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(54) METHOD AND ELECTRONIC CIRCUIT FOR RELAY STOCK DETECTION

(57) Disclosed are a method for picking up the relay coil current vs. time pattern $I(t)$ during a relay switch OFF procedure by observing a negative peak on a 3rd differential curve at the time of an expected relay switching OFF (releasing its NO contact touch) and comparing the

height of that peak to an expected (pre-memorized) height value typical for normally working relay, a three-step C-R differentiator circuit, and an electric household appliance.

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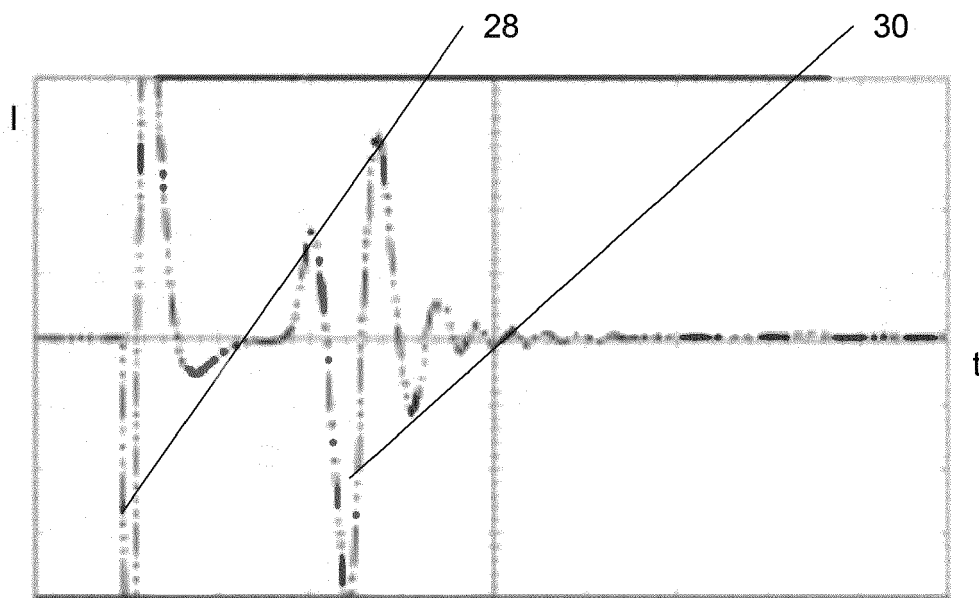


Fig. 4

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Description

[0001] The invention refers to a method enabling a detection if a relay is stuck, an electric circuit adapted to run the method, and an electric household appliance.

[0002] It is an essential security feature of household appliances that a malfunction of a relay is determined, especially if the relay switches high current load. An example for a malfunction is a relay that is stuck after it has been switched off.

[0003] When working normally, as soon as the relay is switched OFF (i.e. the current coil is switched OFF), the armature moves fully back to its relaxed position (open state). This backwards movement is caused by spring power, mostly by two springs, a return spring and a contact compression spring. In addition, when working normally, the armature starts moving backwards delayed after the relay has been switched OFF. The reason for the delay is the fact that the magnetic force has to collapse below a certain level in order to release the anchor. However, sometimes the relay does not open properly, due to various reasons such that the anchor is stuck to the coil.

[0004] A commonly used mechanical relay in different positions is shown in figures 1a to 1c. The relay 1 consists of a static coil 2 and an armature having the following major parts: anchor mechanics 4, anchor return spring (not shown), contact compression spring 6 and movable electric contact 8. The relay has three basic anchor/contact positions. In figure 1a the relay 1 is shown in its normally open state (NO). The coil 2 is not energised and the anchor 4 has not been pulled towards the coil 2. As a consequence, there is no electrical contact between the movable contact 8 and the static contact 10. In figure 1b, the relay 1 is shown in its transition state. In this state, the coil 2 is energised and a magnetic force is built up such that the anchor 4 is slightly pulled towards the coil 2. As a consequence, the electrical contact is created between the movable contact 8 and the static contact 10. In figure 1c, the relay 1 is shown in its full closed state. In this state, the magnetic force is fully established and the anchor 4 is pulled fully towards the coil 6. As a consequence, the electrical contact is fully closed between the movable contact 8 and the static contact 10.

[0005] Beside this shown relay, where the movable contact is firmly connected with the relay armature anchor part, several other types of relays exist. For instance, relays with a reinforced insulation may have a lever mechanism made from insulated material placed between the anchor and movable contact parts. These mechanisms can be in the form of a push-pull-mechanism, adapted to move the movable contact in both directions (ON and OFF). Alternative, only a push-mechanism can be provided, adapted to move the movable contact in push direction (ON) only. The push-pull mechanism may have some movement clearance between anchor and movable contact compression spring, or may even feature some mechanical clearance hysteresis.

[0006] It is an object of the invention to provide a reliable method for stuck relay detection, an electric circuit for a reliable stuck relay detection and an electric household appliance fulfilling high electric safety standards.

