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(54) METHOD FOR GRINDING SMALL ROTARY CUTTING TOOLS BY A GRINDING MACHINE

(57) The present invention relates to a Method for machining small rotary cutting tools (10) by a grinding machine, comprising: a) mounting a workpiece (10a) in a spindle (20) of the grinding machine; b) machining a calibration portion (CP) of the workpiece (10a) by performing one or a plurality of marks (M1, M2, M3, M4) on said workpiece with one abrasive wheel or with a corresponding plurality of abrasive wheels (W1, W2, W3, W4) of different shapes, wherein said one mark or each mark (M1, M2, M3, M4) comprises at least one geometrical feature (R1, R2, a1, a2, L) and two position features (D1, D2) corresponding respectively to a geometrical feature ($R1^w$, $R2^w$, $a1^w$, $a2^w$, L^w) and to the 3D coordinates ($D1^w$, $D2^w$) of the corresponding abrasive wheel, in the X-Y-Z coordinate system of the grinding machine, that has ground the corresponding mark (M1, M2, M3, M4); c) performing measurements of said at least one geometrical feature (R1, R2, a1, a2, L) and said two position features (D1, D2) of said one mark or each mark (M1, M2, M3, M4) of the calibration portion (CP); d) generating a sequence of instructions based on said at least one geometrical feature and on said two position features of said one mark or each mark as measured under step c) to grind said workpiece (10a) to the final and desired shape of the cutting tool (10), and e) controlling the 3D coordinates of said one or more abrasive wheels (W1, W2, W3, W4) in said X-Y-Z coordinate system during grinding operations on the workpiece or on another workpiece according to said sequence of instructions to obtain said cutting tool (10).

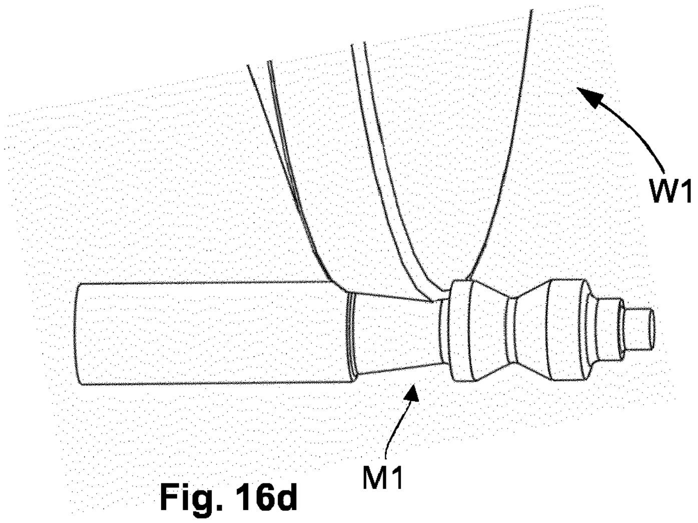

Fig. 16d

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Description

Field of the invention

[0001] The present invention relates to a method for grinding small rotary cutting tools with a very high degree of accuracy. The cutting tools may comprise for example one or more helical flutes with an outer diameter of less than 3mm, with a minimum outer diameter that can be as small as 50 microns or even as small as 30 microns. These cutting tools may be, for example, milling cutters such as end-mill cutters, drills or complex shaped cutting tools. The present invention also relates to a computer-readable storage medium storing instructions to cause a grinding machine to perform a calibration routine and to subsequently grind a cutting tool according to the method disclosed therein.

Description of related art

[0002] The trends in the ultra-high accuracy and micro-miniature manufacturing fields require a fresh look at new machine technology and process techniques.

[0003] For the production of cutting tools, the work carried out in a conventional manner essentially involves the steps of: i) setting the parameters of a cutting tool to be manufactured in an ad-hoc programming and simulation software for generating the profile of the cutting tool to be ground ; ii) selecting and preparing by the operator abrasive wheels of different types that are necessary to perform the different grinding operations to machine the cutting tool to its final and desired shape; iii) measuring the shape of the selected abrasive wheels on a pre-setting optical measurement system; iv) performing machine set-up specific to the cutting tool to be manufactured, and v) performing iterative adjustments of the geometry of the cutting tool by successive grinding of several cylindrical workpieces.

[0004] The smaller the dimensions of the cutting tool to be produced, the greater the number of iterations to obtain the final geometry. Geometry deviations between the virtual tool programmed by the software and the first tool produced are due to different factors, in particular the intrinsic accuracy of the pre-setting optical measurement system for measuring the shape of the abrasive wheels, the intrinsic accuracy of the grinding machine, especially its calibration, the quality of the set-up by the operator, the type of the grinding process, and the intrinsic geometry of the cutting tool.

[0005] The most common way to correct dimensional deviation from the desired shape is to measure the cutting tool after completion and to correct the incorrect values. This has the inconvenient not only to be time consuming as it requires multiple operations, but also to necessitate the use of several blanks of bars or cylindrical workpieces to produce a single cutting tool thereby causing excessive waste of material.

[0006] The major challenge is to know with the highest precision possible the exact shape, dimensions and position of each abrasive wheel in the grinding environment, which is defined by the X-Y-Z coordinate system of the grinding machine.

[0007] Today, calibration measuring devices, external to the grinding machine, such as a pre-setting device or CNC machine with optical measurement are used to measure key geometrical features and the 3D coordinates of the abrasive wheels to calibrate their position and shape inside the grinding machine. These external measuring devices have an accuracy of the order of 10 microns.

[0008] Although, an accuracy of the order of 10 microns is generally high enough for grinding cutting tools with outer diameters exceeding 3mm, such accuracy is not sufficient to avoid fine-tuning the final geometry of the cutting tool by successive trials in order to obtain a cutting tool with outer diameters typically below 3mm, for example as small as 50 microns or even as small as 30 microns. These inaccuracies lead to a considerable loss of time and to the scrapping of a large quantity of blanks of bars or cylindrical workpieces for the production of cutting tools.

[0009] WO2019/197931 discloses a method for machining a workpiece comprising a desired helical groove. The method comprises a step of grinding a calibration groove on the surface of the workpiece according to a predetermined helix pattern of the desired helical groove and by means of an abrasive wheel of a grinding machine. The calibration groove has a calibration length that is equal or smaller than the predetermined length of the desired helical groove and has a calibration depth that is smaller than the predetermined depth of the desired helical groove. The method comprises steps of determining an abrasive wheel dimension of the abrasive wheel and its position by measuring the calibration depth and using the determined wheel dimension and position for grinding the desired helical groove by means of the abrasive wheel.

[0010] This method advantageously reduces the time required for calibrating the machine as the calibration procedure is in an integral part of the machining of the workpiece and with no waste of raw material.

[0011] However, machining a calibration groove requires that the workpiece of desired shape has a certain diameter. This solution is therefore not adapted for calibrating a grinding machine for grinding small rotary cutting tools, in particular rotary cutting tools with an outer diameter of less than 3mm down to 50 microns or even down to 30 microns.

Brief summary of the invention

[0012] Ain aim of the present invention is therefore to provide a method for grinding rotary cutting tools, such as milling cutters, drills or complex shaped tools, with an outer diameter of less than 3mm, and which can be as small as 50 microns or even as small as 30-35 microns.

[0013] Another aim of the present invention is to provide a method for grinding small rotary cutting tools which is easy to implement.

[0014] A further aim of the present invention is to provide a method for grinding small rotary cutting tools which streamlines the manufacturing process for large batches of cutting tools.

[0015] An additional aim of the present invention is to provide a computer-readable storage medium storing instructions for performing by a grinding machine the method disclosed therein.

[0016] According to the invention, these aims are achieved notably by means of a method for machining small rotary cutting tools by a grinding machine, comprising: a) mounting a workpiece in a spindle of the grinding machine; b) machining a calibration portion of the workpiece by performing one or a plurality of marks on said workpiece with one abrasive wheel or with a corresponding plurality of abrasive wheels of different shapes, wherein said one mark or each mark comprises at least one geometrical feature and two position features corresponding respectively to a geometrical feature and to the 3D coordinates of the corresponding abrasive wheel, in the X-Y-Z coordinate system of the grinding machine, that has ground the corresponding mark; c) performing measurements of said at least one geometrical feature and said two position features of said one mark or each mark of the calibration portion; d) generating a sequence of instructions based on said at least one geometrical feature and on said two position features of said one mark or each mark as measured under step c) to grind said workpiece to the final and desired shape of the cutting tool, and e) controlling the 3D coordinates of said one or more abrasive wheels in said X-Y-Z coordinate system during grinding operations on the workpiece or on another workpiece according to said sequence of instructions to obtain said cutting tool.

[0017] In an embodiment, the measurements of one or more geometrical features and of the two position features of said one mark or each mark are performed automatically by a laser imaging system embedded in the grinding machine as soon as the grinding of the calibration portion is completed. These measurements may be obtained for example by performing a laser scan along the calibration portion of the workpiece.

[0018] In an embodiment, each of said plurality of marks is ground with one abrasive wheel of a corresponding plurality of abrasive wheels of different shapes that are necessary to grind said workpiece to the final and desired shape of the cutting tool.

