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# (54) Improvements in and relating to workpiece gauging

(57) A gauge for a grinding machine for in-process gauging of a cylindrical off-axis region of a workpiece, in particular a crankpin (18, 20) of a crankshaft, comprises a pair of parallel struts (48, 50) each pivoted from a rigid support mounted on and movable with a wheelhead (10) which incorporates a grinding wheel (12, 14). The free ends of the struts are pivotally jointed to a plate (40), from which is pivoted a link (36) whose other end is pivotally attached to the gauge or probe (22). A pair of fingers (24, 26) incorporating transducers extend from the gauge around opposite sides of the crankpin for measuring its diameter while being ground. The strut (50) is reciprocated up and down by a servo drive (64) such that, in conjunction with the horizontal motion imparted by the wheelhead, the gauge is caused to follow substantially the same path as the workpiece region.

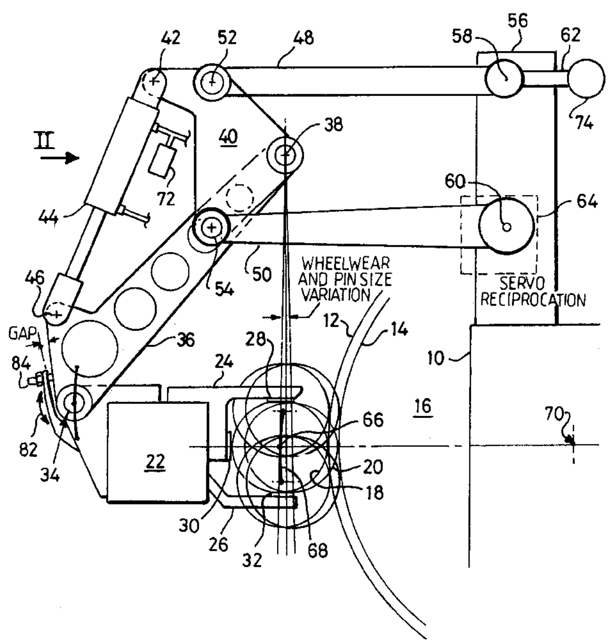


Fig. 1



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## Description

### Field of invention

**[0001]** This invention concerns methods and apparatus for gauging the diameter of a workpiece as it is ground and the invention is of particular application to grinding machines incorporating CBN grinding wheels.

### Background to the invention

**[0002]** Workpiece diameter has been monitored during grinding by engaging diametrically opposite regions of the workpiece by probes during the grinding process and monitoring the distance between the probes electronically. By resiliently urging the probes into contact with the workpiece so an accurate indication of the mean diameter of the workpiece is obtained and as the diameter reduces due to grinding, this is monitored and when a given diameter threshold is reached the necessary control signals are generated to adjust the grinding process accordingly.

**[0003]** The grinding of cylindrical surfaces necessitates the rotation of the workpiece relative to the rotating grinding wheel about the final axis required for the cylindrical ground surface. Historically the rotational speed of the workpiece has been relatively low, of the order of 20-30 rpm. With the development of the CBN grinding wheel and the higher work removal rates achievable using such rates, it is possible and desirable to rotate the workpiece at higher speeds, typically 70-80 rpm so as to obtain the benefits of the CBN grinding medium and the lower machining time.

**[0004]** Where the region of the workpiece which is to be ground is itself concentric of the main axis of the workpiece, so-called cylindrical grinding, the rotating workpiece can be engaged by the two fingers of a relatively fixed probe since relative to the machine frame, the workpiece remains static but for the rotational movement of its surface.

**[0005]** Where the region of the workpiece which is to be ground is eccentric relative to the main axis of rotation of the workpiece, the axis of the cylindrical ground region itself describes a circular motion as the workpiece is rotated about its main axis. Example of such workpiece regions are the crankpins of a crankshaft for an internal combustion engine. Each crankpin must be cylindrical about its own axis but itself is displaced by the throw of the crankshaft relative to the main axis about which the crankshaft rotates.

**[0006]** It is of course necessary to control the diameter of the crankpin just as accurately as the cylindrical journal bearing regions of the crankshaft and gauges have been developed for following the crankpins as they rotate about the axis of the crankshaft during the grinding operation.

**[0007]** At any point in the rotational movement of the crankpin around the main axis of the crankshaft, tangential movement of the crankpin relative to the machine frame can be expressed as two orthogonal components, one parallel to the generally horizontal motion of the wheelhead and the other perpendicular thereto. The horizontal component will be zero at the two midway positions between top and bottom dead centre of the circular path described by the pin, and the vertical component of the motion will be zero at top and bottom dead centre.

**[0008]** By mounting the gauging device on or for movement with the wheelhead, the horizontal component of movement of the pin will be eliminated since the wheel feed moves in sympathy with the horizontal component so as to maintain contact between the grinding wheel and the pin. However no attempt is taken to move the wheelhead vertically and the in-process gauges so far designed have attempted to accommodate the relative vertical movement between the pin and wheelhead by pivoting the gauge in some way or another so as to follow the vertical displacement of the pin above and below the mean positions as the pin rotates around the main axis of the crankshaft.

**[0009]** Whilst this solution has proved to be relatively successful at low speeds of workpiece rotation, the pivoting gauges have proved to be less than accurate at higher workpiece rotational speeds now associated with CBN wheel grinding and at these speeds of rotation gauges have been observed to bounce or even lift off the rotating pin. In either event errors are introduced into the gauging and accurate diameter control of the finished workpiece is impossible.

**[0010]** The problem is further aggravated by the ever-increasing demands for more and more accurate grinding to size and circularity and the present invention sets out to provide an improved gauge and gauging methods which does not suffer from the problems associated with conventional gauges at higher speeds of rotation of the workpiece.

### Summary of the invention

#### (1) Improved in-process gauging method

**[0011]** According to one aspect of the present invention, in a process of in-process gauging whilst grinding a cylindrical part of a workpiece which is radially offset relative to the workpiece axis, such as the crankpin of a crankshaft, using a grinding machine, the gauge is power driven so as to cause the gauge to mimic in phase the crankpin motion about the crankshaft axis.

**[0012]** Preferably a linkage between an anchor point and the gauge extends over or below the workpiece to locate the gauge on the opposite side thereof from the grinding wheel, so that while gauging, the gauge is suspended from the linkage remote from the grinding wheel and is moved by the linkage into engagement with the workpiece and is positively driven through the linkage so as to minimise the rotation of the offset workpiece region engaged by the gauge, about the workpiece axis, in phase therewith.

**[0013]** Preferably the method includes the step of compensating for the weight of the gauge and linkage so that at least during gauging, the gauge is subject only to its own inertia.

**[0014]** In the application of the invention to a method of in-process gauging a cylindrical part of a workpiece which describes a circular path around a central axis of the workpiece as the latter rotates therearound, such as a crankpin of a crankshaft, the method comprises the steps of engaging opposite regions of the workpiece part by gauging fingers of a gauge to determine the distance between the fingers and therefore the diameter of the gauged part, moving the gauge fingers along a first path parallel to the movement of the wheelhead containing the grinding wheel, in synchronism and phase with the wheelhead movement, so that relative movement parallel to the said first path between the cylindrical part being ground and the gauge, is substantially eliminated, and further characterised by moving the gauge along a second path orthogonal to the first path and in synchronism with the movement along the first path, so that the gauge describes a circular path around the workpiece axis which is similar in radius to that of the circular path of the cylindrical part being ground and is controlled so s to be in phase with the movement of the said part as it rotates theraround.

**[0015]** Both of the two orthogonal motions may be achieved by servo motor drives.

**[0016]** The drives may be controlled by information derived from the wheel feed, but preferably additional information for controlling the drives may be obtained from an encoder associated with the rotation the workpiece.

**[0017]** Alternatively the gauge may be attached to a support which is mounted on or is driven by the wheelhead, so as to effect the movement of the gauge along the said first path, while a separate drive is provided for effecting movement of the gauge along the said second path.

