Aug. 12, 1952 P. M. MUELLER 2,606,406

BLADE FINISHING MACHINE

Filed March 21, 1950 5 Sheets-Sheet 1

FIG. 1

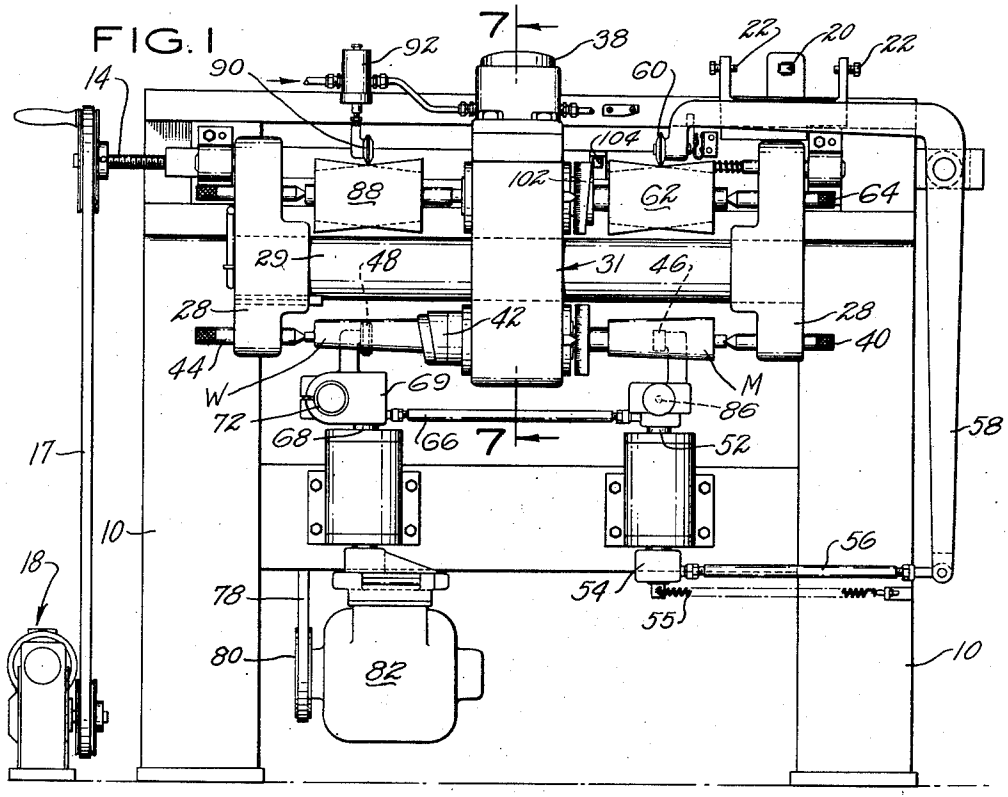
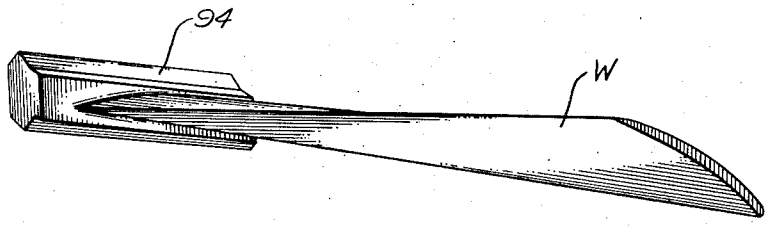


FIG. 10



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Aug. 12, 1952 P. M. MUELLER 2,606,406

