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(54) Method for evaluating grinding parameters of grinding wheel

(57) A method for evaluating grinding parameters of a grinding wheel is provided. With the method, only one grinding process is required to obtain a grinding ratio, a workpiece grinding stiffness, a grinding wheel surface contact stiffness, and a grinding wheel wear stiffness affecting dynamic characteristics of a grinding process through measuring a first width and a second width of a first spiral grinding line on the surface of a workpiece, and a first grinding depth and a second grinding depth relative to the positions of the first width and the second width. Therefore, an user can easily evaluate the quality of the grinding wheel, the workpiece characteristics, and the stability of a grinding dynamic system, thereby solving the grinding chatter problem and helping the grinding management personnel determine whether the grinding wheel meets the demand.

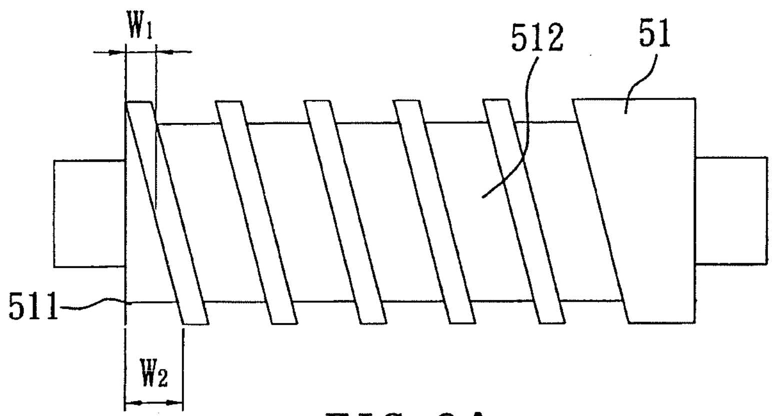

FIG. 6A

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a method for evaluating grinding parameters, and more particularly to a method for evaluating grinding parameters of a grinding wheel.

2. Description of the Related Art

[0002] During a grinding process, the cutting stiffness of a grinding wheel, the cutting stiffness of a ground workpiece, and the contact stiffness between the grinding wheel and the ground workpiece may directly affect the grinding stability. When the above characteristics are inappropriately selected, the grinding vibration may become too strong and affect the ground surface quality of the workpiece. For example, the excessive roll grinding vibration results in grinding roll marks on the surface of the roll, which results in various disadvantageous effects.

(1) The grinding roll mark is directly transferred to a steel coil, resulting in dark and light vibration roll marks on the surface of the steel coil.

(2) The grinding roll mark transferred to the backup roll may cause the dynamic change in a milling force, thereby forming vibration roll marks on the surface of the steel coil.

[0003] After reaching the downstream, the marks on the coil may be eliminated or may also affect the surface of the roll rewinded at the downstream, locally forming another transferring mechanism. Therefore, grinding roll marks must be treated cautiously in a milling operation.

[0004] In a conventional method for evaluating grinding parameters of the grinding wheel, Bartalucci and Lisini [1] applied a static force to the grinding wheel, so as to calculate a static grinding wheel stiffness by measuring the force and its deformation. A dynamic grinding wheel stiffness is also calculated by using an impact experiment, and a comparison result shows that the difference between the two is not significant. However, it is proved later that the grinding wheel contact stiffness obtained by the static experiment is still different from the result of a practical processing procedure.

[0005] Inasaki and Yonetsu [2] also discussed the stiffness of the contact region between the grinding wheel and workpiece on the basis of a Hertzian contact theory, wherein the grinding wheel contact stiffness is similar to a non-linear spring. Hashimoto et al. [3] determined that a power relation exists between the grinding wheel contact stiffness and a plunge force through experiments. Ramos et al. [4] performed a plunge grinding with a stable plunge infeed on a cylindrical grinding machine and recorded a time constant of a grinding force attenuation curve after stopping the infeed under a stable grinding force, thereby deducting a practical grinding depth of the workpiece and a process stiffness. The shortcoming of these methods are the requirement of the use of a dynamometer, and assuming the grinding wheel wear stiffness, ks, and the grinding ratio, r, to be infinite.

[0006] Therefore, it is necessary to provide a method for evaluating the grinding parameters of the grinding wheel to solve the above problem.

[0007] A list of prior art references is shown as follows.

1. B. Bartalucci, G.G. Lisini, "Grinding process instability," Transaction ASME Journal Engineer Industry. Vol. 91, pp.597-606, 1969.

2. I. Inasaki, S. Yonetsu, "Regenerative chatter in grinding," in: Proc. of the 18th Int. Mach.Tool Des. and Res.Conf., Oxford, pp. 423-429, 1977.

3. F. Hashimoto, J. Yoshioka, M. Miyashita, H. Sato, " Sequential estimation of growth rate of chatter vibration in grinding process," Annals of the CIRP, Vol. 33(1), pp. 259-263, 1984.

4. J. C. Ramos, J. Vinolas, F.J. Nieto, "A simplified methodology to determine the cutting stiffness and the contact stiffness in the plunge grinding process," International Journal of Machine Tools and Manufacture, pp. 33-49, 2001.

SUMMARY OF THE INVENTION

[0008] The present invention provides a method for evaluating grinding parameters of a grinding wheel, so as to evaluate the grinding parameters of the grinding wheel of a grinding machine, wherein the grinding machine has a machine grinding static rigidity. The method includes the following steps. In step (a), a workpiece is ground by the grinding wheel along a first direction according to a predetermined total grinding infeed, and a spiral grinding line is formed on a surface of the workpiece. The circumference of the grinding wheel has a grinding wheel line speed, the circumference of the workpiece has a workpiece line speed, the first direction is a direction from a head end to a tail end of the workpiece, and the spiral grinding line located on the head end has a divergent spiral grinding line. In step (b), a first width and a second width of the divergent spiral grinding line are measured along the first direction, and a first grinding depth and a second grinding depth of the workpiece relative to the first width and the second width are measured as well. In step (c), a grinding ratio is calculated according to a ground volume of the grinding wheel and a ground volume of the workpiece. In step (d), a workpiece grinding stiffness is calculated on the basis of the machine structural stiffness, the predetermined total grinding infeed, the first width, the second width, the first grinding depth, and the second grinding depth, and a grinding wheel surface contact stiffness and a grinding wheel wear stiffness are calculated on the basis of the machine structural stiffness, the predetermined total grinding infeed, the first width, the second width, the first grinding depth, the second grinding depth, the grinding wheel line speed, and the workpiece line speed.

