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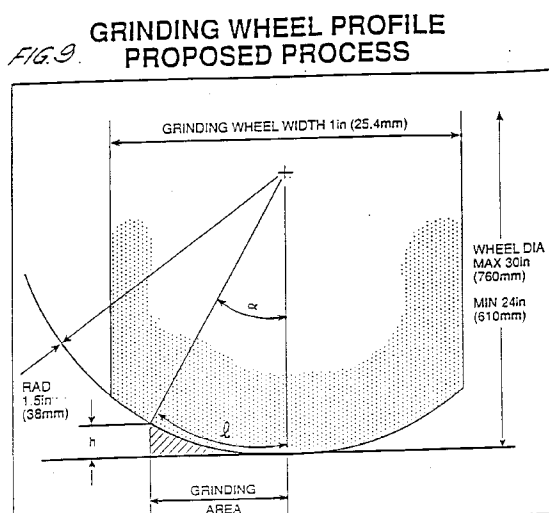
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54 Improvements in or relating to methods of grinding blade tips of turbine/compressor rotors.

57 The disclosure relates to a method of grinding blade tips of a turbine or compressor rotor, comprising the steps of spinning a rotor having one or more sets of blades to be ground on its axis, and using a grinding wheel which is narrower than the blades to be ground and has a convexly curved grinding periphery as seen as cross section. The grinding wheel is rotated about an axis parallel to the rotor axis and the wheel and rotor are moved relative to one another parallel to the axes of the rotor and wheel and in a feed direction orthogonally to the axis of the rotor and wheel to grind the blade tips of the rotor to a required dimension and profile which may be flat, angled, convexly or concavely curved with a simple or complex curvature.



This invention relates to methods of grinding blade tips of turbine/compressor rotors.

Most aircraft gas turbine engines, as well as axial flow turbo-machines used in many other applications have within them disks or rotors which carry a multiplicity of removable or fixed blades. Such structures are used in both compressor and the turbine parts of the engine to respectively compress and expand the working fluid. In some instances the rotating blades have shrouds at their outermost tips and are connected at these locations. More commonly, modern engines have blades that lack shrouds and are only supported at their roots in a rotor disk or drum.

For high efficiency, it is desirable to have the closest possible fit between the tips of the rotating blades and the sealing structure of the circumscribing case of originally manufactured engines. During use, especially during the manoeuvres which aircraft accomplish, there is occasionally rubbing between the blades and the circumscribing abradable sealing ring. In addition, other degradation of the blades occurs as an inevitable result of long hours of use. As a result, the clearance between the blade tips and the case are increased and it is an object of engine overhaul to restore these clearances. To achieve good fits the rotor blades must be precisely ground to within $\pm 0.001''$ ($\pm 0.025\text{mm}$) or less so that they are all at a constant radial distance from the centre line of the engine. This presents a substantial machining problem, both in original parts manufacture and in overhaul.

While the tolerances sought currently are tighter than previously, there has always been a desire to have bladed rotors fit well. In the main this has been achieved by separately machining rotors and blades to close tolerances but this has resulted in an accumulation of tolerances greater than now is acceptable. Consequently, it is currently preferred to machine blades while they are a part of a disk or drum and blade assembly. As the blades are removable type, they necessarily fit somewhat loosely in the rotor disk or drum. Thus, during machining, shims have been placed under the blades to thrust them radially outward to approximately the position they assume during use. Low speed workpiece rotation, common in cylindrical grinding, also tends to have the same effect but in neither case is the seating comparable to that obtained during high speed engine rotation. Typically, horizontal rotary grinding machines have been used to grind the assemblies while they rotate at no more than a few hundred revolutions per minute.

However, the forces accompanying slow rotation or from use of shims are not powerful. It has been found that the older tip grinding process produces a variation in length at individual blades which is too great, much more than $\pm 0.001''$ ($\pm 0.025\text{mm}$) on an 18" to 39" (450mm to 1000mm) diameter rotor assembly. Additionally, the modern type rotor construction the slot which receives the multiplicity of blades runs circumferentially around the rim of the disk or drum. With this configuration, it is not practical to insert shims.

Thus, during machining either the blades and their retention slots have been configured to limit radial inward movement or resilient cushions have been used to sandwich the rotor and thus capture the blades during machining. For the reasons indicated above neither of these approaches is entirely satisfactory in producing the desired accuracy.

The clearance between the rotor blade tips and the outer housing has a critical bearing on engine performances. The main advantages are, improved specific fuel consumption and increased thrust. In some cases as much as 1%. Additionally, closer running tolerances result in significantly reduced engine noise.

In order to achieve accurate clearance with minimum stock removal the grinding process has to simulate in so far as is practical, the operating conditions of the engine and also hold the blades out with sufficient force to withstand the grinding forces imposed on the blades for grinding to take place.

The grinding action produces radial grinding force (FN). The centrifugal force (Mw^2r) generated even by the lightest blade at high rotating speed must be able to compensate the grinding force applied. In addition grinding process produces a burr on each blade which has to be removed.

The methods previously used have involved conventional, universal or modified grinding machines. These methods have been extremely inaccurate and time consuming. A normal universal grinder is not suitable, due to the fact the wheelhead pivot axis is remote from the grinding wheel, resulting in a need to provide for angular adjustment to a high accuracy to establish the correction required in both radial and longitudinal axes for the various stage angles. The problem is further amplified by the fact the blade assemblies are referenced to a longitudinal dimension from which a datum and angular accuracies are required to be held within ± 2 minutes of arc.

A further problem involves the means for measuring the diameter of a rotor assembly. This function is required before, during and after the grinding operation. The measuring system has to take readings of individual blades while the workpiece is rotating at a relatively high velocity of typically 2000 in/sec. (50.8 m/sec.).

Many manufacturing and overhaul facilities use conventional gauging associated with machine shops, including in recent times the use of various non-contact electro-optical measuring systems which allows measurements to be taken while the workpiece is rotating at low velocity of about 150 in/sec. (3.8 m/sec.). Individual blade dimensions measured under static or trivial rotational speeds will not be indicative of those in a rapidly

rotating structure.

This invention provides a method of grinding blade tips of a turbine or compressor rotor, comprising the steps of spinning a rotor having one or more sets of blades to be ground on its axis, providing a grinding wheel which is narrower than the blades to be ground and having a convexly curved grinding periphery as seen as cross section, rotating the grinding wheel about an axis parallel to the rotor axis and moving the grinding wheel and rotor relative to one another in a traverse direction parallel to the axis of the rotor and wheel and a feed direction orthogonally to the axis of the rotor and wheel to grind the blade tips of the rotor to a required dimension and profile which is flat, angled, convexly or concavely curved with a simple or complex curvature.

Preferably, the grinding wheel is moved simultaneously in the feed direction with movement of the rotor in the traverse direction to create said tapered or curved forms.

The wheelhead and or rotor may be moved incrementally in micro steps in grinding a blade tip to the required profile.

Preferably, the grinding wheel is moved with a varying rate in relation to traverse of the rotor to create said curved profiles.

It is further preferred that the blade tips of the rotor are ground to a required dimension and profile in a series of grinding operations.

In any of the above methods, the grinding wheel may be dressed between grinding operations.

In addition a deburring operation may be carried out on the blade tips after grinding.

In a specific method according to the invention the blade lengths may be measured between grinding operations to determine the remaining amount of material to be removed in a succession of operations.