[0019] In an embodiment, the method further comprises a step of performing a direct measurement of one or more geometrical features of said one abrasive wheel or each of said plurality of abrasive wheels by means of a pre-setting device before machining said one mark or each mark of the calibration portion under step b).

[0020] In an embodiment, the method further comprises the step of performing a measurement of the position of the workpiece, along one axis of the X-Y-Z coordinate system of the grinding machine. The 3D coordinates of said one abrasive wheel or each of said plurality of abrasive wheels, in the X-Y-Z coordinate system of the grinding machine, are determined based on said measured position of the workpiece along said axis and said two position features of said one mark or each corresponding mark of the calibration portion performed under step b).

[0021] In an embodiment, said plurality of marks of the calibration portion are performed on the workpiece next to each other along the longitudinal axis of said workpiece or along a transverse axis extending from one end to an opposite end of the calibration portion.

[0022] In an embodiment, the measurements of said at least one geometrical feature and of said two position features of each mark performed under step c) are saved for each abrasive wheel of said plurality of abrasive wheels. These measurements are retrieved for performing at least two successive grinding operations on a workpiece to obtain said rotary cutting tool.

[0023] In an embodiment, the first position feature of said one mark or each mark of the calibration portion defines a first position along a first axis of the three coordinate axes of the X-Y-Z coordinate system of the grinding machine. The first axis coincides with the longitudinal axis of the workpiece.

[0024] In an embodiment, the second position feature of said one mark or each mark of the calibration portion is used to determine the diameter of the corresponding abrasive wheel used for performing said one mark or each mark. A second and a third position along respectively a second and a third axis of said coordinate system are determined based on said diameter to compute the 3D coordinates of said corresponding abrasive wheel.

[0025] In an embodiment, said one mark or each mark of the calibration portion comprises at least one radius to determine at least one radius of the corresponding abrasive wheel.

[0026] In an embodiment, said calibration portion is machined at a distal end portion of the workpiece.

[0027] In an embodiment, the said rotary cutting tool is made from the workpiece which has been previously machined to obtain said calibration portion.

[0028] In an embodiment, the cutting tool comprises a helical flute. The helical flute is machined by controlling the 3D coordinates position of a fluting wheel based in part on at least a first and a second distinct geometrical feature of the fluting wheel.

[0029] In an embodiment, the control of the 3D coordinates position of the fluting wheel for machining the helical flute is further based on one or more of three additional distinct geometrical features of the fluting wheel.

[0030] In an embodiment, the cutting tool is an end-mill cutter comprising end relief faces which are machined by controlling the 3D coordinates of an end-relief wheel based in part on a geometrical feature of the end-relief wheel.

[0031] In an embodiment, the end-mill cutter comprises end gashes which are machined by controlling the 3D coordinates position of a gashing wheel based in part on two distinct geometrical features of the gashing wheel.

[0032] In an embodiment, the end-mill cutter comprises outer diameter relieve lands which are machined by controlling the 3D coordinates position of an outer diameter relief wheel based in part on three distinct geometrical features of the OD relief wheel.

[0033] In an embodiment, the cutting tool comprises a helical flute and wherein the 3D coordinates position of each abrasive wheel of the plurality of abrasive wheels are successively controlled to perform successive grinding operations on the workpiece to the desired shape of the cutting tool with an outer diameter of less than 3mm.

[0034] Another aspect of the invention relates to a computer-readable storage medium storing instructions that when executed by a computer of a grinding machine cause the machine to perform a calibration routine and to grind a cutting tool. The calibration routine comprises: a) retrieving a first set of measurement values of geometrical features and position features of the specific shape of one or of each abrasive wheel of a set of abrasive wheels of different shapes, wherein the first set of measurement values is obtained by a pre-setting device; b) computing a first sequence of instructions based on the first set of measurement values for grinding one or more marks on a workpiece, and c) retrieving and storing a second set of measurement values of at least one geometrical feature and position features of one or more marks performed on the workpiece by said one or each corresponding abrasive wheel of said set of abrasive wheels. The cutting tool is obtained by d) computing a second sequence of instructions based on a virtual cutting tool of a desired shape generated by software and on the second set of measurements values, and e) grinding the cutting tool by executing the second sequence of instructions.

[0035] In an embodiment, during the calibration routine, the first set of measurements values is retrieved under step a) for each of at least two abrasive wheels, preferably for each of at least three abrasive wheels of the set of abrasive wheels of different shapes. The sequence of instructions under step b) is computed for grinding at least two marks, preferably at least three marks next to each other along a distal portion of the workpiece.

Brief Description of the Drawings

[0036] The invention will be better understood with the aid of the description of embodiments given by way of examples and illustrated by the figures, in which:

- Figure 1 shows a perspective view of a cutting tool in the form of an end-mill cutter;
- Figure 2 shows an enlarged perspective view of the end-mill cutter of Figure 1;
- Figure 3 shows a front view of the end-mill cutter of Figure 2;
- Figure 4 shows a side view of a cylindrical workpiece mounted into a spindle of a grinding machine used to machine the end-mill cutter of Figure 1;
- Figure 5 shows a side view of a workpiece in the form of a step bar comprising a pre-machined cylindrical portion,
- Fig. 5a is an enlarged view of the pre-machined portion of Figure 5,
- Figure 6 shows the workpiece of Figure 5 after grinding a calibration portion at a distal end portion of the workpiece,
- Figure 7 shows an enlarged view of the calibration portion of Figure 6 comprising distinct marks performed by respective abrasive wheels of a set of abrasive wheels of different types,
- Figure 8 shows an enlarged view of one the marks of Figure 7 performed with an abrasive wheel of a first type,
- Figure 9 shows a side view of the abrasive wheel of said first type,
- Figure 10 shows an enlarged view of another mark of Figure 7 performed with an abrasive wheel of a second type,
- Figure 11 shows a side view of the abrasive wheel of said second type,
- Figure 11a shows a partial side view of an abrasive wheel designed to perform the same type of grinding operation as the abrasive wheel of Figure 11,
- Figure 12 shows an enlarged view of another mark of Figure 7 performed with an abrasive wheel of a third type,
- Figure 13 shows a side view of the abrasive wheel of said third type,
- Figure 14 shows an enlarged view of another mark of Figure 7 performed with an abrasive wheel of a fourth type,
- Figure 15 shows a side view of the abrasive wheel of said fourth type,
- Figures 16a to 16d shows schematically a sequence of operations performed by the abrasive wheels of the first, second, third and fourth type to obtain the

calibration portion of Figure 7, and

- Figure 17 shows a pre-calibration measurement of an abrasive wheel by means of a pre-setting device.

Detailed Description of possible embodiments of the Invention

[0037] There is a need for reliable and cost-effective manufacturing of small rotary cutting tools, generally with an outer diameter of less than 3mm, in particular milling cutters, such as the end-mill cutter shown in Figures 1 to 3, drills or complex shaped tools. To machine cutting tools with such small diameters, conventional calibration methods as those described above are not suitable as they do not allow to determine the shape of the abrasive wheels with a very high precision level.

[0038] The method disclosed therein is suitable to calibrate a CNC grinding machine to grind rotary cutting tools with an outer diameter as small as 50 microns or even as small as 30-35 microns.

[0039] With reference to Figures 4 to 7, an elongated workpiece, for example a cylindrical workpiece 10a, is mounted in a spindle 20 of a grinding machine. The workpiece is first pre-machined in the form of a step bar, as shown in Figure 5, with a distal cylindrical portion 10c of a diameter exceeding the outer diameter of the cutting tool to be ground by a value typically between 5 and 20 microns. For example, the diameter of the cylindrical distal portion 10c is between 0.205 and 0.22 mm for a cutting tool with an outer diameter of 0.2mm.

[0040] A calibration portion CP is then ground at a distal end portion 10b (Figure 4) as shown in particular in Figures 6 and 7. Not only does this calibration portion CP allows to determine specific geometrical features for a set of abrasive wheels W1, W2, W3, W4 of different shapes but also permits to determine the 3D coordinates of each abrasive wheel in the cartesian coordinate system of the grinding machine, and this with a very high degree of accuracy for both the geometrical features of the abrasive wheel and its 3D ordinates. This high degree of accuracy may advantageously have a precision of less than 3-4 microns, and preferably in the order of one micron. The step bar can be machined directly on the grinding machine used to grind the calibration portion CP for the calibration of the grinding machine or by another machine.

[0041] With reference to Figure 7, the calibration portion CP comprises different distinctive marks M1, M2, M3, M4 machined next to each other. These distinctive marks can be ground along the longitudinal axis Z of the cylindrical workpiece 10a or along a transverse axis A^T extending from one side to an opposite side of the pre-machined portion 10c as shown in Figure 5a. The number of marks and their respective specific geometrical and position features depend on the desired and final shape of the cutting tool 10. For some cutting tools of simple shapes, a unique type of abrasive wheel may be sufficient for machining the cutting tool to the desired shape. In that case, performing only one mark on the calibration portion may be sufficient for certain shapes of the cutting tool but in most cases different distinctive marks M1, M2, M3, M4 are needed to determine deferent geometrical features of the abrasive wheel in order to grind the cutting tool to its final shape.

