July 17, 1956 M. W. SCHIAVONE 2,754,637

SHROUDED TURBINE BLADE AIRFOIL GRINDER

Filed July 1, 1954 2 Sheets-Sheet 1

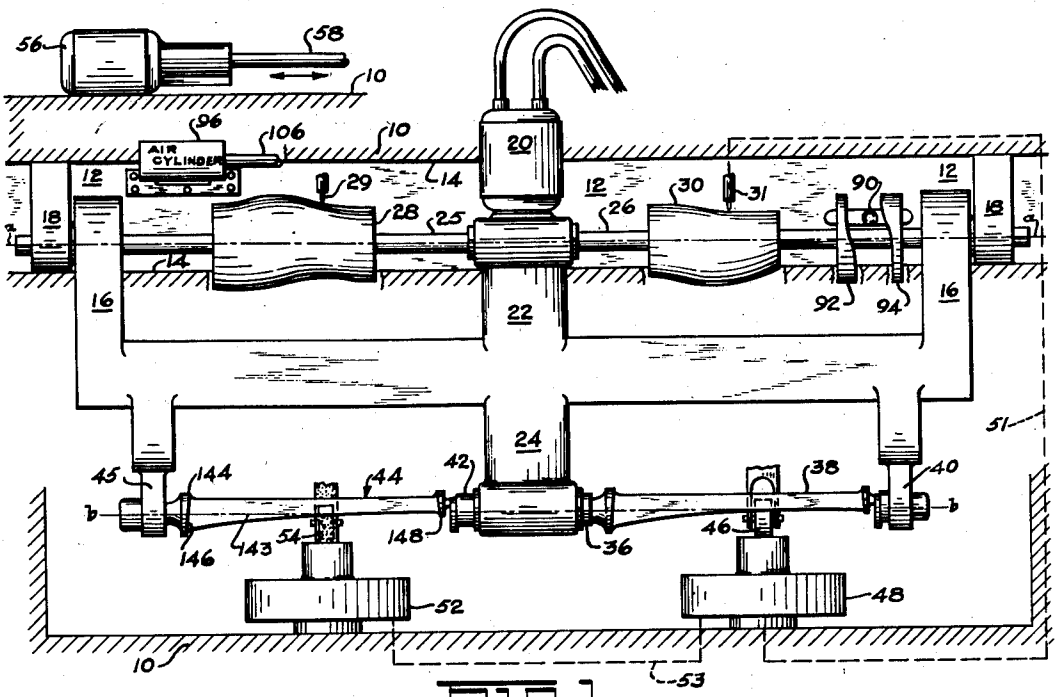


FIG. 1

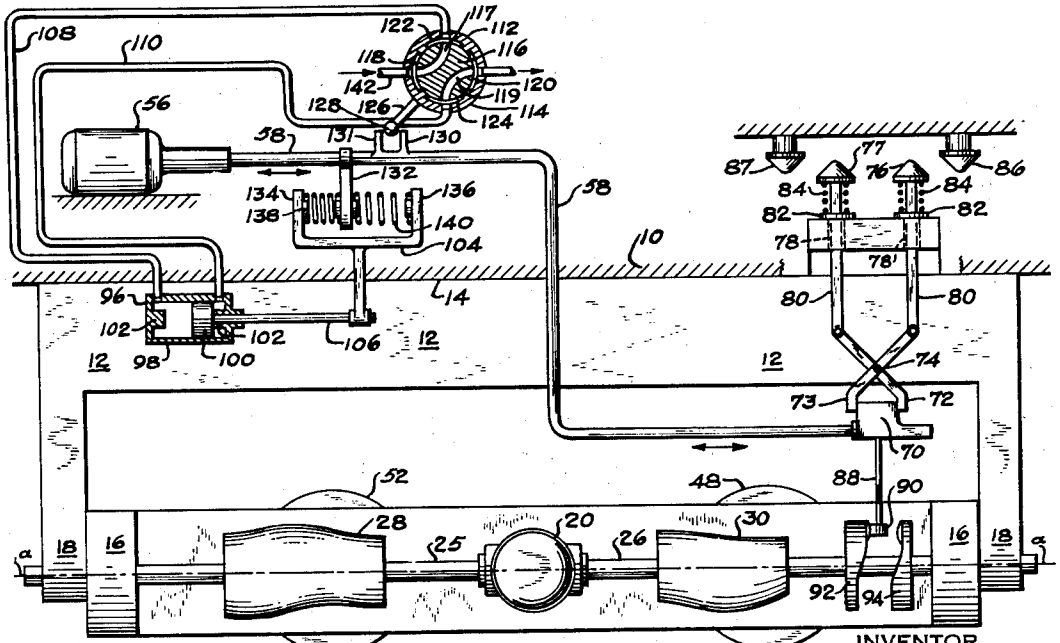


FIG. 2

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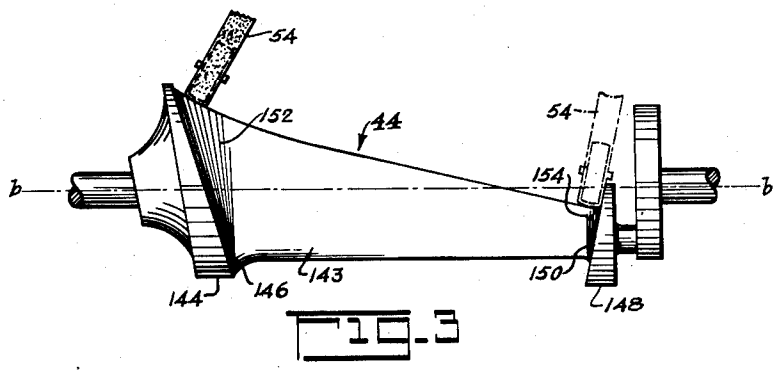


FIG. 3

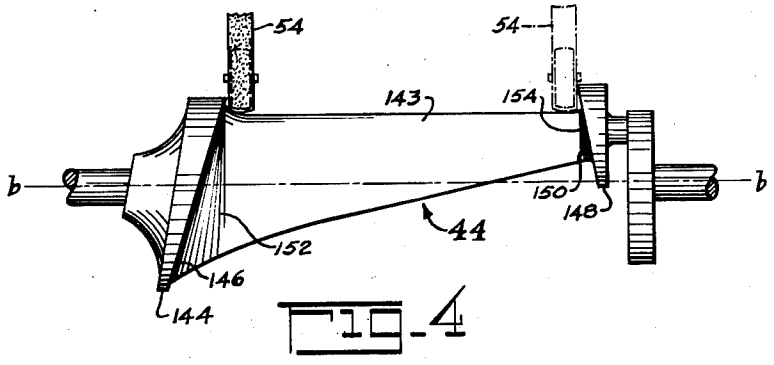


FIG. 4

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SHROUDED TURBINE BLADE AIRFOIL GRINDER

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Application July 1, 1954, Serial No. 440,641

8 Claims. (Cl. 51—144)

This invention relates to a blade grinding machine, particularly a grinding machine adapted to grind a turbine blade shrouded at both its root and its tip.

In the conventional turbine blade grinding machine the blade, or work, is held in a special fixture which brings the work against the grinding mechanism at the proper attitude. The work is operatively connected through the fixture, through a series of cams, and through a master follower to a master airfoil. Generally, a compounding cam is incorporated in these machines. This cam controls the reciprocation of the movable portion of said machine at one end point of said movable portion's traversing feed. This controlled reciprocating motion is particularly of use when the piece of work incorporates a flange which is not perpendicular to the longitudinal axis of said work. This controlled reciprocation permits grinding the blade surface parallel to said flange without gouging out the flange itself. However, this motion has heretofore been obtainable at only one end of the traversing stroke of the movable portion of said machine. Of late, turbine blades having flanges at both ends, that is, shrouded at both root and tip, have come into prominence. The prior procedure in these cases has been to grind a portion of the blade surface down to one flange, remove the work from the fixture, invert it about its longitudinal axis, replace it in the work fixture, and grind the remaining portion of the blade surface to the second flange. Unfortunately, it is almost impossible to precisely relocate the blade in the fixture. Consequently, a clearly discernible ridge appears on the surface of the work at the point where the first portion of the grinding meets the second portion of the grinding. This results in a great number of scrapped blades of the requirement of hand dressing the ridge on the blade surface with the attendant inaccuracy of the blade profile at this point.