[0007] This object is solved by a method with to the features of claim 1, by an electric circuit with the features of claim 4 and by a household appliance with the features of claim 8. Advantageous embodiments are disclosed in the dependent claims, the description and the figures.

[0008] According to the invention, a method for relay stuck detection, comprises the steps:

- calculating the 3rd derivative of a detected coil current $I(t)$ of a monitored relay during its switch OFF time,
- detecting at least one peak on a 3rd differential curve based on that 3rd derivative,
- comparing the peak value with a stored peak value representing a part of a switch OFF behaviour of a standard relay,
- evaluating at least on the basis of the peak comparison if the monitored relay is defective.

[0009] According to the invention, the stuck relay detection works on the low voltage side by detecting if there is a change in a 3rd derivative peak of the $I(t)$ curve outside a given tolerance, which appears at the time of an expected time when the relay contact switches OFF. Preferably, the negative peak value is taken into account. The switch OFF time is the interval or period of time between a de-energizing of the relay coil to switch OFF normally open (NO) relay contact and time point when the relay contacts release their touch. This is notably the time between two large negative peaks on 3rd derivative peaks.

[0010] If there is no significant difference between the compared first peaks, a comparison between a second peak on the 3rd differential curve and a second stored peak value representing a part of the switch OFF behaviour of the standard relay is taken into account for the evaluation. This can be the case if the detected first peak has an amplitude (negative amplitude) that is similar than the amplitude (negative amplitude) of the first stored peak directly after the relay has been switched OFF. At first sight, it seems that the detected relay works well, as a first 3rd derivative peak having a high amplitude appears when the contacts lose their contact. However, in order to review this, a second peak value is detected and compared with stored second peak value.

[0011] In order to check if the detected relay switch-OFF time differ from a stored switch-OFF time, which can also be a signal for a failure of the relay, a calculated time difference between the detected first peak and the detected second peak of the monitored relay is compared with a stored time difference between the stored first peak and the stored second peak and taken into account for the evaluation. Thus, the switch OFF time can also indicate a possible relay

failure, but preferably, the time difference is not sufficient to confirm if the relay is stuck.

[0012] In other words; the inventive method follows the following workflow during its switch OFF procedure:

Precondition

- The detection workflow requires one time switching ON and OFF the tested relay.
- The ON and OFF procedures may follow instantly one after another, even with almost zero relay switch on state duration. Moreover, if the relay is already in ON state, just switching OFF procedure is good enough for the detection.
- For each of detected relay (or relay type group), standard (expected) switch OFF time and standard height of 3rd derivative peak for normally working relay, with their reasonable inaccuracy intervals, are pre-memorized by controlling microcontroller.

Detection

- Picking up the relay coil current versus time pattern $I(t)$ during relay switch OFF procedure. Differentiating the $I(t)$ by three-step differentiator, or by any other way, inclusive digital procedure by a microcontroller respectively.
- Observing a negative peak on 3rd differential curve at the time of expected relay switching OFF (releasing its NO contact touch).
- Comparing the height of that peak to expected (pre-memorized) height value typical for normally working relay.

Evaluation of stuck (fatal error) state of tested relay

- If compared height of said 3rd derivative peak is significantly higher than pre-memorized value for normally working relay, or significantly lower, and/or totally missing, the relay is stuck.
- In addition, if relay Switch OFF time differ significantly from expected (pre-memorized) one, the relay may have some significant problem. This can be finally confirmed by evaluation of 3rd derivative peak as per point 1. The switch OFF time difference may indicate possible relay failure, but is not sufficient to confirm stuck relay contact.

[0013] In general, an expected relay switching OFF time confirms the positive peak on 1st derivative $I(t)$ curve. Depending on particular relay type, the expected relay switch OFF time for stuck relay can be shorter, untouched or even longer than that for normally working relay. If the relay armature is not movable due to stuck contacts for instance, said derivative peaks disappear at all.

[0014] The workflow according to the invention works well for relays with relay armature firmly connected to movable contact and its compression spring and for push-pull type armature relays with low mechanical clearance and/or mechanical hysteresis. The details of electrical voltage/current values of $I(t)$ curve, its derivatives and particular peaks respectively are relay type specific and should be adjusted and pre-memorized for relay types used to define status of normally working relay.

[0015] The proposed stuck relay detection technique can be used as standalone feature or as an add-on feature if the appliance already uses zero cross relay switching technique as exemplary described in WO 2020/020555 A1 of the applicant. Both the techniques can form very powerful tool to switch the appliance relays, to monitor and predict their health status and to detect possible failure of relay switching contacts. All the control and detection is made solely on relay low voltage side without any measurement or controlling on its high voltage side.

[0016] According to the invention, an electronic circuit adapted to relay stuck detection, comprises a relay having a coil to be monitored and three subsequent differentiators in series each calculating one derivative of the relay coil current over the time $I(t)$, wherein between the first differentiator and the second differentiator a low pass filter is provided and wherein the output signal of the first differentiator and the output signal of the second differentiator is amplified by a first amplifier and by a second amplified, respectively.