BLADE FINISHING MACHINE

Filed March 21, 1950 5 Sheets-Sheet 2

FIG. 2

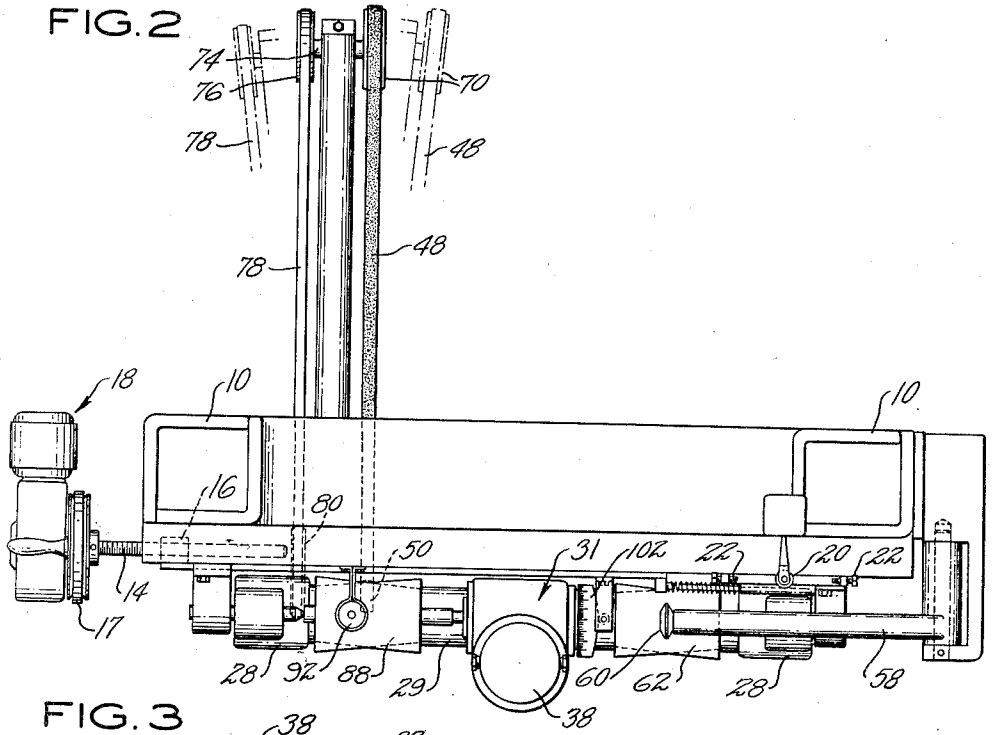
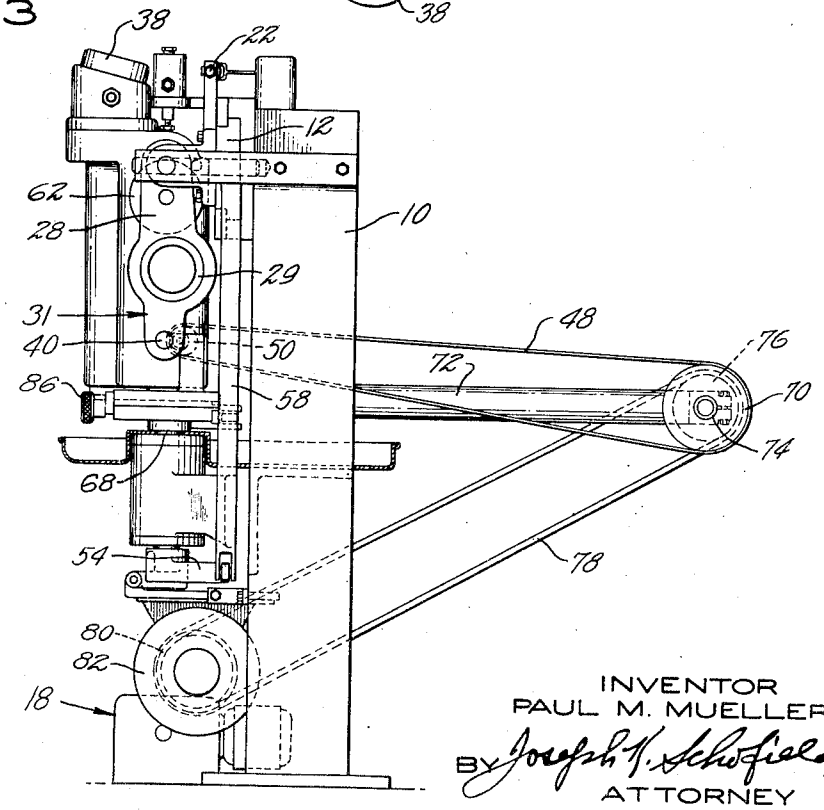


