(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 December 2005 (15.12.2005)

PCT

(10) International Publication Number
WO 2005/119383 A2

(51) International Patent Classification[7]: G05B 19/19, B23Q 15/02

(21) International Application Number: PCT/EP2005/052514

(22) International Filing Date: 1 June 2005 (01.06.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
BO2004A000356 4 June 2004 (04.06.2004) IT

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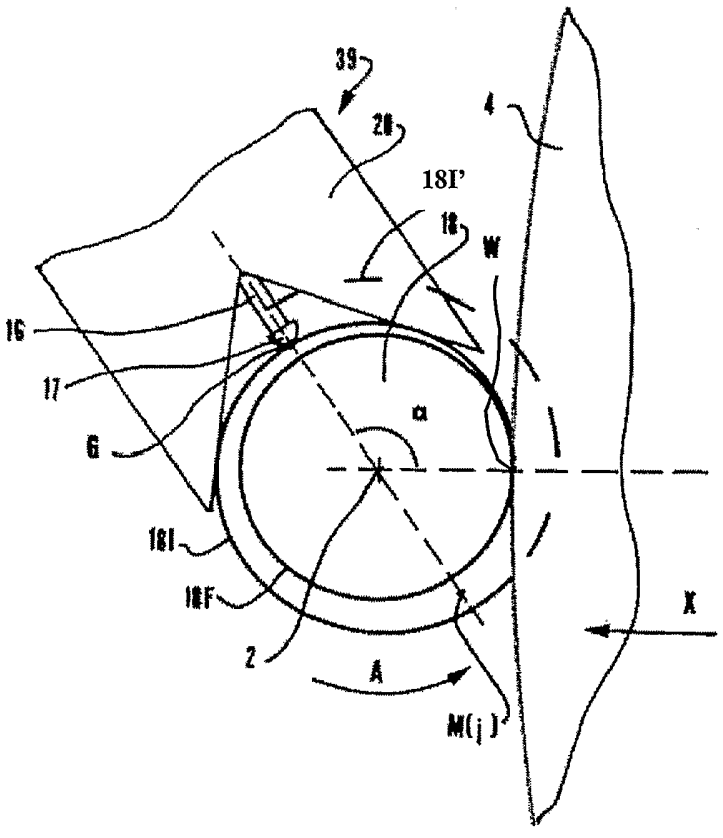
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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),

[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR CONTROLLING THE MACHINING OF MECHANICAL PIECES



(57) Abstract: A method and a relevant apparatus for controlling the machining of a piece (18,38) rotating in a numerical control machine tool (33) includes the steps of detecting instantaneous values (V(i)) indicative of the dimensions of the piece during the machining, performing dynamic processing of the detected instantaneous values and controlling at least one machining phase on the basis of the processing. The method includes dynamic calculation of average values (M(j)) of sequences of the detected values, acquisition of a variation index (P) indicative of the average values trend during the machining and of a correction coefficient (K) that allows for the delay of the calculated average values with respect to the actual dimensions of the piece, and processing of an instantaneous dimension (RI) of the piece that is transmitted to the numerical control of the machine tool for controlling the machining.

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European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:

— *of inventorship (Rule 4.17(iv)) for US only*

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

DESCRIPTION

«METHOD AND APPARATUS FOR CONTROLLING THE MACHINING OF MECHANICAL PIECES»

Technical Field

The present invention relates to a method for controlling the machining of a piece in rotation in a machine tool by means of a checking apparatus, including the following steps: detecting instantaneous values indicative of radial dimensions of the piece, processing the detected instantaneous values, and controlling at least one machining phase on the basis of the detected and processed instantaneous values.

The invention also relates to an apparatus for checking a piece in rotation during the machining in a numerical control machine tool, including a checking head adapted to cooperate with the piece in rotation and emit electric signals indicative of the dimensions of the piece, and a processing and display device connected to the checking head and to the numerical control of the machine tool, and adapted to receive the signals from the checking head, detect and process instantaneous values, and provide the numerical control with signals indicative of the dimensions of the piece.

Background Art

It is known to carry out the machining of mechanical pieces, more specifically in numerical control grinding machines, with in-process checking, i.e. by utilizing gauging heads or other checking and/or measuring apparatuses that detect dimensions of the piece during the machining and signal the reaching of a preset dimension in order to control the stop of the machining and/or the transition to a subsequent machining phase.

European patent application No. EP-A-0791873 discloses a specific method of machining in a grinding machine, according to which the machined piece is a crankpin of a crankshaft that rotates with orbital motion about the main axis of the shaft while the grinding-wheel slide translates with respect to such axis.

In the machining of this type of pieces, the reaching of the extremely high standards of accuracy that are nowadays required is difficult owing to the concurrent requirement of ever shorter production times. In fact, the machining cycles must be very short, with a high ratio between the machining feed rate of the grinding-wheel in movement towards the pin (that determines the stock removal rate), and the shaft rotation speed. As a consequence, the cross-section of the machined pin has, instant-by-instant and up to a final phase, for example the "sparkout" phase, an accentuated axial asymmetry, that is radial dimensions that considerably vary - in relation with the requested accuracy - from one point of the circumference to the other. This makes the in-process checking, carried out by known heads with one or more feelers that contact just certain pin surface areas, necessarily separate from the area that is actually machined at that instant, particularly difficult.

The method of machining according to the mentioned patent application No. EP-A-0791873 foresees a sequence of steps including a stop at an intermediate position during the grinding-wheel slide machining feed towards the pin (while the slide continues to displace in order to follow the orbitally rotating pin without removing material) when the in-process checking head signals the exceeding of a preset diameter dimension, by a certain margin higher than the desired final dimension. The method also foresees that the dimensions detected in one or more pin revolutions, when the grinding-wheel slide is in the intermediate position, be processed for calculating an average value from which there is determined the amount of the subsequent grinding-wheel slide feed necessary for reaching the desired

dimension. The checking head is retracted and inactive in the last part of the machining, that foresees the grinding-wheel slide machining feed of the determined amount and a final "sparkout" phase, whereupon the grinding-wheel slide is stopped again.

