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(54) **Power hand tool with enhanced feedback**

(57) The inventions relates to a power hand tool having a rotational shaft driven by a driving unit, wherein the hand tool comprises a sensor for detecting a movement of a housing, a speed control unit for controlling the speed of the rotational shaft and a protection circuit set up to control the speed control unit for protecting a user of the hand tool based on the detected movement, wherein the

protection circuit is set up to decrease the speed of the rotational shaft (preferably via the speed control unit) by a variable amount to different speed levels above zero, wherein the variable amount is depending on the amount of the detected movement.

The invention further relates to an according method and to a battery for such a hand tool.

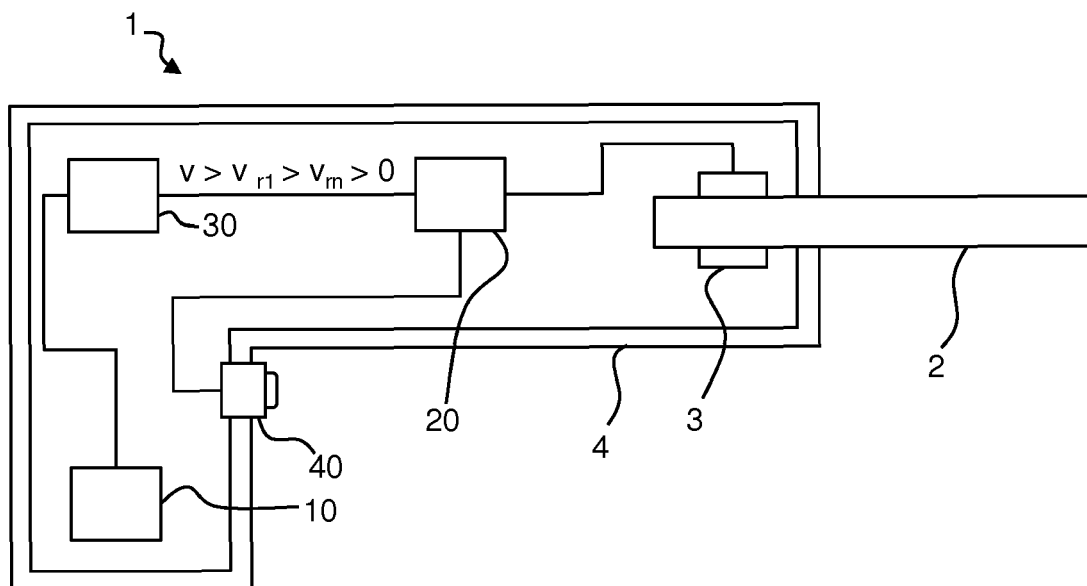


Fig. 1

Description

[0001] This invention relates to a power hand tool, used for construction works, especially to electric hand tools having a powered rotational shaft, like e.g. a drill hammer, whereby the hand tool comprises protection means for protecting the user from dangerous situations, for example if the drill bit of a drilling tool has got stuck within the material to be drilled.

[0002] The prior art EP 1 201 373 B1 describes a safety circuit for generating a control signal when the future angle of deflection of the casing of an at least partly rotary electric hand tool is exceeded. A rate of rotation sensor directly measuring the rotational speed is connected for signal transmission purposes to a comparing element. The derived control signal, after comparison with a predetermined threshold value, interrupts the current path of the electrical drive via at least one of a controllable power cut-out switch and a controllable clutch unit that interrupts the power flux from the electrical drive to the tool spindle.

[0003] The prior art WO 2006/045072 A2 describes a control system for use in a power tool, including a rotational rate sensor having a resonating mass and a controller electrically connected to the rotational rate sensor. The rotational rate sensor detects lateral displacement of the resonating mass and generates a signal indicative of the detected lateral displacement, such that lateral displacement is directly proportional to a rotational speed at which the power tool rotates about an axis of the rotary shaft. Based on the generated signal, the controller initiates a protective operation (e.g. pulsing the motor) to avoid undesirable rotation of the power tool. A second protective operation (e.g. disengaging the motor from the rotary shaft), which is different than the first protective operation, may be performed.

[0004] The inventors found it very disadvantageous that based on the known protective provisions, the user is not able to anticipate critical situations well enough. The object of the invention therefore was to provide to the user a power hand tool that allows him to anticipate critical situations better. This object is achieved by the subject matter of the independent claims; preferred embodiments are specified by the dependent claims.

[0005] Particularly, this object is achieved by a power hand tool having a rotational shaft driven by a driving unit, wherein the hand tool comprises a sensor for detecting a movement of a housing (preferably the rotational shaft is held by the housing), a speed control unit for controlling the speed of the rotational shaft and a protection circuit set up to control the speed control unit for protecting a user of the hand tool based on the detected movement, wherein the protection circuit is set up to decrease the speed of the rotational shaft (preferably via the speed control unit) by a variable amount to different speed levels above zero, wherein the variable amount is depending on the amount of the detected movement.

[0006] Furthermore particularly, the object of the invention is also preferably achieved by a control method for a power hand tool having a rotational shaft driven by a driving unit, comprising the steps:

- detecting a movement of a housing (preferably the rotational shaft is held by the housing) of the hand tool by a sensor of the hand tool,
- controlling a speed of the rotational shaft by a speed control unit,
- controlling the speed control unit by a protection circuit for protecting a user of the hand tool based on the detected movement, wherein the speed of the rotational shaft is decreased by a variable amount to different speed levels above zero, wherein the variable amount is depending on the amount of the detected movement.

[0007] Hereby, information on the current movement of the housing is used to create a protective reaction of the tool that is more finely adapted to the amount of the movement of the housing, giving the user a better differentiable feedback instead of - as in the prior art - just an "OFF"-Switch reaction or a sequential/combined initiation of two or more different protective operations. According to the invention and in contrast to the prior art, the amount of one specific protective operation (i.e.: reduction of the speed) is varied according to the variation of the movement of the housing, resulting in multiple reduced speed levels between zero speed and normal, unaffected (by the protection circuit) speed. The speed is not only shut down, but the speed is decreased in multiple levels (digitally continuous) or continuously. With this better feedback, the user is able to adapt to the tool better and he may learn how to prevent critical situations better. This is giving the user the chance to change the use of the tool so as to prevent a critical situation and the user may then just continue working. For example, if the tool is a drilling machine and the user is beginning to tilt the machine during the process of drilling, the housing may begin to shake, the function f may cause a gentle decrease of the speed depending on the amount the housing is shaking, signaling the user that he will approach a critical situation. He is tilting the tool further and the speed of the rotational shaft is therefore reduced further. Like that, he not only realizes that there is some need for correcting the current operation of the tool, but he may also, because of the different speed levels, perceive an information into which direction a corrective movement should be made to prevent or to get out of the critical state.

[0008] A power hand tool may preferably be understood as tool that a user has to hold with one or two hands and that uses power to perform a work operation at some object. Preferably the power is electric power. The tool is for example an electric screw driver, angle or surface grinder, wall chaser. Preferably it is a drilling tool or combined drill-hammer-tool. The tool may be grid or battery powered.

[0009] A housing of the hand tool may preferably be understood as the elements covering electric and/or turning parts of the hand tool. The housing preferably comprises one or more areas for manually gripping the hand tool.