FIG. 3



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BLADE FINISHING MACHINE

Filed March 21, 1950 5 Sheets-Sheet 3

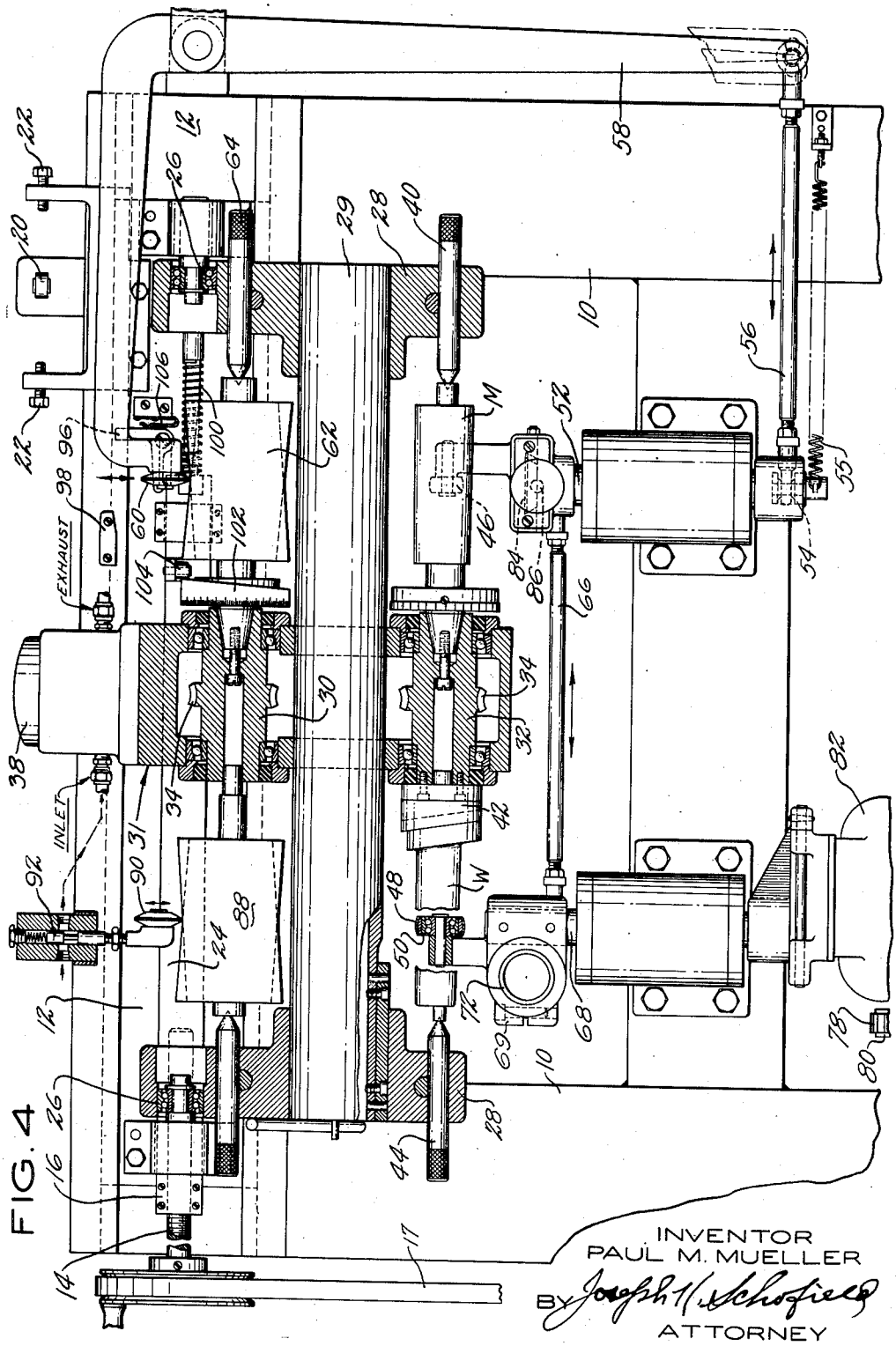


FIG. 4

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BLADE FINISHING MACHINE

Filed March 21, 1950 5 Sheets-Sheet 4

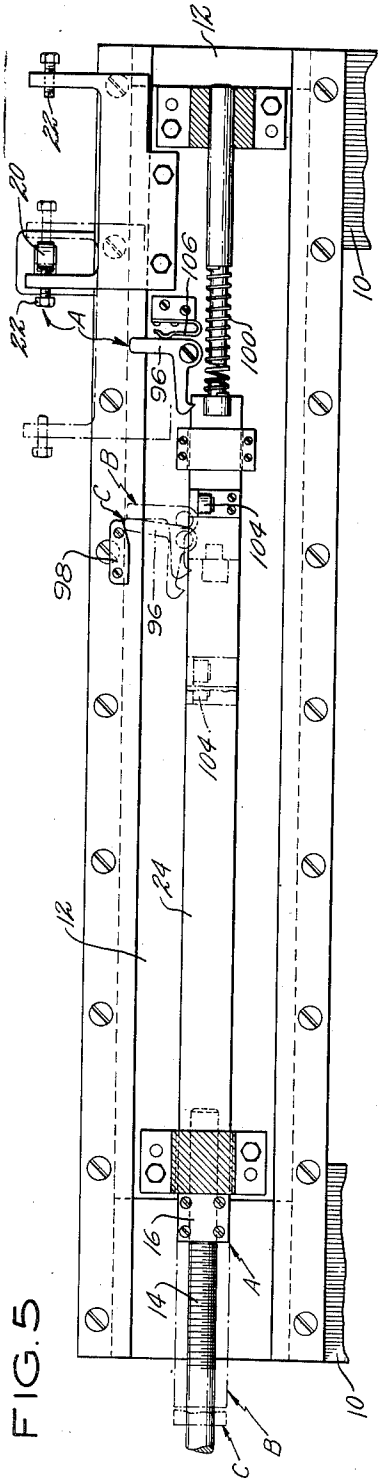


FIG. 5

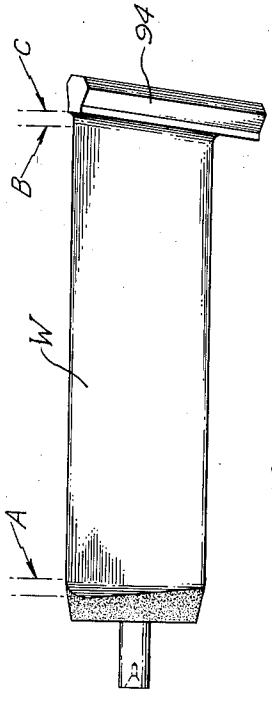


FIG. 6

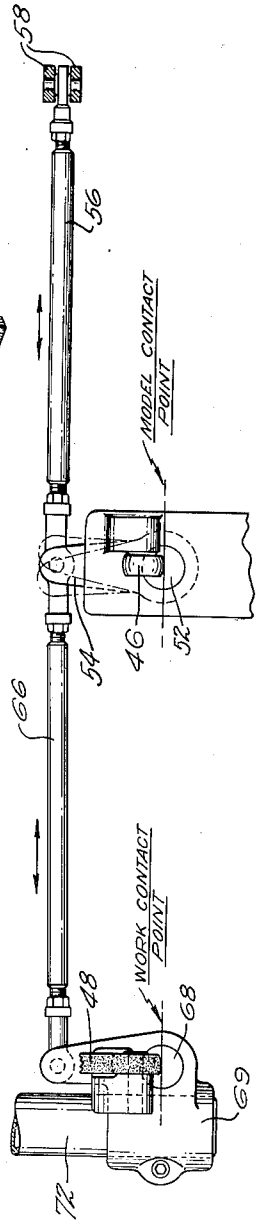


FIG. 8

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BLADE FINISHING MACHINE

Filed March 21, 1950 5 Sheets-Sheet 5

FIG. 7

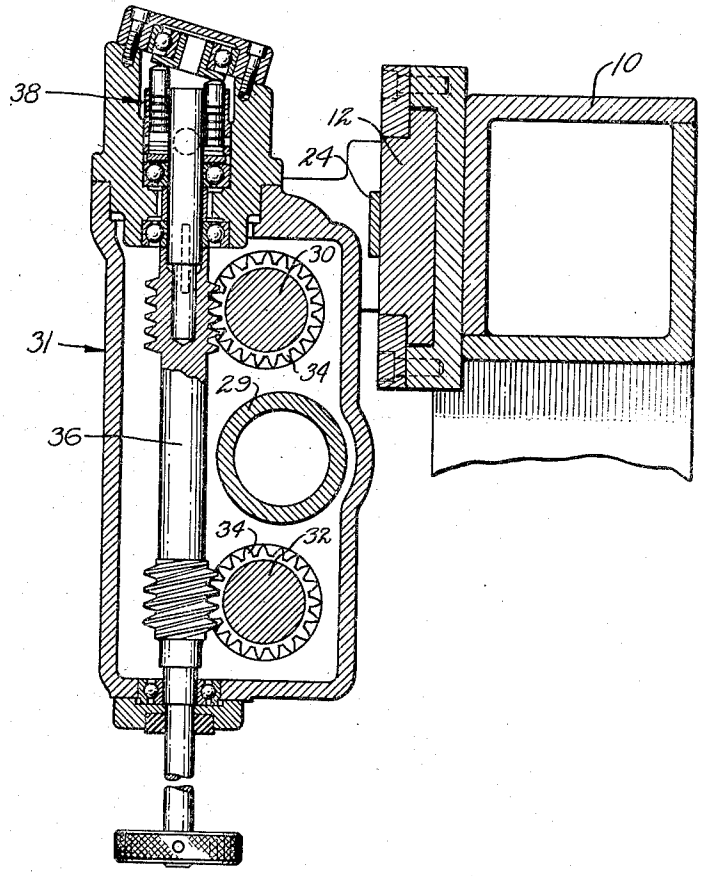
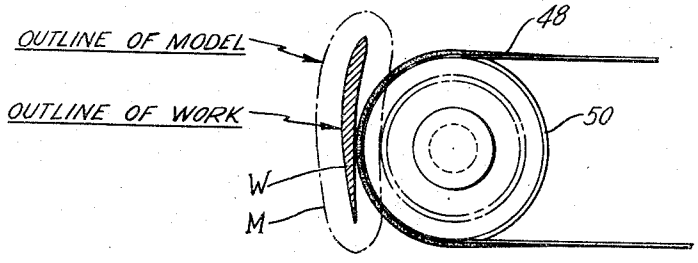


FIG. 9



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2,606,406

UNITED STATES PATENT OFFICE

2,606,406

BLADE FINISHING MACHINE

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Application March 21, 1950, Serial No. 151,011

12 Claims. (Cl. 51—144)

1

This invention relates to a finishing machine for turbine blades and the like, and particularly to a machine of the gun stock lathe type for finishing the active surfaces of blades used in jet propulsion turbines, by means of an abrasive charged flexible band driven at high speed in contact with the blade surface being finished.

Blades of this type, in general, have air foil sections disposed normally along a locus or axis at an angle to a prismatic supporting base. Each section of the blade is twisted about the locus or axis to form a continuous, warped, helical surface, the degree of twist usually increasing as the section distance increases from the base. Each section also usually differs from its neighbor, those nearest the base being thicker and stronger to resist the high centrifugal forces of the turbines due to high rotational speeds at which these turbine wheels rotate.

It will be apparent that such a surface can be generated from a three-dimensional cam whose instantaneous section is analogous to, or conjugate with, the equivalent instantaneous section of the foil, and which has the same instantaneous degree of warp.

An object of the invention is to provide a machine of the above described type that will accurately generate the desired contours on turbine and other blades to give them a smooth, continuous air foil or other surface throughout their entire effective areas from a special master model.

Another object of the invention is to provide a machine that will operate over the entire effective area of a turbine or other type blade with the abrasive surface of an abrasive band contacting the surface of the blade at a point where the band passes over a small roller, and by relative longitudinal traversing motions of the blade and band, and while the blade is being rotated about its longitudinal axis.

Another object of the invention is to provide a supplemental axial movement compounded with a steady feed and in timed relation to the rotation of the work, so that an oblique portion of the foil surface adjacent the supporting portion of the blade can be finished uniformly and blend smoothly into the extended portion of the foil surface.

A still further object of the invention is to provide rotation controlling means providing a substantially uniform surface speed of the blade surface as it passes the abrasive band.