[0017] The differentiators reliable enable to calculate the 3rd derivate according to the inventive method. The low pass filter eliminates efficiently higher interferences frequencies.

[0018] In order to eliminate inductive peaks from the relay coil and/or in order to avoid voltage peaks which can appear when a relay is switched OFF, a flyback diode can be provided in parallel to the relay coil.

[0019] In order to pick-up the relay current $I(t)$ of the monitored relay, a resistor provided for measuring a voltage can be positioned in series with the relay coil.

[0020] Alternatively, a resistor is positioned in series with the flyback diode in order to pick-up the relay current $I(t)$ of the monitored relay.

[0021] According to the invention, an electric household appliance comprises an inventive electric circuit. Such a household appliance fulfils a high electric safety standard as any malfunction of a relay will be detected easy and reliable.

[0022] In the following, preferred embodiments of the present invention are explained with respect to the accompanying drawings. As is to be understood, the various elements and components are depicted as examples only, may be facultative and/or combined in a manner different than that depicted. Reference signs for related elements are used comprehensively and not defined again for each figure. Shown is schematically in

Fig. 1a, 1b and 1c: a standard relay and in three basic positions,

Fig. 2a a first relay coil current $I(t)$ pattern and its three derivatives when switching OFF a relay with normally movable NO contact the switch OFF time,

Fig. 2b: an isolated 3rd derivate curve illustrated in figure 2a,

Fig. 3: an isolated 3rd derivate curve of another well working relay with normally movable NO contact during the switch OFF time,

Fig. 4: the isolated 3rd derivate curve of a not properly working standard relay during the switch OFF time,

Fig. 5: a second relay coil current $I(t)$ pattern and its three derivatives when switching OFF a relay with abnormally movable NO contact during the switch OFF time,

Fig. 6 an embodiment of an electric circuit according to the invention,

Fig. 7 a detail of the electric circuit in figure 6, and

Fig. 8 an alternative to the detail shown in figure 7.

[0023] Figure 2a shows a $I(t)$ pattern 12 when switching OFF a relay 1 with normally movable NO contact. The second and third derivatives 18, 20 are uncompensated for slight time delays coming from time constants of each differentiator circuits. Each curve peaks are relative in their measures, controllable by differentiator electronics to facilitate the detection. Figure 2a shows an isolated 3rd derivate curve 20 of the relay 1.

[0024] The exact time of the relay switch OFF defines the middle of positive peak on the first derivate curve 16. It should be noted that this time point does not fit with time point of a local positive peak at the $I(t)$ curve 14, it happens a bit earlier. Irregularities shown in the current $I(t)$ curve 14 are based on from mechanical dynamics of the relay armature.

[0025] When comparing the $I(t)$ curve 14 to a body trajectory in physics of mechanical dynamics, its first derivative dI/dt 16 represents speed of position change, its second derivative d^2I/dt^2 18 represents acceleration and its third derivative d^3I/dt^3 20 represents jerk. The jerk means a sudden change in body acceleration. Such mathematical representation is an acceptable view on relay behaviour, because a relay armature movement defines at any time an instant value of a relay anchor gap. This defines further an instant value of a relay coil inductance. In the figures, any peak on the jerk curve is a point of sudden strike or collision the moving body (relay armature) is exposed to. The peaks on the third derivative curve 20, indicating sudden changes in armature acceleration.

[0026] In the event the relay moving contact is stuck, the relay armature is exposed to a sudden, sharp jerk, when trying to move during the switch OFF procedure. This is detectable by a peak 24 on the third derivative curve 20 and appears at the expected time of contact touch releasing. If the contact is normally movable, the expected peak 24 at a second breakpoint should be rather small. The reason for the peak 24 is a sudden mass addition due to the moving of the armature parts. If the movable contact is stuck, for instance welded together with static contact part, the moving armature is subjected to a sudden strike, when trying to peel it off, to release it from static contact part. This state can be detected by the large peak 24 on the d^3I/dt^3 curve appearing at a time of expected contact touch releasing.

[0027] If the movable contact of the relay were stuck for some reason, the second negative peak 24 on 3rd derivative curve 20 would be much higher due to sharp relay armature acceleration change, when jerking coming from stuck contact. This is illustrated in figures 3 and 4.

[0028] The principle of stuck relay detection is to detect a significant change in the 3rd derivative peaks 24, which appears at the time of expected time t_2 when the relay contact switches OFF.

[0029] Each relay has following key parameters, which may be relay type specific:

- Switch OFF time ($t_1 - t_2$): time interval between de-energizing relay coil to switch OFF normally open (NO) relay contact and time point when the relay contacts release their touch. This is notably the time between two large negative peaks on 3rd derivative peaks 22, 24
- Height (amplitude) of 3rd derivative peak of relay coil $I(t)$ curve, which appears when the contacts release their touch.