[0010] A rotational shaft driven by a driving unit may preferably be understood as the piece of the hand tool that is turned by the driving unit (e.g., a motor, preferably electric motor) and that is transmitting the work power to the work piece, preferably via a drill bit or saw blade or the like.

[0011] A sensor for detecting a movement of the housing may preferably be understood as a configuration for optically/mechanically or electromechanically sensing a movement of the housing and providing a, preferably electric, signal proportional to the movement. Preferably, a movement of the housing is an acceleration or a difference of the absolute orientation compared to a reference orientation, particularly preferably it is the velocity of change of orientation of the housing or a rotation rate. For example, the sensor is a Coriolis force based sensor, measuring the velocity of the change of orientation of the housing. As the protection circuit is set up to decrease the speed by a variable amount depending on the amount of the movement, a detection according to the invention is preferably a detection of an amount of the movement and not only a detection of the fact, whether a movement is taking place or not. Detecting may therefore be understood as measuring or sensing an amount of a movement. The sensor may be attached to a battery of the power hand tool.

[0012] A speed control unit for controlling the speed of the rotational shaft may preferably be understood as one or more components set up for having a steerable impact (increase/decrease) on the speed and/or the torque of the rotational shaft. Such components may comprise a break, the motor (engine), a clutch, an open- or closed-loop controller connected to one or more of those components.

[0013] A protection circuit set up to control the speed control unit may preferably be understood as an electronic circuit (analog or digital) connected to the speed control unit. The protection circuit may be attached to a battery of the power hand tool.

[0014] Decreasing the speed by a variable amount to different speed levels above zero may preferably be understood as: starting from a normal speed, not affected by the protection circuit, the speed is lowered to one lower speed level and then to at least one even lower speed level, wherein the lower speed level and the at least one even lower speed level are higher than zero, i.e. the rotational shaft is turning and not standing still. Therefore, the amount of speed reduction from the normal speed level to the lower speed level is different to the amount of speed reduction from the normal speed level to the even lower speed level, and therefore variable. Preferably, the protection circuit is also set up to decrease the speed of the rotational shaft to zero, depending on the amount of the detected movement, i.e. an emergency switch off.

[0015] The variable amount is depending on the amount of the detected movement, which may preferably be understood as a relation between the amount of speed reduction and the amount of the detected movement. The amount of the detected movement may for example be the velocity of the movement (e.g., rotation) of the housing or the acceleration of the movement of the housing or a relative, preferably angular displacement compared to a reference position.

[0016] In a further preferred embodiment according to the present invention the protection circuit has an input terminal and an output terminal, wherein the input terminal is connected to the sensor and the output terminal is connected to the speed control unit, wherein the protection circuit is set up to output a signal s_{out} at the output terminal being defined by values according to a function f of a signal s_{in} at the input terminal. In a further preferred method according to the invention, the protection circuit is correspondingly set up and a signal s_{out} is output at the output terminal being defined by values according to a function f of a signal s_{in} at the input terminal.

[0017] Hereby, the multiple reduced speed levels above zero can be easily created, without setting certain threshold values. Preferably, the function has the property to output a value causing a lower rotational speed for an input value representing a higher amount of the movement of the housing. Preferably, if the highest possible amount of movement is input to the function, the function will return an output value causing a speed of zero, and if the lowest possible amount of movement is input to the function, the function will return an output, that is not affecting the currently speed set by the user. A simple example of such a function could be a linear function connecting this Maximum and Minimum, however, it should be noted that many other different function descriptions exist that serve the purpose of providing a reduction of the speed with an increase of the amount of the movement of the housing.

[0018] In a further preferred embodiment or method according to the present invention the function f is a continuous function.

[0019] By this set-up / method, the user gains even a better feedback as the information on the current movement of the housing of the hand tool is captured and processed by the function so as to result in a continuous reduction of the speed according to the amount of the detected movement. This provides the great chance to the user to feel a very detailed effect of his/her movements on the (security) state of the machine and he can adapt his handling of the machine very advantageously to prevent critical situations.

[0020] A continuous function f may preferably be understood as a function without substantial jumps. Particularly preferable, it is a function, for which small changes in the input result in small changes in the output. Small may preferably be understood as being less than 20 %, preferably 10 % particularly preferably 5 % of the input range, respectively output

range. In the case of digital signals, the continuous function f according to the invention may be understood as a function, in which the value at a digital point (sample point) is the same or off by at most a maximum difference from its neighbors. In other words, if x_1 and x_2 are two adjacent points in a digital space, $|f(x_1) - f(x_2)| \leq \text{maximum difference}$, wherein the maximum difference is preferably less or equal than 13 %, preferably less or equal than 7 %, particularly preferable less or equal than 4 % of the output range of the function given the input range defined by s_{in} . The continuous function therefore has not only 1, 2 or 3 possible output values but a larger (at least of a factor 2 greater) number of possible output values. Preferably the function has equal or more than 8, equal or more than 16, equal or more than 32, or equal or more than 64 output values given the input range defined by s_{in} . By this, the output given in response to the measured movement can be considered and perceived by the user as being smooth, yielding in a finer and more useful feedback and allowing him to react earlier before the tool gets into a critical state - like that, the user may be able to easily prevent the critical state.

[0021] In a further preferred embodiment according to the present invention the protection circuit is set up to determine the values of the preferably continuous function f by calculation. In a further preferred method according to the present invention the values of the continuous function f are calculated.

[0022] Hereby, an advantageous technical realization of generating the output s_{out} is given. The calculation may be digital or analog. In contrast to a threshold comparison, the input signal s_{in} does not need to be compared to one or more thresholds by use of a comparing unit and then a specific output value is chosen - instead, the input signal s_{in} can be processed straight forward with one single function term (for example one line of code) or one analog circuit, realizing that function. In comparison to a look-up-table or threshold method, the approach of calculation is superior also with regard to the amount of memory or number of reference voltages needed, which yields a simpler digital/analog circuit.

[0023] In a further preferred embodiment according to the present invention the protection circuit is set up to perform the calculation by the use of (preferably exclusively) one or more of the following operations: addition; subtraction; multiplication; division; exponentiation; logarithmic calculation; negation; evaluation of a trigonometric function. Preferably, within the method according to the invention, the calculation is performed correspondingly.

[0024] Hereby, a smooth calculation according to a continuous function, providing multiple reduced output speed levels above zero can be performed. These operations may be realized either as part of an analog circuit (by the use of accordingly connected analog devices) and/or a digital computing unit, e.g. as a software on a microcontroller.

[0025] In a further preferred embodiment according to the present invention the protection circuit is set up to decrease the speed of the rotational shaft by the variable amount to different speed levels without comparing the amount of the detected movement to one or more thresholds.

[0026] Hereby, the amount of memory or number of reference voltages needed can be minimized. Preferably, the protection circuit is set up to determine the values of the preferably continuous function f without comparing s_{in} (or a signal proportional to s_{in}) to one or more thresholds. In case of a realization of the protection circuit as digital signal, a threshold comparison in the course of sampling an analog signal from the sensor may be present though - this is not considered as a threshold comparison for determining the values of the continuous function f .

[0027] In a further preferred embodiment according to the present invention the protection circuit is set up for preprocessing a signal of the sensor, preferably s_{in} , by calculating a moving average of it. In a further preferred method according to the present invention, a signal of the sensor is preprocessed correspondingly.

