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G. E. COMSTOCK, 3RD., ET AL

2,695,478

APPARATUS AND METHOD FOR GRINDING

Filed Dec. 29, 1952

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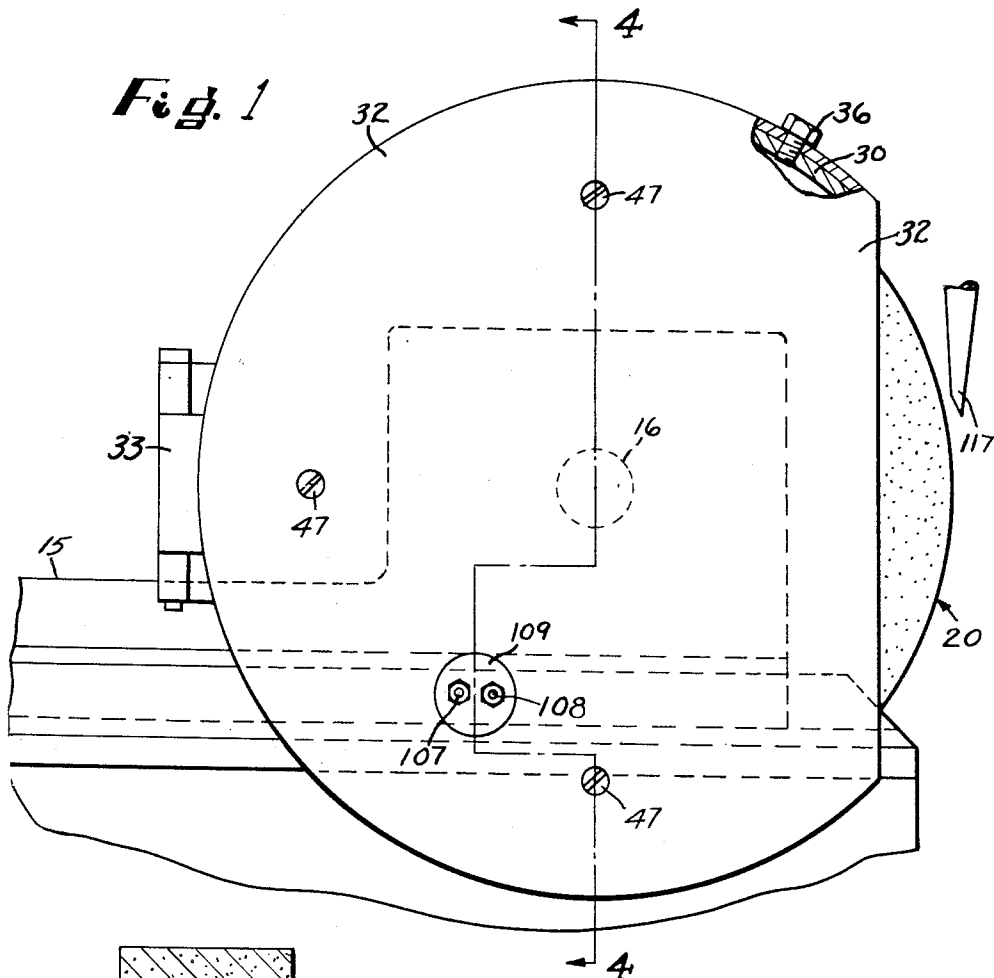
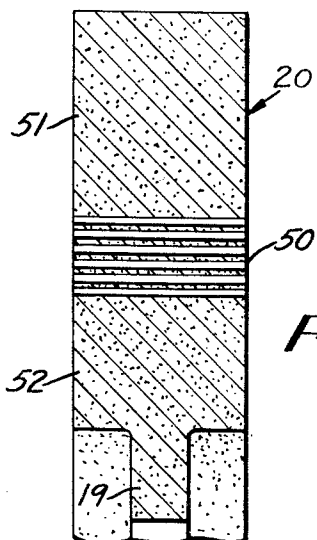
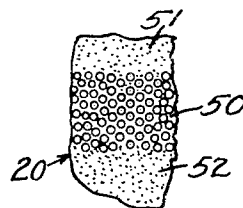