[0009] In the method for evaluating grinding parameters of the grinding wheel of the present invention, only one grinding process is required to obtain the workpiece grinding stiffness, the grinding wheel surface contact stiffness, and the grinding wheel wear stiffness by measuring geometric sizes of the surface of the workpiece after grinding, so as to obtain the relevant process parameters that would affect the dynamic characteristics of the grinding process, thus solving the grinding chatter problem and helping the grinding management personnel determine whether the grinding wheel meets the demand. Therefore, the user can easily evaluate the quality of the grinding wheel, the workpiece characteristics, and the stability of a grinding dynamic system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

FIG. 1 is a schematic simulative view of a grinding dynamic stiffness;

FIG. 2 is a systematic block diagram of a grinding dynamic system;

FIG. 3 is a Nyquist diagram of a grinding system feature equation according to the present invention;

FIG. 4 is a schematic view of a method for evaluating grinding parameters of a grinding wheel according to the present invention;

FIG. 5 is a schematic view of a process of forming a spiral grinding line on the surface of a workpiece according to the present invention;

FIGs. 6A to 6C are schematic views of measuring widths and grinding depths of the divergent spiral grinding line according to the present invention;

FIG. 7 is a schematic view of a ground volume of the workpiece according to the present invention; and

FIG. 8 is a schematic view of calculating a process stiffness by using a process stiffness identification model according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0011] FIG. 1 is a schematic simulative view of a grinding dynamic stiffness, and FIG. 2 is a systematic block diagram of a grinding dynamic system. The relevant parameters of the dynamic mode are described as follows. k_m: a machine structural stiffness, k_c: a grinding wheel surface contact stiffness, k_s: a grinding wheel wear stiffness, k_w: a workpiece grinding stiffness, T_s: a grinding wheel rotating cycle, T_w: a workpiece rotating cycle, G_s and G_w: grinding wheel and structure dynamic functions, d_m: a relative displacement amount of the grinding wheel and the workpiece, d_s: a grinding wheel total wear amount; d_w: a workpiece total wear amount, ${}_{\Delta}d_s$: a grinding wheel instant wear amount, ${}_{\Delta}d_w$: a workpiece instant wear amount, d_f: a total grinding infeed, and f_r: a plunge grinding force. In FIG. 1, the grinding wheel surface contact stiffness, the grinding wheel wear stiffness, and the workpiece grinding stiffness are represented by equivalent springs k_c, k_s, and k_w, respectively.

[0012] As shown in FIGs. 1 and 2, the grinding of the workpiece, the wear of the grinding wheel, the deformation of the grinding wheel, and the deflection of the machine may affect the grinding dynamic system, and the parameters affecting the grinding dynamic system include the machine structural stiffness k_m, the grinding wheel surface contact stiffness k_c, the workpiece wear stiffness k_w, and the grinding wheel wear stiffness k_s, in which k_c, k_w and k_s are referred to as the process stiffness for short.

[0013] When the total infeed d_f is given, the generated plunge grinding force f_r may affect the grinding of the workpiece, the wear of the grinding wheel, the deformation of the grinding wheel, and the deflection of the machine. The grinding of the workpiece and the wear of the grinding wheel may be generated by regenerative effects resulting from rotation of the workpiece and the grinding wheel (i.e. $e^{-sT}{}_s$ and e^{-sTw} in FIG. 2). A phase difference exists between the previous pass and the current grinding pass, and the phase difference result in the non-uniformity of the grinding depth and change of the grinding force, thereby resulting in a vibration behavior that generates the regenerative effect. The grinding wheel regenerative effect e^{-sT_s} and the workpiece regenerative effect e^{-sT_w} may move a pole of the grinding system towards the right half plane, causing the grinding system unstable (that is, a grinding chatter occurs). Therefore, the regenerative effect of the grinding wheel and the workpiece is the main factor affecting the grinding chatter.

[0014] A transfer function of the grinding dynamic system of FIG. 2 is shown in equation (1) as follows:

$$\frac{F(s)}{d_f} = \frac{1}{\dfrac{1}{k_w(1-\mu e^{-sT_w})} + \dfrac{1}{k_s(1-e^{-sT_s})} + \left[G_w(s)+G_s(s)\right] + \dfrac{1}{k_c}} \qquad (1)$$

in which the characteristic equation of the equation (1) is:

$$-\left(\frac{1}{k_c} + \frac{1}{k_w}\frac{1}{1-e^{-j\omega T_w}} + \frac{1}{k_s}\frac{1}{1-e^{-j\omega T_s}}\right) = G(j\omega) \qquad (2)$$

[0015] Here, the function F(s) is used to represent a plunge grinding force f_r, $G=G_w+G_s$, and may be considered as $1/k_m$. Then, equation (2) is drawn as a Nyquist diagram, as shown in FIG. 3. In FIG. 3, when a feature straight line L1 of the left half part intersects with an arc line C1 of the transfer function of the grinding dynamic system of the right half part, the dynamic instability phenomenon occurred. Therefore, whether the grinding is stable or not depends on a distance D1 between the feature straight line L1 of the left half part and the arc line C1 of the transfer function of the grinding dynamic system of the right half part. That is, the smaller the grinding wheel surface contact stiffness k_c, the workpiece grinding stiffness k_w, the grinding wheel wear stiffness k_s, and other process stiffness are, the more stable the grinding dynamic system is. In FIG. 3, a value of the distance D1 is $\dfrac{1}{k_c} + \dfrac{1}{2k_w} + \dfrac{1}{2k_s}$.

[0016] The method for evaluating the grinding parameters of the grinding wheel of the present invention can accurately evaluate the grinding wheel surface contact stiffness k_c, the workpiece grinding stiffness k_w, and the grinding wheel wear stiffness k_s of the grinding dynamic system, so as to solve the grinding chatter problem and help the grinding management personnel determine whether the grinding wheel meets the demand.

[0017] FIG. 4 is a schematic view of the method for evaluating the grinding parameters of the grinding wheel according to the present invention. In this embodiment, the method is be used to evaluate the grinding parameters of a grinding wheel of a grinding machine, including the grinding wheel surface contact stiffness k_c, the workpiece grinding stiffness k_w, and the grinding wheel wear stiffness k_s. The grinding machine has a machine structural stiffness, and the machine structural stiffness can be measured by a stiffness measuring experiment.

[0018] In Step S41, a workpiece (for example, a work roll) is ground by the grinding wheel along a first direction according to a predetermined total grinding infeed, and a spiral grinding line is formed on a surface of the workpiece.

The circumference of the grinding wheel has a grinding wheel line speed, the circumference of the workpiece has a workpiece line speed, the first direction is a direction from a head end to a tail end of the workpiece, and the spiral grinding line located on the head end has a divergent spiral grinding line. When the grinding wheel grinds the workpiece along the first direction, the first mark of the spiral grinding line formed on the cut-in position of the workpiece may form grinding depths with continuous width changes on the surface of the workpiece, thus forming the divergent spiral grinding line.

[0019] In Step S41, the grinding wheel line speed is calculated on the basis of a constant (PI), a diameter and a rotation speed of the grinding wheel, and the workpiece line speed is calculated on the basis of a constant (PI), a diameter and a rotation speed of the workpiece.

[0020] The grinding wheel line speed can be represented by an equation (3) as follows:

$$V_s = \pi \times D_s \times f_s \tag{3}$$

[0021] The workpiece line speed can be represented by an equation (4) as follows:

$$V_w = \pi \times D_w \times f_w \tag{4}$$

[0022] In equations (3) and (4), π is a constant, D_s is the grinding wheel diameter, f_s is rotation speed of the grinding wheel, D_w is the diameter of the workpiece, and f_w is the rotation speed of the workpiece.

[0023] In addition, in Step S41, the grinding wheel is moved along the first direction at a relative moving speed, and ground parts of the surface of the workpiece do not overlap, so that the spiral grinding line is formed on the surface of the workpiece.