Another object of the invention is to provide a swinging or oscillating means for the abrasive band so that its contact with the warped foil

2

surface is essentially a line lying in the foil surface at all times, so that the full width of the abrasive band may be utilized and the appearance of the surface finish may be improved.

With the above and other objects in view, the invention may include the features of construction and operation set forth in the following specification and illustrated in the accompanying drawings.

In the accompanying drawings annexed hereto and forming a part of this specification, I have shown the invention embodied in a surface finishing machine of the work and model swinging type, adapted for operating on standard or conventional forms of turbine blades, but it will be understood that the invention can be otherwise embodied and that the drawings are not to be construed as defining or limiting the scope of the invention, the claims appended to this specification being relied upon for that purpose.

In the drawings, which show a preferred single work spindle form of the invention:

Figure 1 is a front elevation of a complete machine adapted to completely finish the entire effective surface of turbine and other types of blades.

Figure 2 is a plan view of the machine shown in Figure 1.

Figure 3 is a side elevation of the machine shown in Figure 1.

Figure 4 is a front elevation of the operative parts of the machine shown in the above mentioned figures, parts being shown on an enlarged scale and some of the parts being shown in section.

Figure 5 is a front elevation of the main and auxiliary slide for axially moving the work piece during rotation and while the finishing operation is being effected adjacent an obliquely disposed supporting portion of the blade.

Figure 6 is a longitudinal view of a blade adapted to be finished in the machine shown and described in this application.

Figure 7 is a vertical, transverse section on the plane of line 7—7 in Figure 1 through the rotating mechanism for the cam and work piece shafts.

Figure 8 is a plan view of the mechanism for simultaneously oscillating the abrasive band and master or model following roller.

Figure 9 is an end view showing the relationship between the model and roller and between the blade and grinding belt, and

Figure 10 is a perspective view of a completely finished blade.

In the above mentioned drawings, there has been shown but one embodiment of the invention for operating on a single blade which is now deemed preferable, but it is to be understood that changes and modifications may be made within the scope of the appended claims without departing from the spirit of the invention.

Briefly, and in its preferred aspect, the invention may include the following principal parts: first, a base or frame on which is mounted a horizontally movable slide; second, a carriage on said slide adapted to swing about a horizontal axis and move horizontally therewith; third, two parallel shafts supported on said carriage and adapted to be rotated on axes parallel to the direction of movement of the side and to the axis about which the carriage swings, the rotation of the shafts being at the same speed and preferably in the same direction by any convenient means; fourth, a master, three-dimensional cam or model and work piece mounted coaxially for rotation with one shaft; fifth, a pair of three-dimensional cams and a face cam for the supplemental axial motion mounted coaxially on the second shaft; sixth, a cam or model following roller mounted on the frame in a manner presently to be described, and engaging against the peripheral surface of the model; seventh, an abrasive band passing over a pulley mounted similarly to the model following roller and adapted to contact the perpiheral surface of the blade or other work blank being finished; eighth, means for simultaneously oscillating the cam follower roller and the pulley over which the abrasive band passes; ninth, a speed control for the rotation of the work blank to vary the rotative speed during each revolution of the work blank; tenth, traversing means for axially feeding the work blank past the abrasive band; and eleventh, supplemental means to traverse the work blank axially back and forth a short distance during each rotation of the work blank when the work blank is being operated on adjacent an oblique supporting end.

Referring more in detail to the figures of the drawings, and first to Figure 4, it will be seen that there has been provided a frame 10 at the upper front portion of which is mounted a transversely movable main slide 12. The slide 12 is mounted for horizontal movement along suitable guideways and its movement is effected by rotation of a power driven screw 14. The screw 14 preferably is mounted for rotation within the frame 10 and is retained against endwise motion by any suitable enclosure. A nut 16 in a member fixed to, and moving normally with, the slide 12 engages the screw 14, so that by rotation of the screw 14, as by belt connections 17, to a reversible motor 18, the direction of movement of the slide 12 and its attached parts may be reversed. A limit switch 20 mounted on the upper portion of the frame 10 may have its switch arm in the path of adjustable abutments 22 carried by the slide 12, so that by varying the positions of the abutments, the length and limits of travel of the slide 12 may be varied over a wide range.

For a purpose presently to be described, the main slide 12 has mounted on it an auxiliary or supplemental slide 24 for relative longitudinal movements in the direction of movement of the main slide 12. On the slide 12, and the supplemental slide 24, are interengaging guideways to maintain the alignment of the slides 12 and 24 throughout their movements. The supplemental slide 24 is shown in the form of a long bar extending along, and set into, the front surface of slide 12. It is on this bar, or supplemental slide 24, that the operating nut 16 is mounted for effecting movements of the main slide 12.

On the slide 12 are aligned horizontal bearings 26 upon which a carriage 28 may swing about a horizontal axis. The swinging carriage 28 comprises end radial arms maintained in proper alignment by an elongated shaft 29 secured to each arm. Centrally of the shaft 29 is the housing 31 within which are driving connections for horizontally mounted shafts 30 and 32. These shafts 30 and 32 are short, parallel and horizontally mounted and rotated at the same speed and in the same direction by worm gears 34 mounted thereon in mesh with worms on a vertical shaft 36. To rotate the vertical shaft 36 and the horizontal shafts 30 and 32, a small motor 38, such as the fluid type motor shown in Figures 4 and 7, may be used. This motor 38 may be driven through flexible hose connections from a suitable source of fluid under pressure (not shown).