[0030] In figure 3 and 4, a 3rd derivate of coil current $I(t)$ of a normal working relay (figure 3) and of a monitored relay (figure 4) is given. A high first negative peak 22 and a low second negative peak 24 after a specific period of time ($t_1 - t_2$) are clearly detectable. The specific period of time is the switch-OFF time of the relay.

[0031] As can be seen, both curves 20, 26 shows high first negative peaks 22, 28 at the beginning of the switch-OFF time. In order to clarify, if the monitored relay is working abnormal, i.e. if it is stuck, second peaks 24, 30 on both third derivate curves 20, 26 are detected and compared regarding their (negative) amplitude and their time difference ($t_1 - t_2$) measured from the appearance of the first peaks 22, 26 to the appearance of the second peaks 24, 30. In the shown case, the second negative peak value 30 of the monitored relay appears earlier and has a higher negative value than the stored second peak 24 of the normal working relay. Both the smaller time difference ($t_1 - t_2$) and the higher amplitude give a hint to a malfunction of the monitored relay.

[0032] Moreover, the movable contact can be stuck also in a position beyond its standard fully closed state. This may happen due to scattering (removing) part of relay contact material in course of relay ageing.

[0033] For a proper detection, it is important to understand if the relay armature is still movable (despite the movable contact is stuck for some reason) or not. That means, one can face two different situations:

- a) The relay armature which drives the movable contact is still movable. The contact compression spring is flexible, although the movable contact is fixed (stuck).
- b) The stuck contact blocks any armature movement. The movable contact is fixed in such a way that the relay coil magnetic force is unable to move the relay anchor at all.

[0034] If the relay armature still moves, the 3rd derivative curve 30 showing a high first peak 28 and a high second peak 30 as illustrated in Fig.4. The event that the relay magnetic force system cannot move the armature is illustrated in figure 5.

[0035] As shown in the pattern 31 of Fig. 5, if the relay armature does not move during the relay switching OFF, the $I(t)$ curve 32 is similar to a standard exponential $I(t)$ curve observed at an electromagnetic coil with fixed inductance. There are no significant first peaks on any of said derivative curves 36, 38, 40. In particular, there is only a small first negative peak 34 on the 3rd derivate curve 40 and no second peak 42 on the 3rd derivative curve at the expected relay switch OFF time at all.

[0036] In figure 6, a preferable analogue circuit diagram to generate 1st, 2nd, and 3rd derivatives of an $I(t)$ curve by three-step C-R differentiator 42 is given. The electronic circuit 42 is adapted to relay stuck detection, comprising a relay L1 having a coil to be monitored and three subsequent differentiators C1, R3; C3, R6 and C4, R9 in series, each calculating one derivative of the relay coil current over the time $I(t)$. Between the first differentiator C1, R3 and the second differentiator C3, R6 a low pass filter R2, C2, R5, R4 is provided. The output signal of the first differentiator C1, R3 and the output signal of the second differentiator C3, R6 is amplified by a first amplifier U1 and by a second amplifier U2, respectively. For instance, the first C-R differentiator step includes R1, R2, C1, R3, U1, C2, R4, R5.

[0037] In detail, the elements of the of three-step C-R differentiator circuit 42 are as followed:

- S1 - electronic switch controlling the relay, switched usually by a microcontroller
- L1 - relay electromagnetic coil driving the relay armature
- D1 - flyback diode eliminating inductive peaks from L1
- V1, V2 - power source for symmetric powering of U1 and U2
- R1 - relay coil current pick-up resistor
- C1,R3; C3,R6; C4,R9 - 1st, 2nd, and 3rd C-R differentiators
- U1 - operational amplifier, amplification, and low pass filtering of 1st derivative $I(t)$
- R2, C2, R5, R4 - low pass filtering and 1st derivative amplifying
- U2 - operational amplifier for 2nd derivative amplifying
- R7, R8 - 2nd derivative amplification
- 1stDer, 2ndDer, 3rdDer - each derivative output voltages

[0038] An $I(t)$ curve pick-up technique is to pick up the voltage from a measuring resistor which is connected in series to the relay coil, or in series to the relay flyback diode D1 (diode suppressing inductive voltage peaks when switching the relay). When the measuring resistor in series with flyback diode D1 is used, it is possible to measure only the current when the relay is switched OFF. This does not limit the proposed 3rd derivative stuck relay detection.

[0039] Figure 7 is a detailed view 44 of figure 6 and shows a basic schematic representation for picking up the $I(t)$ curve and converting it into voltage. A resistor R1 provided for measuring a voltage in order to pick-up the relay current $I(t)$ of the monitored relay L1 is in series with the relay coil.

[0040] In figure 8, an alternative 46 to the embodiment shown in figure 7 is illustrated. The resistor R1 provided for measuring the voltage in order to pick-up the relay current $I(t)$ of the monitored relay L1 is positioned in series with the

flyback diode D1.