[0024] FIG. 5 is a schematic view of a process of forming the spiral grinding line on the surface of the workpiece according to the present invention. The workpiece 51 is a work roll. As shown in FIGs. 4 and 5, in this embodiment, Step S41 includes the following sub-steps. In Step S411, a grinding origin x_0 is marked on the head end 511 of the workpiece 51. In Step S412, the workpiece 51 is ground by the grinding wheel 52 from a grinding origin x_0 along the first direction (as shown by an arrow parallel to the work roll in the upper part of FIG. 5), so as to form the spiral grinding line 512. Preferably, before Step S411, the method further includes trimming the surfaces of the grinding wheel 52 and the workpiece 51.

[0025] After trimming the surfaces of the grinding wheel 52 and the workpiece 51, the grinding wheel 52 contacts the workpiece 51, the x coordinate is recorded to serve as the grinding origin x_0 (as shown in 5(a)), and then the grinding wheel 52 exits (as shown in FIGs. 5(b) and 5(c)). Next, the grinding wheel 52 is moved to a position of a predetermined grinding depth d_f (total grinding infeed); at this time, the value of the x coordinate must be set to x_0-d_f (as shown in FIG. 5(d)). Finally, the grinding is performed along the first direction according to the predetermined rotation speed of the workpiece 51, the rotation speed of the grinding wheel 52, and a frame (not shown) speed, so as to form the spiral grinding line 512 (as shown in FIG. 5(e)) on the surface of the workpiece 51.

[0026] FIGs. 6A to 6C are schematic views of measuring widths and grinding depths of the divergent spiral grinding line according to the present invention. As shown in FIGs. 6A to 6C and Step S42, a first width w_1 and a second width w_2 of the divergent spiral grinding line 512 are measured along the first direction, and a first grinding depth d_1 and a second grinding depth d_2 of the workpiece 51 relative to the first width w_1 and the second width w_2 are measured. In this embodiment, Step S42 includes the following sub-steps. In Step S421, the first width w_1 and the first grinding depth w_2 are measured along the first direction from a lateral periphery of the head end 511 of the workpiece 51 (as shown in FIG. 6B). In Step S422, the workpiece 51 is rotated by an angle, preferably 60 degrees. In Step S423, the second width w_2 and the second grinding depth d_2 are measured along the first direction from the lateral periphery of the head end 511 of the workpiece 51 (as shown in FIG. 6C).

[0027] In the present invention, the first width w_1, the first grinding depth d_1, the second width w_2 and the second grinding depth d_2 are measured with a distance measuring instrument, and the distance measuring instrument may be a displacement meter. Preferably, a probe of the distance measuring instrument approaches a cut-in position of the workpiece.

[0028] In Step S43, a grinding ratio is calculated on the basis of a ground volume of the grinding wheel and a ground volume of the workpiece. In this embodiment, the ground volume of the grinding wheel is calculated on the basis of a width of the grinding wheel and the diameters of the grinding wheel before and after grinding, and the ground volume of the workpiece is calculated on the basis of the diameter of the workpiece, the grinding depth and width of the spiral grinding line. Preferably, in Step S43, the diameters of the grinding wheel before and after grinding are measured with a PI-tape, and the grinding depth of the spiral grinding line is measured with the displacement meter.

[0029] FIG. 7 is a schematic view of the ground volume of the workpiece according to the present invention. A plurality of rectangular strips in FIG. 7(b) respectively correspond to the ground volume of the workpiece of each spiral grinding line 512 in FIG. 7(a). The grinding ratio r is defined as ground volume of the workpiece/ground volume of the grinding wheel. The grinding ratio r is obtained by using the depth change of the spiral grinding line 512 from the head end 511 to the tail end 513 of the workpiece 51 together with the wear amount of the diameter of the grinding wheel. After calculation, the grinding ratio r can be represented by an equation (5) as follows:

$$r = \frac{4D_w \sum D}{\left(D_{s1}^2 - D_{s2}^2\right)} \tag{5}$$

in which D_w is the diameter of the workpiece, D is the depth of each spiral grinding line depth, D_{s1} is the diameter of the grinding wheel before grinding, and D_{s2} is the diameter of the grinding wheel after grinding.

[0030] In Step S44, a workpiece grinding stiffness k_w is calculated on the basis of the machine structural stiffness k_m, the predetermined total grinding infeed d_f, the first width w_1, the second width w_2, the first grinding depth d_1, and the second grinding depth d_2. A grinding wheel surface contact stiffness k_c and a grinding wheel wear stiffness k_s are calculated on the basis of the machine structural stiffness k_m, the predetermined total grinding infeed d_f, the first width w_1, the second width w_2, the first grinding depth d_1, the second grinding depth d_2, the grinding wheel line speed V_s, and the workpiece line speed V_w.

[0031] In this embodiment, before Step S44, the method further includes establishing a process stiffness identification model, and then calculating the workpiece grinding stiffness k_w, the grinding wheel surface contact stiffness k_c, and the grinding wheel wear stiffness k_s by using the process stiffness identification model.

[0032] FIG. 8 is a schematic view of calculating a process stiffness by using the process stiffness identification model according to the present invention. For the establishment of the identification model, the results of a double grinding process performed by two grinding wheels with different widths are required, and the known machine structural stiffness, the predetermined total grinding infeed, and other conditions are also required for calculation of the process stiffness. The conditions necessary for the identification include: (1) the widths of the two grinding wheels, and the predetermined total grinding infeed of the two grinding process, (2) the machine structural stiffness (measured by the experiment), (3) the grinding depths of the workpiece ground by the two grinding wheels with different widths (obtained by measuring the shape after grounding).

[0033] As shown in FIGs. 1, 2, and 8, when a plunge grinding force f_r generated during grinding is applied to the grinding dynamic system, a total deformation of three equivalent springs k_c, k_s, and k_w (respectively equivalent to the grinding wheel surface contact stiffness k_c, the grinding wheel wear stiffness k_s, and the workpiece grinding stiffness k_w) is:

$$d_c + d_s + d_m + d_w = d_f \tag{6}$$

[0034] After the equation (6) is divided by the plunge grinding force f_r, an equation (7) is obtained:

$$\frac{d_c + d_s + d_m + d_w}{f_r} = \frac{d_f}{f_r} \tag{7}$$

[0035] The left side of equation (7) represents an integrated flexibility of the three springs including the grinding wheel surface contact stiffness k_c, the grinding wheel wear stiffness k_s, and the workpiece grinding stiffness k_w, so equation (7) can be further represented as:

$$\frac{1}{k_c}+\frac{1}{k_s}+\frac{1}{k_m}+\frac{1}{k_w}=\frac{d_f}{f_r} \quad (8)$$

[0036] When the grinding wheels with the different widths are used for grinding, the value of the machine structural stiffness k_m is fixed. In addition, it is assumed that the grinding wheel surface contact stiffness k_c, the grinding wheel wear stiffness k_s, and the workpiece grinding stiffness k_w are directly proportional to the width of the grinding wheel w, so equation (8) can be converted to:

$$\frac{1}{wk_{cu}}+\frac{1}{wk_{su}}+\frac{1}{k_m}+\frac{1}{wk_{wu}}=\frac{d_f}{f_r} \quad (9)$$

in which k_{cu} is the grinding wheel contact stiffness of a unit width, k_{su} is the grinding wheel wear stiffness of a unit width, and k_{wu} is the workpiece grinding stiffness of a unit width, in which the unit of the three is N/m-mn.