Fig. 2

Fig. 3

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5 Sheets-Sheet 2

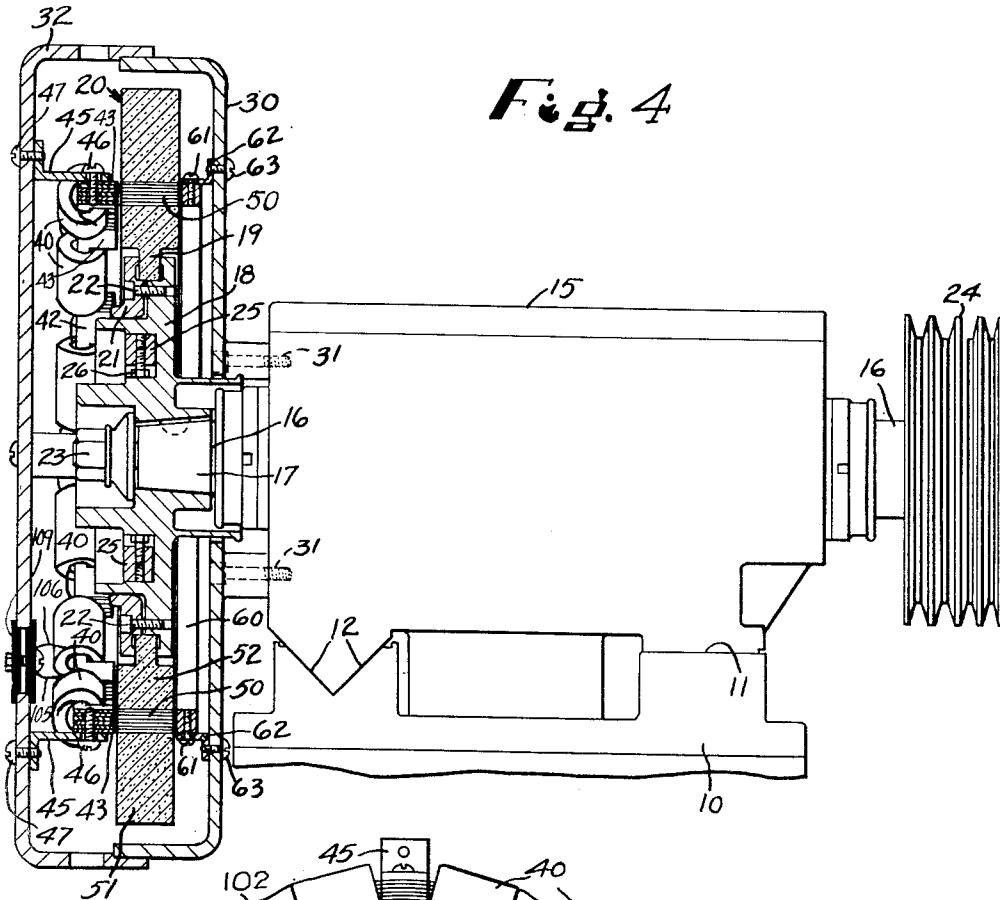


Fig. 4

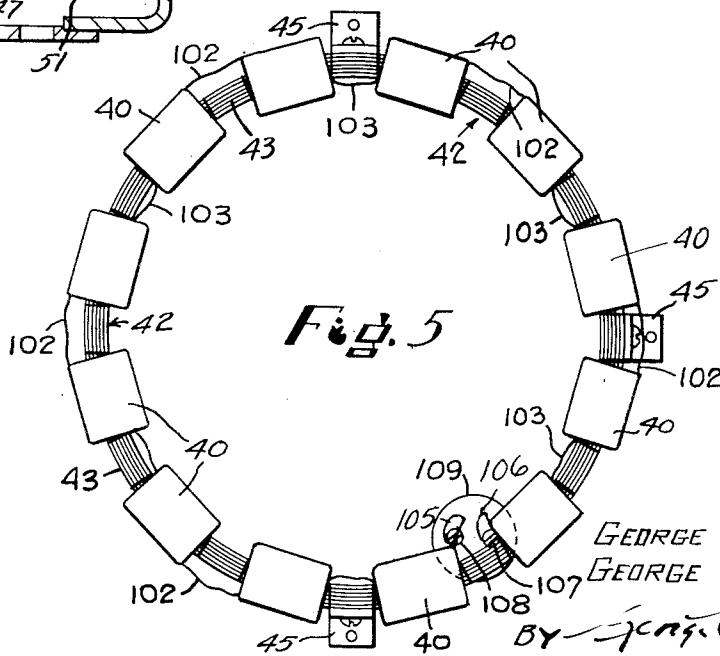


Fig. 5

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5 Sheets-Sheet 4

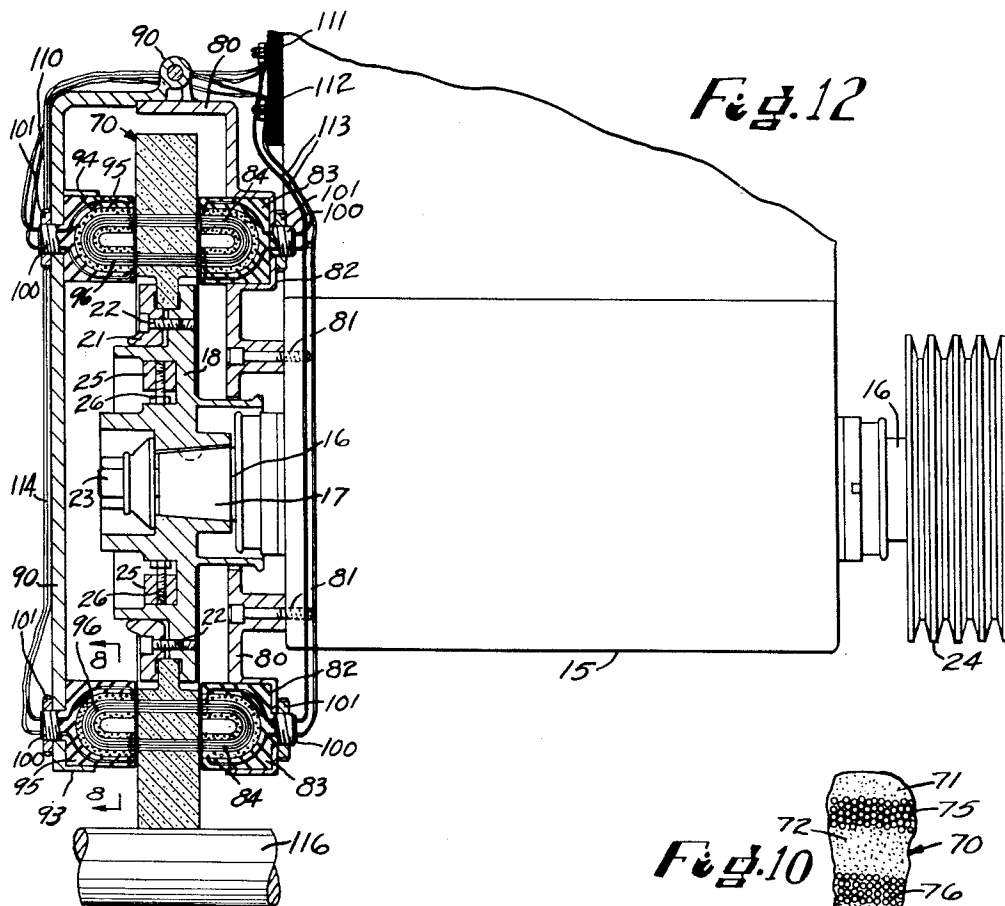


Fig. 12

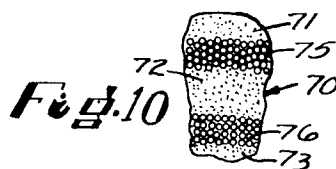


Fig. 10

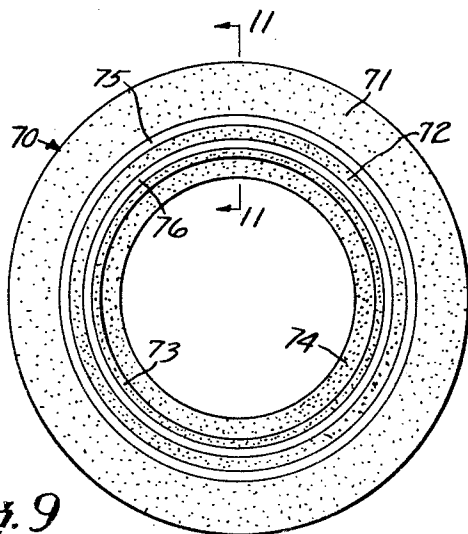


Fig. 9

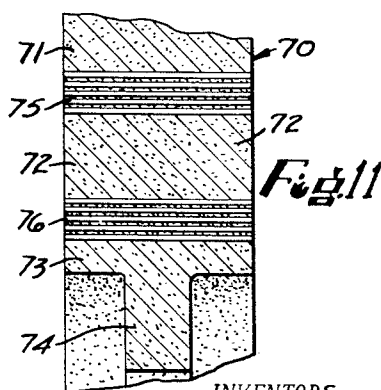


Fig. 11

