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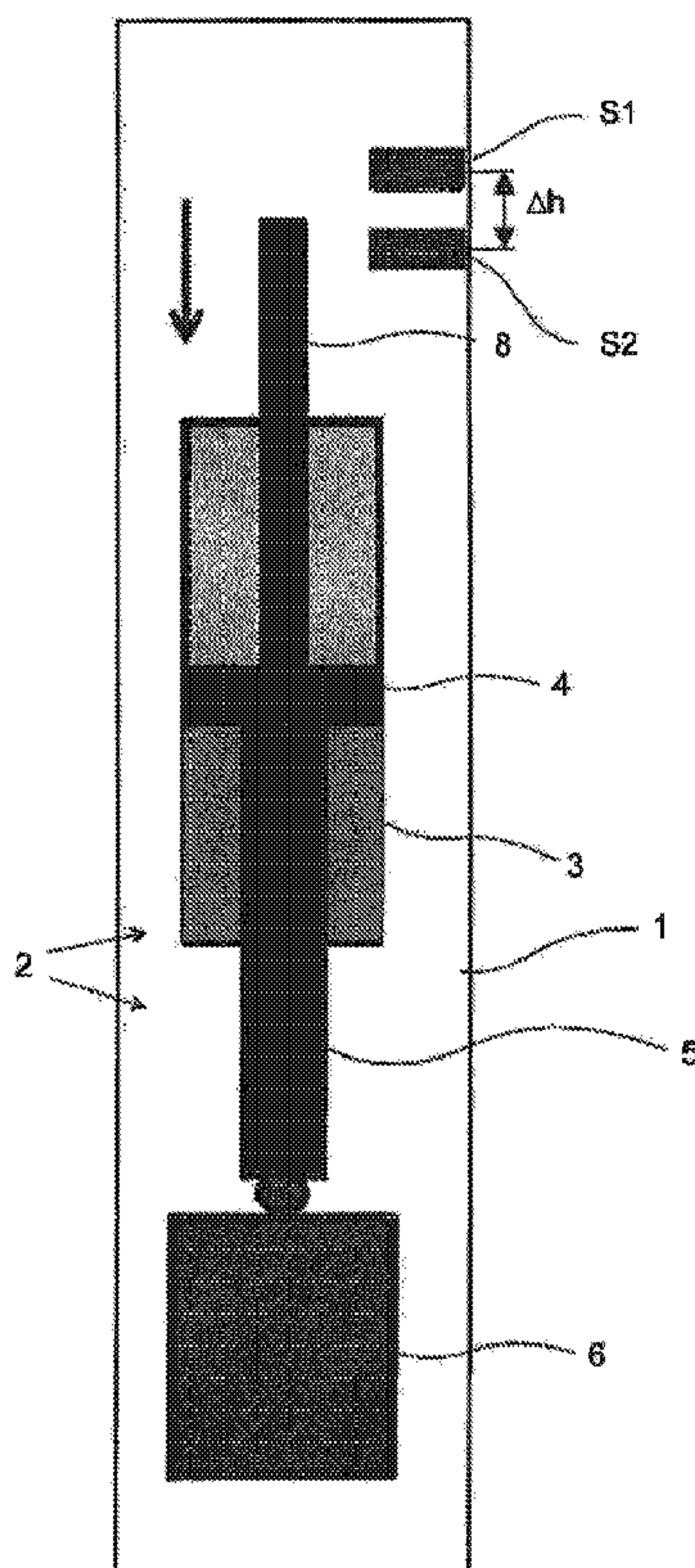


Fig. 1

(57) Abrégé/Abstract:

The invention relates to a method for optimizing the driving of a pile (7), the method comprising: - driving the pile (7) into the ground by a pile-driving machine comprising a hammer ram (1) to be placed against the pile (7) and a block (6) that is movable back and

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forth therein; - moving the block (6) applied for driving the pile (7) towards the end of the pile (7) with a given impact energy (W_{kin}); - determining the value of a kinetic variable (Q1) of the impact, proportional to the kinetic energy of the block (6) used for driving the pile, when the block (6) is moving towards the pile (7) in the pile driving direction; - determining the value of a kinetic variable (Q3) of the return motion, proportional to the kinetic energy of the block (6), when the block (6) is returning, after an impact on the pile (7), in a direction opposite to the pile driving direction: - calculating a kinetic variable ratio (Q1/Q3) by means of the determined kinetic variable (Q1) of the impact motion and kinetic variable (Q3) of the return motion; - comparing the obtained kinetic variable ratio (Q1/Q3) with a predetermined target value ($Q1/Q3_{tav}$) for the kinetic variable ratio (Q1/Q3), producing the shortest possible total pile driving time (t_{tot}) for the pile (7); - adjusting the impact energy (W_{kin}) of the next impact in such a way that the kinetic variable ratio (Q1/Q3) determined by the kinetic variable (Q1) of the impact motion and the kinetic variable (Q3) of the return motion of the next impact will be changed towards the target value ($Q1/Q3_{tav}$).

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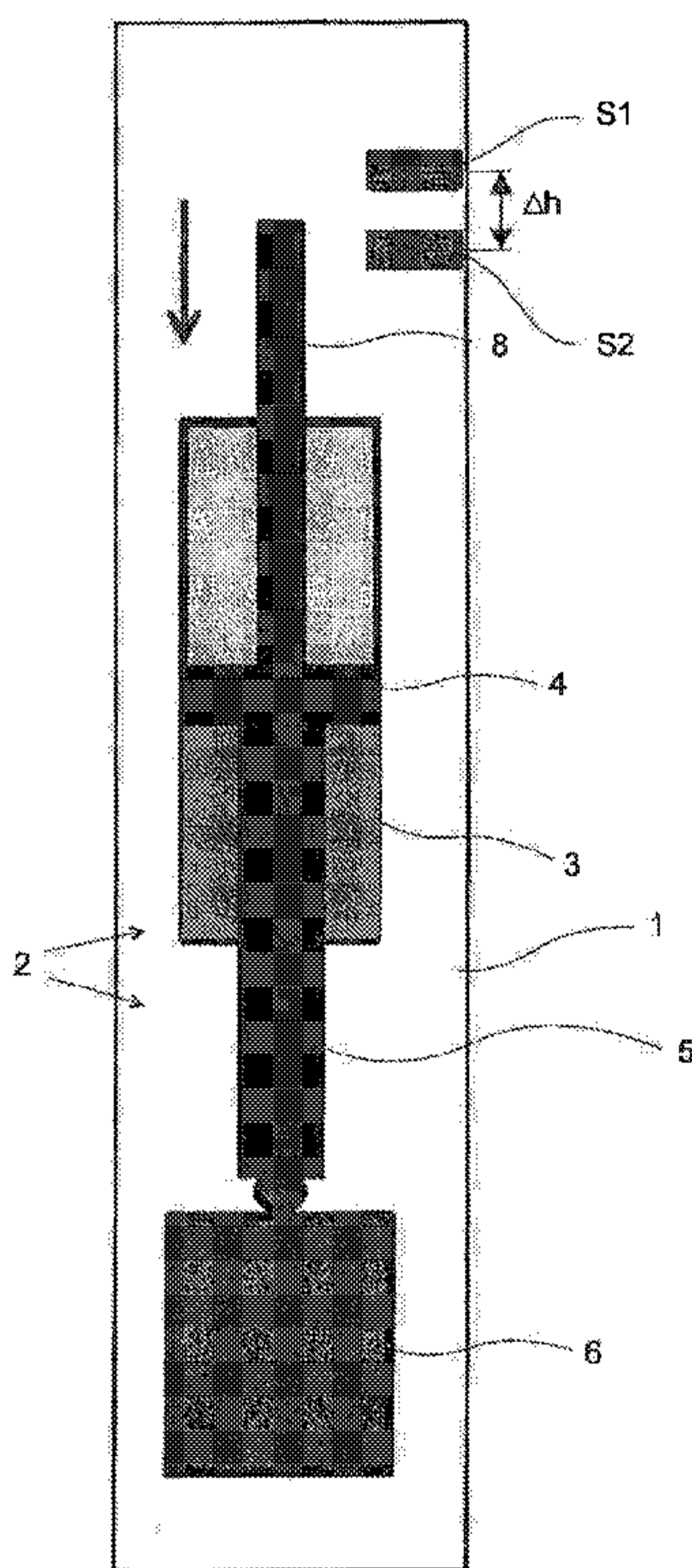
(54) **Title:** A METHOD FOR PILE-DRIVING

