March 10, 1964 A. KURIS ETAL 3,123,950

ULTRASONIC CLEANING OF GRINDING WHEELS

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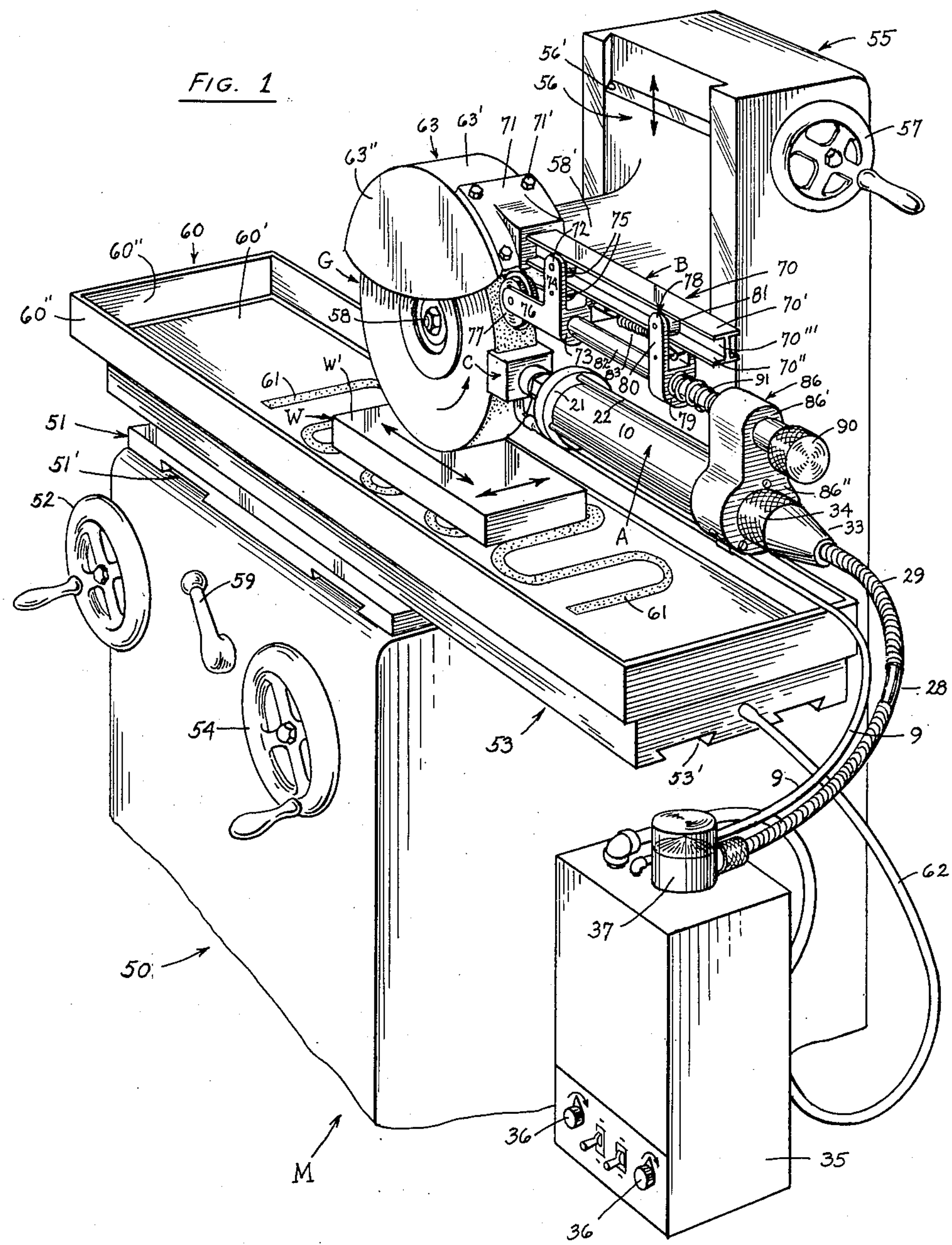
FIG. 1



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ULTRASONIC CLEANING OF GRINDING WHEELS

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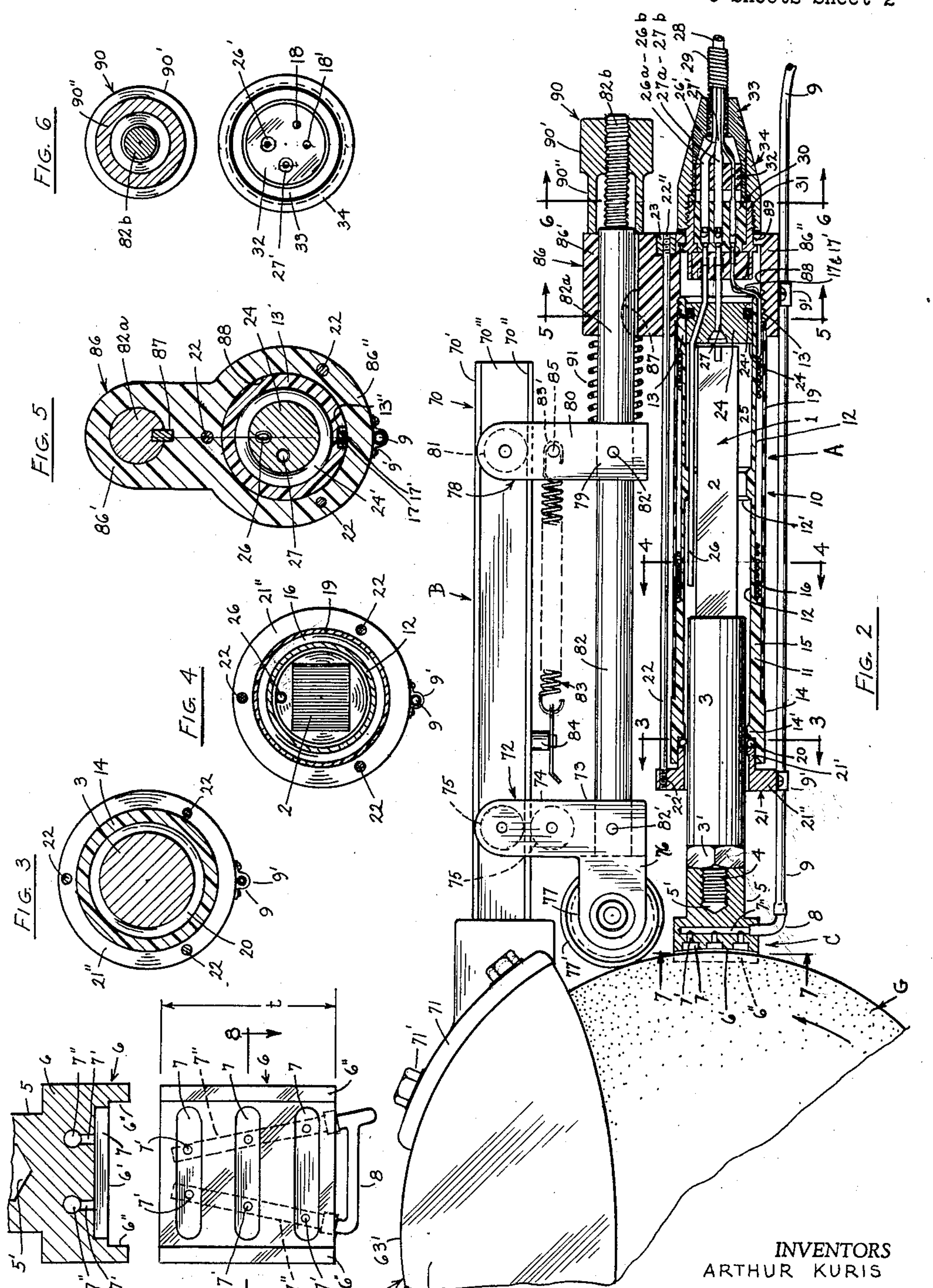

FIG. 2 FIG. 3 FIG. 4 FIG. 5 FIG. 6 FIG. 7 FIG. 8

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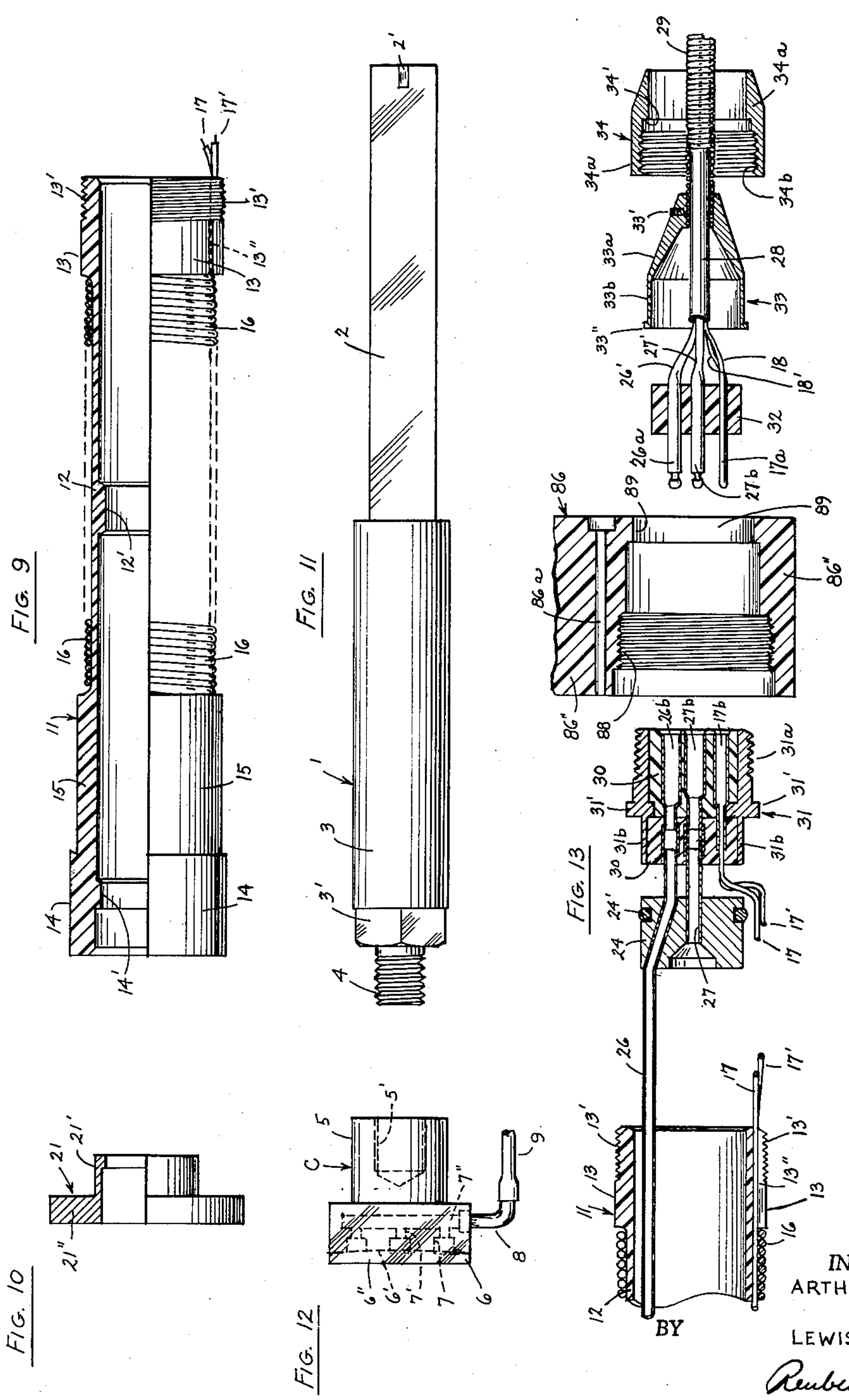

FIG. 9 FIG. 10 FIG. 11 FIG. 12 FIG. 13

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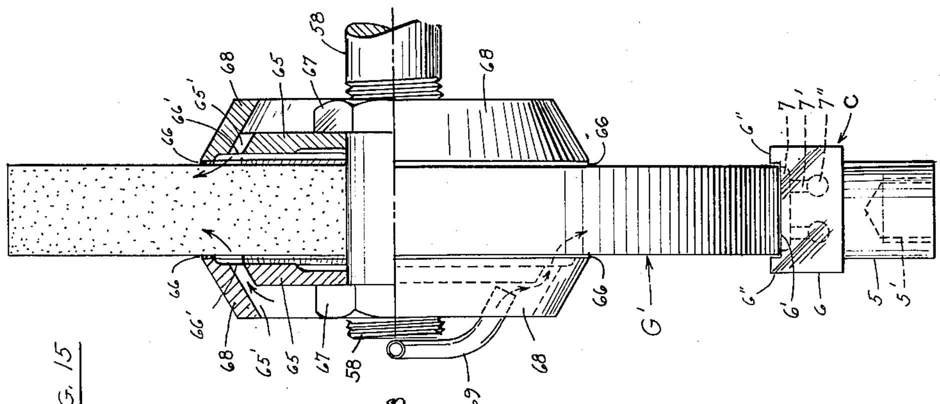

