Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 2980503 C 2023/05/09

(11)(21) **2 980 503**

(12) **BREVET CANADIEN
CANADIAN PATENT**

(13) **C**

(86) **Date de dépôt PCT/PCT Filing Date:** 2016/03/23
(87) **Date publication PCT/PCT Publication Date:** 2016/09/29
(45) **Date de délivrance/Issue Date:** 2023/05/09
(85) **Entrée phase nationale/National Entry:** 2017/09/21
(86) **N° demande PCT/PCT Application No.:** EP 2016/056310
(87) **N° publication PCT/PCT Publication No.:** 2016/150986
(30) **Priorité/Priority:** 2015/03/23 (DE102015104289.4)

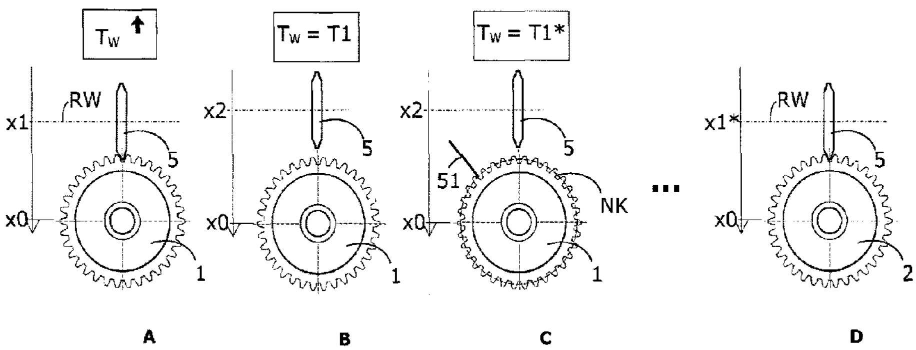
(51) **Cl.Int./Int.Cl.** *G05B 19/404* (2006.01), *B23Q 15/22* (2006.01)

(72) **Inventeurs/Inventors:**
WEBER, JURGEN, DE;
RIBBECK, KARL-MARTIN, DE;
BLASBERG, HERBERT, DE

(73) **Propriétaire/Owner:**
KLINGELNBERG AG, CH

(74) **Agent:** ROBIC

(54) Titre : PROCEDE SERVANT A FAIRE FONCTIONNER UN MACHINE A USINAGE DE DENTURE
(54) Title: METHOD FOR OPERATING A GEAR-PROCESSING MACHINE



(57) **Abrégé/Abstract:**
Method for operating a gear cutting machine comprising the following steps: - machining a first workpiece (1) in the machine, wherein the first workpiece (1) heats up due to the machining, - determining at least one characteristic workpiece variable in the first workpiece (1) in the heated state, wherein a measuring device of the machine is used for the determination, - determining a compensation on the basis of the at least one characteristic workpiece variable of the first workpiece (1) and at least one characteristic workpiece variable of a reference workpiece, wherein - the characteristic workpiece variable of the reference workpiece is determined in the machine after a steady-state temperature has been reached, - at least one compensation value is determined in the course of determining the compensation, - adjusting of the machine setting by taking into account the at least one compensation value, - and machining a further workpiece (2) in the machine.

(12) NACH DEM VERTRAG ÜBER DIE INTERNATIONALE ZUSAMMENARBEIT AUF DEM GEBIET DES PATENTWESENS (PCT) VERÖFFENTLICHTE INTERNATIONALE ANMELDUNG

(19) Weltorganisation für geistiges Eigentum
Internationales Büro

(43) Internationales Veröffentlichungsdatum
29. September 2016 (29.09.2016)

WIPO | PCT

(10) Internationale Veröffentlichungsnummer
WO 2016/150986 A1

(51) Internationale Patentklassifikation:
G05B 19/404 (2006.01) ***B23Q 15/22*** (2006.01)

(21) Internationales Aktenzeichen: PCT/EP2016/056310

(22) Internationales Anmeldedatum:
23. März 2016 (23.03.2016)

(25) Einreichungssprache: Deutsch

(26) Veröffentlichungssprache: Deutsch

(30) Angaben zur Priorität:
102015104289.4 23. März 2015 (23.03.2015) DE

(71) Anmelder: **KLINGELNBERG AG** [CH/CH]; Binzmühlestrasse 171, 8050 Zürich (CH).

(72) Erfinder: **WEBER, Jürgen**; Weststrasse 3, 42499 Hückeswagen (DE). **RIBBECK, Karl-Martin**; Heidestrasse 17, 42897 Remscheid (DE). **BLASBERG, Herbert**; Lindenbergstrasse 30, 42499 Hückeswagen (DE).

(74) Anwalt: **HEUSCH, Christian**; Ant-IP GmbH, Kirchplatz 2, 82387 Antdorf (DE).

