This invention relates to apparatus for copying grinding work pieces of non-cylindrical contour in which the grinding or other tool is actuated by a pattern or master to produce the desired contour on the work piece.

The usual method of grinding rotateable non-cylindrical work pieces is to mount the work on a crank along with a pattern which rotates in engagement with a follower to rock the crank which rotates toward and away from a grinding wheel. The pattern and follower are usually held in engagement by a spring which is strong enough to insure constant engagement between the parts during rotation. The construction of pattern or master cam is usually sufficiently rigid that the force exerted by the spring is not enough to cause any deflection.

Where the pattern is a turbine blade or another article of relatively light construction, the force of such a spring holding the pattern against a follower would cause considerable strain on the pattern with resultant inaccuracy in the model being ground.

It is an object of this invention to provide a machine wherein the work piece and pattern are mounted in the same relation as in conventional cam grinding, but the pattern controls the movement of the wheel rather than the work.

A further object is to provide a simple form of control for the wheel supporter actuating loader which will be of maximum sensitivity to the contour of the pattern.

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viding a constant pressure in that end of the cylinder and eliminating valve 42, line 43, and nozzle 47. This leaves lines 34 and 35 to the left end of the cylinder 20 and to nozzle 36 respectively, both of which originate in valve 33 as the connecting link for transmitting the contour of the workpiece to the grinding wheel support 12 and grinding wheel 13 rotatably mounted on said support. This is accomplished by adjusting the pressure in line 34 above and below the constant pressure in line 45 by movement of valve 55 relative to nozzle 36 in response to the rotation of pattern 62 to effect a predetermined controlled reverse flow of fluid through valve 33 and nozzle 36 in the direction of the cylinder 20. These changes in pressure in line 35 and nozzle 36. The portion directed to cylinder 20 is further divided, in that, a variable portion thereof is discharged through valve 33 depending upon the condition under which cylinder 20 is functioning. If piston 21 is not moving, all of the fluid passing through restriction 39 will be discharged through line 32. The pressure in line 35 will vary inversely as the distance between valve 55 and nozzle 36. As the space between said valve and said nozzle increases, the pressure in line 34 decreases under the control of valve 33. This is practically a straight line variation. The pressure in line 34 and the left end of the cylinder 20 will vary directly as the pressure in line 35 since valve 33 keeps both pressures equal, although both may increase or decrease. The flow of fluid passing through nozzle 36 is constant and thus, it is not affected by changes in temperature, load, etc. For any given change in the position of valve member 55, the change in pressure in lines 34 and 35 and the left end of cylinder 20 will be the same. It is only by keeping the flow from nozzle 36 constant that it is possible for piston 21 to move the tool support exactly in accordance with the contour of pattern 62. The pressure in line 35 is dependent upon the distance of the valve member 55 from nozzle 36. The discharge from nozzle 36 is dependent regardless of its rate of movement or other variable factors such as temperature, load and so forth. The constant flow at nozzle 36 is essential since it is the only way to provide a true reflection of the contour of the pattern transmitted through the fluid connection in the form of a corresponding variation in pressure on one side of the cylinder 20 relative to the fixed pressure in the opposite side of said cylinder. The jet of fluid emerging from nozzle 36 is in effect, similar to a mechanical lever. A change in the rate of flow would be equivalent to a change in the ratio of the lever arm with a corresponding change in effect on the movement of the cutting tool toward and from the workpiece.

Pressure in line 34 acts on pressure switch 150 to close a circuit from L2 through lines 151 and 152 to the motor for driving pump 40. There is a direct connection from L1 through line 153 to said motor which is shown. Pump 30 then expels fluid through valve 33 and line 45 to the head end of cylinder 20. The direction of movement of piston 21 and therefore wheel base 12 and grinding wheel 13 will be determined by changes in pressure in line 34. Such changes in pressure will be effected by movement of valve 55 to change the rate of discharge of fluid from nozzle 36 in response to rotation of model 62 in engagement with follower 61. As valve 55 is moved toward nozzle 36 restricting the open-

for the flow of fluid therefrom, the pressure increase in line 35 is reflected through valve 33 and line 34 to the rod end of cylinder 20. Piston 21 is moved to the right to position grinding wheel 13 for grinding that portion of the work piece 80 corresponding to the portion of the model 62 in engagement with the follower 61. As said model rotates, shoe 61 and valve 55 may move to the left in following the contour of said model, thus increasing the space between valve 55 and nozzle 36 and reducing the pressure in line 35 and the left end of cylinder 20 to a point less than the pressure in the right end of cylinder 20. This change of pressure will then move the left to position wheel 13 for grinding another portion of work piece 80 corresponding to that portion of model 62 then in engagement with follower 61. Since there is no reversing valve for directing fluid alternately to opposite ends of cylinder 20, the means for changing direction of movement of piston 21 is dependent only on the change in pressure in line 35 and this is reflected immediately at the rod end of cylinder 20, thus eliminating delay incidental to the operation of a reversing valve. The function of valve 42 is reflecting the variation in discharge from nozzle 47 on the pressure in line 43 just as valve 55 reflects a variation in discharge from nozzle 36 on the pressure in line 34. Thus, as piston 62 actuates valve member 55, the discharges from nozzles 36 and 47 are restricted alternately in accordance with the contour of said pattern 62 and with consequent reciprocation of piston 21 and grinding wheel 13 relative to workpiece 80.