The method according to the mentioned European patent application attempts to solve the problems introduced by the contrasting rising requirements in terms of production speed and accuracy of the results.

However, the proposed machining cycle is burdened by controls and additional operations, for interrupting and then continuing the machining feed of the grinding-wheel slide before reaching the desired dimension, that are in contrast with the machining time reduction requirements. Furthermore, such additional operations contribute to deteriorate the involved electric and mechanic components and represent possible additional causes of grinding machine failures and malfunctions.

Apparatuses for the in-process checking of crankpins in orbital motion are described in the international patent application No. WO-A-9712724, filed by the same applicant of the present patent application. Such apparatuses include checking heads with a Vee-shaped reference element that rests on two points on the surface of the pin to be checked, and a movable feeler that contacts such surface between the two rest points and transmits the displacements to transducer means along a direction that substantially corresponds to the bisecting line of the "Vee".

The apparatuses produced by the owner of the present patent application according to the teachings of the patent application No. WO-A-9712724 guarantee excellent results from a metrological point of view, utmost applicative simplicity and low forces of inertia, and the standards of performance that are reached in the related applications in grinding machines confirm the remarkable quality and reliability of the adopted solutions.

However, the requirements for higher machining speed while

maintaining unchanged or increased the degree of accuracy, cause the previously mentioned inconveniences even with such apparatuses.

Disclosure of the Invention

An object of the present invention is to provide a method and an associated apparatus for controlling the machining of mechanical pieces that enables a considerably accurate and reliable machining in extremely short times.

This and other objects are achieved by a method according to claim 1 and an apparatus according to claim 12.

A method and an apparatus according to the invention can be advantageously utilized for controlling the operations for grinding pins in orbital motion.

One of the advantages that a method and an apparatus according to the invention provide consists in the possibility of efficiently compensating possible errors due, for example, to the use of apparatuses with "Vee" shaped reference element.

Brief Description of the Drawings

The invention is hereinafter described with reference to the enclosed sheets of drawings that show a preferred embodiment of the invention and are given by way of non-limiting example, wherein:

figure 1 is a side view of a measuring apparatus mounted on the grinding-wheel slide of a crankshaft grinding machine, shown in working condition during the checking of a crankpin;

figure 2 shows, in simplified and enlarged form, a detail of figure 1;

figure 3 is a block diagram of a preferred embodiment of a control method according to the present invention; and

figure 4 is a graph representing the trend of some quantities detected and calculated according to the method

of figure 3.

Best Mode for Carrying Out the Invention

Figure 1 illustrates an apparatus according to the invention for controlling the machining of a piece in a machine tool, more specifically an in-process device for checking a crankpin **18** of a crankshaft **34** in a grinding machine with computer numerical control ("CNC") **33**. The crankpin **18** has substantially cylindrical shape and defines an axis of symmetry **2**. A main journal **38** of the crankshaft **34** can be checked by the same apparatus. Many constructional features of the apparatus correspond to those shown and described in the mentioned patent application No. WO-A-9712724.

In the embodiment shown in figure 1, a grinding-wheel **4** is coupled to a grinding-wheel slide **1** that defines an axis of rotation **3** for the grinding-wheel **4**. A worktable **23** supports - and defines an axis of rotation **8** for - the crankshaft **34**. The grinding-wheel slide **1** carries a support device with a support element **5** and a first **9** and a second **12** rotating, coupling element. The support element **5** supports, by means of a rotation pin **6** defining a first axis of rotation **7** parallel to the axis of rotation **3** of the grinding wheel **4** and to the axis of rotation **8** of the crankshaft **34**, the first rotating, coupling element **9**. In turn, the coupling element **9** supports, by means of a rotation pin **10** defining a second axis of rotation **11** parallel to the axis of rotation **3** of the grinding-wheel **4** and to the axis of rotation **8** of the crankshaft **34**, the second rotating, coupling element **12**. At the free end of the coupling element **12** there is coupled a tubular guide casing **15** wherein there can axially translate a transmission rod **16** carrying a feeler **17** for contacting the surface of the pin **18** to be checked. The tubular casing **15**, the rod **16** and the feeler **17** are part of a measuring or checking head **39**, that also includes a support block **19**,

fixed to the lower end of the tubular guide casing **15**. The block **19** supports a reference device **20**, Vee-shaped, adapted to engage the surface of the pin **18** to be checked, by virtue of the rotations allowed by the rotation pins **6** and **10**. The transmission rod **16** is movable substantially along the bisecting line of the Vee of the reference device **20**, or according to a direction that is slightly angular with respect to the bisecting line.

The support block **19** further supports a guide device **21** that, as described in the mentioned international patent application No. WO-A-9712724, serves to guide the reference device **20** to engage the pin to be checked and maintain contact with the pin while the reference device **20** displaces away from the pin, for limiting the rotation of the first coupling element **9** and of the second coupling element **12** about the axes of rotation **7**, **11** defined by the pins **6** and **10**.

The axial displacements of the transmission rod **16** with respect to a reference position are detected by means of a measurement transducer, fixed to the casing **15**, for example a transducer **41** of the LVDT or HBT type (per se known and herein not described in detail), with fixed windings and a ferromagnetic core that is movable with the transmission rod **16**.

The transducer **41** of the head **39** is connected to a processing and display device **22**, in turn connected to the numerical control **33** of the grinding machine.

The crankshaft **34** to be checked is positioned on the worktable **23**, between a spindle and a tailstock, not shown, that define the axis of rotation **8**, coincident with the main geometric axis of the crankshaft **34**. The crankpin **18** and the main journal **38** rotate about the axis **8**, the former by performing an orbital trajectory.