The following is a description of some specific embodiments of the invention, reference being made to the accompanying drawings, calculations and tables in which:

Figure 1 is a perspective view of a grinding apparatus for grinding blade tips of a multi-stage turbine/compressor rotor.

Figure 2 is a diagrammatic illustration of an existing process for a stage without angle that is with parallel blade tips;

Figure 3 is a diagrammatic illustration of an existing process for a particular stage and blade tip angle;

Figure 4 is a diagrammatic illustration of the process according to the invention for grinding the blade tips to a requested angle for a particular rotor stage;

Figure 5 is a similar illustration to Figure 3 for stage with parallel blade tips;

Figure 6 is a diagrammatic illustration of part of a multi-stage rotor on which significant dimensions are indicated;

Figure 7 is a diagrammatic illustration of two blades in successive stages on which significant dimensions are indicated;

Figure 8 is an illustration of the forces acting during cylindrical grinding;

Figure 9 is an illustration of a grinding wheel profile according to the invention on which significant dimensions are identified; and

Figure 10 is a diagram showing stock removal on a rotor at stage 3 utilising the method of the invention.

Reference is made firstly to Figure 1 of the drawings which shows a computer controlled machine tool suitable for grinding blade tips of a multi-stage turbine or compressor rotor. The machine tool comprises a rigid base 10 on which an elongate table 11 is mounted for linear movement in the direction of the axis denoted by the letter z on Figure 1. At one end of the table a work drive unit 12 is mounted including a rotary chuck 13 to receive one end of the rotor shaft and having a motor drive 14. At the other end of the table there is a pedestal 15 on which a freely rotatable chuck 16 is mounted in alignment with chuck 13 to support the other end of the rotor. Both the work drive unit and the pedestal are adjustable along the table to cater for different rotor lengths.

A wheelhead unit 17 is mounted part-way along the table on a further base 18, the wheelhead including a rotatable grinding wheel 19 having a motor drive 20, de-burr unit 21 and dresser unit 22. A blade measuring unit 23 is provided on the opposite side of the table to the wheelhead.

The wheelhead is mounted on the base for feed/withdraw movement in the direction of the axis denoted by the letter x on Figure 1 towards and away from the work piece. The grinding wheel itself is retractable on the wheelhead unit in the direction indicated by the arrow A to engage with the dresser unit located at the rear of the wheelhead for dressing the wheel when required. The grinding wheel is rotated in the direction indicated by the arrow B on the wheel by the drive motor so that the blade tips at each stage move continuously past the grinding wheel to be ground by the wheel.

The forces acting during cylindrical grinding are illustrated on the diagram of Figure 8 and are as follows:

FN - Radial Grinding Force

FT - Tangential Grinding Force

FA - Axial Grinding Force

FG - Resultant Grinding Force

The cutting force in cylindrical grinding are resolved into tangential, radial and axial force components relative to the workpiece and wheel.

The tangential force together with the peripheral speed of the wheel mainly determines the power required for grinding.

The radial force, which is normally the largest component, is of importance because of its direct effect on the machine and workpiece deflections.

The axial force on the other hand is generally very small by comparison with the tangential and radial components and therefore need not be considered.

Grinding forces have been the subject of much study. Investigations have shown that the radial force lies between 2.5 to 3 times the tangential force.

Conventional blade tip grinding machine tools currently in use employ a square profile grinding wheel having a width in excess of the width of the blade tip to be ground so that the whole of the tip can be acted at once by a simple feed movement of the grinding wheel transverse to the direction of axis of rotation of the rotor. This is illustrated diagrammatically in Figure 2 of the drawings in which the grinding wheel is indicated at 25 and the blade tip at 26. The axis of rotation of the grinding wheel extends parallel to the axis of rotation of the rotor and the grinding wheel is fed in the direction of the x-axis into the blade tips to remove the stock indicated at 27. In a typical turbine/compressor rotor, the blade tips of certain stages along the rotor will be parallel to the rotor axis and others will be angled to conform to the encircling casing. The wheelhead is rotatable about the vertical or y-axis to angle the grinding wheel as illustrated in Figure 3 to grind the angled ends of the blade tips at each stage along the rotor. The arrangement for angling the wheelhead may, for example, be in accordance with the construction described and illustrated in U.K. Patent No. 2076323.

These arrangements enable only a limited range of profiles to be formed on the tip blades, that is parallel or angled cut, and in many instances it would be beneficial to be able to form other profiles including curved profiles to ensure that the blade tips conform closely to the profile of the encircling casing in which they operate.

The electric motors for creating the movement of the wheelhead in the direction of the x-axis and the movement of the table in the direction of the z-axis have controllers operated under the direction of the machine computer which provide both rapid traverse for feed/withdrawal between grinding operations and precision incremental movement at constant or varying rates in accordance with the profile of the blade tip to be ground. The simplest blade form is a blade without an angled end, that is a blade end parallel to the rotor axis as illustrated in Figure 3. In this case, the blade tip is reduced to the required dimension by a series of passes in which the table is traversed with a continuous movement past the blades with incremental advances of the wheel between passes until the tips of the blades at that stage have been ground to the requested dimension. Figure 4 shows an angled blade end and in this case the grinding wheel is advanced to a location offset to the shorter said of the blade to a location corresponding to the full depth of cut required on the blade at that end. The grinding operation is then commenced with the table moving the blade into the wheel continuously or incrementally at a constant rate and the wheel head retracting continuously or incrementally at a constant rate determined in accordance with the rate of movement of the table. Again the blade tip is subjected to a succession of grinding operations until the tip has been ground to the requisite depth of cut and angle on the blade end as illustrated in Figure 4.

The following table refers to the dimensions of the grinding wheel identified on Figure 9 and relates the depth of cut h to the length of grinding area 1.

Depth of Cut h in (mm)	Angle α Deg	Length of grinding area ℓ in (mm)
0.050 (1.270)	15°	0.392" (10.0)
0.005 (0.127)	4.7°	0.123" (3.1)
0.002 (0.051)	3°	0.079 (2.0)
0.001 (0.025)	2.1°	0.055 (1.4)
0.0005 (0.013)	1.5°	0.039 (1.0)
0.0002 (0.005)	1°	0.026 (0.7)
0.0001 (0.002)	0.7°	0.019 (0.5)

For curved blade tips the table and wheelhead are moved incrementally in microsteps and a number of points up to and in some instances in excess of ninety are calculated which the wheel periphery must reach on the blade tip taking into account correction for changes in wheel radius angle of contact. The table and wheelhead rates of movement are calculated so that the wheel periphery and blade tip reach each point simultaneously. The curve is therefore created by a succession of a large number of very small flats. The computer has a radius/circular interpolation program which calculates the points which the grinding wheel must reach in traversing the end of the blade tip and for controlling the incremental movement of the wheelhead and table with the table moving at a constant feed rate and the wheelhead feed rate varying in order to produce the requisite curved profile on the blade tip. Thus the program calculates the feed rate of the wheelhead and this changes in order to make the line of wheel contact move from one point to the next as the table moves at a fixed feed rate. Again the table is moved in a succession of passes with respect to the grinding wheel until the blade tips at that stage have been ground to the required profile and dimension.

Figure 6 illustrates a typical rotor and the following is a table of typical data for such a rotor.

