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(54) **MACHINE TOOL FOR THE MACHINING OF ROTARY PARTS WITH GROOVE-LIKE PROFILES BY A GENERATING METHOD**

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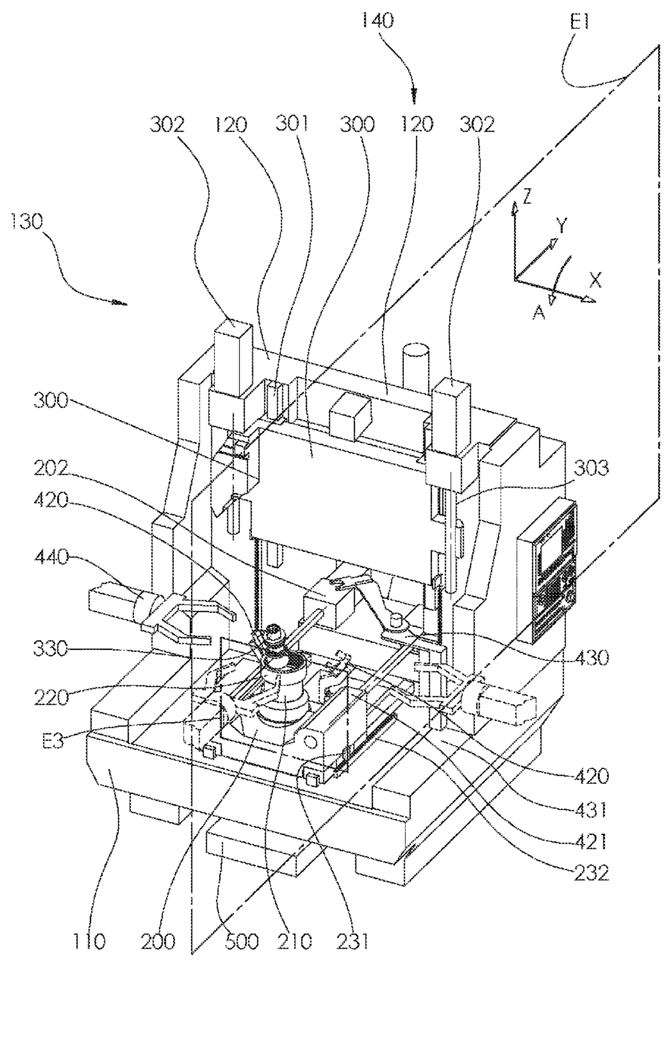
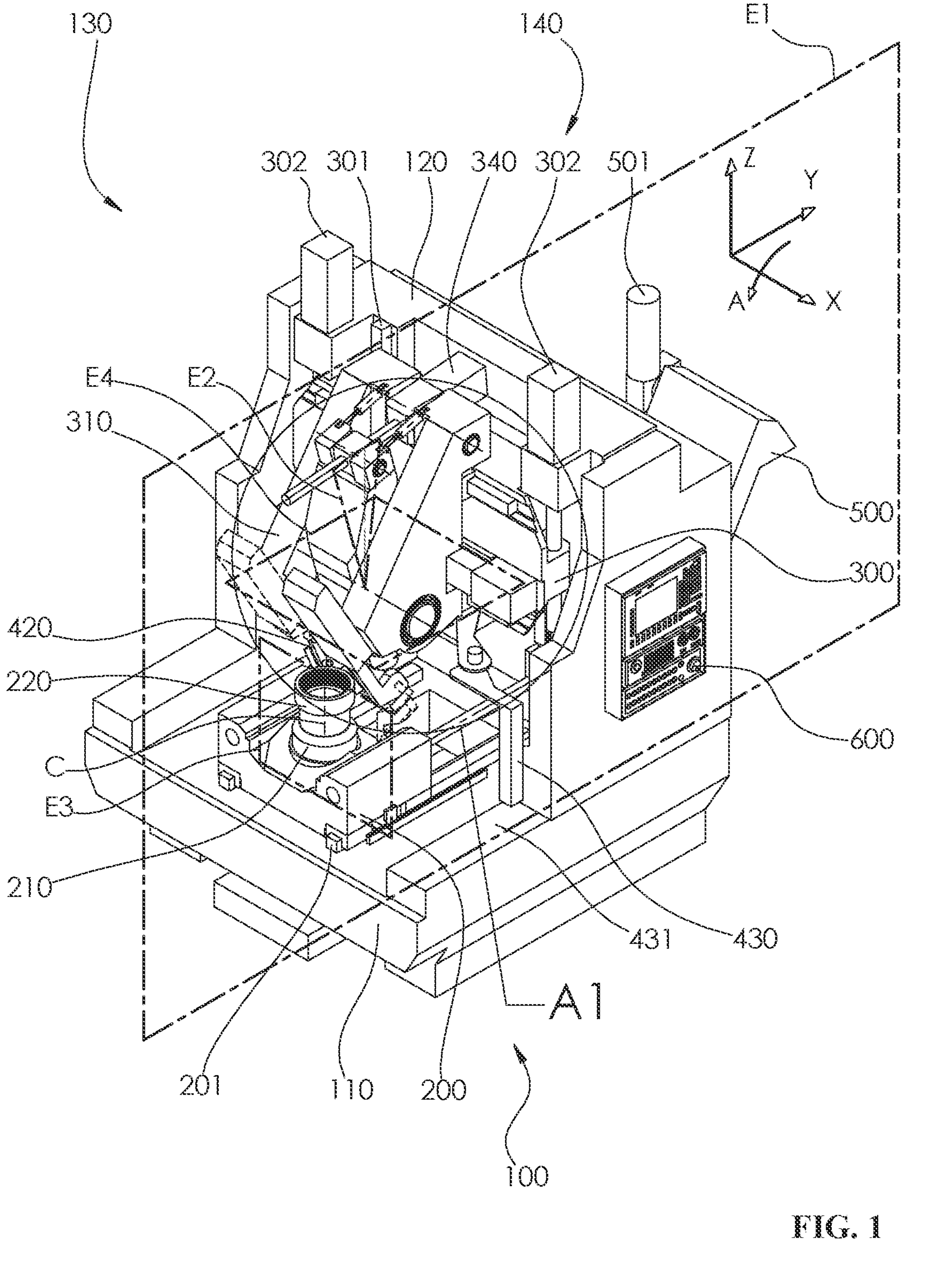
(57) **ABSTRACT**

A machine tool is designed for the machining of rotary parts with groove-shaped profiles, in particular gears, by a generating method. On the one hand, a Y slide (**200**) is arranged on a machine bed (**100**), the Y slide being displaceable along a Y direction and carrying a workpiece spindle (**210**). The workpiece spindle drives a workpiece (**220**) to rotate about a workpiece axis (C). On the other hand, a Z slide (**300**) is arranged on the machine bed. The Z slide is arranged along a Z direction running parallel to a center plane (E**1**) spanned by the Y direction and the workpiece axis. An X slide (**310**) is arranged on the Z slide and can be displaced along an X direction relative to the Z slide (**300**). The X direction is perpendicular to the center plane. A tool spindle (**320**) is arranged on the X slide, which drives a tool to rotate about a tool axis. The tool spindle can be swiveled relative to the X slide in a swivel plane (E**2**), which runs parallel to the center plane, about a swivel axis (A).

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140
E1
302
301
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Y
A
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E4
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C
E3
210
431
430
A1
201
110
200
100