[0042] For most applications, however a set of abrasive wheels of different types as illustrated in Figures 9, 11, 13, 15 are required to grind the cutting tool to the desired shape. In the illustrated embodiments, the end-mill cutter of Figures 1 to 3 has been ground using four abrasive wheels of different shapes, namely the fluting wheel W1 of Figure 9, the outer diameter relief wheel W2 of Figure 10, referred hereafter as OD relief wheel, the gashing wheel W3 of Figure 13 and the end relief wheel W4 of Figure 15.

[0043] Within the context of the present invention, the term "fluting wheel" shall be understood as any abrasive wheel whose specific shape is adapted to grind helical flutes of the end-mill cutter 10 as shown in Figure 2. A cutting wheel W1, as illustrated in Figure 9, is an example of an abrasive wheel adapted to grind helical flutes. Similarly, the term "OD relief wheel" shall be understood as any abrasive wheel whose specific shape is adapted to grind the outer diameter relieve lands 18 of the end-mill cutter 10 of Figure 2. A grinding wheel W2, as shown in Figure 11, is an example of an abrasive wheel adapted to grind outer diameter relieve lands. Similarly, the term "gashing wheel" shall be understood as any abrasive wheel whose specific shape is adapted to grind end gashes 16 of the end-mill cutter 10 of Figure 2. An example of the shape of a gashing wheel W3 is shown in Figure 13. Similarly, the term "end relief wheel" shall be understood as any abrasive wheel whose specific shape is adapted to grind end relief faces 14 of an end-mill cutter 10 as shown in Figure 3. A cup wheel W4, as shown in Figure 15, is an example of an abrasive wheel adapted to grind end relief faces of the end-mill cutter 10 of Figure 3.

[0044] In addition, the term "grinding operation" shall be understood as one type of grinding operation among several types of operations that are needed to grind the cutting-tool to its final and desired shape. A grinding operation may include for example flute grinding, gash grinding, end-relief grinding, OD grinding etc.

[0045] Successive grinding operations with several abrasive wheels, for example with four different abrasive wheels W1, W2, W3, W4, must be performed to grind an end-mill cutter 10, according to an embodiment, with an outer diameter of less than 3mm. In that case, the distal end portion 10b of the cylindrical workpiece or blunt is machined to perform four distinct marks M1, M2, M3, M4 with respective abrasives wheels W1, W2, W3, W4 to obtain the calibration portion CP. The general shape of calibration portion CP as illustrated in Figure 7 is just an example among different other shapes that can characterize the geometrical and position features of one or more abrasive wheels of a particular shape.

[0046] Prior to performing successive grinding operations on the workpiece 10a for grinding the calibration portion CP whose geometry may depend on the final and desired shape of the cutting tool to be ground, geometrical and position features of each abrasive wheel of the set of abrasive wheels W1, W2, W3, W4 necessary to grind the cutting tool are measured by a pre-setting measuring device. To that end, each abrasive wheel is mounted for example onto a stand whose dimensions correspond to those of the spindle of the grinding machine onto which the abrasive wheel is intended to be mounted. The abrasive wheel is thus positioned in the exact same position relative to the stand and relative to the spindle when mounted thereon for grinding the cutting tool. The 3D coordinates $D1^w$, $D2^w$ of the abrasive wheel in the coordinate system of the grinding machine can thus be measured.

[0047] Pre-calibration measurements of each abrasive wheel, shown in Figure 17, consist typically of a measurement of a profile of a continuous portion of the abrasive wheel. Values of key geometrical features of the abrasive wheel, such as R1, R2, a1, a2 and values of position features Z and ØD of the abrasive wheel, are retrieved from this profile with an accuracy of approximately 10 microns. These values are used to estimate the key geometrical features and the 3D coordinates of the abrasive wheel in the grinding machine in order to be able to grind the different marks M1, M2, M3, M4 of the calibration portion CP.

[0048] This calibration portion CP is obtained in this example by performing successive grinding operations on the distal end portion 10b of the cylindrical workpiece 10a as shown in Figures 16a to 16d. A first mark M3 is ground with the gashing wheel W3, a second mark M4 is then ground with the end relief wheel W4, the third mark M2 is then ground with the OD relief wheel W2 and finally the fourth mark M1 is ground with the fluting wheel W1.

[0049] Each of these marks M1, M2, M3, M4 has therefore geometrical features R1, R2, a1, a2, L and position features D1, D2 which are specific to the abrasive wheel that ground it. Geometrical features of this specific abrasive wheel can be determined with a very high degree of accuracy by measuring the geometrical features of the mark. In addition, additional geometrical features of each of these marks, referred therein as position features, can be used to determine the 3D coordinates $D1^w$, $D2^w$ of the abrasive wheel in the X-Y-Z coordinates system of the grinding machine.

[0050] Various methods may be used to measure the geometrical and position features of the different marks M1, M2, M3, M4 of the calibration portion CP. In an advantageous embodiment, one or more geometrical features and two position features of each mark M1, M2, M3, M4 are measured with a laser imaging system embedded in the grinding machine. The laser imaging system is already used to measure at regular intervals diameter and external shape of the cutting tool to carry out any necessary corrections automatically during grinding to ensure unattended automatic cycle production of cutting tools. This laser imaging system, with an accuracy below 3-4 microns and preferably in the order of one micron, can thus perform in-situ a laser scan along the longitudinal axis of the calibration portion CP thereby avoiding the need to disassemble the workpiece 10a from the spindle 20 in order to perform the measurement. This streamlines the manufacturing process as the cutting tool 10 can be ground to its final and desired shape just after preforming a laser scan. This is particularly important when large batches of cutting tools are to be produced, wherein the cutting tool once ground to its final shape is automatically replaced by a workpiece for the production of cutting tools without any human intervention.

[0051] Alternatively, the measurements of the geometrical and position features of the different marks M1, M2, M3, M4 of the calibration portion CP can be done externally to the grinding machine by means for example of a microscope also with an accuracy below five microns and preferably in the order of one micron.

[0052] The geometrical features of each abrasive wheel W1, W2, W3, W4 and their 3D coordinates in the cartesian system of the grinding machine can thus be determined with a high degree of accuracy from the measurement of these different marks M1, M2, M3, M4. This high-precision calibration is essential for machining small rotary cutting tools with an outer diameter of less than 3mm, especially for cutting tools having an outer diameter of less than 100 microns, for example as small as 50 microns or even as small as 30-35 microns.

[0053] With reference to Figure 8, the mark M1 of the exemplary calibration portion CP of Figure 7 has been ground by the fluting wheel W1 represented in Figure 9. This mark M1 comprises several distinctive geometrical features specific to the fluting wheel, namely the radius R1 and R2, the angles a1, a2, the length *L* which are specific to different geometrical features $R1^w$, $R2^w$, $a1^w$, $a2^w$, L^w of the fluting wheel W1 as shown in Figure 9. The mark comprises two additional position features D1, D2 that can be used to determine the 3D coordinates $D1^w$, $D2^w$ of the fluting wheel W1 in the cartesian (X-Y-Z) coordinate system of the grinding machine.

[0054] More particularly, the first position feature D1 is used to determine the z-coordinate $D1^w$ of the abrasive wheel W1, i.e. its position along the first axis Z of the horizontal plane of the cartesian coordinate system, while the second position features D2 is used to determine the x-coordinate $D2^w$ of the abrasive wheel W1, i.e. its position along the second axis X of the horizontal plane since $D2^w$ corresponds to the diameter of the fluting wheel W1. The second position feature D2 is also used to determine y-coordinate of the abrasive wheel W1, i.e. the its position along the third axis Y (vertical axis) of the cartesian coordinate system as the diameter of the wheel W1 also corresponds to the third axis.

[0055] A measurement of the position of the cylindrical workpiece 10a when mounted in the spindle 20 of the grinding machine must however be done to have a referential for determining the exact position of the workpiece 10a along the first axis Z. This measurement can be done for example with the embedded laser imaging system which senses the distal end of the cylindrical workpiece 10a. By knowing the exact position of the workpiece 10a along the first axis Z and the first and second position features D1, D2, the exact 3D coordinates $D1^w$, $D2^w$ of the abrasive wheel W1 can be determined.

[0056] A sequence of instructions is then computed by a CNC grinding machine using known mathematical models of abrasive wheel movements which are corrected to take into account the offset between the preset values used by the mathematical models and those measured on the calibration portion CP. These corrections are performed for one or more geometrical feature and the two position features of each abrasive wheel of a set of abrasive wheels W1, W2, W3, W4 of different types/shapes required to perform the different grinding operation to obtain the cutting tool. The sequence of instructions may be for example pre-programed by means of a software based on a given numerical model of a cutting tool of a desired shape.

[0057] The 3D coordinates of the different abrasive wheels are afterward controlled by the sequence of instructions for performing successive and preferably different grinding operations on a workpiece to machine the cutting tool to is desired shape.