An actuator device comprises a double-acting cylinder **28**, for example of the hydraulic type. The cylinder **28** is supported by the grinding-wheel slide **1** and comprises a rod **29**, coupled to the piston of the cylinder, carrying at the

free end a cap **30**. An arm **14** is coupled at an end to the element **9** and carries an abutment with an idle wheel **26** at its opposite end. When the cylinder **28** is activated for displacing the piston and the rod **29** towards the right (with reference to figure 1), the cap **30** contacts the abutment **26** and causes the displacement of the checking apparatus to a rest position according to which the reference device **20** is separate from the surface of the pin. An overhang **13** is rigidly fixed to the support element **5** and a coil return spring **27** is coupled to the overhang **13** and to the arm **14**. When the rod **29** retracts, in order to allow the apparatus to displace to the checking condition, and the cap **30** disengages from the abutment, or idle wheel **26**, the support block **19** approaches the crankpin **18** (or the main journal **38**) through rotation of the coupling elements **9, 12**, and the apparatus reaches and maintains the checking condition, substantially in the way described in the hereinbefore mentioned international patent application No. WO-A-9712724 which is referred to for a more detailed description. The cooperation between the crankpin **18** or the main journal **38** and the reference device **20** is maintained thanks to the force of gravity. The action of the coil spring **27** is particularly important in the checking of the crankpin **18** in orbital motion shown in figure 1. In fact, the tension of the spring **27** increases with the lowering of the support block **19** and partially and dynamically counterbalances the forces due to the inertia of the component parts of the checking apparatus that move by following the displacements of the crankpin **18**. In this way it is possible, for example, to avoid over stresses between the reference device **20** and the crankpin **18**, at the lower position (identified by reference number **18''**), that could cause the deformation of the Vee of the reference device **20**. On the other hand, since during the raising movement of the apparatus (due to rotation of the crankpin towards the upper position **18'**) the pulling action of the spring **27** decreases, the inertial forces that - at the upper position

18' - would tend to release the engagement between the Vee-shaped reference device **20** and the crankpin **18** can be properly counterbalanced. In this latter case it should be realized that the counterbalancing action is achieved by diminishing the pulling action of the spring **27**. In other words, the coil return spring **27** does not cause any pressure between the reference device **20** and the crankpin **18** that mutually cooperate, as described above, simply owing to the force of gravity.

The transducer **41** of the head **39** sends to the processing and display device **22** signals the values of which are indicative of the position of the transmission rod **16** and thus of the feeler **17**. In such device **22**, that includes a memory unit **24**, the signals arriving from the head **39** are processed as described hereinafter with reference to figures 2, 3, and 4.

Figure 2 shows, in simplified form, the feeler **17**, the transmission rod **16** and the Vee-shaped reference device **20** of the head **39** in the phase for the in-process checking of the crankpin **18**. The latter phase is also shown in figure 1, in which the grinding wheel **4** is represented while it is grinding the external surface of such pin **18** that rotates in orbital motion about the axis **8** of the shaft **34** and, consequently, about its axis **2**, in the sense indicated by the arrow **A**. In this phase the grinding-wheel slide **1** performs, on reception of controls from the numerical control **33**, translation displacements with respect to the axis **8** along a direction **X** in order to follow the orbital motion displacements of the pin **18**, and an additional machining feed, also along the direction **X** with respect to the axis **2** of the pin **18**, for removing material from the surface of the pin **18**. Many types of machine tools can foresee displacements of the worktable **23** in order to implement the mentioned following and/or machining displacements.

Two circular lines **18I** and **18F** schematically show the profile of the external surface of the pin **18** at the

instant **I** and, respectively, the final profile of the surface that it would be possible to obtain by stopping at the same instant **I** the machining feed of the grinding-wheel slide **1**. It should be realized that in figure 2 the helical shape of the profile **18I**, that depends on the ratio between the machining feed rate of the slide **1** and the rotation speed of the pin **18**, is shown, for illustrative purposes, in an intentionally exaggerated way with respect to actual size.

In the cross-section of figure 2, the points on the surface of the pin **18** that instant-by-instant are in contact with the grinding-wheel **4** and with the feeler **17** are indicated by references **W** and **G** and identify, respectively, a machining area and a checking area. The direction of displacement of the rod **16**, that includes the point **G**, is substantially incident to the axis **2** of the pin **18** and forms an angle α with respect to the straight line, that is also incident to the axis **2** of the pin **18**, where the point **W** of contact with the grinding wheel **4** lies.

It should be realized that, from a conceptual point of view, while the checking area can be identified with the point **G**, the machining area has a certain extension in a direction perpendicular to the plane of the figures 1 and 2. However, in the present description, for the sake of simplicity and clarity, reference is made just to the point **W** of contact between the pin **18** and the grinding-wheel **4** at the illustrated cross-section.

The signals, sent by the head **39** during the rotation of the pin **18** and detected at a predetermined frequency in the device **22**, define a sequence of instantaneous values **V(i)** that are proportional to radial dimensions of the pin **18**. As shown in figure 2, at any instant **I** the radial dimension of the pin **18** at the point **W** in contact with the grinding wheel **4** differs from the dimension detected by the head **39** at the point **G**. Therefore, each detected instantaneous value **V(i)** indicates after a certain delay the dimension actually reached at the point **W** of machining.

A first processing, that takes place in the device **22**, enables to dynamically calculate an average value **M(j)** given by

$$\mathbf{M(j)} = \frac{\sum_{i=s-(N-1)}^{s} V(i)}{N} \qquad (1)$$

where **s** is a progressive number that identifies the most recently detected instantaneous value **V(i)**, and **N** is the number of instantaneous values **V(i)** detected in a complete rotation of the shaft **34** about the axis **8** and stored in the unit **24**.

The average value **M(j)**, or instantaneous rolling average, enables among other things to compensate alterations of the detected values **V(i)** introduced by the Vee-shaped device **20** that, by contacting the surface of the pin **18**, is sensitive to shape errors of the pin **18** that cause unwanted displacements of the feeler **17**. The rolling average **M(j)** is continuously updated further to the detecting of every fresh instantaneous value **V(i)** of the sequence. At the instant **I** the average value **M(j)** of the instantaneous values **V(i)** detected in the previous complete rotation, is also "in delay" with respect to the dimension machined at the point **W**. Figure 2 shows the radial position of the average value **M(j)** at the instant **I** and a broken line **18I'** indicates part of the profile on the basis of which there is calculated the average value **M(j)**.

A method according to the present invention for controlling the machining of a pin with the apparatus shown in figures 1 and 2 is hereinafter described with reference to the block diagram of figure 3 and the graph of figure 4.