An object of this invention is to incorporate into the conventional grinding machine a system of compounding cams which will permit the continuous grinding of the work regardless of the fact that a blade is shrouded at both of its ends. Removal of the work from the fixture during the grinding operation is thereby eliminated as is the necessity for hand-dressing any surface ridge resulting from such a discontinuity in the grinding operation.

Further objects and advantages of this invention will be apparent in reading the detailed description below in which:

Fig. 1 is a simplified drawing of the machine;

Fig. 2 is a schematic diagram of the invention incorporated in the grinding machine;

Fig. 3 is a representative turbine blade mounted in the special fixture; and

Fig. 4 is the same turbine blade after being rotated 180 degrees from the position illustrated in Fig. 3.

Referring first to Fig. 1, **10** is a main frame or supporting structure of the subject grinding machine, **12** is a movable work supporting member mounted in guide rails **14** of the main frame **10**. The movable member **12** has a head portion **16** hingedly mounted on bearings **18** which

permit the head **16** to oscillate in pendulum-like fashion about a pivot axis *a—a*. The head portion **16** of said movable work supporting member **12** comprises, among other parts, a hydraulic spindle drive motor **20**, an upper spindle portion **22**, and a lower spindle portion **24**. The upper spindle portion **22** carries a pair of cam shafts **25** and **26** driven therefrom, said camshaft **25** carrying a velocity cam **28** and the camshaft **26** carrying a wave or normalcy cam **30**. The lower spindle portion **24** rotatably drives an airfoil master shaft **36** which attaches to an airfoil master **38**. Said airfoil master **38** is retained on its other end by a master tailstock **40**. The lower spindle portion **24** also rotatably drives a work element shaft **42** carrying a work element **44** which is held on its other end by a work element tail stock **45**. The rotational speed of the shafts **36** and **42** may be varied by regulating the flow of fluid to the hydraulic spindle drive motor **20** which drives said shafts. This can be done through a velocity cam follower **29** riding on said velocity cam **28**, said follower **29** through suitable linkage controlling a valve (not shown) which regulates the flow of fluid to said hydraulic motor **20**. The axis of rotation *b—b* is common for both of said shafts **36** and **42**. An airfoil master follower roller **46** is mounted on a master swivel table **48** operated by a wave cam follower **31** riding on the wave cam **30** through suitable linkage schematically shown as line **51** in Fig. 1 so as to keep said master roller normal to the surface of said airfoil master being contacted. For grinding the work element **44**, a grinding belt **54** is driven by suitable mechanism supported on a swivel table **52**. The swivel table **52** is connected to master swivel table **48** by suitable linkage schematically indicated at **53** in Fig. 1 so that the table **52** swings with the table **48** to keep the grinding belt **54** at all times normal to the portion of the work element surface contacted thereby as illustrated in Figs. 3 and 4. Mounted on the main frame **10** is a hydraulic drive mechanism **56** which actuates a drive rod **58** hereinafter referred to as the power member. Said power member **58** transmits horizontal translational motion to the movable member **12** through means described below.