[0058] In the illustrated embodiment, the fluting wheel W1 is used to grind the flutes 12 of the end-mill cutter 10 illustrated in Figure 2. For diameters of such small dimensions, the 3D coordinates of the fluting wheel W1 in the X-Z-Y reference frame of the grinding machine must be as accurate as possible. This accuracy is critical to the success of the machine set-up and avoids several grinding iterations until a tool is obtained within the specifications and tolerance.

[0059] The 3D coordinates are calculated based on geometrical features comprising at least the radius R1 and the angle a1 of the fluting wheel W1 as measured directly on the mark M1 of the calibration portion CP of the workpiece. For particular profile types of helixes, in conjunction with the geometrical features R1 and a1, one or more of the following geometrical features of the fluting wheel are also used: the width L, the chamfer a2 and the transition radius R2.

[0060] The 3D coordinates of the fluting wheel W1, which have been previously measured by a pre-setting device as described above, are adjusted based on the measurements of position features D1, D2 of the mark M1 which precisely calibrate the position $D1^w$, $D2^w$ of the fluting wheel W1 in the cartesian system of the grinding machine. Movements of the fluting wheel W1 for a flute grinding operation are computed, using known mathematical models and according to the above geometrical features and the calibrated 3D coordinates of the fluting wheel W1 in the cartesian system of the grinding machine.

[0061] With reference to Figure 10, the mark M2 of the exemplary calibration portion CP of Figure 7 has been ground by the OD relief wheel W2 represented in Figure 11. This mark M2 comprises several distinctive geometrical features specific to this wheel, namely the radius R1 and the angles a1, a2 which are specific to different geometrical features $R1^w$, $a1^w$, $a2^w$ of the OD relief wheel W1 as shown in Figure 11. As for the mark M1 of the calibration portion, the mark M2 comprises two additional positions features D1, D2 that can be used to determine the 3D coordinates $D1^w$, $D2^w$ of the OD relief wheel W2 in the in the cartesian coordinate system of the grinding machine as explained above with respect to the fluting wheel.

[0062] Movements of the OD relief wheel W2 for an OD grinding operation are computed, using known mathematical models and according to the above geometrical features $R1^w$, $a1^w$, $a2^w$ and the calibrated 3D coordinates $D1^w$, $D2^w$ of the OD relief wheel W2 in the cartesian system of the grinding machine. The OD grinding operation consists in grinding the outer diameter relieve lands 18 of the end-mill cutter 10 illustrated in Figure 2.

[0063] Referring to Figure 12, the mark M3 of the exemplary calibration portion CP of Figure 7 has been ground by the gashing wheel W3 represented in Figure 12. This mark M3 comprises at least two distinctive geometrical features specific to this wheel, namely the radius R1 and the angle a1 which are specific to corresponding geometrical features $R1^w$, $a1^w$ of the gashing wheel W3 as shown in Figure 13. As for the mark M1 and M2 of the calibration portion, the mark M3 comprises two additional position features D1, D2 that can be used to determine the 3D coordinates $D1^w$, $D2^w$ of the gashing wheel W3 in the in the cartesian coordinate system of the grinding machine as explained above with respect to the fluting wheel.

[0064] Movements of the gashing wheel W3 for a gash grinding operation are computed, using known mathematical models and according the two above geometrical features $R1^w$, $a1^w$ as well as the 3D coordinates $D1^w$, $D2^w$ of the gashing wheel W3. The gash grinding operation consists in grinding end gashes 16 of the end-mill cutter 10 as shown in Figure 2.

[0065] Referring to Figure 14, the mark M4 of the exemplary calibration portion CP of Figure 7 has been ground by the end relief wheel W4 represented in Figure 15. This mark M4 comprises one geometrical feature R1 corresponding to the radius $R1^w$ of the gashing wheel W4 as shown in Figure 15. As for the mark M1, M2 and M3 of the calibration portion CP, the mark M4 comprises two additional position features D1, D2 that can be used to determine the 3D coordinates of the end relief wheel as explained above.

[0066] Movements of the end relief wheel W4 for an end-relief grinding operation are computed, using known mathematical models and according to at least the above geometrical features $R1^w$ and the 3D coordinates $D1^w$,

$D2^w$ of the end relief wheel W4. The end-relief grinding consists in grinding end relief faces 14 of the end-mill-cutter 10 illustrated in Figure 3.

[0067] The shape of a specific abrasive wheel assigned to a specific type of grinding operation may vary significantly as the skilled person decides himself what shape to give to an abrasive wheel according to his experience but also according to the wheels at his disposal. For example, the OD relief wheel W2 shown in Figure 11 may have another shape such as the one illustrated in Figure 10a and yet still adapted to achieve the same grinding operation. In this case, the geometrical features $R1^w$ and $a1^w$ in Figure 11 correspond to the geometrical feature $R1^{w'}$ and a1w' in Figure 11a.

[0068] The disclosed method for machining small rotary cutting tools may therefore be used independently of the shape of the abrasive wheel designed for a specific type of grinding operation.

[0069] For cutting tools of simple shape, just one or two abrasive wheels may be sufficient to machine the cylindrical workpiece to its final shape. In case of a cutting tool of simple shape that may require only one abrasive wheel to perform all the grinding operations, the abrasive wheel may, in some cases, still need to perform several marks on the calibration portion of the workpiece during the calibration of the grinding machine in order to determine different distinct geometrical features of the abrasive wheel that are necessary to perform all grinding operations. Yet, a single mark may be sufficient to characterize the geometrical and position features of the abrasive wheel to grind a cutting tool of a particular simple shape.

[0070] The disclosed method has the advantage to calibrate all the abrasive wheels necessary to grind a cutting tool to its final and desired shape by grinding a calibration portion on a workpiece that will eventually be machined by successive grinding operations of different types to obtain the cutting tool, thereby reducing the waste of raw material.

[0071] The grinding machine comprises a software storing instructions that when executed by a processing unit of the grinding machine cause the machine to perform the method as described above for machining small rotary cutting tools 10 with a diameter core of less than 3mm. The method executed by the software calibrates the geometrical features and the 3D coordinates for each abrasive wheel W, W2, W3, W4 with a high degree of accuracy, for example down to a micron.

[0072] In that respect, the software is configured to retrieve a first set of measurement values of key geometrical features and position features ØD, Z along a profile of at least one abrasive wheel obtained by a pre-setting optical device. An example of such profile is shown in Figure 17. Key geometrical features may be for example a first and second radii R1, R2 and a first and second angles a1, a2 of the abrasive wheel. The number of times this operation is performed is defined by the number of abrasive wheels W1, W2, W3, W4 required to grind a cutting tool to its final and desired shape. The first set of measurement values obtained by the pre-setting optical device has typically an accuracy in the order of 10 microns which is not precise enough to grind cutting tool with an outer diameter of less than 3mm.

[0073] A first sequence of basic instructions is then computed based on the first set of measurement values to control the movements of each abrasive wheel W1, W2, W3, W4 to perform distinct marks M1, M2, M3, M4 along the longitudinal axis of a distal portion of the workpiece. The software then retrieves a second set of measurement values of at least one geometrical feature and two position features of each mark M1, M2, M3, M4 performed on the workpiece which is specific to a particular type of abrasive wheel.

[0074] As mentioned previously, the positions and geometrical features of the distinct marks M1, M2, M3, M4 may be measured by a laser imaging system embedded in the grinding machine. The laser imaging device is mounted to perform a laser scan along the longitudinal axis of the distal portion of the workpiece to acquire the second set of measurement values without the need to remove the workpiece from the spindle of the grinding machine.

[0075] The second set of measurements values has typically an accuracy of approximately one micron. This accuracy allows the grinding of cutting tools with dimensional deviation remaining within an acceptable range for tools having an outer diameter of less than 3mm, which can be as small as 50 microns or even 30-35 microns.

[0076] Alternatively, the measurements of the geometrical and position features of the different marks M1, M2, M3, M4 of the calibration portion CP can be done externally to the grinding machine by means for example of a microscope also with an accuracy down to the micron. In this case, the software may retrieve data from these measurements which are sent to computer of the grinding machine. In an alternative embodiment, the software may provide a user-interface comprising fields to input manually the second set of measurement values.

[0077] A sequence of instructions for the movements of one or more abrasive wheels is then computed based on known mathematical models and according to the second set of measurements values for machining the cutting tool.

[0078] In an advantageous embodiment, a set of measurements values corresponding to each abrasive wheel of a set of abrasive wheels of different type can be stored and retrieved for grinding additional cutting tools requiring any of these specific abrasive wheels for grinding a particular portion during the manufacturing of the cutting tool.

[0079] Various modifications and variations to the described embodiments of the invention will be apparent to those skilled in the art without departing from the scope of the invention as defined in the appended claims. For example, the above method may of course be adapted to any other rotary-cutting tool, for example other type of milling cutters, such as slab mill, face mill, straight fluted mill or different types of drills such as multiple fluted drill, straight fluted drill, counter sinking drill, etc..