Fig. 1

(57) **Abstract:** The invention relates to a method for optimizing the driving of a pile (7), the method comprising: - driving the pile (7) into the ground by a pile-driving machine comprising a hammer ram (1) to be placed against the pile (7) and a block (6) that is movable back and forth therein; - moving the block (6) applied for driving the pile (7) towards the end of the pile (7) with a given impact energy (W_{kin}); - determining the value of a kinetic variable (Q1) of the impact, proportional to the kinetic energy of the block (6) used for driving the pile, when the block (6) is moving towards the pile (7) in the pile driving direction; - determining the value of a kinetic variable (Q3) of the return motion, proportional to the kinetic energy of the block (6), when the block (6) is returning, after an impact on the pile (7), in a direction opposite to the pile driving direction; - calculating a kinetic variable ratio (Q1/Q3) by means of the determined kinetic variable (Q1) of the impact motion and kinetic variable (Q3) of the return motion; - comparing the obtained kinetic variable ratio (Q1/Q3) with a predetermined target value ($Q1/Q3_{tav}$) for the kinetic variable ratio (Q1/Q3), producing the shortest possible total pile driving time (t_{tot}) for the pile (7); - adjusting the impact energy (W_{kin}) of the next impact in such a way that the kinetic variable ratio (Q1/Q3) determined by the kinetic variable (Q1) of the impact motion and the kinetic variable (Q3) of the return motion of the next impact will be changed towards the target value ($Q1/Q3_{tav}$).

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A METHOD FOR PILE-DRIVING

Field of the invention

- 5 The invention relates to a method for optimizing pile-driving.

Background of the invention

10 Conventionally, the impact energy of piles to be driven into ground by a pile-driving machine is adjusted by the driver of the pile-driving machine. This is done so that the driver of the machine follows the driving of the pile into the ground visually and/or watches measurement results produced by measuring devices monitoring the motion of the hammer ram, for example the progress of sinking (*i.e.* the advance) of the pile, or the load carrying capacity determined on the basis of it, and uses this to adjust the impact energy produced by the mass, *i.e.* block, moving inside the hammer ram (normally by adjusting the height of lifting the block). Normally, based on his experience, the driver tends to select an advance with which the total time taken for driving the pile into the ground would be as short as possible, wherein the total time taken for piling a given area or building can be minimized as well.

25 A drawback of the known method is the fact that using it, the pile can be driven using too much or too little impact energy (irrespective of the driver's experience). Using too much impact energy has the drawback that when the impact energy produced by the block is increased, the stroke frequency is normally reduced, because the greater impact energy will require a larger travel path (*i.e.* height for hoisting the block). As a result, in spite of the greater advance of the pile, the total time taken for driving the pile into the ground may be prolonged with respect to the velocity that could possibly be achieved with a slightly smaller impact energy. Using too much impact energy may, in the worst case, even cause breaking of the pile, because when the load carrying capacity is very small in relation to the impact energy, the shock wave effective on the end of the pile as a result of the impact will cause a tension on the pile, which tension may in such a case exceed the tensile strength of the pile. Using too little impact energy, in turn, has the drawback that the potential energy produced by the impact energy will not

produce a sufficiently great force to exceed the load carrying capacity of the pile. As a result, the pile will not sink into the ground in the intended way, but the impact energy exerted on the pile is largely returned to the block. The drawbacks of the present method are particularly pronounced when the driver of the pile-driving machine is inexperienced.

Brief summary of the invention

It is an aim of the invention to provide a novel method, by which the driving of the pile into the ground, for providing the desired load carrying capacity, can be performed faster and more securely than before in such a way that the pile is not damaged during the pile driving process.

The aim of the invention is achieved by the method according to the invention, because for adjusting the impact energy in the method, during each driving impact on the pile, a kinetic variable Q_1 of the impact is measured by measuring devices in connection with the hammer ram during the impact, which variable is proportional to the kinetic energy of the block during the impact, and a kinetic variable Q_3 of the return motion is measured during the return motion, which variable is proportional to the kinetic energy of the block during the return motion; on the basis of the kinetic variable ratio Q_1/Q_3 it is then possible to determine, how far the pile has advanced by the effect of each driving impact. Thus, by determining a kinetic variable ratio Q_1/Q_3 such that gives the shortest total pile driving time t_{tot} and by controlling the kinetic energy of the impact on the basis of the same, each driving impact can be made optimal so that the advance produced by it will result in a total pile driving time t_{tot} of the pile as short as possible, wherein the driving of the pile into the ground will always be performed as fast as possible.