FIG. 1

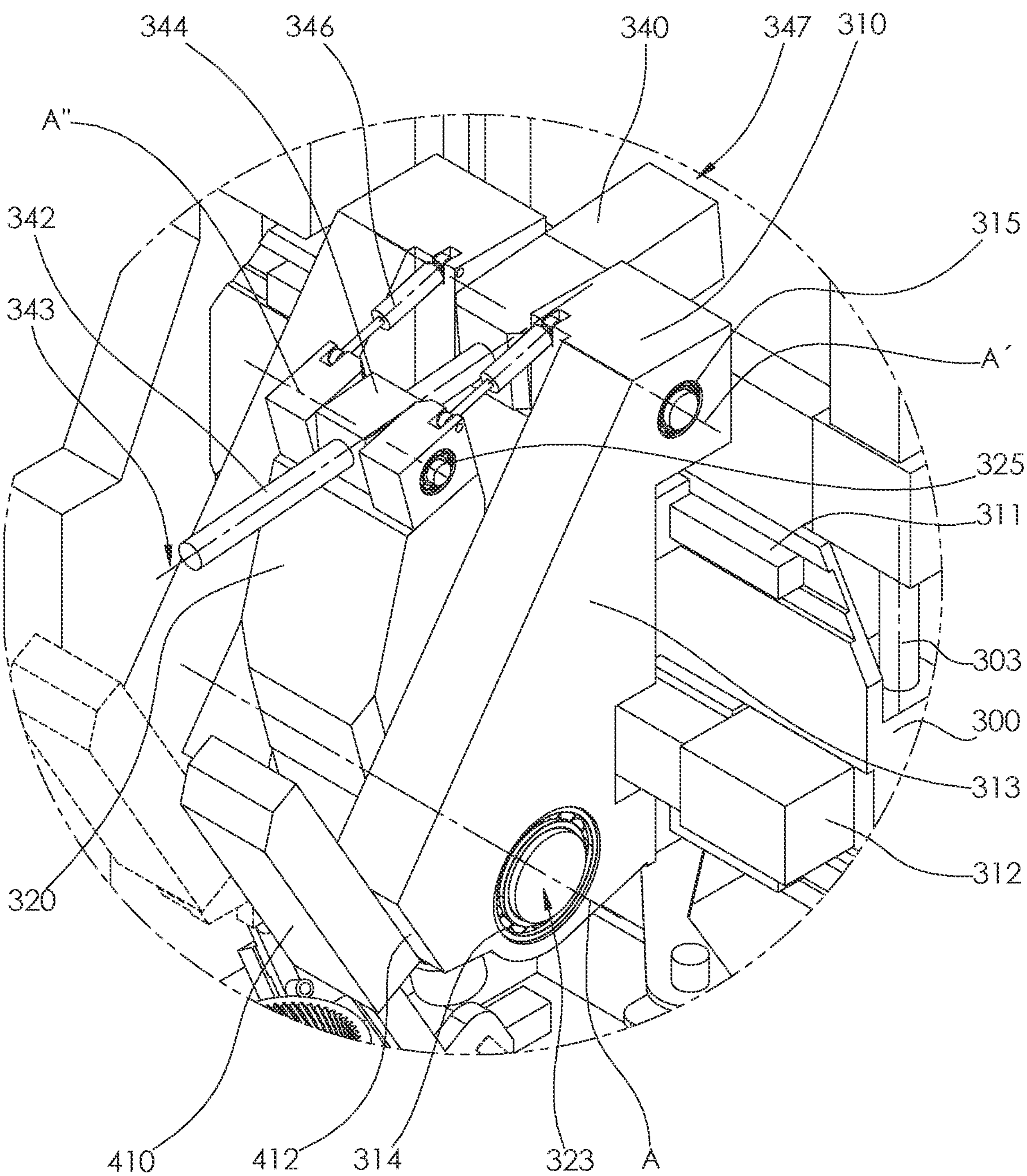
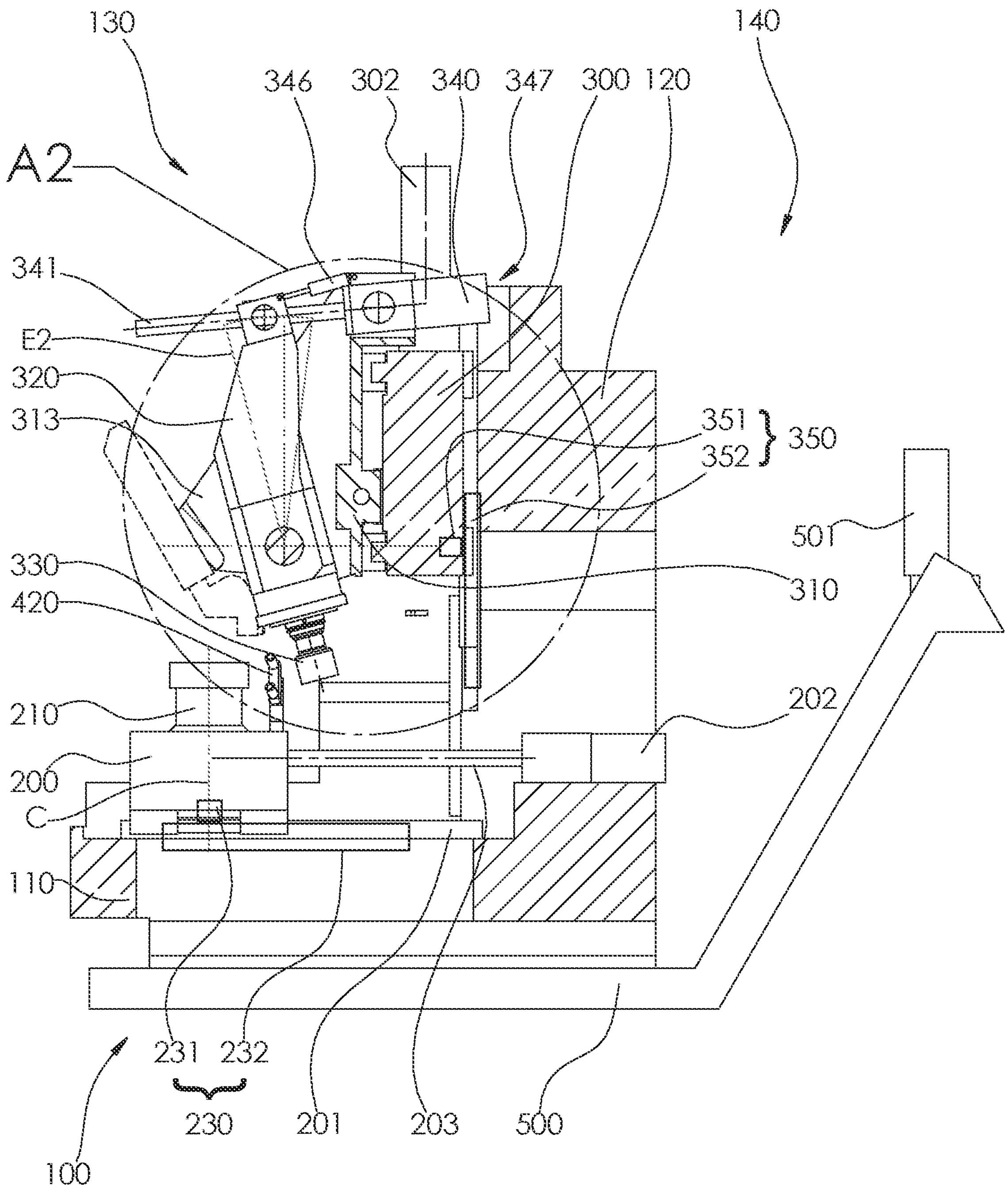

344
346
340
347
310
A"
342
315
343
A´
325
311
303
300
313
320
312
410
412
314
323
A

FIG. 2


130
140
346
302
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347
300
120
A2
341
E2
320
313
351
352
350
501
330
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310
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202
200
C
110
231
232
230
201
203
500
100