[0041] If the resistor R1 is connected in series with relay coil L1, the I(t) curve is picked up in both cases; when switching the relay L1 ON and OFF. If the resistor R1 is incorporated in the flyback diode circuit (flyback diode D1), picking-up is possible only for the switch OFF procedure. In this case, the resistor R1 does not lower the voltage on the relay L1 during its switching ON procedure.

[0042] Disclosed are a method for picking up the relay coil current vs. time pattern I(t) during a relay switch OFF procedure by observing a negative peak on a 3rd differential curve at the time of an expected relay switching OFF (releasing its NO contact touch) and comparing the height of that peak to an expected (pre-memorized) height value typical for normally working relay, a three-step C-R differentiator circuit, and an electric household appliance.

Reference list

[0043]

1	relay
2	coil
4	anchor
6	contact compression spring
8	movable contact
10	static contact
12	pattern
14	current (I) curve
16	first derivate dI/dt curve
18	second derivate d^2I/dt^2 curve
20	third derivate d^3I/dt^3 curve - standard relay
22	first peak - standard relay
24	second peak - standard relay
26	third derivate d^3I/dt^3 curve - monitored relay, armature is movable
28	first peak - monitored relay, armature is movable
30	second peak - monitored relay, armature is movable
31	pattern
32	current (I) curve - monitored relay, armature is stuck
34	first peak - monitored relay, armature is stuck
36	first derivate dI/dt curve
38	second derivate d^2I/dt^2 curve
40	third derivate d^3I/dt^3 curve - standard relay
42	electric circuit / three-step C-R differentiator circuit
44	electric circuit detail
46	alternative to electric circuit detail 44
48	electronic switch controlling the relay, switched usually by a microcontroller
50	relay electromagnetic coil driving the relay armature
52	flyback diode eliminating inductive peaks from L1
54	power source for symmetric powering of U1 and U2
56	relay coil current pick-up resistor
58	1 st , 2 nd and 3 rd C-R differentiators
60	operational amplifier, amplification, and low pass filtering of 1 st derivative I(t)
62	low pass filtering and 1 st derivative amplifying
64	operational amplifier for 2 nd derivative amplifying
66	2 nd derivative amplification
68	each derivative output voltages
70	expected first time of contact touch releasing
72	expected second time of contact touch releasing
74	Switch OFF time

Claims

1. Method for relay stuck detection, comprising the steps:

- calculating the 3rd derivative of a detected coil current $I(t)$ of a monitored relay during its switch OFF time,
- detecting at least one peak (28, 34) on a 3rd differential curve (26, 40) based on that 3rd derivative,
- comparing the peak value (28, 34) with a stored peak value (22) representing a part of a switch OFF behaviour of a standard relay,
- evaluating at least on the basis of the peak comparison if the monitored relay is defective.

2. Method according to claim 1, wherein a comparison between a second peak (30) on the 3rd differential curve (26) and a second stored peak (24) on the 3rd differential curve (20) representing a part of the switch OFF behaviour of the standard relay is taken into account for the evaluation.

3. Method according to claim 1 or 2, wherein a calculated time difference between the detected first peak (28) and the detected second peak (30) of the monitored relay is compared with a stored time difference (t_1 to t_2) between the stored first peak (22) and the stored second peak (24) and taken into account for the evaluation.