In the present application, the kinetic variable ratio Q_1/Q_3 refers to the relationship Q_1/Q_3 between a variable Q_1 that is proportional to the kinetic energy of the block during the impact and a variable Q_3 that is proportional to the kinetic energy of the block during the corresponding return motion. The kinetic variable Q_1 of the impact and the kinetic variable Q_3 of the return motion, as well as the kinetic variable ratio Q_1/Q_3 determined by these can thus, in different applications of the invention, refer to, for example, the time

taken for travelling a given distance, *i.e.* the impact time T1, and the time taken for travelling the same distance during the return motion of the block, *i.e.* the return motion time T3, determined in a corresponding way, as well as the motion time ratio T1/T3 determined by these; the impact velocity V1 and
5 the return motion velocity V3 determined in a corresponding way; or the kinetic energy W1 of the impact and the kinetic energy W3 of the return motion, determined in a corresponding way, as well as the kinetic energy ratio W1/W3 determined by these. All of these will, in principle, give a ratio that produces the corresponding information which, in the present patent
10 application, is called the kinetic variable ratio Q1/Q3. The kinetic variable ratio Q1/Q3 has been found to work well in evaluating the driving of the pile into the ground, because it indicates how large a relative proportion of the kinetic energy used for the impact is returned back to the block. If the proportion is very high (the kinetic variable ratio is high), it means that a large part
15 of the impact energy is returned to the block and the impact has not caused sinking (advancing) of the pile into the ground. On the other hand, if the proportion is low (the kinetic variable ratio is low), it means that a large part of the impact energy has been consumed in sinking, *i.e.* advancing, of the pile. In order to provide an optimal pile driving process, the ratio should have a
20 given value, because on the basis of the total time taken for driving one pile into the ground, it is easy to conclude that there is a given optimal value for the ratio (kinetic variable ratio), at which impacts can be produced, to drive the pile into the ground in the shortest possible time. In addition to the variables mentioned above, the kinetic variable ratio Q1/Q3 can also be formed by
25 other variables proportional to the kinetic energies of the impact and the return motion (such variables could be *e.g.* the acceleration of the block in the direction of the impact motion and in the direction of the return motion, or the resultant of the forces effective on the block during the impact and the return motion).

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The method according to the invention has the advantage that the driving of the pile into the ground by the pile-driving machine is always performed in the fastest possible way, even if the driver of the pile-driving machine were still inexperienced. Moreover, the method according to the invention reduces the
35 risk of driving the pile using so much impact energy that the pile is damaged.

Description of the drawings

In the following, some advantageous embodiments of the invention will be described in more detail with reference to the appended drawings, in which

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Fig. 1 is a principle view of a mechanism for moving the block of a pile-driving machine to be operated according to the method of the invention,

10 Fig. 2 is a principle view of different phases of the motions of the block during a single driving impact, and

Fig. 3 is a principle view showing times T1, T2, and T3 measured by position sensors S1 and S2 fastened to a hammer ram in the way shown in Fig. 1.

15

Detailed description of some advantageous embodiments of the invention

Figure 1 shows the operating principle of a mechanism 2 for moving a block 6 movable inside a hydraulically operated hammer ram 1 of a pile-driving machine. It comprises a hydraulic cylinder 3 extending in the longitudinal (vertical) direction of the hammer ram 1, and a piston 4 movable therein. A piston rod 5 extends from the piston 4 to the block 6 underneath the cylinder. Thus, when the piston 4 is moved back and forth inside the hydraulic cylinder 3 by pressurized medium supplied to different sides of the piston 4 in an alternating manner, the block 6 underneath the hydraulic cylinder 3 moves a corresponding distance in the vertical direction of the hammer ram 1. This reciprocating motion is utilized in driving a pile 7 by placing the hammer ram 1 on the pile 7 in such a way that when the block 6 comes to the lower position, it hits the top end of the pile 7. Normally, a cushioning is placed between the end of the pile 7 and the block 6, for suitably damping the impact caused by the block so that the pile will not be damaged by the impacts effective on it.

35 In the hammer ram 1 shown in Fig. 1, the travel distance of the piston 4 can be adjusted by adjusting the total quantity (volume) of pressurized medium to

be supplied to its different sides during the motion. Normally, the piston 4 and the block 6 fastened to it and spaced by the length of the piston rod 5 will achieve the greater velocity, the greater the travel distance (stroke) of the piston 4 and thereby the block 6. However, the force by which the block is accelerated, in addition to the potential energy caused by its mass, will also influence the velocity achieved by the block. In this way, by adjusting the velocity of the piston 4 and thereby the height of lifting the block 6, as well as the pressure effective in the hydraulic cylinder, it is possible to change the velocity v_1 achieved by the block 6 and thereby the kinetic energy produced by the block, *i.e.* the so-called impact energy W_{kin} .

The impact energy W_{kin} achieved by means of the downwards moving block can be calculated by the formula

$$W_{kin} = \frac{m_H v_1^2}{2} \quad (1)$$

in which

m_H = the mass of the block,

v_1 = the velocity of the block immediately before the impact.

In the embodiment of Fig. 1, a measuring rod 8 extends upwards from the piston, the motion of the rod being monitored by an upper position sensor S1 and a lower position sensor S2 placed above the cylinder. The distance between the upper position sensor S1 and the lower position sensor S2 is Δh , as shown in Fig. 2. The position sensors S1 and S2 are connected to a control unit in the pile-driving machine, arranged to use the position sensors S1 and S2 for measuring the time T1 (impact time) taken by the measuring rod 8 when the end of the measuring rod 8 passes first the upper position sensor S1 and then the lower position sensor S2 as the piston moves downwards. Correspondingly, the time T2 (impact delay time) is the time taken by the measuring rod 8 when it is below the lower position sensor T2 during the impact, and the time T3 is the time (return motion time) taken by the measuring rod 8 when it has first passed the position sensor S2 and then the position sensor S1. The impact time T1, the impact delay time T2 and the return

motion time T_3 are shown in the principle view of Fig. 3. The distance h_1 is the travel distance passed by the measuring rod 8 after it has passed the lower position sensor S2 before the block 6 hits the end of the pile 7. The hammer ram can also be implemented in such a way that no measuring rod extends from the piston above the cylinder, but the motion of the piston and/or the block is monitored by measuring arrangements implemented in another way. For example, when position sensors are used, the position sensors may be arranged to measure the position of the block directly or further the position of another point connected to the block and moving with the block and/or with the piston.

On the basis of the impact time T_1 and the return motion time T_3 , it is possible to determine the velocity V_1 of the impact motion and the velocity V_3 of the return motion, and correspondingly, on the basis of the velocity V_1 of the impact motion and the velocity V_3 of the return motion and the mass m_H of the block, to determine the kinetic energy W_1 of the impact and the kinetic energy W_3 of the return motion. Thus, all the kinetic variables T_1 , V_1 and W_1 of the impact motion are proportional to the kinetic energy of the block during the impact (that is, they are kinetic variables Q_1 of the impact motion in the sense of the present application), and all the kinetic variables T_3 , V_3 and W_3 of the return motion are proportional to the kinetic energy during the return motion (that is, they are kinetic variables Q_3 of the return motion in the sense of the present application). The velocity V_1 of the impact motion can be determined on the basis of the impact time T_1 by dividing the distance Δh by the impact time T_1 , and the return motion velocity V_2 on the basis of the return motion time T_3 by dividing the distance Δh by the return motion time T_3 . If the velocity V_1 is to correspond to the actual velocity v_1 right before the block hits the end of the pile, the velocity of the impact motion should be measured by measuring the instantaneous velocity v_1 right before the impact and the instantaneous velocity v_3 right after the impact. Another alternative is to determine the velocities v_1 and v_3 on the basis of the measured velocities V_1 and V_3 , knowing that the velocity v_1 is proportional to the velocity V_1 and the velocity v_3 is proportional to the velocity V_3 . For measuring the velocities, it is also possible to apply other measuring methods than measuring by the position sensors S1 and S2. The measurement can be taken, for example, by a sensor fastened to the side of the block and measuring the velocity of the

block directly or the time (T1 and T3) taken for travelling a given distance Δh during the impact and the return motion. Further, the velocity or time could be measured by using e.g. an optical positioning/speed measurement method, or an ultrasonic method of measurement.