[0028] Hereby, the influence of jitter movements that occur during normal operation of the hand tool are eliminated or reduced. The preprocessed signal is then fed to the protection circuit.

[0029] In a further preferred embodiment or method according to the present invention the protection circuit is an analog circuit.

[0030] Hereby, one alternative realization is given. By use of an analog circuit, a nearly ideal continuous function may be achieved.

[0031] In a further preferred embodiment or method according to the present invention the protection circuit comprises or is part of a digital computing unit.

[0032] Hereby, another alternative realization is given. By use of a digital computing unit, the function may be easily programmed, changed or adapted. In this case, a nearly ideal continuous function may be achieved. The continuous function f according to the invention may be understood as the function, in which the value at a digital point (sample point) is the same or off by at most a maximum difference from its neighbors. In other words, if x_1 and x_2 are two adjacent points in a digital space, $|f(x_1) - f(x_2)| \leq \text{maximum difference}$, wherein the maximum difference is preferably as mentioned above. Preferably the function has more equal or more output values as mentioned above.

[0033] Preferably, s_{out} is generated by a Digital-to-Analog-Converter or as a (pulse width) modulated binary signal, wherein the modulation is done according to the function f . In this case, s_{out} is obviously defined by values according to the function f , as the modulation of s_{out} is defined by the function f .

[0034] In a further preferred embodiment or method according to the present invention the digital computing unit has an input resolution p_{in}^{min} and an output range r_{out} , wherein the digital computing unit is set up for computing the continuous function f depending on s_{in} , wherein for every change of s_{in} in the amount of p_{in}^{min} , the change of s_{out} is maximally 10

% of r_{out} .

[0035] Hereby, the function f is considered continuous for digital signals - this corresponds to the above mentioned definition $|f(x_1) - f(x_2)| = p_{in}^{min} \leq 10\%$ of r_{out} . A maximal possible jump of the function when going from one sample point of s_{in} to the next sample point of s_{in} is defined by this. The possible jump of the function (y-axis-direction) is smaller or equal to this maximal jump. Therefore, the resulting signal is smooth enough for the purpose of the invention according to the embodiment including the continuous function.

[0036] An input resolution may preferably be understood as the smallest distinguishable difference between two values of s_{in} and/or the smallest distinguishable difference between two values of any signal acquired (A-to-D-Conversion) by the digital computing unit. An output range may preferably be understood as the range defined by the highest and lowest possible value of the function given the interval of input values and/or the range defined by the highest and lowest possible value that the digital circuit is able to generate at its output.

[0037] In a further preferred embodiment or method according to the present invention the digital computing unit has an output resolution p_{out}^{min} and the digital computing unit is set up for computing the continuous function f depending on s_{in} , wherein for every change of s_{in} in the amount of P_{in}^{min} , the change of s_{out} is maximally p_{out}^{min} .

[0038] Hereby, a similar definition of the continuous function f in the case of digital signals is given, however, with relating the maximum difference of neighboring sample points to the output resolution of the digital computing unit and not to the output range.

[0039] An output resolution may preferably be understood as the smallest distinguishable difference between values of any signal that is output (D-to-A-Conversion) by the digital computing unit. Preferably, p_{out}^{min} is smaller than 10 % of the output range of the computing unit.

[0040] In a further preferred embodiment according to the present invention the hand tool comprises a user input means for receiving an information about the speed desired by the user, wherein the variable amount is also depending on a state of the user input means. In a further preferred method according to the present invention the variable amount is also depending on a state of a user input means of the hand tool.

[0041] Hereby, the user has a further improved feedback as the protection might only reduce the speed substantially when really needed - instead, in situations that are not critical although there is a strong movement of the housing, the speed is not affected too strong. The output of the protection circuit is influenced by the current operational state of the hand tool. Preferably, the protection circuit is therefore set up to output the signal s_{out} also depending of a state of the user input means and/or the protection circuit is outputting the signal s_{out} also depending of a state of the user input means.

[0042] A user input means may preferably be understood as any means, which the user is (manually) operating to control the speed and/or the torque of the hand tool. It is for example a switch, button, most preferably a trigger button as usually used in known drilling tools. Preferably the user input means has more than two states (e.g., more than just on/off, but at least one, preferably a plurality of in-between states).

[0043] This embodiment and the remaining embodiments that including the consideration of the user input means state may preferably be used not necessarily with the feature of the protection circuit being set up to decrease the speed of the rotational shaft by a variable amount to different speed levels above zero, wherein the variable amount is depending on the amount of the detected movement - this broader idea (limited to the user input means) may be subject of a divisional application. I.e., in case the user input means is present, the protection circuit may be set up to decrease the speed from normal to zero with only one or even no reduced speed level in between, however the reduced speed level and or a threshold, at which the speed is reduced or set to zero, depends on the state of the user input means. Other features combined with this or the following user input means embodiments may still be combined with this modified embodiment.

[0044] In a further preferred embodiment according to the present invention the protection circuit has a further input terminal to which the user input means is connected and the (preferably continuous) function f is also a (preferably continuous) function of a signal s_{in2} at the further input terminal. In a further preferred method according to the present invention the protection circuit is correspondingly set up and outputting the signal s_{out} at the output terminal being defined by values according to the function f which is also a (preferably continuous) function of a signal s_{in2} at the further input terminal.

[0045] Hereby, a technical simple realization of the signal is provided. And the same computing unit (analog or digital) may be used for calculating the function f . Preferably, the function f is only continuous with respect to s_{in} (which means, that with respect to s_{in2} there may exist considerable jumps of the function value), particularly preferably it is continuous with respect to both, s_{in} and s_{in2} .

[0046] In a further preferred embodiment according to the present invention, if the user input means is in a state representing a lower power demand by the user, a decrease of the speed of the rotational shaft is smaller than a decrease of the speed if the user input means is in a state representing a higher power demand by the user. In a further preferred method according to the present invention an amount, by which the speed of the rotational shaft is reduced, is smaller, if the user input means is in a state representing a lower power demand by the user, than an amount, by which the speed of the rotational shaft is reduced, if the user input means is in a state representing a higher power demand by the user.

[0047] Hereby, an advantageous adaption of the protective circuit to the current operation state is given. As the speed is decreased less, when the user input means is in a state representing a lower power demand, the protective circuit is more sensible when the hand tool is running at a higher power level, than at a lower power level. This is very good, as at a higher power level, it might be more crucial to protect the user and furthermore, there might exist cases where the user indeed wants to shake the tool and at the same time have a slow rotation of the tool, e.g. when the user wants to free a stuck drilling bit or the like - in this situation, the user will not be disturbed by an onset or a too strong onset of some protective reaction of the tool, as for example a complete breaking. The protection circuit is hence set up to decrease the speed of the rotational shaft less, if the user input means is in a state representing a lower power demand by the user than if the user input means is in a state representing a higher power demand by the user. Preferably, the function f is configured to cause the speed control unit to decrease the speed of the rotational shaft accordingly less.

[0048] In a further preferred embodiment according to the present invention one or more of the protection circuit and the sensor is disposed in or on a battery of the hand tool, wherein the battery is detachable from the hand tool and connectable to a different hand tool.