The aforementioned structure describes a conventional grinding belt machine which is specifically designed for grinding the surfaces of compressor and turbine blades or the like, which machine operates as follows. The hydraulic drive mechanism **56** imparts horizontal reciprocating translational movement to the power member **58** which in turn transmits such motion to the movable member **12**. The airfoil master **38** and the work element to be ground, **44**, carried in the lower spindle portion **24** which is part of said movable member **12**, thereby acquire this reciprocating motion, the length of a stroke of said reciprocating motion being previously set according to the length of the piece of work to be ground. Besides this reciprocating translational movement, the airfoil master **38** and the work element **44** are being rotated in the manner described above. Consequently, the airfoil master follower roller **46** describes a helical path along the airfoil master **38**. In addition, as previously stated, the connection **51** between the cam follower **31** and the swivel table **48** is effective to rotatively position said table so that its roller **46** is at all times normal to the portion of the master airfoil surface contacted by said roller. This composite relative movement between the airfoil master and the roller **46** is duplicated exactly between the grinding belt **54** and the work element **44** through components and in the manner described. The master roller **46**, furthermore, causes the pivoted head portion **16** of the movable member **12** to swing about axis *a—a* so that the limit to which the grinder **54** can approach the axis of rotation *b—b* of the work element **44** is determined by the

relation between the master roll **46** and the axis of rotation *b—b* of the master airfoil **38**.

Fig. 2 is a schematic drawing of the grinding machine best illustrating the new features, partially shown in Fig. 1, permitting the continuous grinding of a work element having flanges at two opposite ends. Mounted on the power member **58** and integral therewith is a clutch block **70**. Attached to the movable member **12** are a pair of pawls, a right pawl **72** and a left pawl **73**, pivoted about pivot pin **74** which is carried by said movable member **12**. Connected to said pawls at the end farthest removed from the clutch block **70** are a pair of trip latch buttons, a right button **76** and a left button **77**, which pass through passageways **78** in said movable member **12**. Seated on the movable member **12** and concentric with the trip latch button arms **80** are a pair of washers **82**. A pair of springs **84** are disposed in compression between said trip latch buttons **76** and **77** and said movable member **12** for urging said pawls **72** and **73** toward their clutch engaging position. A pair of fixed trips, a right trip **86** and a left trip **87**, are attached to the main frame **10** so that one trip will depress its corresponding button when said button is carried by the movable member **12** into a position where said button will slide on said trip.

A compounding cam follower rod **88** is connected to the power member **58** and actuated thereby. A compounding cam follower roller **90** is attached to the end of said rod **88** and is free to rotate about an axis coincident with the longitudinal centerline of said rod **88**. The roller **90** is disposed between two compounding cams, a left hand compounding cam **92** and a right hand compounding cam **94**. Said compounding cams are mounted on the camshaft **26** which is carried by the movable member **12** and is driven by the hydraulic motor **20**. As shown in Fig. 2, the roller **90** rides clear of both compounding cams, except at each cam's profile high spot, when the pawls **72** and **73** are engaging the clutch block **70**; the compounding cams rotate at all times. The contour of each compounding cam is designed to impart a predetermined movement to the movable head **12** when that particular compounding cam is operative.

A piston-cylinder assembly **96** operating on a suitable fluid is mounted on the movable member **12** and comprises a cylinder **98** with a piston **100** slidably mounted therein. Bosses **102** are provided at either end of the cylinder **98** for limiting the sliding motion of said piston. A yoke **104** is connected to the piston rod **106** and moves in conjunction with said piston **100**. Fluid line connections **108** and **110** permit fluid pressure to be applied to either side of said piston **100** thereby actuating said piston. Said fluid connections **108** and **110** are connected by suitable means to fluid valve **112** comprising a casing **114** and a rotatable member **116**. The casing **114** contains a fluid inlet port **118**, a fluid exhaust port **120**, and ports **122** and **124** connected by suitable means to the fluid connections **108** and **110** respectively. Passageways **117** and **119** are located in the rotatable member **116**. Connected to said rotatable member is a valve actuating rod **126** which is operatively connected to the power member **58** through a head portion **128** on said rod **126** disposed between a pair of lugs, a right lug **130** and a left lug **131**, said lugs being integral with the power member **58**. The power member **58** also has an arm **132** disposed between the left leg **134** and the right leg **136** of yoke **104**. A pair of springs are disposed for compression between the arm **132** and the legs of said yoke **104**, the spring **138** being disposed between said arm and the left leg **134** and the spring **140** being disposed between the arm and right leg **136**.