**[0018]** The said separate drive may comprise a linear actuator drive, operating at right angles to the first path.

**[0019]** Alternatively the gauge may be suspended from the end of an oscillating beam structure, pivotally mounted to a wheelhead mounted support, counterbalanced to compensate for the gauge and linkage weight, and driven by a reciprocating drive.

**[0020]** A preferred beam structure comprises of a pair of rigid struts forming part of a parallelogram which at their inboard ends are pivoted about two axes separated in a direction perpendicular to the direction of the said first motion on the wheelhead support, and at their outboard ends are joined by another rigid member so as to space apart the two outboard ends by the same distance as the spacing between the two said separated axes.

**[0021]** The movement along the said second path is effected by reciprocally pivoting the parallelogram structure so that the two parallel rigid members are lifted above and lowered below a mean position in each case by a distance which is equal to that between the main axis of the workpiece and the axis of the cylindrical part being ground. In the case of a crankpin, this equates to the so-called throw of the crankshaft.

**[0022]** According to a preferred aspect of the invention at their midway position, the struts forming the two parallel sides of the parallelogram are generally parallel to the said first path.

**[0023]** Typically the gauge housing is suspended from the outboard end of the parallelogram by an elongate structure pivotally joined to the outboard parallelogram strut, and extending in a downward direction therefrom to position the gauge near to the workpiece, to enable the gauge and the fingers thereof to be moved generally laterally into and out of engagement with the workpiece region to be gauged by movement of the said elongate structure.

**[0024]** The lateral movement of the gauge may be achieved by angular movement of the said elongate structure relative to the main parallelogram of struts.

**[0025]** The elongate structure may comprise a further pair of struts the lower ends of which are pivotally attached at two spaced apart points to the gauge housing, and the method further includes the step of altering the length of one of the said further pair of struts.

**[0026]** Where pivoting of the housing relative to the other strut is restricted, shortening or increasing the length of the said one strut will cause the gauge housing to describe an arc of a circle centered about the point at which the said other strut is pivotally joined to the parallelogram of struts.

**[0027]** If the length of the arc is short relative to the length of the said other strut, the angular movement of the gauge housing will approximate to straight line movement, which facilitates the engagement and disengagement of the gauge fingers with the workpiece region to be gauged.

**[0028]** Although the true motion of the gauge consequent on synchronous reciprocal motion of a parallelogram of struts pivoted will in fact describe an arc of a circle rather than a straight line, by selecting appropriate lengths for the struts forming parallel sides of the parallelogram of struts and for the said two further struts, the radius of the circle of which the motion forms an arc can be relatively large, and the arc will approximate to a straight line over the relatively small distance needed to accommodate the throw of a typical automotive engine crankshaft.

**[0029]** Preferably therefore the length of the struts forming the parallelogram of struts and the length of the two said second pair of struts is selected so that the actual movement of the gauge relative to the wheelhead approximates to a vertical straight line.

**[0030]** According to a particularly preferred feature of the invention one of said further pair of struts is pivotally attached to a pivot displaced to one side of the outboard strut joining the outboard ends of the parallel struts forming the parallelogram of struts, and the position of the displaced pivot is selected so as to lie generally vertically above the workpiece axis.

**[0031]** Conveniently the other of said further pair of struts is pivotally attached to a pivot displaced to the other side of the said outboard strut.

**[0032]** A significant improvement can be obtained if the radius of the arcuate path through which the gauge moves as it follows the cyclic displacement of the workpiece region being ground, is selected to be equal to the distance between the grinding wheel axis and the axis of the cylindrical workpiece region being ground when the latter is at a mid-way position between the top and bottom dead centre of its movement, and if the centre of curvature of the said arcuate path corresponds to the axis of the grinding wheel.

(2) Improved gauge

**[0033]** The invention also lies in a gauge for determining the diameter of an off-axis cylindrical workpiece region during grinding (which region describes a circular path around the main axis of rotation of the workpiece during the grinding process), wherein the gauge has two spaced apart fingers for engaging the region to be gauged, and two drives are provided to positively drive the gauge so that a midpoint between the spaced apart fingers traverses the same locus as does the axis of the cylindrical region being ground, in phase therewith so that relative movement between the gauge and the workpiece region being ground is limited to non-circularity or eccentricity of the workpiece region relative to its own central axis.

**[0034]** A gauge according to the present invention is therefore distinct from devices hitherto proposed where reaction forces between the workpiece and the workpiece engaging fingers of the gauge have been relied on to introduce at least one component of motion of the gauge, to enable the workpiece engaging fingers to follow the movement of the workpiece region and remain in contact therewith during the rotation thereof.

**[0035]** Thus in contrast to prior art proposals, a gauge operating in accordance with the present invention theoretically requires no reactive force between it and the workpiece to cause the gauge fingers to follow the movement of the workpiece.

**[0036]** In order to ensure positive engagement of the fingers and the workpiece region, a small spring or other force producing device may be provided to urge the fingers towards the workpiece region to cause the latter to be lightly gripped therebetween.

**[0037]** In a preferred embodiment, the spring may be dispensed with if one of the fingers is L-shaped and pivoted about the apex of the gauge is moved into contact with the workpiece region, so that the leg of the L-shaped finger makes contact with the said region causing the L-shaped finger to pivot and bring the other limb of the L into contact with the said region opposite the point engaged by the other finger of the gauge.

**[0038]** When set up correctly, any forces acting on the gauge fingers therefore merely arise where the fingers have to move from the position which the positive drive to the gauge determines they should occupy, due to out-of-roundness or eccentricity of the workpiece region being gauged.

(3) Provision for emergency retraction of wheelhead

**[0039]** In the event of an emergency stop a drive rapidly retracts the grinding wheel relative to the workpiece so as to disengage the two. Where the gauge is carried by a linkage which itself is rigidly attached to the wheelhead, (as is preferred), and the linkage extends over and beyond the workpiece so that the gauging fingers engage the workpiece from the side opposite to that engaged by the grinding wheel, any sudden reverse motion of the wheelhead could damage the workpiece, the gauging fingers, and/or the gauge, as well as other parts of the machine.

**[0040]** According therefore to another aspect of the invention in a method of in-process gauging the diameter of an off-axis cylindrical workpiece region during grinding, in the manner as aforesaid, in the event of an emergency stop the gauge is either positively retracted away from the workpiece in a direction opposite to the movement of the wheelhead, or is permitted rapid and unimpeded movement relative to the wheelhead.

**[0041]** Unimpeded movement may be achieved by forming part of the gauge supporting structure from one or more collapsible, or telescopic, members or from at least one member which includes a fracture link which breaks when subjected to excessive force, thereby to enable immediate and unimpeded relative movement of the two parts now separated, and thereby unimpeded movement between the gauge and the wheelhead assembly.

(4) Gauging apparatus embodying the invention

**[0042]** A preferred apparatus for performing a gauging method as aforesaid comprises three pivotally joined rigid struts forming with a rigid support a jointed parallelogram, the two parallel struts being pivotally joined at their inboard ends to the said rigid support, and the latter being carried by the wheelhead of a grinding machine whereby the parallelogram of struts will advance and retract in synchronous phase with the wheelhead, and wherein the strut which is pivotally joined to the outboard ends of the two parallel struts (the outboard strut) comprises a mounting for two spaced apart pivots which are displaced from the points at which the said outboard strut is pivotally joined to the two said parallel struts, from which pivots two further struts are pivotally connected, and wherein the said two further struts are pivotally joined at their outboard ends to a gauge housing having two fingers for engaging during gauging two diametrically opposite points of a cylindrical off-axis workpiece region, and drive means is provided for reciprocally pivoting the parallelogram of struts so that the gauge housing attached to the said two further struts describes a motion generally perpendicular to the motion of the wheelhead movement, whereby the two movements in combination cause the gauge housing to describe substantially the same circular path as the off-axis cylindrical region of the workpiece to be engaged by the gauge as the workpiece is rotated about its main axis.

**[0043]** Preferably one of the two spaced apart pivots at the outboard end of the parallelogram to which one of the said two further struts is attached lies vertically above the axis of the workpiece.