[0049] Hereby, expensive components like the sensor and/or the protection circuit may be used for different hand tools and therefore, the required number of components may be smaller.

[0050] Preferably, the different hand tools are set up to calibrate themselves to the one or more of the protection circuit and the sensor disposed in or on the battery after the battery has been attached or set up to calibrate the one or more of the protection circuit and the sensor disposed in or on the battery to the respective hand tool after the battery has been attached. In a further preferred method according to the present invention the control method contains a corresponding calibration step.

[0051] Hereby, different functions f or different sensor calibrations (e.g., sensor gain, sensing range) may be used for different hand tools. The hand tools may be of the same type or preferably of a different type, e.g. a drilling tool and a wall grinding tool or screw driving tool. For example, the function f could be calibrated to be less sensitive (less reduction of speed for the same amount of movement of the housing) in the case of a screw driver, because there, the user is expected to move and slant the tool deliberately whereas in the case of a drilling tool (especially drill hammer), the function f should be comparably more sensitive as holes shall be straight (so less deliberate movement by the user) and security is more important as higher speeds and/or torques are present.

[0052] This embodiment and the remaining embodiments that include the set up with the detachable battery may preferably not necessarily include the feature of the protection circuit being set up to decrease the speed of the rotational shaft by a variable amount to different speed levels above zero, wherein the variable amount is depending on the amount of the detected movement - this broader idea (limited to the detachable battery) may be subject of a divisional application. I.e., in case the detachable battery having one or more of the protection circuit and the sensor is present, the protection circuit may be set up to decrease the speed from normal to zero with only one or even no reduced speed level in between. Other features combined with this or the following detachable battery embodiments may still be combined with this modified embodiment.

[0053] With respect to one or more of the protection circuit and the sensor being disposed in or on a battery of the hand tool according to the invention, the object of the invention is furthermore achieved by a detachable battery for a hand tool, wherein the battery comprises one or more of the protection circuit and the sensor, being disposed in or on the battery.

[0054] Embodiments of the present invention will now be described - by way of example only - with reference to the accompanying drawings, whereby

Fig. 1 is an overview of a hand tool according to the invention,

Fig. 2 is an overview of a hand tool according to the invention based on Fig. 1 wherein the protection circuit is set up for outputting a signal according to a function, which is continuous,

Fig. 3 shows an example of a digital continuous function f ,

Fig. 4 is an overview of a hand tool based on Fig. 2, wherein s_{out} is also depending on the state of the user input means, here a trigger button,

Fig. 5 shows an example of a continuous function f that is depending on the input of the sensor and the input of the trigger button,

Fig. 6 shows a continuous function f as in Fig. 5 wherein f is only continuous with respect to the sensor signal,

Fig. 7 shows a continuous function f as in Fig. 6, however with more output values with respect to the input of the trigger button,

Fig. 8 shows an overview of a hand tool based on Fig. 1, 2 or 4, wherein the hand tool has a detachable battery comprising the sensor,

Fig. 9 shows the battery.

[0055] Fig. 1 is an overview of a power hand tool 1 according to the invention. It has a rotational shaft 2 driven by a

driving unit 3. The hand tool 1 comprises a sensor 10 for detecting a movement of a housing 4 of the hand tool 1, a speed control unit 20 for controlling the speed of the rotational shaft 2 and a protection circuit 30 set up to control the speed control unit 20 for protecting a user of the hand tool 1 based on the detected movement. The protection circuit 30 is set up to decrease the speed v of the rotational shaft 2 by a variable amount to different speed levels $v_{r1} \dots v_{rn}$ above zero, e.g. $n=2, 3, 4$ or higher, wherein the variable amount is depending on the amount of the detected movement. In this exemplary case, the hand tool 1 is electric, having an electric motor 3, which is activated by a trigger button 40 connected to the speed control unit 20.

[0056] When the hand tool 1 is used, following steps are performed:

- detecting a movement of the housing 4 of the hand tool 1 by a sensor 10 of the hand tool 1,
- controlling a speed of the rotational shaft 2 by a speed control unit 20,
- controlling the speed control unit 20 by a protection circuit 30 for protecting a user of the hand tool 1 based on the detected movement, wherein the speed of the rotational shaft 2 is decreased by a variable amount to different speed levels above zero, wherein the variable amount is depending on the amount of the detected movement.

[0057] Hereby, hand tool 1 is not only switched off or decreased one time before it is switched off. The multiple reduced speed levels above zero provide a better feedback to the user how far/close the state of the machine is from/to a critical situation.

[0058] Fig. 2 is an overview of a hand tool 1 based on Fig. 1 wherein the protection circuit 30 is set up for outputting a signal s_{out} according to a function f , which is continuous. The protection circuit 30 has an input terminal 31 and an output terminal 32, wherein the input terminal 31 is connected to the sensor 10 and the output terminal 32 is connected to the speed control unit 20. The protection circuit 30 is set up to output a signal s_{out} at the output terminal 32 being defined by values according to a function f of a signal s_{in} at the input terminal 31. The function f is a continuous function. An example of f is given in a small diagram in the lower right. For example, if s_{in} represents speed of the movement of the housing 4 (low speed = low value of s_{in} ; high speed = high value of s_{in}) and s_{out} represents the speed that the speed control unit 20 applies to the rotational shaft 2 (low speed = low value of s_{out} ; high speed = high value of s_{out}), then this function f has the following effect: the higher the speed of the movement of the housing 4, the lower the speed of the rotational shaft 2. The function f is providing many-preferably uncountable - speed levels of the rotational shaft 2 depending on the speed of the movement of the housing 4.

[0059] In this example, the protection circuit 30 is further set up to determine the values of the function f by calculation. No thresholds are being used for determining the values of the function f .

[0060] Hereby, a very fine and sensitive feedback depending on the movement of the housing is provided to the user.

[0061] Fig. 3 shows an example of a digital continuous function f (solid line), which is the case if the protection circuit 30 comprises or is part of a digital computing unit. The digital computing unit has an input resolution p_{in}^{min} and an output range r_{out} , wherein the digital computing unit is set up for computing the continuous function f depending on s_{in} , wherein for every change of s_{in} in the amount of p_{in}^{min} , the change of s_{out} is maximally 10 % of r_{out} . Furthermore, the digital computing unit has an output resolution p_{out}^{min} and the digital computing unit is set up for computing the continuous function f depending on s_{in} , wherein for every change of s_{in} in the amount of p_{in}^{min} , the change of s_{out} is maximally p_{out}^{min} . In this case, the protection circuit 30 is set up to generate thirteen different reduced speeds of the rotational shaft 2.

[0062] This function is considered continuous, as it is an approximation of a continuous function (dotted line) and therefore quasi-continuous. Hereby, although the function is digital, it is smooth enough to provoke the advantageous effect of a continuous function according to the invention, i.e., a very fine and sensitive feedback depending on the movement of the housing.

[0063] Fig. 4 is an overview of a hand tool 1 based on Fig. 2, wherein s_{out} is also depending on the state of the trigger button 40 as user input means. The trigger button 40 is representing a means for receiving an information about the speed desired by the user. The variable amount, by which the speed is reduced, is also depending on a state of the trigger button 40. Here, the protection circuit 30 is further set up to output the signal s_{out} also depending of a state of the trigger button 40. The protection circuit 30 has a further input terminal 33 to which the trigger button 40 is connected and the continuous function f is also a function of a signal s_{in2} at the further input terminal 33. An exemplary function is shown in the lower right, the function being now a plane in the space given by s_{in} , s_{in2} and s_{out} .