[0037] According to the result deducted from the assumption, when the grinding is performed by using two grinding wheels of the same specification and having respective widths w_1 and w_2, an equation (10) and an equation (11) can be obtained from equation (9):

$$\frac{1}{w_1k_{cu}}+\frac{1}{w_1k_{su}}+\frac{1}{k_m}+\frac{1}{w_1k_{wu}}=\frac{d_f}{f_{r1}} \quad (10)$$

$$\frac{1}{w_2k_{cu}}+\frac{1}{w_2k_{su}}+\frac{1}{k_m}+\frac{1}{w_2k_{wu}}=\frac{d_f}{f_{r2}} \quad (11)$$

in which f_{r1} and f_{r2} are the respective plunge grinding forces of the two grinding processes. In addition, the workpiece grinding stiffness is equal to the result of dividing the plunge grinding force f_r by the practical grinding depth D, and thus an equation (12) and an equation (13) are obtained.

$$w_1k_w=\frac{f_{r1}}{D_1} \quad (12)$$

$$w_2k_w=\frac{f_{r2}}{D_2} \quad (13)$$

[0038] Through equations (10) to (13) and $ks=kw\times$grinding wheel line speed/workpiece feeding speed$\times$grinding ratio (r), process stiffness identification equations (14) to (16) (i.e. the process stiffness identification model) are obtained.

$$k_w = \frac{d_f\left(D_1 - D_2\right)k_m}{D_1 D_2\left(w_1 - w_2\right)} \quad (14)$$

$$k_c = \frac{r d_f\left(D_1 - D_2\right)k_m V_s}{r V_s d_f\left(D_2 w_2 - D_1 w_1\right) + D_1 D_2\left(w_1 - w_2\right)\left(r V_s + V_w\right)} \quad (15)$$

$$k_s = \frac{r d_f\left(D_1 - D_2\right)k_m V_s}{D_1 D_2\left(w_1 - w_2\right)V_w} \quad (16)$$

[0039] It can be seen from the result deducted from the identification equations that the calculation of the process stiffness requires two practical depths ground by grinding wheels with different widths.

[0040] In the present invention, only one grinding process is required. In Step S41, when the workpiece is ground by the grinding wheel along the first direction, the first mark of the spiral grinding line formed on the cut-in position of the workpiece may form the divergent spiral grinding line with the grinding depths having continuous width changes. In Step S42, the first width w_1 and the second width w_2 of the divergent spiral grinding line are measured, the first grinding depth d_1 and the second grinding depth d_2 of the workpiece relative to the first width w_1 and the second width w_2 are measured, and then the process stiffness and the grinding ratio is obtained by using equations (3)-(5) and (14)-(16).

[0041] In addition, after Step S44, the method further includes controlling the stability of the grinding process on the basis of the workpiece grinding stiffness k_w, the grinding wheel surface contact stiffness k_c, and the grinding wheel wear stiffness k_s. That is, after the workpiece grinding stiffness k_w, the grinding wheel surface contact stiffness k_c, and the grinding wheel wear stiffness k_s are calculated, equations (1) and (2) are used and a Nyquist diagram is drawn to determine whether the grinding wheel meets the demand, thereby ensuring the stability of the grinding dynamic system and solving the grinding chatter problem.

[0042] In the method for evaluating grinding parameters of the grinding wheel of the present invention, only one grinding process is required to obtain the workpiece grinding stiffness, the grinding wheel surface contact stiffness, and the grinding wheel wear stiffness by measuring geometric sizes of the surface of the workpiece after grinding, so as to obtain the relevant process parameters that will affecting the dynamic characteristics of the grinding process, thereby solving the grinding chatter problem and helping the grinding management personnel to determine whether the grinding wheel meets the demand. Therefore, the user can easily evaluate the quality of the grinding wheel, the workpiece characteristics, and the stability of a grinding dynamic system.

[0043] While the embodiments of the present invention have been illustrated and described, various modifications and improvements can be made by those skilled in the art. The embodiments of the present invention are therefore described in an illustrative but not restrictive sense. It is intended that the present invention may not be limited to the particular forms as illustrated, and that all modifications that maintain the spirit and scope of the present invention are within the scope as defined in the appended claims.

Claims

1. A method for evaluating grinding parameters of a grinding wheel (52), for evaluating the grinding parameters of the grinding wheel (52) of a grinding machine, wherein the grinding machine has a machine structural stiffness, the method is **characterized in** comprising the steps of:

   (a) grinding a workpiece (51) by the grinding wheel (52) along a first direction according to a predetermined total grinding infeed, and forming a spiral grinding line (512) on a surface of the workpiece (51), wherein the circumference of the grinding wheel (52) has a grinding wheel line speed, the circumference of the workpiece (51) has a workpiece line speed, the first direction is the direction from a head end (511) to a tail end (513) of the workpiece (51), and the spiral grinding line (512) located on the head end (511) has a divergent spiral grinding line (512);

(b) measuring a first width and a second width of the divergent spiral grinding line (512) along the first direction, and measuring a first grinding depth and a second grinding depth of the workpiece (51) relative to the first width and the second width;

(c) calculating a grinding ratio on the basis of a ground volume of the grinding wheel (52) and a ground volume of the workpiece (51); and

(d) calculating a workpiece grinding stiffness on the basis of the machine structural stiffness, the predetermined total grinding infeed, the first width, the second width, the first grinding depth, and the second grinding depth, and calculating a grinding wheel surface contact stiffness and a grinding wheel wear stiffness on the basis of the machine structural stiffness, the predetermined total grinding infeed, the first width, the second width, the first grinding depth, the second grinding depth, the grinding wheel line speed, and the workpiece line speed.

2. The method according to Claim 1, wherein the machine structural stiffness is measured by a stiffness measuring experiment.

3. The method according to Claim 1, wherein in Step (a), the grinding wheel line speed is calculated on the basis of a circular constant, a diameter and a rotation speed of the grinding wheel (52), and the workpiece line speed is calculated on the basis of the circular constant, a diameter and a rotation speed of the workpiece (51).

4. The method according to Claim 1, wherein in Step (a), the grinding wheel (52) is moved along the first direction at a relative moving speed and ground parts on the surface of the workpiece (51) do not overlap, so that the spiral grinding line (512) is formed on the surface of the workpiece (51).

5. The method according to Claim 1, wherein Step (a) comprises:

(a1) marking a grinding origin on the head end (511) of the workpiece (51); and

(a2) grinding the workpiece (51) with the grinding wheel (52) from the grinding origin along the first direction, so as to form the spiral grinding line (512).

6. The method according to Claim 5, wherein before Step (a1), the method further comprises trimming the surfaces of the grinding wheel (52) and the workpiece (51).

7. The method according to Claim 1, wherein Step (b) comprises:

(b1) measuring the first width and the first grinding depth along the first direction from a lateral periphery of the head end (511) of the workpiece (51);

(b2) rotating the workpiece (51) by an angle; and

(b3) measuring the second width and the second grinding depth along the first direction from the lateral periphery of the head end (511) of the workpiece (51).

8. The method according to Claim 7, wherein in Steps (b1) and (b3), the first width, the first grinding depth, the second width, and the second grinding depth are measured by a distance measuring instrument.

9. The method according to Claim 8, wherein the distance measuring instrument is a displacement meter.

10. The method according to Claim 8, wherein a probe of the distance measuring instrument approaches a cut-in position of the workpiece (51).