(81) Bestimmungsstaaten *(soweit nicht anders angegeben, für jede verfügbare nationale Schutzrechtsart)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Bestimmungsstaaten *(soweit nicht anders angegeben, für jede verfügbare regionale Schutzrechtsart)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), eurasisches (AM, AZ, BY, KG, KZ, RU, TJ, TM), europäisches (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Veröffentlicht:

— *mit internationalem Recherchenbericht (Artikel 21 Absatz 3)*

(54) Title: METHOD FOR OPERATING A GEAR CUTTING MACHINE

(54) Bezeichnung : VERFAHREN ZUM BETREIBEN EINER VERZAHNUNGSBEARBEITENDEN MASCHINE

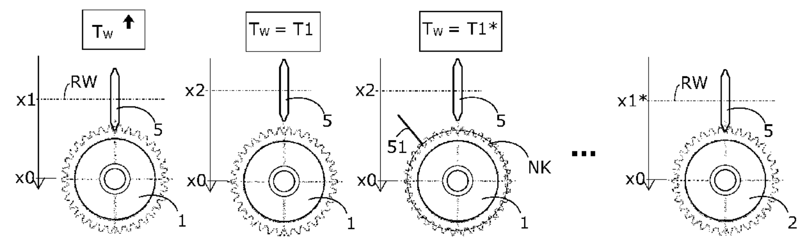


Fig. 3A Fig. 3B Fig. 3C Fig. 3D

(57) Abstract: Method for operating a gear cutting machine comprising the following steps: - machining a first workpiece (1) in the machine, wherein the first workpiece (1) heats up due to the machining, - determining at least one characteristic workpiece variable in the first workpiece (1) in the heated state, wherein a measuring device of the machine is used for the determination, - determining a compensation on the basis of the at least one characteristic workpiece variable of the first workpiece (1) and at least one characteristic workpiece variable of a reference workpiece, wherein - the characteristic workpiece variable of the reference workpiece is determined in the machine after a steady-state temperature has been reached, - at least one compensation value is determined in the course of determining the compensation, - adjusting of the machine setting by taking into account the at least one compensation value, - and machining a further workpiece (2) in the machine.

(57) Zusammenfassung: Verfahren zum Betreiben einer verzahnungsbearbeitenden Maschine mit den folgenden Schritten: - Durchführen der Bearbeitung eines ersten Werkstücks (1) in der Maschine, wobei sich das erste Werkstück (1) aufgrund

[Fortsetzung auf der nächsten Seite]

WO 2016/150986 A1

WO 2016/150986 A1

der Bearbeitung erwärmt, - Ermitteln mindestens einer charakteristischen Werkstückgröße an dem ersten Werkstück (1) im erwärmten Zustand, wobei zum Ermitteln eine Messvorrichtung der Maschine zum Einsatz kommt, - Durchführen einer Kompensationsermittlung anhand der mindestens einen charakteristischen Werkstückgröße des ersten Werkstücks (1) und mindestens einer charakteristischen Werkstückgröße eines Referenzwerkstücks, wobei - die charakteristische Werkstückgröße des Referenzwerkstücks in der Maschine nach dem Erreichen einer Beharrungstemperatur ermittelt wurde, - im Rahmen der Kompensationsermittlung mindestens ein Kompensationswert ermittelt wird, - Anpassen der Maschineneinstellung unter Berücksichtigung des mindestens einen Kompensationswerts, - Durchführen der Bearbeitung eines weiteren Werkstücks (2) in der Maschine.

Method for operating a gear-processing machine

Area of the Invention

[0001] The subject matter of the invention is a method for operating a gear-processing machine. In particular, it relates to a method for temperature compensation in a gear-processing machine.

Background of the Invention, Prior Art

[0002] There are various methods for the chip removing processing of gearwheels. The correspondingly designed machines are referred to here as gear-processing machines.

[0003] It is known that the temperature of the gear-processing machine increases with time because of various procedures in the machine. In continuous operation of a machine, it reaches a so-called steady-state temperature. The steady-state temperature results in a thermally stationary state. In this state, the temperature of the machine has thermally stabilized. A stabilization of the heat flows thus occurs over time, which results in a stationary state.

[0004] It is also known that inaccuracies can occur in a machining process because of thermal expansion processes. This is because, *inter alia*, the greatly varying elements of the machine experience a thermal expansion with increasing temperature. A corresponding thermal contraction occurs upon cooling. On the one hand, the dimensions of the individual machine elements change with increasing temperature of the machine. Since numerous elements are connected to one another in a machine, tensions (and warping) can occur because of different coefficients of expansion, which are displayed in nonlinear expansion behavior, which cannot be computed accurately, of the machine.

[0005] The thermal behavior of a machine is influenced by the effect of heat sources and heatsinks. A differentiation is made in the case of thermal effects between internal and external influences. For example, the heat emission of motors is considered to be an internal influence. A further internal influence results from the cutting interaction of a tool with a workpiece, because mechanical energy is converted into heat here. External influences are, for example, the ambient temperature in a machine shop.

[0006] It is immediately apparent that the length, for example, of a cantilever, which is connected on one side to a machine stand, for example, increases with increasing temperature. Such a cantilever experiences a linear expansion in the longitudinal direction. In the case of complicated machine elements and more complex geometries, for example, a spindle bearing, the relationships are significantly more complex.

[0007] The operating accuracy of chip producing machines is substantially dependent on how accurately the movements in the three-dimensional space between the tool and the workpiece can be executed. Finally, relative deviations during the movement of the tool relative to the workpiece result due to all temperature-related effects. These relative deviations result in deviations on the workpiece.