List of references

[0080]

Cutting tool 10 (e.g. end-mill cutter)
Cylindrical workpiece 10a
Distal end portion 10b
Helical flute 12
End relief faces 14
End gashes 16
Outer diameter relieve lands 18
Spindle 20
Calibration portion CP
Marks M1, M2, M3, M4
Geometrical features of the marks R1, R2, a1, a2, L
Position features of the marks D1, D2
Abrasive wheels W1, W2, W3, W4
Geometrical features of the wheels $R1^w$, $R2^w$, $a1^w$, $a2^w$, L^w
Position features of the wheels $D1^w$, $D2^w$

Claims

1. Method for machining small rotary cutting tools (10) by a grinding machine, comprising:

a) mounting a workpiece (10a) in a spindle (20) of the grinding machine;
b) machining a calibration portion (CP) of the workpiece (10a) by performing one or a plurality of marks (M1, M2, M3, M4) on said workpiece with one abrasive wheel or with a corresponding plurality of abrasive wheels (W1, W2, W3, W4) of different shapes, wherein said one mark or each mark (M1, M2, M3, M4) comprises at least one geometrical feature (R1, R2, a1, a2, L) and two position features (D1, D2) corresponding respectively to a geometrical feature ($R1^w$, $R2^w$, $a1^w$, $a2^w$, L^w) and to the 3D coordinates ($D1^w$, $D2^w$) of the corresponding abrasive wheel, in the X-Y-Z coordinate system of the grinding machine, that has ground the corresponding mark (M1, M2, M3, M4);
c) performing measurements of said at least one geometrical feature (R1, R2, a1, a2, L) and said two position features (D1, D2) of said one mark or each mark (M1, M2, M3, M4) of the calibration portion (CP);
d) generating a sequence of instructions based on said at least one geometrical feature and on said two position features of said one mark or each mark as measured under step c) to grind said workpiece (10a) to the final and desired shape of the cutting tool (10), and
e) controlling the 3D coordinates of said one or more abrasive wheels (W1, W2, W3, W4) in said X-Y-Z coordinate system during grinding operations on the workpiece or on another workpiece according to said sequence of instructions to obtain said cutting tool (10).

2. Method according to claim 1, wherein the measurements of one or more geometrical features (R1, R2, a1, a2, L) and of said two position features (D1, D2) of said one mark or each mark (M1, M2, M3, M4) are performed automatically by a laser imaging system embedded in the grinding machine once step b) completed, for example by performing a laser scan along the calibration portion (CP) of the workpiece (10a).

3. Method according to claim 1 or 2, wherein each of said plurality of marks (M1, M2, M3, M4) is ground with one abrasive wheel of a corresponding plurality of abrasive wheels (W1, W2, W3, W4) of different shapes that are necessary to grind said workpiece (10a) to the final and desired shape of the cutting tool (10).

4. Method according to any preceding claim, further comprising a step of performing a direct measurement of one or more geometrical features of said one abrasive wheel or each of said plurality of abrasive wheels (W1, W2, W3, W4) by means of a pre-setting device before machining said one mark or each mark (M1, M2, M3, M4) of the calibration portion (CP) under step b).

5. Method according to any preceding claim, further comprising the step of performing a measurement of the position of the workpiece, along one axis (Z) of the X-Y-Z coordinate system of the grinding machine, wherein the 3D coordinates ($D1^w$, $D2^w$) of said one abrasive wheel or each of said plurality of abrasive wheels (W1, W2, W3, W4), in the X-Y-Z coordinate system of the grinding machine, are determined based on said measured position of the workpiece along said axis and said two position features (D1, D2) of said one mark or each mark (M1, M2, M3, M4) of the calibration portion performed under step b).

6. Method according to any preceding claim, wherein said plurality of marks (M1, M2, M3, M4) of the calibration portion (CP) are performed on the workpiece (10a) next to each other along the longitudinal axis (Z) of said workpiece or along a transverse axis (A^T) extending from one end to an opposite end of the calibration portion.

7. Method according to any preceding claim, wherein the measurements of said at least one geometrical feature (R1, R2, a1, a2, *L*) and of said two position features (D1, D2) of each mark (M1, M2, M3, M4) performed under step c) are saved for each abrasive wheel of said plurality of abrasive wheels (W1, W2, W3, W4), and wherein said measurements are retrieved for performing at least two successive grinding operations on a workpiece to obtain said rotary cutting tool.

8. Method according to any preceding claim, wherein the first position feature (D1) of said one mark or each mark (M1, M2, M3, M4) of the calibration portion (CP) defines a first position along a first axis (Z) of the three coordinate axes of the X-Y-Z coordinate system of the grinding machine, said first axis coinciding with the longitudinal axis of the workpiece.

9. Method according to the preceding claim, wherein the second position feature of said one mark or each mark (M1, M2, M3, M4) of the calibration portion (CP) is used to determine the diameter (D2) of the corresponding abrasive wheel (W1, W2, W3, W4) used for performing said one mark or each mark, and wherein a second and a third position along respectively a second and a third axis of said coordinate system are determined based on said diameter to compute the 3D coordinates of said corresponding abrasive wheel.

10. Method according to any preceding claim, wherein said one mark or each mark (M1, M2, M3, M4) of the calibration portion comprises at least one radius (R1, R2) to determine at least one radius of the corresponding abrasive wheel (W1, W2, W3, W4).

11. Method according to any preceding claim, wherein said calibration portion (CP) is machined at a distal end portion (10b) of the workpiece.

12. Method according to any preceding claim, wherein the said rotary cutting tool is made from the workpiece (10a) which has been previously machined to obtain said calibration portion (CP).

13. Method according to any preceding claim, wherein the cutting tool (10) comprises a helical flute (12), and wherein the 3D coordinates of each abrasive wheel of said plurality of abrasive wheels (W1, W2, W3, W4) are successively controlled to perform successive grinding operations on said workpiece (10a) to the desired shape of the cutting tool (10), with a core diameter of less than 3mm.

14. Computer-readable storage medium storing instructions that when executed by a computer of a grinding machine cause the machine to perform a calibration routine and to grind a cutting tool comprising:

a) retrieving and storing a first set of measurement values of geometrical features (R1, R2, a1, a2) and position features (Z, ØD) of the specific shape of one or of each abrasive wheel of a set of abrasive wheels (W1, W2, W3, W4) of different shapes, wherein the first set of measurement values is obtained by a pre-setting device,

b) computing a first sequence of instructions based on said first set of measurement values for grinding one or more marks (M1, M2, M3, M4) on a workpiece,

c) retrieving and sorting a second set of measurement values of at least one geometrical feature (R1, R2, a1, a2, L) and position features (D1, D2) of one or more marks (M1, M2, M3, M4) performed on the workpiece (10a) by said one or each corresponding abrasive wheel of said set of abrasive wheels (W1, W2, W3, W4),

d) computing a second sequence of instructions based on said second set of measurements values, and

e) grinding the cutting tool by executing said second sequence of instructions.

15. Computer-readable storage medium according to the preceding claim, wherein the first set of measurements values is retrieved under step a) for each of at least two abrasive wheels, preferably for each of at least three abrasive wheels of a said set of abrasive wheels (W1, W2, W3, W4) of different shapes, and wherein the sequence of instructions under step b) is computed for grinding at least two marks, preferably at least three marks (M1, M2, M3, M4) next to each other along a distal portion of the workpiece.