FIG. 15

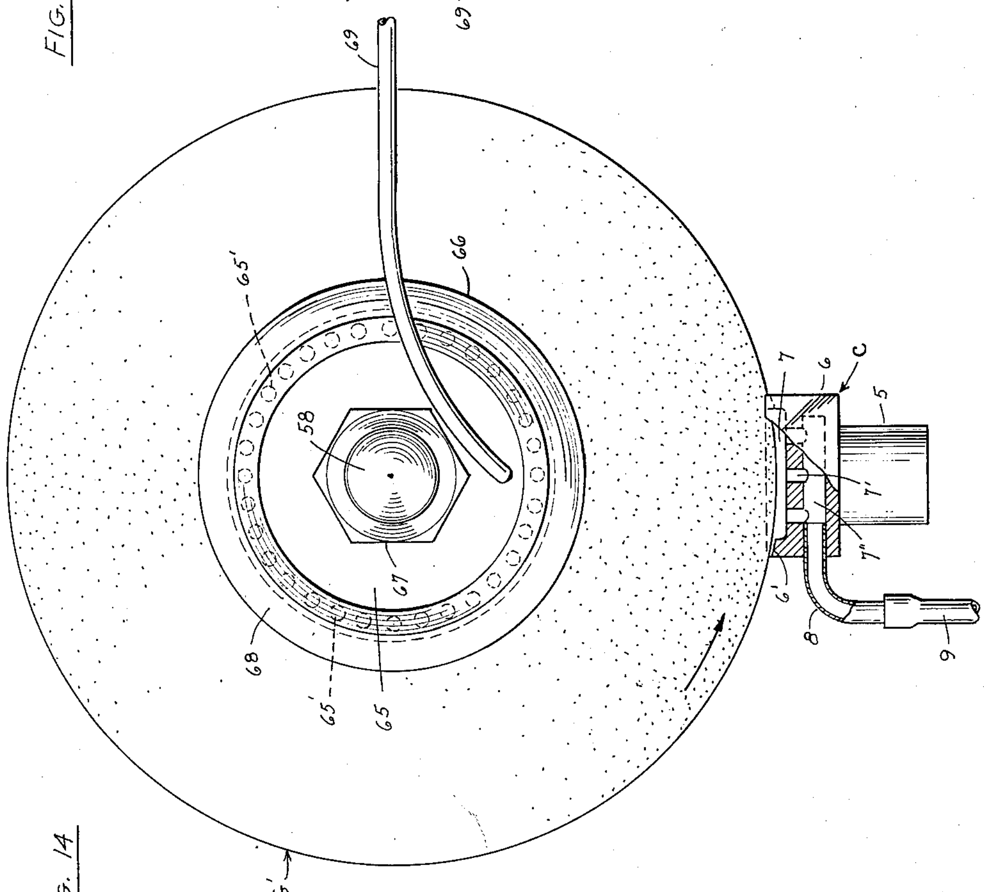

FIG. 14

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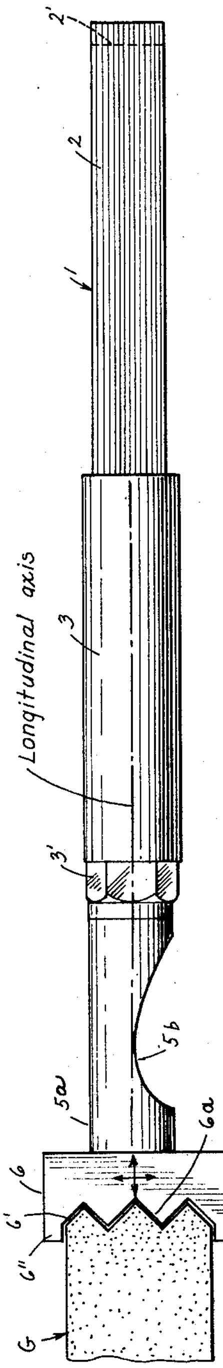

FIG. 16

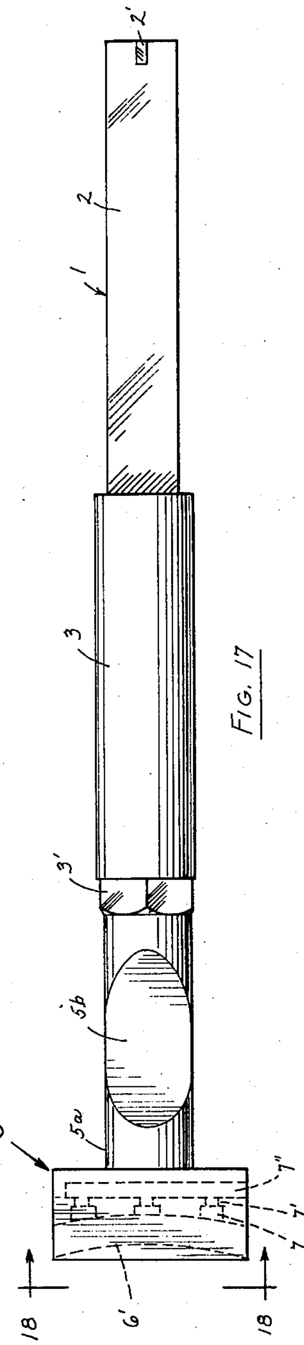

FIG. 17

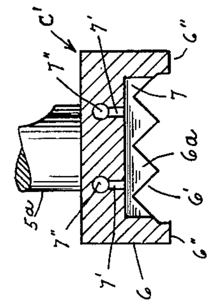

FIG. 20

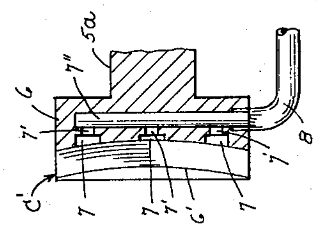

FIG. 19

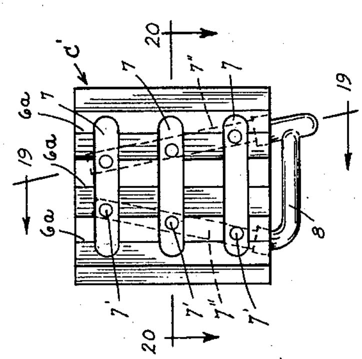

FIG. 18

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FIG 21

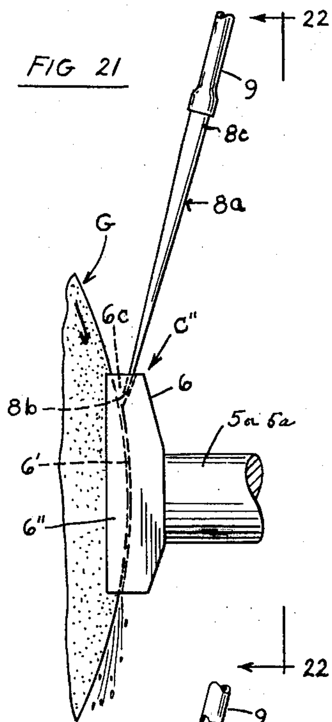


FIG. 22

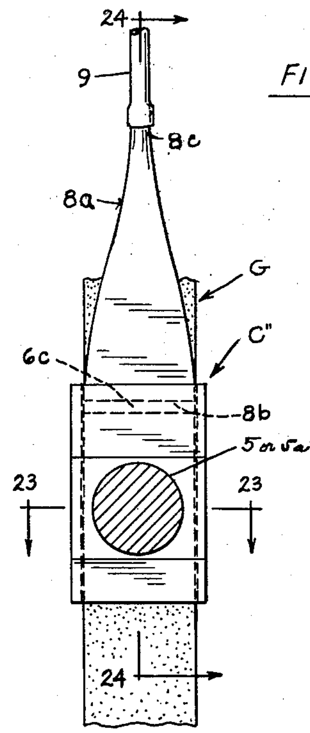


FIG. 24

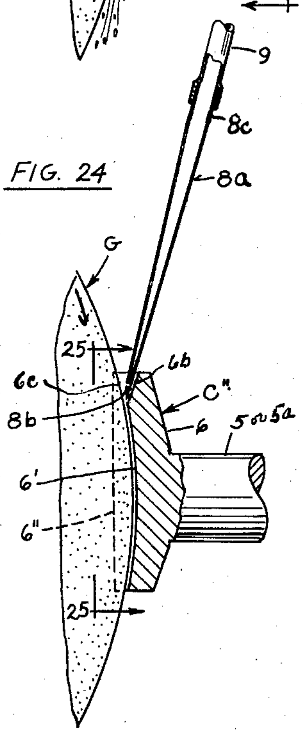


FIG. 25

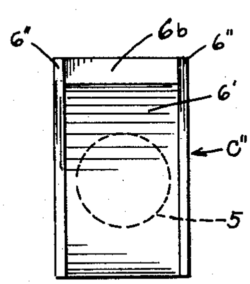
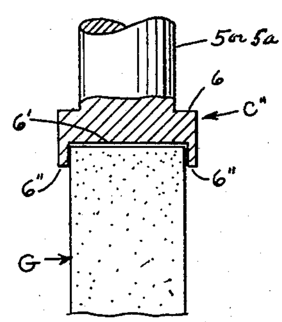


FIG. 23



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United States Patent Office

3,123,950
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ULTRASONIC CLEANING OF GRINDING WHEELS

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Filed Aug. 4, 1959, Ser. No. 831,590
16 Claims. (Cl. 51—262)

This invention relates to ultrasonic cleaning of grinding wheels, and more particularly to an improved method and means for removing metallic or other impacted material from grinding or other surfaces by the cavitational action of a wetting liquid while the liquid is maintained in residence at a limited cleaning site area of the surface to be cleaned, and while the surface is rotating or moving at working speeds.

In its broader aspects, this invention is directed to the provision of a method and means for the removal of impacted and tenaciously adhering material and debris by cavitational action from relatively flat, cylindrical, elliptical or contoured surfaces of such character that the surface cannot be immersed in or readily covered by a film of cleaning fluid. For example, surfaces which are lineally moving, or rotating, or otherwise in motion at such speeds as to cause a liquid layer normally applied thereto to be thrown therefrom, or which surfaces are inverted, or vertical in position, or otherwise so positioned or inclined that gravitational forces would tend to remove the layer or film of liquid normally applied thereto, can be effectively cleaned by the application of the principles of this invention. Since this invention finds ideal application for the removal of work material and debris impacted between the grains of abrasive wheels which rotate at relatively high speed, the method and means of this invention will be particularly described for the purpose of illustration in connection with the cleaning of abrasive wheel surfaces.

In the grinding and polishing of metallic and other relatively hard workpieces by the use of coarse or fine grained abrasive wheels, the wheel surface soon becomes clogged with workpiece particles which progressively reduces the speed of grinding and polishing. Prior to the advent of this invention, it has been the customary practice to apply wire brushes and/or sharp pointed tools to the grinding wheel surface to loosen and remove the embedded particles from the abrasive wheel surface and thus restore the wheel surface to reasonable grinding or polishing effectiveness.

Present methods of cleaning abrasive wheel surfaces inexorably remove useful abrasive grains and increase the speed of wear of the grinding wheel surface with each cleaning operation, are only partially effective in cleaning the grinding wheel surfaces, fail to restore the grinding wheel surface to maximum grinding or polishing efficiency and materially add to the overall cost of grinding and/or polishing workpieces to acceptance standards. Additionally, the method and means currently employed for cleaning abrasive wheel surfaces, requires substantial mechanical skill and attention in order that the cleaning operation is not performed in a manner which is detrimental to the required precisional shape or surface texture of the finished workpiece.

To perform the grinding and polishing operation with efficiency, it is essential that the cleaning method and device be made and adapted to continuously perform the cleaning function while the grinding and polishing wheel is in rotative operation and performing grinding or polishing work. For effective grinding and polishing action, grinding and polishing wheels normally rotate at peripheral speeds in the approximate order of 1,500 to 7,000 linear feet per minute, or 25 to 120 lineal feet (7 to 35 meters) per second. Due to the high centrifugal forces

generated at the periphery of the grinding or polishing wheel when rotated at required grinding or polishing speed, cavitational liquid cannot be maintained at the cleaning site in amounts sufficient to produce effective cavitational action by ultrasonic techniques, by simply spraying the liquid onto the wheel surface adjacent the cleaning site area, as suggested by Luthman et al., U.S. Patent 2,858,652. Without effective cavitational action, embedded workpiece particles and loosened grains will not be withdrawn from the grinding wheel surface.

For effective cavitational action, the working face of the grinding wheel cleaning shoe should preferably be spaced from the grinding wheel surface at the cleaning site, for a distance not substantially in excess of ten-thousandths of an inch (0.25 mm.) and preferably in the order of about five to ten thousandths of an inch (0.125 to 0.250 mm.), and that this spacing be uniformly and continuously maintained during the grinding and polishing operation, irrespective of the continuing wearing away of the grinding wheel surface.

The outstanding and unexpected results obtained by the practice of the method and means of this invention are attained by a series of features, steps and elements assembled and working together in inter-related combination. Actual tests have demonstrated that by the application of the cleaning method and means of this invention, grinding and polishing speeds are attainable which are a multiplicity of times greater than heretofore known or practiced, with accompanying substantially less wear on the grinding or polishing wheel surface and consequent longer life of the grinding or polishing wheel, together with the attainment of unexcelled precision grinding and polishing accuracy.

Cleaning devices made in accordance with this invention may be mounted and attached to any suitable fixed support which is adjacent to the grinding or polishing wheel of the grinding machine, as for example, the protective guard or housing which partially encircles the grinding or polishing wheel. The device of this invention is compact in design, and can be operated to maintain the grinding or polishing wheel in thoroughly clean and sharp condition at all times as the grinding work proceeds, without interfering with the grinding or polishing work being performed, and with little or no attention on the part of the grinding or polishing machine operator.

In its essential aspects, this device includes a vibrator assembly which embraces a transducer unit to which a biased alternating current is supplied to vibrate the transducer unit at high frequency and relatively small amplitude. A cleaning shoe is rigidly secured by a connecting body to the output end of the transducer unit, and which has a head section presenting a working or cleaning face whose shape closely conforms to the grinding or polishing surface to be cleaned. The head section of the cleaning shoe presents side flange portions whose inner faces overlap the sides of the grinding or polishing wheel, with only sufficient minute clearance to permit the grinding wheel periphery to rotate therebetween.

This invention further comprehends the provision of means for supplying a cleaning fluid in sufficient volume and under sufficient pressure to effectively inject the cleaning fluid into the gap space between the working face of the cleaning shoe and the surface to be cleaned and in a manner to maintain a sufficient layer of cleaning fluid in said gap space for cavitational action when the vibrator assembly is energized and the abrasive wheel rotated. In accordance with this invention, partial confinement of the liquid layer in the gap space between the shoe working face and adjacent cleaning site area of the surface to be cleaned may be effected by the provision of confining means which form a part of the cleaning shoe, or confining means which is independently supported in closely adjacent relation to the side faces of the rotating grinding wheel. The maintenance of a liquid layer at the cleaning site may be further facilitated by the provision of a series of spaced and relatively small reservoir slots impressed into the shoe working face, confined within the boundaries of the shoe working or cleaning face, and extending transversely thereof.

A sufficient quantity of pressurized cleaning liquid to maintain a cavitating layer of cleaning liquid between the shoe working face and the cleaning site area of the surface to be cleaned, may be supplied by the provision of suitable passages within the cleaning shoe; or by driving the cleaning fluid with wedging force into the gap space in the direction of rotation of the abrasive wheel.

This invention further comprehends the provision of a suspension support for the vibrator assembly which may be fixed to and supported by the grinding wheel housing or guard positioned adjacent the grinding wheel. The suspension support incorporates a finger manipulated micrometer adjuster designed to manually establish the desired and predetermined spacing gap between the cleaning face of the cleaning shoe and the grinding surface of the wheel at the cleaning site. This finger manipulated micrometer adjuster also provides a means whereby the cleaning face of the cleaning shoe can be shaped into conformity with the peripheral shape of the grinding wheel, and which is accomplished by advancing the cleaning face of the cleaning shoe into grinding contact with the rotating grinding wheel, and then backing off the shoe cleaning face to provide the desired depth of spacing gap. Thus, by this simple micrometer adjustment, the preferred gap spacing between the cleaning shoe working face and the grinding wheel periphery at the cleaning site can be quickly made.