[0008] Productivity and accuracy are important aspects of machine tools. The thermal accuracy of machines is gaining more and more significance in consideration of strongly increased demands in the matter of manufacturing precision. Particularly in the case of small manufacturing batches and therefore changing machine tasks, a thermally stable state cannot be achieved. In the case of machines which are in continuous use, the accuracy gains significance above all after an interruption. Moreover, one wishes to reduce the discards which typically occur after an interruption until the machine has again reached the steady-state temperature to some extent. Thus, in addition to accuracy, this also relates to questions of cost-effectiveness.

[0009] One common approach is to keep machine and surroundings at a consistent temperature level. The deformation of the machine may be avoided by way of a uniform temperature. For this purpose, on the one hand the machine shop has to be climate-controlled and, on the other hand, the machine has to be continuously operated. The expenditure in costs and energy is correspondingly high.

[0010] Another approach is monitoring the deformation of the machine by way of integrated sensors. On the basis of a mathematical model, in which the data of the sensors are further processed, the foundation can be formed for an approximate prediction of the flaws, which would arise on the workpiece. If these flaws are known, the machine can thus adapt accordingly and compensate for the flaws. The expenditure is also high here. Moreover, there have been no technological approaches up to this point which meet the high accuracy requirements.

[0011] In consideration of the above statements, the following object results. It relates to finding an approach which enables compensating for temperature-related changes of a machine. Above all, this relates to improving the accuracy of a machining process in a machine immediately after an interruption, to thus reduce the discards. A pause which is preferably longer than 15 minutes is referred to as an interruption.

Summary

[0012] According to an aspect, a method for operating a gear-processing machine is provided. The method includes: carrying out the machining of a first workpiece in the machine, wherein the first workpiece heats up because of the machining; determining at least one characteristic workpiece variable on the first workpiece in the heated state, wherein a measuring device of the machine is used for the determination; carrying out a compensation determination on the basis of the at least one characteristic workpiece variable of the first workpiece and at least one characteristic workpiece variable of a reference workpiece; wherein the characteristic workpiece variable of the reference workpiece was determined in the machine after reaching a steady-state temperature, and at least one compensation value is determined in the scope of the compensation determination; adapting the machine setting in consideration of the at least one compensation value; and carrying out the machining of a further workpiece in the machine.

Date Reçue/Date Received 2022-05-31

[0013] Further preferred embodiments can be inferred from the claims appended hereto.

DRAWINGS

[0014] Further details and advantages of the invention will be described hereafter on the basis of exemplary embodiments and with reference to the drawings.

FIG. 1 shows a schematic front view of a gear-processing machine, in which the method according to the invention can be used;

Date Reçue/Date Received 2022-05-31

FIG. 2A shows a perspective view of a part of an exemplary gear-processing machine having measuring device, in which the method according to the invention can be used, wherein a workpiece is being machined at the moment shown;

FIG. 2B shows a perspective view of a part of the gear-processing machine of Fig. 2A, wherein the measuring device of the machine is being used at the moment shown (this relates here to a structure having a measuring probe, which is referenced before the measurement);

FIG. 3A shows a top view of a tool and a workpiece of an exemplary gear-processing machine having measuring device, wherein the workpiece is machined using the tool at the moment shown;

FIG. 3B shows a top view of the tool in the workpiece of Fig. 3A, wherein the tool is moved away relative to the workpiece at the moment shown;

FIG. 3C shows a top view of the tool and the workpiece of Fig. 3A, wherein the measuring device of the machine is being used at the moment shown;

FIG. 3D shows a top view of the tool and a second workpiece, wherein the workpiece is machined using the second tool at the moment shown.

DETAILED DESCRIPTION

[0015] Terms are used in conjunction with the present invention, which are also used in relevant publications and patents. However, it is to be noted that the use of these terms is only to serve for better comprehension. The inventive concept and the scope of protection of the patent claims are not to be restricted in the interpretation thereof by the specific selection of the terms. The invention may be readily transferred to other term systems and/or technical fields. The terms are to be applied accordingly in other technical fields.

[0016] Fig. 1 shows a schematic view of a (gearwheel) machine 100 equipped according to the invention. The machine 100 is a gear-processing machine. The actual machining space – in which gearwheels (corresponding blanks 4 are shown on the right in the region of a workpiece supply 10) are machined – is located behind the panel 11, which can be provided with viewing windows 12, for example.

A (CNC) controller 41 can be housed in the housing of the same machine 100 or in a separate housing 40.

[0017] The machine 100 is especially designed for the cutting machining (for example, grinding or milling) of the tooth flanks of gearwheels. Since this primarily relates to the mass production of gearwheels here, reference is made hereafter to a first workpiece 1, a second workpiece 2, and a third workpiece 3. Numerals are used here to specify a chronological sequence. The first workpiece 1 is machined in chronological sequence before the second and each further workpiece. The second workpiece 2 is machined after the workpiece 1 and before the workpiece 3. It is important to note in conjunction with the present invention that the second workpiece 2 does not have to be machined directly after the first workpiece 1 and the third workpiece 3 does not have to be machined directly after the second workpiece 2.