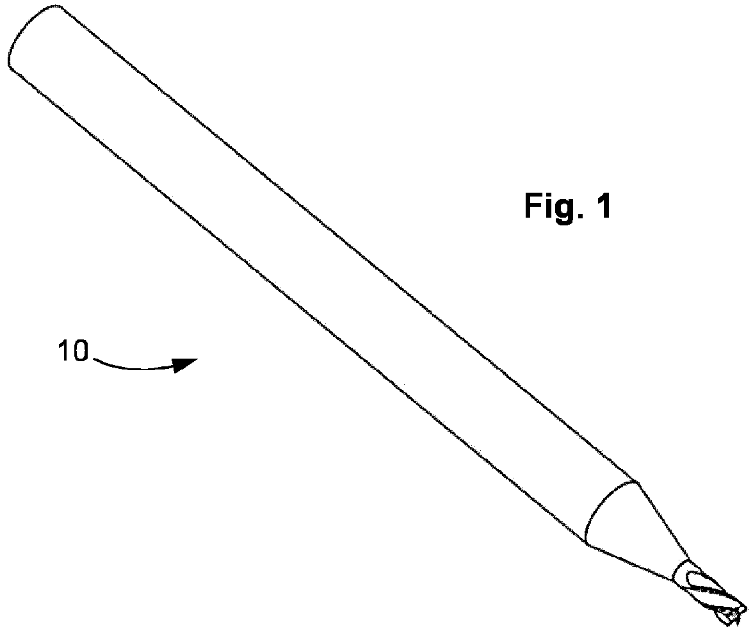


Fig. 1

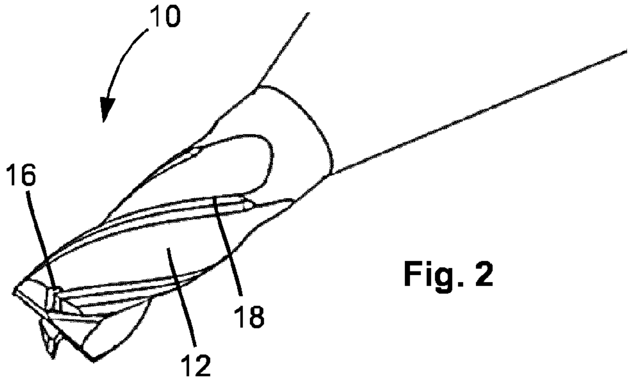


Fig. 2

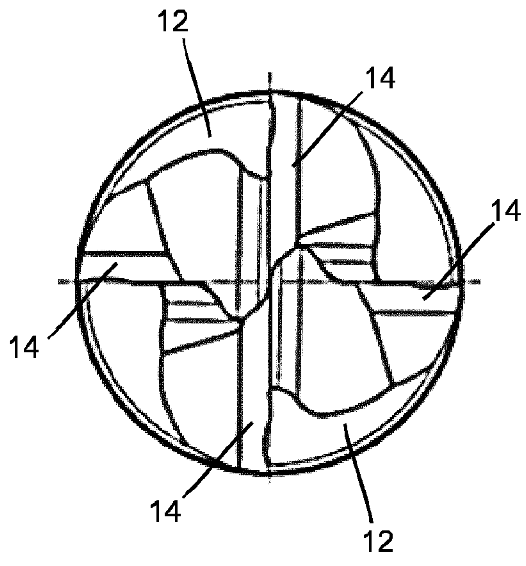


Fig. 3

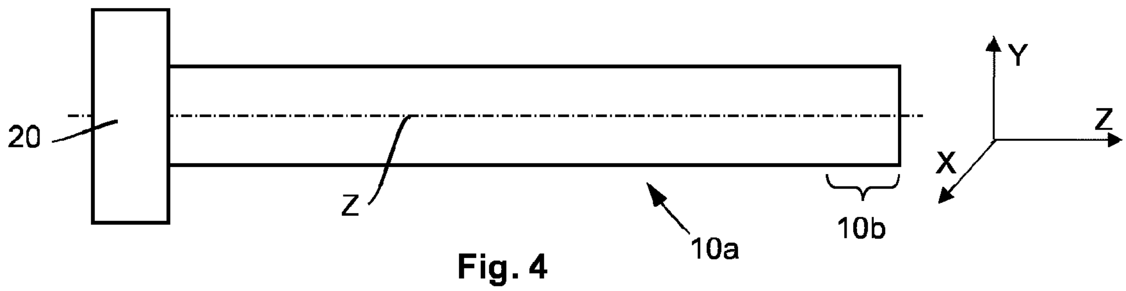


Fig. 4

Fig. 5

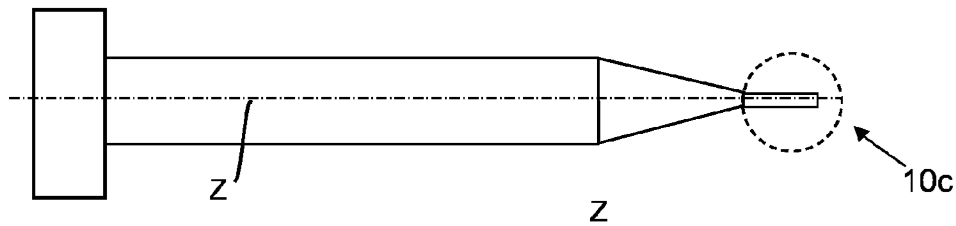


Fig. 5a

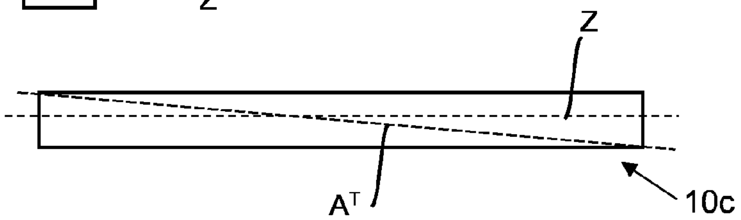
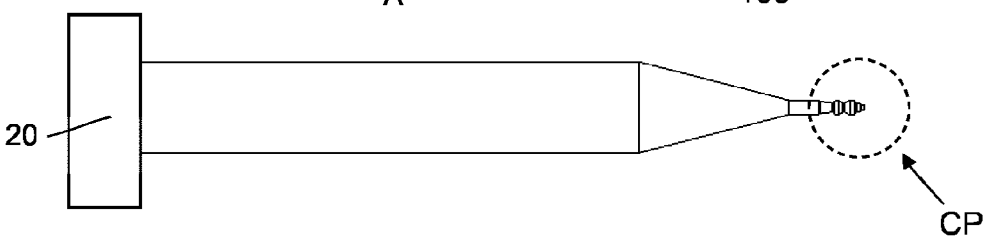