The high speed grinding efficiencies attainable by the use of the method and means of this invention, also requires the use of a cleaning liquid having a low surface tension with wetting or detergent properties, operating in conjunction and in cooperation with the factors above discussed. When a pressurized wetting liquid of low surface tension is captivated within the spacing gap at the cleaning site by the use of a cleaning shoe constructed in accordance with this invention, and whose working face is adjusted to provide a spacing gap between the shoe working face and the peripheral surface of the grinding wheel at the cleaning site by the means above described, and which is preferably not in substantial excess of ten-thousandths (0.25 mm.) of an inch, effective cavitational action of the low surface tension wetting liquid at the cleaning site is assured, and which cavitational action possesses such force and strength as to forcibly pull or suck embedded workpiece particles and loose abrasive grains from the grinding and polishing surface with such effectiveness and efficiency as to maintain the grinding surface of the rotating wheel thoroughly clean for a substantial period of time before the wheel grinding surface needs to be dressed.

The method and means of this invention are applicable to the cleaning of relatively flat grinding wheel surfaces as well as irregular or contour formed grinding wheel surfaces, such as are used in thread and contour grinding. Where the grinding wheel surface is relatively flat or straight edged, the transducer unit to which the cleaning shoe is attached may be designed to produce substantially only a longitudinal component of motion extending substantially normal to the relatively flat wheel surface to be cleaned. Where the grinding wheel surface is of contoured shape, as required by contour shaping operations, the vibrator unit should desirably have a lateral component of motion as well as a longitudinal motion component. By a proper shaping of the connecting body and neck portion of the cleaning shoe, selectively shaped elliptical or substantially circular motion strokes can be produced at the working face of the cleaning shoe to insure effective cleaning of the contoured surface of the grinding wheel.

Other objects and advantages of this invention will become apparent as the disclosure proceeds.

Although the characteristic features of this invention will be particularly pointed out in the claims, the invention itself, and the manner in which it may be made and used, may be better understood by referring to the following description taken in connection with the accompanying drawings forming a part hereof, in which:

FIG. 1 is a perspective view of a grinding wheel cleaning device made in accordance with this invention in operative relation to a grinding wheel associated with one of the many forms of grinding machines with which this device may be used;

FIG. 2 is a side view of the grinding wheel cleaning device mounted in operative relation to a grinding wheel, certain parts of the device being shown in section to illustrate structural details;

FIG. 3 is a transverse section of the vibrator assembly of the device as the same would appear when viewed along line 3—3 of FIG. 2;

FIG. 4 is another transverse section of the vibrator assembly of the device as the same would appear when viewed along line 4—4 of FIG. 2;

FIG. 5 is a transverse section of the suspension hanger and the vibrator assembly of the device as supported thereby, and as the same would appear when viewed along line 5—5 of FIG. 2;

FIG. 6 is another transverse section of the device as the same would appear when viewed along line 6—6 of FIG. 2;

FIG. 7 is an underface view of one form of cleaning shoe which is connected to the transducer unit of the vibrator assembly and which is maintained in predetermined cavitational relation to the periphery of the grinding wheel, and as the same would appear when viewed along line 7—7 of FIG. 2;

FIG. 8 is a transverse section of the cleaning shoe as the same would appear when viewed along line 8—8 of FIG. 7;

FIG. 9 is a side view, partly in section, of the casing which forms a part of the vibrator assembly and which supports and contains a part of the transducer unit;

FIG. 10 is a side view partly in section of the supporting collar which is applied to the head end of the casing shown in FIG. 9;

FIG. 11 is a side elevational view of the transducer unit designed to be partially telescoped into the casing of the vibrator assembly;

FIG. 12 is a side elevational view of the cleaning shoe shown in FIGS. 2, 7, and 8 in exploded relation to the transducer unit shown in FIG. 11;

FIG. 13 is a longitudinal section of certain components of the vibrator assembly in exploded relation and which illustrate the structural components thereof and the manner in which they are assembled together;

FIG. 14 is an elevational view, partly in section, of a cleaning shoe made in accordance with this invention and designed to be connected to the transducer unit, this view showing the cleaning shoe in operative association with a porous grinding wheel to which a wetting liquid or detergent is supplied adjacent the hub portion thereof;

FIG. 15 is a plan view of the cleaning shoe shown in operative relation to the porous grinding wheel as illustrated in FIG. 14, this view also showing further details of the hub discs which are attached to the sides of the porous grinding wheel and which direct the wetting liquid into the porous grinding wheel;

FIG. 16 is a side view of a modified form of transducer unit having a modified form of grinding wheel cleaning shoe attached to the operating end thereof, and whose shape, form and dimension attributes are such as to produce a combination of longitudinal and lateral vibrations at the working face of the shoe to thereby clean a grinding wheel whose working periphery is of irregular form;

FIG. 17 is another side view of the transducer unit and associated cleaning shoe shown in FIG. 16 as the same would appear when viewed at right angles to that shown in FIG. 16;

FIG. 18 is an underface view of the working face of the cleaning shoe shown in FIGS. 16 and 17, and as the same would appear when viewed in the direction of the arrows **18—18** of FIG. 17;

FIG. 19 is a longitudinal section of the cleaning shoe shown in FIGS. 16, 17 and 18 and as the same would appear when viewed along line **19—19** of FIG. 18;

FIG. 20 is a fragmentary transverse section of the cleaning shoe shown in FIGS. 18 and 19 as the same would appear when viewed along line **20—20** of FIG. 18;

FIG. 21 is a side elevational view showing a fragmentary part of an abrasive wheel and a modified form of cleaning shoe associated therewith, with means for injecting a pressurized cleaning liquid into the gap space between the shoe cleaning face and cleaning site area of the abrasive wheel periphery, with the liquid injection taking place in the direction of rotation of the wheel;

FIG. 22 is a front face view of the modified cleaning shoe, the liquid injecting means and the adjacent fragmentary part of the abrasive wheel to which it is applied, and as the same would appear when viewed in the direction of the arrows **22—22** of FIG. 21;

FIG. 23 is a transverse section of the modified cleaning shoe as the same would appear when viewed along line **23—23** of FIG. 22, and as the same would be mounted in gap forming relation to the cleaning site area of the abrasive wheel periphery;

FIG. 24 is a longitudinal section of the modified cleaning shoe, a fragmentary part of the liquid injection means and a part of the abrasive wheel periphery, as the same would appear when viewed along line **24—24** of FIG. 22; and

FIG. 25 is an underface view of the modified cleaning shoe showing the liquid confining flanges of the cleaning shoe, the cleaning face thereof and the tapered mouth portion thereof for facilitating the injection of the cleaning fluid, as the same would appear when viewed in the direction of the arrows **25—25** of FIG. 24.

Similar reference characters refer to similar parts throughout the several views of the drawings and the specification.

Grinding wheel cleaning devices made in accordance with this invention are adapted to be mounted in operative relation to the grinding wheel of almost any type and form of grinding machine, and may be intermittently or continuously operated during any or all periods the grinding wheel is performing grinding work on a work surface. To more fully illustrate and explain the use and function of wheel cleaning devices of this invention, one form of this device is shown in FIG. 1 in mounted association with one of the many forms of grinding machines with which the device is adapted to be used.

The grinding machine M as shown in FIG. 1 for purposes of illustration, comprises a table or base section **50** which supports a transversely reciprocable table plate **51** whose sliding movement may be guided by a pair of transverse guide ribs and cooperating guide slots **51'**, with the transverse movement of the table plate **51** automatically or manually manipulated by suitable mechanism contained within the base section **50**, through the agency of a hand wheel **52** conveniently positioned on the front wall of the base section **50**. The numerous different kinds and types of grinding machines with which the grinding wheel cleaning device of this invention may be associated also usually includes a longitudinally reciprocable table plate **53** which may be supported on the transversely reciprocable table plate **51**, and whose longitudinally sliding movement is guided as by a pair of of longitudinally extending guide ribs and cooperating guide slots **53'**. The longitudinally reciprocable table plate **53** may also be manipulated by mechanism contained within the base section **50** which is manually activated as the hand wheel **54** conveniently mounted on the front wall of the base section **50**.

The grinding wheel G of the typical grinding machine M may be supported by a pedestal column **55** extending upwardly from the base section **50**, and whose front face supports a vertically reciprocable grinding wheel mounting plate **56**, whose vertical sliding movement may be guided by a pair of cooperating guide ribs and guide edges **56'** which form part of the pedestal column **55**. Sliding movement of the vertical mounting plate **56** may be effected by suitable mechanism contained within the pedestal column **56** and which may be manually manipulated as by means of a hand wheel **57** conveniently and accessibly mounted on the pedestal column **55**.

The grinding wheel G is suitably fixed to the end of a rotatably founted grinding wheel supporting shaft **58** which is journaled on the vertical mounting plate **56** and is rotated directly or indirectly by a constant speed or variable speed motor contained either in the pedestal column **55** or the base section **50**, and whose operation is suitably controlled as by a manually manipulated control lever **59** which may be conveniently and accessibly mounted on the front wall of the base section. That portion of the grinding wheel shaft which extends between the grinding wheel G and vertical mounting plate **56** may be suitably encased and protected by a shaft enclosing housing **58'** as shown in FIG. 1.

Grinding wheels G as commonly used may vary in diameter from four to twenty or more inches (10 to 50 cm.), with a peripheral thickness varying from one-fourth of an inch or less to six inches (0.5 to 30 cm.) or more, depending upon the grinding work to be performed. Grinding wheels are also rotated at speeds which may vary from a few hundred r.p.m. up to four thousand r.p.m. or more, depending upon the diameter of the grinding wheel and the work to be performed.

Grinding wheels are normally composed of grains or particles of very hard abrasive materials bonded together by a bonding plastic or metal, or bonded by sintering or the like. A workpiece lubricant and wheel coolant is normally applied to the periphery of the grinding wheel as by discharging the coolant directly adjacent the workpiece area being ground and the wheel periphery, or by feed the coolant internally of a porous grinding wheel and which is then forced to the grinding wheel periphery by the centrifugal forces of rotation. During the grinding operation, particles of metal or like material removed from the workpiece being ground, will soon clog the pores or become impacted between the grains of the abrasive wheel periphery and thus greatly reduced the grinding efficiency and speed of grinding, unless removed. The grinding wheel cleaning device of this invention is ideally adapted for the continuous cleaning and removal of workpiece particles embedded in the peripheral surface of the grinding wheel and abrasive grains loosened from the peripheral surface of the grinding wheel during the grinding operation, with resultant substantial increase in the speed of grinding, reduction in grinding wheel wear, improvement in the quality and accuracy of the grinding work performed, and reduction in lost time normally resulting when the grinding wheel is cleaned by the methods and means presently used.

In the typical form of grinding machine shown in FIG. 1, a relatively flat workpiece W is shown for purposes of illustration, which may be supported within a suitable workpiece supporting tray **60** presenting a bottom wall **60'** and enclosing side walls **60''**. To maintain the workpiece W in fixed position, the bottom wall **60'** of the tray **60** may be provided with a suitable holding or magnetic element **61** designed to fixedly hold the workpiece in position during the grinding operation. The workpiece supporting tray **60** may be fixedly supported by the longitudinally reciprocal table plate 53 so that the workpiece W as supported in the tray 60 may be longitudinally manipulated as by the hand wheel 54, and also transversely manipulated as by the hand wheel 52. The work surface W′ of the workpiece W to be ground may be brought into grinding contact with the rotating grinding wheel G by a vertical manipulation of the grinding wheel as by the hand wheel 57. While a relatively flat faced workpiece W is shown in FIG. 1 for purposes of illustration, it will be appreciated that numerous shapes and forms of work surfaces may be ground in accordance with the form and mounting arrangement of the grinding wheel. It will also be appreciated that suitable jigs and fixtures well known in the art may be employed to support and hold the workpiece in grinding position, and any suitable means may be employed for disposing of the removed workpiece particles and grinding wheel particles and recovering the coolant liquids deposited in the workpiece supporting tray 60, as by the provision of a drain tube 62 connected to the workpiece supporting tray 60 and through which the debris may be removed for disposal.

To protect the workmen operating the grinding machine from flying particles removed from the workpiece, and abrasive grains loosened from the grinding wheel, and to also confine the spray of coolant liquid spun from the surface of the grinding wheel, it is customary to cover a substantial part of the grinding wheel with a suitable protective guard 63 having a generally arcuately shaped peripheral wall 63′ extending a substantial distance around the grinding wheel periphery, and fixed to a pair of spaced side walls 63″ which telescope over the sides of the grinding wheel, and which thus serve to deflect particles and coolant spun from the periphery of the rotating wheel into the workpiece supporting tray 60 for drainage removal. In the form of the invention shown in FIG. 1, the grinding wheel guard 63 is rigidly connected to the grinding wheel shaft housing 58′, but may otherwise be supported in any desired manner which will not obstruct the performance of the grinding operation.

The grinding wheel cleaning device of this invention is desirably positioned on one side of the grinding wheel in a manner not to obstruct or interfere with the grinding operation, and for purposes of illustration the grinding wheel cleaning device of this invention is shown in FIG. 1 as rigidly connected to and mounted on the grinding wheel guard housing 63. The device comprises a vibrator assembly A which may be adjustably supported on a carriage B, one end of which is fixed to the guard housing 63. The carriage B is constructed to maintain the cleaning shoe C of the vibrator assembly A in precise predetermined relation to the peripheral surface of the grinding wheel to be cleaned.

As shown in FIGS. 1 and 2, the supporting carriage B may comprise a supporting rail 70 whose cross-section is in the form of an I-beam, presenting upper and lower flanges 70′ and 70″ joined by a connecting web 70‴. One end of the rail member is rigidly fixed to a supporting bracket 71 which may be rigidly secured as by bolts 71′ to the peripheral wall 63′ of the guard housing. The supporting rail 70 extends in a direction generally radially of the grinding wheel G, and provides support for a pair of suspension brackets 72 and 78 constructed as shown in FIGS. 1 and 2.

The suspension bracket 72 presents a suspended body section 73 having a pair of arms 74 extending therefrom. Two traveling rollers 75, formed of metal, plastic, hard rubber or like wear-resistant material, may be rotatably mounted on the paired arms 74 and designed to roll along the opposite faces of the lower flange 70″ of the supporting rail 70. The body section 73 of the suspension bracket 72 may also be provided with a pair of forwardly projecting arms 76 between which a guide roller 77 is rotatably mounted. The guide roller 77 has a wear-resistant peripheral surface 77′ designed to freely roll on the periphery of the adjacent grinding wheel G as shown in FIGS. 1 and 2, and provides the means for precisely maintaining the position of the working face of the cleaning shoe C of the vibrator assembly A in proper manually adjusted relation to the periphery of the grinding wheel.

The suspension bracket 78 also presents a body section 79 having a pair of spaced arms 80 extending therefrom, and which rotatably support a traveling roller 81 which rolls on the lower flange 70″ of the supporting rail 70. The traveling roller 81 associated with suspension bracket 78, and the upper roller 75 associated with suspension bracket 72, have a diameter which closely approximates the distance between the inner surfaces of the upper flange 70′ and lower flange 70″ of the supporting rail 70 so that the suspension brackets 72 and 78 supported thereby have a non-vibrating movement on the supporting rail 70.