Stage	Angle K	Radius J in (mm)	Dia D in (mm)	Dim H in (mm)	Grinding R.P.M.	Surface Speed ft/min (m/s)	Surface Speed in/sec
1	14°04'	11.848" (300.94)	23.696" (601.88)	-0.221 (-5.61)	1615	10 019 (50.9)	2004
2	13°48'	11.133 (282.78)	22.266 (565.56)	2.809 (71.35)	1723	10 043 (51)	2008
3	10°01'	10.643 (270.33)	21.286 (540.66)	5.387 (136.83)	1800	10 030 (50.9)	2006
4	10°56'	10.258 (260.55)	20.516 (521.10)	7.750 (196.85)	1855	9 965 (50.6)	1993
5	8°36'	9.987 (253.67)	19.974 (507.34)	9.788 (284.62)	1901	9 940 (50.5)	1988
6	5°16'	9.711 (246.66)	19.422 (493.32)	11.892 (302.06)	1954	9 935 (50.5)	1987
7	4°39'	9.591 (243.61)	19.182 (487.22)	13.579 (344.91)	1978	9 933 (50.5)	1987
8	2°22'	9.516 (241.71)	19.032 (483.41)	15.259 (387.58)	2000	9 965 (50.6)	1993
9	0°00'	9.488 (241.00)	18.976 (481.99)	16.939 (430.25)	2000	9 936 (50.5)	1987

Figure 7 illustrates a pair of typical blades in successive stages of the rotor and the following is a table of typical data for the blades.

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The automatic cycle is fully controlled by the NC (numeric control) part program. A typical cycle is as follows:-

1. Load the rotor into chucks in the floor mounted loading fixture.
2. Transfer the rotor and chucks to the machine and fasten into machine pedestals.
3. Check the runout of the rotor and adjust using the chucks if necessary.
4. Fasten pedestal half caps and secure rotor sliding guard.
5. Press the machine cycle button to start machining.
6. The machine will check that all cycle start conditions are valid.
7. The control will request the grinding wheel to be started if a grind is to take place and the grinding wheel is not already running.
8. The work motor will be started after a time period when the chuck bearings have been lubricated.
9. The rotor will run up to programmed speed.
10. The table slide will traverse to the start grind position plus the distance set above finished size for the particular stage (stage 1).
11. The wheelhead slide will advance from the clear point (retracted) position to the start grind position plus the distance set above finished size.
12. The table and the wheelhead slides will traverse the grinding wheel across the stage face (linear interpolation) grinding the blades at programmable rates and distance set up in the part program. The distance set at this point say 0.015 ins. (0.38mm) above the final size.
13. The wheelhead is retracted to the clear point position.
14. The wheelhead slide will traverse to dress position. Dressing is from a rotating diamond roller mounted to the underslide at the rear of the grinding wheel. After dress cycle the wheelhead slide will traverse to the clear position.
15. Steps 9 to 14 will be repeated for each stage to be ground.
16. The grinding wheel and the rotor will stop.
17. The de-burr unit mounted on the wheelhead slide is advanced into position (in front of the grinding

wheel).

18. The de-burr will run to speed and the rotor will run up to programmed de-burr speed.

19. The table slide will traverse to the start de-burr position for the particular stage (stage 1).

20. The wheelhead slide is advanced until the brush makes contact with the blades at a programmable torque value set in the part program.

21. The table and the wheelhead slides will traverse the de-burr brush across the stage face (linear interpolation).

De-burr takes place in both directions of rotation of the brush for a programmable time.

22. The wheelhead is retracted to the clear point position.

23. Steps 19 to 22 will be repeated for each stage to be de-burred.

24. The de-burr brush and the rotor will stop.

25. The de-burr unit is retracted.

26. Steps 8 to 13 will be repeated for Stage 1. The distance set at this point say 0.010 ins. (0.254mm) above final size.

27. The table size is positioned for laser gauge calibration.

28. The gauge is calibrated against gauge calibration blocks which are fitted on the table.

29. The table slide is positioned and the gauge slide is advanced to measure the radius of each blade. Using the gauge measurement, the wheelhead slide position is determined and updated.

30. The gauge slide is retracted.

31. Step 14 will be repeated.

32. Steps 10 to 13 will be repeated.

The distance set at this point say 0.005 ins.

(0.127mm) above final size.

33. Steps 26 to 32 will be repeated for each stage to be ground.

34. Steps 16 to 25 will be repeated for each stage to be de-burred.

NOTE: At this point of the machine cycle each stage to be ground is 0.005 ins. (0.127mm) above final size and de-burred.

35. Steps 9 to 12 and 29 to 30 will be repeated with feed increments of:-

0.003 ins. (0.076mm);

0.001 ins. (0.025mm);

0.0005 ins. (0.013mm);

0.0002 ins. (0.005mm);

0.0002 ins. (0.005mm);

0.0001 ins. (0.002mm);

to final size using the previous gauge measurement as a target to determine the size position (in-process gauging).

36. Step 14 will be repeated.

37. Steps 35 to 36 will be repeated for each stage to be ground.

38. A printout is produced showing the radius of each blade in a stage. Any blades out of tolerance are identified on the printout together with the average, maximum and minimum.

39. Steps 16 to 22 will be repeated for Stage 1.

40. Step 39 will be repeated for each stage to be de-burred.

41. Steps 24 to 25 will be repeated.

42. The table size is positioned at a location suitable for the rotor to be unloaded from the machine.

43. Unsecure the rotor sliding guard and pedestal half caps.

44. The rotor is removed from the machine, placed in the floor mounted loading fixture and chucks unclamped.

Figure 10 illustrates a succession of grinding operations on a rotor stage and the following is a table of data for a typical grinding cycle:

Wheel position see Figure 10	Depth of cut ins (mm)	Distance from size ins (mm)	Linear interpolation speed ins/mm (mm/sec)	Blade length x thickness ins (mm)	Volume of stock in ³ (mm ³)	Volumetric removal rate "Q" W in ³ /mm/in (mm ³ /sec/mm)	Time Sec
GRIND 1	0.050 (1.27)	0.015 (0.38)	0.10 (0.042)	0.83x0.1 (21x2.5)	41.0x10 ⁻⁴ (67)	11.0x10 ⁻⁴ (0.011)	600
DE-BURR, DRESS							225
GRIND 2	0.005 (0.127)	0.010 (0.254)	0.25 (0.105)	0.83x0.1 (21x2.5)	4.1x10 ⁻⁴ (6.7)	8.4x10 ⁻⁴ (0.009)	240
GAUGE, DRESS							105
GRIND 3	0.005 (0.127)	0.005 (0.127)	0.25 (0.105)	0.83x0.1 (21x2.5)	4.1x10 ⁻⁴ (6.7)	8.4x10 ⁻⁴ (0.009)	240
DE-BURR, GAUGE, DRESS							285
GRIND 4	0.003 (0.076)	0.002 (0.051)	0.25 (0.105)	0.83x0.1 (21x2.5)	2.5x10 ⁻⁴ (4)	8.0x10 ⁻⁴ (0.008)	240
GAUGE, DRESS							105
GRIND 5	0.001 (0.025)	0.001 (0.025)	0.28 (0.120)	0.83x0.1 (21x2.5)	8.3x10 ⁻⁵ (1.32)	4.3x10 ⁻⁴ (0.004)	210
GAUGE							60
GRIND 6	0.0005 (0.013)	0.0005 (0.013)	0.28 (0.120)	0.83x0.1 (21x2.5)	4.1x10 ⁻⁵ (0.68)	3.0x10 ⁻⁴ (0.003)	210
GAUGE							60
GRIND 7	0.0002 (0.005)	0.0003 (0.007)	0.28 (0.120)	0.83x0.1 (21x2.5)	1.6x10 ⁻⁵ (0.263)	2.0x10 ⁻⁴ (0.002)	210
GAUGE							
GRIND 8	0.0002 (0.005)	0.0001 (0.002)	0.28 (0.120)	0.83x0.1 (21x2.5)	1.6x10 ⁻⁵ (0.263)	2.0x10 ⁻⁴ (0.002)	210
GAUGE							
GRIND 9	0.0001 (0.002)	0	0.28 (0.120)	0.83x0.1 (21x2.5)	0.8x10 ⁻⁵ (0.105)	1.3x10 ⁻⁴ (0.0016)	210
GRIND 10	0	0	0.28 (0.120)	0.83x0.1 (21x2.5)	0	0	210
GRIND 11	0	0	0.28 (0.120)	0.83x0.1 (21x2.5)	0	0	210
GAUGE, DOCUMENT SIZE, DE-BURR, DRESS							270
Approximate time per stage (sec)							3900
Strong possibility that the time cycle quoted will be improved after grinding trials							