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5 Sheets-Sheet 5

Fig. 13

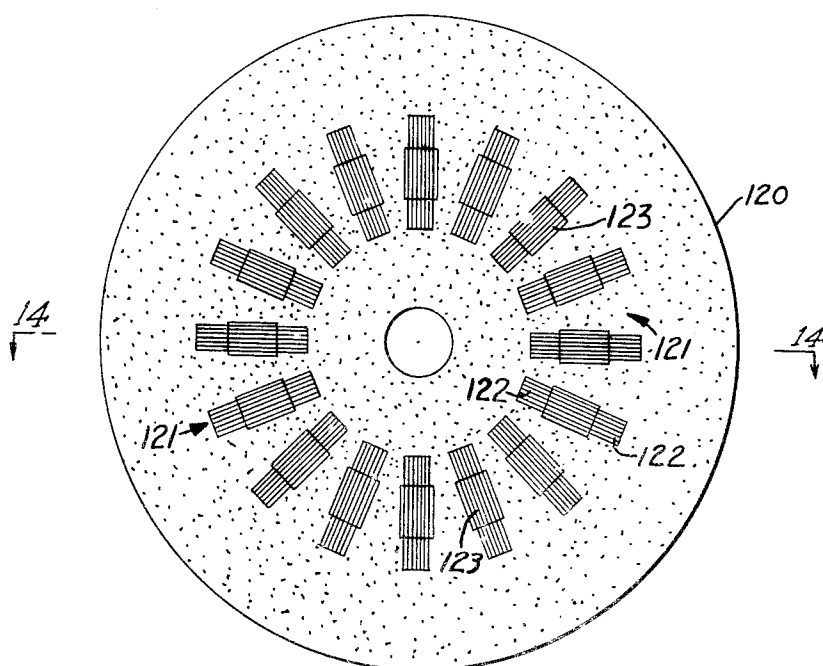
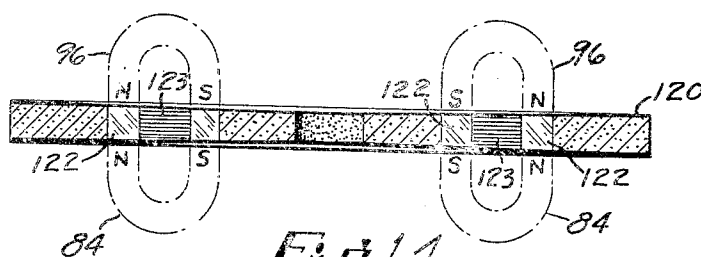


Fig. 14

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1

2,695,478

APPARATUS AND METHOD FOR GRINDING

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Application December 29, 1952, Serial No. 328,464

20 Claims. (Cl. 51—72)

The invention relates to apparatus and method for grinding.