**[0044]** Preferably one of the said two further struts is adjustable in length and drive means is provided to achieve the alteration of the strut length so that relative movement can be obtained between the gauge and the non-adjustable strut therefore the parallelogram of struts.

**[0045]** If the gauge is relatively fixed in relation to the other strut, adjustment of the length of the said one strut will produce arcuate movement of the gauge relative to the parallelogram of struts.

**[0046]** Thus by shortening or lengthening the adjustable strut, the gauge can be swung in an arcuate path and where the gauge is adjacent the workpiece this movement enables spaced apart fingers protruding from the gauge to straddle the workpiece region which is to be gauged to enable the fingers to lightly grip diametrically opposite regions of the said workpiece region.

**[0047]** In an alternative arrangement the support for the parallelogram of struts may be separate from the wheelhead and movement of the said parallelogram of struts in sympathy with the wheelhead is achieved by a separate servo drive responsive to control signals derived from the wheelfeed signals and/or from signals from an encoder associated with the headstock.

(5) Preferred gauge design

**[0048]** According to a preferred feature of the invention, the gauge includes two parallel spaced apart fingers for lightly engaging diametrically opposite regions of the workpiece region, and a further workpiece engaging element which is located approximately mid-way between the said two fingers and is displaced relative to a line joining the said two fingers by a distance commensurate with the radius of the workpiece region which is to be gauged, so that the said element will engage a point on the surface of the workpiece region which is diametrically opposite the point of contact with the grinding wheel.

**[0049]** The workpiece engaging element may be a separate member independently movable relative to the housing and therefore to the two fingers.

**[0050]** Alternatively and preferably the element may comprise a right angled extension to one of the said two fingers. This results in a composite finger having two workpiece region engaging portions which subtend a right angle. Preferably this is pivotable about the apex of the L and the other finger is mounted so that its workpiece region engaging portion diametrically opposite one of the two workpiece region engaging portions of the composite finger, and is movable relative to the said composite finger in such a way as to accommodate diameter variations of the cylindrical workpiece region.

**[0051]** Variation in diameter is determined by noting movement of the second finger relative to the composite finger during grinding, inward relative movement of the said finger corresponding to a reduction in diameter.

**[0052]** A light spring may be provided so as to introduce positive engagement between the fingers and the workpiece region being gauged, so that they lightly grip the workpiece region therebetween.

(6) Computer control during gauging

**[0053]** Electrical signals corresponding to the mean diameter determined upon initial engagement between the fingers and the workpiece region, and subsequently to changes in diameter during grinding, may be derived from one or more transducers associated with the fingers. The signals may be transmitted as feedback signals to a computer adapted to control the overall operation of the machine.

(7) Gauge support structure geometry

**[0054]** In accordance with a preferred feature of the invention, the pivot for the non-extensible strut joining the outboard strut of the parallelogram of struts to the gauge housing, defines a pivot axis which is parallel to the axis of the off-axis cylindrical region of the workpiece being ground, and remains generally vertically thereabove as a consequence of its movement with the wheelhead.

(8) Accommodation of changing wheel diameter due to wear

**[0055]** Since the diameter of a grinding wheel reduces during use and in the case of a CBN wheel can reduce typically from 600mm to 595mm due to wheel wear, the movement of the gauge and associated fingers must be capable of accommodating the different positions of the wheelhead and different distances through which it must move, to enable workpiece region engagement with the reducing wheel diameter due to wear. Where the pivot on the said outboard strut of the parallelogram from which the non-extensible gauge supporting strut is pivoted, is itself positioned generally above the axis of rotation of the workpiece region being ground, the movement of the gauge describes an arcuate path centered about the said outboard strut pivot axis.

**[0056]** Since the actual change in diameter is small in relation to its overall diameter, by ensuring that the radius of the arcuate path of the gauge is also large in relation to the change in diameter of the grinding wheel, the movement of the gauge required to accommodate changing wheel diameter can be thought of as a straight line.

(9) Preferred form of extensible strut

**[0057]** The extensible strut may comprise at least in part a pneumatic cylinder, movement of the piston therein producing the variation in overall length of the strut, and control means is provided for supplying air to the cylinder to extend or retract the cylinder as required.

**[0058]** Alteration of the length of the strut pivotably moves the gauge housing about the end of the non-extensible strut and therefore relative to the parallelogram of rigid struts, and in turn relative to the workpiece region to be gauged, to facilitate the engagement and disengagement of the latter by the gauge fingers.

**[0059]** A single acting cylinder with spring return may be employed, the latter acting to shorten the length of the strut if air pressure is removed. If a strong spring is employed, this feature may be used to retract the gauge in an emergency stop scenario.

**[0060]** If a double acting cylinder is employed, air pressure may be removed and the cylinder fully vented as soon as the fingers are in contact with the workpiece region.

**[0061]** Once vented an emergency stop and wheelhead retraction can be accommodated by the freely floating piston in the cylinder, which permits free and unrestricted rearward pivoting of the gauge housing under the reaction force between the gauge and the workpiece.

**[0062]** Emergency retract may be required before the cylinder has been fully vented (for example during the approach of the probe to the workpiece), and to this end a pressure relief valve is preferably provided in the airline feeding the cylinder to extend the strut length, such that if an emergency stop occurs during the said approach, any reaction force due to the sudden engagement of the fingers with the workpiece will be transmitted back to the cylinder to generate a back pressure in the airline which overcomes the relief valve and enables the cylinder to vent, thereby to accommodate rapid reverse movement of the gauge due to retraction of the wheelhead.

(10) Compensating for the gauge and linkage mass

**[0063]** Preferably torque generating means is provided so that a turning movement is produced about the pivot of at least one of the parallel struts of the said parallelogram, the direction and magnitude of which is such as to compensate for the opposite turning movement about that pivot created by the mass of the gauge linkage.

**[0064]** In one arrangement, one of the two parallel struts of the parallelogram extends beyond the pivot point where it is attached to the wheelhead mounted support, and the turning moment of the extended section of the strut is adapted to generally counterbalance the weight of the gauge and supporting structure, so that a very small force is needed to reciprocally pivot the array of struts and the gauge (and/or to move the gauge relative to the struts for engagement and disengagement of the workpiece region), and no additional force is required to counterbalance the gravitational forces acting about the pivot occasioned by the weight of the gauge and the supporting structure.

**[0065]** The counterbalancing may be achieved by the weight of the extended section of the said strut. Alternatively or in addition a spring may be employed acting about the pivot.

**[0066]** Alternatively a servo drive acting at the pivot point or any combination of spring/weight/drive may be employed.

(11) Reciprocal drive to gauge supporting structure

**[0067]** The reciprocal pivoting movement imparted to the gauge support structure is preferably simple harmonic motion with frequency and amplitude control.

**[0068]** A positive reciprocal pivoting of the parallelogram of struts is most simply obtained by means of a reciprocating servo drive acting about the axis of an appropriate pivot point. Where the structure is mounted to a support extending from the wheelhead, the preferred pivot point is one of the pivots on the said support.

**[0069]** Typically the drive means serves to reciprocally pivot the rigid strut associated therewith about the pivot axis, and by virtue of the pivoted parallelogram structure, this reciprocal motion is transmitted to the gauge.

**[0070]** When so mounted and driven, the gauge mounted outboard from the parallelogram of struts will normally follow the same locus as the axis of the off-axis cylindrical region of the workpiece being ground (as it rotates about the main axis of the workpiece). Thus in the case of a crankshaft rotated about its main axis, the gauge will describe the same circular movement around the crankshaft axis as does the crankpin it is gauging, thereby removing all need for the crankpin to drive the gauge.

**[0071]** Where the reciprocating servo mechanism is controlled by signals derived from a computer, the latter is preferably programmable to adjust the frequency and amplitude and phase of the reciprocal movement, to compensate for any variation in the speed of rotation of the workpiece region during rotation and/or to cater for different eccentricities.