[0064] Hereby, the need of protection is automatically adapted to the current state of the machine or the current state desired by the user.

[0065] Specific examples of possible functions f depending on s_{in} and s_{in2} are depicted in Fig. 5, 6 and 7. For all those examples, the function f leads to the protection circuit 30 being set up to decrease the speed of the rotational shaft 2 less, if the trigger button 40 is in a state representing a lower power demand by the user than if the trigger button 40 is in a state representing a higher power demand by the user. If the trigger button 40 is in a state representing a lower power demand by the user, a decrease of the speed of the rotational shaft 2 is smaller than a decrease of the speed if the trigger button 40 is in a state representing a higher power demand by the user. In these figures, a low s_{in} means a

low amount of the movement of the housing 4, a low s_{in2} means a trigger, that is nearly completely (or completely) released, wherein in a high s_{in} means a high amount of the movement of the housing 4 and a high s_{in2} means a trigger 40 that is nearly completely (or completely) pressed down. The lower s_{out} , the lower is the resulting speed of the rotational shaft 2. Therefore, one can see for every of the illustrated functions that for the same s_{in} a low s_{in2} leads to a higher s_{out} , than a high s_{in2} . For example, if the user desires a very slow operation of the tool 1 (low power demand), he is pressing the trigger 40 only in a very low amount. In this operational state, there is not much danger because of the low speeds of the rotational shaft 2. In this state, the protective action will be less accentuated because of the chosen functions f , which means, that the user may have a considerable movement of the housing 4, however, the protective reaction of the tool 1 is not as heavy as it would be for the same housing movement at an operational state, at which the user wants to operate the tool 1 with higher power (trigger 40 pressed further pressed down). This is giving the user more freedom in less critical situations.

[0066] Fig. 5 shows an example of a continuous function f that is depending on the input of the sensor and the input of the trigger button and that is continuous with respect to s_{in} and s_{in2} . Fig. 6 shows a continuous function f as in Fig. 5, wherein f is only continuous with respect to the sensor signal s_{in} . Fig. 7 shows a continuous function f as in Fig. 6, however with more output values with respect to the input of the trigger button s_{in2} . These are alternative realizations of a 2-variate function f , wherein the smoothest function (Fig. 5) provides the best feedback for the user, compared to the less smooth function in Fig. 7 or even the least smooth function of Fig. 6. A function having the properties of the one in Fig. 5, may be expressed as:

$$s_{out} = \ln((0.1 + s_{in2}) * (-s_{in}) + 2.08) \text{ OR } s_{out} = 1 - ((3 * s_{in2})^2) * s_{in} - 2 * s_{in}^2;$$

[0067] a function having the properties as the one in Fig. 6 may be expressed as:

$$s_{out} = \ln((0.1 + 0.00001 * s_{in2}) * (-s_{in}) + 2.08) + 2 - s_{in} * 0.01 * (s_{in2} - 0.25) / \text{abs}(s_{in2} - 0.25);$$

a function having the properties as the one in Fig. 7 may be expressed as:

$$s_{out} = \ln((0.1 + 0.00001 * s_{in2}) * (-s_{in}) + 2.08) + 2 - s_{in} * 0.01 * (s_{in2} - 0.1) / \text{abs}(s_{in2} - 0.1) - s_{in} * 0.01 * (s_{in2} - 0.3) / \text{abs}(s_{in2} - 0.3) - s_{in} * 0.01 * (s_{in2} - 0.4) / \text{abs}(s_{in2} - 0.4);$$

for s_{in} from 0 to 0.33 and s_{in2} from 0 to 0.5 wherein $\ln$ is the natural logarithm and abs the absolute value function, respectively. These are exemplary realizations of f and it should be noted that there exist many other possible formulations, which are also covered by the inventive concept.

[0068] Fig. 8 shows an overview of a hand tool 1 based on Fig. 1, 2 or 4, wherein the hand tool has a detachable battery 50 comprising the sensor 10 - instead, the protection circuit 30 or both, the protection circuit 30 and the sensor 10 could be comprised by the battery 50. The battery 50 is detachable from the hand tool 1 and connectable to a different hand tool 1', which in this case is an angle grinder. Fig. 9 shows the battery 50 for the tools 1, 1' according to Fig. 8, comprising the sensor 10.

[0069] With this invention, an enhanced power hand tool with an integrated protection circuit has been presented, which provides a better feedback to the user. By decreasing the speed not only by one, but by multiple different steps before performing an emergency shutdown, the user can get a differentiated feeling of the impact of his actions and therefore, the handling of the tool and the efficiency of working with the tool is greatly enhanced. The user may learn how to prevent critical situations or foresee critical situations earlier and perform corrective actions. A particularly well working embodiment includes the speed reduction according to a continuous or quasi-continuous (in case of digital signals) function. The feedback is still further enhanced, if a signal of the manual user input means of the tool is considered.

Reference signs

[0070]

1 power hand tool

	2	rotational shaft
	3	driving unit
	4	housing
	10	sensor
5	20	speed control unit
	30	protection circuit
	31	input terminal
	32	output terminal
	33	further input terminal
10	40	trigger button
	50	battery
	v	speed of the rotational shaft
	v_{r1}, v_{rn}	reduced speed levels
	p_{in}^{min}	input resolution
15	p_{out}^{min}	output resolution
	r_{out}	output range

Claims

1. Power hand tool (1) having a rotational shaft (2) driven by a driving unit (3), wherein the hand tool (1) comprises a sensor (10) for detecting a movement of a housing (4) of the hand tool (1), a speed control unit (20) for controlling the speed of the rotational shaft (2) and a protection circuit (30) set up to control the speed control unit (20) for protecting a user of the hand tool (1) based on the detected movement, **characterized in that** the protection circuit (30) is set up to decrease the speed (v) of the rotational shaft (2) by a variable amount to different speed levels ($v_{r1} \dots v_{rn}$) above zero, wherein the variable amount is depending on the amount of the detected movement.
2. Hand tool (1) according to claim 1, wherein the protection circuit (30) has an input terminal (31) and an output terminal (32), wherein the input terminal (31) is connected to the sensor (10) and the output terminal (32) is connected to the speed control unit (20), wherein the protection circuit (30) is set up to output a signal s_{out} at the output terminal (32) being defined by values according to a function f of a signal s_{in} at the input terminal (31).
3. Hand tool (1) according to claim 2, wherein the function f is a continuous function.
4. Hand tool (1) according to claim 2 or 3, wherein the protection circuit (30) is set up to determine the values of the function f by calculation.
5. Hand tool (1) according to one of the preceding claims, wherein the protection circuit (30) is set up to perform the calculation by the use of one or more of the following operations: addition; subtraction; multiplication; division; exponentiation; logarithmic calculation; negation; evaluation of a trigonometric function.
6. Hand tool (1) according to one of the preceding claims, wherein the protection circuit (30) is an analog circuit.
7. Hand tool (1) according to one of the claims 1 to 5, wherein the protection circuit (30) comprises or is part of a digital computing unit.
8. Hand tool (1) according to claim 7 and 3, wherein the digital computing unit has an input resolution p_{in}^{min} and an output range r_{out} , wherein the digital computing unit is set up for computing the continuous function f depending on s_{in} , wherein for every change of s_{in} in the amount of p_{in}^{min} , the change of s_{out} is maximally 10 % of r_{out} .
9. Hand tool (1) according to claim 7 and 3, wherein the digital computing unit has an output resolution p_{out}^{min} and the digital computing unit is set up for computing the continuous function f depending on s_{in} , wherein for every change of s_{in} in the amount of p_{in}^{min} the change of s_{out} is maximally p_{out}^{min} .
10. Hand tool (1) according to one of the preceding claims, wherein the hand tool (1) comprises a user input means (40) for receiving an information about the speed desired by the user, wherein the variable amount is also depending on a state of the user input means.