[0018] Exemplary details of the operating range of a machine 100 are shown in Figures 2A and 2B. The example shown is a machine 100 which comprises a worm grinding wheel as a tool 5 and is designed for the roller grinding of spur gears. The invention can also be used in other machines (for example, in a machine for grinding bevel gears). The rotary drive (spindle drive) of the tool 5 is identified by the reference sign 6. The cutting machining of the workpiece 1 using the tool 5 is shown in Fig. 2A. At the moment shown, the tool 5 is operatively connected to the workpiece 1.

[0019] It can be inferred from Figures 2A and 2B that the machine 100 has clamping means for clamping a workpiece to be machined (for example, a blank 4). The workpiece 1 is clamped on the workpiece spindle 7 in Figures 2A and 2B. The clamping means cannot be seen directly. In addition, the machine 100 comprises a tool clamping means for chucking a gear-processing tool 5 (for example, a grinding or milling tool) for the cutting machining of the tooth flanks of the workpiece 1. The tool clamping means cannot be seen in the figures, since they are seated in the region between the tool 5 and the rotary drive 6.

[0020] In addition, the machine 100 comprises a measuring device 50, as shown in very schematic form in Figures 2A and 2B. This measuring device 50 is a component of the machine 100 in all embodiments, i.e., the measuring device 50 is fastened on the machine 100. The measuring device 50 according to Figures 2A and 2B is designed so that it can be referenced. The referencing enables the most accurate possible measuring on the workpiece 1 in spite of temperature-related changes, which can also affect the measuring device 50.

[0021] The measuring device 50 is preferably designed in all embodiments so that it can be moved away, so as not to be damaged during the machining of the workpiece 1 using the tool 5. It is indicated by way of example in Fig. 2A and Fig. 2B that the measuring device 50 can have a telescoping structure. In Fig. 2A, the telescoping structure is retracted and the actual sensor 51 is folded or pivoted away. In Fig. 2B, the telescoping structure is extended and the sensor 51 has been folded or pivoted into a tooth gap.

[0022] In all embodiments, the machine 100 preferably comprises a reference point or a reference surface 13, which is indicated in Figures 2A and 2B. This reference point or this reference surface 13 is designed as temperature-stable or temperature-neutral, so that a reference is available within the machine 100, which is not subject to temperature-related displacements or changes. The acquisition of a reference variable from a reference point or a reference surface 13 is referred to here as referencing.

[0023] The measuring device 50 is preferably designed as temperature-neutral in all embodiments, so that corrupted measurement results are not obtained due to temperature changes.

[0024] In all embodiments, the measuring device 50 is preferably positioned as close as possible to the workpiece spindle 7 and not in the region of the tool 5 (temperature neutral with respect to its location relative to the workpiece 1) or the measuring device 50 is to be referenced before the measurement (see Figures 2A and 2B). Otherwise, measuring would occur incorrectly during a measurement after a pause (cooling).

[0025] In all embodiments, the measuring device 50 preferably comprises a temperature-neutral and rigid construction, so that it also remains stable under various temperature influences. The essential elements of the measuring device 50 can be constructed, for example, from a combination of carbon fiber composite materials and ceramic (for a minimum weight and high for a high level of rigidity). The measuring standards which are used can be manufactured, for example, from a temperature-neutral ceramic. Additionally or alternatively, the measuring device 50 can be embodied as temperature-compensated (for example, having an active dynamic temperature compensation).

[0026] In machines 100 which are equipped with a reference point or a reference surface 13, the measuring device 50 can get a spatial reference during referencing, for example, by the sensor 51 scanning the reference point or the reference surface 13. The coordinate values of the reference point or the reference surface 13 can then be used during subsequent computations as a computer reference, for example.

[0027] Because of the cutting machining, a workpiece temperature T_W results, which reaches the value T1 indicated in Fig. 2A. After the machining is completed, a relative movement is executed in the machine 100 to separate the tool 5 from the workpiece 1. The corresponding state is shown in Fig. 2B. The workpiece 1 slowly cools down. A workpiece temperature T_W results, which assumes the value T1* indicated in Fig. 2B. The following statement applies in this case: T1 > T1*.

[0028] The measuring device 50 is now used, as indicated in Fig. 2B. At least one characteristic workpiece variable W.1 of the workpiece 1 is ascertained by means of the measuring device 50. This is performed according to the invention as immediately as possible after the machining of the workpiece 1. This means the workpiece 1 is still hot upon the ascertainment of the characteristic workpiece variable W.1.

[0029] Several exemplary numeric values from practice are provided hereafter. The steady-state temperature T_{VH} of a machine 100 is dependent, *inter* *alia*, on the ambient temperature. Temperature differences between a machine just put into operation and an operationally-hot machine of 20° to greater than 30° result during milling, for example. The temperatures of the workpieces 1 can increase to up to 60°C after milling machining, i.e., they experience a temperature increase by approximately 40°C due to the machining. The temperature changes on a grinding machine are significantly below these values.