The operation of this grinding machine incorporating the subject invention is as follows. The hydraulic motor **56** moves the power member **58** in Fig. 2 left and right in a reciprocating motion. The words left and right as hereinafter used refer to the apparatus as viewed in Figs. 1 and 2. The power member is positively connected to the movable member **12** when the clutch block **70**, mounted on said power member, is held between the pawls **72** and **73** mounted on said movable member. If, as illustrated in Fig. 2, the power member **58** is moving towards the left, the clutch block pushes on the left pawl **73** which in turn pulls along the movable member. The master airfoil and the work element, mounted in the movable member as described previously, are also moved toward the left. At the same time the lugs **130** and **131** are moving to the left with the right hand lug **130** pushing on the valve actuating rod head portion **128** thereby rotating said valve rotatable member **116** in a clockwise direction. Some time prior to the end of the leftward stroke the rotatable member **116** is then in the position illustrated in Fig. 2. With the valve **116** in this position, fluid will flow from the cylinder **98** through passageway **110**, into passageway **119**, and then out of the exhaust port **120**. At the same time fluid will flow from an external fluid pressure supply passage **142**, through inlet port **118**, into passageway **117**, to port **122**, thence through passageway **108** into said cylinder thereby moving the piston **100** to the right. The piston will carry the yoke **104** to the right so that leg **134** of said yoke and arm **132** of the power member will compress the spring **138**. The ports **118**, **120**, **122** and **124** are circumferentially elongated, as shown, in order to keep the described relationship between the ports and the rotatable member's passageways **117** and **119** for a desired period of time so that spring **138** is compressed before the clutch disengages, as is hereinafter described. Said ports remain in this condition throughout the remainder of the stroke.

Near the end of the stroke towards the left, the left hand trip latch button **77** contacts the left hand trip **87**. Said trip depresses the button which rotates the right pawl **72** about the pivot pin **74** in a counterclockwise direction thereby permitting said pawl to override the clutch block. The compressed spring **138** then urges the movable member **12** ahead of the power member **58** towards the left so that the right hand compounding cam **94** contacts the compounding cam follower roller **90**. Said spring **138** holds the cam **94** against the follower roller **90** whereby, as the cam rotates, the profile of the cam determines the motion of the movable member **12** along its guide means **14**.

As previously stated, when the pawls **72** and **73** are engaged the roller **90** rides clear of both cams **92** and **94** except that said roller **90** engages the high spot of each cam. Hence, once the pawl **72** has disengaged the clutch block **70** the pawl **72** can only re-engage said clutch block when the roller **90** contacts the cam high spot. However, while the motion of the movable member **12** is being determined by the cam **94** at the left end of the stroke of said member **12** engagement of the trip **87** and button **77** prevents re-engagement of the pawl **72** with the clutch block **70**.

When the power member **58** begins the return stroke towards the right, the follower roller **90** engages the cam **94** to push the movable member **12** to the right. The button **77** is promptly moved to the right beyond the trip **87** so that when the roller **90** next contacts the high point on the cam **94** the spring **84** is effective against the left button **77** to swing the right pawl **72** downward into re-engagement with the clutch block **70**. The clutch block **70**, pawls **72** and **73** and trip buttons **76** and **77** are now again in the relative positions illustrated in Fig. 2. As the power member **58** moves to the right the lug **131** thereon is effective to rotate the valve element **116** in a counterclockwise direction. Prior to the end of the rightward stroke of the power member **58** the valve element **116** reaches a position in which the port **122** and fluid connection **108** are in communication with the drain port **120** through the valve passage **119** and the port **124** and fluid connection **110** are in communication with the inlet port **118** and its supply passage **142** through the valve passage **117**. As a result, the piston **100** travels to

the left to its opposite end position thereby relieving the spring 138 and compressing the spring 140. Near the end of the rightward stroke of the power member 58 the trip button 76 is depressed by the trip 86 thereby raising the left pawl 73 to disengage it from the clutch 70. The previously compressed spring 140 is then effective to hold the movable member cam 92 to the right against the cam follower roller 90 whereupon the motion of the movable member 12 at the end of its rightward stroke is determined by the cam 92 just, as previously described, the cam 94 determines the motion of the movable member 12 at the end of its leftward stroke.