One object of the invention is to provide precision grinding apparatus adapted to remove stock at a high rate and adapted also to produce an excellent finish. Another object of the invention is to provide a precision grinding apparatus capable of grinding the hardest of materials at a high rate of stock removal. Another object is to grind at high rate with minimum heating of the work. Another object is to reduce wheel wear.

Another object is to provide simple grinding apparatus giving a high rate of production. Another object is to provide grinding apparatus which can be embodied in a light weight machine which, at low grinding pressure, will remove stock at a high rate. Another object is to provide a grinder with apparatus to set a grinding wheel carried thereby in rapid radial vibration. Another object is to produce supersonic vibrations in a grinding wheel. Another object is to provide a grinding wheel capable of being vibrated, preferably supersonically, in a synchronous radial fashion meaning that all around the circumference the vibrations travel in generally radial lines in phase. Another object is to produce in a grinding wheel balanced vibrations or vibrations exerting no resultant thrust on the wheel spindle but not exactly radial. Another object is to produce standing waves in a grinding wheel for the promotion of grinding.

Another object is to incorporate magnetostrictive elements in a grinding wheel whereby a high frequency magnetic field will cause the wheel to vibrate thus to promote grinding action. Other objects are to incorporate such magnetostrictive elements in vitrified wheels, in resinoid bonded wheels and in other types of wheels. Another object is to provide a superior cutting off wheel.

Other objects will be in part obvious or in part pointed out hereinafter.

In the accompanying drawings illustrating some of many possible embodiments of the mechanical features of this invention,

Figure 1 is a side elevation of a wheel head cross slide unit including wheel guard and wheel,

Figure 2 is a partial axial sectional view on an enlarged scale of a grinding wheel constructed in accordance with the invention,

Figure 3 is a fragmentary elevation of a portion of the face of the grinding wheel,

Figure 4 is a sectional view taken on the line 4—4 of Figure 1,

Figure 5 is an elevation of the electromagnetic unit used in an illustrative embodiment of the invention,

Figure 6 is a sectional view illustrating one manner of molding a wheel according to the invention, one half of the molding apparatus being illustrated,

Figure 7 is a side elevation of a wheel head cross slide unit in another embodiment of the invention,

Figure 8 is a cross sectional view on an enlarged scale taken on the line 8—8 of Figure 12,

Figure 9 is a side elevation of the grinding wheel in the second embodiment of the invention,

Figure 10 is a fragmentary view on an enlarged scale of the wheel of Figure 9,

Figure 11 is a cross sectional view on an enlarged scale taken on the line 11—11 of Figure 9,

Figure 12 is a horizontal sectional view taken on the line 12—12 of Figure 7 further illustrating the second embodiment of the invention,

Figure 13 is an elevation of a magnetostrictive grind-

2

ing wheel illustrating a further embodiment of the invention,

Figure 14 is a sectional view taken on the line 14—14 of Figure 13.

Referring to Figure 4, a grinding machine base is indicated at 10 and has a flat way 11 and V-ways 12 supporting complementary shaped portions of a wheel head-cross slide unit 15. We will not describe a complete grinding machine since the invention is embodied in a grinding wheel and its mounting and these may be components of any type of grinding machine known, and in some cases (as in some centerless grinding machines) there may be no cross slide for the grinding wheel.

A wheel spindle 16 is mounted in bearings in the wheel head 15 and the bearings are not illustrated because many satisfactory constructions are known. Mounted on a tapered portion 17 of the wheel spindle 16 is a wheel holding plate 18 engaging an inwardly directed annular flange 19 of a grinding wheel 20 which is clamped to the plate 18 by means of a ring 21 held to the plate 18 by bolts 22. The plate 18 is shown as keyed to the portion 17 of the spindle 16 and held thereon by means of a nut 23. Secured to the spindle 16 at the end opposite the grinding wheel 20 is a pulley 24 by means of which the spindle can be driven. Balancing weights 25 held in place by screws 26 are preferably provided to balance the wheel 20 as vibrations due to unbalance are not wanted, those produced according to the invention being of a different character as will hereinafter appear. A wheel guard 30 is secured to the head 15 by means of bolts 31. Comparing now Figures 1 and 4, a wheel guard cover 32 is connected to the wheel guard 30 by means of a hinge 33 and the cover can be locked in closed position by means of a screw 36.

Referring now to Figures 4 and 5, we provide a plurality of electromagnets 40. Alternate magnets are wound in opposite directions so that at one instant the polarities will be in N-S-S-N-N-S-S-N-N-S-S-N-N-S-S-N-N-S-S-N arrangement around the circle and this presupposes an even number of magnets, as shown. To provide this arrangement of polarities it suffices to wind adjacent magnets oppositely. A single laminated core 42 with pole pieces 43 extends through all of the magnets and this can be made by cutting the components from different sized sleeves of soft iron then vulcanizing the component rings together with rubber having only enough sulphur to yield a soft rubber. After the core 42 with pole pieces 43 has been made, the electromagnet windings 40 are formed by winding insulated wire between the pole pieces 43. The core 42 is attached to the inside of the cover 32 by means of brackets 45 and screws 46 and 47 and thus the electromagnetic unit of Figure 5 is held in place by the cover 32. The tapped holes in the core 42 which receive the screws 46 should be coated with an insulating layer of resin or the like.