[0030] Since blanks 4 or workpieces 1 are machined in the machine 100 which are turned parts, for example, the circumferential surface thereof (cylinder lateral surface in a spur gear or truncated cone surface in a bevel gear) are not are not accurately dimensioned. The scanning of the circumferential surface using the measuring device 50 therefore does not result in usable workpiece variables, even if the measuring device 50 operates accurately in the event of changing temperatures or measures in a temperature-compensated manner. According to the invention, the characteristic workpiece variable W.1 is therefore preferably determined in all embodiments on surfaces or points which were just machined in the machine 100. In the example of Fig. 2B, the sensor 51 penetrates into a tooth gap, to scan the gap width therein, for example. The gap width can be scanned, for example, on the pitch circle NK of the workpiece 1 and supplied for further processing as the characteristic workpiece variable W.1.

[0031] Further aspects of the invention will be described hereafter on the basis of the method steps which are executed during the operation of the gear-processing machine 100. The machine 100 according to the invention is distinguished in that it is designed for carrying out the method described in greater detail hereafter. A suitable machine 100 preferably also comprises, in addition to the required axes, clamping means, and drives, the mentioned measuring device 50. Furthermore, software is used, which is installed in the machine 100 or in a system connectable to the machine 100.

[0032] The method preferably comprises the following steps:

- The machining of a first workpiece 1 is carried out in the machine 100 (see Fig. 2A), wherein the first workpiece 1 heats up because of the machining. The workpiece 1 reaches a temperature of $T_W = T1$.

- At least one characteristic workpiece variable W.1 is then determined on the first workpiece 1 in the heated state (here at $T_W = T1^*$), wherein the sensor 51 of the machine 100 is used for the determination. A corresponding snapshot is shown in Fig. 2B.
- A so-called compensation determination is then carried out. This is performed on the basis of the at least one characteristic workpiece variable W.1 of the first workpiece 1 and on the basis of at least one characteristic workpiece variable W.R of a reference workpiece R. In the above-mentioned example, for example, the gap width of the first workpiece 1 at $T_W = T1^*$ is compared to the gap width of a reference workpiece R. It is to be noted in this case that the characteristic workpiece variable W.R of the reference workpiece R has also been determined in the hot state. The characteristic workpiece variable W.R of the reference workpiece R was preferably also determined at a temperature which approximately corresponds to the temperature $T1^*$. In all embodiments, the characteristic workpiece variable W.R of the reference workpiece R is preferably determined in the machine 100 after reaching the steady-state temperature T_{VH}. This means this characteristic workpiece variable W.R was determined after the machine 100 was operated for a long time and was therefore in the thermally stabilized state. At least one compensation value is determined in the scope of the compensation determination. In the mentioned example, for example, the following situation is conceivable. Because of the fact that the temperature of the machine 100 was still below the steady-state temperature T_{VH} during the machining of the first workpiece 1, the workpiece 1 has somewhat different dimensions than the reference workpiece R. In the described example, for example, the gap width of the reference workpiece R is somewhat greater than the gap width of the first workpiece 1. The difference of the two gap widths (i.e., the difference of the two characteristic workpiece variables W.R and W.1) is computed in the scope of the compensation determination. A compensation value can be determined therefrom for the machining of the next workpiece 2 in the machine 100. In a completing method, in which the profile of the tool 5 specifies the shape of the tooth gaps on the workpiece, the compensation value can specify that during the machining of the next workpiece 2, the tool 5 has to plunge somewhat deeper into the tooth gap to be machined.

- At least one machine setting is now adapted on the basis of the compensation value. In the mentioned example, for example, the plunging depth is changed in consideration of the compensation value.
- The machining, for example, of the second workpiece n = 2 in the machine 100 is then performed. The gap width which was previously determined to be excessively small on the workpiece 1 is thus compensated for on the workpiece 2.

[0033] This example is clarified further on the basis of Figures 3A to 3D. A spur gear is shown as the first workpiece 1 in these Figures. A grinding disk is used as the tool 5 in the scope of a completing method. The profile of the tool 5 determines the shape of the tooth gaps on the workpiece 1.

[0034] A fixed coordinate axis x is shown on the left in each of Figures 3A to 3D. This coordinate axis x is used solely to illustrate the relationships.

[0035] The rotational axis of the tool RW is in the plane of the drawing in Figures 3A to 3D. It can be seen in Fig. 3A that the tool 5 is plunged with its rotational axis RW up to a position x1 into the tooth gap of the workpiece 1. The rotational axis RA of the workpiece 1 is perpendicular to the plane of the drawing and is located fixed here at the position x = x0.

[0036] After the workpiece 1 has been machined, workpiece 1 and tool 5 are separated in relation to one another. This step is shown in Fig. 3B. In the example shown, the workpiece 1 remains in the previous position x = x0 and the rotational axis RW of the tool 5 is moved back together with the tool 5 (from the position x1 to the position x2 here). The determination of the characteristic workpiece variable W.1 of the first workpiece 1 is now performed. For this purpose, a sensor 51 is plunged into a tooth gap of the workpiece 1 and moved toward the left and toward the right tooth flank of this tooth gap. This can be performed, for example, on the pitch circle NK. The compensation determination is now carried out (preferably by computer by means of software) to determine whether and to what extent the gap width of the first workpiece 1 deviates from a gap width of a reference workpiece R used as a reference variable W.R.