The suspension brackets 72 and 78 are maintained in predetermined fixed spaced relation by a supporting rod 82 which may extend into appropriate holes formed in the body sections 73 and 79 of the suspension brackets 72 and 78, and suitably fixed thereto as by set screws or rivets 82′, as shown in FIG. 2. The periphery of the guide roller 77 associated with suspension bracket 72 may be maintained in contact with the periphery of the grinding wheel G, regardless of wear and diameter reduction of the grinding wheel, by means of a coiled tension spring 83 as shown in FIG. 2, one end of which is adjustably fixed to a suitable lug 84 rigidly connected to and extending from the lower flange 70″ of the supporting rail 70. The other end of the tension spring 83 may be provided with a hook portion 83′ which may be hooked over a transverse pin 85 extending between the paired supporting arms 80 of the suspension bracket 78.

The supporting rod 82 presents an end extension 82*a* which extends beyond the adjacent suspension bracket 78, and which provides support for a suspension hanger 86. The suspension hanger 86 presents an upper body portion 86′ having a bore extending therethrough so that it may be telescoped over the rod extension 82*a* of the supporting rod 82 and locked against rotative movement by a longitudinally extending key 87 as shown in FIGS. 2 and 5. The suspension hanger 86 also presents a lower body portion 86″ having a threaded bore into which one end of the casing which forms a part of the vibrator assembly A may be detachably connected in a manner hereafter described.

The rod extension 82*a* of the supporting rod 82 is provided with a terminal end portion 82*b* having external threads thereon and to which an adjusting cap 90 is applied. The adjusting cap 90 has a knurled head portion 90′, by means of which it can be manually rotated, and a tubular skirt portion 90″ whose terminal end is designed to have bearing contact with the adjacent end face of the upper body portion 86′ of the suspension hanger 86, as shown in FIG. 2. A coiled compression spring 91 is telescoped over the end extension 82*a* of the supporting rod 82 and interposed between the adjacent end face of the body section 79 of the suspension bracket 78 and the adjacent end face of the upper body portion 86′ of the suspension hanger 86. By a suitable manipulation of the adjusting cap 90, the position of the suspension hanger 86 which supports the vibrator assembly A may be precisely adjusted to place the working face of the grinding wheel cleaning shoe C in precise spaced relation to the peripheral surface of the grinding wheel G prior to initiation of the grinding wheel cleaning operation. Once the cleaning shoe C has thus been manually adjusted in precise spaced relation to the peripheral surface of the grinding wheel G, the contact roller 77 will thereafter maintain the contact face of the cleaning shoe C in the desired set position with respect to the peripheral surface of the grinding wheel during subsequent grinding operations, irrespective of the wear on the peripheral surface of the grinding wheel resulting from workpiece grinding action. The contact roller 77 of the device B above described, is particularly adapted for use with relatively soft grinding wheels which are subjected to substantial wear during the grinding operation, and which contact roller 77 operates to maintain a uniform depth of gap space between the working face 6' of the cleaning shoe C and the rapidly eroding peripheral surface of the grinding wheel, as manually adjusted by the adjusting cap 90. Where the grinding wheel is relatively hard, and subjected to comparatively little wear during extended grinding periods when the wheel cleaning device of this invention is employed, the rider wheel 77 may be held out of contact with the periphery of the grinding wheel, as by clamping the suspension brackets 72 and 78 in fixed position to the supporting rail 70, and only using the adjusting cap 90 for manually adjusting the depth of the spacing gap as periodically required.

The vibrator assembly A comprises a transducer unit 1 which includes a transducer section 2 rigidly fixed to one end of a connecting body 3 whose other end supports the cleaning shoe C, as shown in FIGS. 1, 2, 11 and 12. The transducer section 2 and a substantial part of the connecting body 3 is contained within a housing 10 which includes a tubular casing 11 which may be molded from non-conductive plastic or the like and which may be shaped in the form shown in FIGS. 2 and 9. The tubular casing 11 presents a tubular body section 12 which terminates in an enlarged boss portion 13 at the tail end thereof and which is provided with external threads 13'. The head end of the tubular casing 11 presents an external boss portion 14 which merges into an intermediate boss portion 15 of slightly lesser diameter and which in turn merges into the tubular body section 12 of the casing. Since the tubular body section 12 of the casing 11 presents a relatively thin wall, the same may be reinforced by an internal circumferentially extending enlargement or rib 12' as shown in FIGS. 2 and 9, which may be formed as an integral part of the casing 11.

The suspension hanger 86 provides the means for adjustably supporting the vibrator assembly A in wheel cleaning position. The lower body portion 86'' of the suspension hanger 86 is provided with an internally threaded bore 88 into which the externally threaded boss portion 13 of the casing 11 of the vibrator assembly A may be threaded, prior to mounting the suspension hanger 86 on the end extension 82*a* of the supporting rod 82 of the carriage B. The threaded bore 88 of the suspension hanger 86 terminates in an inwardly extending lip portion 89 as shown in FIGS. 2 and 13 which provides the means for rigidly but detachably connecting other components of the vibrator assembly A in operative relation to its casing 11 as hereinafter described.

The transducer section 2 and a substantial part of the connecting body 3 of the transducer unit 1, is inserted into the mouth end of the casing 1 and supported therein by a resilient sealing ring 20 which is positioned approximately at the node of motion of the connecting body 3, and in abutting relation to an internal abutment shoulder 14' forming an integral part of the casing 11. A clamping collar 21 having an axial hole therein, and through which the connecting body 3 of the transducer unit 1 loosely telescopes, presents a tubular skirt portion 21' whose terminal end is brought into abutment against the sealing ring 20 as shown in FIG. 2, thereby clamping the sealing ring 20 between the abutment shoulder 14' of the casing 11 and the skirt portion 21' of the clamping collar 21.

The clamping collar 21 presents a flange portion 21'' flaring outwardly from the skirt portion 21'. After the skirt portion 21' of the clamping collar 21 has been inserted into the head end of the casing and in abutting relation to the sealing ring 20, the clamping collar 21 may be secured to the suspension hanger 86 as by a plurality of tie rods 22, three of which are used in the device illustrated in FIGS. 2 and 5. The head end of each of the tie rods 22 may be provided with a threaded end portion 22' inserted in a suitable threaded aperture in the flange portion 21'' of the clamping collar 21, with the tail end 22'' of each tie rod 22 inserted into a bored hole 86*a* in the lower body portion 86'' of the suspension hanger 86. Tension is then applied to each tie rod 22 by manipulating a clamping nut 23 applied to the threaded tail end 22'' of each tie rod 22. The housing 10 of the vibrator assembly is thus rigidly supported at both ends thereof from the suspension hanger 86.

An enamel coated wire winding 16 is snugly wound around the outer circumference of the tubular body section 12 of the casing 11 and between the enlarged boss portion 13 and the intermediate boss portion 15 of the casing as shown in FIG. 2. The terminal lead wires 17—17' from the winding 16 are pocketed in a longitudinal slot 13'' formed in the outer surface of the boss portion 13 as shown in FIG. 13, with the terminal lead wires 17—17' extending outside of the tail end of the casing 11. The winding 16 is enclosed within a tubular jacket 19 as shown in FIG. 2. The head end of the tubular jacket 19 snugly telescopes over the intermediate boss portion 15 of the casing and is supported thereby, and the tail end of the tubular jacket 19 telescopes over and is supported by the adjacent end of the boss portion 13.

A closure plug 24 is inserted into the tail end of the casing 11 as shown in FIG. 2. The closure plug 24 is provided with a circumferentially extending groove in which a resilient sealing gasket 24' is positioned and which provides a leak-proof seal between the plug 24 and the tail end of the casing 11. The closure plug 24 and associated sealing gasket 24' at the tail end of the casing 11, and the resilient and conformable sealing ring 20 at the head end of the casing 11, define therebetween an internal chamber 25 to which a coolant is supplied, and which maintains the transducer section 2 of the transducer unit 1 as inserted therein, as well as the winding 16 and casing 11 and the housing 10 as a whole, in relatively cool condition during operation of the vibrator assembly A.

As shown in FIGS. 2 and 13, a liquid or gaseous coolant is supplied to the interior chamber 25 by a coolant inlet tube 26 which extends a substantial distance into the chamber 25 and thence extends through the closure plug 24 to the exterior side thereof. A coolant outlet tube 27 extends axially through the closure plug 24 and emerges through the exterior side thereof. The coolant inlet and outlet tubes 26 and 27 insure adequate circulation of the coolant in the cooling chamber 25.

The outer terminal ends of the coolant inlet tube 26 and coolant outlet tube 27 are detachably connected, as by means of male and female connecting ampules 26*a*—26*b* and 27*a*—27*b* respectively, to a coolant supply capillary 26' and a coolant discharge capillary 27' which extend to a more distant source of coolant supply and coolant disposal as shown in FIGS. 1 and 13. The coolant supply capillary 26' and coolant discharge capillary 27' are contained within a flexible conduit 28. The vibrator connecting end of the flexible conduit 28 may be strengthened and reinforced by a flexible protective guard 29 which may be in the form of a flexible wire coil wound around the conduit as shown in FIGS. 2 and 13. The flexible conduit 28 also contains biased alternating current supply wires 18—18' whose terminal ends are designed to be detachably connected to the terminal ends of the lead wires 17—17' from the winding 16 as by means of detachable prongs and socket connectors 17*a*—17*b* as shown in FIG. 13.

The female ampule portions 26*b* and 27*b* to which the coolant inlet tube 26 and coolant outlet tube 27 are respectively connected, are contained within and supported by a supporting plug 30 as shown in FIG. 13. The plug 30 also contains and supports the socket connector portions 17*b* to which the lead wires 17—17' are connected. The supporting plug 30 is tightly fitted within an internal tubular sleeve 31 presenting a circumferentially extending external rib 31' positioned medially of the length thereof, thereby dividing the tubular sleeve 31 into an externally threaded portion 31*a* and a tubular skirt portion 31*b* on opposite sides of the external rib 31'.

A secondary plug 32 supports the male ampule portions 26*a* and 27*a* to which the coolant supply and outlet tubes 26' and 27' are connected as shown in FIG. 13. The secondary plug 32 also supports the prong portions 17*a* to which the biased current supply wires 18—18' are connected. The male ampule portions 26*a* and 27*a* and the prong connector portions 17*a* as supported by the secondary plug 32, are designed for plug insertion into the female ampule portions 26*b* and 27*b* and the socket connector portions 17*b* as supported by the plug 30 contained within the internal sleeve 31.

An adapter 33 telescopes over the flexible protective guard 29 and is secured thereto as by a set screw 33' as shown in FIG. 13. The adapter 33 presents a tapered neck portion 33*a* which snugly surrounds the flexible protective guard 29, and a tubular skirt portion 33*b* which terminates in a circumferentially extending external rib 33''. When assembled, the skirt portion 33*b* is designed to snugly telescope over the secondary plug 32, and the outer face of the external rib 33'' is designed to be drawn into snug abutment against the adjacent end face of the tubular sleeve 31; and the external rib 31' of the tubular sleeve 31 which contains the supporting plug 30 is designed to be brought into snug abutment against the inside face of the inwardly extending lip portion 89 of the suspension hanger 86, as shown in FIGS. 2 and 13.

After the prong and socket connectors 17*a*—17*b* associated with the lead wires 17—17' and current supply wires 18—18' have been connected together, and after the coolant inlet and outlet tubes 26 and 27 have been connected to the coolant supply and discharge capillaries 26' and 27' by the connecting ampules 26*a*—26*b* and 27*a*—27*b*, the plug supporting internal sleeve 31 and the conduit adapter 33 are locked to the inwardly extending lip portion 89 of the suspension hanger 86 by a connecting sleeve 34. The tubular connecting sleeve 34 presents an externally knurled body portion 34*a* and an internally threaded skirt portion 34*b*. The body portion 34*a* presents an internal shoulder 34' adapted to abut against the external rib 33'' of the adapter 33. The internally threaded skirt portion 34*b* of the connecting sleeve is designed to be threaded over the externally threaded portion 31*a* of the tubular sleeve 31. The connecting sleeve 34 may be rotated by the fingers applied to the externally knurled body portion 34*a* thereof, until the terminal end face of its skirt portion 34*b* and the external rib 31' of the internal sleeve 31 tightly clamp the lip portion 89 of the suspension hanger 86 therebetween. Rotative tightening of the connecting sleeve 34 will also draw the internal abutment shoulder 34' at the inner end of the body portion 34*a* of the connecting sleeve 34 against the outer face of the external rib 33'' of the adapter 33, with the external rib 33'' of the adapter 33 in firm abutting relation against the adjacent end face of the tubular sleeve 31. The casing 11, insert plug 24, internal sleeve 31, the associated ampule supporting plug 30 contained in the tubular sleeve, the secondary plug 32, conduit adapter 33, connecting sleeve 34 and suspension hanger 86 are assembled together as a unit, prior to application of the suspension hanger 86 to the end extension 82*a* of the supporting rod 82 as shown in FIG. 2.

The motion generating transducer unit 1 is desirably formed as an integral member and includes a transducer section 2 which is caused to vibrate at high frequency and low amplitude when subjected to the influence of a corresponding high frequency alternating magnetic field as supplied by the winding 16. The longitudinal vibrations thus generated at one end of the transducer section 2, are transmitted to an acoustical impedance transformer section 3 rigidly fixed to one end thereof and which provides a connecting body to which the cleaning shoe C is attached. The transformer section 3 is shaped, formed and designed to engender at the operating face of the cleaning shoe C the type and kind of high frequency and low amplitude motion best suited to produce the most effective cleaning action on the peripheral surface of the rotating abrasive wheel G.

The transducer section 2 of the transducer unit 1 may be any one of a number of electrical mechanical types, such as electrodynamic, piezoelectric or magnetostrictive. However, at the preferred operating frequency in the order of twenty thousand to forty thousand cycles per second, the transducer section 2 is preferably of the magnetostrictive type. The magnetostrictive transducer section 2 may be composed of a compact stack of thin plates or laminates as shown in FIG. 4, formed from a metal such as permanickel, permendur, or other metals which have high tensile strength and are highly magnetostrictive in character, so that the transducer section will longitudinally vibrate to a maximum degree when subjected to the influence of an alternating magnetic field as established by the biased alternating current supplied by the winding 16 in surrounding relation to the transducer section. This alternating magnetic field is effectively established around the transducer section 2 of the transducer unit, since the casing 11 on which the winding 16 is externally wound is formed from a non-conducting and non-magnetic material such as nylon or the like which does not impede the passage of magnetic flux therethrough.