The blocks of the diagram of figure 3 have the following functions:

block **50** - start of the controlling procedure;

block **51** - positioning of the head **39** in the checking position on the pin **18** in orbital motion, while the grinding-wheel slide **1** performs displacements along the direction **X**, including the machining feed towards the pin

18;

block **52** - data acquisition and initialization of control variables;

block **53** - verification about the start of the in-process checking phase, on control of the numerical control **33**;

block **54** - acquisition and storage of an instantaneous value **V(i)** on the basis of signals transmitted from the head **39**;

block **55** - verification about the completion of a first 360° scan performed by the feeler **17** on the surface of the pin **18**;

block **56** - increment in the counter of the acquired instantaneous values **V(i)**;

block **57** - dynamic calculation and storage of the average value **M(j)** of the sequence of instantaneous values **V(i)** acquired in the most recent 360° scan;

block **58** - comparison between the number of stored average values **M(j)** and a preset number;

block **59** - acquisition, more specifically dynamic calculation and storage, of a variation index **P** indicative of the trend of the variations of the **C** most recently acquired and stored average values **M(j)**;

block **60** - dynamic calculation of an instantaneous radial dimension R_I of the pin **18**;

block **61** - transmission of the calculated instantaneous radial dimension R_I to the numerical control **33** of the grinding machine;

block **62** - comparison between the calculated instantaneous radial dimension R_I and a desired nominal dimension R_F;

block **63** - control for stopping the machining feed of the grinding-wheel slide **1**;

block **64** - cancellation of the oldest average value **M(j)** stored in the unit **24**;

block **65** - verification about the fact that the in-process checking phase ends upon control of the numerical control **33**; and

block **66** - end of the controlling procedure.

The graph of figure 4 shows curves **V**, **M** and **R** that represent the trend in time of the sequence of detected instantaneous values **V(i)**, of the average values **M(j)**, and of the calculated instantaneous radial dimensions R_I, respectively.

The method according to the diagram of figure 3 foresees a starting phase in which, concurrently with the physical positioning of the head **39** on the pin **18** that is machined in the grinding machine (block **51**), there occurs the acquisition and setting of some parameters (block **52**), as the rotation speed ω of the piece, that is a machining parameter of the machine, the angle α that identifies the point **G** in which the feeler **17** contacts the surface of the pin **18**, a sampling period **T** of the instantaneous values **V(i)**, and a number **C**, for example set by the operator, that defines the number of average values **M(j)** that must be simultaneously kept in the memory unit **24** in order to carry out suitable processings, as hereinafter described in more detail. It should be realized that the previously mentioned number **N** of instantaneous values **V(i)** detected for each complete pin revolution can be obtained from the parameters regarding the rotation speed ω (for example in rpm) of the piece and the sampling period **T** (for example in seconds) in this way:

$$\mathbf{N} = \frac{60}{\omega * T} \qquad (2)$$

When the numerical control **33** of the grinding machine sends the signal for the start of the in-process checking cycle (block **53**), the phase of acquisition and storage of the samples (block **54, 56**), that is of the instantaneous values **V(i)**, starts. When there is detected the completion of a complete 360° scan (block **55**), for example by checking the acquisition of the **N**-th instantaneous value **V(i)**, a first average value **M(j)** is dynamically calculated (block **57**) by means of the equation (1) and stored in the unit **24**. The phases for the acquisition of instantaneous values **V(i)**

(block **54**) and calculation of subsequent average values **M(j)** (block **57**) continue until (block **58**) the number of average values **M(j)** concurrently present in the memory unit **24** corresponds to the set number **C**. Thus, such average values **M(j)** are utilized for calculating (block **59**) the value of the variation index **P** indicative of the inclination of the curve that represents, in figure 4, the trend in time of the average values **M(j)**, by means of the following equation:

$$\mathbf{P} = \frac{\sum_{j=s-(C-1)}^{s-1}(M(j+1)-M(j))}{C-1} \qquad (3)$$

The index **P** is a negative number that represents the average variation of the average values **M(j)** between a sample and the other on the basis of a predetermined number **C** of average values.

On the basis of the current average value **M(j)**, the variation index **P** and a correction coefficient **K** that considers the evaluation delays introduced by the geometry of the system, more specifically by the mutual arrangement of the points **G** and **W**, there is dynamically calculated (block **60**) the instantaneous radial dimension $\mathbf{R_I}$ as

$$\mathbf{R_I = M(j) + P*K} \qquad (4)$$

where

$$\mathbf{K} = N*\frac{\alpha+180}{360} \qquad (5)$$

In practice **K** is a correction coefficient that considers the previously mentioned number **N** of instantaneous values **V(i)** detected for each complete revolution of the pin and of the delay between the average value **M(j)** and the dimensions reached at the identical instant **I** at the machining point **W**.

With reference to the graph of figure 4, at the instant **I**

- there is detected the value **V(i)**,
- there is calculated and stored the average value **M(j)** on the basis of the **N** instantaneous values **V(i)** with

i = (s-(N-1)),..., s detected in the last 360° rotation,

- there is evaluated the index **P** indicative of the inclination of the curve **M** on the basis of the last **C** average values **M(j)** with j = (s-(C-1)),..., s, and
- there is calculated the instantaneous radial dimension R_I.

The dimension R_I, that is an evaluation of the radial dimension of the pin **18** at the point **W** where the surface of the pin is machined, is transmitted (block **61**) from the processing and display device **22** to the numerical control **33** of the grinding machine. The numerical control **33** can advantageously verify when (block **62**) the instantaneous radial dimension R_I reaches the value of the desired nominal dimension R_F, and consequently control the stop of the machining feed of the grinding-wheel slide **1** (block **63**). It should be realized that the management of the instantaneous radial dimension R_I provided by the device **22** is in any case defined by the numerical control **33** of the machine that controls, as previously stated, the operations described with reference to the blocks **62** and **63** and/or other possible machining displacements on the basis of suitable programs that depend, among other things, on the characteristics of the piece being machined. The end (block **66**) of the in-process checking is likewise determined, after the stop of the machining feed of the grinding-wheel **4** or, for example, at a subsequent moment, upon control of the numerical control **33** (block **65**). The block **64** of figure 3 shows, in simplified form, the updating of the stored average values for keeping in the memory unit **24** just the last **C** calculated average values **M(j)**, for instance by cancelling the oldest value **M(j)** with j = (s-(C-1)) among those utilized for the calculation of the index **P** in order to thereafter replace it with a fresh value in the subsequent processing (block **57**).