FIG.3

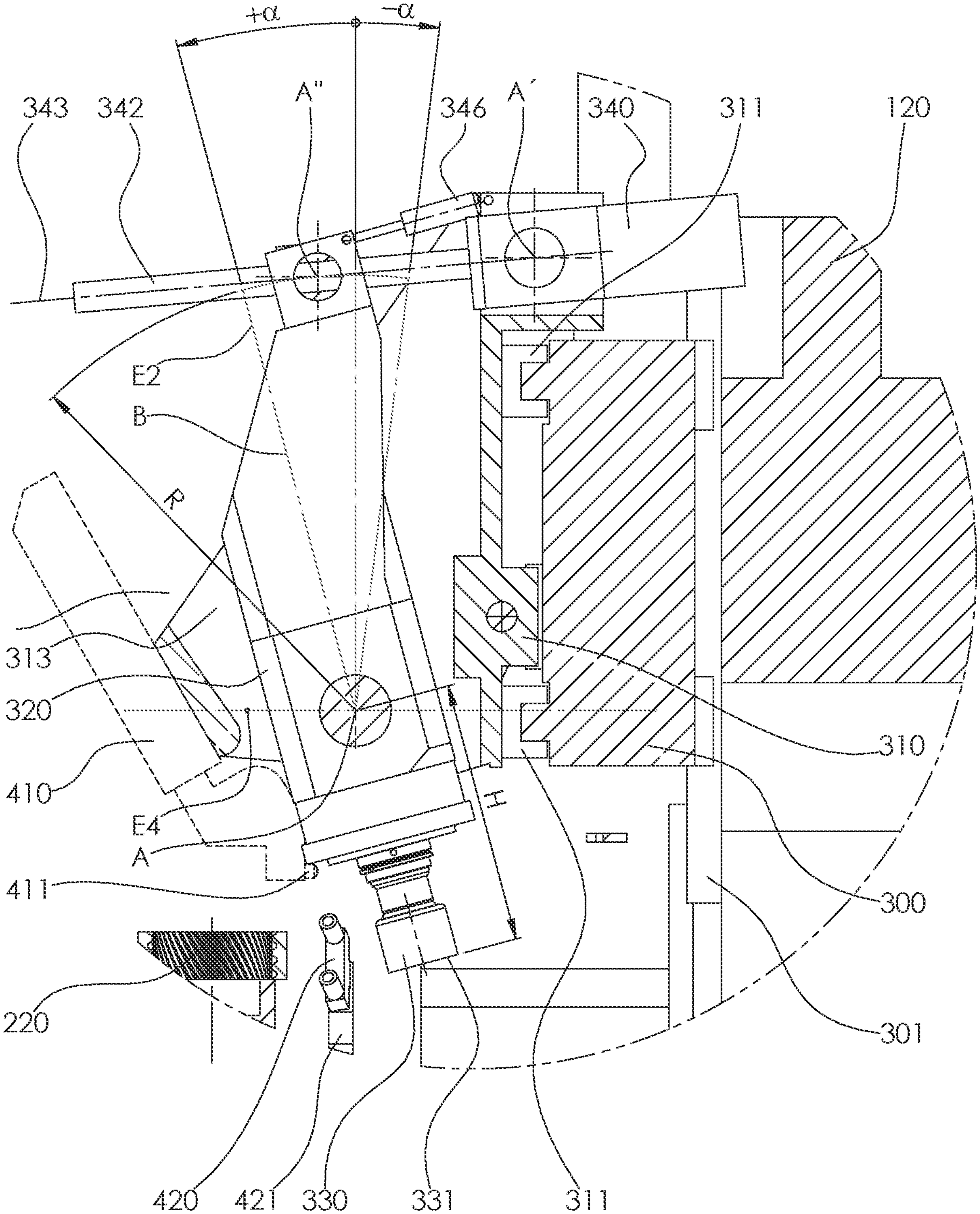
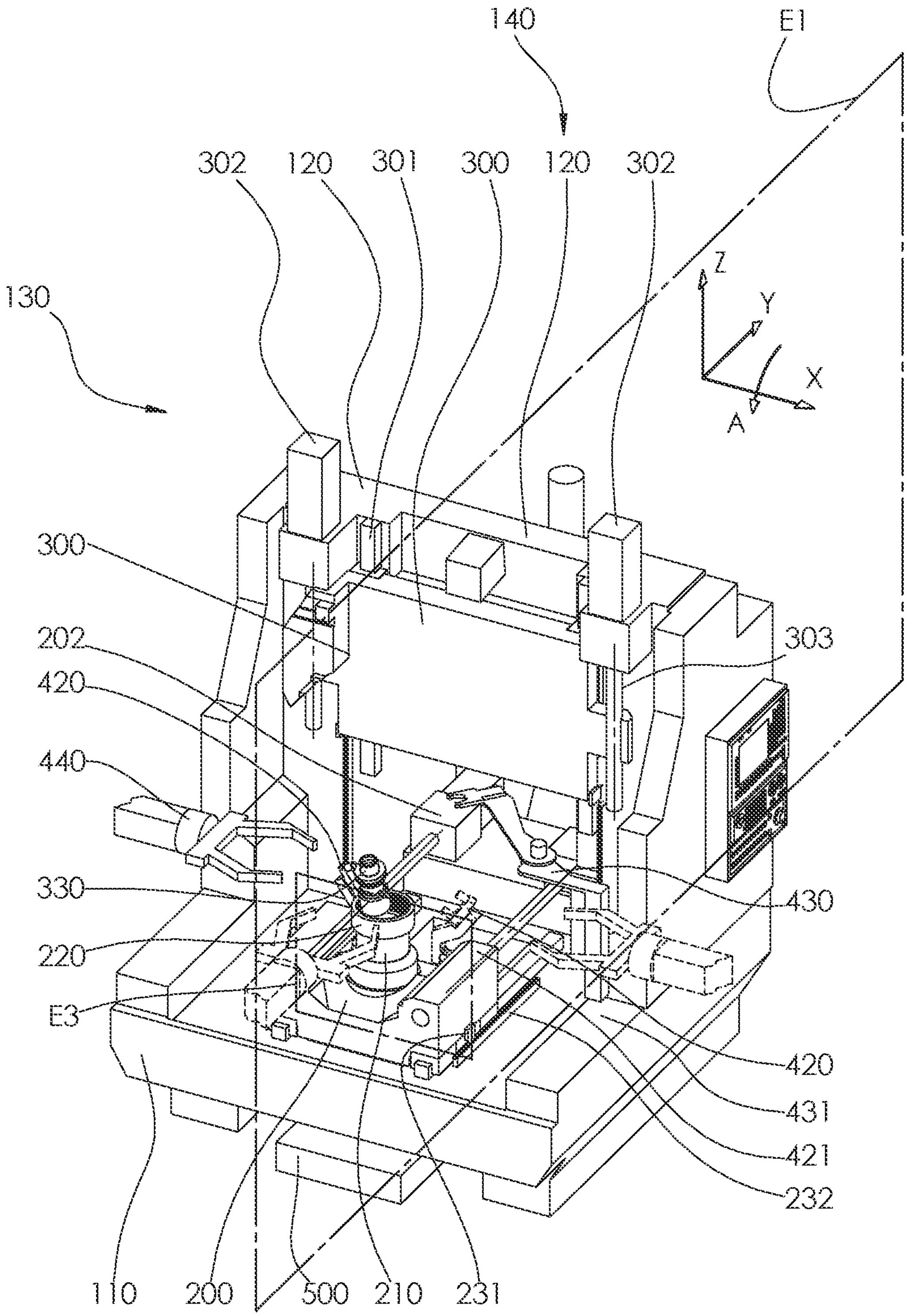
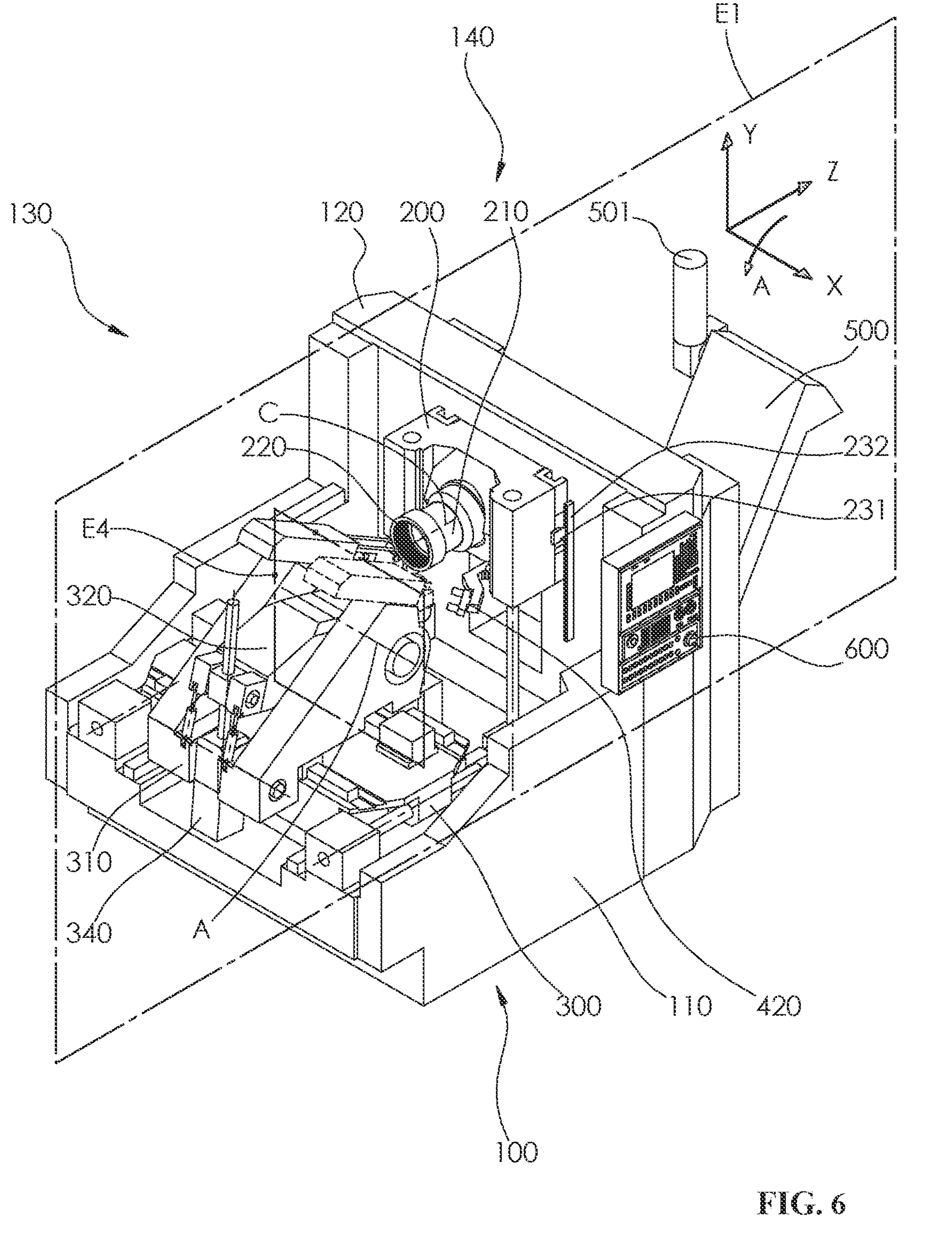

+α
-α
A"
A´
343
342
346
340
311
120
E2
B
R
313
320
410
E4
A
411
220
H
310
300
301
420
421
330
331
311

FIG.4



140
E1
302
120
301
300
120
302
130
Z
Y
X
A
300
202
420
440
330
220
E3
303
430
420
431
421
232
110
200
500
210
231

FIG. 5


E1
140
Y
Z
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130
120
200
210
501
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C
220
232
231
E4
320
600
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340
A
300
110
420
100

FIG. 6

MACHINE TOOL FOR THE MACHINING OF ROTARY PARTS WITH GROOVE-LIKE PROFILES BY A GENERATING METHOD

TECHNICAL FIELD

[0001] The present invention relates to a machine tool which is specially configured for the machining of groove-shaped profiles on rotary parts by a generating method and in particular for the machining by a generating method using gear-shaped tools. The term "machining by a generating method" is used here to refer to all processes in which the tool and workpiece carry out a generating (rolling) movement on each other, including all processes which are occasionally referred to in the technical literature as "crossed axes generation". The groove-shaped profiles can in particular form a toothing. The machine tool may be configured in particular to perform a gear skiving process. The present invention also relates to a process for operating such a machine tool.

PRIOR ART

[0002] In modern production technology, gear skiving (also referred to as hob peeling) is becoming increasingly important for the machining of rotary parts with groove-shaped profiles. Gear skiving has been known as a gear machining process since at least 1910. An early description of the process can be found in DE 243514 C. The gear skiving process is a continuous metal-cutting process for the manufacture of axially symmetrical periodic structures, using gear-shaped tools. The teeth of these tools have cutting edges on their end faces. The tool and the workpiece are mounted on rotary spindles. The axes of rotation of tool and workpiece are arranged skewed to each other. By coupling the rotary movements of tool and workpiece around the axes of rotation, the typical rolling movement is realized. This rolling movement and a feed movement of the tool or the workpiece along the workpiece axis generate a cutting movement during gear skiving. Both external and internal gears can be machined with this cutting process.

[0003] A gear skiving machine often has six driven, numerically controlled axes to generate the rotary motions of the workpiece and tool as well as to position and orient the workpiece and tool relative to each other. The designations of these axes vary depending on the convention used. The following convention is used in this document:

- **[0004]** Swivel axis for the relative orientation of tool spindle and workpiece spindle to each other: A axis:
- **[0005]** rotation axis of the gear skiving tool on the tool spindle: tool axis or B axis;
- **[0006]** rotation axis of the workpiece on the workpiece spindle: workpiece axis or C axis; and
- **[0007]** three linearly independent, but not necessarily perpendicular, linear displacement axes for the relative positioning of the tool spindle and the work spindle to each other: X, Y and Z axes.

[0008] From the state of the art, a wide range of possibilities for the design and arrangement of these axes are known. These possibilities differ first of all with regard to the orientation of workpiece axis and tool axis in space. The workpiece axis, for example, can have a fixed orientation in space or can be swiveled. If the workpiece axis has a fixed orientation in space, it can be aligned horizontally or vertically in space. Depending on whether or not the workpiece axis can be swiveled, the tool axis can have a fixed orientation in space or can be swiveled. If the tool axis has a fixed orientation, this axis can also be aligned vertically or horizontally. These different ways of orienting the workpiece and tool axes lead, among other things, to different operating concepts for loading and unloading of workpieces and to different requirements for chip removal. For each of these variants, there are again a large number of possibilities regarding the arrangement of the different axes relative to the machine bed and relative to each other and regarding the realization of the axes.