Attached to headstock spindle 121 and rotatable therewith is a dog 129 which serves to actuate limit switch 122 once for each revolution of the work 13. Said limit switch 122 completes circuit from L1 through lines 126 and 125 to solenoid 109 which is connected through line 127 to L2. Solenoid 109 is shunted by valve 107 against spring 108 to connect pump 105 through line 106 to line 110, throttle valve 111 and reversing valve 112, which is set to conduct fluid under pressure through line 113 to the head end of traverse cylinder 100 to move piston 101 which is connected through piston rod 102 and bracket 103 to work carriage 11. The energization of solenoid 109 is momentary so that only a small amount of fluid is directed to cylinder 100, sufficient to move carriage 11 and place the next increment of work piece 80 in engagement with grinding wheel 13.

I claim:

1. A machine for grinding non-cylindrical work pieces comprising:
a base, a work support slidably mounted on said base and having means for rotatably supporting a workpiece thereon, a grinding wheel slide mounted on said base for movement toward and from operative position relative to a work piece, a grinding wheel rotatably mounted on said slide, means for effecting said movement comprising a piston and cylinder, one of which is attached to said slide, a source of fluid under pressure connected directly to one end of said cylinder, means for controlling the movement of said wheel slide in accordance with the shape of the piece to be ground comprising a pattern mounted in alignment with the axis of said rotatable wheel supporting means for alignment with the axis of said work piece and rotatable therewith, a follower resiliently mounted on movement with said wheel slide and having a valve member attached thereto, a nozzle in said fluid connection mounted for adjustment relative to said follower and having a restricted opening in the form of a valve restricting fluid flow in line 34, and a workpiece guide member, a connection between said nozzle and the other end of said cylinder and a second supply of fluid under pressure connected to said line.

2. A machine for grinding non-cylindrical work pieces comprising a base, a work support slidably mounted on said base and having means for rotatably supporting a workpiece thereon, a grinding wheel slide mounted on said base for movement toward and from operative posi-
tion relative to said work support, a grinding wheel rotatably mounted on said slide, means for effecting said movement comprising a piston and cylinder, one of which is attached to said slide, a source of fluid under pressure connected directly to one end of said cylinder, means for controlling movement of said wheel slide in accordance with the shape of the piece to be ground, comprising a pattern mounted in alignment with the axis of said rotatable work supporting means for alignment with the axis of said work piece and rotatable therewith, a follower resiliently mounted on said wheel slide for yieldingly engaging said pattern, a supply of fluid under pressure connected to the other end of said cylinder, a nozzle in said fluid connection mounted in fixed relation to said follower and having a restricted opening for directing a jet of fluid against a portion of said follower, said follower being responsive to rotation of said pattern to vary the space between said opening and said portion of said follower and thus vary the pressure at said follower, and a stroke of said cylinder.

3. A machine for grinding work pieces which are irregular in shape comprising a base, a work support slidably mounted on said base and having means for rotatably supporting a workpiece thereon, a grinding wheel rotatably mounted on said base, means for effecting said movement comprising a piston and cylinder, one of which is attached to said slide, a source of fluid under pressure connected directly to one end of said cylinder, means for controlling the movement of said wheel slide in accordance with the shape of the piece to be ground comprising a pattern rotatable therewith, a follower resiliently mounted for movement with said wheel slide, a nozzle mounted for adjustment relative to said follower and having a restricted opening for directing a jet of fluid against a portion of said follower, said connection comprising a valve having means for dividing the fluid supply thereto into predetermined portions, one of which is directed to said nozzle, the other to the other end of said cylinder.

4. In a machine tool, an element movable in opposite directions, means for effecting said movement comprising a piston and cylinder, a source of fluid under pressure connected to one end of said cylinder, a source of fluid under pressure connected to the other end of said cylinder to actuate said motor in opposite directions comprising a by-pass for effecting said movement and means actuated by said pattern for controlling the supply of fluid to one end of said cylinder to effect a reciprocating movement of one of said supports relative to the other in a manner dependent upon the shape of said pattern.

5. In a machine tool, a bed, a work support rotatably mounted thereon, a tool support slidably mounted thereon, means for effecting relative transverse and longitudinal movement of said supports including a motor connected to each of said supports, one of said motors comprising a piston and cylinder, means for rotatably supporting a work piece on said work support, a pattern member rotatable with said work piece, a separate supply of fluid to each end of said cylinder for effecting said transverse movement and means actuated by rotation of said pattern for controlling the supply of fluid to one end of said cylinder to effect a reciprocating movement of one of said supports in a manner dependent upon the shape of said pattern.

