship.

18. In a grinding machine, the combination of a rotary grinding wheel, a reciprocating wheel head in which said wheel is mounted, a rotary support for holding and revolving the work while it is operated upon by said wheel, a variable speed hydraulic motor for revolving said work support, a piston connected with said wheel head, a cylinder in which said piston reciprocates, a hydraulic pump for supplying liquid under pressure to said cylinder, a reversing valve mechanism operable to control the flow of liquid from said pump to said cylinder to reciprocate the piston in said cylinder, means for operating said reversing valve mechanism, and means operable to vary the speed of both said motor and said piston.

WARREN F. FRASER.