[0009] An example of a gear skiving machine with horizontal arrangements of the workpiece and tool spindle is the GS300H machine from JTEKT Corporation, Nagoya, Japan (see brochure "Gear Skiving Centers/Machining Centers Line Up", catalog no. M2027-7E, imprint 170325U). On the tool carrier, the tool spindle is fed radially by means of a vertical slide and the entire tool carrier can be moved horizontally. The tool spindle runs horizontally in space and has a fixed orientation. The workpiece carrier, on a horizontal slide, realizes the axial infeed. The workpiece spindle also runs horizontally in space and can be swiveled around a vertical swivel axis in a horizontal swivel plane.

[0010] A machine with a similar tool carrier is also known from US20150043985A1. In this machine, however, the workpiece spindle can be swiveled around a horizontal axis in a vertical swivel plane.

[0011] However, the far greater number of gear skiving machines have a vertically oriented workpiece axis and a swiveling tool axis. For example, on the LK 300 and LK 500 gear skiving machines from Liebherr Verzahntechnik GmbH, Kempten, Germany, the workpiece spindle is vertically aligned and fixed to the machine bed, while the tool spindle is located above the workpiece spindle and can be moved relative to the machine bed along all three linear displacement axes X, Y and Z and swiveled about an A axis (cf. Brochure "Gear Skiving Machines LK 300/500", Liebherr-Verzahntechnik GmbH, imprint BK LVT-LK300/500-1.0.-07.18_en).

[0012] Also on the 400HP machine from Gleason Corporation, Rochester. USA, the workpiece spindle is vertically aligned and fixed to the machine bed. Such an arrangement is also known from US2017072485A1, FIG. 11. The MSS300 machine from Mitsubishi Heavy Industries Machine Tool Co. Ltd, Shiga, Japan also features a fixed, vertical work spindle. Such an arrangement is also known from US2019076943A1, FIG. 1.

[0013] On the S-250 machine from Profilator GmbH & Co KG, Wuppertal, Germany, the tool spindle is mounted on a slide in such a manner that it can be swivelled around the A axis, and this slide can in turn be moved relative to the machine bed along a linear displacement axis, which is inclined relative to the machine bed. The workpiece spindle can be moved above the tool spindle along two linear displacement axes. On the S-500 machine from Profilator GmbH & Co KG, too, the workpiece spindle can be moved above the tool spindle along two linear displacement axes (see lecture notes by Dr. Claus Kobialka, "Stand der Technik zum Wälzschälen (SCUDDING)" ["State of the art in gear skiving (SCUDDING)"], GETPRO Kongress, Mar. 25 and 26, 2015, Würzburg, Germany).

[0014] A tool spindle arranged at the bottom, which can be swiveled, is also present in the "SynchroSkiver" machine from Präwema Antriebstechnik GmbH, Eschwege, Germany. Here, too, the workpiece spindle can be linearly displaced above the tool spindle along two axes (see brochure “SynchroSkiver”, Präwema Antriebstechnik GmbH, imprint PRW-2015-09-V1-HDM).

[0015] The KPS20 machine from Kashifuji KK also features a swiveling tool spindle, above which the workpiece spindle can be moved along two axes. An arrangement with a swiveling tool spindle at the bottom and a workpiece spindle that can be moved above it is also known from JP2014151382A2, FIG. 1.

[0016] Another concept with a swiveling tool spindle at the bottom and a crosswise movable workpiece spindle above it is also known from US2012328384A1 (FIG. 18).

[0017] On the GMS450 machine from Nachi-Fujikoshi Corp., Toyama. Japan, the workpiece spindle is vertically aligned and can be moved horizontally along one direction relative to the machine bed. On a machine stand, which is firmly connected to the machine bed, a slide above the workpiece spindle can be moved horizontally perpendicular to the direction of movement of the workpiece spindle. On this slide, a vertically displaceable carriage is mounted. The tool spindle is mounted on this slide so that it can swivel around an A axis. The A axis runs parallel to the axis along which the work spindle can be moved on the machine bed. Reference is made to document “GMS450” issued by Nachi-Fujikoshi Corp., Catalog No. M6202E, imprint 2016.9.X. MD-SANWA.

[0018] Also on the PV315 machine from Pittler T & S GmbH, Dietzenbach, Germany, the workpiece spindle is vertically aligned and can be moved along one direction along the machine bed. A machine column can be moved horizontally on the machine bed along a direction perpendicular to direction of movement of the workpiece spindle. The machine stand carries a vertically displaceable slide on which the tool spindle is arranged so that it can be swiveled in a swivel plane parallel to the horizontal displacement direction. Reference is made to the document “Wälzschälen in der Komplettbearbeitung” [“Gear skiving in total machining”] from PITTLER T&S GmbH, imprint PIT-2017.04-EN-HDM.

[0019] Due to the special kinematics during gear skiving, machining forces vary considerably along the cutting edge contact. This is particularly true for the hard fine machining of pre-toothed workpieces. In particular, high and strongly fluctuating axial forces are generated along the tool and workpiece axes on the one hand; on the other hand, high and strongly fluctuating radial forces are also generated, which lead to large bending moments on the tool and workpiece. All in all, these process characteristics have a negative effect on the achievable manufacturing accuracy, especially if the respective NC axes are moved during the machining process. Important factors for achieving high manufacturing accuracy are in particular the static and dynamic rigidity, the damping properties of the machine and a high thermal symmetry. However, these requirements are not yet optimally met by the existing arrangements.

SUMMARY OF THE INVENTION

[0020] It is an object of the present invention to provide a machine tool which is suitable for the machining by a generating method, in particular gear skiving, of rotary parts with groove-shaped profiles, in particular gears, and in particular for their hard fine machining, and which exhibits improved static and dynamic stiffness combined with high thermal stability.

[0021] This object is achieved by a machine tool with the characteristics of claim **1**. Further embodiments are provided in the dependent claims.

[0022] A machine tool for the machining of rotary parts with groove-shaped profiles by a generating method is provided. The machine tool comprises:

[0023] a machine bed;

[0024] a Y slide, which is linearly displaceable along a Y direction relative to the machine bed;

[0025] a workpiece spindle which is arranged on the Y slide and which is configured to clamp a workpiece on it and to drive it to rotate about a workpiece axis (C axis), the workpiece axis extending transversely, preferably perpendicularly, to the Y direction;

[0026] a Z slide which is arranged on the machine bed and is linearly displaceable along a Z direction relative to the machine bed, the Z direction extending parallel to a center plane defined by the Y direction and the workpiece axis, and the Z direction extending at an angle of less than 45°, preferably parallel to the workpiece axis;

[0027] an X slide mounted on the Z slide, the X slide being linearly displaceable along an X direction relative to the Z slide, the X direction being perpendicular to the center plane; and

[0028] a tool spindle which is configured to clamp a generating machining tool, in particular a gear-shaped generating machining tool, on it and to drive it to rotate about a tool axis (B axis), the tool spindle being arranged on the X slide and being pivotable relative to the X slide about a first swivel axis (A axis).

[0029] In this document, two axes are to be understood to extend “transverse” to each other if the two axes are at an angle of more than 45° and less than 135° to each other, in particular at an angle of more than 60° and less than 120°.

[0030] Since the entire X slide including the tool spindle and its swivel mechanism is located on the Z slide, the inertial mass on the Z slide is relatively large. This is particularly advantageous because machining forces acting along the main cutting direction are mainly introduced in the Z direction, and therefore particularly large and strongly fluctuating machining forces and tilting loads occur along this direction. Due to the large inertial mass on the Z slide, a particularly advantageous dynamic behavior is achieved along the Z direction, which is subject to particularly high loads. In addition, the design with a center plane, relative to which the axes are aligned, enables a particularly rigid and thermally stable construction. Finally, the relatively lightweight (low-mass) Y slide, which is independently guided on the machine bed, makes it possible to move the workpiece spindle quickly and precisely along the Y axis between a workpiece change position and a machining position.

[0031] In advantageous embodiments, the first swivel axis (A axis), about which the tool spindle is pivotable relative to the X slide, extends perpendicularly to the center plane, and the tool axis extends perpendicularly to the first swivel axis. In this case, the swivel movement of the tool axis takes place in a swivel plane that is parallel to the center plane and thus reflects the symmetry of the rest of the machine structure. In addition, the tool axis preferably intersects the first swivel axis so that torques around the A axis are minimized.

[0032] This arrangement of the swivel plane parallel to the center plane is particularly advantageous for gear machining processes in which gear-shaped tools are used, such as for gear skiving or gear shaving. However, an arrangement of the first swivel axis (A axis) parallel to the center plane and in particular perpendicular to the X and Z axes is also conceivable; also then the tool axis is advantageously perpendicular to the first swivel axis (A axis) and in particular intersects the first swivel axis. Such an arrangement can be advantageous in particular for generating machining processes with worm-shaped tools such as generating gear grinding or hobbing.

[0033] In advantageous embodiments, the tool spindle is arranged to swivel on the X slide as follows: The machine tool has two first swivel bearings to support the tool spindle on the X slide about the first swivel axis. These first two swivel bearings are arranged on both sides of the tool spindle with respect to the swivel plane and preferably equidistant from the swivel plane.

[0034] The machine tool may comprise an adjustment mechanism for adjusting the orientation of the tool spindle relative to the X slide. This adjustment mechanism may be pivotally connected to the X slide about a second swivel axis, the second swivel axis being parallel to and spaced apart from the first swivel axis, and may also be pivotally connected to the tool spindle about a third swivel axis, the third swivel axis being parallel to and spaced apart from the first swivel axis and the second swivel axis. In this case, there are therefore a total of three swivel axes through which the X slide, the tool spindle and the adjustment mechanism are connected to each other.

[0035] The adjustment mechanism can also be advantageously supported on both sides of the swivel plane. For this purpose, the machine tool can comprise two second swivel bearings for supporting the adjustment mechanism on the X slide about the second swivel axis, the two second swivel bearings being arranged on both sides and preferably equidistant from the swivel plane, and/or it can comprise two third swivel bearings for supporting the adjustment mechanism on the tool spindle about the third swivel axis, the two third swivel bearings likewise being arranged on both sides and preferably equidistant from the swivel plane.