11. The method according to Claim 7, wherein in Step (b2), the workpiece (51) is rotated by 60 degrees.

12. The method according to Claim 1, wherein in Step (c), the ground volume of the grinding wheel (52) is calculated on the basis of a width of the grinding wheel (52) and the diameters of the grinding wheel (52) before and after grinding, and the ground volume of the workpiece (51) is calculated on the basis of the diameter of the workpiece (51), a grinding depth and the width of the spiral grinding line (512).

13. The method according to Claim 12, wherein the grinding depth of the spiral grinding line (512) is measured with the displacement meter.

14. The method according to Claim 1, wherein before Step (d), the method further comprises establishing a process stiffness identification model, and in Step (d), the workpiece grinding stiffness, the grinding wheel surface contact stiffness, and the grinding wheel wear stiffness are calculated by using the process stiffness identification model.

15. The method according to Claim 1, where after Step (d), the method further comprises controlling the stability of a grinding process on the basis of the workpiece grinding stiffness, the grinding wheel surface contact stiffness, and the grinding wheel wear stiffness.

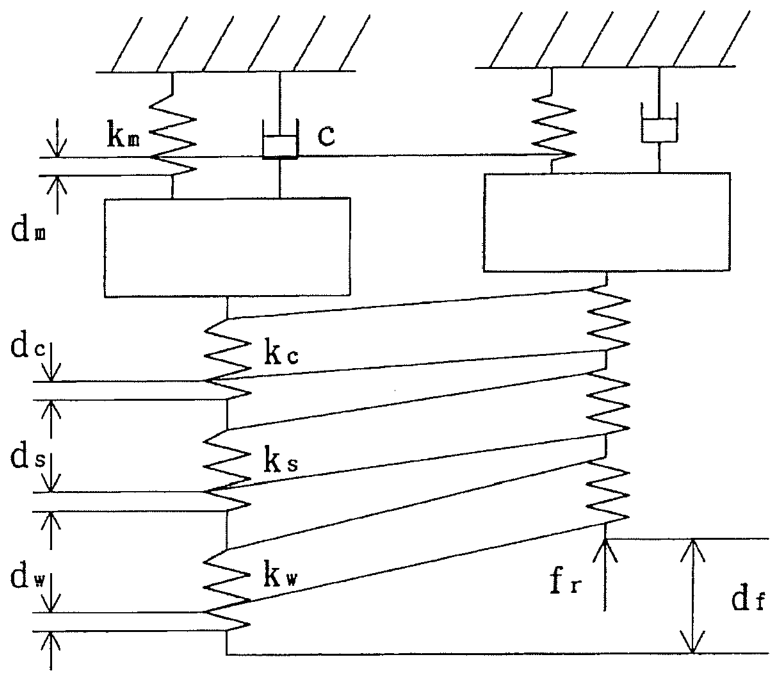

FIG. 1

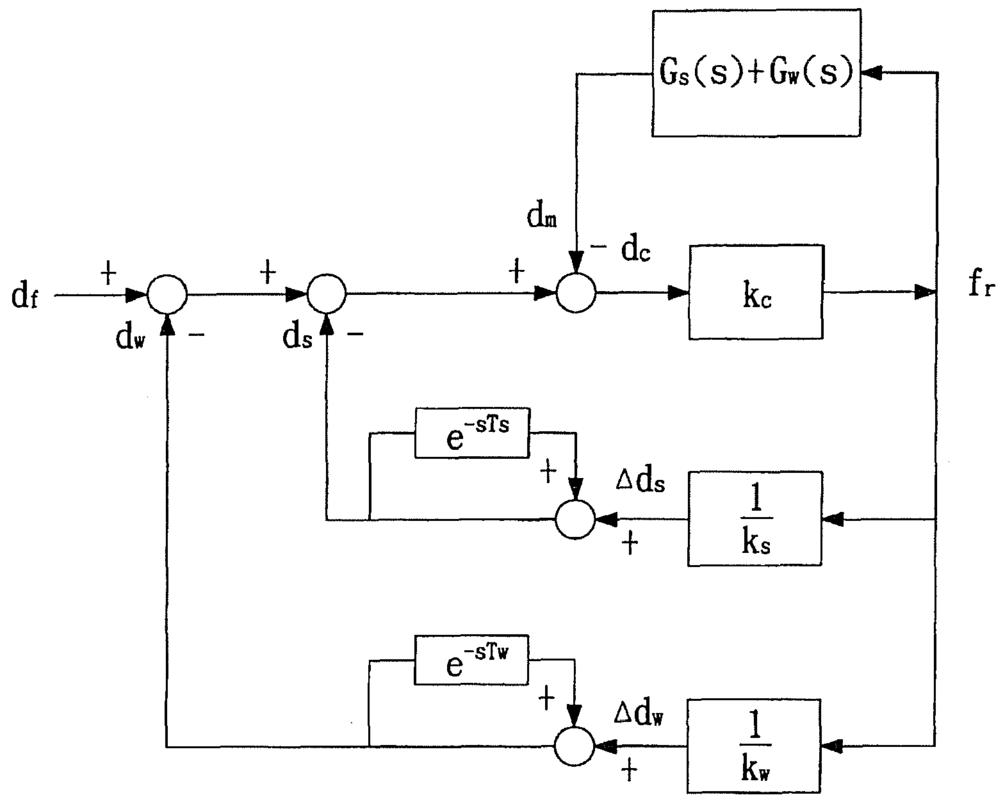

FIG. 2

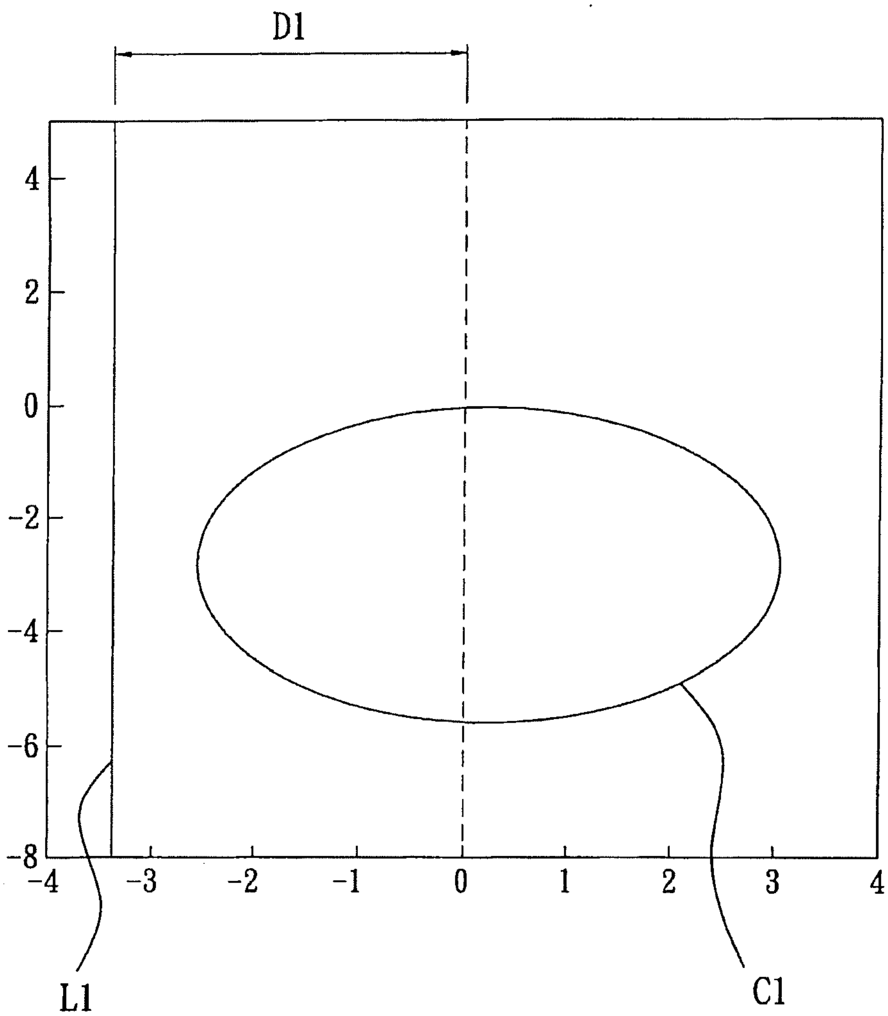

FIG. 3

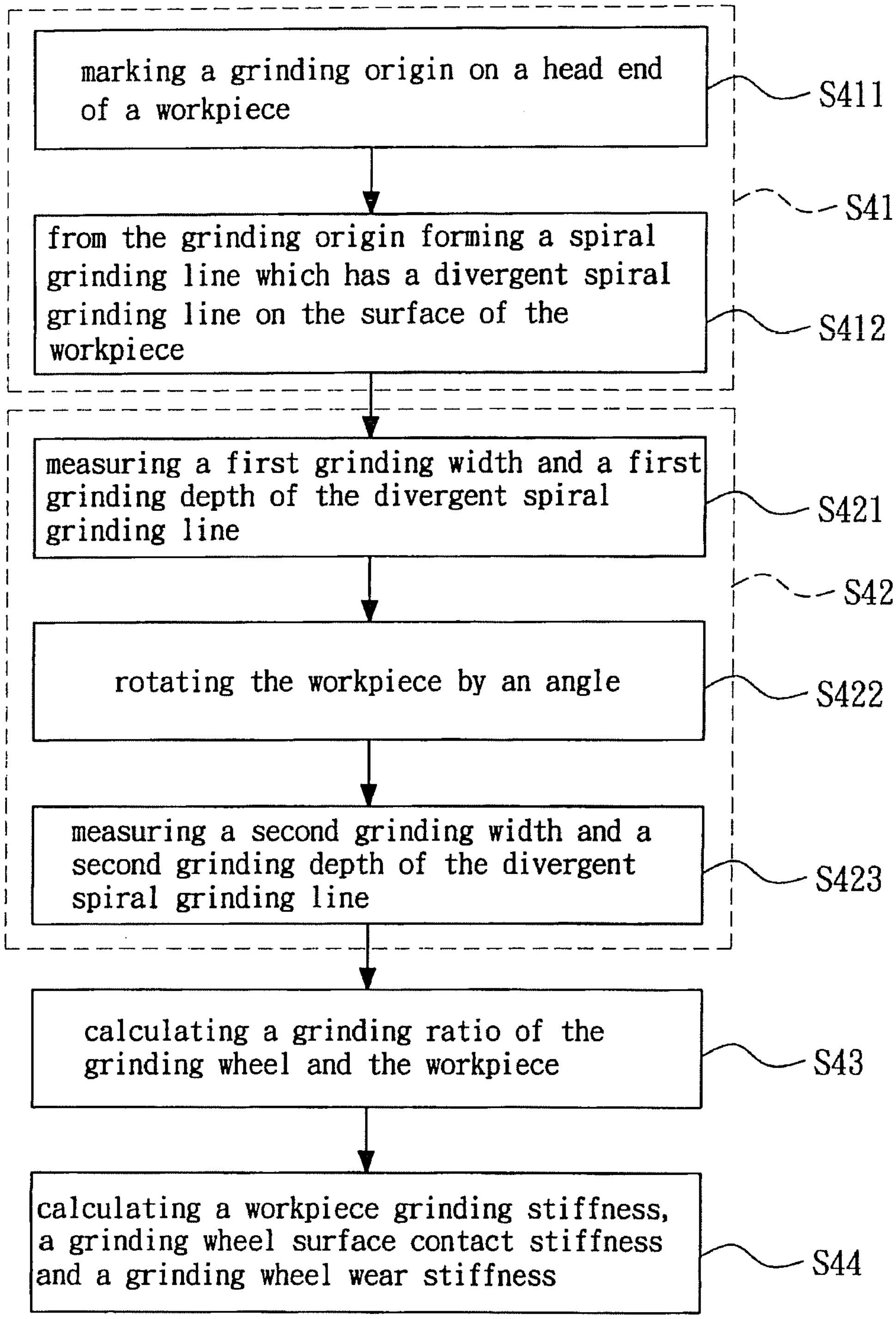
marking a grinding origin on a head end of a workpiece
S411
S41
from the grinding origin forming a spiral grinding line which has a divergent spiral grinding line on the surface of the workpiece
S412
measuring a first grinding width and a first grinding depth of the divergent spiral grinding line
S421
S42
rotating the workpiece by an angle
S422
measuring a second grinding width and a second grinding depth of the divergent spiral grinding line
S423
calculating a grinding ratio of the grinding wheel and the workpiece
S43
calculating a workpiece grinding stiffness, a grinding wheel surface contact stiffness and a grinding wheel wear stiffness
S44