Mounted on the horizontal shaft 32 are first, on one side, a model M, or three-dimensional master extending from, and driven from one end of the shaft 32, the outer or free end of the model or master being supported by a suitable adjustable center 40, as shown. On the opposite side of the lower shaft 32 is a work blank W, supported rigidly at one end by a suitable chuck or holder 42 and supported at its outer free end by a suitable center 44. It will be seen from the above that the model or master M and work blank W will be rotated with their shaft or spindle in exact relation with each other on the same axis, moved horizontally with the slide 12, and swung back and forth simultaneously about the same axis on the pivotally mounted carriage 28.

Engaging the model M at the rear of shaft 32 is a roller 46, and correspondingly engaging the work blank W is an abrasive band 48 passing over a roller 50 positioned similarly to the model following roller 46. By engagement of the model M with its roller 46, which is mounted on the frame in a manner presently to be described, the carriage 28 will be swung in and out about its horizontal, pivotal axis as the model M is rotated. Coincidentally, the axial traverse of the slide 12 will bring all sections of the model M to positions contacting with the model following roller 46. This horizontal motion will generate an analogous contour on the work piece W by abrasion from the band 48 passing over its pulley 50, as the work piece W moves axially and rotatably corresponding to the model M.

The model following roller 46 is pivotally mounted for oscillation at a predetermined radius from a shaft 52 mounted in the frame 10 on a fixed vertical axis. The distance of the roller 46 from its axis of oscillation may be adjusted as by an adjusting screw 86 for a purpose presently to be described. To oscillate the model contacting roller 46 about its vertical axis, a lever 54 attached to vertical shaft 52 forming the pivotal member of the roller 46 at its lower end is attached to a reach arm 56 which in turn is connected to the lower end of a bell crank 53 pivotally mounted in the frame 10. The upper end of the bell crank 58 has a cam roller 60 contacting the periphery of a three-dimensional sweep cam 62. This latter cam 62 is mounted for rotation on the upper horizontal shaft 30 rotatably mounted on the swinging carriage 28 and turns in the same direction and at the same speed as the model M. The outer end of this

cam 62 is supported by a suitable center 64. The sweep cam 62 is so formed that during its rotation the bell crank lever 58 will be oscillated and the model engaging roller 46 also oscillated in timed relation to the rotation of the model. A spring 55 normally forces the shaft 52 and attached parts in one direction.

Connected to the oscillating support for the model following roller 46 by a connecting link 66 is a similar vertically pivoted shaft 68 mounted in the frame 10 for the abrasive band roller 50. This latter oscillating support 68, or shaft, oscillates the driving and connecting means for the abrasive band 48. When the pivotal radii to the connecting link 66 from the oscillating shafts 52 and 68 are identical, as shown, the abrasive band roller 50 and the model engaging roller 46 will be swept through arcs of the same radii, and in timed relation to each other. By these means, the band roller 50 will make identical contact with the work piece W that the model engaging roller 46 makes with the model M. Thus, the accuracy of duplication of the work piece W with the model M is preserved even though the periphery of the three-dimensional sweep cam 62 is in slight error, and line contact between the abrasive band 48 and the foil surface on the workpiece W is lost as a consequence.

In order that the sweep cam need not be made to a high degree of accuracy, it has been found convenient to crown both the model following roller 46 and the band roller 50 a small amount (one or two degrees), the amount of crown being slightly greater than the angular error occurring in machining the cam. Further, the surface of the band roller 50 is composed of a slightly resilient material, such as isoprene or other rubber-like compound, which helps to improve the abrasive action and finish in spite of slight cam errors.

Referring to Figures 2 and 3, it will be seen that the abrasive band 48 passes over a pulley 70 at the rearward end of an elongated, horizontal arm 72 supported by, and oscillating with the vertical shaft 68 and support 69. The pulley 70 is mounted on one end of a short horizontal shaft 74 rotatably supported at the rear end of the oscillating arm 72. On the opposite end of the short shaft 74 is a driving pulley 76 for the abrasive band. To drive the pulleys 70 and 76 and band 48, a belt 78 passes over the driving pulley 76 for the band 48, and over a pulley 80 on the armature shaft of a motor 82 mounted below, and oscillating with the member carrying the cam contacting roller 60. The motor 82, arm 72 and pivotally mounted band 48 all oscillate together and in timed relation to the rotation of the model. As the model following roller 46 and the pulley 50 over which the band 48 passes are similarly crowned, the surface of the work piece W, or blade, will be abraded to a contour similar to that of the model M. Also, as the model and work blank are transversed horizontally by movements of the slide 12, the entire effective length of the work blank W will be finished to contours similar to those of the model M.