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The pile-driving machine including the hammer ram shown in Fig. 1 comprises a programmable control unit and a hydraulic system controlled by the control unit. By means of the hydraulic system controlled by the control unit, pressurized medium (e.g. hydraulic oil) can be supplied to the hydraulic cylinder in the hammer ram so that the piston 4 moving the block 6 can be moved a desired travel distance back and forth at a desired velocity within the hydraulic cylinder. Generally, the downwards motion of the block 6 is called the impact motion, and the upwards motion is called the return motion. The driver of the pile-driving machine can adjust the desired travel distance and/or velocity manually, or the adjustment can be made automatically so that the control unit selects the suitable travel distance, the final velocity of the impact motion and/or the force for accelerating the block (the pressure effective in the hydraulic cylinder) automatically on the basis of the desired impact energy W_{kin} or further by means of software programmed/stored in the control unit. The position sensors S1 and S2 are connected to the control unit, whereby the control unit is capable of adjusting the velocity and/or travel distance of the piston on the basis of measurement data obtained from the position sensors S1 and S2.

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In the hydraulically operated hammer ram 1, pressurized medium is supplied above the piston 4 during the work motion, and the pressurized medium below the piston is returned to a pressure medium tank in the system (that is, the falling of the block downwards is speeded up). Correspondingly, during the return motion, pressurized medium is supplied below the piston 4 and pressurized medium above the piston 4 is returned to the tank (that is, the block is lifted up). In this way, the block 6 can be moved back and forth inside the hammer ram 1 in the vertical direction of the hammer ram 1 during piling so that its velocity is higher during the work motion than during the return motion. Thus, the difference between the velocities is due to the fact that the change (reduction) in the potential energy caused by the mass m_H of the block 6 carries out work which tends to increase the velocity of the block 6 as

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it moves downward, and correspondingly, the same change (increase) in the potential energy tends to slow down the motion of the block 6 as it moves upward.

5 In the time span T2 shown in Fig. 3, that is, during the so-called impact delay, the pile 7 is subjected to not only the impact energy but also the change in potential energy formed by the downwards motion of the block 6 placed against the pile 7, and the pile 7 itself. A part of this motion downwards is caused by elastic deformation of the pile (normally, about 1/3 of the
10 mass of the pile is involved in this part of the change in potential energy), and another part by sinking (*i.e.* advancing) of the pile into the ground. Thus, at this stage, the change in the potential energy carries out work for moving the pile 7 downwards, in addition to the impact energy W_{kin} , in the time span T2 shown in Fig. 3.

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During the impact delay (*i.e.* in the time span T2 shown in Fig. 3), the total energy of the system formed by the pile and the block (when the pile is advancing) can be calculated by the formula:

$$20 \quad W_{tot} = W_{kin} - W_{jou} + W_{pot\delta 1} + W_{pot\delta 2} \quad (2)$$

in which

W_{kin} = impact energy,

25 W_{jou} = elastic energy to be bound in the pile,

$W_{pot\delta 1}$ = change in potential energy, caused by elastic deformation of the pile,

$W_{pot\delta 2}$ = change in potential energy, caused by advancing of the pile.

The elastic energy W_{jou} to be bound in the pile 7 can be calculated by the
30 formula:

$$W_{jou} = \frac{F\delta_1}{2} \quad (3)$$

in which

35

F = the load carrying capacity of the pile,

δ_1 = the displacement (elastic deformation) of the top end of the pile.

The change in potential energy, caused by elastic deformation of the pile 7,
5 can be calculated by the formula:

$$W_{pot\delta_1} = (m_H + \frac{1}{3}m_P)g\delta_1 \quad (4)$$

in which

10

m_P = the mass of the pile,

g = the acceleration due to gravity.

The change in potential energy, caused by advancing of the pile 7, can be
15 calculated by the formula:

$$W_{pot\delta_2} = (m_H + m_P)g\delta_2 \quad (5)$$

in which

20

δ_2 = the advance of the pile.

When the block 6 and the pile 7 are abutting during the impact, part of the
impact energy W_{kin} and the potential energy $W_{pot\delta_1}$ and $W_{pot\delta_2}$ is always
25 bound to the pile 7 itself in the form of elastic energy W_{jou} to be stored in it,
because the pile 7 will be elastically deformed. The rest is consumed in
providing the advance δ_2 of the pile 7 and in friction losses. If the impact
energy W_{kin} is too low, the total energy exerted on the pile is not capable of
subjecting the pile 7 to a force that would make the pile 7 advance, because
30 it is not capable of producing a force F sufficient to cause the pile 7 to
advance, that is, a force corresponding to at least the load carrying capacity
of the pile 7 at the time. In such a situation, most of the impact energy W_{kin}
and the potential energy (of which only $W_{pot\delta_1}$ is included) is bound to the pile
in the form of said elastic energy W_{jou} (and the small remaining part will turn
35 into heat in the form of friction losses). Thus, an impact with too little impact

energy W_{kin} cannot make the pile 7 advance, but most of the elastic energy W_{jou} bound to the pile 7 will return to the block 6 which will pop up (that is, in the direction of the return motion) by the effect of this energy. Consequently, the elastic energy W_{jou} bound to the pile 7 will turn back into kinetic energy and potential energy (which includes the rising up of the end of the pile as its elastic deformation will reverse, and an upwards motion of the block).

If the impact is so strong that the pile 7 will advance, part of the elastic energy W_{jou} will have an effect on the advancing of the pile 7, and yet another part will return as kinetic energy to the block 6. In practice, this is shown, for example, in the times T1 and T3 measured by means of the position sensors S1 and S2 in such a way that in an impact that does not result in advancing of the pile 7, the time T3 is short in relation to the time T1. If, on the other hand, the pile 7 advances, a smaller part of the elastic energy bound to the pile 7 will be returned, by the effect of the impact, back to the block, as kinetic energy moving it upward. As a result, the time T3 will become longer in relation to the time T1. Utilizing this information, it is possible, on the basis of the times T1 and T3 measured by the position sensors S1 and S2, to determine how much the pile 7 will advance by the effect of each impact, and thereby to utilize the times T1 and T3 for evaluating the driving of the pile in the above described way.

As mentioned above, when piling in practice, the aim is to drive the pile 7 to a desired depth into the ground as fast as possible. For controlling this, the total time t_{tot} taken for driving the pile 7 into the ground has to be determined. The total time t_{tot} taken for driving the pile 7 into the ground is equal to the sum of times t_i taken for each single impact. Consequently, the total time t_{tot} taken for driving the pile 7 can be calculated by the formula:

$$t_{tot} = \sum_{i=1}^n t_i \quad (6)$$

, in which

t_{tot} = the total time taken for driving the pile,
 t_i = the time taken for a single impact,
 n = the total number of impacts.