* Assuming average blade thickness:

Stage 1, 2, 3, 4, 5. = approx .100 (2.5mm)
 " 6, 7, 8, 9 = approx .080 (2.0mm)

The machine auto cycle is controlled by a different part program for each rotor. These part programs are kept as a library of canned cycles, graphically illustrated, and selected using soft keys on the control, providing a user friendly man/machine interface. The library of screens or canned cycles is a self-contained module for grinding, dressing, de-burring and gauging.

Data is entered into the parameter column on each screen in response to clear text language prompts displayed at the bottom of each screen page. This is designed in such a way that subsequent alterations and modifications to suit changes in rotor size and to suit other rotors may be carried out by personnel who are not familiar with the machine part programming language.

The task of new and repair grinding has been specifically treated in the machine control. Program blocks

(or screens) may be summed together as required enabling the operator to choose which stages of a rotor need to be ground, de-burred or measured.

A typical repair sequence will be put to a rotor in the machine and do a measurement cycle. It may be necessary to use the de-burr to clean up each of the stages to be measured if the reflectivity of the blade tips is too low for a reliable determination of size by the laser gauge. The blades or stages to be replaced will then be identified from the laser gauge print out and the rotor removed for the necessary work to be undertaken. The rotor will then be re-ground, only the stages that have been re-worked will need to be ground but a full measurement cycle should be undertaken to provide a complete documentation of the rotor.

There is provision in the control for a small offset to be applied to any stage of the rotor being ground. The size of the offset is designed to allow for the clean up of blades in a repair grind situation on blades that may not need replacing.

ADVANTAGES

Reduced contact between the blade and the grinding wheel accordingly reduces the grinding force (FN) and the residual stresses on the blade. An element of great importance in blade tip grinding.

- * Reduced machine content,
3 axis machine against 6 axis required for the existing process.
Reduction in the cost of the machine hence fast return on investment.
- * One wheel profile able to grind different rotors, thus reducing tooling cost and change-over time, i.e. different width wheels, diamond rollers, diamond roller spindles, wheel flanges, etc.

DISADVANTAGES

- * Increased time cycle.

Claims

1. A method of grinding blade tips of a turbine or compressor rotor, comprising the steps of spinning a rotor having one or more sets of blades to be ground on its axis, providing a grinding wheel which is narrower than the blades to be ground and having a convexly curved grinding periphery as seen as cross section, rotating the grinding wheel about an axis parallel to the rotor axis and moving the grinding wheel and rotor relative to one another in a traverse direction parallel to the axes of the rotor and wheel and a feed direction orthogonally to the axis of the rotor and wheel to grind the blade tips of the rotor to a required dimension and profile which may be flat, angled, convexly or concavely curved with a simple or complex curvature.
2. A method as claimed in Claim 1, wherein the grinding wheel is moved simultaneously in the feed direction with movement of said rotor in the traverse direction to create said angled or curved forms.
3. A method as claimed in Claim 2, wherein the grinding wheel is moved with a varying rate in relation to traverse of the rotor to create said curved profiles.
4. A method as claimed in any of the preceding claims, wherein the wheelhead and/or rotor are moved incrementally in microsteps in grinding the blade tip to the required profile.
5. A method as claimed in any of Claims 1 to 4, wherein the blade tips of the rotor are ground to a wherein the blade tips of the rotor are ground to a required dimension and profile in a series of grinding operations.
6. A method as claimed in Claim 5, wherein the grinding wheel is dressed between grinding operations.
7. A method as claimed in Claim 5, wherein the grinding wheel is dressed during grinding.
8. A method as claimed in any of the preceding claims, wherein a deburring operation is carried out on the blade tips after grinding.
9. A method as claimed in any of Claims 1 to 7, wherein the blade tips are de-burred during grinding.
10. A method as claimed in any of the preceding claims, wherein the blade lengths are measured between

grinding operations to determine the remaining amount of material to be removed in a succession of operations.

- 5 **11.** A method as claimed in any of Claims 1 to 9, wherein the blade lengths are measured during grinding to determine the remaining amount of material to be removed in successive grinding operations.