In the graph of figure 4, the instant I_F indicates the moment at which the calculated dimension R_I reaches the

value R_F and, according to the above described example, the numerical control **33** controls the stop of the machining feed of the grinding-wheel slide **1** in the direction **X**, with respect to the pin **18** in orbital motion. The machining continues with a phase in which the grinding-wheel slide **1** continues to perform transversal displacements, with respect to the axis of rotation **8** of the shaft **34**, in order to follow the pin **18** for example in a single orbital rotation of the latter, substantially without machining feed displacements towards the axis **2** of the pin **18**. In this final phase the external surface of the pin **18** is substantially rounded off in order to take on a profile that corresponds to the one shown in figure 2 and identified by reference **18F**.

Thus, the method according to the invention, for example according to the just described embodiment, enables to verify, on the basis of the instantaneous value **V(i)** detected by the head **39**, which is the radial dimension of the pin **18** actually reached at that instant at the point **W** in contact with the grinding-wheel **4**. Consequently it is possible to control in a continuous way the machining of the pin **18**, for example until the reaching of the desired nominal dimension R_F, thus obtaining pieces machined with particular accuracy and reliability in extremely short times, without there being the need to interrupt the machining feed of the grinding-wheel **4**.

The described method can apply to machinings that foresee machining feeds of the grinding-wheel slide **1** at high rate (for example in the order of 15 μm/s) with relatively slow shaft rotations (for example from 20 to 60 rpm) and sampling periods from 0,5 to 4 ms. The number **N** of samples per revolution of the pin can be in the order of the thousand, while the number **C** of average values **M(j)** for the calculation of the index **P** can be, for example, of approximately 10.

A typical value of the angle α is, for example, 120°. It should be realized that in applications as the one

illustrated in figures 1 and 2, the amplitude of the angle α is subject to slight variations during the piece rotation, that depend on the geometric and kinematic features of the system. However, in the checking of the radial dimensions of the pin **18**, these variations, that remain within a range of +/- 5°, are absolutely negligible. In fact, from the equation (5) it follows that an inaccuracy of 5° generates a variation of 1,3% (5/360) the average value **M(j)** being constant, and substantially is not perceived in the calculation of the value $\mathbf{R_I}$.

The correction coefficient **K** calculated by the equation (5) enables to apply the method according to the invention with excellent results. It is also possible to allow for a slight off-set with respect to the point **G** of the **N** detected instantaneous values **V(i)** on the basis of which the average values **M(j)** are calculated, by means of the following equation for the calculation of the correction coefficient:

$$\mathbf{K'} = N * \frac{\alpha + 180}{360} + \frac{1}{2} \qquad (5')$$

However, in almost the totality of cases, when **N** is greater than a few tens (as previously stated, a typical value is of approximately 1000), the difference between **K** and **K'** is not practically detectable.

Other possible variants with respect to the method herein so far described can foresee, among other things, a different calculation of the variation index, for example by evaluating an angle or a ratio between the detected and calculated quantities, instead of the negative number **P** mentioned in the example, with consequent modification of the equation (4) for the calculation of the instantaneous radial dimension $\mathbf{R_I}$.

In a different embodiment, the acquisition of the variation index **P** takes place not by means of calculations, but through direct setting of a value, for example by an operator, on the basis of the machining feed rate. In fact,

when the machining feed rate is constant, the index **P** is also constant and there is no need to dynamically calculate the variation index **P** at each piece rotation. In other words, if the machining speed rate is constant, the inclination of the curve **M** is constant and the processing and display device **22** can be provided with the variation index **P** with no further processing.

The latter embodiment is particularly advantageous when the piece undergoes two or more machining phases, with different machining feed rates. By setting the value of the variation index **P** for each machining phase, it is possible to enhance accuracy in the dynamic calculation of the instantaneous radial dimension R_I when passing from a machining phase to the other, and thus from a machining feed rate to the other.

In another embodiment, it is also possible to dynamically calculate the variation index **P** on the basis of a preset number of initial values **M(j)** and then utilise the calculated variation index **P** for the subsequent processing, in an entirely similar way as described hereinbefore. To minimise errors in calculating the variation index **P**, an average value of a preset number of calculated values of the variation index **P** can be evaluated.

In particular applications in which the nature of the shape errors of the machined piece is substantially a priori known, the average values **M(j)** can be evaluated on the basis of a number of instantaneous values **V(i)** smaller than **N**, or rather on the basis of a movable angular window having a fixed amplitude that can be programmed (for example 120°, or 180° wide).

Obviously the method according to the invention is also feasible in applications in which the instantaneous values **V(i)** detected by the signals of the head **39** undergo other processings for compensating alterations due, for example, to thermal variations or to the limited linearity of the head **39**.

A method and an apparatus according to the invention are

advantageously applied to checkings of pins in orbital motion by means of heads with Vee-shaped reference devices, as herein so far described. Alike method and apparatus are applicable for controlling the machining of the main journal **38** of the shaft **34** described with reference to figure 1.

Furthermore, similar controlling methods and apparatuses, for example employing heads with two feelers that provide signals indicative of diameter dimensions of pieces rotating about their axis, or with contactless checking heads (of optical or other known type) fall within the scope of the present invention and allow, in many applications, to control with identical standard of accuracy, reliability and speed the machining in machine tools as grinding machines.

As previously stated, the method and the apparatus according to the invention enable to have available, instant-by-instant, a value (as $\mathbf{R_I}$) indicative of the actual dimension of the machined part at the area in contact with the tool. The use of such value ($\mathbf{R_I}$) for controlling one or more machining phases is generally defined and managed by the control device of the machine (for example the numerical control **33**).