6. In a machine tool, an element movable in opposite directions, means for effecting said movement comprising a piston and cylinder, one of which is connected to said element, a motor driven pump connected to supply fluid under pressure to one end of said cylinder to move said element away from an operative position, a second motor driven pump having connections to the other end of said cylinder, a pressure operated control means in the circuit to said second motor driven pump, said control means being connected to the pressure line from said first mentioned pump whereby said second pump is actuated by said control means and actuated by said pattern for controlling the supply of fluid to one end of said cylinder to effect a reciprocating movement of one of said supports in a manner dependent upon the shape of said pattern and means to effect said longitudinal movement by predetermined increments.

7. In a machine tool, a bed, a work support rotatably mounted thereon, a tool support slidably mounted thereon, means for effecting relative transverse and longitudinal movement of said supports including a motor connected to each of said supports, one of said motors comprising a piston and cylinder, means for rotatably supporting a work piece on said work support, a pattern member rotatable with said work piece, a separate supply of fluid to each end of said cylinder for effecting said transverse movement and means actuated by rotation of said pattern for controlling the supply of fluid to one end of said cylinder to effect a reciprocating movement of one of said supports in a manner dependent upon the shape of said pattern and means to effect said longitudinal movement by predetermined increments.

8. In a machine tool, a bed, a work support rotatably mounted thereon, a tool support slidably mounted thereon, means for effecting relative transverse and longitudinal movement of said supports including a motor connected to each of said supports, one of said motors comprising a piston and cylinder, means for rotatably supporting a work piece on said work support, a pattern member rotatable with said work piece, a separate supply of fluid to each end of said cylinder for effecting said transverse movement and means actuated by rotation of said pattern for controlling the supply of fluid to one end of said cylinder to effect a reciprocating movement of one of said supports in a manner dependent upon the shape of said pattern and means to effect said longitudinal movement by predetermined increments.
and from operative position relative to a workpiece, a grinding wheel rotatably mounted on said slide, means for effecting said movement comprising a piston and cylinder, one of which is attached to said slide, a source of fluid under pressure connected directly to one end of said cylinder, means for controlling the movement of said wheel slide in accordance with the shape of the piece to be ground comprising a pattern rotatable therewith, a follower resiliently mounted for movement with said wheel slide, a nozzle mounted for adjustment relative to said follower and having a restricted opening for directing a jet of fluid against a portion of said follower, said connection comprising a valve having means for dividing the fluid supplied thereto into predetermined portions, one of which is directed to said nozzle at a fixed rate, the other of which is directed to the other end of said cylinder and means for maintaining equal pressures in both of said portions.

12. A machine for grinding non-cylindrical workpieces comprising a base, a work support slidably mounted on said base and having means for rotatably supporting a workpiece thereon, a grinding wheel slide mounted on said base for movement toward and from operative position relative to said work support, a grinding wheel rotatably mounted on said slide, means for effecting said transverse movement comprising a piston and cylinder, one of which is attached to said slide, a separate source of fluid under pressure connected to each end of said cylinder, means for controlling movement of said wheel slide in accordance with the shape of the piece to be ground comprising a pattern mounted in alignment with the axis of said rotatable work supporting means for alignment with the axis of said workpiece and rotatable therewith, a follower resiliently mounted on said wheel slide for yieldingly engaging said pattern, a nozzle for discharging a part of the fluid supplied to one end of said cylinder, a valve member connected to said follower in position to obstruct the discharge of fluid from said nozzle and a valve responsive to change in pressure in said nozzle to effect a corresponding change in pressure in one end of said cylinder whereby to shift said wheel slide and wheel toward and from a workpiece in accordance with the contour of said pattern.

13. A machine for grinding workpieces which are irregular in shape comprising a base, a work support slidably mounted on said base and having means for rotatably supporting a workpiece thereon, a grinding wheel slide mounted on said base for movement toward and from operative position relative to a workpiece, a grinding wheel rotatably mounted on said slide, means for effecting said movement comprising a piston and cylinder, one of which is attached to said slide, a source of fluid under pressure connected directly to one end of said cylinder, means for controlling the movement of said wheel slide in accordance with the shape of the piece to be ground comprising a pattern rotatable therewith, a follower resiliently mounted for movement with said wheel slide, a nozzle mounted for adjustment relative to said follower and having a restricted opening for directing a jet of fluid against a portion of said follower, said connection comprising a valve having means for dividing the fluid supplied thereto into predetermined portions, means in said valve for directing one of said portions to said nozzle at a fixed rate and means in said valve for directing the other portion to the other end of said cylinder at a pressure which varies directly with the pressure at said nozzle.

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