[0036] In particular, the adjustment mechanism may be of the following design: It may comprise an A drive motor which is pivotable relative to the X slide and drives a threaded spindle to rotate about a threaded spindle axis extending perpendicularly to the first swivel axis, the threaded spindle axis extending in the swivel plane. It may also comprise a spindle nut that is pivotable relative to the X slide and engages with the threaded spindle. In particular, the threaded spindle and the spindle nut can be configured as a ball screw drive. This type of mechanism, with its high transmission ratio, allows a particularly safe, rigid, precise and smooth adjustment of the orientation of the tool spindle about the first swivel axis (A axis). The adjustment can even take place during the machining of a workpiece; clamping for stationary operation is not necessary.

[0037] Preferably, the A drive motor is pivotably mounted on the X slide so that it can swivel about the second swivel axis, and the spindle nut is connected to the tool spindle so that it can swivel about the third swivel axis. However, an inverse arrangement is also conceivable in which the A drive motor is connected to the tool spindle so that it can swivel about the third swivel axis and the spindle nut is connected to the X slide so that it can swivel about the second swivel axis.

[0038] In order to precisely determine the swivel position of the workpiece spindle, the machine tool can comprise:

- [0039] a first angle measuring device configured to determine an angle of rotation of the A drive motor or threaded spindle about the threaded spindle axis; and/or
- [0040] at least one second angle measuring device configured to directly determine a swivel angle of the tool spindle about the A axis relative to the X slide.

[0041] A particularly advantageous arrangement of the adjustment mechanism is as follows: The tool spindle has one end facing the tool (tool end) and one end facing away from the tool (drive end). At the tool end, a generating machining tool is clamped on the tool spindle, which defines a tool reference plane extending perpendicular to the tool axis. In the case of a gear skiving tool, the tool reference plane can be, in particular, a plane that extends through the cutting edges of the tool at the distal end of the tool ("cutting edge plane"). In the case of other types of generating machining tools (e.g. hobs or generating grinding tools), the tool reference plane can generally be any plane of action perpendicular to the tool axis in which the tool interacts with the workpiece during machining. There may be a whole set of such planes on the tool, but usually the range along the tool axis where these planes intersect the tool axis is small compared to the length of the entire tool spindle, so the concrete position of the tool reference plane is not important for the following considerations. For example, the tool reference plane can be assumed to be a plane through the center of that portion of the tool along the B axis that is intended for machining. The first tilting axis (A axis) intersects the tool axis (B axis) between the end of the tool spindle that faces the tool and the end that faces away from the tool. The connection between the tool spindle and the adjustment mechanism is made in the region of the end of the tool spindle that faces away from the tool, i.e. the third swivel axis is in the region of this end facing away from the tool. The first swivel axis (A axis) and the tool reference plane are at a first distance from each other, and the A axis and the third swivel axis are at a second distance from each other. It is advantageous if the second distance and the first distance have a ratio greater than 1, preferably a ratio of 1.5 to 3.

[0042] In this arrangement, the A-axis therefore intersects the tool axis near the tool-side spindle end. This results in very short lever arms for the forces acting on the tool in the X, Y and Z directions, which can have a pulsating characteristic due to the machining process. These forces therefore act on the machine structure with relatively low bending moments and thus generate a relatively low vibration energy that can act on the tool carrier. The large mass of the entire tool carrier also provides effective broadband damping. Furthermore, the movement of the tool in the Y and Z directions caused by the swivel movement around the A axis is small due to the minimized distance of the tool reference plane to the swivel axis.

[0043] For adjusting the orientation of the tool spindle around the A axis, other adjustment mechanisms can be used instead of the threaded adjustment mechanism discussed above, especially a direct drive with torque motor. Although a direct drive is advantageous in terms of a simple design, it is located in the machining area and takes up a lot of space in it. This results in additional collision restrictions between tool and workpiece. In addition, the large space requirement of a direct drive can lead to the fact that on the one hand the X slide must be designed wider and thus ultimately the machine as a whole becomes wider, and that on the other hand the A axis must have a greater distance to the X and Z guides, so that the forces described above act on the tool via larger lever arms on the machine structure, with correspondingly negative consequences for the tendency to vibrate. The version with screw drive discussed above avoids these disadvantages.

[0044] In order to additionally dampen vibrations of the tool spindle around the A axis, the machine tool may have at least one vibration damper, preferably two vibration dampers arranged on both sides and preferably equidistant from the swivel plane, the vibration damper or dampers acting between the tool spindle and the X slide.

[0045] The swivel range of the tool spindle about the first swivel axis (A axis) is preferably asymmetrical, i.e. the tool spindle can preferably be swiveled about the A axis in relation to the X slide in such a way that an axis crossing angle between the tool axis (B axis) and the workpiece axis (C axis) takes on either negative or positive values, the maximum positive value of the axis crossing angle being greater than the magnitude (absolute value) of the smallest negative value. The magnitude of the smallest negative value is preferably not greater than 10°, while the maximum positive value is preferably at least 30°. The axis crossing angle is defined as positive when the tool is inclined toward the X slide and negative when the tool is inclined away from the X slide. The asymmetrical swivel range means that less space is required, and the work spindle or the A axis can be positioned closer to the linear guides of the Z and X slides in order to keep the effective lever arm short with respect to torsion around these linear guides. In addition, the tool center is located closer to the linear guides of the Z and X slides than the A axis when the axis crossing angle is positive, which has an additional positive effect on machining precision. Due to the symmetrical design of the machine with respect to the center plane, an asymmetrical swivel range does not mean a restriction for generating machining, because depending on the direction of the helix angle of the gear to be machined, the tool can be brought into engagement with the gear to be machined during gear skiving by moving the X slide either to the left or right of the center plane. The symmetry of the arrangement of the linear axes with respect to the swivel plane is not affected by the asymmetrical swivel range.

[0046] In some embodiments, the workpiece axis (C axis) runs vertically in space. This enables easy workpiece change and efficient chip removal. In addition, if the C-axis is arranged vertically, the Z-direction preferably also runs vertically in space. In such an arrangement, the weight of the Z slide, together with the X slide mounted on it and the tool spindle, acts along the Z direction, thus further reducing the tendency to vibrate along the Z direction. It is also possible, however, that the C axis runs along a different spatial direction, in particular, horizontally.

[0047] The machine tool preferably comprises two parallel Z linear guides which extend parallel to the Z direction, are arranged on both sides and preferably equidistant from the aforementioned center plane and on which the Z slide is guided along the Z direction relative to the machine bed. A separate Z drive can then be assigned to each of the linear guides to move the Z slide along the Z direction relative to the machine bed. In particular, each of these Z drives can include a drive motor, a threaded spindle and an associated spindle nut. The threaded spindle and spindle nut are preferably configured as a ball screw drive. Such a double Z drive contributes to a high dynamic rigidity and maintains the symmetry in the machine tool structure with respect to the center plane.

[0048] To precisely determine the Z position of the workpiece spindle, the machine tool may comprise one, preferably two Z linear measuring systems, each of the Z linear measuring systems comprising a measuring head mounted on the Z slide and a linear scale mounted on the machine bed. The measuring head of each of the Z linear measuring systems is then preferably arranged to perform a position measurement in an A reference plane that extends perpendicular to the Z direction and contains the A axis. Thus, the measurement is carried out at a defined location that is very well suited for characterizing the position of the workpiece spindle.

[0049] To guide the X slide on the Z slide, the machine tool preferably comprises two X linear guides which are parallel to each other, extending parallel to the X direction, and on which the X slide is guided along the X direction relative to the Z slide. A single X drive may be provided for the X axis, which may in particular comprise a drive motor, a threaded spindle and an associated spindle nut. The threaded spindle and spindle nut are preferably configured as a ball screw drive. However, a double drive is also conceivable here, as indicated above for the Z direction.

[0050] The guidance of the Y slide on the machine bed can be done in a very similar way to the guidance of the Z slide. In particular, the machine tool can comprise two parallel Y linear guides that extend parallel to the Y direction, are arranged on both sides and preferably equidistant from the center plane, and on which the Y slide is guided along the Y direction relative to the machine bed. The machine tool can in turn have two Y drives to move the Y slide along the Y direction relative to the machine bed, one of the Y drives being assigned to each of the Y linear guides. Each of the Y drives can comprise a drive motor, a threaded spindle and an associated spindle nut. The threaded spindle and spindle nut are preferably configured as a ball screw drive.

[0051] Similar to the Z axis, the machine tool may comprise one, preferably two Y linear measuring systems, each of the Y linear measuring systems comprising a measuring head mounted on the Y slide and a linear scale mounted on the machine bed. Each of the measuring heads of the Y linear measuring systems is preferably arranged in such a way that it performs a position measurement in a C reference plane which is perpendicular to the Y direction and contains the workpiece axis (C axis). In this way the measurement is performed at a location that characterizes the position of the workpiece center with respect to the Y direction particularly well.

[0052] Due to the paired drives in the Y and Z axes, the stiffness is improved both against axial movements along the respective direction and against tilting movements around the Y and Z direction.

[0053] The machine tool may comprise at least one of the following additional components.

[0054] a meshing device for determining a position of tooth gaps of the workpiece;

[0055] an optical measuring bridge for measuring the tool and/or the workpiece; and

[0056] a tool changing device for changing the tool.

[0057] For each of the additional components, two alternative mounting structures can be provided, which are arranged on both sides of the center plane. In particular, two alternative mounting structures for the meshing probe can be formed on the X slide on both sides of the center plane. On the Y slide, two alternative mounting structures for the measuring bridge can be formed on both sides of the center plane. Two alternative mounting structures for the tool change device can be formed on the machine bed on both sides of the center plane. In this way, a workpiece loader can be placed in one of several possible locations, depending on the customer's requirements, and the additional components can then be attached to the machine in such a way that they do not collide with the workpiece loader. In the simplest case, each of the fastening structures can include, for example, a fastening surface with suitable bores. In more complex embodiments, a fastening structure can include a three-dimensional structure that is specifically configured for the attachment of the respective additional component.