CLAIMS

1. A method for controlling the machining of a piece (**18,38**) in rotation in a machine tool by means of a checking apparatus, including the following steps:

detecting (**54**) instantaneous values (**V(i)**) indicative of radial dimensions of the piece (**18,38**),

processing (**57,59,60**) the detected instantaneous values (**V(i)**), and

controlling (**62,63**) at least one machining phase on the basis of the detected and processed instantaneous values,

characterized in that the step of processing the instantaneous values (**V(i)**) includes

a dynamic calculation (**57**) of average values (**M(j)**) of said instantaneous values (**V(i)**) during the machining,

an acquisition (**59**) of a variation index (**P**), indicative of the trend of the average values (**M(j)**) during the machining, and

a dynamic calculation (**60**) of an instantaneous dimension (R_I) on the basis of the calculated average value (**M(j)**), the variation index (**P**) and at least one correction coefficient (**K**),

said at least one machining phase being controlled (**62**) on the basis of the calculated instantaneous dimension (R_I).

2. The method according to claim 1, wherein each of said average values (**M(j)**) is dynamically calculated on the basis of a sequence of the instantaneous values (**V(i)**) detected in a complete rotation of the piece (**18,38**) during the machining.

3. The method according to claim 1 or claim 2, for controlling the machining in a grinding machine with a grinding-wheel (**4**) in contact with the piece (**18,38**) in rotation at a machining area (**W**), where said checking apparatus cooperates with the piece (**18,38**) at at least one

checking area (**G**), wherein said correction coefficient (**K**) is evaluated on the basis of the arrangement of said machining area (**W**) and of said at least one checking area (**G**).

4. The method according to claim 3, wherein said instantaneous dimension ($\mathbf{R_I}$) is an evaluation of the dimension of the piece (**18,38**) at said machining area (**W**).

5. The method according to claim 3 or claim 4, wherein said checking apparatus includes a checking head (**39**) with at least one feeler (**17**) in contact with the piece (**18,38**) at said at least one checking area (**G**), wherein said correction coefficient (**K**) is evaluated on the basis of geometric characteristics (α) of the arrangement of said grinding-wheel (**4**) and of said at least one feeler (**17**) with respect to the piece (**18,38**).

6. The method according to claim 5, wherein said checking head (**39**) includes a Vee-shaped reference device (**20**), said at least one feeler (**17**) being movable along a direction substantially coincident with the bisecting line of said Vee, or slightly angular with respect to said bisecting line, wherein the calculated instantaneous dimension ($\mathbf{R_I}$) is a radial dimension.

7. The method according to one of the preceding claims, wherein said variation index (**P**) is calculated.

8. The method according to claim 7, wherein said variation index (**P**) is calculated on the basis of the most recent dynamically calculated average values (**M(j)**).

9. The method according to claim 8, wherein said average values (**M(j)**) on the basis of which said variation index (**P**) is calculated are in a predetermined number (**C**).

10. The method according to claim 9, wherein said variation index (**P**) is calculated by means of the following equation:

$$P = \frac{\sum_{j=s-(C-1)}^{s-1}(M(j+1)-M(j))}{C-1} .$$

11. The method according to one of the preceding claims, for controlling the machining until the reaching of a nominal dimension (R_F) of the piece (**18,38**), wherein the machining of the piece (**18,38**) is controlled on the basis of a comparison (**61**) between the calculated instantaneous dimension (R_I) and said nominal dimension (R_F).

12. An apparatus for checking a piece (**18,38**) in rotation during the machining in a numerical control (**33**) machine tool, including

a checking head (**39**) adapted to cooperate with the piece (**18,38**) in rotation and emit electric signals indicative of the dimensions of the piece (**18,38**), and

a processing and display device (**22**) connected to the checking head (**39**) and to the numerical control (**33**) of the machine tool, and adapted to receive said signals from the checking head (**39**), detect and process instantaneous values (**V(i)**), and provide the numerical control (**33**) with signals indicative of the dimensions of the piece (**18,38**),

characterized in that the processing and display device (**22**) is adapted to perform the dynamic calculation of

average values (**M(j)**) of said instantaneous values (**V(i)**), and

an instantaneous dimension (R_I) of the piece (**18,38**) on the basis of one of said calculated average values (**M(j)**), of a variation index (**P**) indicative of the variation of the average values (**M(j)**) during the machining, and of at least a correction coefficient (**K**),

the processing and display device (**22**) being adapted to provide the numerical control (**33**) with said instantaneous dimension (R_I) of the piece (**18,38**).

13. The apparatus according to claim 12, for controlling the machining in a grinding machine with a grinding-wheel slide (**1**) carrying a grinding-wheel (**4**) in contact with the piece (**18,38**) at a machining area (**W**), wherein said checking head (**39**) cooperates with the piece (**18,38**) at at least one checking area (**G**), the processing and display device (**22**) being adapted to calculate said correction coefficient (**K**) on the basis of the mutual arrangement of said machining area (**W**) and said at least one checking area (**G**).

14. The apparatus according to claim 13, wherein the checking head (**39**) includes a feeler (**17**) and a Vee-shaped reference device (**20**) adapted to contact the piece (**18,38**) to be checked, said at least one feeler (**17**) being movable with respect to the Vee-shaped reference device (**20**).

15. The apparatus according to claim 14, for the checking of a pin (**18**) in orbital motion about an axis of rotation (**8**), wherein the Vee-shaped reference device (**20**) is adapted to contact the pin (**18**) and to maintain said contact substantially thanks to the force of gravity.

16. The apparatus according to claim 15, including a support structure (**5,6,9,10,12**) for supporting in a movable way the checking head (**39**) and enabling the feeler (**17**) and the Vee-shaped reference device (**20**) to maintain contact with the pin (**18**) during its orbital motion.

17. The apparatus according to claim 16, wherein the support structure (**5,6,9,10,12**) is coupled to the grinding-wheel slide (**1**) of the grinding machine and includes reciprocally rotating coupling elements (**9,12**).