One end of the acoustical impedance transformer 3 is rigidly secured as by silver solder to the adjacent end of the transducer section 2, and its other end is either integrally secured or detachably securing to the cleaning shoe C. The transformer section 3 should be made of a strong metal, such as Monel metal, titanium, Phosphor bronze, beryllium copper or the like having high tensile strength. The transducer section 2 of the driving unit should have a length corresponding to one-half wavelength of sound or multiples thereof, traveling longitudinally through the material of the transducer section at the vibration frequency of the transducer section, and the transformer section 3 combined with the cleaning shoe C should have a length corresponding to one-half wavelength of sound or multiples thereof, traveling longitudinally through the material of the transformer section and cleaning shoe, at the vibration frequency of the transducer section 2.

Biased alternating current is supplied to the current supply wires 18—18' by a biased alternating current generator contained in a cabinet 35 as digrammatically illustrated in FIG. 1, and having externally accessible tuning controls 36. The cabinet 35 also may contain a coolant circulation pump (not shown) for the circulation of the transducer coolant through the coolant supply and outlet capillaries 26—27 and 26'—27' and contained in conduit 28 connected to the tail end of the vibrator casing 11. The coolant supply and outlet capillaries 26' and 27' may be connected to a coolant filter 37 of a suitable type associated with the generator cabinet 35 as shown in FIG. 1. The drain tube 62, which drains the cavitational fluid and grinding area coolant collected in the tray 60, may be joined to the generator cabinet 35 and in turn connected to disposal or sewage connections extending from the generator cabinet.

The remarkable cleaning results obtained by the grinding wheel cleaning device of this invention, is in part attained by the maintenance of a layer of wetting liquid between the operating or working face 6' of the cleaning shoe and the peripheral surface of the grinding wheel to be cleaned, with the wetting liquid layer therebetween subjected to the disrupting action of cavitational forces engendered by the high frequency and low amplitude vibration of the working face of the cleaning shoe. The cavitational disruption of the cleaning fluid layer serves to immediately dislodge workpiece particles and fragments embedded in the periphery of the grinding wheel and to also remove loosened abrasive grains therefrom.

The cleaning shoe C as shown in FIGS. 2, 7 and 8 presents a neck section **5** which may be rigidly and integrally attached to the adjacent end of the connecting body **3** of the transducer unit as by silver solder. The cleaning shoe C may also be detachably connected to the adjacent end of the connecting body **3** of the transducer unit **1** by providing the neck section **5** of the cleaning shoe with an internally threaded pocket **5′** into which a threaded stud **4** integral with and extending from the adjacent end of the connecting body **3** is inserted. To insure a rigid connection between the threaded stud **4** and the neck section **5** of the cleaning shoe C, the adjacent end portion **3′** of the connecting body may be made polygonal in shape as shown in FIG. 2, so that a wrench may be applied thereto.

The cleaning shoe C may be integrally formed from a tough and strong metal, and may be formed of the same metal from which the connecting body **3** is composed. The cleaning shoe C includes a head section **6** which is integral with the neck section **5** and which presents a working or cleaning face **6′** which is shaped in substantial conformity with the periphery of the grinding wheel. The head section **6** presents side flanges **6″** shaped and designed to neatly overlap the sides of the grinding wheel to which it is applied. The cleaning face **6′** of the head section **6** may present one or more small reservoir slots **7** extending transversely across the cleaning face **6′** and between the side flanges **6″** of the shoe, and which provide a reservoir for the wetting liquid. Each reservoir slot **7** may be in the order of 3.2 mm. in width and 1.6 mm. in depth, and have a length which approximately corresponds to, but is not greater than, the width or thickness of the peripheral grinding face of the grinding wheel.

The gap space between the working face **6′** of the cleaning shoe and the wheel periphery, may be supplied and filled with cavitational cleaning fluid by the provision of a series of fluid discharge ports uniformly distributed over the cleaning face **6′** of the shoe as shown in FIG. 7, and which respectively communicates with corresponding feeder holes **7′** extending into the shoe body. The feeder holes **7′** communicate with one or more closed end bores **7″** extending into the shoe body in a direction substantially parallel to the shoe side flanges **6″**, and in the direction of rotation of the grinding wheel. The feeder holes **7′** and associated discharge ports may be in the order of one-thirty-second of an inch (0.8 mm.) in diameter. Where the working face **6′** of the cleaning shoe is provided with one or more transverse slots **7**, as shown in FIGS. 2, 7 and 8, the discharge ports of the feeder holes **7′** preferably emerge within the transverse slot or slots **7**. The transverse slots **7** serve to protect the discharge ports of the feeder holes **7′** from cavitational erosion and debris clogging, and also provide small reservoirs for cavitational fluid which facilitates even distribution of the fluid layer in the spacing gap. The open end of the closed end fluid supply bores **7″** in the cleaning shoe are connected to a fluid supply tube **9** by a connecting manifold **8**. The fluid supply tube **9** may be supported by suitable clamps **9′** attached to the flange portion **21″** of the clamping collar **21** and to the lower body portion **86″** of the suspension hanger **86** of the device as shown in FIG. 2. The cavitational fluid is supplied by the supply tube **9** in sufficient volume and under sufficient pressure to maintain the closed end bores **7″**, feeder holes **7′**, reservoir slots **7** and spacing gap filled with fluid during the periods that the rotating grinding wheel is performing grinding or polishing work. As shown in FIG. 1, the wetting liquid supply tube **9** may be connected to a wetting liquid supply reservoir and pressure pump (not shown) contained in the generator cabinet **35**.

The vibrator unit **1** as shown in FIG. 2, assembled from the parts shown in FIGS. 11 and 12, represent a relatively straight connecting body **3**, with the longitudinal axis of the neck section **5** of the cleaning shoe C as shown in FIG. 12 forming a substantially straight line continuation of the longitudinal axis of the connecting body **3**. The connecting body and cleaning shoe C as thus formed are designed for the cleaning of grinding and polishing wheel peripheries presenting a substantially flat peripheral surface, with the shoe cleaning face **6′** executing substantially lineal motion strokes extending longitudinally of the axis of the connecting body **3** and substantially normal to the flat peripheral surface of the grinding and polishing wheel. While the acoustical impedance transformer or connecting body **3** is shown in FIGS. 2 and 3 as having a substantially uniform diameter throughout its length and thus not shaped to materially increase the amplitude of vibration delivered to the working face **6′** of the cleaning shoe C, it will be appreciated that the connecting body **3** may be shaped and formed in the manner disclosed in applicants' U.S. Patent Re. 25,033 to greatly increase the amplitude of vibration executed by the cleaning face **6′** of the cleaning shoe.

When the grinding and polishing periphery of the abrasive wheel is of irregular or contoured shape, for use in the grinding or polishing of irregular or contoured shape workpiece surfaces, it is desirable that the working face **6′** of the cleaning shoe have a lateral component of motion as well as a longitudinal motion component, so that all peripheral faces of the contoured grinding or polishing surface be subjected to the cavitational action of the wetting liquid. FIGS. 16 and 17 show for purposes of illustration a transducer unit **1** and associated cleaning shoe C′ which is formed and proportioned to produce elliptical or substantially circular motion strokes at the working face **6** of the cleaning shoe to thereby effectively clean contoured grinding and polishing surfaces, as for example, a contoured grinding and polishing surface designed to form threads or grooves in the workpiece surface.

In the form of the invention shown in FIGS. 16 and 17, the transducer section **2** may be formed in the same manner as the transducer section **2** shown in FIG. 11, and may be composed of a stack of plates of magnetostrictive metal such as nickel, held in assembled relation by an insert key **2′** which is set in a groove and soldered in position at the free end of the transducer section **2**. The transducer section **2** has a length approximately equal to one-half wavelength of sound traveling longitudinally through the material of the transducer section at the predetermined frequency of vibration. The connecting body **3** shown in FIGS. 16 and 17 may be formed of the same metal as heretofore described and is rigidly secured as by silver solder to the output end of the transducer section **2**.

The cleaning shoe C′ shown in FIGS. 16 and 17 presents a neck section **5*a*** which may be somewhat longer than the neck section **5** shown in FIG. 12 and previously described, and shaped to produce elliptical, circular or orbital motion at the working face **6′** of the cleaning shoe. The particular orbital motion desired at the working face **6′** of the cleaning shoe C′ may be built into the unit by providing a mass eccentricity in the neck section **5*a*** which may be achieved by forming a properly shaped cavity **5*b*** in one side of the neck section **5*a***. The cavity **5*b*** is elongated to reduce localization of high stress regions and provide greater structural stability. In order to obtain the optimum degree of mass eccentricity and compliance reduction, the cavity **5*b*** should be limited to approximately a quarter wavelength of sound traveling longitudinally through the neck section **5*a*** and cleaning shoe C′.

Where a substantially circular motion is desired at the working face **6′** of the cleaning shoe, the depth of the cavity 5b should extend substantially to the longitudinal axis of the connecting body 3. Where it is desired to produce elliptical motion at the working face 6′ of the cleaning shoe whose longer motion stroke extends substantially parallel to the longitudinal axis of the connecting body 3, the depth of the cavity 5b should be correspondingly shallow and should not intersect the longitudinal axis of the connecting body 3. Where it is desired to produce elliptical motion strokes at the working face 6′ of the cleaning shoe C whose longer axis extends parallel to the axis of the grinding wheel to thereby produce a substantially lateral motion component at the contact face 6′, the cavity 5b should be correspondingly greater depth and intersect the longitudinal axis of the connecting body 3.

The cleaning shoe C′ shown in FIGS. 16 and 17 has a head section 6 presenting an arcuate working face 6′ and side flanges 6″ designed to snugly overlap the side faces of the grinding wheel. The working face 6′ is shaped to conform to the contoured grinding or polishing surface of the abrasive wheel, and where the grinding or polishing face of the wheel is designed to form threads or grooves in the workpiece surface, the working face 6′ of the cleaning shoe is provided with correspondingly shaped angular ribs 6a as shown in FIGS. 16–20 extending longitudinally along the arcuate working face 6′ of the cleaning shoe. The longitudinal ribs 6a are intersected by the transversely extending reservoir slots 7 joined by feeder holes 7′ to wetting liquid supply passages or closed end bores 7″ extending in the direction of wheel rotation, and which are in turn joined by a connecting manifold 8 to the wetting liquid supply tube 9 as previously described.

The combined length of the connecting body 3, elongated neck section 5a and head section 6 of the cleaning shoe as shown in FIGS. 16 and 17, is made to approximately correspond to one-half the wavelength of sound or integral multiples thereof traveling longitudinally through the connecting body 3, neck section 5a and shoe C′, at the frequency of vibration established for the unit. Frequencies in the order of twenty to forty thousand cycles per second are preferred, with a total longitudinal excursion of the shoe contact face 6′ in the order of one to two-thousandths of an inch (50 microns). Since higher frequencies produce correspondingly lower amplitudes for a given transducer unit 1, a high frequency setting for the transducer unit will yield motion strokes of correspondingly decreased length.

Another form of cleaning shoe which can be used, is illustrated in FIGS. 21–25. This modified form of cleaning shoe C″ comprises a head section 6 which presents a working face 6′ substantially in shape conformity to the abrasive wheel periphery to be cleaned. The cleaning shoe C″ also desirably presents flange portions 6″ which extend the full length thereof, and whose inside faces snugly telescope over the peripheral rim margins of the abrasive wheel. The inside faces of the flange portions 6″ may be ground into precise shape conformity with the rim edges of the abrasive wheel so as to provide a minimum of leakage space therebetween. The lead end of the body section 6 of this cleaning shoe C″ has a tapered liquid inlet face 6b extending between the side flange portions 6″ of the cleaning shoe and tapers into the plane of the working face 6′.

The acutely angled wedge shaped gap 6c defined between the inclined face 6b and the adjacent peripheral surface of the abrasive wheel, provides a wedge-shaped cavity into which a cleaning liquid can be forcibly injected in the direction of rotation of the abrasive wheel as indicated in FIG. 21. The injection means may comprise a relatively flat and wedge-shaped nozzle 8a presenting a discharge slit 8b which is supported to extend a slight distance into the wedge-shaped cavity 6c at the lead end of the cleaning shoe, and between the inside faces of the flanges 6″ of the cleaning shoe. The nozzle 8a is shaped to insure minimum obstruction to the sheeted flow of pressurized liquid through the discharge slit 8b of the nozzle. To this end, the nozzle 8a has a laterally contracting but side bulging taper which terminates in a substantially tubular portion 8c which may be connected to the wetting liquid supply tube 9 heretofore described.

The pressurized wetting liquid supplied by the tube 9 to the nozzle 8a is sheeted into a relatively thin stream of high velocity and thus injected into the gap space between the working face 6′ of the shoe C″ and the abrasive wheel periphery. Since this injection takes place in the direction of rotation of the wheel periphery, a layer of wetting liquid can be maintained which fills the gap space during operative rotation of the abrasive wheel.

The head section 6 of the cleaning shoe C″ constructed as shown in FIGS. 21–25, is provided with a neck section which may be shaped in accordance with the neck section 5 of the cleaning shoe C as shown in FIGS. 7 and 8, or in accordance with the neck section 5a of the cleaning shoe C′ shown in FIGS. 16–20. This neck section 5 or 5a is integrally or detachably but firmly joined to the connecting body 3 which is in turn rigidly connected to one end of the transducer section 2 as previously described, to provide an assembled transducer unit 1. The neck section 5 or 5a should be attached to the head section 6 of the cleaning shoe C″ so that the longitudinal axis of its neck section is positioned approximately midway between the lead and following ends of its working face 6′. Where the peripheral surface of the abrasive wheel to be cleaned is contoured in shape, the contact face 6′ of the cleaning shoe C″ should be contoured in conformity therewith, as heretofore explained in connection with the description of the cleaning shoe C′.

To obtain optimum grinding efficiency, it is essential that impacted workpiece particles, loosened abrasive grains and like debris be constantly removed from the grinding periphery of the wheel during the grinding operation, so that the abrasive grains bonded to the periphery of the wheel can perform maximum grinding or polishing action. Optimum efficiency in grinding also requires that a liquid be maintained at the cleaning site of the grinding surface for cavitational dislodgment and removal of particle debris.

The problem of maintaining a cavitationally operative layer of liquid at the cleaning site of the grinding periphery of a rapidly rotating abrasive wheel can be appreciated by a calculation of the centrifugal forces acting to spin off the liquid from the periphery of the grinding wheel. The centrifugal forces (F) tending to throw a liquid from the periphery of a circular abrasive wheel may be represented by the following formula:

$$F \text{ (force)} = 4\pi^2 MN^2 r$$

in which formula M represents the mass of the liquid, N is the number of revolutions per second of the abrasive wheel, and r is the radius of the abrasive wheel.