If the same time t is taken for each impact, the total time taken for driving the pile is equal to the number n of impacts needed, multiplied by the time taken for a single impact; that is:

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$$t_{tot} = n * t \quad (7)$$

In practice, this may be the case if the ground is such that the impact energy W_{kin} can be adjusted to be constant. However, because the load carrying capacity of the pile 7 normally increases as the driving proceeds, applying a constant impact energy would result in a situation in which the pile 7 would be driven initially using excessive impact energy and in the end using too little impact energy.

15 In order to drive the pile 7 into the ground as fast as possible, the aim is to minimize the total time t_{tot} taken for driving the pile. Naturally, the total time t_{tot} reaches a minimum when the sum of the times taken for the single impacts is as small as possible. If the impact energy W_{kin} is not constant, there are several alternative solutions to this, because the durations t_i of the single impacts can be different with two different ways of driving the pile into the ground, even if the final result is the same total time t_{tot} taken for driving the pile 7.

25 A framework condition for driving the pile 7 (intact) into the ground altogether is that the impact energy W_{kin} should exceed a value that produces a greater force effective on the pile 7 in the direction of the ground than the load carrying capacity F of the pile 7 and is, on the other hand, smaller than a value that causes such a strong tension impulse on the pile 7 that the pile will be damaged. When driving piles into normal ground to be piled, no pile will, for example, generally sustain being driven into the ground by a single impact. Moreover, such an impact would require so much impact energy that with a typical block weight to pile weight ratio (for example, $m_H/m_P = 1.69$) it would lead to such a long impact that the total time t_{tot} would be considerably longer than when implemented by several impacts with optimal impact energy.

35 Naturally, such a pile-driving machine would not be viable in practice either.

Thus, an optimal way of pile driving, resulting in the shortest possible total time t_{tot} , is always somewhere between these two extreme cases.

In tests carried out with pile-driving machines similar to those shown in Fig. 1, it has been found that with a certain ratio between the time T1 measured in connection with the impact and the time T3 measured during the return motion (that is, with a given motion time ratio T1/T3 in this application), it is possible to achieve the shortest possible total time t_{tot} taken for driving the pile into the ground. Thus, by determining this target (optimal) motion time ratio $T1/T3_{tav}$, it is possible to optimize the driving of the pile 7 into the ground in such a way that the pile 7 can be driven into the ground as fast as possible. The determining can be done experimentally and/or by calculating, knowing the ratio of the times T1, T2 and T3 to the real velocity of the block 6 and thereby to the impact energy obtained. In principle, instead of the impact time T1 and the return motion time T3, it would also be possible to use the velocities corresponding to the times T1 and T3, that is, the impact velocity V1 and the return motion velocity V3 and the velocity ratio V1/V3 formed thereby, for determining the corresponding ratio. Further, the same ratio would be achieved by determining, from the impact velocity V1, the kinetic energy W1 of the impact (which is thus proportional to the impact energy W_{kin}) and the kinetic energy W3 of the return motion and, on the basis of these, the defined kinetic energy ratio W1/W3.

For achieving an optimal pile driving process, the aim should be to adjust the impact energy W_{kin} so that the selected kinetic variable ratio Q1/Q3, for example the motion time ratio T1/T3, the velocity ratio V1/V3 or the kinetic energy ratio W1/W3, would be as close as possible to the target value of these during the whole pile driving process. In the embodiment of Fig. 1 (in which motion times T1, T2, T3 are measured), the target value is the target motion time ratio $T1/T3_{tav}$. As a result, in a pile-driving machine according to Fig. 1, the impact energy W_{kin} of the next impact is always adjusted on the basis of the actual (measured) motion time ratio T1/T3 of the preceding impact. This can be done, for example, by comparing the measured motion time ratio T1/T3 with the target value $T1/T3_{tav}$ for the motion time ratio, wherein the pile 7 can be driven into the ground as fast as possible. Such an adjustment of the impact energy W_{kin} can be implemented by means of soft-

ware in the control unit of the pile-driving machine. This can be arranged, for example, in such a way that the driver of the pile-driving machine selects "automatically optimized pile driving process" from the menu of the control unit, and enters data on the pile to be driven into the ground and on the soil quality/type. Thus, the control unit will find out the target value $T1/T3_{tav}$ for the motion time ratio that is the most suitable for the pile type and the soil type in question, whereby the pile driving process of said pile is implemented in an optimal way. Thus, a corresponding process of optimizing the pile-driving could also be based on kinetic variable ratios $Q1/Q3$ formed by means of other kinetic variables $Q1$ of the impact and kinetic variables $Q3$ of the return motion (where the kinetic variable of the impact should be proportional to the kinetic energy of the block during the impact, and the kinetic variable $Q3$ of the return motion should be proportional to the kinetic energy of the block during the return motion), and their target value $Q1/Q3_{tav}$, such as the velocity ratio $V1/V3$ and its target value $V1/V3_{tav}$, or the kinetic energy ratio $W1/W3$ and its target value $W1/W3_{tav}$.

In the case of the measuring arrangement shown in Fig. 1, the control unit of the pile-driving machine, to which the position sensors $S1$ and $S2$ are connected, determines values of the motion time ratio $T1/T3$ from the motion times $T1$ and $T3$ during the pile driving process, and compares them with the target value $T1/T3_{tav}$. If the motion time ratio $T1/T3$ of the preceding impact is lower than the target value $T1/T3_{tav}$, the control unit will increase the impact energy, and if it is higher, the control unit will decrease the impact energy. This control is automatic so that the real motion time ratio $T1/T3$ determined on the basis of the motion times $T1$ and $T3$ is continuously changed towards the motion time ratio $T1/T3_{tav}$ that is known to result in a minimum total time t_{tot} for driving the pile 7. In practice, however, the load carrying capacity of the pile 7 is changed all the time, so that the continuous control will take care that the pile 7 is driven in an optimal way even if the theoretical optimum situation were not achieved. A way of operation corresponding to this could also be equally well implemented by means of other kinetic variable ratios $Q1/Q3$, such as the velocity ratio $V1/V3$ or the kinetic energy ratio $W1/W3$.

Alternatively, the automatic control in the control unit of the pile-driving machine could be implemented in such a way that from the kinetic variable

ratio $Q1/Q3$ measured after each impact, such as from the motion time ratio $T1/T3$, the velocity ratio $V1/V3$ or the kinetic energy ratio $W1/W3$, and their target values $T1/T3_{tav}$, $V1/V3_{tav}$, $W1/W3_{tav}$, the deviation in the motion time ratio $\Delta T1/T3$, the deviation in the velocity ratio $\Delta V1/V3$, or the deviation in the kinetic energy $\Delta W1/W3$ is calculated by subtracting the measured value from the respective target value. The control unit will then attempt to correct the impact energy so that in the next impact, the deviation from the target value would be as small as possible.