**[0072]** By positively driving the gauge about two orthogonal axes so as to describe a circular movement similar to that of the cylindrical region being ground, the gauging process does not rely on maintaining contact between the workpiece and the gauge to transfer movement of the workpiece region to the gauge to ensure that the latter follows its movement. Instead it is only necessary for the gauge to handle any movement of the gauging fingers relative to the gauge housing, due to variation in diameter and/or circularity and/or eccentricity of the workpiece region which is being gauged. There is likewise no requirement to provide a mechanism for ensuring contact between gauge fingers and workpiece surface during gauging except insofar as to ensure that contact is maintained between the diametrically opposite regions of the workpiece region.

(12) Computer control

**[0073]** Where a computer is employed, an algorithm or look-up table or other software mechanism may be provided for determining the primary motion of the gauge support structure, and additional software may be provided for adjusting parameters of the algorithm, or values in the look-up table, or the control signals derived therefrom, so as to permit fine tuning of the motion as required.

(13) Intermediate drive

**[0074]** Where the gauge support structure (for example the parallelogram of struts) is carried by a support which itself is attached to the wheelhead, no drive is needed to replicate the wheelhead movement, but according to a further aspect of the invention a further such drive may still be provided between the wheelhead and the said support for the gauge support structure, which itself is also under computer control, to allow for fine tuning of the advance and retract movement of the probe in the direction of the wheelhead movement.

**[0075]** Such additional movement as provided by the intermediate drive may for example assist in engagement and dis-engagement of the gauge fingers with the workpiece region.

**[0076]** Where such an additional drive is positioned between the wheelhead and the support for the gauge support structure, an emergency retract condition may generate a control signal for operating this drive to accelerate the gauge support structure so as to move the gauge away from the workpiece opposite to the direction of movement of the wheelhead, so that the probe is positively retracted in an opposite sense to any emergency retract movement of the wheelhead.

**[0077]** Where such a drive (such as a servo drive) is provided between the support structure and the wheelhead, it may also be activated during an emergency retract so as to further assist in moving the gauge clear of the workpiece.

(14) Additional control of gauge

**[0078]** In CNC grinding, the headstock rotates the workpiece and an encoder is normally associated with the headstock which allows instantaneous rotational positional information of the workpiece to be obtained and therefore additionally information about the rotational position of the region of the workpiece which is being ground where this is off-axis. Information from the headstock drive, and in particular the encoder therefor, allows complete synchronisation of the machine and the region being ground, and in the same way as accurate positioning of the wheelhead can be achieved using appropriate servo control signals and servo motors, so a servo drive associated with the gauge support structure (such as a parallelogram of struts as described herein), and acting thereon to reciprocally move the struts so that in combination with the advance and retract movement of the wheelhead the gauge is caused to describe a circular movement, the servo drive can be synchronised with the rotation of the workpiece using the encoder output signals from the headstock.

**[0079]** In this way the gauge can be maintained in strict phase with the rotational movement of the headstock, and therefore the workpiece, so that any variation in instantaneous speed of rotation around the circular path can be detected and transmitted into the movement of the gauge so as to remove any unwanted force between the workpiece and the gauging fingers.

**[0080]** When incorporating this feature, a gauge constructed in accordance with the invention becomes quite distinct from any previous gauge since the gauge fingers can be driven in perfect synchronism and phase with the rotating off-axis workpiece region which is to be gauged and no force needs to act between the gauging fingers and the gauged surface to cause the gauge to follow the movement of the workpiece region.

(15) Provision for lost motion

**[0081]** Where the gauge is carried at the lower end of a pivoted strut and needs to be able to accommodate a small amount of movement caused by non-circularity etc, the gauge housing is preferably attached to the lower end of the said strut, through a lost motion connection.

**[0082]** To this end the gauge housing preferably includes a rigid extension carrying an adjustable stop which is engageable with an external surface of the strut to which the gauge housing is pivotally connected, and the stop is adjustable to prevent the housing from pivoting beyond a certain position relative to the strut. Freedom to accommodate eccentricity and out of roundness is achieved by ensuring that the stop disengages from the strut to create a clearance gap between it and the strut when the gauge has been advanced and the fingers have fully engaged the workpiece region of the gauging.

**[0083]** The gap between the stop and the strut is selected so as to be greater than the maximum relative movement expected between the gauge housing and the strut during gauging.

**[0084]** Alternatively, or in addition, where the final position of the probe during gauging is determined by the extension and retraction of a pneumatic cylinder, the latter may be operated so as to generate the gap previously referred to, by adjusting the length of the strut containing or comprised of the cylinder, (typically by shortening the strut length) after engagement of the workpiece region by the gauge fingers, so as to generate said gap. This permits a free floating movement of the gauge and the fingers relative to the supporting strut.

**[0085]** Where this is provided for, it is not possible to vent the cylinder after the gauge is in place, to permit unrestricted movement during an emergency retract, and to this end, upon an emergency stop signal, both ends of the cylinder must be vented to facilitate the rapid collapse of the piston into the cylinder to accommodate the movement of the wheelhead relative to the workpiece.

**[0086]** In addition or instead, a pressure relief valve may be provided such that any sudden increase in pressure will be vented immediately through the relief valve.

(16) <u>Alternative gauge drive</u>

**[0087]** An alternative arrangement for achieving the rotatable movement of the gauge comprises a pair of rotating cranks mounted for rotation about two vertically spaced apart axes, parallel to the main axis of the workpiece, and joined by a rigid link which extends downwardly below the lower of the two cranks where it is secured to a gauge housing having fingers for engaging diametrically opposite regions around an off-axis cylindrical workpiece region which is rotating about the main axis of the workpiece during grinding, wherein the radius of the cranks and the speed of rotation is selected so as to correspond to the radius of the circular motion of the said off-axis cylindrical region, and to the rotational speed of the said region around the main axis of the workpiece, so that the gauge describes the same circular path in phase with the movement of the said region around the workpiece axis.

**[0088]** The two cranks do not therefore need to be mounted to the wheelhead, but can be mounted on a carriage mounted to the machine structure and driven or pivotable so as to permit engagement and disengagement of the fingers with the workpiece part.

(17) <u>Wheelhead indexing</u>

**[0089]** Where the workpiece includes two or more axially spaced apart off-axis cylindrical regions which are to be ground, and the workpiece remains axially stationary in the machine, the wheelhead must be indexed axially relative to the workpiece to allow the wheel to engage different cylindrical regions therealong such as crankpins along a crankshaft. To this end the gauging device must also follow the axial movement of the wheelhead so that it is always aligned with the workpiece region which is to be ground.

**[0090]** Where the gauge support structure is carried by the wheelhead, this axial displacement will automatically occur.

**[0091]** Where a separate drive is provided which mimics the backward and forward wheelhead movement, and the gauge support structure is movable along the workslide or another slide parallel to the workslide on the opposite side of the workpiece from the workhead, a further drive is needed to follow indexing of the wheelhead to ensure that the remote gauge support structure is always opposite the grinding wheel, so as to engage the appropriate region of the workpiece.

**[0092]** An advantage of an arrangement in which the gauge is supported by a structure which is not attached to the wheelhead, is that during an emergency stop, no emergency withdrawal of the gauge is required and it can stay in contact with the rotating workpiece if desired.

**[0093]** The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a side view of a first embodiment of the invention;

Figure 2 is a front view of the embodiment of figure 1 (in the direction of arrow II in Figure 1);

Figure 3 is a plan view of parts of the apparatus of Figure 1;

Figure 4 is a schematic side view of another embodiment of the invention; and

Figure 5 is a similar view of a further embodiment.

**[0094]** In Figures 1 to 4, a wheelhead is shown at 10 and the unworn and worn perimeters of a CBN grinding wheel are denoted by 12 and 14 respectively.

**[0095]** The corresponding positions of a crankpin to be ground by the grinding wheel 16 are denoted by 18 and 20 respectively. These correspond to the unworn and worn conditions of the CBN wheel and in accordance with the invention a probe 22 having an upper composite finger 24 and lower movable finger 26 is shown engaging the pin in the position 18 of the pin at the beginning of the life of the wheel.