[0058] The machine tool may comprise a chip conveyor located in the center plane below the machine bed. The machine bed may have a central opening to allow chips to drop from a machining zone onto the chip conveyor. The chip conveyor may preferably be arranged to convey chips from a machining area at the front of the machine to a rear area of the machine. Alternatively, however, it is also conceivable to convey the chips in the direction of the front of the machine.

[0059] The machine tool is configured specifically for the machining of rotary parts with groove-shaped profiles, especially gears, by a generating method. For this purpose, the machine tool comprises a controller that is configured to establish a positive coupling between the rotation of the generating machining tool and the rotation of the workpiece. The machine can be used for soft machining, but preferably it is used for hard fine machining of pre-toothed workpieces. The machine tool is particularly suitable for gear skiving, but can also be used for other generating methods, especially for gear shaving, gear honing, generating gear grinding or hobbing.

[0060] A method of machining a workpiece with a machine tool of the above type comprises:

[0061] bringing a generating machining tool clamped on the tool spindle into engagement with the workpiece while the workpiece is clamped on the workpiece spindle, the engagement preferably taking place in an arrangement of the generating machining tool relative to the workpiece in which the tool axis extends offset to the center plane of the machine tool; and

[0062] carrying out a generating machining method on the workpiece with the machine tool.

[0063] In particular, the generating machining tool can be a gear-shaped generating machining tool, e.g. a gear skiving tool.

BRIEF DESCRIPTION OF THE DRAWINGS

[0064] Preferred embodiments of the invention are described in the following with reference to the drawings, which are for explanatory purposes only and are not to be interpreted as limited. In the drawings:

[0065] FIG. **1** shows a perspective view of a machine tool according to a first embodiment:

[0066] FIG. **2** shows an enlarged detailed view in area A**1** in FIG. **1**;

[0067] FIG. **3** shows a sectional view of the machine tool in FIG. **1** in the center plane E**1**;

[0068] FIG. **4** shows an enlarged detailed view in area A**2** in FIG. **3**;

[0069] FIG. **5** shows a perspective view of the machine tool in FIG. **1**, leaving out parts in the area of the X slide; and

[0070] FIG. **6** shows a perspective view of a machine tool according to a second embodiment.

DESCRIPTION OF PREFERRED EMBODIMENTS

First Embodiment: Vertical Workpiece Axis

[0071] FIGS. **1** to **4** show in different views a machine tool according to a first embodiment. In FIG. **5**, parts of the machine are not shown for better visibility, especially the front part of the Z slide and the entire X slide with the tool spindle mounted on it.

[0072] The illustrated machine tool is a machine which is particularly suitable for gear skiving. However, it is also possible to carry out other types of machining processes with such a machine, especially other generating machining processes.

[0073] The machine comprises a machine bed **100**. As can best be seen in FIG. **3**, the machine bed **100** is approximately L-shaped in a side elevation, having a horizontal portion **110** and a vertical portion **120**. The vertical portion of the machine bed **120** separates a front machining area **130** from a rear area **140** of the machine.

[0074] A Y slide **200** is arranged on the horizontal portion **110** of the machine bed **100**. The Y slide can be displaced along a Y direction relative to the machine bed **100**. The Y direction runs horizontally in space. The Y slide **200** carries a workpiece spindle **210**, on which a pre-toothed workpiece **220** is clamped. The Y slide **200** thus serves as a workpiece carrier. The workpiece **220** is driven on the workpiece spindle **210** so that it can rotate about a workpiece axis (C axis). The C axis runs vertically in space, i.e. along the direction of gravity. The C axis and the Y direction together span a center plane E**1** of the machine. The center plane E**1** contains the C axis, independent of the position of the Y slide **200** along the Y direction.

[0075] A Z slide **300** is arranged on the vertical portion **120** of the machine bed **100**. The Z slide can be moved along a Z direction relative to the machine bed **100**. The Z direction is parallel to the center plane E**1**. In the present example, the Z direction runs vertically in space, parallel to the C axis and perpendicular to the Y direction. An X slide **310** is arranged on the Z slide **300**, the X slide carrying a tool spindle **320** and thus forming a tool carrier. The X slide **310** can be displaced along an X direction relative to the Z slide **300**. The X direction runs horizontally in space, perpendicular to the Z direction and the Y direction and thus perpendicular to the center plane E**1**. Together, the Z slide **300** and the X slide **310** form a compound slide rest that enables the tool spindle **320** mounted on it to be moved along the Z and X directions, which are perpendicular to each other.

[0076] The tool spindle **320** drives a generating machining tool mounted on it, in the present case a gear skiving tool

330 ("hob peeling wheel", see FIGS. **3** and **4**), to rotate about a tool axis (B axis, see FIG. **4**). The tool spindle **320** can be swiveled about a first swivel axis (A axis, see FIG. **2**) in relation to the X slide **310**. The A axis is perpendicular to the B axis and perpendicular to the center plane E**1**. The A axis intersects the B axis. The plane in which the B axis swivels is referred to as the swivel plane E**2**. This swivel plane E**2** is perpendicular to the A axis (i.e. it is a normal plane to the A axis) and contains the B axis, regardless of its swivel position about the A axis. It is parallel to the center plane E**1**.

[0077] A chip conveyor **500** is arranged below and behind the machine bed **100** in such a way that it conveys chips from an area below the Y slide **200** to the rear area **140** of the machine. The chip conveyor **500** has a drive **510** for this purpose. Below the Y slide **200**, an opening is arranged in the machine bed **100** for the discharge of the chips produced. Alternatively, the chip conveyor **500** can be arranged so that it conveys the chips to the front instead of to the rear.

[0078] A machine controller with control panel **600** is used to control and operate the machine.

Setting the Orientation of the Tool Spindle Around the A Axis

[0079] When carrying out generating machining operations, it is important that the orientation of the tool spindle **320** about the A axis can be precisely adjusted. For this purpose, the machine is equipped with an appropriate adjustment mechanism.

[0080] FIGS. **2** and **4** show the swivel-mounted tool spindle **320** and the adjustment mechanism for adjusting the orientation of the tool spindle **320** around the A axis. The X slide **310** has a side wall ("cheek") **313** on each side of the swivel plane E**2**, which extends parallel to the swivel plane E**2** and forwards against the Y direction. A sufficiently large recess for the tool spindle **320** is provided between the two cheeks **313**. The tool spindle **320** is located between the cheeks **313** in the swivel plane E**2** and is supported in the corresponding cheek **313** via a swivel bearing **314** in the form of a play-free rolling bearing. The two swivel bearings **314** enable the tool spindle **320** to swivel relative to the X slide **310** about the first swivel axis (A axis).

[0081] In an upper end area of the X slide **310**, an A drive motor **340** is arranged centrally between the cheeks **313**. The A drive motor is mounted on both sides of the swivel plane E**2** in two play-free rolling bearings **315** so that it can swivel on the X slide **310** about a second swivel axis A'. The second swivel axis A' runs parallel to the A axis. The A drive motor **340** drives a threaded spindle **342** to rotate about a threaded spindle axis **343**. The threaded spindle **342** cooperates with a spindle nut **344**. The threaded spindle **342** and the spindle nut **344** are configured as a play-free ball screw drive.

[0082] The spindle nut **344** is connected on both sides of the swivel plane E**2** to an upper end section of the tool spindle **320**. The spindle nut **344** can be swiveled about a third swivel axis A" relative to the tool spindle **320** via two play-free rolling bearings **325**. The third swivel axis A" is again parallel to the A axis.

[0083] By actuating the A drive motor **340**, the threaded spindle **342** is driven to rotate about the threaded spindle axis **343**. This changes the position of the spindle nut **344** along the threaded spindle axis **343**. This causes the tool spindle **320** to swivel about the A axis. Due to the high transmission ratio, a relatively low drive torque of the A drive motor **340** is converted into a relatively high displacement force or a relatively high swivel torque onto the tool spindle **320**. All in all, the swivel movement of the tool spindle **320** can thus be executed very smoothly and precisely. Even during machining, it is possible to change the orientation of the tool spindle **320**. Clamping for stationary operation is not necessary.

[0084] The geometrical conditions prevailing here are explained in more detail in FIG. **4**. The A axis (see FIG. **2**) intersects the B axis in a region that lies between the end of the tool spindle **320** that faces the tool and the end that faces away from the tool. The tool **330** has a number of cutting edges at its free end, which together define a cutting edge plane **331**. This cutting edge plane **331** is a reference plane on the tool. The cutting edge plane **331** is perpendicular to the B axis. The distance of the cutting edge plane **331** from the A axis defines a lever arm H. The distance between the A axis and the third swivel axis A", about which the spindle nut **344** can be swiveled, defines a swivel radius R.

[0085] The radial cutting forces that act between the workpiece and the tool during workpiece machining result in corresponding torques about the A axis. The torque about the A axis for a given radial cutting force in the swivel plane E**2** is proportional to the length of the lever arm H. This torque in turn results in a corresponding axial force on the spindle nut **344** along threaded spindle axis **343**. This force is smaller the larger the swivel radius R. In the present case, the swivel radius R is significantly larger than the lever arm H. Preferably, the ratio R/H is larger than 1 and lies in particular between 1.5 and 3. The A drive motor **340** therefore only needs to absorb correspondingly reduced forces. This is advantageous for the rigidity of the machine with regard to vibrations about the A axis.

[0086] To dampen vibrations about the A axis, additionally two vibration dampers **346** are arranged between the tool spindle **320** and the X slide **310**. These extend on both sides of the swivel plane E**2** between the upper end section of the tool spindle **320** and the upper end section of the X slide **310**, adjacent to threaded spindle **342**.