With the apparatus operating as described above, when the movable member 12 has moved towards the right and the left pawl 73 is disengaged from the clutch block 70 the compounding cam 92 will be controlling the translational motion of said movable member. The work element 44 carried by said movable member will then appear relative to the grinding belt 54 (full line position) as illustrated in Figs. 3 and 4. Fig. 4 shows the work element 44 after having been rotated about axis *b—b* 180° from the position illustrated in Fig. 3. The work element 44, as illustrated, has a work element surface 143 disposed between a left flange 144, having a flange surface 146, and a right flange 148, having a flange surface 150. The compounding cam 92 controls the translational motion so that the grinding belt is able to grind the work element surface 143 immediately adjacent to the flange 144 during the complete revolution of the work element. The shaded part 152 of the surface 143 is the minimum portion of the surface ground while the cam 92 is controlling the translational motion of the work element. If the clutch had remained engaged while the grinding belt came into contact with that shaded portion 152, the result would have been the undesired removal of material from the flange surface 146 by said grinding belt, the amount of material removed and the position of the flanged surface 146 affected increasing as the translational motion continued. The grinding belt 54 shown in dash-dot outline illustrates the relationship of said grinding belt and the flange 148 when the compounding cam 94 controls the translational motion of the work element 44. Said compounding cam 94 is operative when the right pawl 72 disengages the clutch block 70, and permits the grinding belt 54 to grind at least the shaded portion 154 of the work element surface 143 without having said grinding belt interfere with the surface 150 of the flange 148. Thus, the entire surface 143 of the work element 44 can be ground in one single operation without removing said work element from the machine.

While I have described my invention in detail in its present preferred embodiment, it will be obvious to those skilled in the art, after understanding my invention that various changes and modifications may be made therein without departing from the spirit or scope thereof. I aim in the appended claims to cover all such modifications.

I claim as my invention:

1. A grinding mechanism comprising power means; a member connected to said power means for reciprocation thereby; a movable member having means for rotatably supporting a work piece; motor means operatively connected to said work piece supporting means for rotating said supporting means; means for supporting said movable member for reciprocating motion; means for clutching said movable member to said power means connected member; means for disengaging the clutching means near the end of each stroke of said reciprocating motion and for re-engaging said clutching means near the commencement of the next stroke of said reciprocating motion; and cam means connected to said motor means for movement thereby for imparting a predetermined movement to said movable member when said clutching means is disengaged.

2. A grinding mechanism comprising power means; a member connected to said power means for reciprocation thereby; a movable member having means for rotatably supporting a work piece; motor means operatively connected to said work piece supporting means for rotating said supporting means; means for supporting said movable member for reciprocating motion; means for clutching said movable member to said power means connected member; means for disengaging the clutching means near the end of each stroke of said reciprocating motion and for re-engaging said clutching means near the commencement of the next stroke of said reciprocating motion; and means for imparting a predetermined movement to said movable member when said clutching means is disengaged; said last mentioned means including elastic means operatively connected to the movable member, means for straining said elastic means during at least the last portion of each stroke of said reciprocating power means so as to urge said movable member relative to said power means in one or the other direction and cam means connected to said motor means for rotation thereby for controlling the extent of movement of said movable member under the urging of said elastic means.