[0037] In the described example, for example, the gap width of the reference workpiece R is somewhat less than the gap width of the first workpiece 1. The difference of the two gap widths (i.e., the difference of the two characteristic workpiece variables W.R and W.1) is computed in the scope of the compensation determination.

[0038] In a subsequent method step, as shown in Fig. 3D, a further workpiece is machined. The example shown relates to the second workpiece 2. Since the measured gap width on the hot workpiece 1 was greater than on the hot reference workpiece R, in the step of Fig. 3D, the tool 5 does not have to plunge as far into the material of the workpiece 2 as was the case in Fig. 3A. As a compensation value, for example, a value x1* can be determined. The difference (parallel to the x axis) between the value x1 and the value x1* results from a transformation computation. This means the value x1* is determined so that (if the temperature of the machine 100 and the workpiece 2 are the same as in Fig. 3A), in spite of temperature-related deviations, the tool 5 plunges in somewhat less. A workpiece 2 is now manufactured in Fig. 3D, the values of which have been compensated for in the manner of temperature faults. In Fig. 3D: $|x0 - x1^*| > |x0 - x1|$.

[0039] According to the invention, the determination of characteristic workpiece variables can be repeated from time to time while the machine 100 heats up further. Thus, for example, the third workpiece 3 and the fourth to tenth workpieces can be manufactured with the same compensation value as described in conjunction with Fig. 3D. The tenth workpiece can be measured again (as shown in Fig. 3C) in the hot state (like the first workpiece 1 previously). A compensation value can then be determined for the eleventh workpiece. The eleventh workpiece is then machined with application of this compensation value. It can thus be ensured until reaching the steady-state temperature T_{VH} that the workpieces processed in the intervening period of time are relatively dimensionally accurate.

[0040] To preclude faults after an interruption (for example, because an incorrect tool was chucked), before carrying out the machining of the first workpiece 1, the following steps can be carried out on another workpiece 0:

- carrying out the machining of this other workpiece 0 in the machine 100, wherein this other workpiece 0 heats up during the machining,
- determining one or more characteristic variables of this other workpiece 0 in the cooled state, to establish whether this other workpiece 0 corresponds to target values,
- if this other workpiece 0 corresponds to the target values, it is possible to begin with the machining of the first workpiece 1, as described. If this other workpiece 0 should not correspond to the target values, a check thus has to be carried out (for example, by the operator of the machine 100).

[0041] This can be carried out in a separate measuring machine, which is connectable via a closed loop to the machine 100.

List of reference signs

workpiece	0
first workpiece	1
second workpiece	2
third workpiece	3
blanks	4
tool	5
tool drive	6
workpiece spindle	7
workpiece supply	10
panel	11
viewing window	12
reference point/reference surface	13
separate housing	40
(CNC) controller	41
measuring device	50
sensor	51
machine	100
further workpiece	n
pitch circle	NK
reference workpiece	R
rotational axis of the workpiece	RA
characteristic workpiece variable of the first workpiece	W.1
characteristic workpiece variable of the second workpiece	W.2
characteristic workpiece variable of the reference workpiece	W.R
interruption	Δt
rotational axis of the tool	RW
machining temperature	T1
temperature shortly after the machining	T1*
steady-state temperature	T_{VH}
workpiece temperature	T_W
coordinate axis	x
values on the coordinate axis	x0, x1, x2
corrected value on the coordinate axis	x1*

CLAIMS:

1. A method for operating a gear-processing machine, comprising the following steps:
   - carrying out the machining of a first workpiece in the machine, wherein the first workpiece heats up because of the machining,
   - determining at least one characteristic workpiece variable on the first workpiece in the heated state, wherein a measuring device of the machine is used for the determination,
   - carrying out a compensation determination on the basis of the at least one characteristic workpiece variable of the first workpiece and at least one characteristic workpiece variable of a reference workpiece, wherein
     - o the characteristic workpiece variable of the reference workpiece was determined in the machine after reaching a steady-state temperature,
     - o at least one compensation value is determined in the scope of the compensation determination,
   - adapting the machine setting in consideration of the at least one compensation value,
   - carrying out the machining of a further workpiece in the machine.

2. The method according to claim 1, characterized in that the reference workpiece is one of the workpieces which were machined before an interruption in the machine.

3. The method according to claim 1 or 2, characterized in that carrying out the machining of the first workpiece and the determination of at least one characteristic workpiece variable are performed in the machine immediately after an interruption.

4. The method according to any one of claims 1 to 3, characterized in that the steady-state temperature is the temperature of the machine which results on or in the machine in continuous operation.

5. The method according to any one of claims 1 to 4, characterized in that the determination of the characteristic workpiece variables is performed by means

Date Reçue/Date Received 2022-05-31

of a measuring probe of the measuring device, wherein the measuring device is part of the machine and wherein the corresponding workpiece is not re-chucked during the determination of the characteristic workpiece variables.