10 The most suitable target kinetic variable ratio $Q1/Q3_{tav}$, such as the target motion time ratio $T1/T3_{tav}$, the target velocity ratio $V1/V3_{tav}$, or the target kinetic energy ratio $W1/W3_{tav}$ can be determined for each pile as well as for each different soil type. It is also possible to use target values producing different advancing profiles. These, too, can be different for different piles and soil types. In some cases, the target kinetic variable ratio $Q1/Q3_{tav}$, such as, for example, the target motion time ratio $T1/T3_{tav}$, the target velocity ratio $V1/V3_{tav}$ or the target kinetic energy ratio $W1/W3_{tav}$ can vary in different ways during the pile driving process.

20 The location of the position sensors S1 and S2 or other sensors used for measuring the motion of the block in relation to the location of the block moving in the hammer ram can vary in different embodiments of the method according to the invention. For example, in the embodiment of Figs. 1 to 3, the ratio of the times T1, T2 and T3 to the actual velocity of the block 6 can vary in different embodiments. The motion time ratio $T1/T3$ is a ratio indicating the ratio of times taken for the movement of the block in a defined distance Δh during the impact and the return motion. Thus, the value of the motion time ratio depends on the advance of the pile during one impact. As mentioned above, it should not be limited to the ratio of motion times only, because the same information (ratio) utilized in the method according to the invention can also be obtained by examining other variables proportional to the kinetic energies of the impact and the return motion, such as the ratios between the velocities or the kinetic energies of the impact and the return motion. These variables can be measured by applying a variety of measuring arrangements deviating from the above-presented example embodiment. In principle, it is possible to apply, for example, any measuring device for

- measuring the momentary or average velocity of the block, or a measuring device for measuring another suitable variable proportional to the kinetic energy, providing measurement results which can be used for determining a ratio proportional to the kinetic energies of the impact and the return motion,
- 5 and for estimating the advance provided by a single impact on the pile in relation to impacts providing the shortest possible total impact time, and, on the basis of this, for adjusting the impact energy W_{kin} to provide an optimal pile driving process.
- 10 The method according to the invention is not limited to the above described example embodiments but it can be implemented in different ways within the scope of the appended claims.

Claims:

1. A method for optimizing the driving of a pile (7), the method comprising:
- 5 - driving the pile (7) into the ground by a pile-driving machine comprising a hammer ram (1) to be placed against the pile (7) and a block (6) that is movable back and forth therein;
 - moving the block (6) applied for driving the pile (7) towards the end of the pile (7) with a given impact energy (W_{kin});
 - 10 - determining the value of a kinetic variable (Q1) of the impact, proportional to the kinetic energy of the block (6) used for driving the pile, when the block (6) is moving towards the pile (7) in the pile driving direction;
 - determining the value of a kinetic variable (Q3) of the return motion, proportional to the kinetic energy of the block (6), when the block (6) is returning, after an impact on the pile (7), in a direction opposite to the pile driving direction;
 - 15 - calculating a kinetic variable ratio (Q1/Q3) by means of the determined kinetic variable (Q1) of the impact and kinetic variable (Q3) the return motion;
 - comparing the obtained kinetic variable ratio (Q1/Q3) with a predetermined target value ($Q1/Q3_{tav}$) for the kinetic variable ratio (Q1/Q3), producing the shortest possible total pile driving time (t_{tot}) for the pile (7);
 - 20 - adjusting the impact energy (W_{kin}) of the next impact in such a way that the kinetic variable ratio (Q1/Q3) determined by the kinetic variable (Q1) of the impact and the kinetic variable (Q3) of the return motion of the next impact will be changed towards the target value ($Q1/Q3_{tav}$).
- 25
2. The method according to claim 1, wherein the impact energy (W_{kin}) of the next impact is determined by utilizing the impact energy (W_{kin}) used in the preceding impacts and the real kinetic variable ratio (Q1/Q3) obtained by it.
- 30
3. The method according to claim 2, wherein the value of the impact energy (W_{kin}) is increased if the real impact variable ratio (Q1/Q3) of the preceding impact is higher than the target impact variable ratio ($Q1/Q3_{tav}$).
- 35
4. The method according to claim 2 or 3, wherein the value of the impact energy (W_{kin}) is decreased if the real impact variable ratio (Q1/Q3) of the preceding impact is lower than the target impact variable ratio ($Q1/Q3_{tav}$).

5. The method according to claim 1, wherein the difference of the kinetic variable ratios, *i.e.* the deviation ($\Delta Q1/Q3$) in the kinetic variable ratio, is calculated from the kinetic variable ratio ($Q1/Q3$) and the target kinetic variable ratio ($Q1/Q3_{lav}$).
6. The method according to claim 5, wherein the deviation in the kinetic variable ratio ($\Delta Q1/Q3$) is minimized by adjusting the impact energy (W_{kin}) of the block (6).
7. The method according to any of the claims 1 to 6, wherein before starting the pile driving process, the target variable ratio ($Q1/Q3_{lav}$) is determined by calculating on the basis of the cross-sectional area, length, and type of the pile, and/or the soil properties, by optimizing the impact energy (W_{kin}) so that by impacts producing an equal advance, the pile (7) can be driven to the determined depth in a time (t_{tot}) as short as possible.
8. The method according to any of the claims 1 to 6, wherein the target kinetic variable ratio ($Q1/Q3_{lav}$) is determined so that by impacts producing different advances, the pile (7) can be driven to the determined depth in a time (t_{tot}) as short as possible.
9. The method according to any of the claims 1 to 8, using the impact time ($T1$) as the kinetic variable ($Q1$) of the impact motion and the return motion time ($T3$) as the kinetic variable ($Q3$) of the return motion, as well as the motion time ratio ($T1/T3$) determined on the basis of these.
10. The method according to any of the claims 1 to 8, using the impact velocity ($V1$) as the kinetic variable ($Q1$) of the impact motion and the return motion velocity ($V3$) as the kinetic variable ($Q3$) of the return motion, as well as the velocity ratio ($V1/V3$) determined on the basis of these.
11. The method according to any of the claims 1 to 8, using the kinetic energy ($W1$) of the impact motion as the kinetic variable ($Q1$) of the impact motion and the kinetic energy ($W3$) of the return motion as the kinetic variable

(Q3) of the return motion, as well as the velocity ratio ($V1/V3$) determined on the basis of these.