Referring now to Figures 2, 3, and 4, the grinding wheel 20 has therein a ring 50 of magnetostrictive rods embedded in resinous material, such as phenol-formaldehyde. The axes of the rods are parallel to the axis of the wheel 20. The rods can be made of any suitable magnetostrictive material of which nickel and an alloy of 45% nickel and 55% iron are good examples. Magnetostrictive material either expands or contracts in a magnetic field along the axis of the field; nickel and the nickel-iron alloy mentioned have opposite responses under some circumstances so that one or the other may be used but not both in the same ring.

Outside of the ring 50 is a wheel zone 51 of abrasive and bond; inside of the ring 50 is a wheel zone 52 of abrasive and bond merging with the flange 19 also made of abrasive and bond. In certain cases the zone 52 might be very much smaller relatively than as shown in the drawings.

Referring now to Figure 6, one way to make the wheel 20 is as follows: The wheel zone 51 and the ring 50 are separately made. The wheel zone 51 is made in the customary manner for making vitrified bonded grinding wheels which is so well known we need not describe it. The ring 50 is formed and the resin is only partially cured. The wheel zone 51 with the ring 50 inside of it

are then placed in a mold having a central arbor 53, a bottom plate 54, and a top plate in two sections; an outer section 55 covering the wheel zone 51 and the ring 50, and an inner section 56 to form the zone 52 and flange 19; the bottom plate 54, arbor 53 and the inner section 56 of the top plate being shaped to leave a cavity the exact shape of these parts when the mold is closed. Before the inner section 56 of the top plate is placed on the arbor 53, the space therearound and inside of the ring 50 is filled with a mixture of abrasive grains and phenol-formaldehyde resin made in the well known manner, then the inner section 56 of the top plate is placed on the arbor and on top of the mixture, and the entire assembly is pressed in a hot press thereby curing the resin under compression to cause the ring 50 to be in compression against the zone 51. It is best to use also a mold ring 57 gripping the plates 54 and 55 during the molding.

On the other hand all three of the flanges 19, the zone 51 and the zone 52 can be made of abrasive grains bonded with phenol-formaldehyde resin and these portions can readily be molded integral with the ring 50 by well understood molding technique. Here again it is preferred to use a hot press in order to unite the parts firmly into an integral whole. In general, whether the zone 51 is vitrified bonded abrasive or phenol-formaldehyde bonded abrasive, we prefer to have a large volume percentage of abrasive and a minimum of pores as thereby the vibrations will be better transmitted.

The continuous winding of the electromagnets 40 is connected to two sources of electric current. The one, known as the biasing current, is direct current. The other is high frequency alternating current in the supersonic range, that is to say from about 16,000 cycles per second up to about 200,000 cycles per second. We need not describe how to produce alternating current of frequency in the above range since this is known technology.

The magnetic flux passes from the pole pieces 43 through the ring 50 to a laminated high permeability ferrous metal ring 60 held by screws 61 to brackets 62 held by screws 63 to the inside of the wheel guard 30. As in the case of the tapped holes for the screws 46, it is best to coat the tapped holes for the screws 61 with resin or the like and also to insulate the ring 60 from the brackets 62. These precautions minimize Foucault or eddy current losses. This ring 60 causes the magnetic flux to flow nearly along the axes of the magnetostrictive rods rather than across them because the reluctance is high transverse of the rods and providing a path of high permeability across the ends of the rods has this result. Consequently, with the power on, the ring 50 vibrates at supersonic frequency by expanding and contracting in the direction of the axis of the rods of which it is composed. This produces as a resultant radial vibrations in the wheel 20 but since the ring 50 is concentric with the axis of the wheel, there is little or no effect upon the bearings in the wheel head 15 nor upon the spindle 16.

Referring now to Figure 12, it will be noted that it is like Figure 4 except that in Figure 4 the section is vertical while in Figure 12 the section is horizontal. The same wheel head 15 journals the same spindle 16 having a tapered portion 17 and the spindle is driven by the same pulley 24. The grinding wheel 70 is, however, a little different. It has, as better shown in Figures 9, 10 and 11, an outer abrasive portion 71, an intermediate abrasive portion 72, an inner abrasive portion 73, and a flange 74. It further has a pair of rings of magnetostrictive rods 75 and 76. These may be made in the same manner as the ring 50 and may consist of any good magnetostrictive rods having the same response. Furthermore the wheel can be made by the technique already described in connection with Figure 6 but with additional molding steps to mold the portions 73 and 74 with the ring 76 in place after the portion 72 has been molded with the ring 75 in place. Thus the outer abrasive portion 71 could be vitrified bonded abrasive while the portions 72 and 73 and 74 could be resin bonded abrasive, or the portions 71, 72, 73 and 74 could all be resin bonded abrasive.

The flange 74 of the wheel 70 is held by the wheel holding plate 18 and the ring 21 which is secured to the plate 18 by the bolts 22 as in the first described embodiment of the invention. Also the plate 18 is secured on the tapered portion 17 by means of the nut 23 and furthermore balancing weights 25 held in place by screws 26 may be provided.