Taking for example, a six inch (or about 15 cm.) diameter abrasive wheel, the centrifugal force F tending to spin off a one gram mass of liquid from the grinding wheel periphery, at different revolutions of the wheel per second, is as follows:

Rev./Sec. (N)	1	10	20	30	50	60	100
Centrifugal Force (F)	0.3g	30g	120g	270g	750g	1,030g	3,000g

In the above computation, N represents the number of revolutions per second of the grinding wheel, and F is the magnitude of the force which tends to drive off the fluid mass, given as a multiple of the earth's gravitational acceleration g. From the above computation and formula, it is evident that the force (F) increases quadratically with the number of revolutions per second (N). At a speed of about 60 r.p.s., or about 3600 r.p.m., the centrifugal force tending to spin off the liquid from the wheel periphery is greater than a thousand times g. It is also evident that the adhesion of the fluid to the peripheral surface of the grinding wheel would have to be greater than the force F tending to spin off the liquid, if the liquid is to remain on the wheel at the cleaning site.

The remarkably effective abrasive wheel cleaning results realized by the practice of the method and the use of the cleaning device of this invention, is attained by the provision of a method and means for maintaining a liquid layer between the work face of the cleaning shoe and the peripheral grinding surface, notwithstanding the force F acting to spin off the liquid from the rotating wheel periphery, and then simultaneously subjecting the liquid layer pocketed between the working face of the cleaning shoe and the wheel periphery, to the cavitational effects of ultrasonic vibration. The remarkable cleaning efficiency resulting from the practice of this invention is attained by establishing a series of factors operating in interrelated and cooperative combination, including the following:

The working or contact face 6′ of the cleaning shoes C, C′ and C″ should be shaped to substantially conform to the peripheral grinding face of the grinding wheel. Since the grinding wheel undergoes a gradual reduction in diameter as abrasive grains are worn off during the grinding operation, with a corresponding change in curvature of its peripheral grinding surface, the working face 6′ of the cleaning shoe may be reshaped into substantially arcuate conformity with the grinding periphery of the reduced diameter grinding wheel, and the shape of the shoe working face maintained within the limits required for high grinding efficiency by occasionally moving the working face 6′ of the cleaning shoe into grinding contact with the periphery of the grinding wheel and thereby reshape the contact surface 6′ in conformity therewith. This adjustment may be conveniently and quickly made by a corresponding manipulation of the adjusting cap 90 associated with the carriage B of the device.

As a further condition, the working face 6′ of the cleaning shoes C, C′ and C″ should preferably be set, when not under vibration, in spaced relation to the peripheral grinding surface of the grinding wheel at a distance of approximately five to ten-thousandths of an inch (.125 to .25 mm.) with the vibrator unit 1 designed to produce a stroking movement of the working face in the order of one to two-thousandths of an inch (.025 to .050 mm.). This gap spacing depth contributes to the maintenance of the liquid layer between the working face 6′ of the cleaning shoe C and the peripheral grinding surface of the wheel and resultant effective debris removing cavitation of the liquid layer.

The head section 6 of the cleaning shoes C, C′ and C″ should present side flanges 6″ which snugly overlap the side faces of the abrasive wheel for a distance of approximately one eighth of an inch (0.32 cm.) and so that the space defined between the inside faces of the side flanges 6″ closely conforms to the width of the grinding periphery of the abrasive wheel. This minute clearance can be effectively assured by the expedient of actually grinding off the inside faces of the side flanges 6″ during initial rotation of the abrasive wheel, thereby providing for a minimum clearance sufficient only to avoid any impediment to the rotation of the grinding wheel.

The retention of an adequate quantity of cleaning liquid at the cleaning site as defined between the working face 6′ of the cleaning shoe C and the adjacent area of the grinding periphery of the rotating wheel, is predicated upon the continuous supply of an adequate pressurized quantity of liquid to the cleaning site, the maintenance of the gap space between the working face of the cleaning shoe and the peripheral grinding surface of the wheel substantially filled with liquid at all times, and the wetting tenacity of the liquid itself.

Two methods may be used to insure an adequate supply of cleaning liquid at the cleaning site as defined between the working face of the cleaning shoe and the adjacent area of the abrasive wheel periphery. In the method shown in FIGS. 2, 7, 8, 18, 19 and 20, the wetting liquid supplied under pressure by the supply tube 9, is injected through the manifold 8, closed end bores 7″ and feeder holes 7′ to maintain a cavitatable layer of wetting liquid at the cleaning site between the working face of the cleaning shoe and the adjacent area of the grinding wheel periphery. In the method shown in FIGS. 21–25, the lead end of the shoe presents a tapered face 6*b* which defines a wedge-shaped mouth or gap 6*c* which directs the injected liquid stream supplied by nozzle 8*a* and supply tube 9, into the gap space between the working face of the cleaning shoe and the adjacent area of the grinding wheel periphery, in the direction of rotation of the abrasive wheel. In both methods, the wetting liquid is injected in sufficient quantity and under sufficient pressure to fill the gap space between the shoe working face and cleaning site area of the wheel periphery with wetting liquid during operative rotation of the abrasive wheel.

While the grinding wheel cleaning method and device of this invention is particularly adapted for cleaning nonporous grinding wheels as most commonly used, the method and device of this invention can also be advantageously used for cleaning the peripheral surface of porous grinding wheels in which the grinding area between the workpiece and porous wheel is supplied with a coolant fed through the porous structure of the wheel. By way of example, there is shown in FIGS. 14 and 15, a porous grinding wheel G′ which is attached to the grinding wheel shaft 58 as by the provision of a pair of clamp plates 65 positioned over sealing gaskets 66, and drawn tightly against the sides of the wheel by adjusting nuts 67 threaded to spaced threaded portions of the wheel shaft 58. The clamp plates 65 present a multiplicity of closely spaced liquid feeder holes 65′ extending around the periphery thereof and which are outwardly inclined with respect to the wheel axis as indicated in FIGS. 14 and 15. Correspondingly aligned holes 66′ are provided in the sealing gaskets 66 to permit the liquid to flow through the aligned holes 65′ and 66′ and into the porous structure of the grinding wheel G′.

Each of the clamping discs 65 is surrounded by a retainer ring 68 of truncated conical shape, with its larger end snugly seated against the outer rim of the adjacent sealing gasket 66. Liquid is fed into both retainer rings 68 by suitable liquid supply tubes 69. Rotation of the porous grinding wheel G′ causes the liquid to hug the inside faces of the retainer rings 68 and further serves to drive the liquid through the aligned inclined holes 65′ and 66′ in the clamp plates 65 and sealing gasket 66, and into the body of the porous wheel. The centrifugal forces in the order of the aforestated magnitudes generated by the rotation of the porous abrasive wheel, then drive the liquid to the peripheral surface of the grinding wheel.

Some of the liquid emerges from the peripheral surface of the grinding wheel at the grinding area between the workpiece surface being ground and the wheel periphery, to thereby cool and lubricate the area of the workpiece being ground. The remaining liquid impelled through the porous structure of the wheel serves to cool the wheel itself. Some of the liquid coolant driven through the porous wheel structure is also trapped in the spacing gap between the working face 6′ of the shoe C and the wheel periphery as shown in FIGS. 14 and 15. The cleaning shoe C shown in these figures may be constructed substantially as heretofore described, and the same coolant liquid of cavitational capabilities as fed through the porous wheel structure, is also supplied by the supply tube 9, manifold 8, closed end bore 7″ and feeder holes 7′ to the spacing gap. It will thus be noted that the liquid layer supplied to the spacing gap by the feeder holes 7′, is further augmented by coolant liquid driven through the porous wheel structure and trapped in the spacing gap. A full layer of coolant liquid capable of being vigorously cavitated is thereby maintained in the spacing gap, and when the working face 6′ of the shoe is vibrated by the vibrator unit heretofore described, the embedded particle debris is extracted from the peripheral surface of the porous wheel as a result of the combined forces of cavitational action and pushing pressure exerted by the liquid centrifugally driven through the rotating porous wheel structure and emerging at the spacing gap.

The employment of the method and means of this invention, operates to maintain the liquid in residence at the cleaning site and pocketed in the spacing gap between the working face of the cleaning shoe and adjacent area of the peripheral grinding surface of the rotating wheel, by an inter-related combination of the following features:

(1) The provisions of a working face 6′ for the cleaning shoe which is substantially in conformity to the peripheral surface of the grinding wheel, with a clearance distance or spacing gap depth between the contact face 6′ of the cleaning shoe and the adjacent peripheral area of the rotating wheel, in the order of five to ten-thousandths of an inch (.125 mm. to .25 mm.).

(2) The provision of side flanges 6′ on the cleaning shoe whose inside faces are in minute clearance relation to the side faces of the wheel, with a clearance therebetween in the order of one to two-thousandths of an inch (.025 mm. to .250 mm.). This feature further serves to maintain a full cavitatable layer of liquid in the spacing gap.

(3) The wetting liquid should be injected in sufficient quantity and under sufficient pressure to maintain a layer of wetting liquid in the spacing gap between the shoe working face and the periphery of the rotating abrasive wheel, notwithstanding expected substantial leakage and outflow of the wetting liquid from the cleaning site and around the side flanges of the cleaning shoe or other liquid confining means which can at best be only partially effective in their liquid confining ability.

(4) The production of cyclic motion strokes at the working face of the cleaning shoe of high frequency and relatively low amplitude; and preferably in the ultrasonic range of twenty to forty thousand cycles per second, with an amplitude of approximately only one-thousandth of an inch (.025 mm.) or less.

(5) Another factor which also contributes to the remarkable cleaning power obtained by the practice of the method and means of this invention, is the use of a cleaning liquid having low surface tension, with wetting or detergent properties. In general, the wetting liquid may comprise the anionic or cationic hydrophylic groups of wetting agents. The anionic hydrophylic group includes: phosphates and phosphoric acids, persulphates and thiosulphates; sulfonamides; and sulfamic acids. The cationic groups include the nitrogen and quarternary ammonium compounds. A number of liquids commonly used for cooling, lubricating and cleaning the workpiece area being ground, also constitute satisfactory cavitational liquids, and the same liquid may be used for both purposes.

By an inter-related combination of the method and means above described, a liquid layer can be maintained in the spacing gaps and subjected to such intense cavitational action and disruptive forces as to rip out workpiece particles and fragments which are firmly impacted between the abrasive grains of the wheel, with resultant cleaning effects which far exceed the simple arithmetical sum of the individual effects produced by the individual factors above enumerated. This is amply illustrated by the results achieved by the use of the method and means illustrated in FIGS. 1–13 and FIGS. 14 and 15, and mounted to clean a six inch (15 cm.) diameter abrasive wheel rotating at approximately 3400 r.p.m. while in the process of grinding a brass workpiece.

The following results were obtained from plunge grinds on a ten-inch brass workpiece.

	Depth of Grind (In Inches)	Degree of Loading	Mat'l Lost From Wheel In Cleaning (In Inches)	Grinding Conditions and Technique
(1)	.005-.008 (0.13-0.22 mm.)	Fully	.020 (0.50 mm.)	Dry grinding (without liquid without vibration).
(2)	.020-.030 (0.50-0.77 mm.)	do	.015-020 (0.38-0.50 mm.).	Normal grinding (water, without vibration).
(3)	.030-.045 (0.77-1.15 mm.)	do	.018 (0.44 mm.)	Detergent grinding (light detergent; no vibration).
(4)	.030-.045 (0.77-1.15 mm.)	do	.015 (0.38 mm.)	Vibration used with water supplied thru cleaning shoe.
(5)	.030-.045 (0.77-1.15 mm.)	do	.015 (0.38 mm.)	Vibration using water supplied thru porous wheel.
(6)	Over 1.500 (40 mm.)	Slightly	None	Vibration using detergent supplied thru cleaning shoe.
(7)	Over 2.000 (50 mm.)	do	do	Vibration using detergent supplied thru porous wheel and cleaning shoe.

The above tabulation shows the comparative results obtained from seven separate plunge grind tests on a ten-inch brass workpiece using the same six-inch (15 cm.) diameter abrasive wheel in all tests (Norton 19A150–L8V–150 grit) at a vibrational frequency of 28,000 cycles per second with the abrasive wheel rotating at 3,420 revolutions per minute.

In Test 1, no liquid was applied to the abrasive wheel, and after five to eight-thousandths of an inch (0.13 to 0.22 mm.) of material had been removed from the brass workpiece, the abrasive wheel periphery was fully loaded with workpiece particles. In the subsequent dressing of this loaded abrasive wheel using a pointed work tool as standard procedure, it was necessary to remove twenty-thousandths of an inch (0.50 mm.) of the abrasive wheel periphery to prepare the abrasive wheel for further use, after having ground only five to eight-thousandths of an inch (0.13 to 0.22 mm.) from the workpiece surface.

In Test 2 using normal grinding with water, and without vibration, approximately twenty to thirty-thousandths of an inch (0.50 to 0.77 mm.) of the brass workpiece surface was ground off before the abrasive wheel surface was fully loaded. Using a pointed tool as standard procedure, approximately fifteen to twenty-thousandths (0.38 to 0.50 mm.) of an inch of the abrasive wheel periphery had to be removed to clean the abrasive wheel for another run.

In Test 3 a low surface tension wetting fluid or detergent liquid was applied to the abrasive wheel during grinding, with no vibration, and thirty to forty-five thousandths of an inch (0.77 to 1.15 mm.) was ground off from the brass workpiece before the periphery of the wheel become loaded with workpiece particles. To clean the wheel, using a standard pointed tool for the purpose, it was necessary to remove eighteen-thousandths of an inch (0.44 mm.) from the wheel periphery to clean the wheel for another run.

In Test 4, an ultrasonically vibrated cleaning shoe was applied to the abrasive wheel and the cleaning shoe supplied with water through a passage in the tool. Here again, only thirty to forty-five-thousandths of an inch (.77 to 1.15 mm.) of the material was removed from the brass workpiece before the abrasive wheel was fully loaded with abrasive workpiece particles, notwithstanding the application of ultrasonic vibration to the cleaning shoe supplied with water through the cleaning shoe head. After grind loading the abrasive wheel in Test 4, it was necessary to apply a pointed tool to remove the compacted debris from the peripheral surface thereof, and fifteen-thousandths of an inch (0.38 mm.) of the abrasive grinding wheel surface was necessarily removed to condition the abrasive wheel for re-use.

In Test 5, an ultrasonically vibrated cleaning shoe was applied to the peripheral surface of a porous grinding wheel, with water supplied through the porous wheel, and with no water supplied through the cleaning shoe. After thirty to forty-five-thousandths of an inch (0.77 to 1.15 mm.) of the brass workpiece surface had been removed in this test, the peripheral surface of the abrasive wheel was fully loaded with impacted debris, necessitating the removal of fifteen-thousandths of an inch (0.38 mm.) from the abrasive wheel surface by the use of a standard pointed tool to recondition the abrasive wheel for reuse.