11. Hand tool (1) according to at least claim 10 and claim 2, wherein the protection circuit (30) has a further input terminal (33) to which the user input means (40) is connected to and wherein the function f is also a function of a signal s_{in2} at the further input terminal (33).

12. Hand tool (1) according to claim 10 or 11, wherein, if the user input means (40) is in a state representing a lower power demand by the user, a decrease of the speed of the rotational shaft (2) is smaller than a decrease of the speed if the user input means (40) is in a state representing a higher power demand by the user.

13. Hand tool (1) according to one of the preceding claims, wherein one or more of the protection circuit (30) and the sensor (10) is disposed in or on a battery (50) of the hand tool (1), wherein the battery (50) is detachable from the hand tool (1) and connectable to a different hand tool (1').

14. Detachable battery (50) for a hand tool (1) according to claim 13, wherein the battery (50) comprises one or more of the protection circuit (30) and the sensor (10), being disposed in or on the battery (50).

15. Control method for a power hand tool (1) having a rotational shaft (2) driven by a driving unit (3), comprising the steps:

- detecting a movement of a housing (4) of the hand tool (1) by a sensor (10) of the hand tool (1),
- controlling a speed of the rotational shaft (2) by a speed control unit (20),
- controlling the speed control unit (20) by a protection circuit (30) for protecting a user of the hand tool (1) based on the detected movement,

characterized in that,

the speed of the rotational shaft (2) is decreased by a variable amount to different speed levels above zero, wherein the variable amount is depending on the amount of the detected movement.