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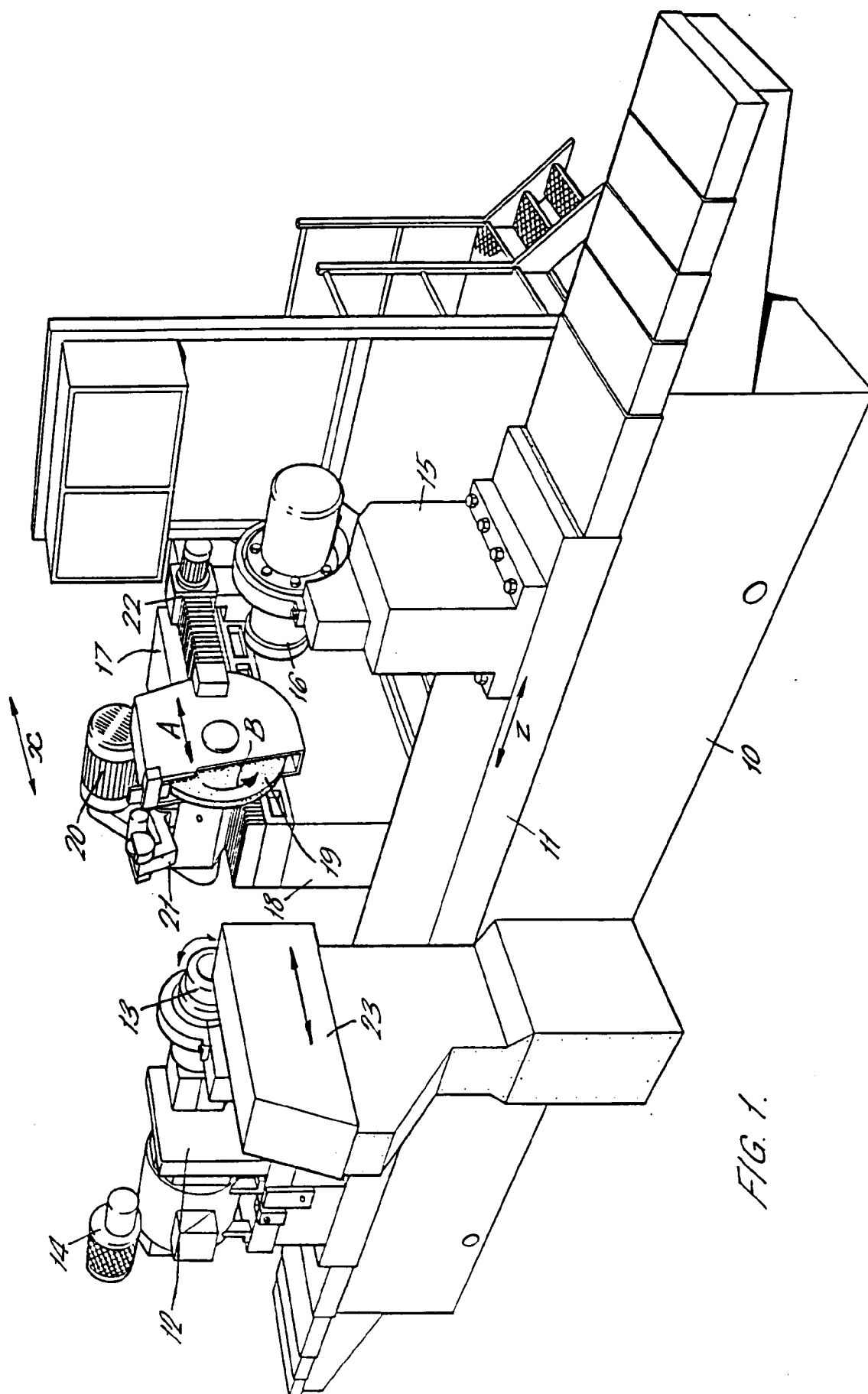
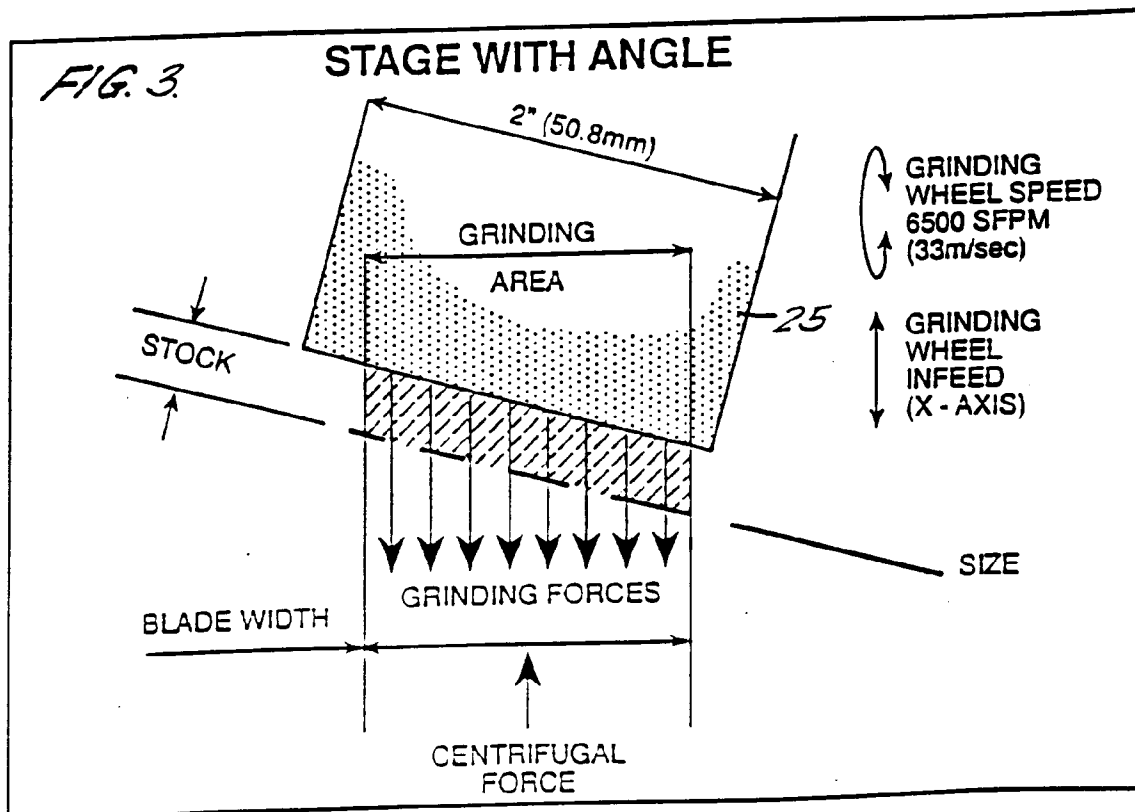