**[0096]** Pads 28 and 30 on the composite finger 24 engage two regions of the pin separated by a right angle, and a pad 32 on the finger 26 engages the pin diametrically opposite the region engaged by pad 28. The probe 22 includes one or more transducers (not shown) for determining the spacing between the subsequent movement of the fingers, and therefore the diameter, and changes in the diameter, of the pin being ground.

**[0097]** The probe is itself pivotally attached at 34 to the lower end of a rigid link 36 the upper end of which is pivotally attached at 38 to a closure plate 40. A second separate pivot point 42 on the plate 40 provides the upper mounting point for a pneumatic piston and cylinder 44 the outboard end of the piston rod being pivotally connected at 46, at the lower end of the rigid strut 36.

**[0098]** The plate 40 provides a closure to a parallelogram of struts the longer sides of which are made up of the two struts 48 and 50, which are pivotally attached to the plate 40 at 52 and 54 respectively. At their opposite ends they are pivotally attached to an upright rigid support member 56 at 58 and 60 respectively. The support 56 is mounted on the wheelhead 10 and moves therewith.

**[0099]** A servo drive 64 reciprocally pivots the rigid strut 50 about the pivot axis 60 so as to reciprocally raise and lower the probe 22 and since the motion is arcuate, the mid-position between the two pads 28 and 32 (denoted by reference numeral 66) will in fact describe an arcuate path as identified by 68. By making the effective centre of the arcuate path 68 the same as the centre of rotation of the wheel 16 (denoted by reference numeral 70), so the arcuate path described by the centre of the rotating workpiece region being ground as it maintains contact with the wheel 16, as the latter advances and retracts, will correspond substantially with the arcuate path 68 described by the mid-position of the pads 28 and 32.

**[0100]** In this way the force acting between the pads 28, 30, 32 and pin being ground is restricted to that generated by the resilience within the probe 22 and it is only necessary for the probe to counteract inertia forces due to out of roundness and eccentricity and the like of the workpiece region being ground. It is not necessary for reactive forces to be accommodated or generated so as to maintain contact between the pad and the workpiece.

**[0101]** In order to accommodate emergency retract, a pressure relief valve 72 is provided to vent the airline supplying the pneumatic cylinder 44 in an emergency.

**[0102]** In addition or alternatively, the cylinder 44 may be vented at both ends as soon as the probe pads 28, 30 and 32 are in contact with the workpiece region to be ground, so that in the event of an emergency retract, the cylinder 44 presents no resistance to the rapid inward movement of the piston (not shown) thereby permitting rapid relative movement between the wheelhead and the probe, as the wheel is retracted.

**[0103]** A counterbalance weight 74 is carried at the end of an extension 62 of the arm 48.

**[0104]** Figures 2 and 3 show how the support 56 can be mounted laterally of a grinding wheel housing 76. Similar reference numerals are employed in Figures 2 and 3 to denote the same parts as shown in Figure 1 and by comparing Figures 1 and 3 it will be seen that the two arms 48 and 50 are bent approximately midway along their length to cause the outboard ends of 48 and 50 to finish up generally opposite the grinding wheel housing 76, but displaced by a suitable distance from the wheel 16 to allow for the gauge housing 22 and its probes 24, 26 to be mounted thereon from the arms 36, 44, beyond the region occupied by the crankshaft workpiece whose pins are to be ground and gauged.

**[0105]** The bends are denoted by reference numerals 78, 80 in Figures 2 and 3.

**[0106]** A lost motion connection is provided between the arm 36 and the housing 22, which pivots relative to 36 at 34. To this end a finger 82 extends rearwardly and upwardly from the housing 22 and includes a locking nut and threaded adjuster screw 84 which can be rotated so as to alter a gap between the end of the screw and the arm 36. By careful adjustment the screw end can be held one or two millimetres off the arm 36 when the gauge feelers 28, 32 engage a pin. The gauge assembly then "floats" if the cylinder 44 is depressurised. The weight of the housing 22 will introduce a turning movement about 34 when the feelers are disengaged from the pin, but clockwise pivoting of the housing 22 about 34 is restricted by engagement of the screw 84 with the arm 36.

**[0107]** Re-engagement of another pin by the gauge, causes the housing 22 to rotate in a counter clockwise sense as the two feelers 28, 32 grip the pin, causing the screw 84 to move away from the arm 36 again, to once again produce the operating gap.

**[0108]** In the event of an emergency retract of the wheelhead, so as to disengage the wheel 16 from the pin being ground, initial movement of the gauge in the same direction as the wheel is accommodated by sliding of the feelers 28, 32 relative to the pin, but then the reaction force acting through pad 30 causes the cylinder 44 to collapse permitting relative movement of 56 and the arm 36 to occur. The lower end of 36 moves upwardly as the arm 36 pivots about 38. This shifts the gauge backwardly and upwardly away from the pin, so preventing damage to the workpiece and/or the gauge.

**[0109]** In Figure 4 the two arms 48, 50 are replaced by a triangular assembly 86 mounted on the wheelhead adjacent the wheel housing and carrying a vertical slideway on which a linear motion drive 90 is carried. The latter is programmable under computer control to slide up and down the slideway 88 as required to raise and lower a plate 92 carried by the drive unit. The drive 90 may be pneumatic of electromagnetic.

**[0110]** The remainder of the gauge support is similar to that shown in Figures 1 to 3 and the component parts are similarly identified. Thus the gauge housing 22' is positioned to the lower end of an arm 36' at 34' and the upper end of arm 36' is pivoted to the plate 90 at 38. Likewise a pneumatic piston and cylinder 44' is pivoted at 42' and 46'.

**[0111]** A similar stop 84 and arm 82 is provided to provide lost motion between arm 36' and housing 22' as described in relation to Figure 1.

**[0112]** The linear movement of drive 90 and plate 92 is translated into linear vertical movement of the housing 22' and any relative horizontal movement between the fingers 24', 26' and the pin 20' is accommodated by the long flat pads 28', 32' as before.

**[0113]** The drive 90 is programmed so as to move in synchronism with the wheel feed and crankshaft rotation, so that the gauge follows the circular path of the pin being ground.

**[0114]** Figure 5 shows how two rotating cranks 94, 96 can transmit a simple harmonic motion via rigid connecting rod 98 to a gauge housing 22" pivotally attached at 100 to the lower end of the rod 98, with lost motion provided by an arm 82" and screw 84", similar to the similar items described with reference to Figure 1 and Figure 4.

**[0115]** By appropriately driving the cranks, so the gauge will describe a circular path at a desired frequency and speed - which can vary during the circular path if desired. A computer (not shown) suitably programmed, provides the control signals.

**[0116]** The cranks are carried on a slide 102, itself slidable relative to a support 104 attached to the machine structure (as opposed to the wheelhead) and also be capable of horizontal or rotational displacement relative to the machine structure for engaging and disengaging the gauge fingers 24", 26" from the workpiece W. Horizontal movement of the slide 102 is also under computer control, and is provided to allow for initial engagement and final disengagement of the fingers 24", 26" and the workpiece W.

## Claims

1. A method of in-process gauging whilst grinding a cylindrical region of a workpiece on a grinding machine using a wheelhead mounted grinding wheel, the region being radially offset relative to, and rotating about, the central axis of the workpiece, in which a gauge is power driven so as to cause the gauge to mimic in phase the motion of the region about the workpiece axis.

2. A method according to claim 1 further comprising the step of applying a linkage between an anchor point and the gauge, the linkage extending over or below the workpiece region to locate the gauge on the opposite side thereof from the grinding wheel, so that during gauging the gauge is suspended from the linkage remote from the grinding wheel, is moved by the linkage into engagement with the region to be gauged, and is positively driven through the linkage so as to rotate about the workpiece axis in phase with the rotation of the region therearound.

3. A method according to claim 2 which includes the step of compensating for the weight of the gauge and linkage, so that at least during gauging, the gauge is subject only to its own inertia.