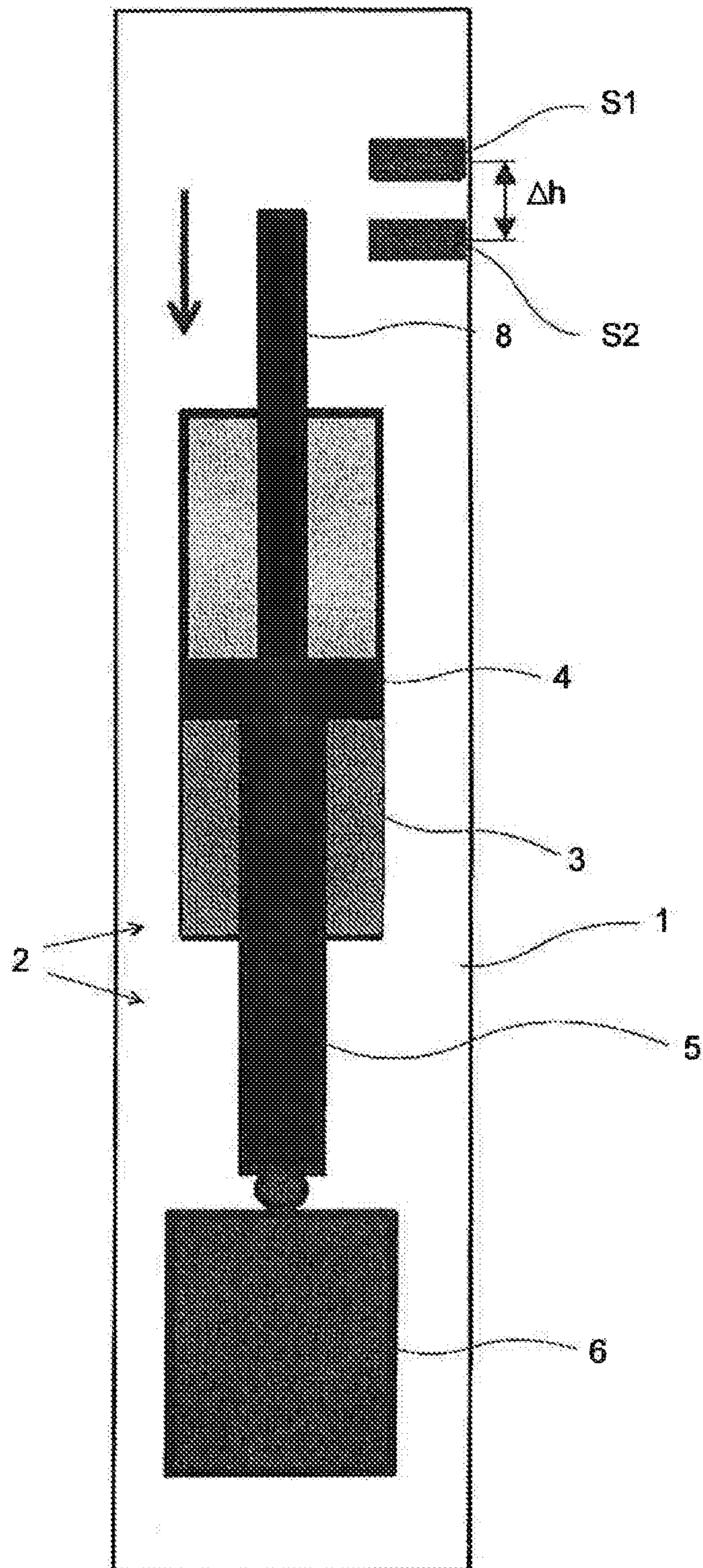


Fig. 1

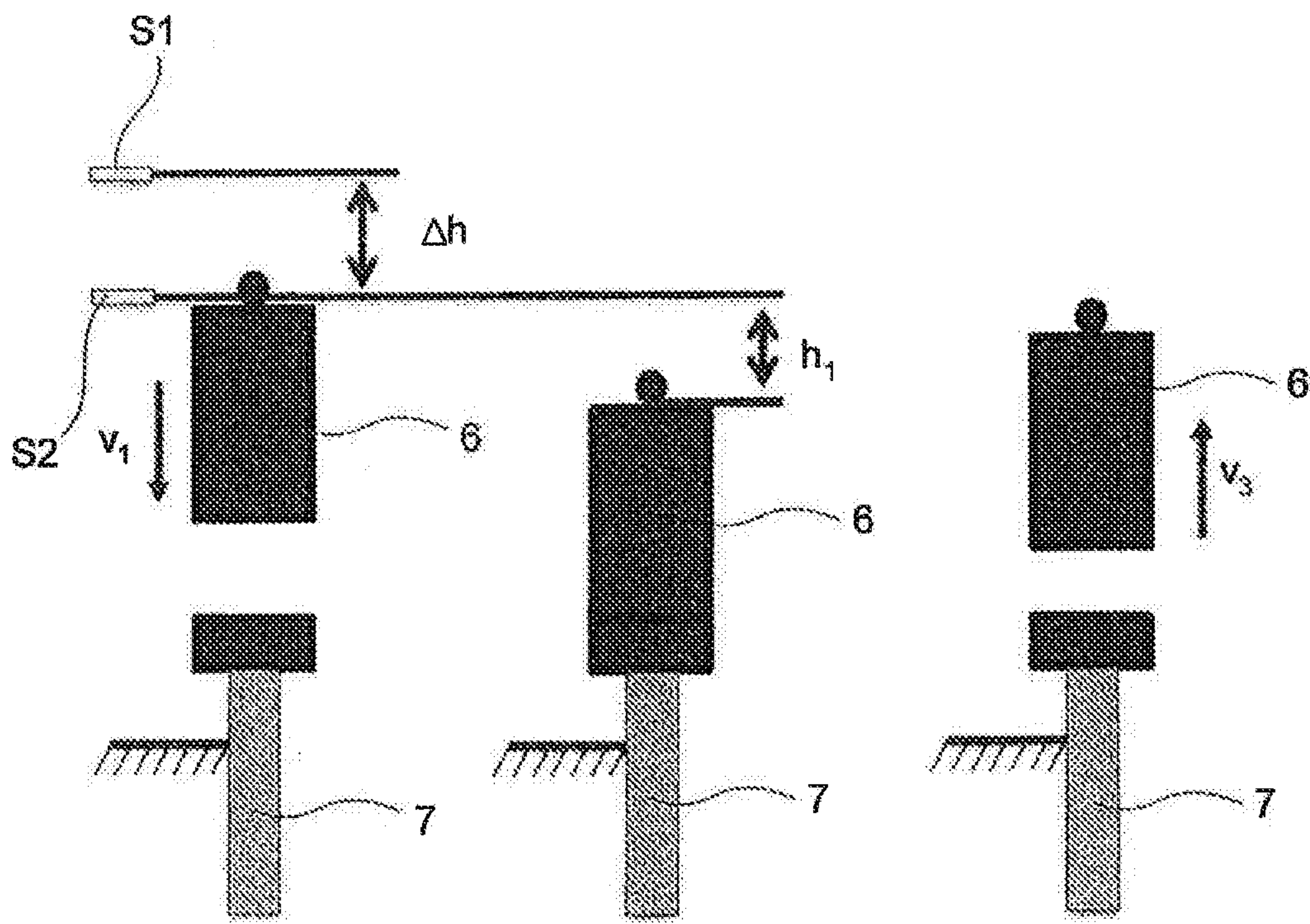


Fig. 2