FIG. 4

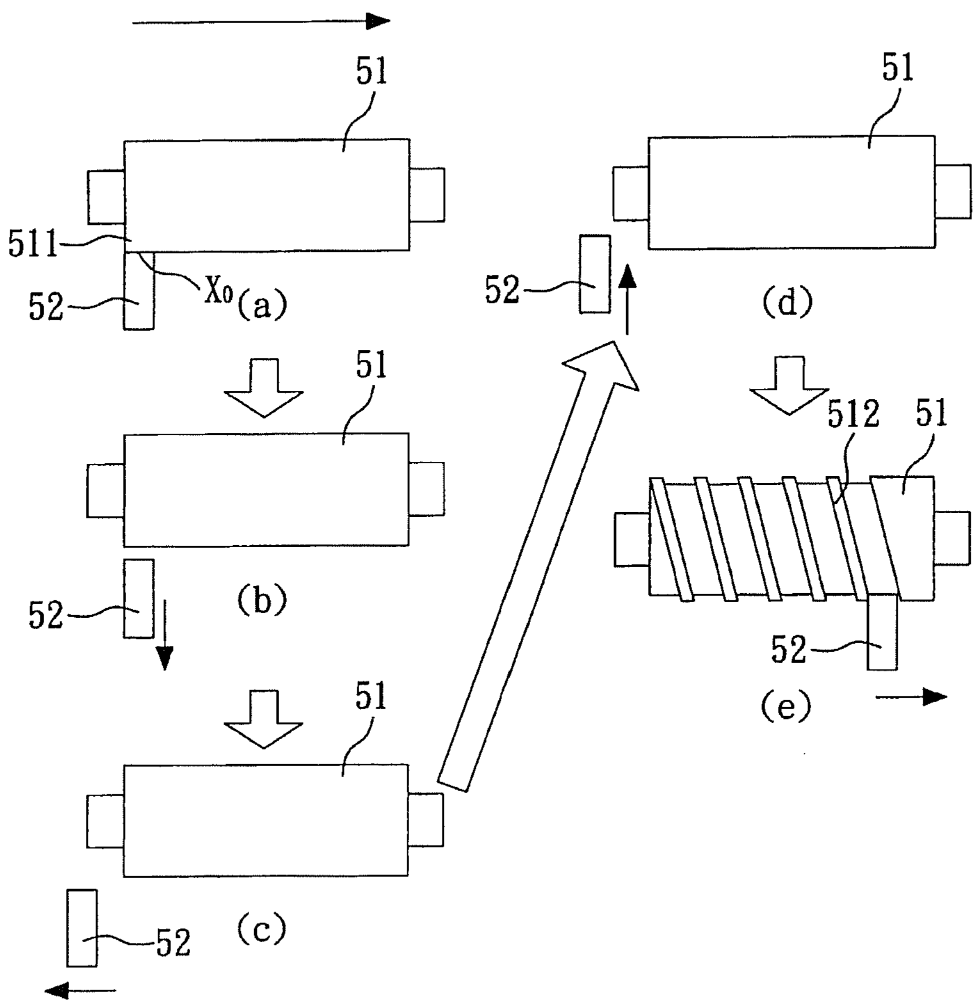

FIG. 5

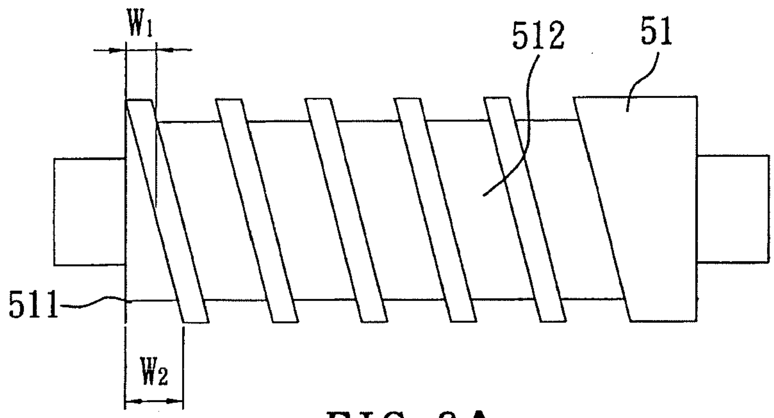

FIG. 6A

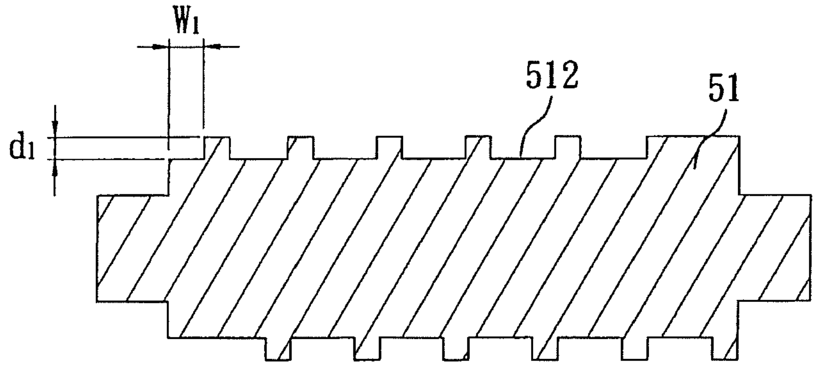

FIG. 6B

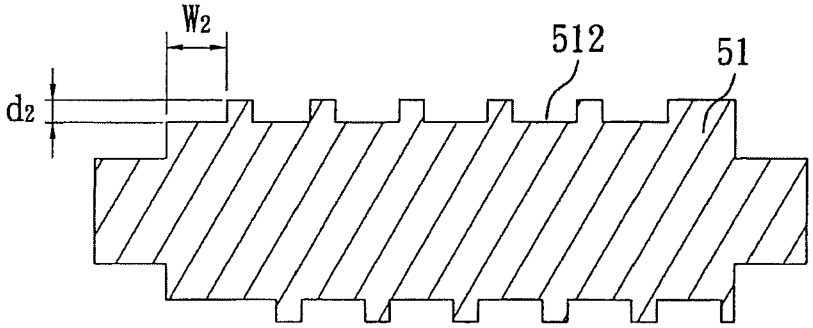

FIG. 6C

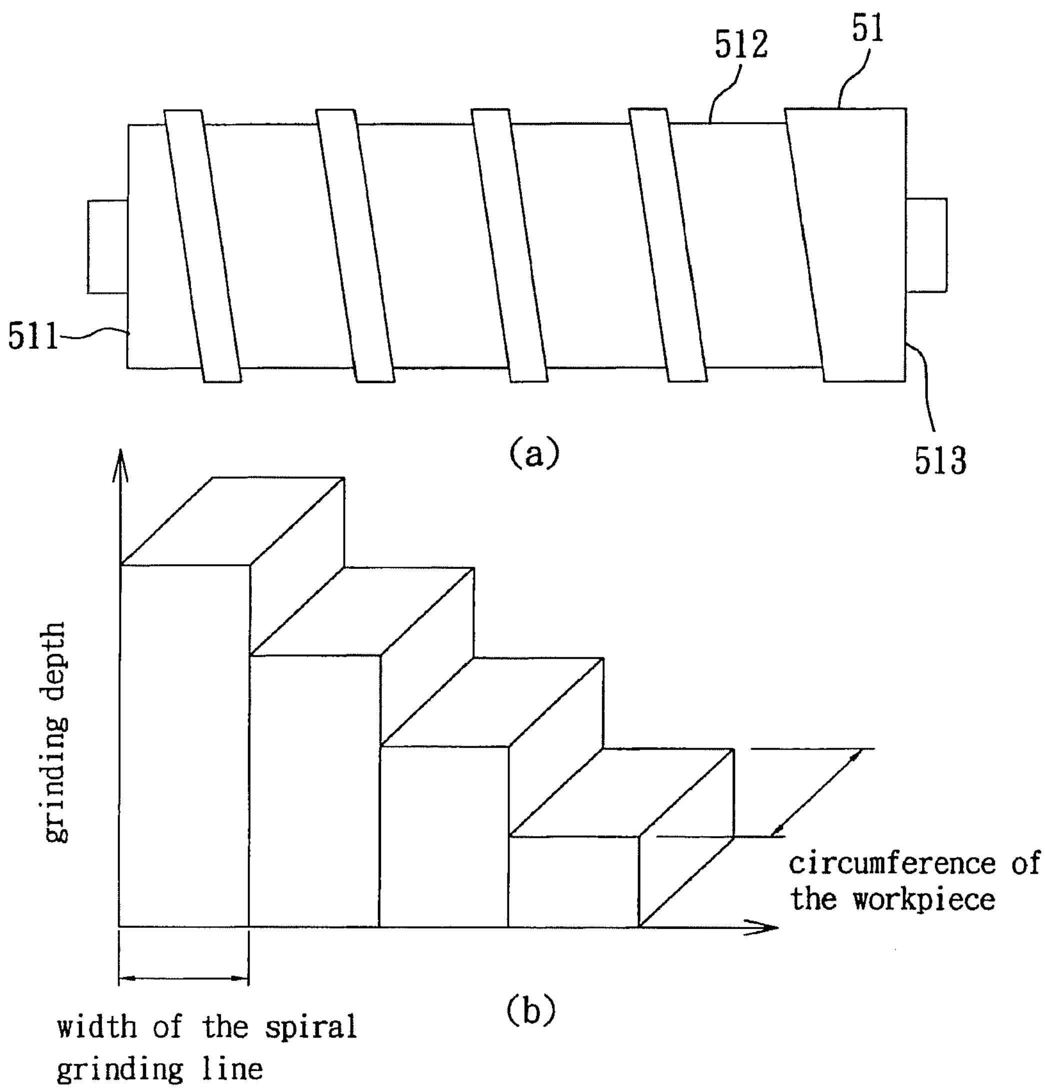
512
51
511
(a)
513
grinding depth
circumference of
the workpiece
width of the spiral
grinding line
(b)