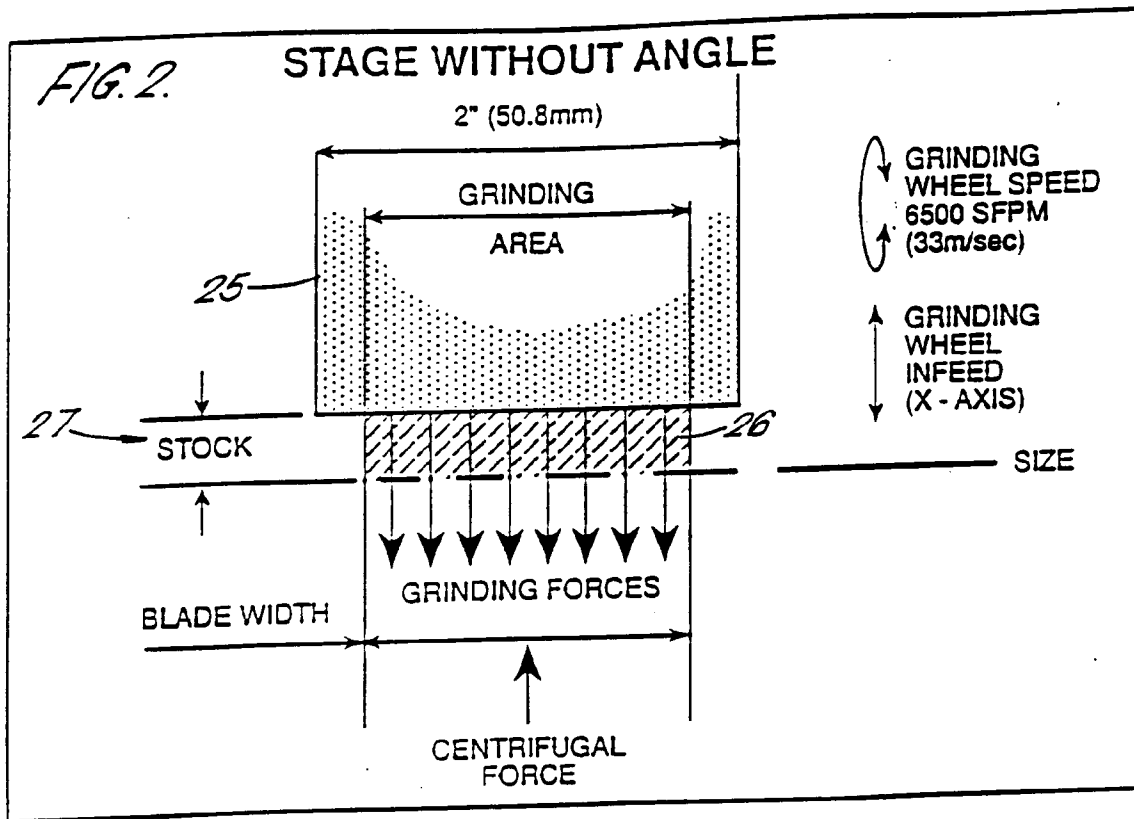
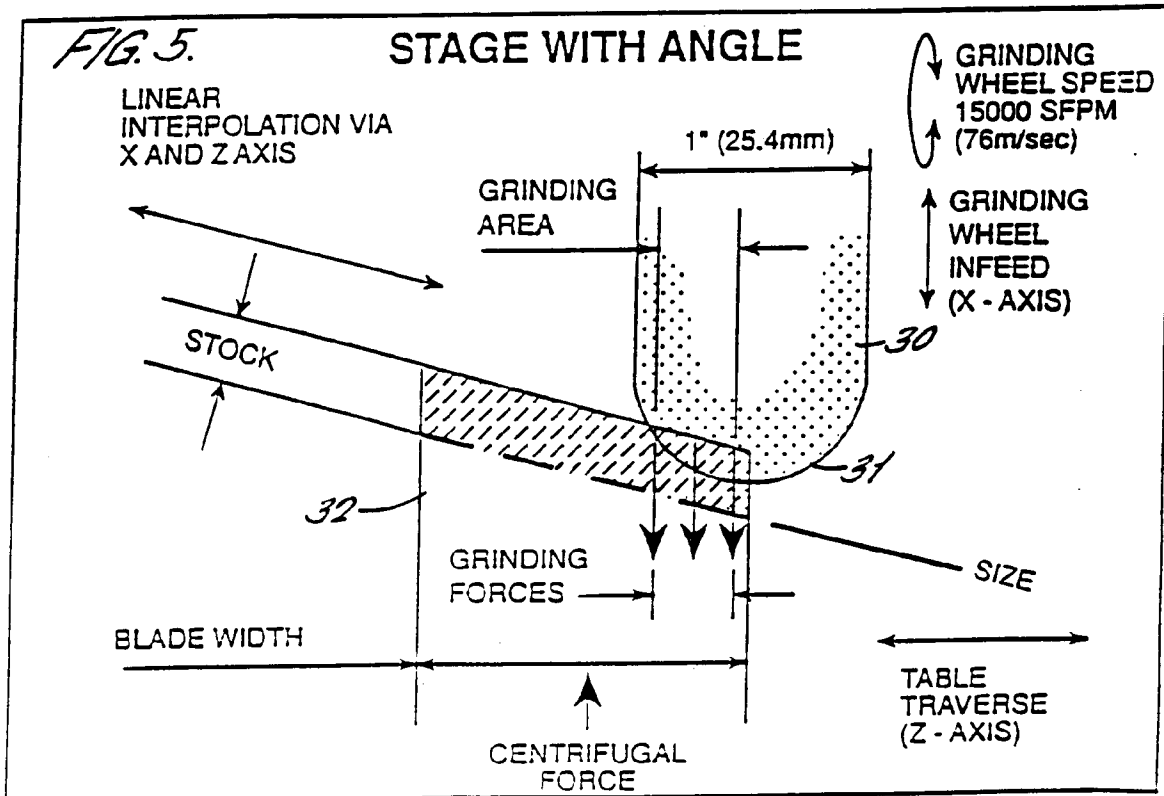
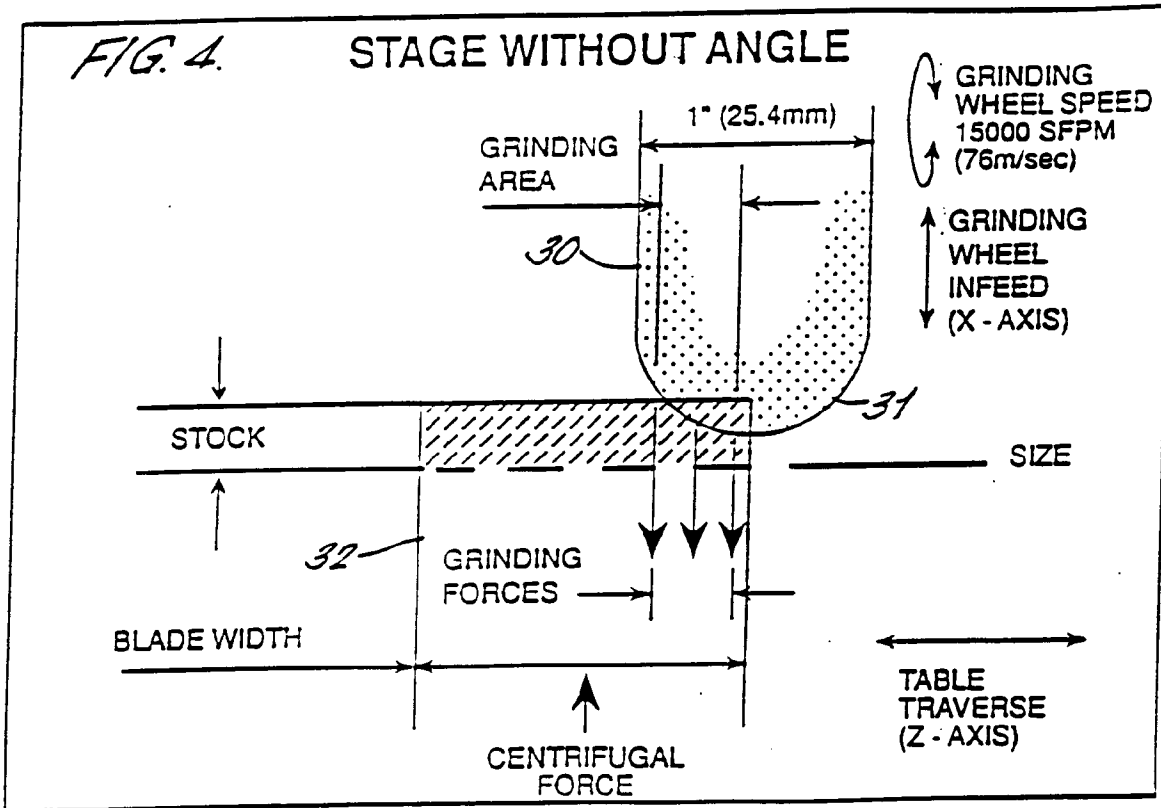