4. A method according to any one of claims 1 to 3 further comprising the steps of engaging opposite sides of said region by a pair of gauging fingers of the gauge to determine the distance between the fingers and therefore the diameter of the gauged region, moving the fingers along a first path parallel to the movement of the wheelhead in synchronism and phase therewith so that relative movement parallel to the said first path between said region and the gauge is substantially eliminated, and moving the gauge along a second path orthogonal to the first path and in synchronism with the movement along the first path, whereby the gauge describes a circular path around the workpiece axis whose radius is similar to that of the circular path of the region being ground and is controlled so as to be in phase with the rotation thereof.

5. A method according to claim 4 comprising the step of attaching the gauge to a support mounted on or driven by the wheelhead, so as to effect the movement of the gauge along said first path, while providing a separate drive for effecting movement of the gauge along said second path.

6. A method according to claim 4 comprising the step of suspending the gauge from the end of an oscillating beam structure which is pivotally mounted to a wheelhead mounted support, counterbalancing the structure to compensate for the gauge and linkage weight, and applying a reciprocating drive.

7. A method according to any one of claims 4 to 6 in which the second path of the gauge is arcuate, being selected to be equal to the distance between the grinding wheel axis and the axis of said region when the latter is at a mid-way position between the top and bottom dead centre of its movement.

8. A method according to claim 7 in which the centre of curvature of said arcuate path corresponds to the axis of the grinding wheel.

9. A method according to any one preceding claim in which, in the event of an emergency stop, the gauge is either positively retracted away from the workpiece in a direction opposite to the movement of the wheelhead, or is permitted rapid and unimpeded movement relative to the wheelhead.

10. Apparatus for determining the diameter of an off-axis cylindrical workpiece region which describes a circular path around the main axis of rotation of the workpiece during a grinding process, comprising a gauge having two spaced apart fingers for engaging said region, and at least one drive means to positively drive the gauge is a circular path, whereby a midpoint between the spaced apart fingers travers-

es the same locus as does the axis of the region to be ground, and in phase therewith, so that relative movement between the gauge and the region is limited to non-circularity or eccentricity of the region relative to its own central axis.

**11.** Apparatus according to claim 10 further comprising a small spring or other force producing device for urging the fingers towards the region, causing the latter to be lightly gripped between the fingers.

**12.** Apparatus according to claim 10 in which one of the fingers is L-shaped and pivoted about its apex for movement into contact with the workpiece region, so that one limb of the L-shaped finger makes contact with the said region causing the L-shaped finger to pivot and bring the other limb of the L into contact with the said region opposite the point engaged by the other finger of the gauge.

**13.** Apparatus according to any one of claims 10 to 12 for use on a grinding machine, comprising three pivotally joined struts forming with a rigid support a jointed parallelogram, the two parallel struts being pivotally joined at their inboard ends to the rigid support, and the latter being carried by means moveable with a wheelhead which incorporates a grinding wheel, whereby the parallelogram of struts advances and retracts in synchronous phase with the wheelhead, and wherein the outboard strut which is pivotally joined to the outboard ends of the two parallel struts comprises a mounting for two spaced apart pivots, from which first and second struts are pivotally connected, wherein the first strut is pivotally joined at its outboard end to said gauge, and the second strut is connected to the outboard end of the first strut at a pivot adjacent to the pivot for said gauge, and wherein said drive means is connected for reciprocally pivoting the parallelogram of struts so that the gauge describes a motion generally perpendicular to the motion of the wheelhead, whereby during rotation of the workpiece the two movements in combination cause the gauge to describe substantially the same circular path as the workpiece region engageable by the gauge.

**14.** Apparatus according to claim 13 in which one of said spaced apart pivots to which said first strut is attached, lies vertically above the axis of the workpiece region.

**15.** Apparatus according to claim 13 or claim 14 in which said second strut is adjustable in length, and drive means is provided to achieve the alteration of its length so that relative movement can be obtained between the gauge and the first strut, and therefore the parallelogram of struts.

**16.** Apparatus according to any one of claims 13 to 15 in which said rigid support is separate from the wheelhead and movement of said parallelogram of struts in sympathy with the wheel head is achieved by a separate servo drive responsive to control signals derived from wheel feed signals and/or from signals from an encoder associated with a headstock for mounting the workpiece.

**17.** Apparatus according to any one of claims 13 to 16 in which the two fingers of the gauge lightly engage diametrically opposite points of the workpiece region, and a further workpiece engaging element is located approximately mid-way between the two fingers and displaced relative to a line joining the two fingers by a distance commensurate with the radius of the region to be gauged, to enable said element to engage a point on the surface of the workpiece region which is diametrically opposite the point of grinding contact with the region.

**18.** Apparatus according to claim 17 in which said element is a separate member independently movable relative to the gauge and therefore to the two fingers.

**19.** Apparatus according to any one of claims 10 to 18 further comprising one or more transducers associated with the fingers from which are derived electrical signals, corresponding to the mean diameter determined upon initial engagement between the fingers and the workpiece region, and subsequently corresponding to changes in diameter during grinding.

**20.** Apparatus according to any one of claims 13 to 19 in which the pivot between the first strut and the outboard strut defines a pivot axis which is parallel to the axis of said region and remains generally vertically thereabove as a consequence of its movement with the wheelhead.

**21.** Apparatus according to any one of claims 13 to 20 in which the second strut comprises at least in part a pneumatic cylinder, movement of a piston therein producing the variation in overall length of the strut, and further comprising control means for supplying air along an airline to the cylinder to extend or retract the cylinder as required.

**22.** Apparatus according to claim 21 in which the cylinder is a single acting cylinder with a return spring, the spring acting to shorten the length of the strut if air pressure is removed.

**23.** Apparatus according to any one of claims 13 to 22 further comprising torque generating means for producing a turning movement about the pivot of at least one of the parallel struts of the said parallelogram, the direction and magnitude of which is such as to compensate for the opposite turning movement about that pivot created by the weight of the gauge and supporting structure.

**24.** Apparatus according to any one of claims 13 to 22 in which one of the two parallel struts extends beyond the pivot point where it is attached to the rigid support, and the turning moment of the extended section of the strut is adapted to generally counterbalance the weight of the gauge and supporting structure, so that a reduced force is needed to reciprocally pivot the gauge and structure.

**25.** Apparatus according to any one of claims 10 to 24 in which said drive means comprises a reciprocating servo drive imparting to the gauge a simple harmonic motion with frequency and amplitude control.

**26.** Apparatus according to any one of claims 13 to 25 comprising a further drive between the wheel head and said rigid support for the gauge support structure, which itself is also under computer control, to allow for fine tuning of the advance and retract movement of the gauge in the direction of the wheelhead movement.

**27.** Apparatus according to any one of claims 13 to 26 in which the workpiece is mounted on a headstock with which an encoder is associated to allow instantaneous rotational positional information of the workpiece to be obtained, and in which said drive means comprises a servo drive associated with the gauge support structure and acting thereon to reciprocally move the parallel struts, so that in combination with the advance and retract movement of the wheelhead the gauge is caused to describe a circular movement, and in which the servo drive is synchronised with the rotation of the workpiece using output signals from the headstock encoder.

**28.** Apparatus according to any one of claims 13 to 27 in which the gauge is attached to the lower end of the first strut through a lost motion connection.

**29.** Apparatus according to any one of claims 13 to 28 in which said means moveable with a wheelhead and said drive means, which jointly produce a circular movement of the gauge, are constituted by a pair of rotating cranks mounted for rotation about two vertically spaced apart axes, parallel to the main axis of the workpiece, and joined by a rigid link which extends downwardly below the lower of the pair of cranks where it is secured to the gauge, wherein the radius of the cranks and the speed of rotation is selected so as to correspond to the radius of the circular motion of the workpiece region, and to the rotational speed of the region around the main axis of the workpiece, so that the gauge describes the same circular path in phase with the circular motion of the region.