6. The method according to any one of claims 1 to 5, characterized in that the interruption occurred for one of the following reasons:
   - stoppage of the machine because of a shutdown,
   - stoppage of the machine because of maintenance or repair,
   - stoppage of the machine because of refitting.

7. The method according to any one of claims 1 to 5, characterized in that the interruption lasts at least 15 minutes.

8. The method as claimed in any one of claims 1 to 3, characterized in that a stoppage of the machine counts as an interruption if a temperature measured on or in the machine is less by more than 10% than the steady-state temperature, which results on or in the machine in continuous operation.

9. The method as claimed in any one of claims 1 to 3, characterized in that before carrying out the machining of the first workpiece, the following steps are carried out on another workpiece:
   - carrying out the machining of this other workpiece in the machine, wherein this other workpiece heats up during the machining,
   - determining one or more characteristic variables of this other workpiece in the cooled state, to determine whether this other workpiece corresponds to target values.

Date Reçue/Date Received 2022-05-31

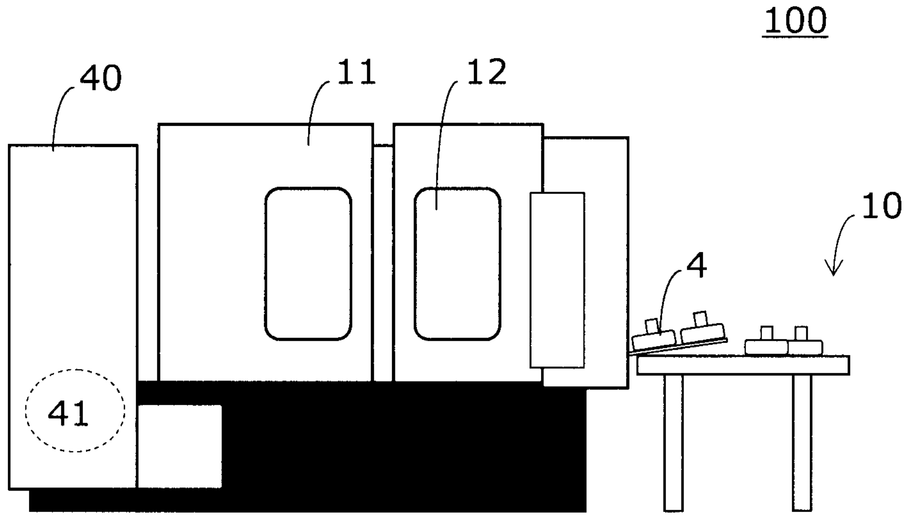


Fig. 1

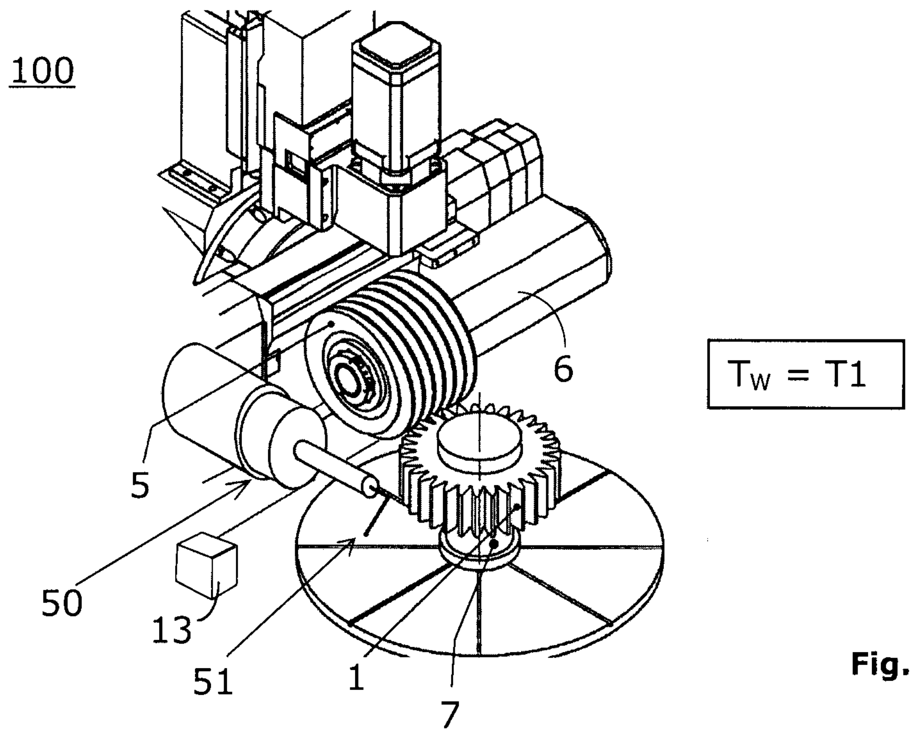
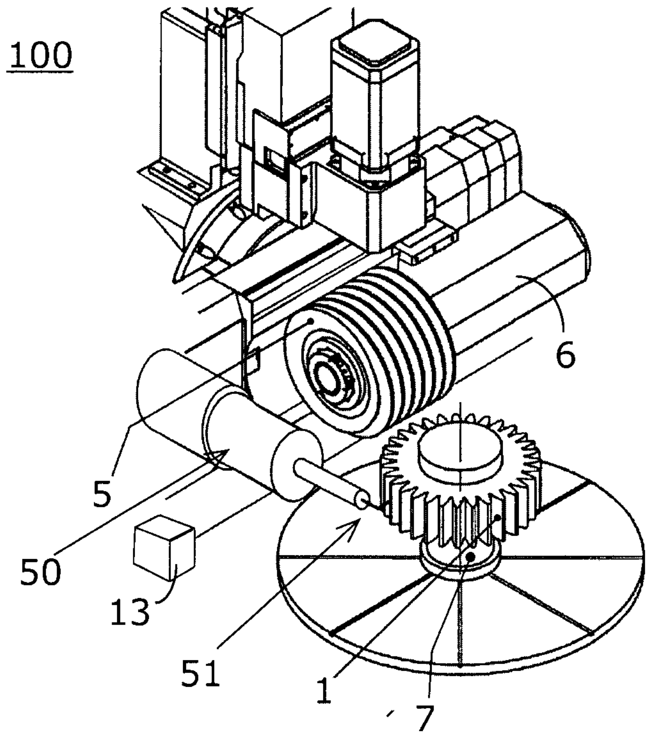