3. Apparatus for grinding the surface of a work element, said work element having a flange at each of two opposite ends with said flanges being inclined to the axis about which a work element is rotated during the grinding operation; said apparatus comprising a movable member having means for rotatably supporting a work element; motor means mounted on said movable member and connected to said work element supporting means for rotating said supporting means; guide means mounting said work element supporting movable member for linear movement therealong; power means; a member connected to said power means for reciprocation thereby; clutch means engageable for connecting said work element supporting movable member and said power member so that reciprocation of said power member causes reciprocation of said work element supporting movable member along its said guide means; means operative to disengage said clutch means adjacent to the end of each stroke of said power member and to re-engage said clutch means during the initial portion of the next stroke of said power member; and cam means connected to said motor means for rotation thereby for moving said work element supporting movable member along said guide means in a predetermined manner when said clutch means is disengaged.

4. Apparatus for grinding the surface of a work element, said work element having a flange at each of two opposite ends with said flanges being inclined to the axis about which a work element is rotated during the grinding operation; said apparatus comprising a movable member for supporting a work element; guide means mounting said work element supporting member for linear movement therealong; power means; a member connected to said power means for reciprocation thereby; clutch means engageable for connecting said work element supporting movable member and said power member so that reciprocation of said power member causes reciprocation of said work element supporting movable member along its said guide means; means operative to disengage said clutch means adjacent to the end of each stroke of said power member and to re-engage said clutch during the initial portion of the next stroke of said power member; and means operative for moving said work element supporting movable member along said guide means in a predetermined manner when said clutch means is disengaged; said last mentioned means including elastic means operatively connected to said work element supporting movable member, means for straining said elastic means during at least the last portion of each stroke of said reciprocating member so as to urge said work element supporting movable member relative to said power member in one or the other direction along said guide

means, a cam follower on said power member, a pair of cams carried by said work element supporting member, means for rotating said cams during operation of said apparatus, said cams and cam follower being so disposed that when the clutch means is engaged they do not affect the motion of the work element supporting member and when said clutch means is disengaged said spring means is effective to move one or the other of said cams into engagement with said follower, depending on the direction of motion of said power member, for controlling the movement of said work element supporting member along its said guide means.

5. Apparatus for grinding the surface of a blade for turbines, compressors, or the like in which said blade has a flange portion at each end inclined to the longitudinal axis of said blade; said apparatus comprising a movable member having blade supporting means and means for rotating said blade supporting means; blade grinding means; means for oscillating said movable member about a pivot axis to maintain said blade grinding means in contact with the blade to be ground as the blade rotates; guide means for mounting said blade supporting movable member for linear movement along said guide means; power means; a member connected to said power means for reciprocation thereby; clutch means engageable for connecting said movable member to said power member so that reciprocation of said power member causes reciprocation of said blade supporting movable member along its guide means; means for disengaging said clutch means near the end of each stroke of said reciprocating motion and for re-engaging said clutch means during the initial portion of the next stroke of said reciprocating motion; and means for imparting a predetermined movement to said movable member when said clutch means is disengaged, said last mentioned means including elastic means operatively connected to the blade supporting movable member, means for straining said elastic means during at least the last portion of each stroke of said reciprocating member so as to urge said blade supporting movable member relative to said power member in one or the other direction along said guide means, and means for controlling the extent of movement of said blade support movable member along its said guide means under the urging of said elastic means.

6. Apparatus for grinding the surface of a blade for turbines, compressors, or the like in which said blade has a flange portion at each end inclined to the longitudinal axis of said blade; said apparatus comprising a movable member having blade supporting means and means for rotating said blade supporting means; blade grinding means; means for oscillating said movable member about a pivot axis to maintain said blade grinding means in contact with the blade to be ground as the blade rotates, guide means for mounting said blade supporting movable member for linear movement along said guide means; power means; a member connected to said power means for reciprocation thereby; clutch means engageable for connecting said movable member to said power member so that reciprocation of said power member causes reciprocation of said blade supporting movable member along its guide means; means for disengaging said clutch means near the end of each stroke of said reciprocating motion; means for re-engaging said clutch means during the initial portion of the next stroke of said reciprocating motion; and means for imparting a predetermined movement to said movable member when said clutch means is disengaged; said last mentioned means comprising a piston and cylinder assembly mounted on said blade supporting movable member for linear movement therewith; a pair of opposed springs operatively connected between said piston and said power member, means operative for supplying a fluid under pressure to one end of said cylinder for straining one of said pair of springs during at least the last portion of each stroke of said power member in one direction and to the other end of said cylinder for straining the other of said pair of springs during at least the last portion of each stroke of said power member in the opposite direction so as to urge said blade supporting member relative to said power member in one or the other direction along said guide means; and means for controlling the extent of movement of said blade support movable member along its said guide means under the urging of one of said springs.