[0087] For precise machining of the workpiece in a generating machining process such as the gear skiving process, precise knowledge of the orientation of the tool spindle **320** about the A axis, i.e. of the angle α between the B axis and the C axis (see FIG. **4**), is important. The angle α is also referred to in this document as the axis crossing angle. The machine preferably features two independent angle measuring devices for precise measurement of this angle. One of the angle measuring devices measures the angle of rotation of the threaded spindle **342**, this information can be used to indirectly determine the position of the spindle nut **344** along the threaded spindle **342** and therefore the tilt angle of the tool spindle **320**. This first angle measuring device is integrated in the A drive motor **340** and is indicated in FIG. **2** by reference sign **347**. At least one other angle measuring device measures directly the tilt angle of tool spindle **320** about the A axis and therefore the axis crossing angle α. This further angle measuring device is integrated in one of the two swivel bearings **314** and indicated by reference sign **323** (see FIG. **2**).

[0088] As illustrated in FIG. **4**, the axis crossing angle α can assume both positive and negative values. The axis crossing angle α is defined as positive when the tool **330** is inclined toward the X slide **310** and negative when the tool **330** is inclined away from the X slide **310**. The swivel range of the tool spindle **320** is asymmetrical: The axis crossing angle α can assume significantly larger positive than negative values. Specifically, the swivel range can be from −5° to +35°, but other swivel ranges are also possible. Due to the almost mirror-symmetrical design of the machine with respect to the center plane E**1**, this does not mean that the generating machining process is restricted to only one helix direction of the gear to be machined, because depending on the helix direction, the tool **330** can be brought into engagement with the gear to be machined either to the left or right of the center plane E**1**.

Positioning of the Tool Carrier in Z and X Direction

[0089] As already mentioned, the machine is designed in such a way that the position of the tool spindle **320** is adjustable both along the Z direction and along the X direction. The Z displacement is used for axial feed and the X displacement or a combination of X and Y displacements for radial infeed in generating machining. Since machining forces fluctuate particularly strongly along the Z direction, the adjustment along the Z direction is carried out with a Z slide **300** that is guided directly on the machine bed **100**; the X slide **310** is mounted on this Z slide as a tool carrier. This means that a much greater inertial mass needs to be moved along the Z direction than along the X direction. This helps to keep the amplitude of vibrations along the Z direction, which might be excited by the fluctuating machining forces, small.

[0090] In order to guide the Z slide **300** relative to the machine bed **100**, two parallel Z linear guides **301** are provided on the vertical portion **120** of the machine bed, extending parallel to the Z direction and being arranged on both sides symmetrically to the center plane E**1**. The Z slide **300** is guided on these linear guides **301** along the Z direction relative to the machine bed **100**. Each of the linear guides **301** is assigned a Z drive motor **302**. Each of these Z drive motors **302** interacts with the Z slide **300** via a play-free ball screw drive **303** to drive the Z slide **300** along the Z direction (see FIG. **5**). The Z linear guides **301**, Z drive motors **302** and ball screw drives **303** are each constructed almost identically in pairs and arranged symmetrically to each other with respect to the center plane E**1**. The two Z drive motors are either separately position-controlled ("double drive") or work together in master-slave operation.

[0091] In order to dampen vibrations along the Z direction, each Z linear guide **301** is optionally assigned a vibration damper not shown in the drawing. This vibration damper can be configured in particular according to Swiss patent application 1023/18 of Aug. 24, 2018. The vibration dampers are also identically constructed in pairs and arranged symmetrically.

[0092] Each of the two Z linear guides **301** is assigned a Z linear measuring system **350** in order to determine the position of the Z slide **300** on the machine bed **100** as accurately as possible (see FIG. **3**). The two Z linear measuring systems **350** are also identically constructed and arranged symmetrically with respect to the center plane E**1**. Each of these Z linear measuring systems has a measuring head **351**, which is attached to an outer surface of the Z slide **300**. In addition, each Z linear measuring system has a linear scale **352** attached to the machine bed **100**. The measuring head **351** is mounted so that it performs a position measurement in a plane E**4** that is perpendicular to the Z direction (i.e. a plane normal to the Z direction) and contains the A axis. This plane E**4** is particularly suitable for characterizing the position of the A axis relative to the machine bed **100** with respect to the Z direction and is therefore also referred to as the A reference plane.

[0093] In order to guide the X slide **310** on the Z slide **300**, two X linear guides **311** are provided on the Z slide **300**, parallel to each other, which extend parallel to the X direction and on which the X slide **310** is guided along the X direction relative to the Z slide. An X drive motor **312** is used to adjust the position of the X slide **310** along the X direction.

Positioning of the Workpiece Carrier in Y-Direction

[0094] The guidance and displacement of the Y slide **200** (i.e., the workpiece carrier) relative to the machine bed **100** along the Y direction is very similar to the guidance and displacement of the Z slide **300** along the Z direction. On the horizontal portion of the machine bed **100**, two parallel Y linear guides **201** are arranged symmetrically to the center plane E**1**. The Y slide **200** runs on these linear guides **201**. To drive the Y slide **200**, a separate Y drive motor **202** is assigned to each of the two linear guides **201** (see FIG. **3**). Each of the Y drive motors **202** interacts with the Y slide **200** via a play-free ball screw drive **203**. Again, the Y drive motors **202** can be separately position-controlled or operated in master-slave mode. In order to dampen vibrations along the Y direction, each linear guide **201** is optionally assigned a vibration damper (not shown in drawings), which can be configured according to Swiss patent application 1023/18 dated Aug. 24, 2018.

[0095] Each of the two linear guides **201** is assigned a Y linear measuring system **230**. Each of these Y linear measuring systems comprises a measuring head **231** mounted on the outside of the Y slide **200** and a linear scale **232** mounted on the machine bed **100**. The measuring head **231** carries out its position measurement in a plane E**3** that is perpendicular to the Y direction (i.e. a plane normal to the Y axis) and contains the C axis. This plane E**3** is particularly suitable for characterizing the position of the C axis relative to the machine bed **100** with respect to the Y direction and is therefore also referred to as the C reference plane.

[0096] As with the Z axis, all relevant components of the Y axis are identical in pairs and arranged symmetrically to the center plane E**1**, in particular the Y linear guides **201**, the Y drive motors **202**, the ball screw drives **203**, the vibration dampers and the Y linear measuring systems **230**.

Meshing Device

[0097] For the hard fine machining of pre-toothed workpieces, a meshing device **410** is arranged on the X slide **310**, which is configured to determine the angular position of the tooth gaps of the workpiece **220** with respect to the C axis without contact, so that the tool **330** can be brought into engagement with a pre-toothed workpiece **220** without collision. For this purpose, the meshing device **410** has a meshing probe **411** arranged at its lower end, which measures the tooth gaps in a known manner. The single meshing device **410** can be attached to either of the two cheeks **313** of the X slide **310**. For this purpose, the two cheeks have mounting surfaces **412** with corresponding holes on the front side (see FIG. **2**).

Measuring Bridge

[0098] In FIG. **3**, an optical measuring bridge **420** can be seen particularly well, which is mounted on the Y slide **200**

and is used to measure the tool **330**. In particular, the measuring bridge can be a laser measuring bridge with laser and photodetector. The measuring bridge **420** can be located either to the left or right of the center plane E**1** on the workpiece carrier **200**. For this purpose, corresponding mounting surfaces **421** with corresponding holes are provided on the Y slide **200** to the left and right of the center plane E**1** (see FIG. **4**). The tool can be measured in particular according to WO 2019/115332 A1.

Tool Changer

[0099] FIG. **5** schematically shows a changing device **430** for the automatic changing of the tool. The changing device is attached to the machine bed **100** and can also be arranged either to the left or right of the center plane E**1**. For this purpose, corresponding mounting surfaces **431** and holes are provided on the machine bed **100**.

Workpiece Loader

[0100] As shown in FIG. **5**, the machine is optionally equipped with a workpiece loader **440**. The workpiece loader can remove a finished workpiece **220** from the workpiece spindle **210** and replace it with a blank to be machined, or it can exchange the workpiece clamping device. Depending on the customer's requirements, the workpiece loader **440** can be located to the left or right of the center plane E**1**.

[0101] To avoid collisions with the meshing device **410**, the measuring bridge **420** or the tool changer **430** during the workpiece change, these additional components are arranged either to the left or right of the center plane E**1**, depending on the position of the workpiece loader **440**. The corresponding arrangement will be determined during the project planning phase of the machine according to the customer's requirements.

[0102] Alternatively, the workpiece loader can also be positioned at the front end of the machining area **130** in the center plane E**1**, as also indicated in FIG. **5**. If desired, it is also possible to arrange the workpiece loader at the rear of the machine so that the loading and unloading process takes place through an opening in the vertical portion **120** of the machine bed. For this purpose, the chip conveyor **500** is arranged rotated by 180° relative to the arrangement of FIGS. **1** to **6**, so that its rising section with the drive comes to rest at the front end of the machining area **130**. Due to the limited accessibility, however, this arrangement of the workpiece loader is only useful in exceptional cases.

Second Embodiment: Horizontal Workpiece Axis

[0103] While the machine of the first embodiment has a vertically aligned workpiece axis C, it is also conceivable to align the workpiece axis C horizontally without deviating from the principles described above. This is illustrated in FIG. **6**. Equal-acting parts carry the same reference signs as in FIGS. **1** to **5**.

[0104] Again, the machine bed **100** has a horizontal portion **110** and a vertical portion **120**. Unlike in the first embodiment, the Y slide **200**, which serves as a workpiece carrier, can now be displaced vertically on the vertical portion **120**, i.e. the Y direction is now vertical. Accordingly, the C axis now runs horizontally. As before, the C axis runs in a center plane E**1**, and the Y slide **200** on the machine bed **100** is guided symmetrically to the center plane by two linear guides. The Z slide **300** can now be moved horizontally on the horizontal portion **110** of the machine bed **100** parallel to the C axis, i.e. the Z direction is now horizontal. The Z slide is again guided symmetrically to the center plane by two linear guides. The X slide **310**, which serves as the tool carrier, is arranged on the Z slide **300** as in the first embodiment. It is constructed in the same way as in the first embodiment.

Method of Operation

[0105] A method of operation for a machine according to the first embodiment (FIGS. **1** to **5**) is now discussed.