Fig. 2A



$T_W = T1^*$

Fig. 2B

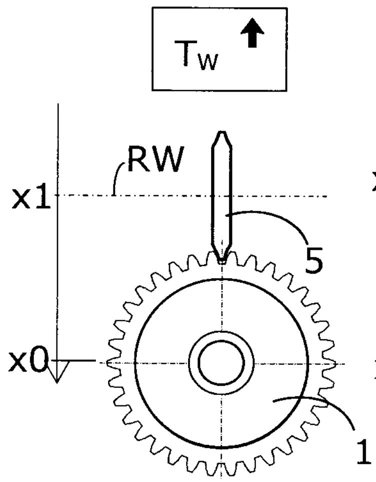


Fig. 3A

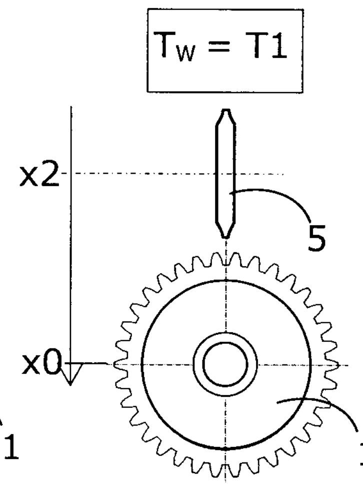


Fig. 3B

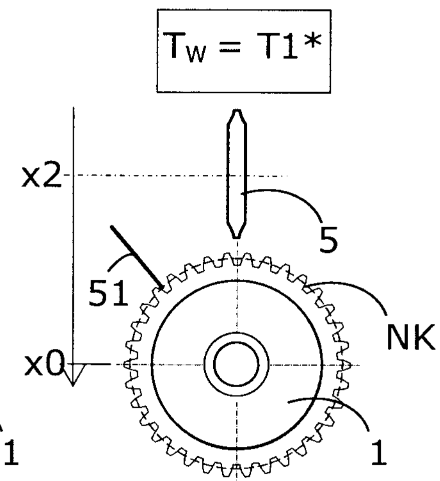


Fig. 3C

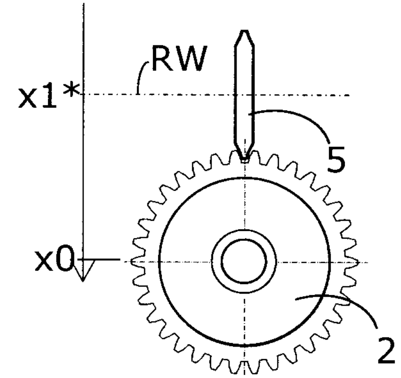
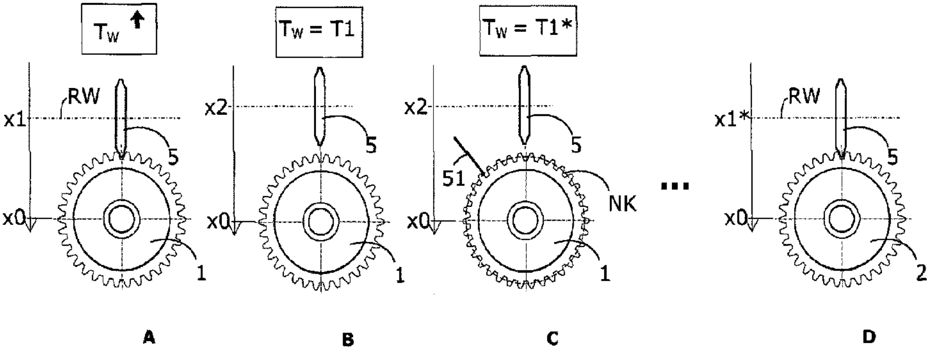


Fig. 3D



T_W
$T_W = T1$
$T_W = T1^*$
RW
x1
x2
x0
x1*
5
51
NK
1
2
...
A
B
C
D