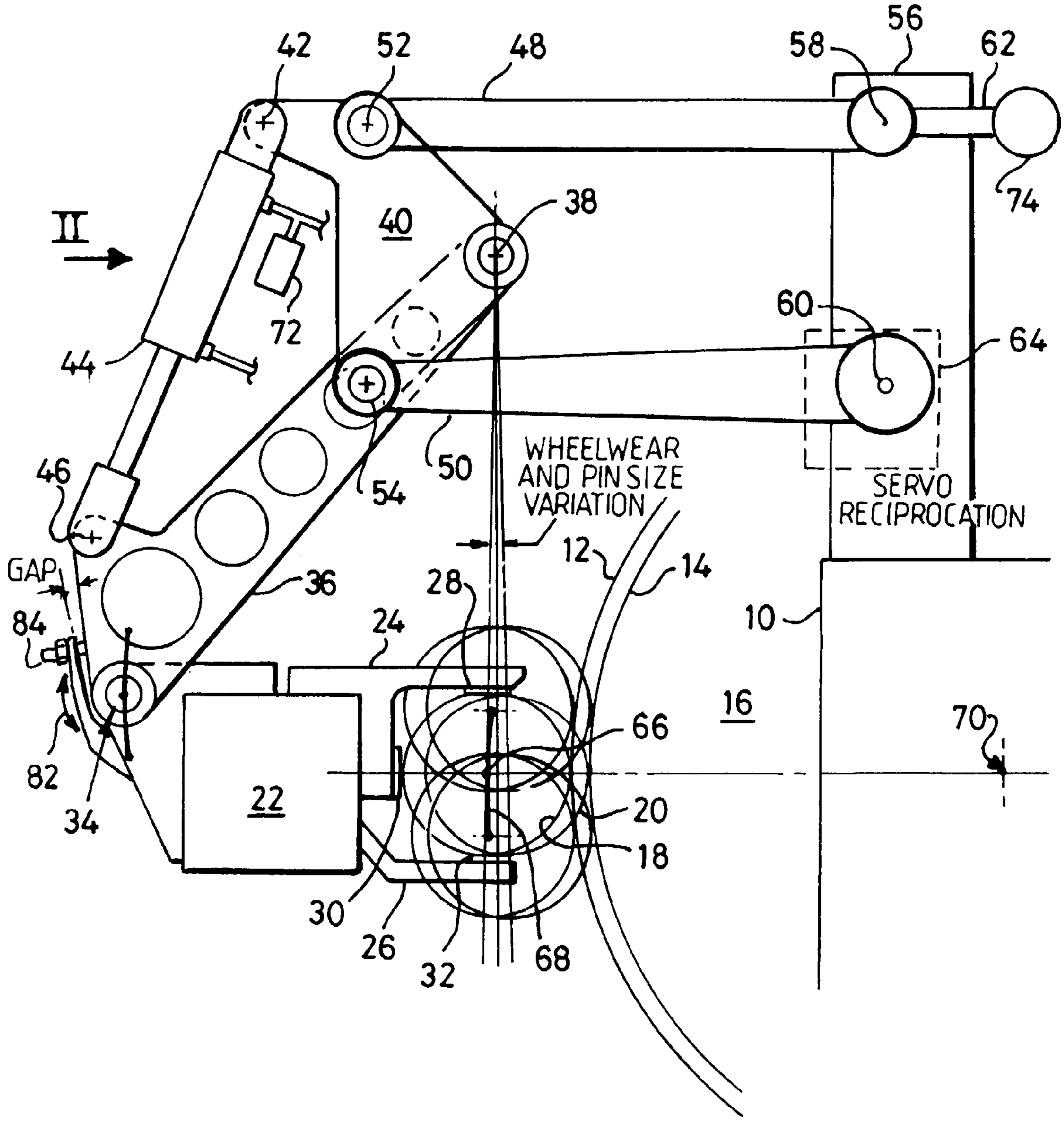
42
52
48
58
56
62
74
II
40
38
72
44
60
64
46
54
50
WHEELWEAR
AND PIN SIZE
VARIATION
SERVO
RECIPROCATION
GAP
36
12
14
28
84
24
10
16
66
70
82
22
20
34
18
30
26
68
32

Fig. 1

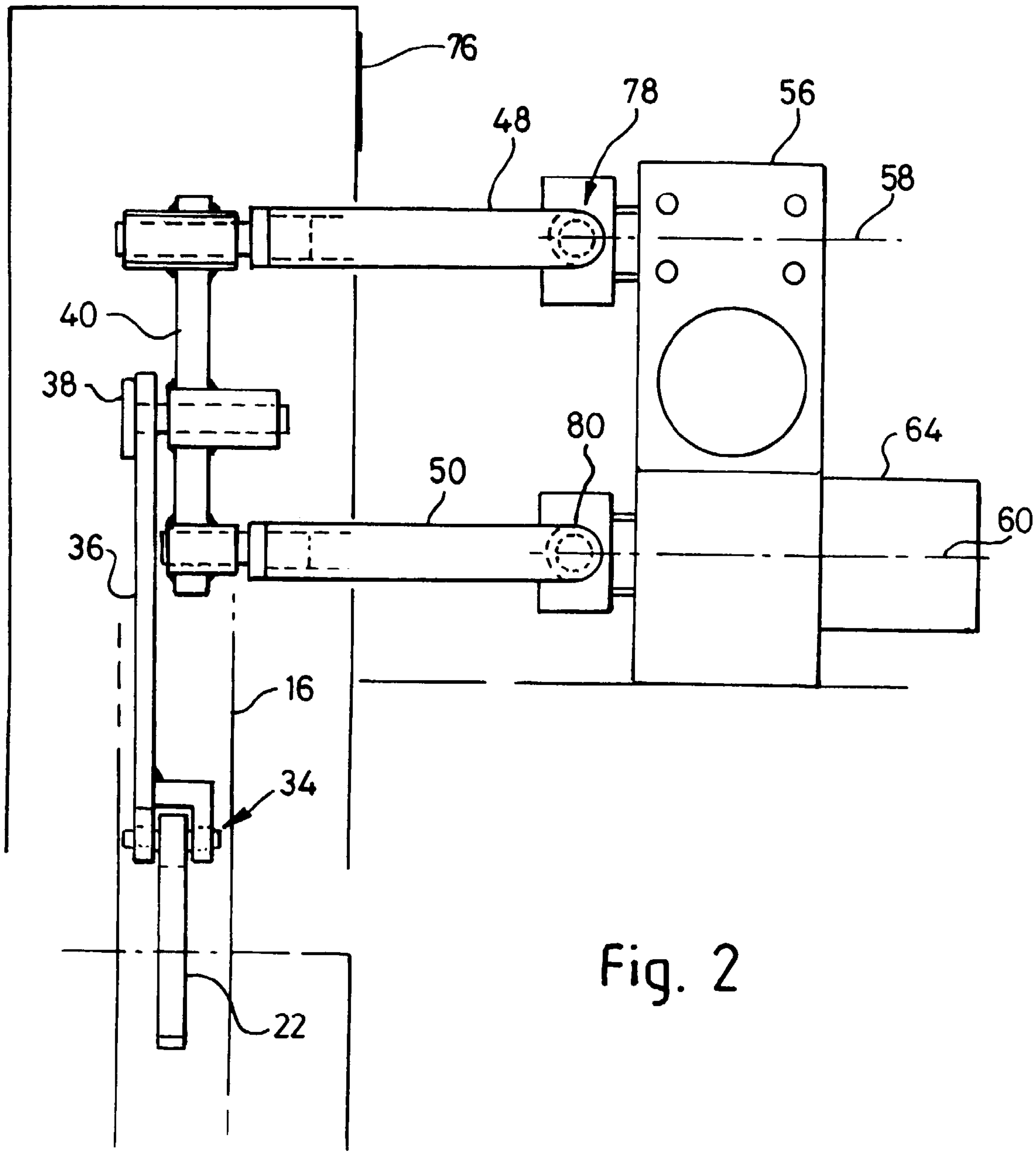


Fig. 2

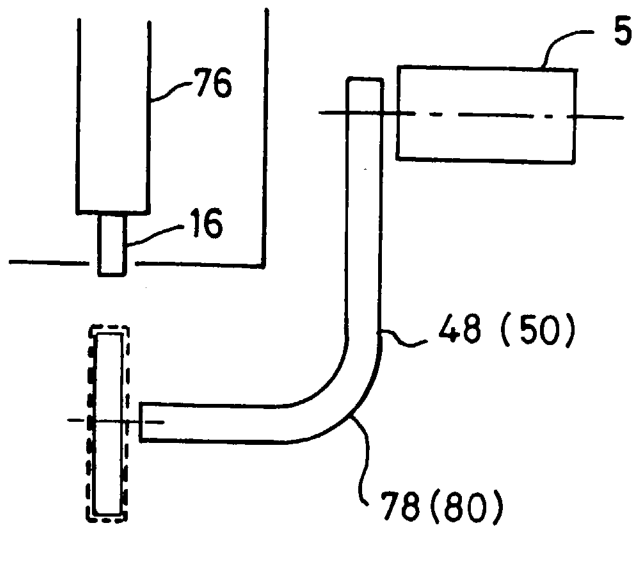
56
76
16
48 (50)
78 (80)