While Tests 4 and 5 demonstrated that a somewhat greater amount of material was removed from the brass workpiece using ultrasonic vibration and water supplied through the cleaning shoe or porous wheel, before the peripheral surface of the abrasive wheel was loaded with impacted debris, as compared to the standard method whose results are given in Test 2, the improvement is a matter of degree only.

In Test 6, an ultrasonically vibrated cleaning shoe was applied to the abrasive wheel, and a low surface tension wetting agent under pressure was fed to the cleaning shoe, using the method and devices of this invention. After grinding off one and one-half inches (3.8 cm.) from the brass workpiece, during which the method and techniques of this invention were applied, the peripheral surface of the grinding wheel contained only a slight amount of impacted debris therein, with no noticeable wear on the peripheral surface of the grinding wheel.

In Test 7, a low surface tension wetting agent or detergent was supplied to the spacing gap through both the porous grinding wheel and the cleaning shoe in the manner illustrated in FIGS. 14 and 15, and ultrasonic vibration was applied to the cleaning shoe to cavitate the liquid as thus supplied to the spacing gap. In this Test 7, over two inches (5 cm.) of material was removed from the brass workpiece, resulting in only a slight amount of impacted debris at the peripheral surface of the abrasive wheel, and with no noticeable resultant wear or abrasive grain loss from the grinding wheel periphery.

It is evident from Test 3, that the use of a low surface tension wetting agent or detergent in place of water in connection with standard grinding practice as shown in Test 2, adds no substantial improvement to the grinding and cleaning operation. Nor is the operation materially improved by the use of an ultrasonically vibrated cleaning shoe internally supplied with water as shown in Test 4, nor by the use of an ultrasonically vibrated cleaning shoe with the water supplied to the porous structure of a grinding wheel as shown in Test 5.

Only by the use of an ultrasonically vibrated cleaning shoe, in association with a low surface tension wetting agent or detergent supplied under confined and pressurized conditions to the spacing gap in accordance with this invention, can the astounding results set forth in Tests 6 and 7 be achieved. Tests 6 and 7 demonstrate that by the use of the method and devices of this invention, cleaning of the working surface of an abrasive wheel can be accomplished as the grinding and polishing work proceeds, with the grinding and polishing surface of the wheel maintained at maximum operating efficiency, without interruption of the grinding or polishing work, and with the minimum amount of wheel wear or loss of abrasive grains from the grinding wheel surface.

The vibrator assembly A may be assembled at the factory in association with the suspension hanger **86**, before the suspension hanger **86** is applied to the supporting rod **82** of the carriage B. The housing **10** including the wire wound tubular casing **11**, closure plug **24**, ampule supporting plug **30**, internal tubular sleeve **31**, secondary plug **32**, conduit adapter **33** and connecting sleeve **34** are first assembled with the suspension hanger **86** in the manner heretofore described. The transducer unit, with cleaning shoe C attached to the outer end thereof, may then be inserted through the clamping collar **21** and resilient sealing ring **20** as shown in FIG. 2, and the tie rods **22** then applied to the clamping collar **21** and suspension hanger **86**. Before tightening the nuts **23** at the tail ends of the tie rods **22**, the transducer unit **1** can be oriented to fit the cleaning shoe C to the periphery of the abrasive wheel. The suspension hanger **86** may then be applied to the end extension **82***a* of the support rod **82** previously mounted as by the rail **70** to the abrasive wheel guard housing **63**. By manipulating the micrometer adapter **90**, the contact face of the cleaning shoe C is precisely adjusted to establish the proper spacing gap between the contact face **6'** of the shoe and grinding wheel surface.

The vibrator assembly **10** may be variously constructed within the purview of this invention, as long as it incorporates a transducer unit adapted to vibrate the working face of the cleaning shoe at frequencies in the order of twenty to forty thousand cycles per second and at correspondingly low amplitudes. The transducer unit **1** may be water cooled as shown in FIG. 2, or the same may be cooled by a stream of forced air or other circulating coolant. The relative size and length of the transducer unit **1**, the weight and shape of the cleaning shoe and the area of its contact face, and the cyclic frequency and amplitude of vibration, are factors which determine the input power required. The vibrator assembly shown in FIG. 2, applied to an abrasive wheel which is six inch (15 cm.) in diameter and approximately one-half inch (1.25 cm.) in thickness, requires only a relatively small amount of input power, and can be effectively operated with an input power of approximately one hundred watts.

The device of this invention can be manufactured and assembled for attachment to the protective guard or housing or other stationary element of almost any abrasive wheel grinding or polishing machine. This device can be supplied with an assortment of cleaning shoes C, C' or C'' to accommodate abrasive wheels of different widths and peripheral surface contours, and may be interchangeably attached to the transducer unit **1**. Alternatively, a series of transducer units **1** may be supplied with a different form of cleaning shoe C, C' or C'' permanently attached thereto in cases where the particular shape, weight, and form of the cleaning shoe must be taken into account in establishing the wavelength and construction of the transducer unit **1**.

The problem of maintaining abrasive wheels clean of debris, and in efficient operating condition, is solved by the practice of this invention. All necessary adjustments are provided for establishing complete cavitational action at the cleaning site, with automatic compensation for wear of the abrasive wheel. The use of the relatively simple method and means of this invention, result in a vast saving in grinding and polishing costs, and constitute an outstanding advance in grinding and polishing practices.

From the above disclosure, it is evident to those skilled in the art that the principles of this invention are applicable to the removal of embedded and impacted substances and debris from relatively flat, contoured and ovaloid surfaces of various types and kinds and is particularly applicable where the surface to be cleaned cannot be immersed in the cleaning fluid, or where a layer of cleaning fluid cannot otherwise be retained on the surface because of the relatively high speed of travel or rotation of the surface, or because the surface to be cleaned occupies a vertical, inclined or downwardly facing position, or because the forces of gravity or motion tend to strip the layer of cleaning fluid or liquid from the surface where cavitational action is to be applied.

In all situations where gravity or movement conditions prevent the normal retention of a cleaning fluid layer on the surface to be cleaned, such surfaces can nevertheless be cleaned in accordance with this invention by confining the cleaning liquid in the form of a relatively thin layer at the cleaning site of the surface to be cleaned by a combination of two or more of the following expedients, namely: (1) providing a cleaning shoe whose working face closely conforms to the cleaning area of the surface to be cleaned; (2) maintaining the shoe working face in spaced relation to the surface to be cleaned to provide a cavitatable fluid receiving spacing gap whose depth is in the order of five to ten-thousands of an inch (0.125 to 0.25 mm.); (3) providing some liquid confining means in surrounding relation to the working face of the cleaning shoe which is at least partially effective in retaining the liquid within the boundaries of the shoe working face; (4) supplying and directing the cleaning fluid into the gap space between the shoe working face of the immediately adjacent cleaning site area of the surface to be cleaned, in sufficient quantity and under sufficient pressure, notwithstanding substantial leakage around the confining means, to establish a full layer of the cleaning liquid at the cleaning site which can be subjected to cavitational action; (5) vibrating the working face of the cleaning shoe at ultrasonic frequencies and relatively low amplitudes; and (6) using a cleaning liquid characterized by low surface tension.

The cleaning liquid must be applied to the cleaning site to substantially fill the gap space between the shoe working face and the surface to be cleaned, in sufficient quantity and under sufficient pressure to maintain the gap space filled with cleaning liquid, notwithstanding leakage or some substantial out-flow of cleaning liquid from the confined space. By the use of a detergent or wetting liquid of low surface tension and high wetting characteristics, augmented by the supply of sufficient wetting liquid under sufficient pressure to establish and maintain a relatively full layer of wetting liquid at the cleaning site, and with some confining means in surrounding relation to the cleaning site and associated with the cleaning shoe or independent of the cleaning shoe, and which is at least partially effective in its confining ability, almost any relatively flat, contoured or ovaloid surfaces can be successfully cleaned and impacted debris removed therefrom, notwithsanding the speed of travel or the gravity forces tending to strip the cleaning fluid from the surface.

It is understood that the cleaning devices above described are to be taken as illutsrative only, and that various structural modifications and changes can be made therein to accommodate the particular operating conditions, as will be evident to those skilled in the art.

While certain novel features of this invention have been disclosed herein and are pointed out in the claims, it will be understood that various omissions, substitutions, and changes may be made by those skilled in the art without departing from the spirit of this invention.

What is claimed is:

1. A device effective to remove impacted material from the peripheral working surface of an abrasive wheel during working rotation thereof at production grinding peripheral speeds of not less than 25 feet per second which includes, a cleaning shoe which presents a cleaning face shaped in substantially arcute conformity to the peripheral working surface of the abrasive wheel with which it is associated, a pair of guide flanges extending along the opposite sides of said cleaning face and presenting inner surface portions designed to snugly overlap opposite side face portions of the abrasive wheel with minimal wheel rotative clearance therebetween, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the peripheral working surface of the abrasive wheel to be cleaned to provide a cavitational gap therebetween extending in the direction of rotation of the abrasive wheel and defined between the inner surfaces of said guide flanges, means for vibrating said cleaning shoe at ultrasonic frequencies in a general radial direction and at a stroking amplitude which is less than one-half the radial depth of the cavitational gap defined between the shoe cleaning face and the adjacent peripheral working surface of the abrasive wheel, and means for injecting a cleaning fluid into said cavitational gap in sufficient quantity and under sufficient pressure to establish an effective cavitating layer of cleaning fluid in said cavitational gap which is confined to flow between said guide flanges, cleaning face and the adjacent peripheral working surface of the abrasive wheel and thence to discharge from said cavitational gap during working rotation of the abrasive wheel in the direction of rotation.

2. A device effective to remove impacted material from the peripheral working surface of an abrasive wheel during working rotation thereof at production grinding peripheral speeds of not less than 25 feet per second which includes, a cleaning shoe which presents a cleaning face shaped in substantially arcuate conformity to the peripheral working surface of the abrasive wheel with which it is associated, a pair of guide flanges extending along the opposite sides of said cleaning face and presenting inner surface portions designed to snugly overlap opposite side face portions of the abrasive wheel with minimal wheel rotative clearance therebetween, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the peripheral working surface of the abrasive wheel to be cleaned to provide a cavitational gap therebetween extending in the direction of rotation of the abrasive wheel and defined between the inner surfaces of said guide flanges, means for vibrating said cleaning shoe at ultrasonic frequencies in a general radial direction and at a stroking amplitude which is less than one-half the radial depth of the cavitational gap defined between the shoe cleaning face and the adjacent peripheral working surface of the abrasive wheel, and means positioned between the inner surfaces of said guide flanges for injecting a cleaning fluid into said cavitational gap in sufficient quantity and under sufficient pressure to establish an effective cavitating layer of cleaning fluid in said cavitational gap during working rotation of the abrasive wheel and whereby said fluid layer flows through and from said gap in the direction of wheel rotation.

3. A device effective to remove impacted material from the peripheral working surface of an abrasive wheel during working rotation thereof at production grinding peripheral speeds of not less than 25 feet per second which includes, a cleaning shoe which presents a cleaning face shaped in substantially arcuate conformity to the peripheral working surface of the abrasive wheel with which it is associated, a pair of guide flanges extending along the opposite sides of said cleaning face and presenting inner surface portions designed to snugly overlap opposite side face portions of the abrasive wheel with minimal wheel rotative clearance therebetween, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the peripheral working surface of the abrasive wheel to be cleaned to provide a cavitational gap therebetween extending in the direction of rotation of the abrasive wheel and defined between the inner surfaces of said guide flanges, means for vibrating said cleaning shoe at ultrasonic frequencies in a general radial direction and at a stroking amplitude which is less than one-half the radial depth of the cavitational gap defined between the shoe cleaning face and the adjacent peripheral working surface of the abrasive wheel, and means for injecting a cleaning fluid into said cavitational gap in sufficient quantity and under sufficient pressure to establish an effective cavitating layer of cleaning fluid in said cavitational gap during working rotation of the abrasive wheel, said fluid injecting means including a main fluid passage extending

into the body of the cleaning shoe and presenting a closed end and an open end, a plurality of fluid distributing passages branching from said main fluid passage and terminating in spaced fluid discharge ports in the cleaning face of the shoe, and a fluid supply duct in flow communication with the open end of said main fluid passage.

4. A device effective to remove impacted material from the peripheral working surface of an abrasive wheel during working rotation thereof at production grinding peripheral speeds of not less than 25 feet per second which includes, a cleaning shoe which presents a cleaning face shaped in substantially arcuate conformity to the peripheral working surface of the abrasive wheel with which it is associated, a pair of guide flanges projecting from the opposite sides of said cleaning face and presenting inner surface portions designed to snugly overlap opposite side face portions of the abrasive wheel with minimal wheel rotative clearance therebetween, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the peripheral working surface of the abrasive wheel to be cleaned to provide a cavitational gap therebetween extending in the direction of rotation of the abrasive wheel and defined between the inner surfaces of said guide flanges, means for vibrating said cleaning shoe at ultrasonic frequencies in general radial direction and at a stroking amplitude which is less than one-half the radial depth of the cavitational gap defined between the shoe cleaning face and the adjacent peripheral working surface of the abrasive wheel, and means for injecting a cleaning fluid into said cavitational gap in sufficient quantity and under sufficient pressure to establish an effective cavitating layer of cleaning fluid in said cavitational gap during working rotation of the abrasive wheel, said fluid injecting means including a main fluid passage extending into the body of the cleaning shoe and positioned between the inner surfaces of said guide flanges and extending in the general direction of rotation of the abrasive wheel and presenting a closed end and an open end, a plurality of fluid distributing passages branching from said main fluid passage and terminating in spaced fluid discharge ports in the cleaning face of the shoe, a fluid supply duct in flow communication with the open end of said main fluid passage, and means independent of said vibratory cleaning shoe for supporting said fluid supply duct in stationary position.

5. A device effective to remove impacted material from the peripheral working surface of an abrasive wheel during working rotation thereof at production grinding peripheral speeds of not less than 25 feet per second which includes, a cleaning shoe which presents a cleaning face shaped in substantially arcuate conformity to the peripheral working surface of the abrasive wheel with which it is associated, a pair of guide flanges extending along the opposite sides of said cleaning face and presenting inner surface portions designed to snugly overlap opposite side face portions of the abrasive wheel with minimal wheel rotative clearance therebetween, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the peripheral working surface of the abrasive wheel to be cleaned to provide a cavitational gap therebetween extending in the direction of rotation of the abrasive wheel and defined between the inner surfaces of said guide flanges, means for vibrating said cleaning shoe at ultrasonic frequencies in a general radial direction and at a stroking amplitude which is less than one-half the radial depth of the cavitational gap defined between the shoe cleaning face and the adjacent peripheral working surface of the abrasive wheel, and means for injecting a cleaning fluid into said cavitational gap in sufficient quantity and under sufficient pressure to establish an effective cavitating layer of cleaning fluid in said cavitational gap during working rotation of the abrasive wheel, said fluid injecting means including a plurality of spaced main fluid passages extending into the body of the cleaning shoe and each presenting a closed end and an open end, a plurality of fluid distributing passages branching from each of said main fluid passages and terminating in spaced fluid discharge ports in the cleaning face of the shoe, and a fluid supply duct in flow communication with the open end of each of said main fluid passages.