Still referring to Figure 12, a wheel guard 80 is secured

to the wheel head 15 by means of bolts 81. This wheel guard 80 has recessed portions 82 receiving insulating blocks 83 made of suitable resin such as phenol formaldehyde resin and embedding horseshoe-shaped electromagnets 84 whose pole faces are opposite the ends of the magnetostrictive rods of the rings 75 and 76. In this embodiment of the invention the wheel guard cover 90 is mounted on a hinge 91 secured to the wheel guard 80 and, as shown in Figure 7, may be locked in place by means of a bolt 92. This wheel guard cover 90 has secured to it metal plates 93 and 94 partially supporting blocks 95 of insulating material such as a resin as in the case of the blocks 83, and these blocks 95 likewise have embedded therein horseshoe-shaped electromagnets 96 the pole faces of which are opposite the ends of the magnetostrictive rods of the rings 75 and 76. The resin of the blocks 83 and 95 is molded into stud portions 100 which project through the recesses 82 in the case of the blocks 83 and through the wheel guard cover 90 in the case of the blocks 95, and nuts 101 on the stud portions 100 assist in securing the respective blocks in place.

As in the case of the electromagnets 40, the electromagnets 84 and 96 are connected to two sources of electric current. One source is the biasing current and is direct current and the other source is the high frequency alternating current in the supersonic range from about 16,000 cycles per second to about 200,000 cycles per second. The windings and the electrical connections are made so that at given instants of time the poles at the opposite ends of the rods of the rings 75 are opposite poles and the poles at the opposite ends of the rods of the rings 76 are opposite poles. This describes the polarity due to alternating current but furthermore the direct current flows through the windings so that the same situation results continuously, that is to say the polarity due to the direct current alone is opposite on opposite sides of the rings 75 and 76. The alternating current alternately strengthens and cancels the polarity due to the biasing current which makes the rods vibrate magnetostrictively at the frequency of the A. C. Now if, in either embodiment of the invention, the peak voltage of the alternating current is the same as the voltage of the direct current, the magnetic field in the electromagnets goes from zero to full strength due to the combined currents at the frequency of the A. C. This condition is usually preferred. If the voltage of the D. C. is more than the peak voltage of the A. C. the field in the electromagnets will strengthen and weaken with the frequency of the A. C. Either of these conditions causes the magnetostrictive rods to vibrate with the frequency of the A. C. But if the voltage of the D. C. is less than the voltage of the A. C. the rods will vibrate at double the frequency of the A. C. only successive vibrations will be of different amplitudes until the voltage of the D. C. reaches zero in which case the vibrations will all be of the same amplitude but of double the frequency of the A. C. With a given source of A. C. to work with we may sometimes cut out the D. C. power source thus to double the frequency in the magnetostrictive rods.

The electromagnets 40 are connected by wires 102 and 103 as shown in Figure 5. In Figure 4 the ends 105 and 106 of the windings on the electromagnets 40 are shown. The magnets are thus wound in series. In Figure 1 we show binding posts 107 and 108 to which these ends 105 and 106 are connected. These binding posts 107 and 108 extend between insulating washers 109 and hold them in place in opposite sides of a hole through the cover 32. The biasing D. C. and high frequency A. C. sources are connected by wires (not shown) to these binding posts 107 and 108. In Figures 7 and 12 we show a pair of wires 110 extending from the left hand rear magnet 96 to binding posts 111 and 112 respectively, a pair of wires 113 extending to these binding posts respectively from the right hand rear electromagnet 84, a pair of wires 114 extending from the left hand front electromagnet 96 to the binding posts 111 and 112 respectively and a pair of wires 115 extending from the right hand front electromagnet 84 to the binding posts 111 and 112 respectively and by connecting wires, not shown, the biasing current and the high frequency current are connected to these binding posts 111 and 112 and thus the electromagnets 84 and 96 may be energized in the manner herein described. In the embodiment of Figures 7 and 12 the electromagnets are connected in parallel.

Considering now the vibration of the wheels, we prefer

that they shall vibrate in resonance with one node at the axis of the wheel. This result can be achieved by causing a wheel to vibrate at its fundamental frequency across its diameter, or at any harmonic thereof. The fact that we can use harmonics greatly extends the versatility of this invention for the diameter of the grinding wheel could be from three or four inches to thirty or forty inches. In many machine tool grinding machines the grinding wheels are large, frequently thirty inches in diameter when they are new, and to cause such wheels to vibrate in resonance without using frequencies in the sonic range we must, in many cases, make use of a harmonic of the fundamental frequency.

We desire to avoid the sonic frequencies for two reasons. In the first place, in general, vibrations in the sonic frequencies do not aid the grinding operation as much as do vibrations in the supersonic frequencies. In the second place sonic frequency vibrations involve audible sound, which could be very loud, and this would be distressing to the operator and others in the vicinity of the grinder.

Electrical apparatus for delivering electric energy at supersonic frequencies is usually adjustable to vary the frequency over quite a wide range and so therefore we can achieve our objective of causing the wheel to vibrate in resonance. Resonance is indicated by the action of an ammeter in one of the circuits of the high frequency generator; when the ammeter reading suddenly rises while tuning the frequency, it is a sign that a resonant frequency has been reached.

But this resonant frequency may, in some cases, be the resonant frequency of the magnetostrictive rods in the ring or rings and we can operate the machine satisfactorily on this resonant frequency. It is in most cases a matter of which frequency delivers the most power to the wheel and this can be determined by the ammeter. Even if, with one or more rings of rods in resonance and the wheel not in resonance the axis of the wheel is no longer at a node, the effect upon the wheel spindle 16 is small due to the fact that in each embodiment the electromagnets and the rings are located symmetrically and in circles coaxial with the wheel and its spindle, so that wave impulses on one side are cancelled by wave impulses on the other side all around the axis.