To minimize distortion of the model M from pressure exerted by its follower, its sectional dimensions are increased so that it is much thicker and stiffer than the work piece W being finished. The increased thickness of the model M, which is a uniform envelope about its basic periphery from end to end of the model, is compensated for by a difference in diameter and position of the roller 46 contacting the model and the pulley 50 over which the abrasive band 48 passes. It will be evident from Figure 8, that if the radial distance of the model follower roller 46 from its axis of oscillation is displaced a short distance from the corresponding radial distance of the pulley 50, the work piece will be generated with either a positive or negative envelope about the basic profile. This relative radial displacement of the roller 46 and pulley 50 can be used to bring the foil to exact desired size even though the abrasive band 48 may become thinner through wear, or the pulley for the band reduced from basic size by redressing its crown. This introduces an error in duplication of such small amount that it is negligible in all practical cases. The dovetail slide 84 and micrometer screw 86 shown in Figure 4 are for the purpose of effecting this displacement of the model following roller 46 radially toward and from the model surface.

In axial alignment with the cam 62 for oscillating the abrasive band 48 and model following roller 46, and rotatable therewith, is a velocity cam 88 driven with the first mentioned cam 62 and engaged by a vertically movable roller 90. As the cam 88 is traversed horizontally, simultaneously with the work piece W and other cams, the roller 90 engages its cam periphery along its entire length. The roller 90 is connected to a throttle controlling valve 92 in the fluid admitting line for the fluid motor 38, thus controlling the rate of rotation of the work piece W and parts rotating therewith. Variations in the peripheral contours of the velocity cam 88 will therefore vary the opening of the valve 92 and thus control the speed of rotation of the model M and work piece W. By properly varying the contour axially and peripherally of the cam 92, the rotative speed of the work piece W can be varied during each rotation so that the surface speed of the work piece, as portions pass the abrasive band 48 and while in contact therewith, will be substantially uniform.

Work pieces, such as compressor and turbine blades for which the present machine is particularly adapted, frequently have their attaching surfaces 94 at one end of the blade disposed obliquely to the axis of the blade, as shown in Figures 6 and 10 of the drawings. To enable the blade surfaces at this attaching or supporting end to be completely finished, where the foil surface merges with the support, a supplemental axial movement is provided for the work piece W and model cam M during rotation and while being operated on adjacent its supporting end.

In Figure 5, the rotating feed screw 14 held against endwise motion engages a nut 16 on the operating member 24 for the slide 12. The slide 12 and its operating slide 24 are normally locked together by a latch 96 and both members travel as a unit throughout most of the traverse over the foil surface of the blade being finished. In this state, the grinding path on the foil position of the blade is a uniform helix determined by the rate of traverse by rotation of the feed screw 14 controlling movements of the slides and the foil rotation by its connections from its motor.

When the grinding path approaches the oblique portion of the foil surface adjacent the supporting base, the latch 96 on slide 12 is tripped by engagement of an arm thereon with a block 98 on a fixed part of the base. This frees the main slide 12 from the operating slide 24. In this position, a spring 100 forces a follower 104 on the operating slide 24 against a face cam 102 keyed

to the shaft 30; the main slide 12 is then oscillated axially back and forth in accordance with the contour of cam 102 during its rotation. This axial motion is supplementary to the steady feed motion from the feed screw 14. In this state, the grinding path is a diagonal helix which will cover the oblique portion of the foil where it merges with the support.

As the feed continues by rotation of the screw 14, the limit switch 29 will be tripped at an adjusted position and the feed reversed. The compound motion will continued as the feed motion continues to the right, until the latch 96 is again free from its block 98, so that its spring 106 will again latch the main and operating slides 12 and 24 is a unit again. The axial relationship of the face cam 102 and the latch 96 is such that the high point of the cam 102 will just relieve the latch 96 of spring pressure once each revolution, thus insuring a relatch when the feed has reached the proper point in the traverse. When relatched, the operating and main slides again move as a unit by rotation of the feed screw 14.

I claim as my invention:

1. A blade finishing machine comprising a base, a slide movable horizontally thereon, a swinging carriage on said slide, a model and work piece mounting spindle rotatably mounted on a horizontal axis on said swinging carriage, a model following roller on said base, a traveling abrasive band, a pulley supported on said base over which said abrasive band passes while in engagement with a work piece on said spindle, a cam rotatably mounted on said swinging frame, and actuating means engaging said cam to simultaneously oscillate said roller and pulley an axes parallel to each other in timed relation to each other.

2. A blade finishing machine comprising a base, a slide movable horizontally thereon, a swinging carriage on said slide, a model and work piece mounting spindle rotatably mounted on a horizontal axis on said swinging carriage, a model following roller on said base, a traveling abrasive band, a pulley supported on said base over which said abrasive band passes while in engagement with a work piece on said spindle, means to simultaneously oscillate said roller and pulley on axes parallel to each other in timed relation to each other and to the rotation of said model and work piece spindle, and means to adjust the radius of oscillation of one of said oscillated members.

3. A blade finishing machine comprising a base, a slide movable horizontally thereon, a carriage on said slide adapted to swing about a horizontal axis, a model and work piece mounting spindle rotatably mounted on a horizontal axis on said swinging carriage, a model following roller on said base, a traveling abrasive band, a pulley supported on said base over which said abrasive band passes while in engagement with a work piece on said spindle, a cam mounted on said swinging frame and rotated in timed relation to said work piece spindle, and means engaging said cam to simultaneously oscillate said roller and pulley about parallel axes normal to the axis of rotation of said model and work piece spindle.