Fig. 3

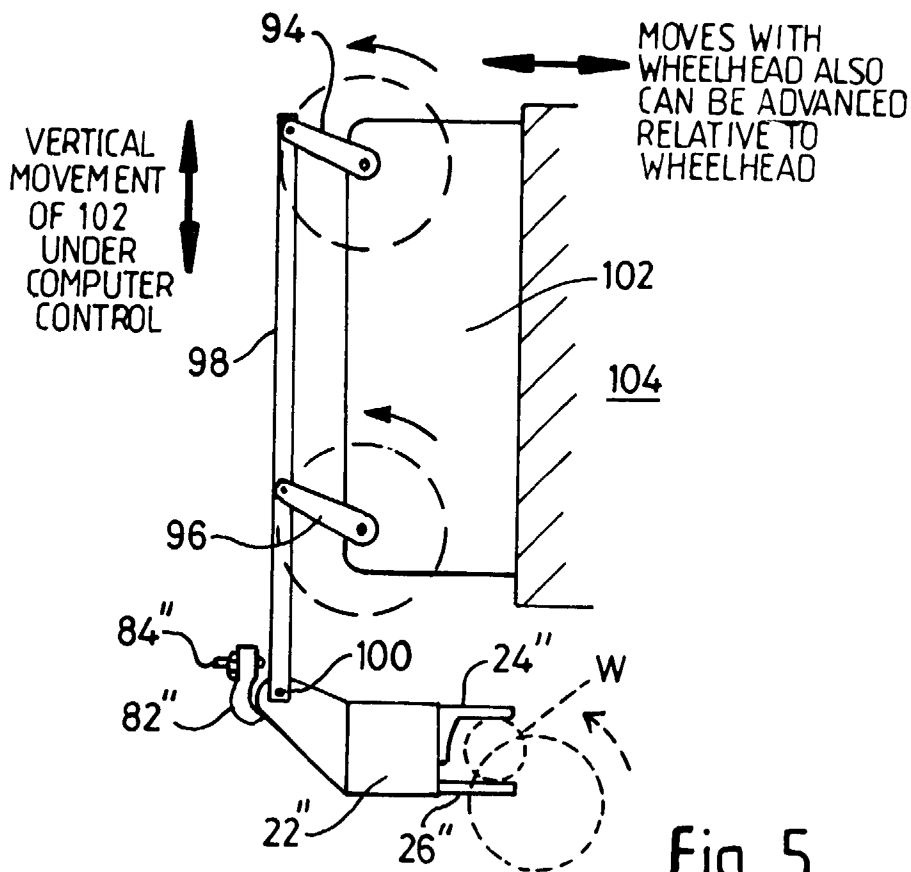
94
MOVES WITH WHEELHEAD ALSO CAN BE ADVANCED RELATIVE TO WHEELHEAD
VERTICAL MOVEMENT OF 102 UNDER COMPUTER CONTROL
102
98
104
96
84"
100
24"
W
82"
22"
26"

Fig. 5

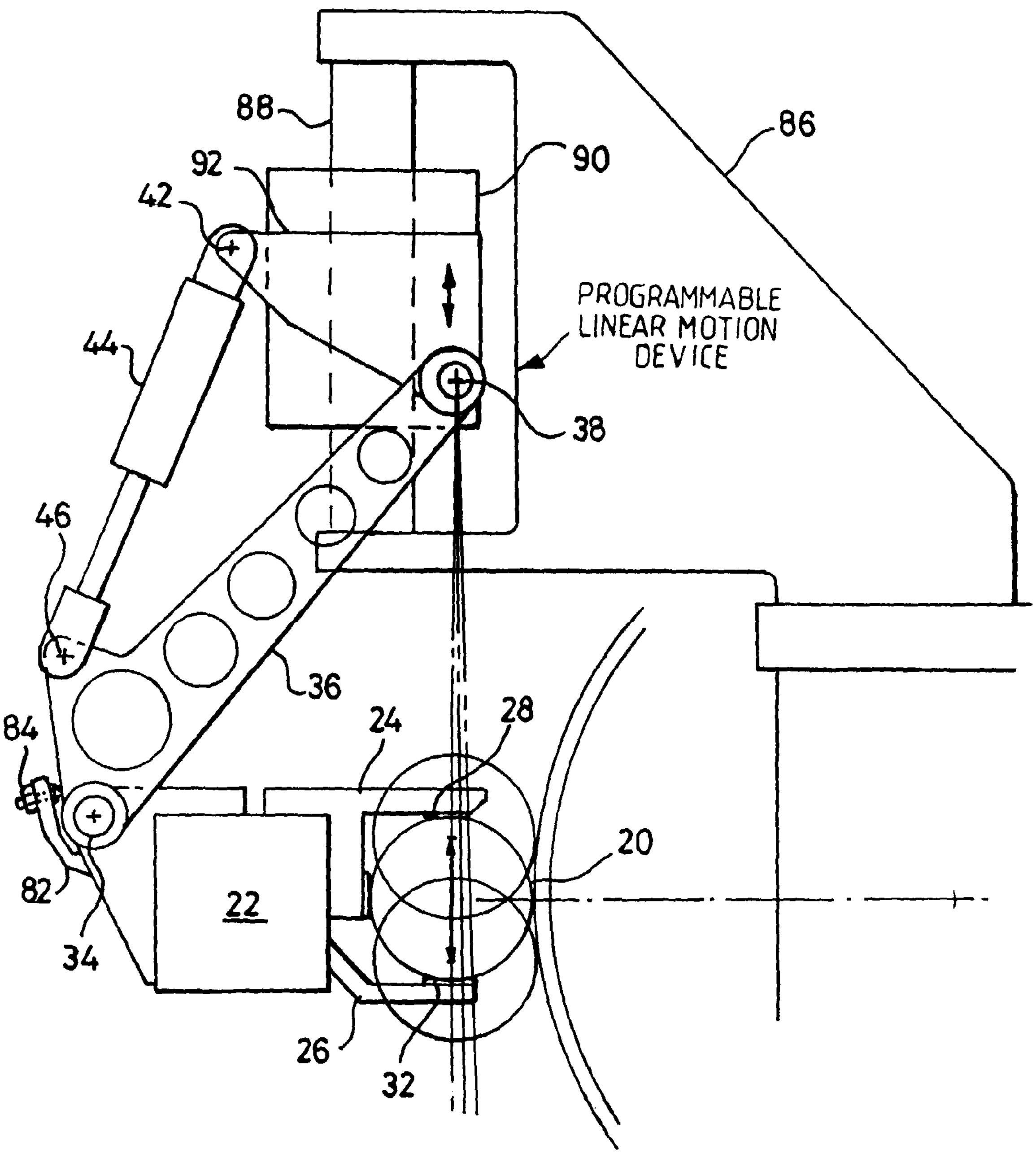
88
86
92
90
42
PROGRAMMABLE
LINEAR MOTION
DEVICE
44
38
46
36
84
24
28
20
22
82
34
26
32

Fig. 4