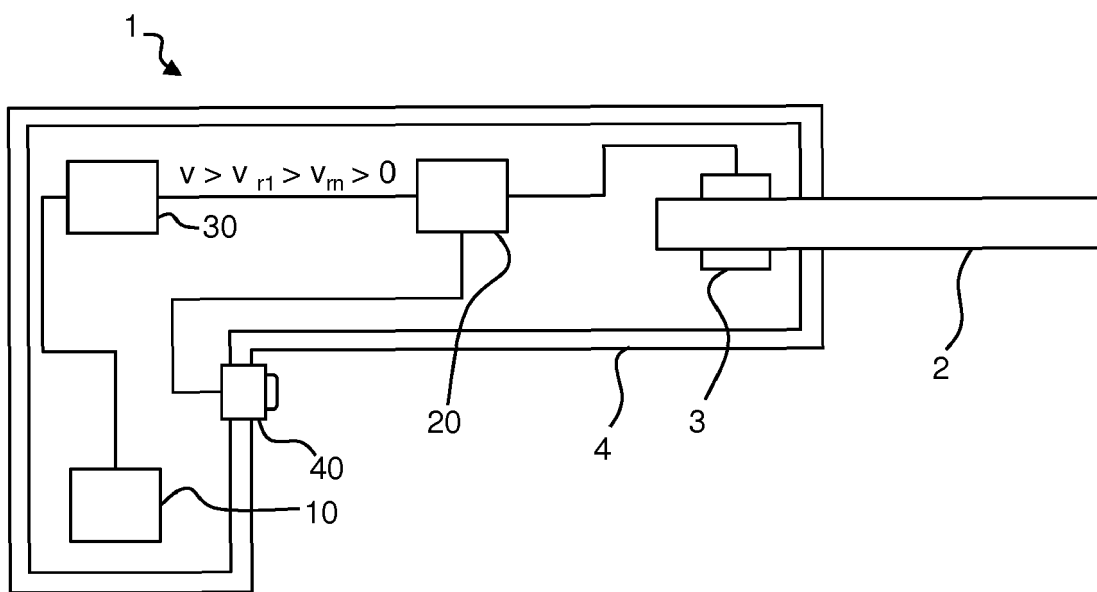


Fig. 1

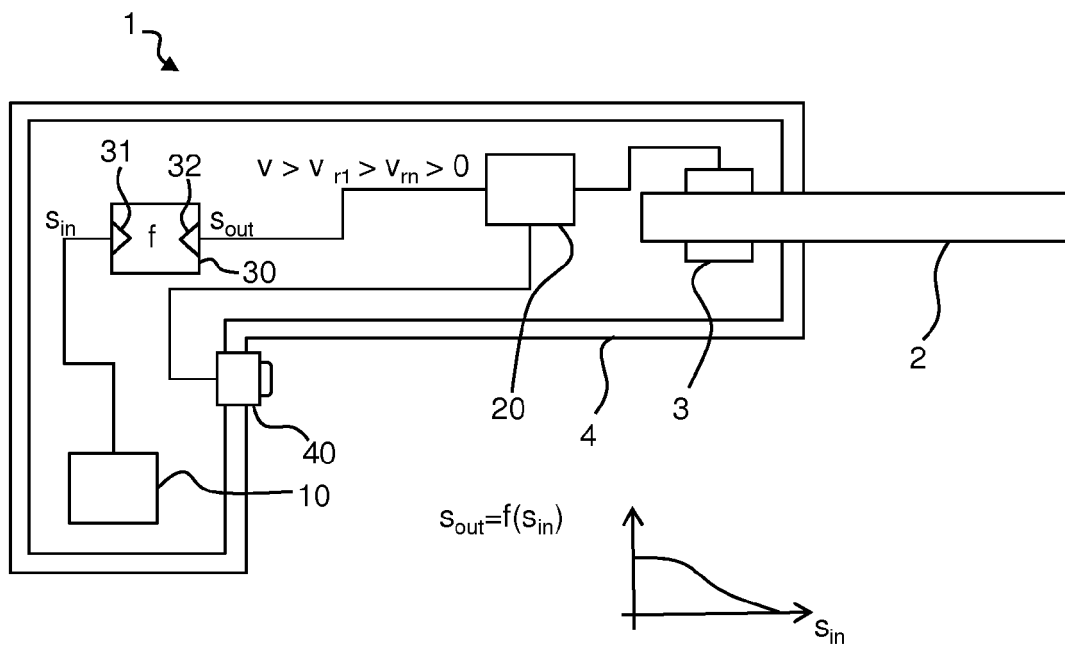


Fig. 2

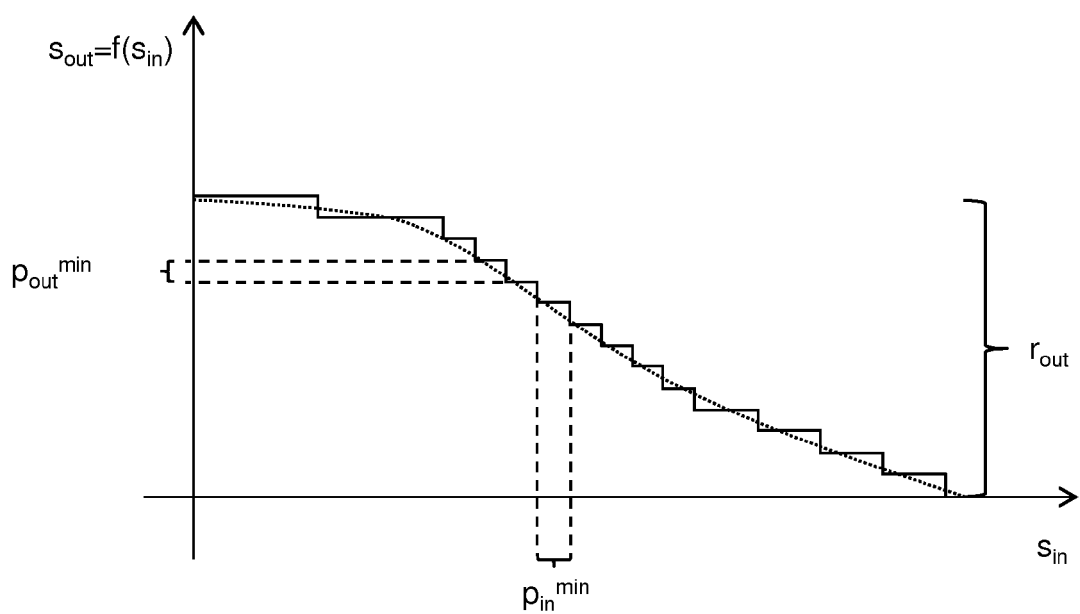


Fig. 3

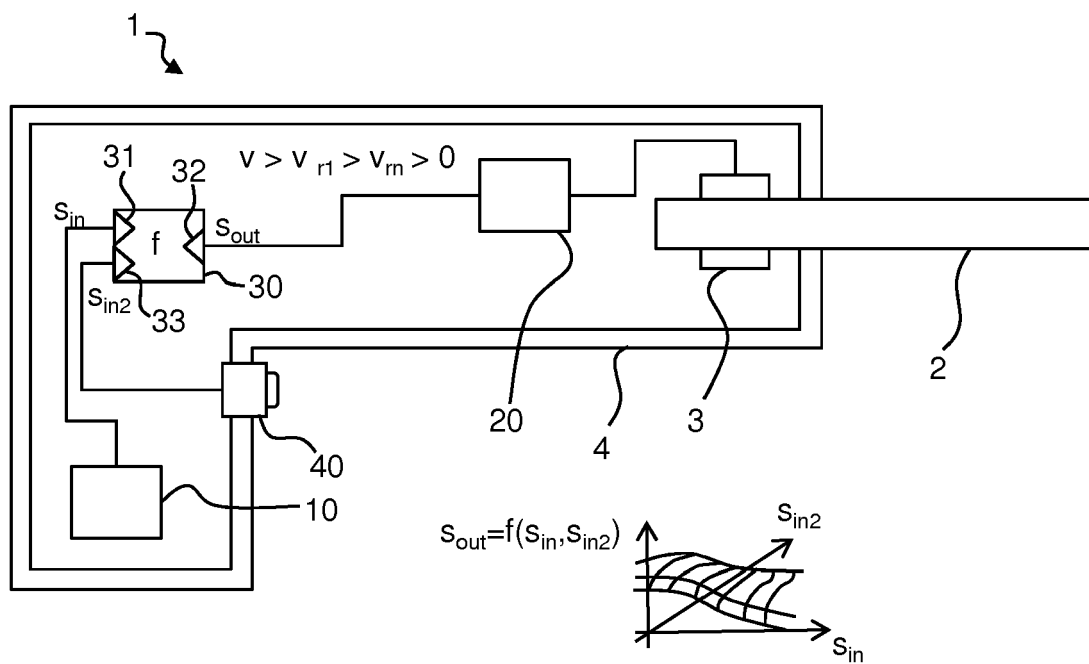


Fig. 4

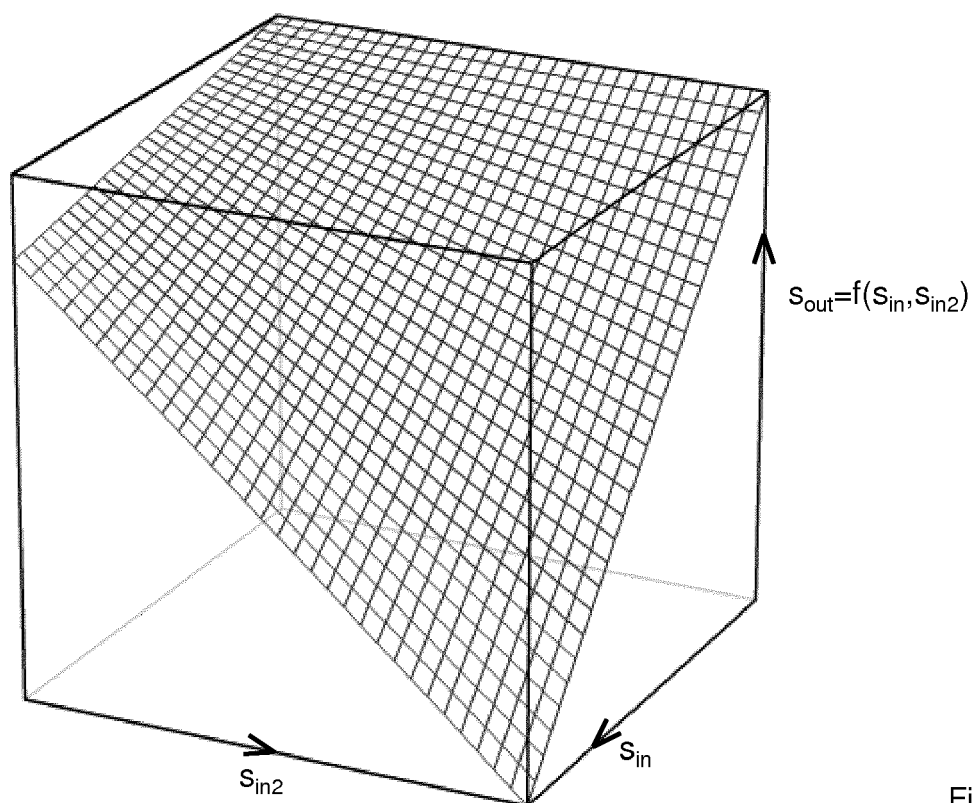


Fig. 5