4. A finishing machine for turbine blades comprising in combination, a base, a slide movable horizontally thereon, a swinging carriage mounted on said slide, two shafts on said carriage mounted parallel to the axis of oscillation of said carriage, means to rotate said shafts simultaneously in the same direction and at the same speed, a model and work piece spindle mounted on one shaft, a cam mounted on said second shaft, a model follower mounted on said base, an abrasive members mounted on said base engaging said work piece, and means to simultaneously oscillate said model follower and abrasive member about parallel axes normal to the rotation of said model and work piece spindle.

5. An abrasive machine comprising a base, rotating and swinging means for a model and work piece mounted in alignment with each other, a roller on said base traversing said model, an abrasive band passing over a pulley supported on said base and traversing said work piece, means to simultaneously oscillate said roller and pulley in synchronism with the rotation of said model and work piece, and means to traverse said model and work piece past said roller and pulley respectively while said model and work piece are free to swing about an axis parallel with the axis of rotation of said model and work piece to maintain contact of said model with its roller, whereby said abrasive band will contact and finish the surface of said work piece to contours determined by said model.

6. An abrasive machine comprising a base, rotating and swinging means for a model and work piece rotatably mounted on a shaft in alignment with each other, a roller on said base traversing said model, an abrasive band passing over a pulley supported on said base traversing said work piece, means to simultaneously oscillate said roller and pulley in synchronism with the rotation of said model and work piece spindle about an axis normal to the axis of rotation of said model and work piece, and means to traverse said model and work piece past said roller and pulley respectively while said model and work piece are free to swing about an axis parallel with the axis of rotation of said model and work piece to maintain contact of said model with its roller, whereby said abrasive band will contact and finish the surface of said work piece to contours determined by said model.

7. A blade finishing machine comprising a base, a slide movable thereon, a swinging carriage on said slide, a model and work piece spindle rotatably mounted on said carriage on an axis parallel to the axis of oscillation of said carriage, a model following roller on said base, a traveling abrasive band, a pulley supported on said base over which said abrasive band passes while in engagement with said work piece, a cam rotatably mounted on said swinging frame on an axis parallel to the axis of said work piece and model, and means actuated by said cam to control the speed of rotation of said work piece spindle.

8. A blade finishing machine comprising a base, a slide movable thereon, a swinging carriage on said slide, a model and work piece spindle rotatably mounted on a horizontal axis on said carriage, a model following roller on said base, a traveling abrasive band, a pulley supported on said base over which said abrasive band passes while in engagement with said work piece, a cam rotatably mounted on said swinging frame for moving said model and work piece axially, a motor to rotate said model and work piece while said model and work piece are maintained in contact with said roller and abrasive band respectively, and means to control the speed of rotation of said motor during each rotation of said work piece.

9. A blade finishing machine comprising a base, a slide movable thereon, a swinging carriage on said slide, a model and work piece spindle rotat-

ably mounting said model and work piece on a common axis on said carriage, a model following roller on said base, a traveling abrasive band, a pulley supported on the base over which said abrasive band passes while in engagement with said work piece, a cam rotatably mounted on said swinging frame for moving said model and work piece axially, a motor to rotate said model and work piece while said model and work piece are maintained in contact with said roller and abrasive band respectively, a cam rotatable at the same speed as said work piece, and speed controlling means for said motor, whereby the speed of rotation of said work piece may be varied during each revolution while said work piece is being traversed axially past said abrasive band.

10. A blade finishing machine comprising a base, a slide movable thereon, a swinging carriage on said slide, a model and work piece spindle rotatably mounting said model and work piece on a common axis on said carriage, a model following roller mounted in said base, a traveling abrasive band engaging the surface of said work piece, means to continuously traverse said model and work piece simultaneously past said roller and abrasive band, and supplementary means comprising a face cam on said work spindle to move said model and work piece axially back and forth during each rotation thereof during said continuous traversing movement while said band is operating on portions of the blade adjacent its attaching end.

11. A blade finishing machine comprising a base, a slide movable thereon, a swinging carriage on said slide, a model and work piece spindle rotatably mounting said model and work piece on a common axis on said carriage, a model following roller mounted in said base, a traveling abrasive band engaging the surface of said work piece, means to continuously traverse said carriage and slide axially during the finishing operation, and supplemental means comprising a face cam on said work spindle to move said carriage axially back and forth limited distances when

the band is operating adjacent one end of said blade, said back and forth motion taking place during each rotation of said work piece.

12. A blade finishing machine comprising a base, a slide movable thereon, a swinging carriage on said slide, an operating slide for said first mentioned slide and carriage, a model and work piece spindle rotatably mounting said model and work piece on a common axis on said carriage, a model following roller mounted in said base, a traveling abrasive band engaging the surface of said work piece, means to continuously move said operating slide in one direction during operation, latching means for coupling said first mentioned slide and operating slide together for movement in unison, means to uncouple said slides when said band is operating adjacent one end of their travel, and a face cam on said carriage rotatable with said model and work piece spindle engaging a follower on said operating slide, whereby when said first mentioned slide and carriage are uncoupled from their operating slide, said model and work piece spindle, during each rotation, will be moved axially back and forth independently of said operating slide.

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