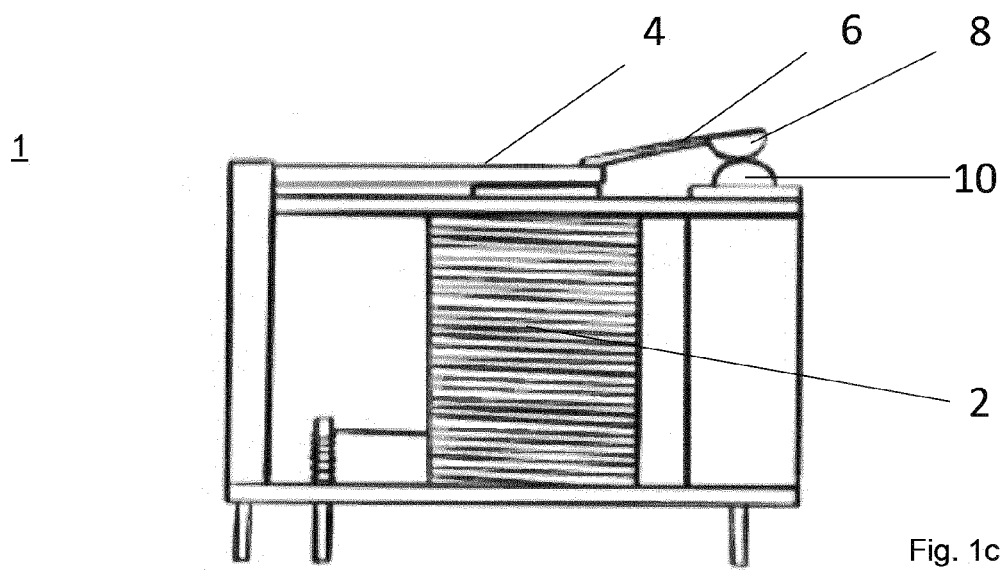
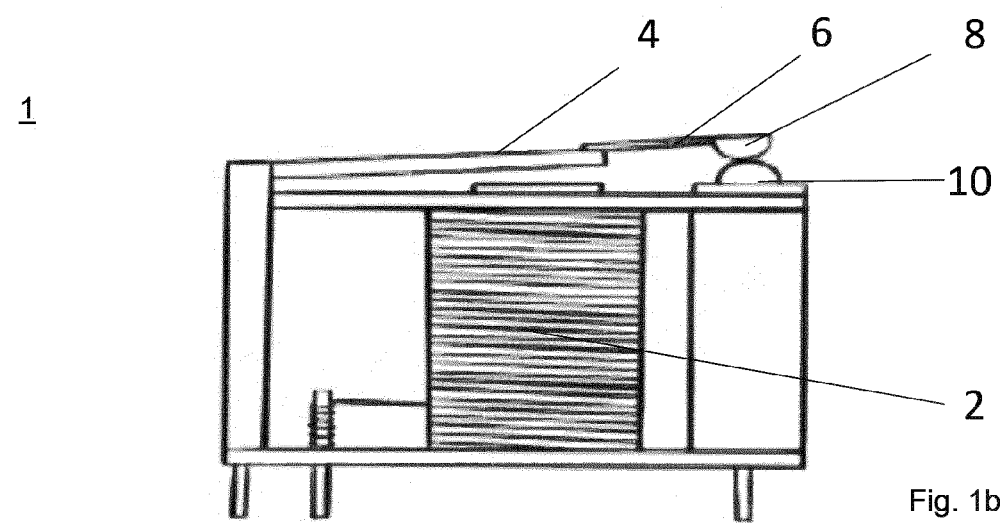
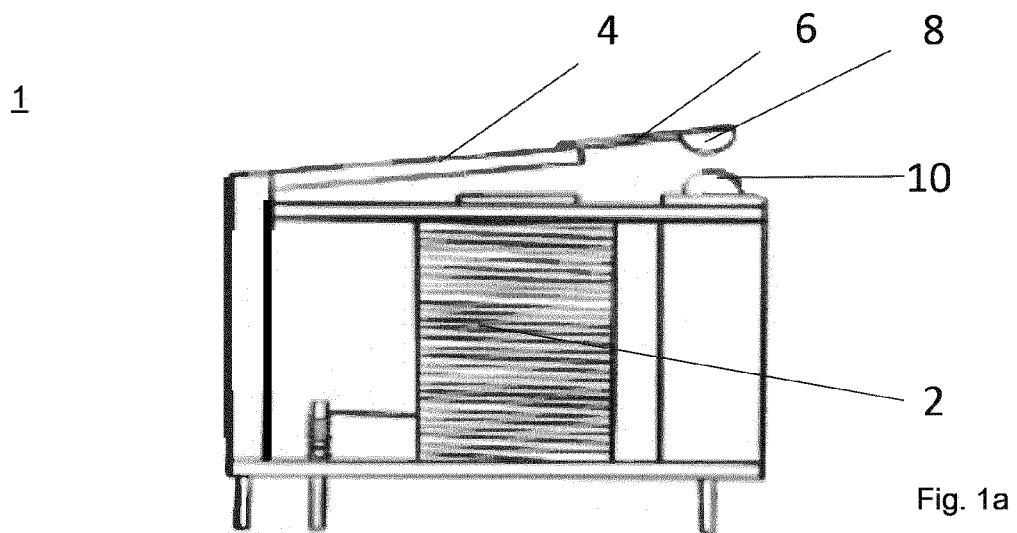
4. Electronic circuit adapted to relay stuck detection, comprising a relay (L1) having a coil to be monitored and three subsequent differentiators (C1, C3 and C3, R6 and C4, R9) in series, each calculating one derivative of the relay coil current over the time $I(t)$, wherein between the first differentiator (C1, R3) and the second differentiator (C3, R6) a low pass filter (R2, C2, R5, R4) is provided and wherein the output signal of the first differentiator (C1, R3) and the output signal of the second differentiator (C3, R6) is amplified by a first amplifier (U1) and by a second amplified (U2), receptively.

5. Electronic circuit according to claim 4, wherein a flyback diode (D1) is positioned in parallel to the relay coil (L1).

6. Electronic circuit according to claim 4 or 5, wherein a resistor (R1) provided for measuring a voltage in order to pick-up the relay current $I(t)$ of the monitored relay (L1) is in series with the relay coil (L1).

7. Electronic circuit according to claim 4 or 5, wherein a resistor (R1) provided for measuring a voltage in order to pick-up the relay current $I(t)$ of the monitored relay (L1) is in series with the flyback diode (D1).