18. The apparatus according to one of claims from 12 to 17, wherein the processing and display device (**22**) is

adapted to perform the dynamic calculation of said variation index (**P**) on the basis of the most recent dynamically calculated average values (**M(j)**).

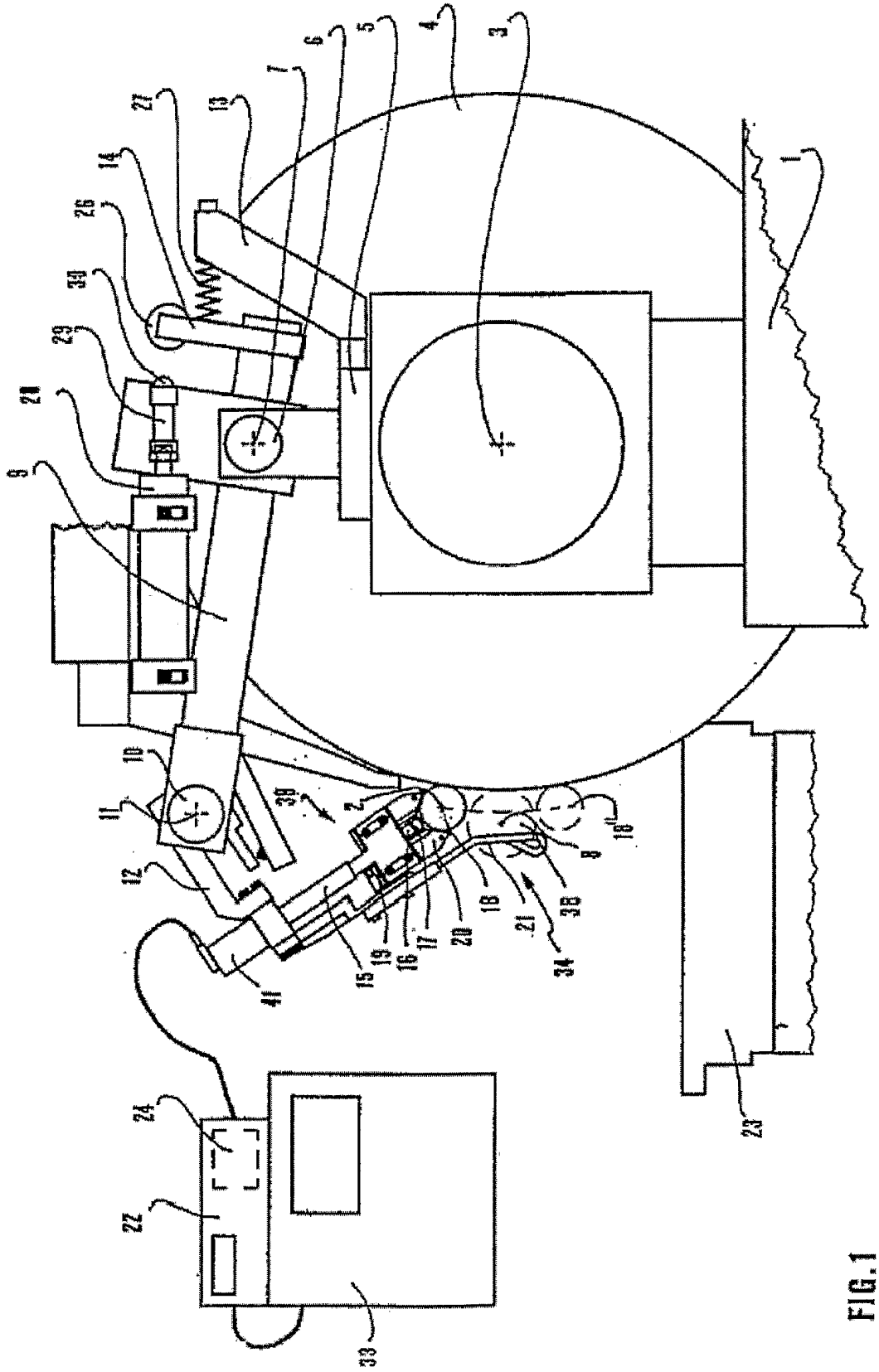

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FIG.1

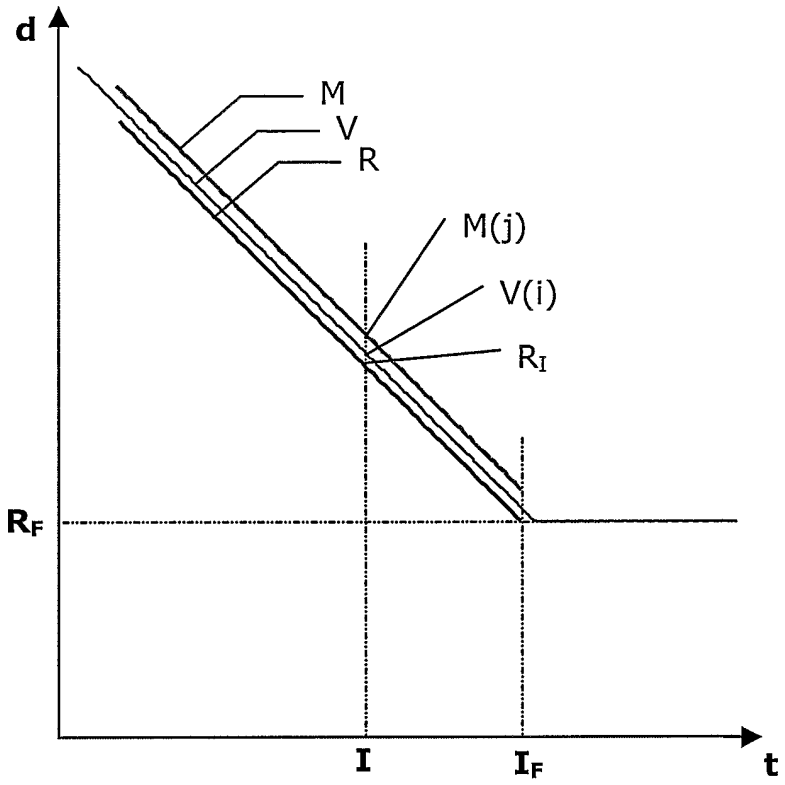


FIG. 4

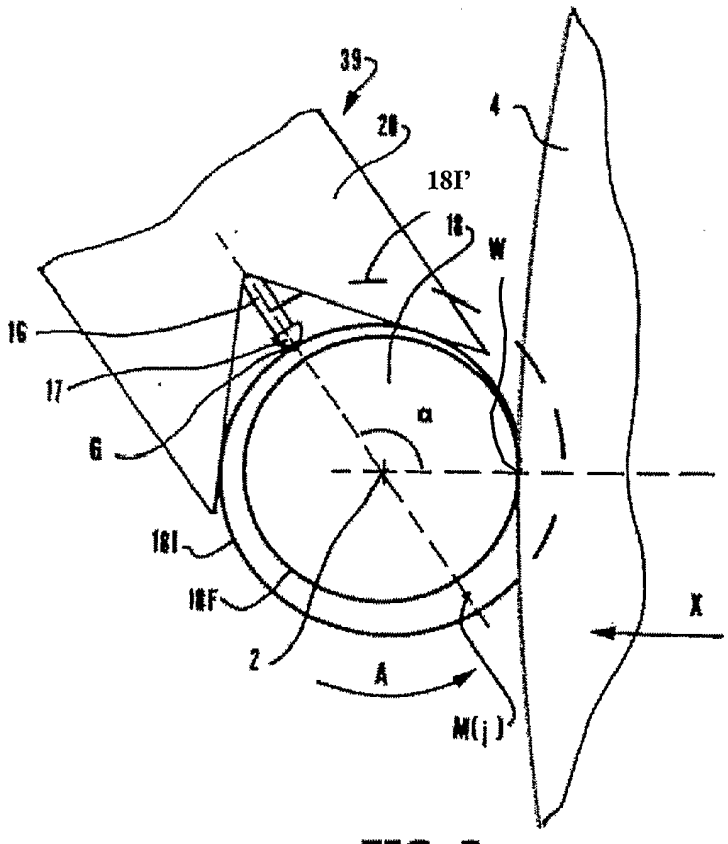


FIG. 2

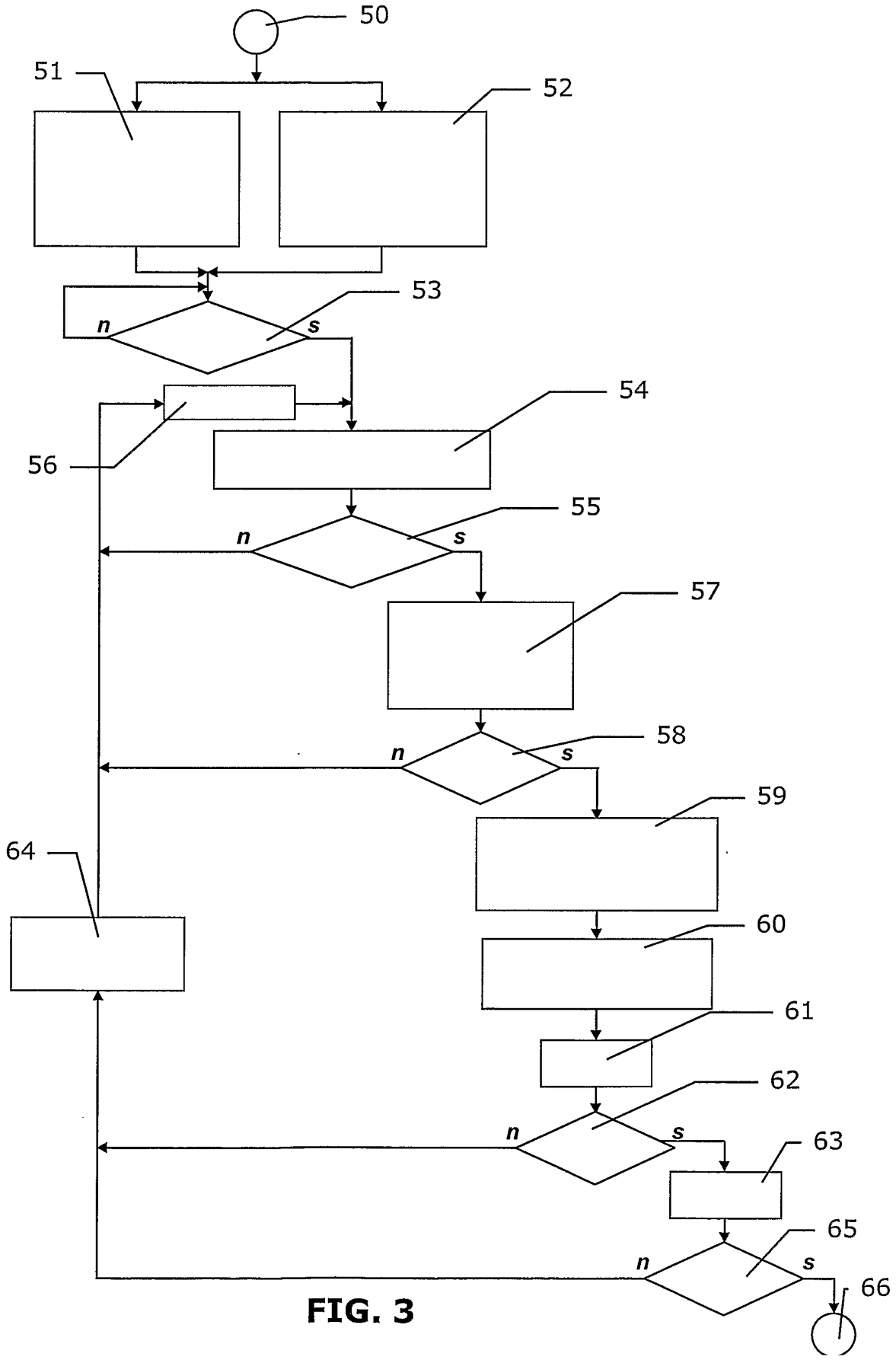


FIG. 3