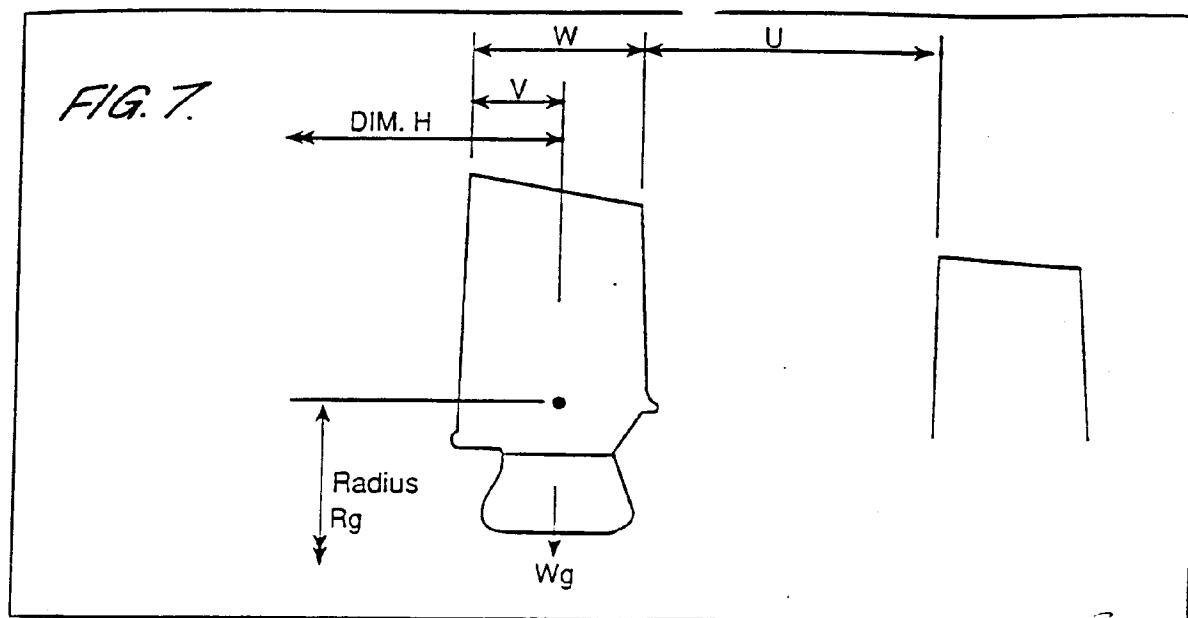
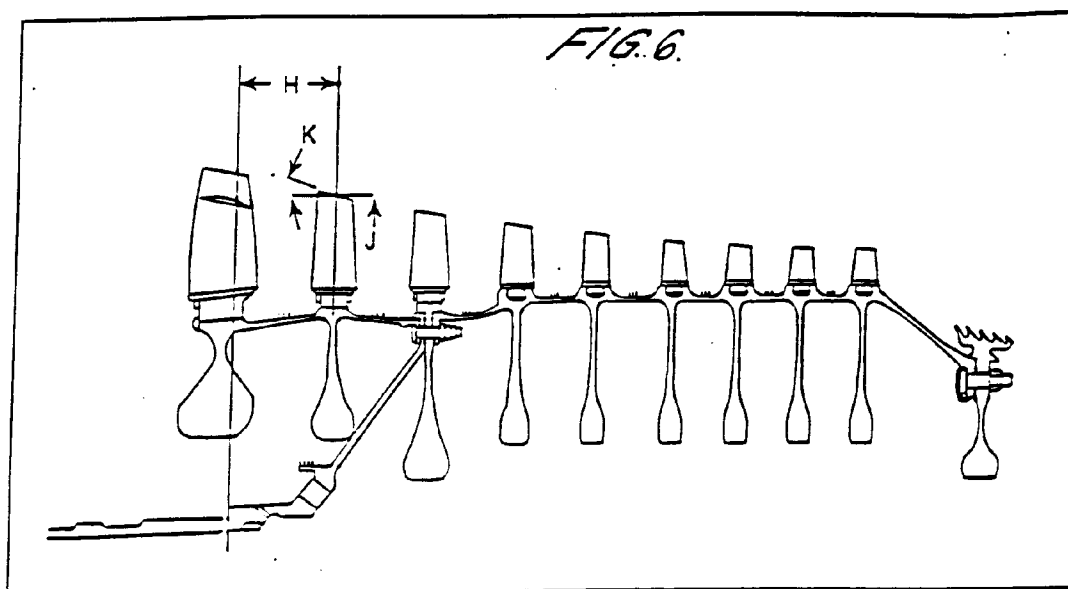
FIG. 1.