8. Electric household appliance comprising an electric circuit according to one of the preceding claims 4 to 7.



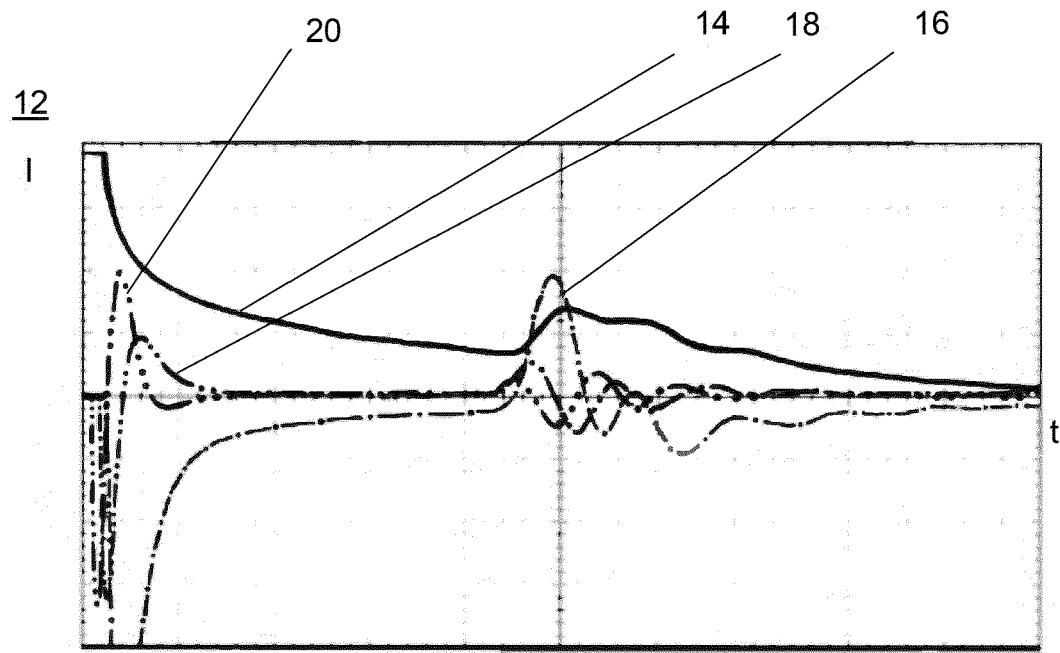


Fig. 2a

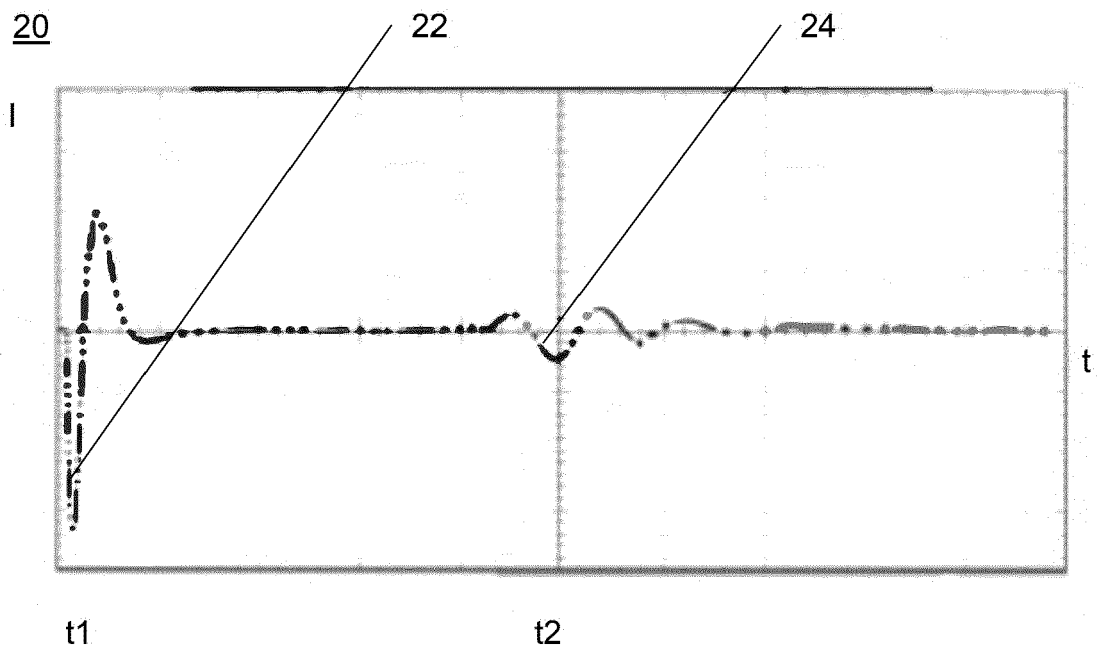
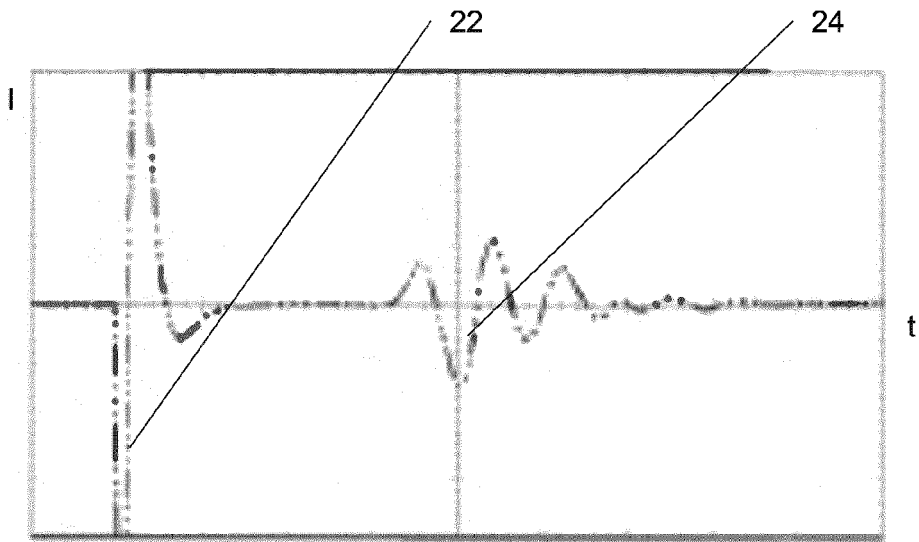