In the first described embodiment more power can be put into the wheel than in the second embodiment due to the greater number of electromagnets in the first embodiment. And in the first embodiment a greater amount of power can be used. But in the second embodiment the power is to a large extent concentrated where it is most effective. It will be understood that the resultant vibrations perpendicular to the axis of the wheel spread out in all directions in the plane perpendicular to such axis. For that reason there is also some loss in the second embodiment and if the power is available it is preferred to vibrate the wheel all around the circle.

High frequency, especially supersonic, vibrations have an eroding effect on work pieces, especially hard and brittle work pieces. Thus in accordance with the invention the work piece is both ground and eroded by vibrations. Furthermore the vibrating blows delivered by the abrasive granules are believed to create an entry for them into the work piece thereby assisting the grinding action. Usually we use grinding coolant, preferably water which may have a rust inhibitor therein. Water or other coolant is delivered to the grinding line between work piece 116 (see Figure 12) and the wheel by the usual nozzle 117 (Figures 1 and 12). Supersonic vibrations cause, in the presence of water, cavitation which has a strongly erosive effect and the high rate of cutting hard work pieces may be in part due to cavitation.

Grinding wheels supersonically excited in accordance with the invention will grind all materials that can be ground at all but the material removed factor is increased most markedly and to the greatest extent when hard brittle materials such as the hard carbides, oxides, borides, nitrides and silicides are ground. Some of these materials can hardly be ground at all with wheels the abrasive of which is aluminum oxide. Some of these materials, such as boron carbide, can hardly be ground at all with wheels the abrasive of which is silicon carbide. But we can grind boron carbide with supersonically vibrated silicon carbide abrasive grinding wheels.

The part of the wheel which grinds (51 in Figure 2 and 71 in Figures 9, 10 and 11) can be made of abrasive bonded with any known bond, such as vitrified bond and

phenol-formaldehyde bond already mentioned, also aniline-formaldehyde resin bond, alkyd resin bond, magnesium oxychloride bond, rubber bond, butadiene acrylic nitrile copolymer bond, butadiene styrene copolymer bond, shellac bond, glass bond and sodium silicate bond. The abrasive can be aluminum oxide of any variety—fused alumina regular or white or in discrete crystals or corundum or emery; or it can be silicon carbide of any variety—green, gray or black, or diamonds can be used. It is preferred to use bonds which transmit sound with a velocity as near to that at which the abrasive transmits it as possible; hence the vitrified type of bond is usually preferred.

Referring now to Figures 13 and 14, we therein illustrate the invention embodied in a cut-off wheel 120. This wheel can be made by bonding abrasive, for example fused alumina or silicon carbide, with phenol-formaldehyde resin and it is preferable to use a large volume percentage of abrasive and to hot press the wheel to get a strong abrasive packing which will well transmit the vibrations. We make magnetostrictive units 121 each one of which comprises a pair of plurality of plates 122 of highly permeable ferrous metal, the plates being separated and bonded together by resin or vulcanized rubber or the like, and a rectangular parallelepiped collection of magnetostrictive rods 123 interposed between each pair of collections of plates 122. A grinding machine is provided like that shown in Figure 12 with horseshoe electromagnets 84 and 96 on either side of the wheel 120 and we might have as many electromagnets 84 and as many electromagnets 96 as there are magnetostrictive units 121, in this case 16. The polarity and the windings can be arranged as already explained in connection with Figure 12 so that at a given instant of time the polarity may be as shown in Figure 14 where north poles are opposed to south poles so that the magnetic flux must flow into the plates 122 and through the magnetostrictive rods 123. It will be noted that in this embodiment of the invention the rods vibrate radially of the wheel which is the most effective condition. Wheels constructed along the lines of Figures 13 and 14 can also be used for other kinds of grinding operations, that is to say they are in nowise limited to use as cutting off wheels but may be used for cylindrical grinding, surface grinding and in many other grinding operations. Of course, as in other embodiments of the invention, the magnets 84 and 96 are energized by alternating current with supersonic frequency and preferably also by biasing direct current.

It will be seen that the bonds mentioned are all of them non-conductors of electricity. Any electrical non-conductive bond can be used so therefore we should not be limited to particular ones. Metal bonds cannot be used because they would absorb the power by the creation of eddy currents. In fact they would quickly heat up. But the bond could have metal particles insulated from each other as in the wheel mounting of Van der Pyl's U. S. Patent No. 2,150,886 because in such a bond the eddy currents would only be minute. In every case our bond is a matured bond, meaning it is heat set.

It will be seen that in the embodiment of the invention illustrated in Figures 2, 3, 9, 10 and 11 the magnetostrictive rods are parallel to the axis of the wheel while in the embodiment illustrated in Figure 13 the magnetostrictive rods extend practically radially of the wheel. However in each embodiment of the invention the magnetostrictive rods are perpendicular to a radius line of the wheel at a point 90 degrees circumferentially from their location therein.