Fig. 6



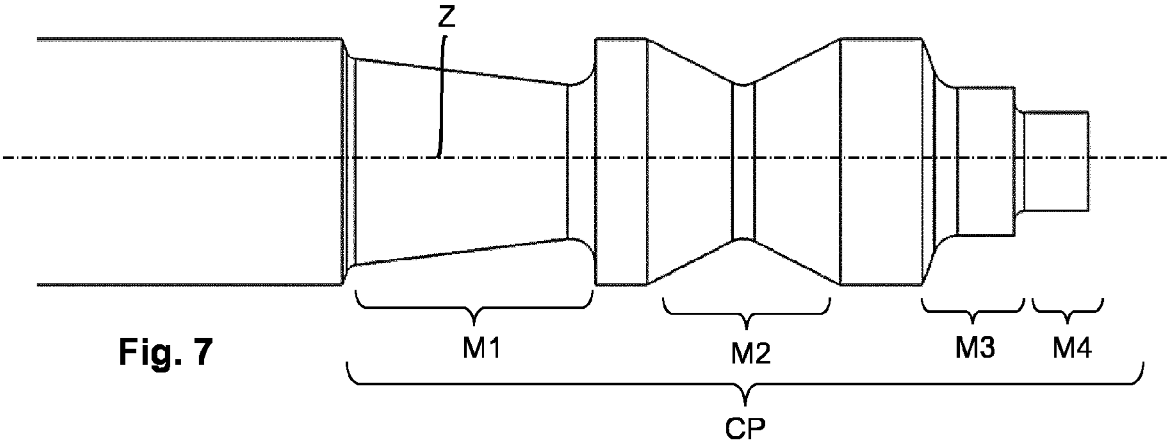


Fig. 7

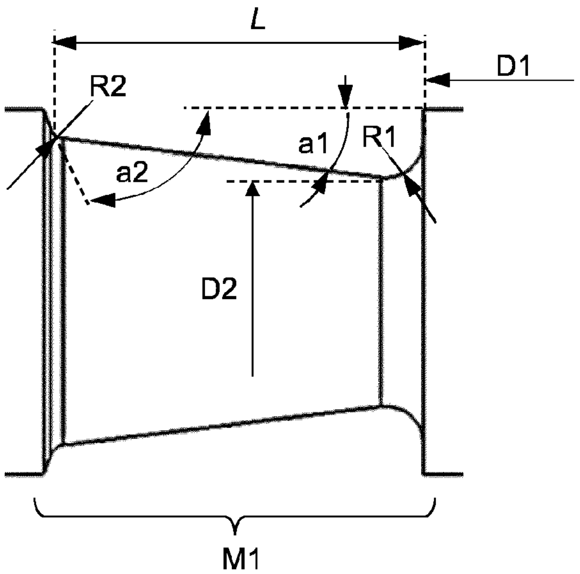


Fig. 8

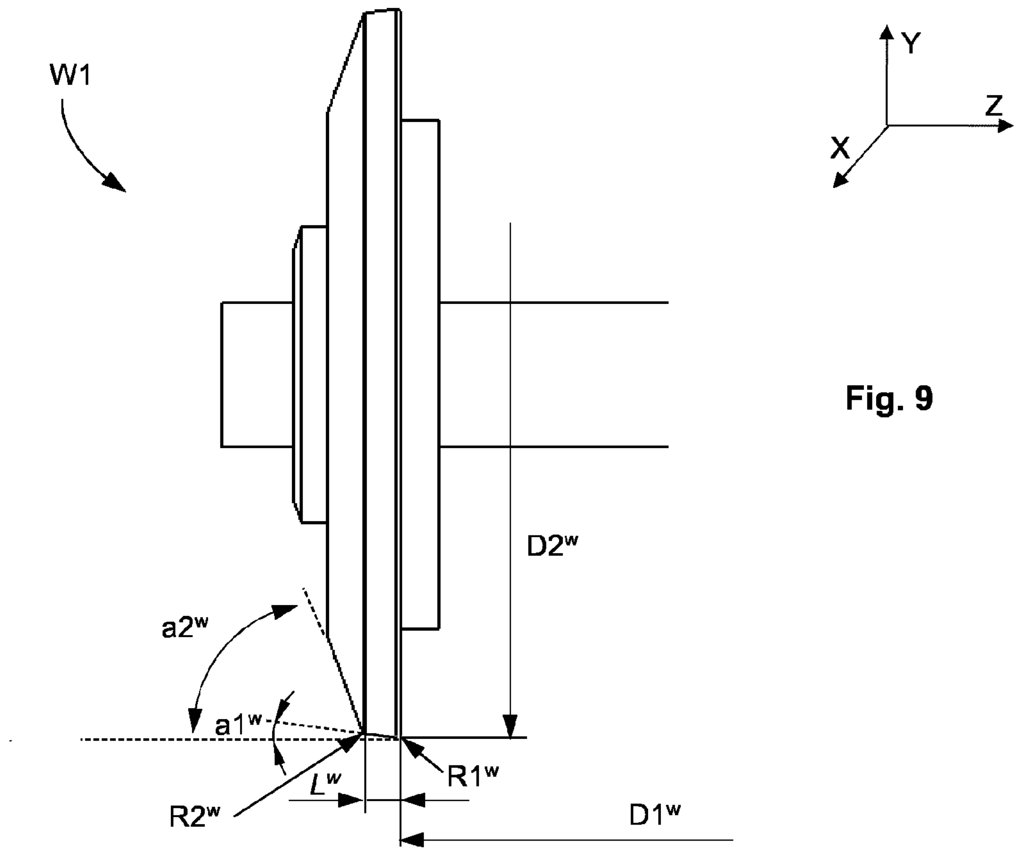


Fig. 9

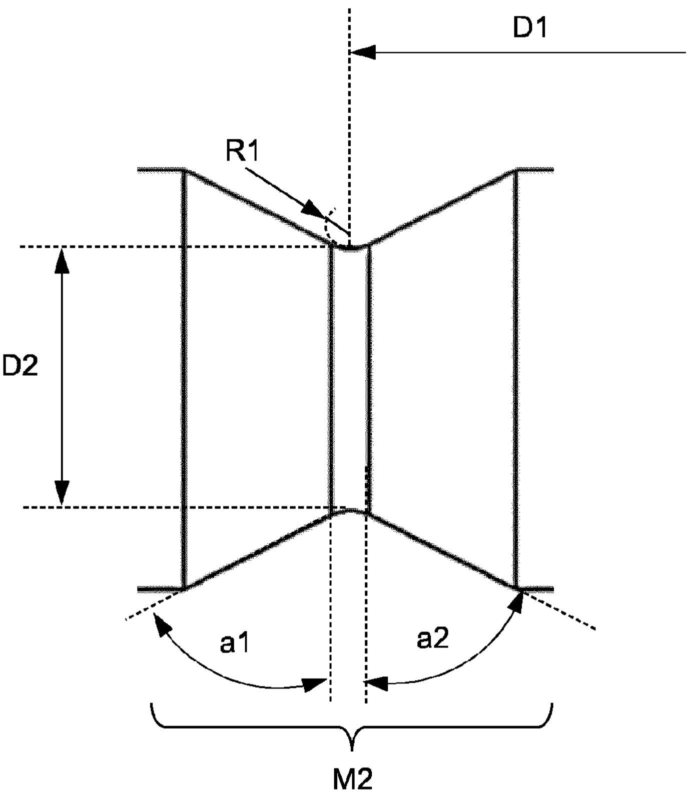


Fig. 10

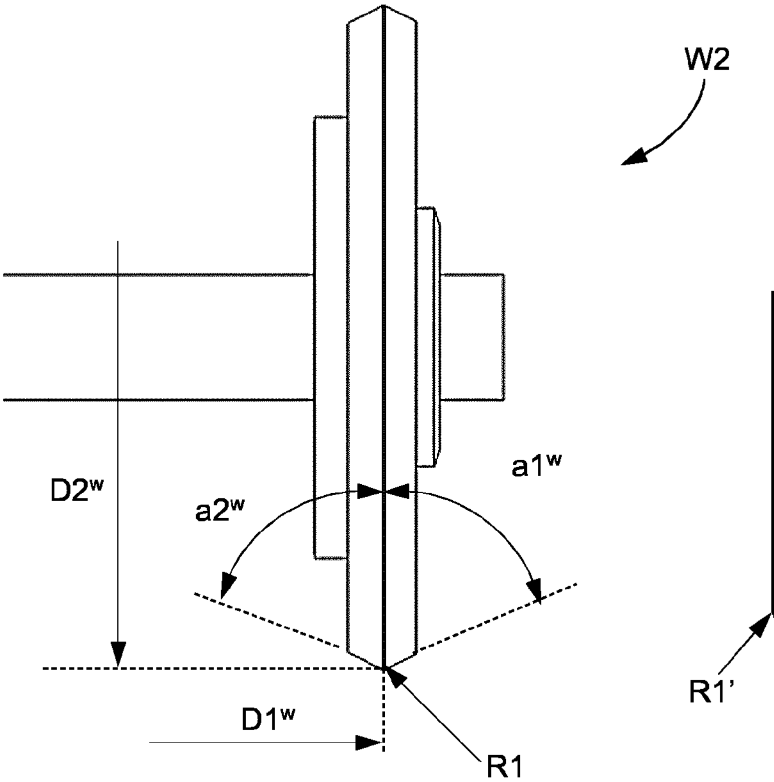


Fig. 11

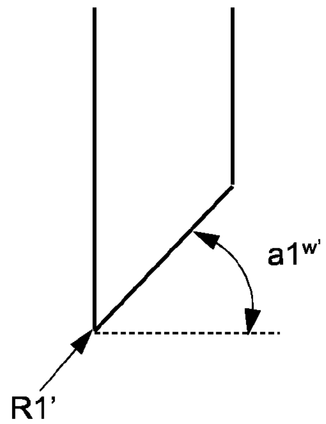


Fig. 11a

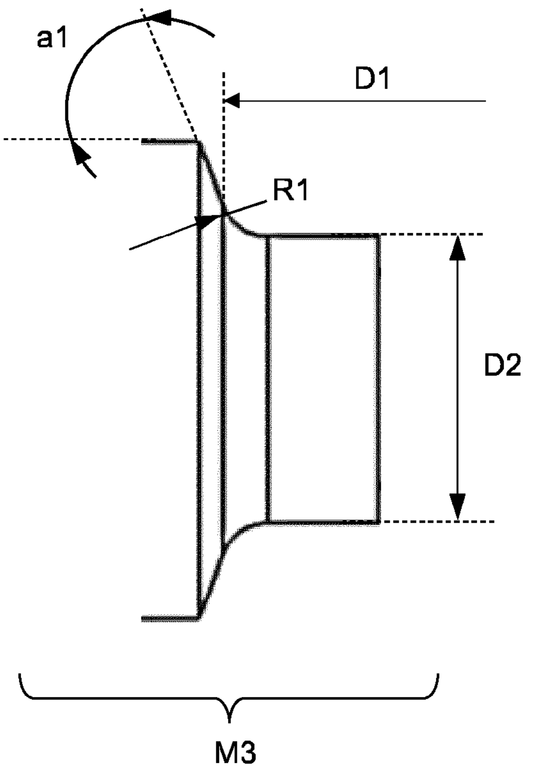


Fig. 12

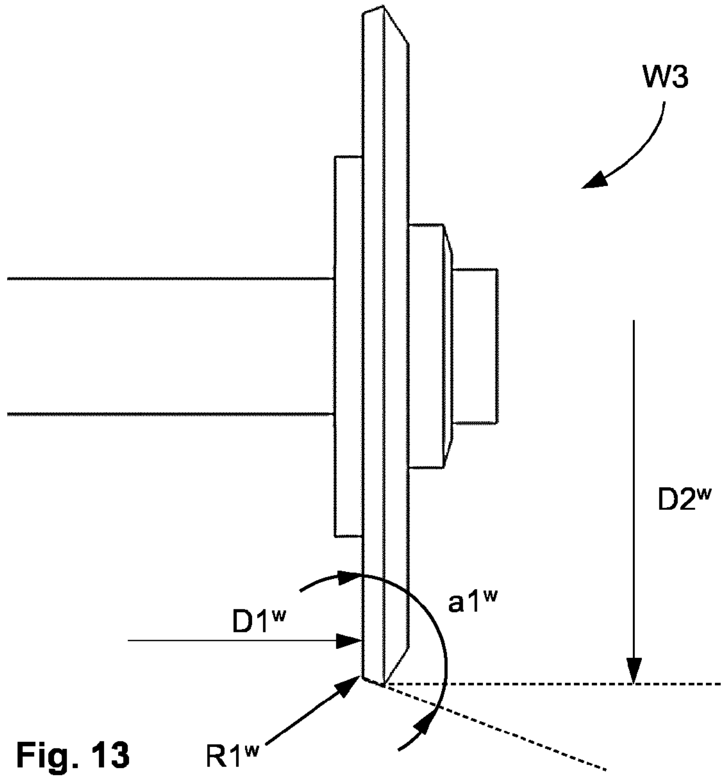


Fig. 13

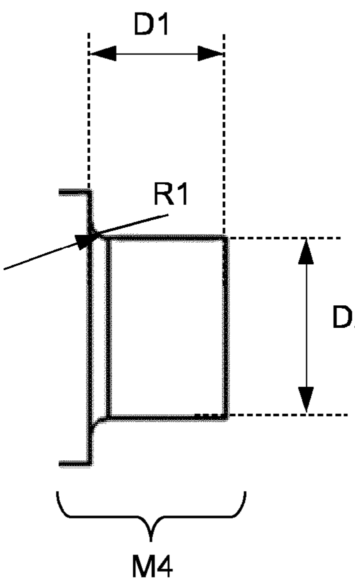


Fig. 14

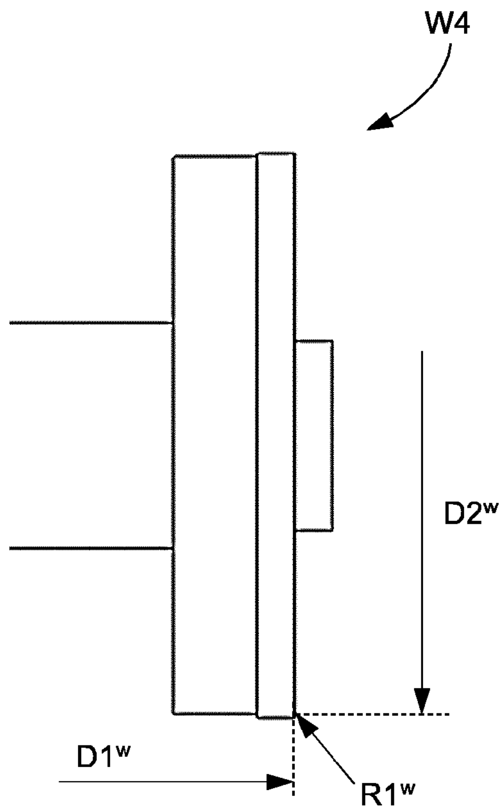


Fig. 15

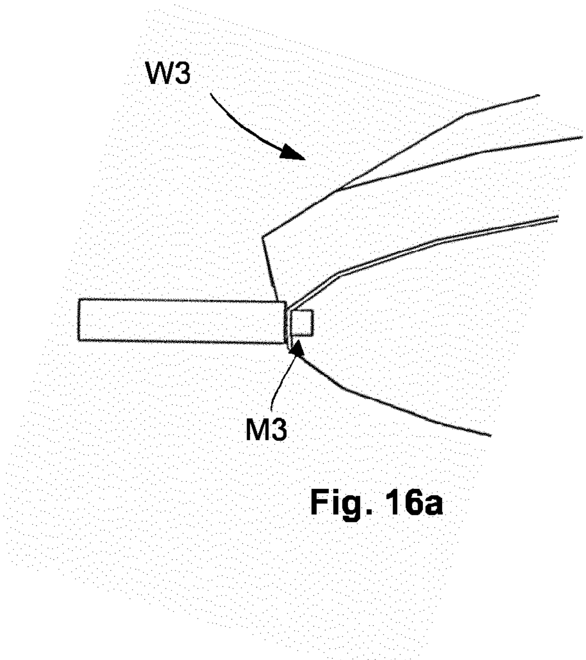