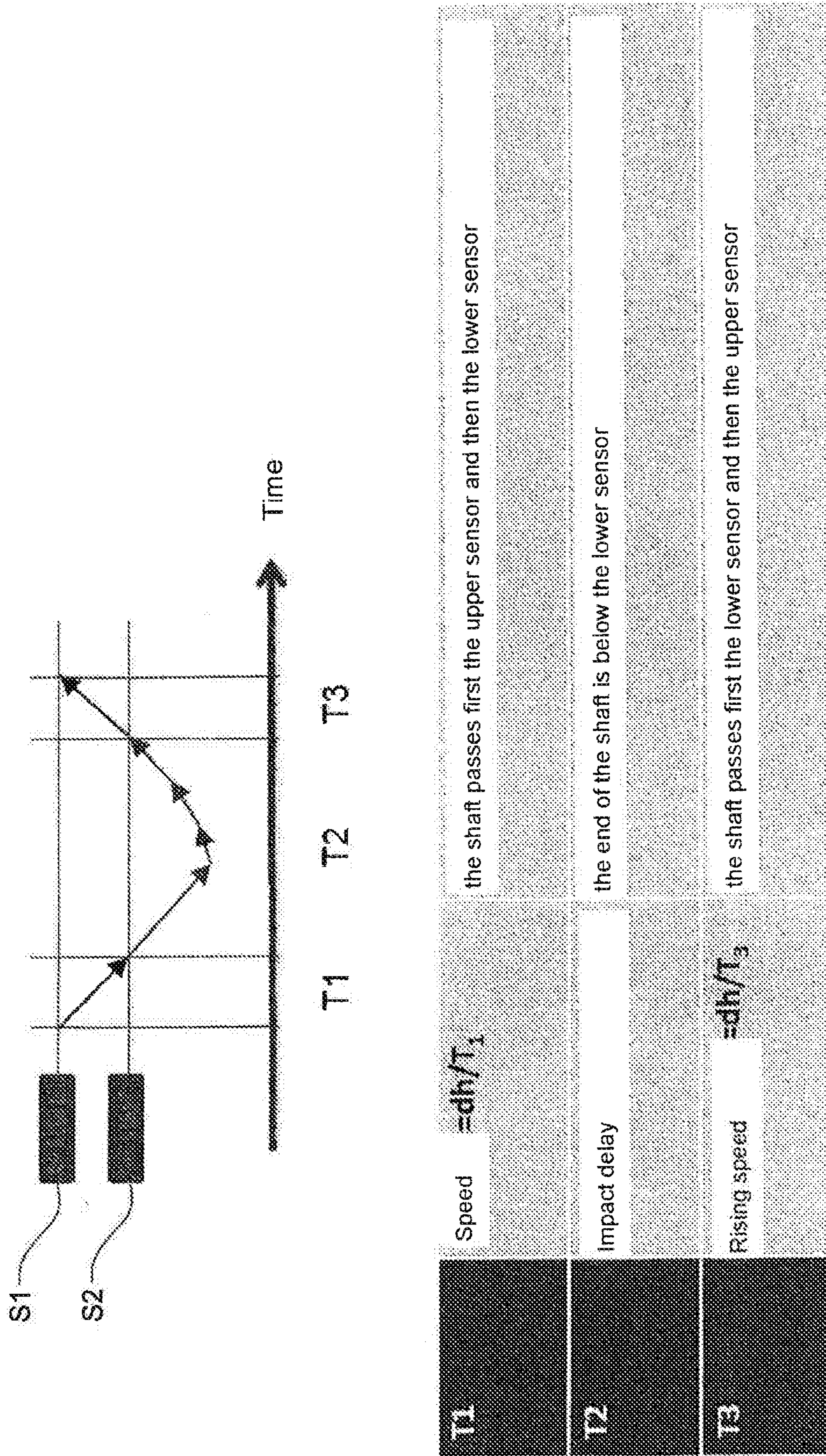


Fig. 3

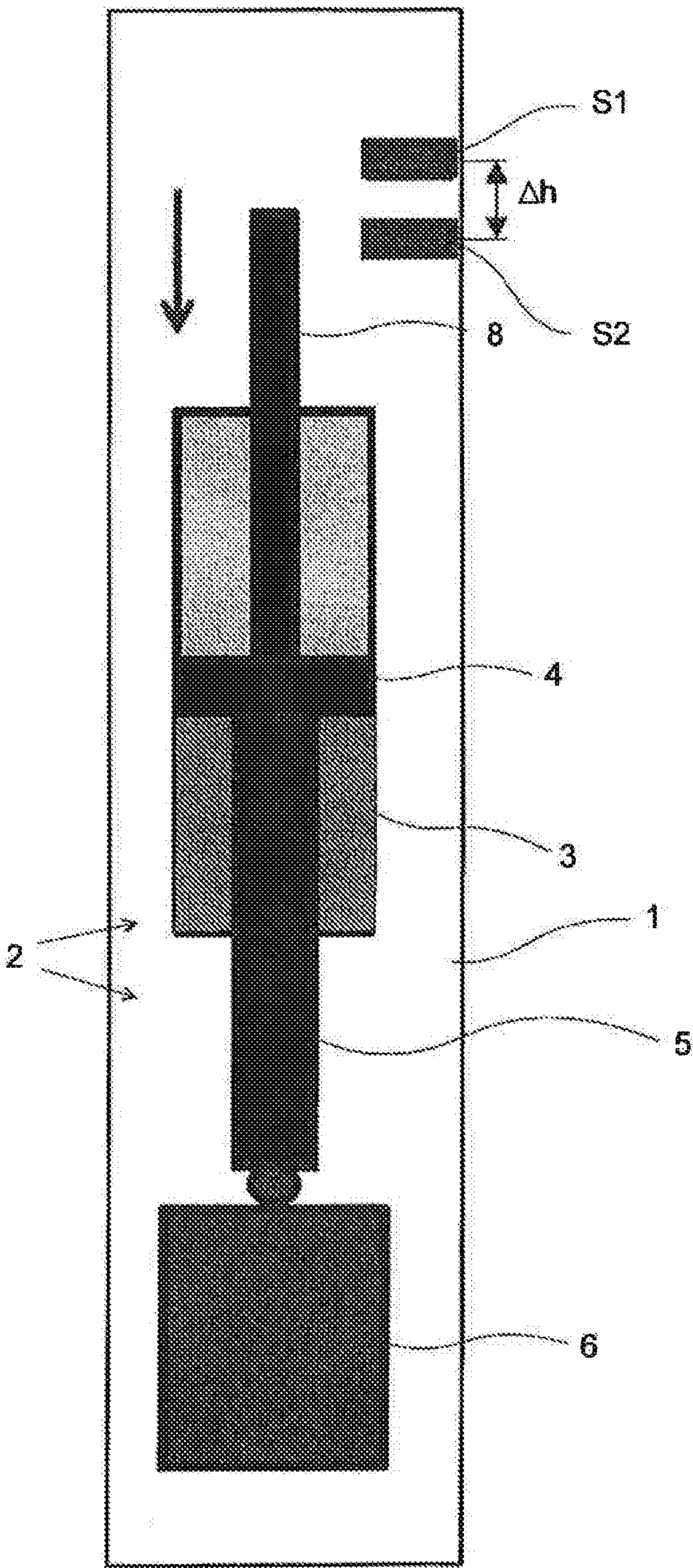


Fig. 1