It will thus be seen that there has been provided by this invention an apparatus and method for grinding in which the various objects hereinabove set forth together with many thoroughly practical advantages are successfully achieved. As many possible embodiments may be made of the above invention and as many changes might be made in the embodiments above set forth it is to be understood that all matter hereinbefore set forth or shown by the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

We claim:

1. A grinding wheel of abrasive material composed of abrasive grains bonded together with matured electrically non-conducting bonding material, said wheel being circular, and a ring of magnetostrictive metal which is at least 45% nickel embedded in said wheel in a position

coaxial with the wheel and integrally bonded to the abrasive material.

2. A grinding wheel according to claim 1 in which the ring of magnetostrictive metal is a ring of magnetostrictive metal rods the axes of which are substantially parallel to the axis of the wheel.

3. A grinding wheel according to claim 2 in which there are a plurality of rings of magnetostrictive metal rods.

4. A grinding wheel according to claim 1 in which there are a plurality of rings of magnetostrictive metal.

5. A grinding wheel of abrasive material composed of abrasive grains bonded together with matured electrically non-conductive bonding material, said wheel being circular, and a plurality of sets of magnetostrictive rods of metal which is at least 45% nickel embedded in said wheel with each set of rods perpendicular to the axis of the wheel.

6. A grinding wheel according to claim 5 in which at each end of each set of rods there is a mass of magnetically highly permeable metal.

7. A grinding wheel according to claim 6 in which the sets of rods form a ring of sets coaxial with the wheel radially of the wheel.

8. A grinding wheel according to claim 5 in which the sets of rods form a ring of sets coaxial with the wheel radially of the wheel.

9. A grinding wheel of abrasive material composed of abrasive grains bonded together with matured electrically non-conducting material, and a continuous ring of rods of magnetostrictive metal embedded in said wheel said ring being coaxial with said wheel and said rods being parallel to the axis of said wheel.

10. Grinding apparatus comprising a grinding wheel comprising abrasive grains bonded together with electrically non-conducting bonding material and containing magnetostrictive metal elements, and electromagnetic means arranged about said spindle in geometrically balanced positions relative to the axis of said spindle with the poles of the electromagnetic means close to the locus of a side of said grinding wheel and said poles being so positioned that the lines of force will penetrate said wheel to vibrate said magnetostrictive elements embedded therein when the electromagnetic means is excited with high frequency alternating current.

11. Grinding apparatus according to claim 10 in which the electromagnetic means consists of horseshoe magnets.

12. Grinding apparatus comprising a wheel spindle, a grinding wheel on said spindle, said grinding wheel being composed of abrasive grains bonded together with matured electrically non-conductive bonding material, said wheel being circular, a plurality of magnetostrictive elements embedded in said wheel, electromagnetic means arranged about said wheel on at least one side thereof with the poles of the electromagnetic means close to said side and said poles being so positioned that the lines of force penetrate said wheel and flow through the magnetostrictive elements embedded therein, whereby when said electromagnetic means is connected to a source of high frequency alternating current said magnetostrictive elements will vibrate at high frequency.

13. Grinding apparatus according to claim 12 in which the electromagnetic means is embodied in an even number of electromagnets arranged symmetrically of the wheel

with respect to the axis of the spindle with each electromagnet diametrically opposite one on the other side at the same distance from the axis.

14. Grinding apparatus according to claim 13 in which the magnetostrictive means includes rods which are perpendicular to a radius line of the wheel at a point 90 degrees circumferentially from their location therein.

15. Grinding apparatus according to claim 14 in which the magnetostrictive means includes radial rods.

16. Grinding apparatus comprising a wheel spindle, a grinding wheel on said spindle, said grinding wheel being composed of abrasive grains bonded together with matured electrically non-conductive bonding material, said wheel being circular, a plurality of magnetostrictive rods parallel to the axis of said wheel embedded in said wheel, electromagnetic means arranged about said wheel on at least one side thereof with the poles of the electromagnetic means close to said side and said poles being so positioned that the lines of force penetrate the wheel and flow through the magnetostrictive rods embedded therein, whereby when said electromagnetic means is connected to a source of high frequency alternating current said magnetostrictive rods will vibrate at high frequency.

17. Method of grinding consisting in rotating a grinding wheel of abrasive material composed of abrasive grains bonded together with matured electrically non-conducting bonding material, said wheel being a circular disc, and coincidentally vibrating said wheel in the plane of the disc with vibrations which are canceled at the axis of the wheel but travel to the periphery thereof, said grinding wheel grinding a work piece placed against its periphery, the frequency of said vibrations being above 16,000 cycles per second.

18. Method of grinding according to claim 17 in which liquid principally consisting of water is flowed to the locus where the periphery of the wheel is in contact with the work piece.

19. Method of grinding consisting in rotating a grinding wheel which is a circular disc while coincidentally vibrating said wheel in the plane of the disc with vibrations which are canceled at the axis of the wheel but travel to the periphery thereof, said grinding wheel grinding a work piece placed against its periphery, the frequency of said vibrations being above 16,000 cycles per second.

20. Method of grinding according to claim 19 in which liquid principally consisting of water is flowed to the locus where the periphery of the wheel is in contact with the work piece.

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1,605,796	Tanzler	Nov. 2, 1926
1,936,023	Jordan	Nov. 21, 1933
2,032,484	Jeppson	Mar. 3, 1936
2,054,771	Larsson	Sept. 15, 1936
2,070,944	Hillix	Feb. 16, 1937
2,428,781	Bowlus	Oct. 14, 1947