Fig. 16a

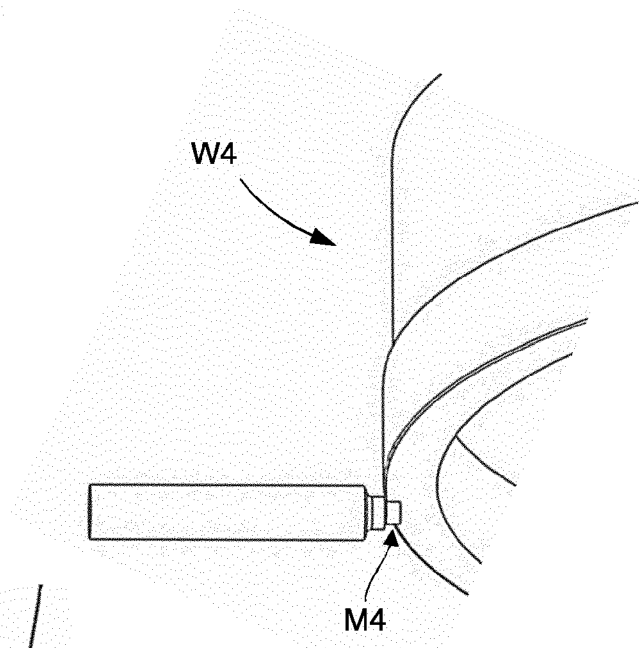


Fig. 16b

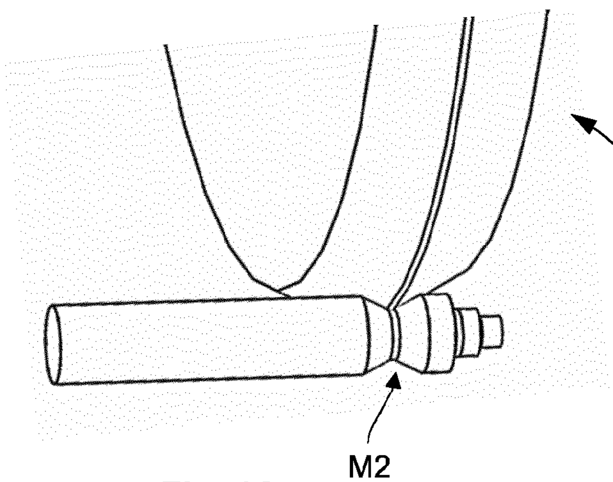


Fig. 16c

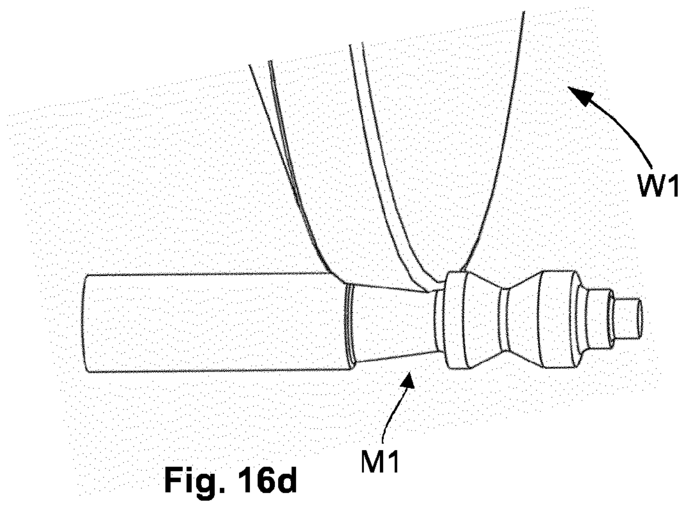


Fig. 16d

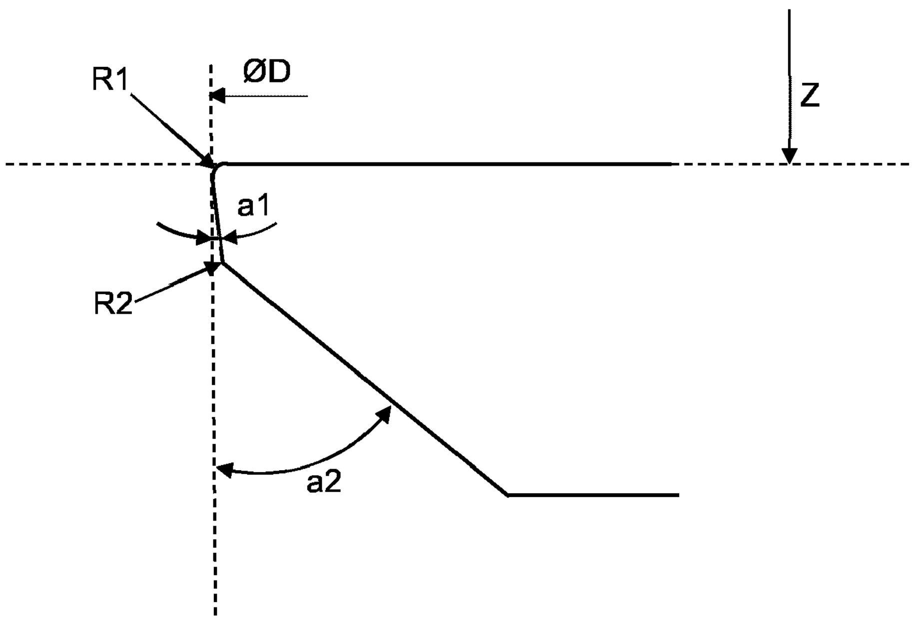


Fig. 17

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EUROPEAN SEARCH REPORT

Application Number
EP 22 19 9941

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			B24B

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	30 March 2023	Bermejo, Marco

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