[0106] In order to machine a workpiece blank, the Y slide **200** is first brought into a workpiece change position against the Y direction, the workpiece change position being illustrated in FIGS. **1** to **3**. In this position, the workpiece loader **440** is used to remove the last finished workpiece **220** from the workpiece spindle **210** and the workpiece blank to be machined is placed on the workpiece spindle **210** and clamped. Then the Y slide **200** is moved along the Y direction to a machining position as illustrated in FIG. **5**.

[0107] In the case of hard fine machining, the Z slide **300** and the X slide **310** are now positioned in such a way that the meshing device can measure the tooth gaps of the blank. In this way, the angular position of the tooth gaps of the blank is determined.

[0108] The Z slide **300** and the X slide **310** are then brought into a position in which the tool **330** meshes with the blank, as illustrated in FIG. **5**. The B axis extends offset either to the left or to the right of the center plane of the machine tool, depending on the helix angles of the workpiece and the tool. Now the generating machining of the blank is carried out in the usual way. The tool **330** and the workpiece **220** rotate at a fixed ratio of their rotational speeds. This positive coupling is carried out electronically by the machine controller.

[0109] If desired, the tool is measured with the aid of the measuring bridge **420**. In the case of a gear skiving tool, this can be done, for example, in a manner described in WO 2019/115332 A1. Such measurement can be carried out, for example, after each tool change and periodically after a certain number of machining operations.

[0110] If the tool has to be changed, this is preferably done with the changing device **430**.

Modifications

[0111] It goes without saying that the invention is not limited to the embodiments described above, but that various modifications are possible without leaving the scope of the invention.

[0112] For example, in the first embodiment, the Y direction can also be at an angle to the horizontal, but still parallel to the center plane E**1**. This may be advantageous under certain circumstances for design reasons or for reasons of loading and unloading the workpiece spindle. The Z direction does not necessarily have to be parallel to the C axis as long as this direction also remains parallel to the center plane E**1**. The symmetry of the machine is not destroyed by such modifications.

[0113] A variety of other modifications are possible. In particular, the machine can also be used for other generating machining processes than gear skiving. In this case, the tools that are typical for the respective process, preferably gear-wheel-shaped tools, are used. Combinations of two or more machining processes can also be carried out successively on the same machine. It is conceivable, for example, that a workpiece is first processed by gear skiving and then by gear honing.

[0114] In addition to hard fine machining, the machine can also be used for soft machining, whereby only the meshing probe must be put out of operation and tools typical of the soft machining process are used.

1. A machine tool for the machining of rotary parts with groove-shaped profiles by a generating method, the machine tool comprising:

a machine bed;

a Y slide linearly displaceable along a Y direction relative to the machine bed;

a workpiece spindle arranged on the Y slide and configured to clamp a workpiece thereon and to drive it to rotate about a workpiece axis (C), the workpiece axis (C) extending transversely to the Y direction;

a Z slide arranged on the machine bed and linearly displaceable along a Z direction relative to the machine bed, the Z direction running parallel to a center plane defined by the Y direction and the workpiece axis, and the Z direction extending at an angle of less than 45° to the workpiece axis;

an X slide arranged on the Z slide and linearly displaceable along an X direction relative to the Z slide, the X direction being perpendicular to the center plane; and

a tool spindle configured to drive a generating machining tool about a tool axis,

the tool spindle being arranged on the X slide and being pivotable relative to the X slide about a first swivel axis.

2. The machine tool according to claim **1**,

wherein the first swivel axis is perpendicular to the center plane,

wherein the tool axis is perpendicular to the first swivel axis, and

wherein the tool spindle is pivotable about the first swivel axis in a swivel plane that extends parallel to the center plane.

3. The machine tool according to claim **2**, wherein the machine tool comprises two first swivel bearings for pivotably supporting the tool spindle on the X slide about the first swivel axis, wherein the two first swivel bearings are arranged on both sides of the tool spindle with respect to the swivel plane.

4. The machine tool according to claim **2**, comprising an adjustment mechanism for adjusting the orientation of the tool spindle relative to the X slide,

wherein the adjustment mechanism is connected to the X slide so as to be pivotable about a second swivel axis, the second swivel axis extending parallel to and spaced apart from the first swivel axis-(A), and

wherein the adjustment mechanism is connected to the tool spindle so as to be pivotable about a third swivel axis, the third swivel axis extending parallel to and spaced apart from the first swivel axis and the second swivel axis.

5. The machine tool according to claim **4**,

wherein the machine tool comprises two second swivel bearings for pivotably supporting the adjustment mechanism on the X slide about the second swivel axis, wherein the two second swivel bearings are arranged on both sides of the swivel plane, and/or

wherein the machine tool comprises two third swivel bearings for pivotably supporting the adjustment mechanism on the tool spindle about the third swivel axis, wherein the two third swivel bearings are arranged on both sides of the swivel plane.

6. The machine tool according to claim **4**, wherein the adjustment mechanism comprises:

an A-drive motor, which is mounted on the X slide so as to be pivotable about the second swivel axis

a threaded spindle drivable by the A-drive motor to rotate about a threaded spindle axis extending perpendicular to the first swivel axis, the threaded spindle axis extending in the swivel plane; and

a spindle nut which is in engagement with the threaded spindle (**342**) and is connected to the tool spindle (**320**) so as to be pivotable about the third swivel axis (A").

7. The machine tool according to claim **6**, comprising:

a first angle measuring device configured to determine a rotation angle of the threaded spindle about the threaded spindle axis; and/or

a second angle measuring device configured to directly determine a swivel angle of the tool spindle about the first swivel axis relative to the X slide.

8. The machine tool according to claim **4**,

wherein the tool spindle has an end that faces the tool and an end that faces away from the tool,

wherein a generating machining tool is clamped on the tool spindle at the end that faces the tool, the generating machining tool defining a tool reference plane, the tool reference plane extending perpendicularly to the tool axis,

wherein the first swivel axis intersects the tool axis between the end of the tool spindle that faces the tool and the end that faces away from the tool,

wherein the first swivel axis and the tool reference plane extend at a first distance from each other,

wherein the first swivel axis and the third swivel axis extend at a second distance from each other, and

wherein the second distance and the first distance have a ratio greater than 1.

9. The machine tool according to claim **1**, comprising:

at least one vibration damper acting between the tool spindle and the X slide in order to damp vibrations of the tool spindle about the first swivel axis.

10. The machine tool according to claim **1**,

wherein the tool spindle is pivotable relative to the X slide about the first swivel axis in such a manner that an axis crossing angle between the tool axis and the workpiece axis is able to takes on negative and positive values between a smallest negative value and a maximum positive value, and

wherein the maximum positive value of the axis crossing angle is greater than a magnitude of the smallest negative value.

11. The machine tool according to claim **1**, wherein the workpiece axis runs vertical in space.

12. The machine tool according to claim **1**,

wherein the machine tool comprises two mutually parallel Z linear guides on which the Z slide is guided along the Z direction relative to the machine bed, the Z linear guides extending parallel to the Z direction and being arranged on both sides of the center plane, wherein the machine tool comprises two Z-drives for moving the Z slide along the Z direction relative to the machine bed, and

wherein each of the Z-drives is assigned to one of the Z linear guides.

13. The machine tool according to claim **12**, comprising at least one, preferably two Z linear measuring systems, each of the Z linear measuring systems comprising a measuring head mounted on the Z slide and a linear scale mounted on the machine bed, and wherein the measuring heads of the Z linear measuring systems are arranged such that they carry out a position measurement in an A-reference plane which is perpendicular to the Z direction and contains the first swivel axis.

14. The machine tool according to claim **1**,

wherein the machine tool comprises two parallel Y linear guides which extend parallel to the Y direction, are arranged on both sides of the center plane and on which the Y slide is guided along the Y direction relative to the machine bed,

wherein the machine tool comprises two Y drives for moving the Y slide along the Y direction relative to the machine bed, and

wherein in each case one of the Y drives is assigned to each of the Y linear guides.

15. The machine tool according to claim **14**, comprising at least one Y linear measuring system, each Y linear measuring systems comprising a measuring head mounted on the Y slide and a linear scale mounted on the machine bed, and wherein the measuring heads of the Y linear measuring systems are arranged in such a way that they perform a position measurement in a C reference plane which is perpendicular to the Y direction and contains the workpiece axis.

16. The machine tool according to claim **1**,

wherein the machine tool comprises at least one of the following additional components:

a meshing device for determining a position of tooth gaps of the workpiece;

an optical measuring bridge for measuring the workpiece and/or the tool; and

a tool changing device for changing the tool, and

wherein the machine tool has two alternative fastening structures for each of the additional components, the alternative fastening structures being arranged on both sides of the center plane.

17. The machine tool according to claim **1**,

wherein the machine tool comprises a chip conveyor, and

wherein the machine bed has a central opening to allow discharge of chips onto the chip conveyor.

18. The machine tool according to claim **1**, comprising a controller configured to establish a positive coupling between a rotation of the generating machining tool and a rotation of the workpiece.

19. A method of machining a workpiece with a machine tool according to claim **1**, the method comprising:

bringing a generating machining tool clamped on the tool spindle into engagement with the workpiece while the workpiece is clamped on the workpiece spindle, wherein the engagement takes place in an arrangement of the generating machining tool relative to the workpiece in which the tool axis extends offset to the center plane of the machine tool; and

carrying out a generating machining operation on the workpiece with the machine tool.

20. The method according to claim **19**, wherein the generating machining tool is gear-shaped.

21. The method according to claim **19**, wherein the generating machining tool is a gear skiving tool.

22. The machine tool according to claim **1**, wherein the workpiece axis extends perpendicularly to the Y direction.

23. The machine tool according to claim **1**, wherein the Z direction extends parallel to the workpiece axis.

24. The machine tool according to claim **2**, wherein the first swivel axis intersects the tool axis.

25. The machine tool according to claim **3**, wherein the two first swivel bearings are equidistant from the swivel plane.

26. The machine tool according to claim **8**, wherein the generating machining tool is gear-shaped.

27. The machine tool according to claim **8**, wherein the generating machining tool is a gear skiving tool.

28. The machine tool according to claim **8**, wherein the generating machining tool comprises a plurality of cutting edges arranged at a distal end of the tool, and wherein the tool reference plane extends through the cutting edges of the tool.

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