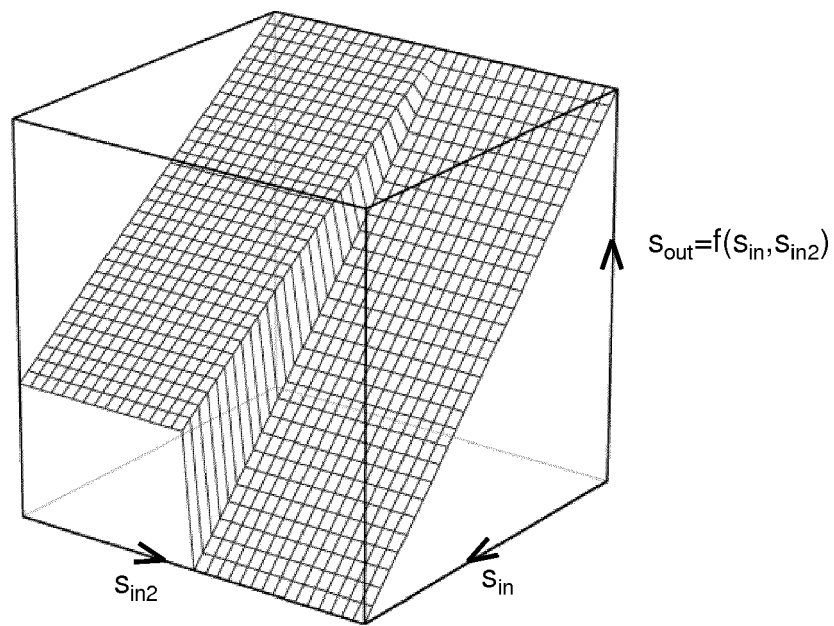


Fig. 6

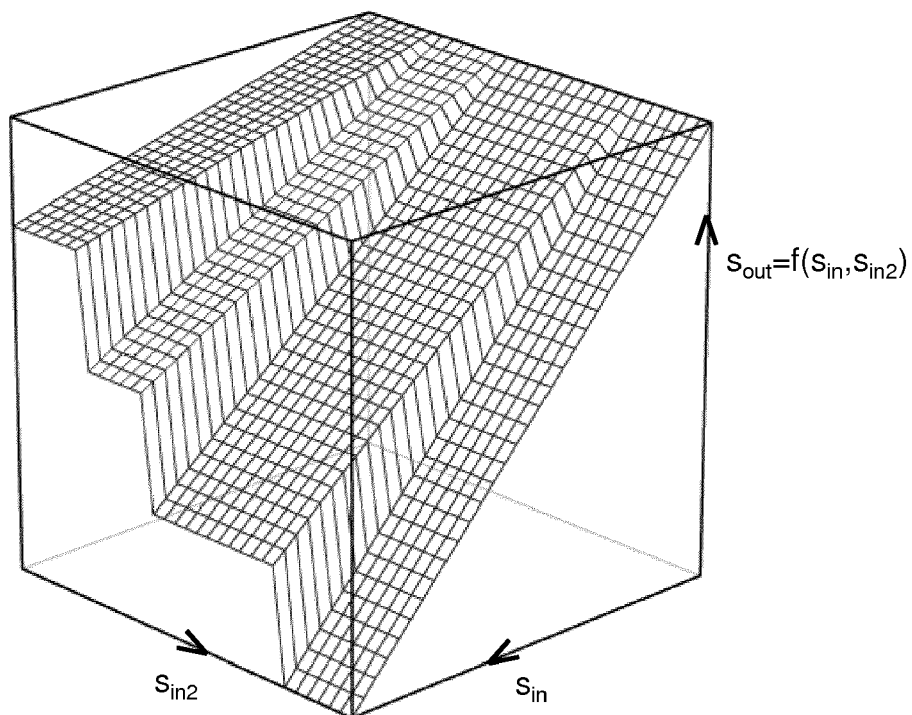


Fig. 7

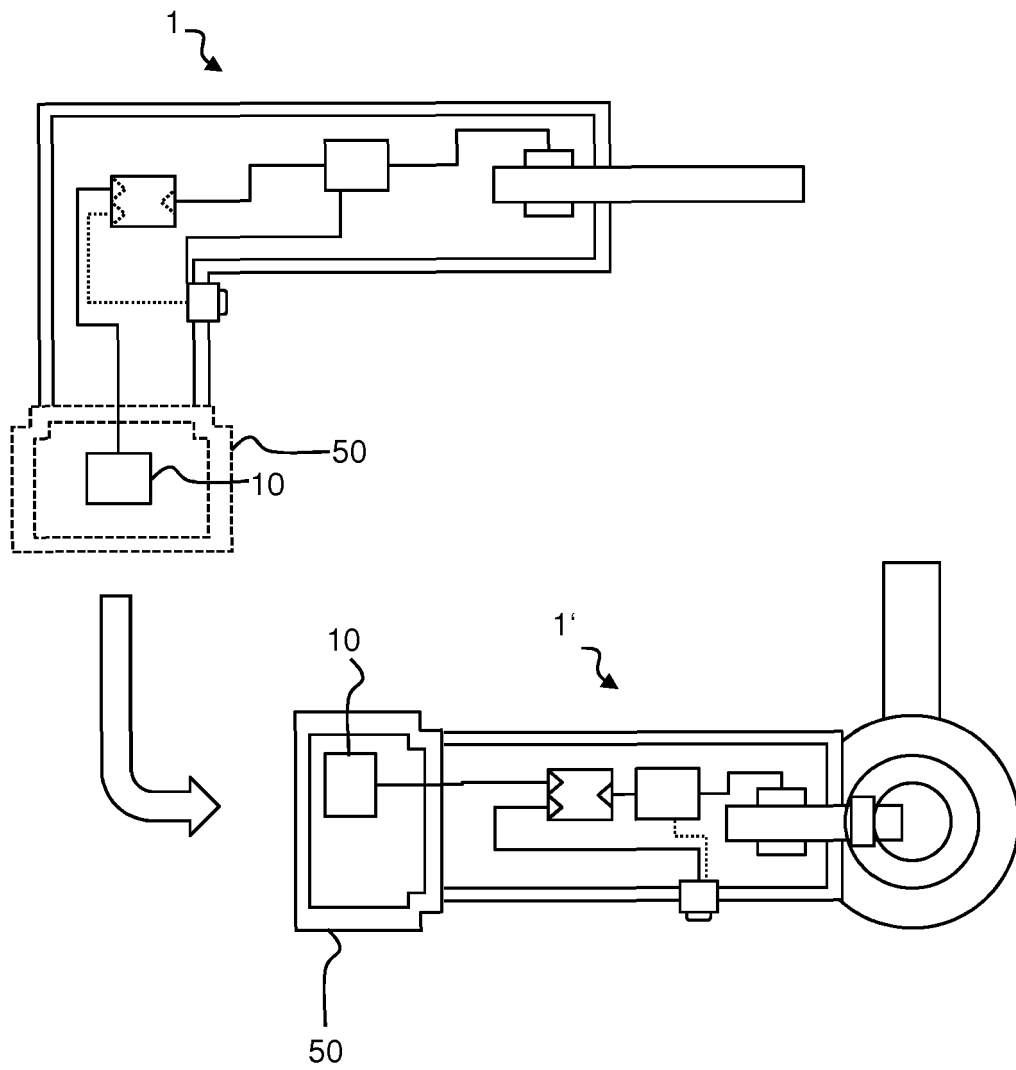


Fig. 8

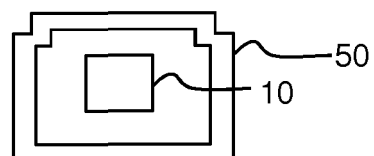


Fig. 9



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