EXISTING PROCESS



PROPOSED PROCESS





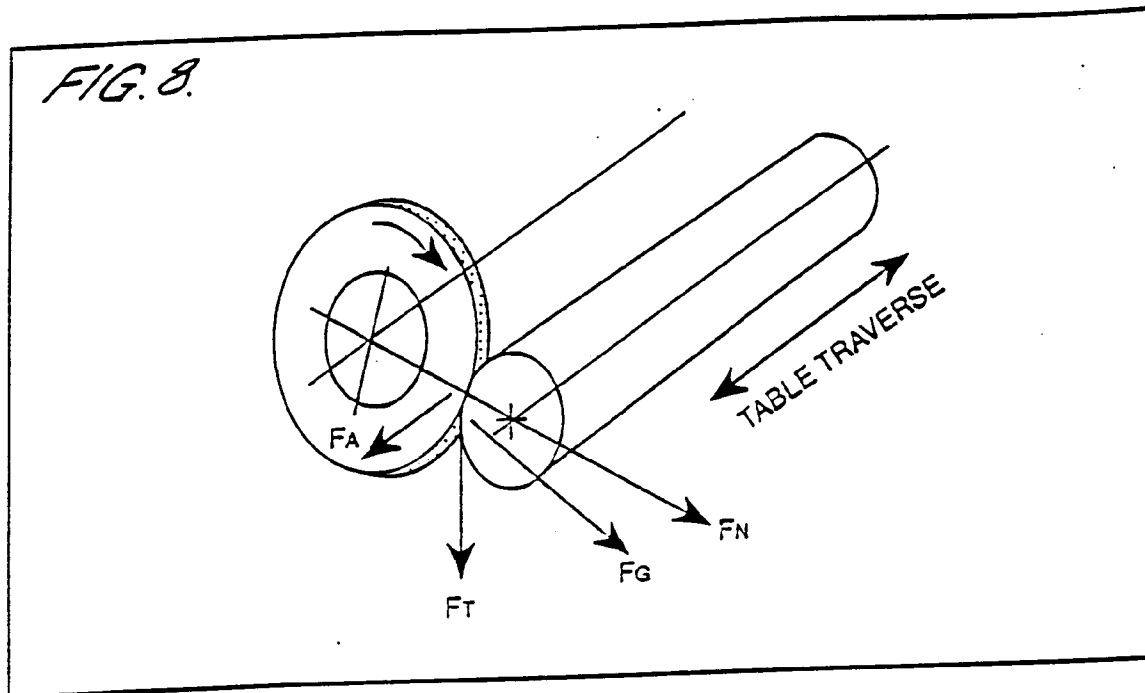


FIG. 9. GRINDING WHEEL PROFILE
PROPOSED PROCESS

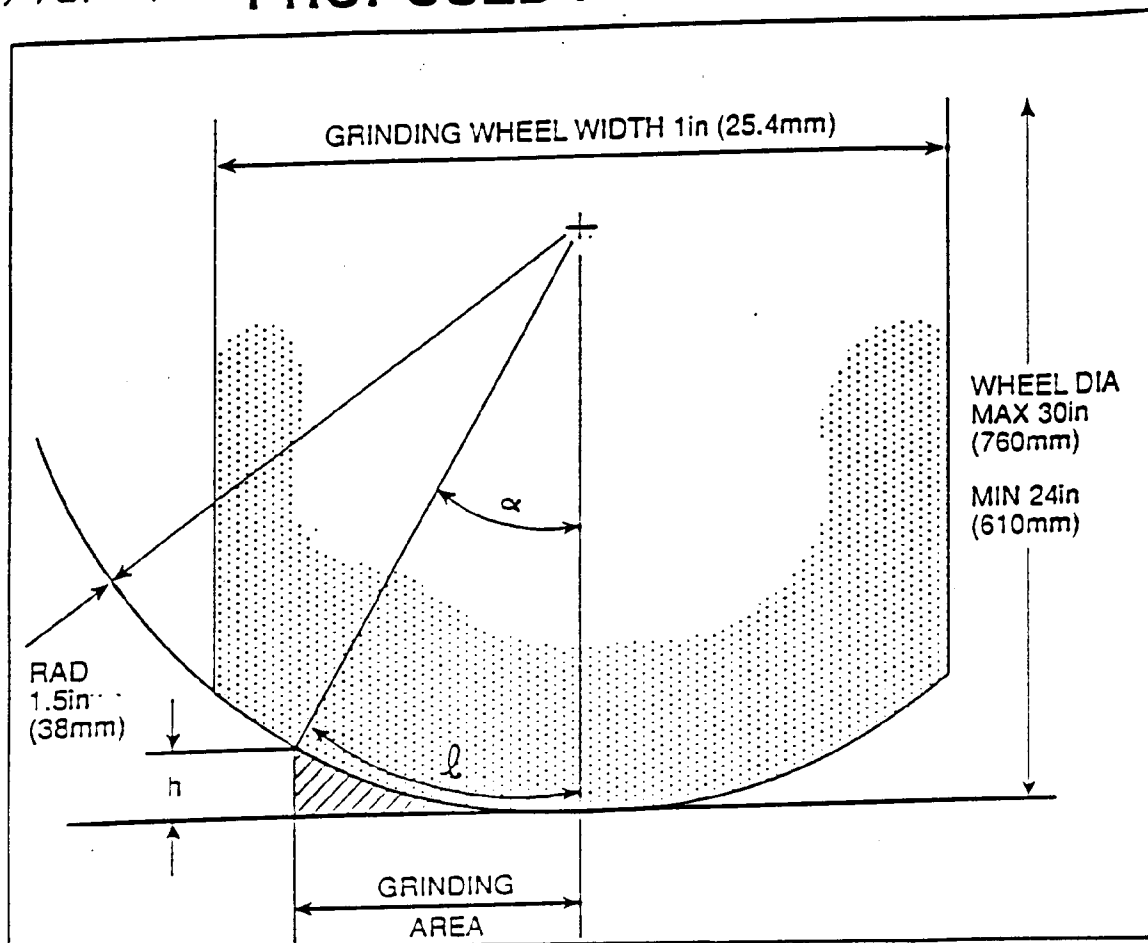
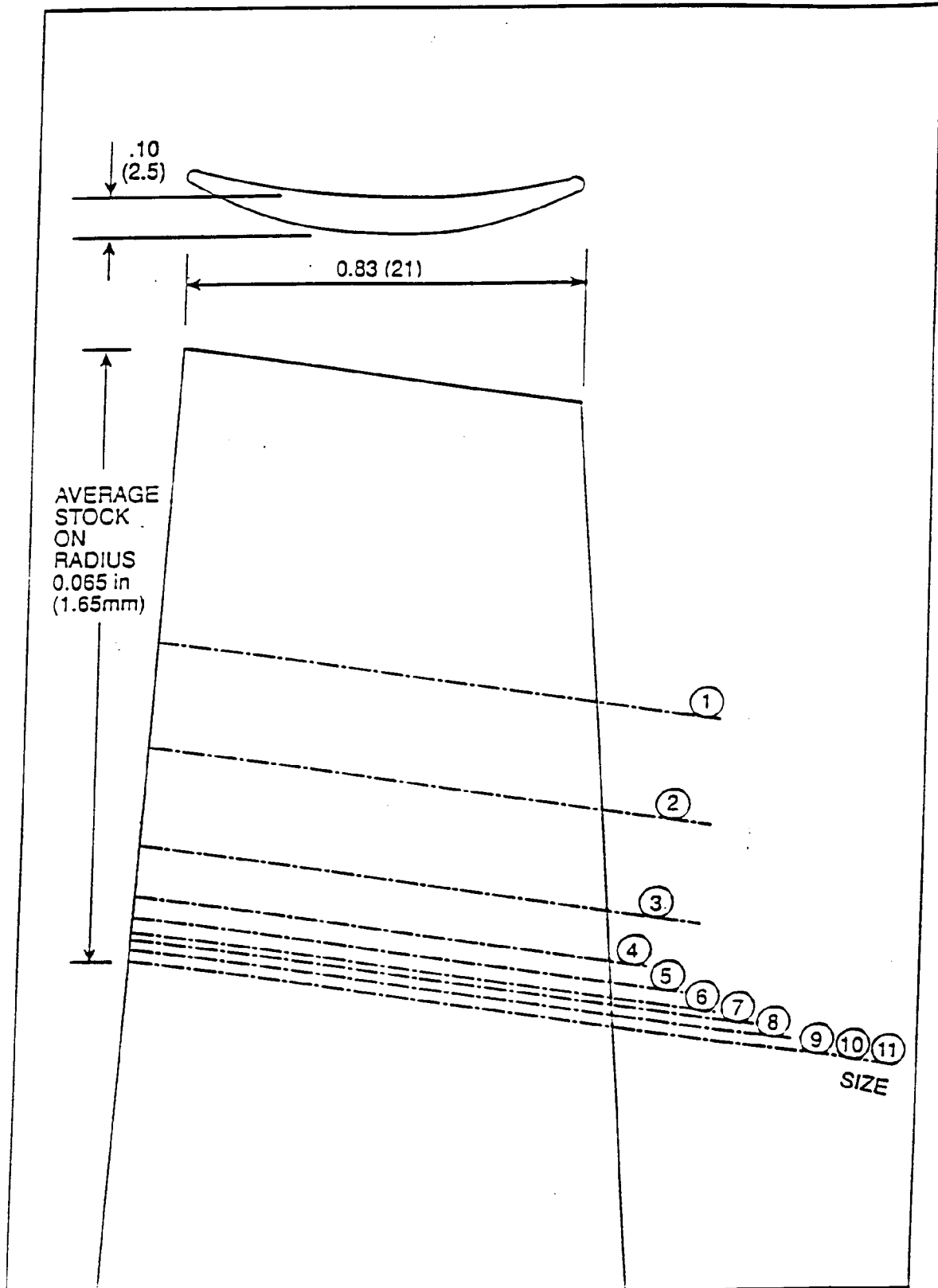


FIG. 10.

ROTOR - STAGE





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number

EP 93 30 7124

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	PATENT ABSTRACTS OF JAPAN vol. 12, no. 343 (M-741)(3190) 14 September 1988 & JP-A-63 102 864 (NGK INSOLATORS LTD) 7 May 1988 * abstract *	1-11	B24B5/36 B24B19/14
Y	EP-A-0 128 110 (UNITED TECHNOLOGIES CORPORATION) * claims 1-12; figures 1-5 *	1-11	
A	EP-A-0 441 627 (KOBELCO COMPRESSORS (AMERICA), INC.) * abstract; figures 1-6 *	1-4	
A	WERKSTATTSTECHNIK, ZEITSCHRIFT FÜR INDUSTRIELLE FERTIGUNG vol. 79, no. 8, August 1989, BERLIN DE pages 419 - 422 P. LÜTJENS 'Profilschleifen auf moderner CNC-Flachschleifmaschinen' * page 421, paragraph 4 - page 422, paragraph 5; figures 4,5,8 *	1-3	
A,D	GB-A-2 076 323 (KEIGHLEY GRINDERS (MACHINE TOOLS) LIMITED) * abstract; figures 1-3,9 *	1,6-9	
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 10 DECEMBER 1993	Examiner CUNY J.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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