6. A device effective to remove impacted material from the peripheral working surface of an abrasive wheel during working rotation thereof at production grinding peripheral speeds of not less than 25 feet per second which includes, a cleaning shoe which presents a cleaning face shaped in substantially arcuate conformity to the peripheral working surface of the abrasive wheel with which it is associated, a pair of guide flanges extending along the opposite sides of said cleaning face and presenting inner surface portions designed to snugly overlap opposite side face portions of the abrasive wheel with minimal wheel rotative clearance therebetween, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the peripheral working surface of the abrasive wheel to be cleaned to provide a cavitational gap therebetween extending in the direction of rotation of the abrasive wheel and defined between the inner surfaces of said guide flanges, means for vibrating said cleaning shoe at ultrasonic frequencies in a general radial direction and at a stroking amplitude which is less than one-half the radial depth of the cavitational gap defined between the shoe cleaning face and the adjacent peripheral working surface of the abrasive wheel, and means for injecting a cleaning fluid into one end of said cavitational gap and in the general direction of wheel rotation in sufficient quantity and under sufficient pressure to establish an effective cavitating fluid layer in said gap during working rotation of the abrasive wheel and which is confined by said guide flanges as it flows through said gap, said fluid injecting means including a stationary nozzle inclined in the direction of wheel rotation and having a discharge mouth positioned between said guide flanges in close proximity to one end of said cavitational gap and to the peripheral surface of the abrasive wheel, and means for supplying cleaning fluid under pressure to said nozzle.

7. A device effective to remove impacted material from the peripheral working surface of an abrasive wheel during working rotation thereof at production grinding peripheral speeds of not less than 25 feet per second which includes, a cleaning shoe which presents a cleaning face shaped in substantially arcuate conformity to the peripheral working surface of the abrasive wheel with which it is associated, a pair of guide flanges extending along the opposite sides of said cleaning face and presenting inner surface portions designed to snugly overlap opposite side face portions of the abrasive wheel with minimal wheel rotative clearance therebetween, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the peripheral working surface of the abrasive wheel to be cleaned to provide a cavitational gap therebetween extending in the direction of rotation of the abrasive wheel and defined between the inner surfaces of said guide flanges, means for vibrating said cleaning shoe at ultrasonic frequencies in a general radial direction and at a stroking amplitude which is less than one-half the radial depth of the cavitational gap defined between the shoe cleaning face and the adjacent peripheral working surface of the abrasive wheel, and means for injecting a cleaning fluid into one end of said cavitational gap and in the general direction of wheel rotation in sufficient quantity and under sufficient pressure to establish an effective cavitating fluid layer in said gap during working rotation of the abrasive wheel and which is confined by said guide flanges as it flows through said gap, said fluid injecting means including a stationary nozzle inclined in the direction of wheel rotation and having a discharge mouth positioned between said guide flanges and in close proximity to one end of said cavitational gap and to the peripheral surface of the abrasive wheel, said discharge

mouth having a width approximating the width of said shoe cleaning face and a height which is not less than the radial depth of the cavitational gap, and means for supplying cleaning fluid under pressure to said nozzle.

8. A device effective to remove debris from a work surface during linear travel thereof which includes, a cleaning shoe which presents a cleaning face shaped in substantial conformity to the work surface with which it is associated, a pair of guide flanges extending along the opposite sides of said cleaning face and presenting surface portions in minute spaced relation to the work surface with minimal travel clearance therebetween, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the work surface to be cleaned to provide a cavitational gap therebetween extending in the direction of travel of the work surface and defined between the inner surfaces of said guide flanges, means for vibrating said cleaning shoe at ultrasonic frequencies in a direction substantially perpendicular to the work surface to be cleaned and at a stroking amplitude which is less than one-half the depth of the cavitational gap defined between the shoe cleaning face and the adjacent work surface, and means positioned between said guide flanges for injecting a cleaning fluid into one end of said cavitational gap and in the general direction of travel of the work surface and in sufficient quantity and under sufficient pressure to establish an effective cavitating fluid layer in said gap during travel of the work surface and which is confined by said guide flanges as it flows through said gap, said fluid injecting means including a stationary nozzle inclined in the direction of travel of the work surface and having a discharge mouth positioned between said guide flanges and in close proximity to one end of said cavitational gap and to the work surface, said discharge mouth having a width approximating the width of said shoe cleaning face and a height which is not substantially less than the depth of the cavitational gap, and means for supplying cleaning fluid under pressure to said nozzle.

9. A device effective to remove debris from a work surface during linear travel thereof which includes, a cleaning shoe which presents a cleaning face shaped in substantial conformity to the work surface with which it is associated, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the work surface to be cleaned to provide a cavitational gap therebetween extending in the direction of travel of the work surface, means for vibrating said cleaning shoe at ultrasonic frequencies in a direction substantially perpendicular to the work surface to be cleaned and at a stroking amplitude which is less than one-half the depth of the cavitational gap defined between the shoe cleaning face and the adjacent work surface, and means for injecting a cleaning fluid into said cavitational gap during linear travel of the work surface which flows through and from said gap in the direction of linear travel of the work surface, said fluid injecting means including a main fluid passage extending into the body of the cleaning shoe and presenting a closed end and an open end, a plurality of fluid distributing passages branching from said main fluid passage and terminating in spaced fluid discharge ports in the cleaning face of the shoe, a fluid supply duct in flow communication with the open end of said main fluid passage, and means independent of said vibratory cleaning shoe for supporting said fluid supply duct in stationary position.

10. A device effective to remove debris from a work surface during linear travel thereof which includes, a cleaning shoe which presents a cleaning face shaped in subsantial conformity to the work surface with which it is associated, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the work surface to be cleaned to provide a cavitational gap therebetween extending in the direction of travel of the work surface, means for vibrating said cleaning shoe at ultrasonic frequencies in a direction substantially perpendicular to the work surface to be cleaned and at a stroking amplitude which is less than one-half the depth of the cavitational gap defined between the shoe cleaning face and the adjacent work surface, and means for injecting a cleaning fluid into said cavitational gap during linear travel of the work surface which flows through and from said gap in the direction of travel of the work surface, said fluid injecting means including a plurality of spaced main fluid passages extending into the body of the cleaning shoe and each presenting a closed end and an open end, a plurality of fluid distributing passages branching from each of said main fluid passages and terminating in spaced fluid discharge ports in the cleaning face of the shoe, a fluid supply duct in flow communication with the open end of each of said main fluid passages, and means independent of said vibratory cleaning shoe for supporting said fluid supply ducts in stationary position.

11. A device effective to remove impacted material from the transversely contoured working periphery of a contour grinding wheel during working rotation thereof at production grinding peripheral speeds of not less than 25 feet per second which includes, a cleaning shoe which presents a cleaning face shaped in substantially contour conformity with the contoured working periphery of the grinding wheel with which it is associated, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the contoured working periphery of the grinding wheel to provide a cavitational gap therebetween extending in the direction of rotation of the grinding wheel, means for injecting a cleaning fluid into said cavitational gap during rotation of the grinding wheel in sufficient quantity and under sufficient pressure to establish an effective cavitating layer of cleaning fluid in said cavitational gap during working rotation of the grinding wheel and which flows through said gap in the direction of working rotation of the grinding wheel, and means for vibrating said cleaning shoe at ultrasonic frequency and in a manner to establish a generally ovaloid motion pattern of the shoe cleaning face whose axes of ovaloid movement extend generally radially and transversely of the grinding wheel, said vibrating means including a magnetostrictive transducer designed to produce longitudinal vibrations extending substantially radially of the grinding wheel, and a vibration transmitting connecting body rigidly secured to one end of said transducer and to said cleaning shoe, said connecting body having its axis of symmetry asymmetric to the axis of symmetry of said cleaning shoe whereby the longitudinal vibration delivered by the transducer to said connecting body produces combined longitudinal and lateral vibrations at the shoe cleaning face.

12. A device effective to remove impacted material from the transversely contoured working periphery of a contour grinding wheel during working rotation thereof at production grinding peripheral speeds of not less than 25 feet per second which includes, a cleaning shoe which presents a cleaning face shaped in substantially contour conformity with the contoured working periphery of the grinding wheel with which it is associated, a pair of guide flanges extending along the opposite sides of said cleaning face and presenting inner surface portions designed to snugly overlap opposite side face portions of the grinding wheel with minimal wheel rotative clearance therebetween, means for adjustably supporting the shoe cleaning face in predetermined spaced proximity to the contoured working periphery of the grinding wheel to provide a cavitational gap therebetween extending in the direction of rotation of the grinding wheel and defined between the inner surfaces of said guide flanges, means for injecting a cleaning fluid into said cavitational gap during rotation of the grinding wheel in sufficient quantity and under sufficient pressure to establish an effective cavitating layer of cleaning fluid in said cavitational gap which is confined to flow between said guide flanges and cleaning face of the cleaning shoe and the adjacent contoured

working surface of the grinding wheel and in the direction of working rotation of the abrasive wheel, and means for vibrating said cleaning shoe at ultrasonic frequency and in a manner to establish a generally ovaloid motion pattern of the shoe cleaning face whose axes of ovaloid movement extend generally radially and transversely of the grinding wheel, said vibrating means including a magnetostrictive transducer designed to produce longitudinal vibrations extending substantially radially of the grinding wheel, and a vibration transmitting connecting body rigidly secured to one end of said transducer and to said cleaning shoe, said connecting body having its axis of symmetry asymmetric to the axis of symmetry of said cleaning shoe whereby the longitudinal vibration delivered by the transducer to said connecting body produces combined longitudinal and lateral vibrations at the shoe cleaning face.

13. The method of removing workpiece debris and loosened abrasive grains from the peripheral grinding surface of a grinding wheel and thereby maintaining the peripheral grinding surface in effective grinding condition while the wheel is performing grinding work and rotating at a peripheral working speed of not less than twenty-five feet per second which includes, conducting a continuous flow of a cleaning liquid having wetting and detergent properties from an exterior source in a direction ranging from substantially tangentially to radially of the peripheral ginding surface of the rotating grinding wheel and confined between the sides thereof while the rotating wheel is performing grinding work, guiding the cleaning liquid flow into a cavitational gap defined between the peripheral grinding surface of the rotating grinding wheel and a substantially stationary cleaning surface shaped in substantial conformity to the wheel periphery and between stationary confining surfaces snugly overlapping the sides of the rotating grinding wheel with minimal clearance therebetween, vibrating said cleaning surface in a substantially radial direction at high frequency and at a stroking amplitude which is less than one-half of the radial depth of said cavitational gap, and injecting said cleaning liquid flow into said cavitational gap in sufficient quantity and under sufficient pressure to establish an effective cavitational layer between said cleaning surface and the periphery of the rotating grinding wheel while performing grinding work and which flows through and from said cavitational gap in the direction of wheel rotation.

14. The method of removing workpiece debris and loosened abrasive grains from the peripheral grinding surface of a grinding wheel and thereby maintaining the peripheral grinding surface in effective grinding condition while the wheel is performing grinding work and rotating at a peripheral working speed of not less than twenty-five feet per second which includes, conducting a continuous flow of a cleaning liquid having wetting and detergent properties from an exterior source in a direction ranging from substantially tangentially to radially of the peripheral grinding surface of the rotating grinding wheel and confined between the sides thereof while the rotating wheel is performing grinding work, guiding the cleaning liquid flow into a cavitational gap defined between the peripheral grinding surface of the rotating grinding wheel and a substantially stationary cleaning surface shaped in substantial conformity to the wheel periphery and between stationary confining surfaces snugly overlapping the sides of the rotating grinding wheel with minimal clearance therebetween, vibrating said cleaning surface in a substantially radial direction at high frequency and at a stroking amplitude in the order of one-half to one-tenth of the radial depth of said cavitational gap, and injecting said cleaning liquid flow into said cavitational gap in sufficient quantity and under sufficient pressure to establish an effective cavitational layer between said cleaning surface and the periphery of the rotating grinding wheel while performing grinding work and which flows through and from said cavitational gap in the direction of wheel rotation.

15. The method of removing workpiece debris and loosened abrasive grains from the peripheral grinding surface of a grinding wheel and thereby maintaining the peripheral grinding surface in effective grinding condition while the wheel is performing grinding work and rotating at a peripheral working speed of not less than twenty-five feet per second which includes, conducting a continuous flow of a cleaning liquid having wetting and detergent properties from an exterior source in a direction ranging from substantially tangentially to radially of the peripheral grinding surface of the rotating grinding wheel and confined between the sides thereof while the rotating wheel is performing grinding work, guiding the cleaning liquid flow into the leading end of a cavitational gap defined between the peripheral grinding surface of the rotating grinding wheel and a substantially stationary cleaning surface shaped in substantial conformity to the wheel periphery and between stationary confining surfaces snugly overlapping the sides of the rotating grinding wheel with minimal clearance therebetween, vibrating said cleaning surface in a substantially radial direction at high frequency and at a stroking amplitude which is less than one-half the radial depth of said cavitational gap, and injecting said cleaning liquid flow into said cavitational gap in sufficient quantity and under sufficient pressure to establish an effective cavitational layer between said cleaning surface and the periphery of the rotating grinding wheel while performing grinding work and which flows through and from said cavitational gap in the direction of wheel rotation.

16. The method of removing working debris and loosened abrasive grains from the contoured peripheral working surface of a contour grinding wheel and thereby maintaining the contoured peripheral working surface in effective grinding condition while the wheel is performing contour grinding work and rotating at a peripheral working speed of not less than twenty-five feet per second which includes, conducting a continuous flow of a cleaning liquid having wetting and detergent properties from an exterior source in a direction ranging from substantially tangentially to radially of the contoured peripheral surface of the rotating contour grinding wheel and confined between the sides thereof while the wheel is performing grinding work, guiding the cleaning liquid flow into a cavitational gap defined between the contoured peripheral working surface of the rotating grinding wheel and a stationary surface shaped in substantial conformity to the contoured wheel periphery and between stationary confining surfaces snugly overlapping the sides of the rotating grinding wheel with minimal clearance therebetween, and generating high frequency ovaloid vibrations at said correspondingly contoured cleaning surface whose motion components are directed both radially and laterally of the contour grinding wheel and whose radial component of orbital vibration has a stroking amplitude which is less than one-half the radial depth of said cavitational gap, said cleaning liquid flow being injected into said cavitational gap in sufficient quantity and under sufficient pressure to establish an effective cavitational layer between said stationary cleaning surface and the contoured periphery of the rotating grinding wheel while performing grinding work and which flows through and from said cavitational gap in the direction of wheel rotation.

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