FIG. 7

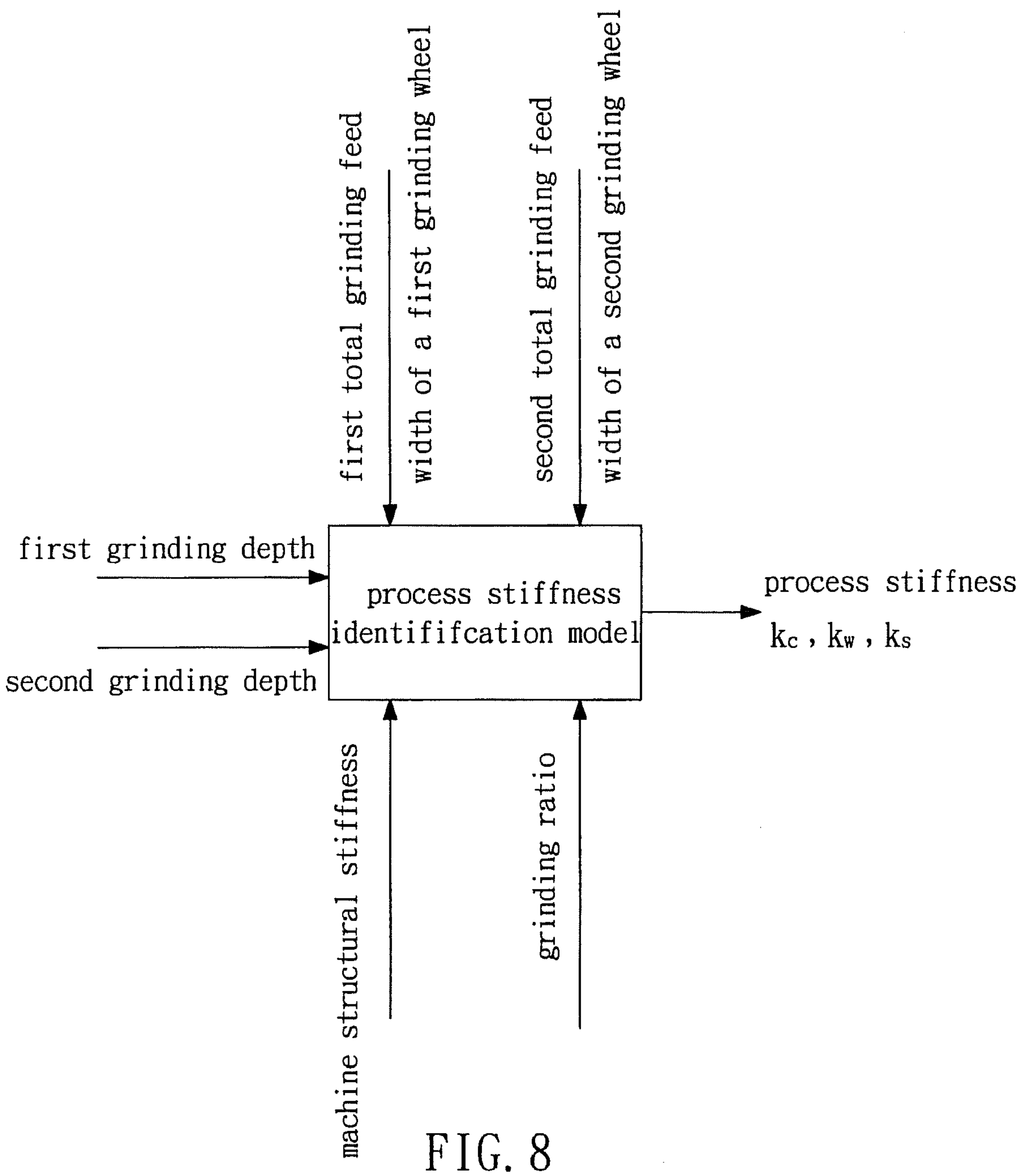
first total grinding feed
width of a first grinding wheel
second total grinding feed
width of a second grinding wheel
first grinding depth
second grinding depth
process stiffness identififcation model
process stiffness
kc , kw , ks
machine structural stiffness
grinding ratio

FIG. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 09 16 7657

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
D,A	RAMOS: "A simplified methodology to determine the cutting stiffness and the contact stiffness in the plunge grinding process" INTERNATIONAL JOURNAL OF MACHINE TOOLS AND MANUFACTURE, ELSEVIER, US, vol. 41, 1 January 2001 (2001-01-01), pages 33-49, XP009126369 ISSN: 0890-6955 * the whole document * -----	1-15	INV. B24B49/03 B24B5/04
D,A	BARTALUCCI: "Grinding process instability" TRANSACTIONS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS,SERIES B: JOURNAL OF ENGINEERING FOR INDUSTRY, ASME. NEW YORK, US, vol. 91, 1 January 1969 (1969-01-01), pages 597-606, XP009126371 ISSN: 0022-0817 * the whole document * -----	1-15	TECHNICAL FIELDS SEARCHED (IPC)
D,A	HASHIMOTO F ET AL: "Growing Mechanism of Chatter Vibrations in Grinding Processes and Chatter Stabilization Index of Grinding Wheel" CIRP ANNALS, ELSEVIER BV, NL, CH, FR, vol. 33, no. 1, 1 January 1984 (1984-01-01), pages 259-263, XP009126370 ISSN: 0007-8506 * the whole document * ----- -/--	1-15	B24B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	2 December 2009	Janzon, Mirja

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EUROPEAN SEARCH REPORT

Application Number
EP 09 16 7657

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
D,A	INASAKI: "Regererenerative chatter in grinding" 18TH INTERNATIONAL MACH. TOOL DES. AND RES.CONFERENCE,, 1 January 1977 (1977-01-01), pages 423-429, XP009126368 * the whole document * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)

1

The present search report has been drawn up for all claims

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- **B. Bartalucci ; G.G. Lisini.** Grinding process instability. *Transaction ASME Journal Engineer Industry,* 1969, vol. 91, 597-606 **[0007]**
- **I. Inasaki ; S. Yonetsu.** Regenerative chatter in grinding. *Proc. of the 18th Int. Mach.Tool Des. and Res.Conf.,* 1977, 423-429 **[0007]**
- **F. Hashimoto ; J. Yoshioka ; M. Miyashita ; H. Sato.** Sequential estimation of growth rate of chatter vibration in grinding process. *Annals of the CIRP,* 1984, vol. 33 (1), 259-263 **[0007]**
- **J. C. Ramos ; J. Vinolas ; F.J. Nieto.** A simplified methodology to determine the cutting stiffness and the contact stiffness in the plunge grinding process. *International Journal of Machine Tools and Manufacture,* 2001, 33-49 **[0007]**