7. Apparatus for grinding the surface of a blade for turbines, compressors, or the like in which said blade has a flange portion at each end inclined to the longitudinal axis of said blade; said apparatus comprising a movable member having blade supporting means and means for rotating said blade supporting means; blade grinding means; means for oscillating said movable member about a pivot axis to maintain said blade grinding means in contact with the blade to be ground as the blade rotates; guide means for mounting said blade supporting movable member for linear movement along said guide means; power means; a member connected to said power means for reciprocation thereby; clutch means engageable for connecting said movable member to said power member so that reciprocation of said power member causes reciprocation of said blade supporting movable member along its guide means; means for disengaging said clutch means near the end of each stroke of said reciprocating motion and for re-engaging said clutch means during the initial portion of the next stroke of said reciprocating motion; and means for imparting a predetermined movement to said movable member when said clutch means is disengaged; said last mentioned means comprising a piston and cylinder assembly mounted on said blade supporting movable member for linear movement therewith; a pair of opposed springs operatively connected between said piston and said power member, means operative for supplying a fluid under pressure to one end of said cylinder for straining one of said pair of springs during at least the last portion of each stroke of said power member in one direction and to the other end of said cylinder for straining the other of said pair of springs during at least the last portion of each stroke of said power member in the opposite direction so as to urge said blade supporting member relative to said power member in one or the other direction along said guide means, a pair of cams and cam follower means cooperating so that when said clutch is disengaged said spring means is effective to maintain said cam follower means in contact with one or the other of said cams depending upon the direction of movement of said blade support movable member along its guide means.

8. Apparatus for grinding the surface of a blade for turbines, compressors or the like in which said blade has a flange portion at each end inclined to the longitudinal axis of said blade; said apparatus comprising a movable member having blade supporting means and means for rotating said blade supporting means; blade grinding means; means for oscillating said member about a pivot axis to maintain said blade grinding means in contact with the blade to be ground as said blade rotates; guide means for mounting said blade supporting member for linear movement along said guide means; power means; a member connected to said power means for reciprocation thereby; clutch means engageable for connecting said members so that reciprocation of said power member causes reciprocation of said blade supporting movable member along its said guide means; means operative to disengage said clutch means adjacent to the end of each stroke of said power member and to re-engage said clutch means during the initial portion of the next stroke of said power member; and means operative for moving said blade supporting member along its said guide means in a predefermined manner when said clutch means is disengaged; said last mentioned means comprising a piston and cylinder assembly mounted on said blade supporting member for linear movement therewith with the axis of said piston and cylinder assembly being disposed parallel to the direction of said linear movement, a pair of opposed

springs each operatively connected between said piston and said power member, means operative for supplying a fluid under pressure to one end of said cylinder for straining one of said springs during at least the last portion of each stroke of said power member in one direction and to the other end of said cylinder for straining the other of said springs during at least the last portion of each stroke of said power member in the opposite direction so as to urge said blade supporting member relative to said power member in one or the other direction along said guide means, a cam follower on said power member, a pair of cams carried by said blade supporting member, and means for rotating said cams during operation of said apparatus so that when said clutch means is disengaged during one stroke of the power member one of said springs is effective to move said movable member to maintain one of said cams against said follower and when the clutch means is disengaged during the next

stroke of the power member the other of said springs is effective to move said movable member to maintain the other of said cams against said follower, said cam follower being disposed between said cams and the cams being disposed sufficiently far apart so that when the clutch is engaged they do not affect the motion of the blade supporting member.

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