Fig. 2b

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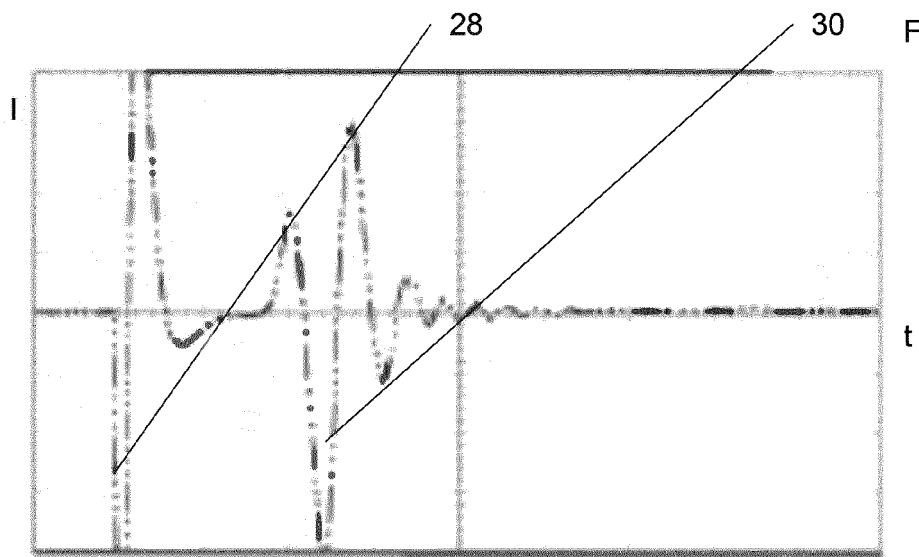


Fig. 3

Fig. 4

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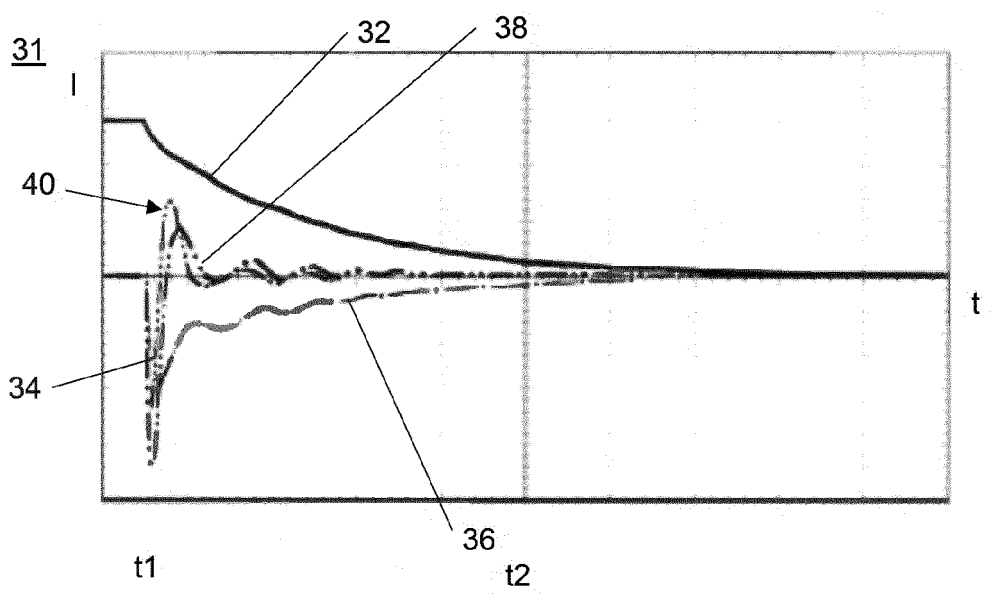


Fig. 5

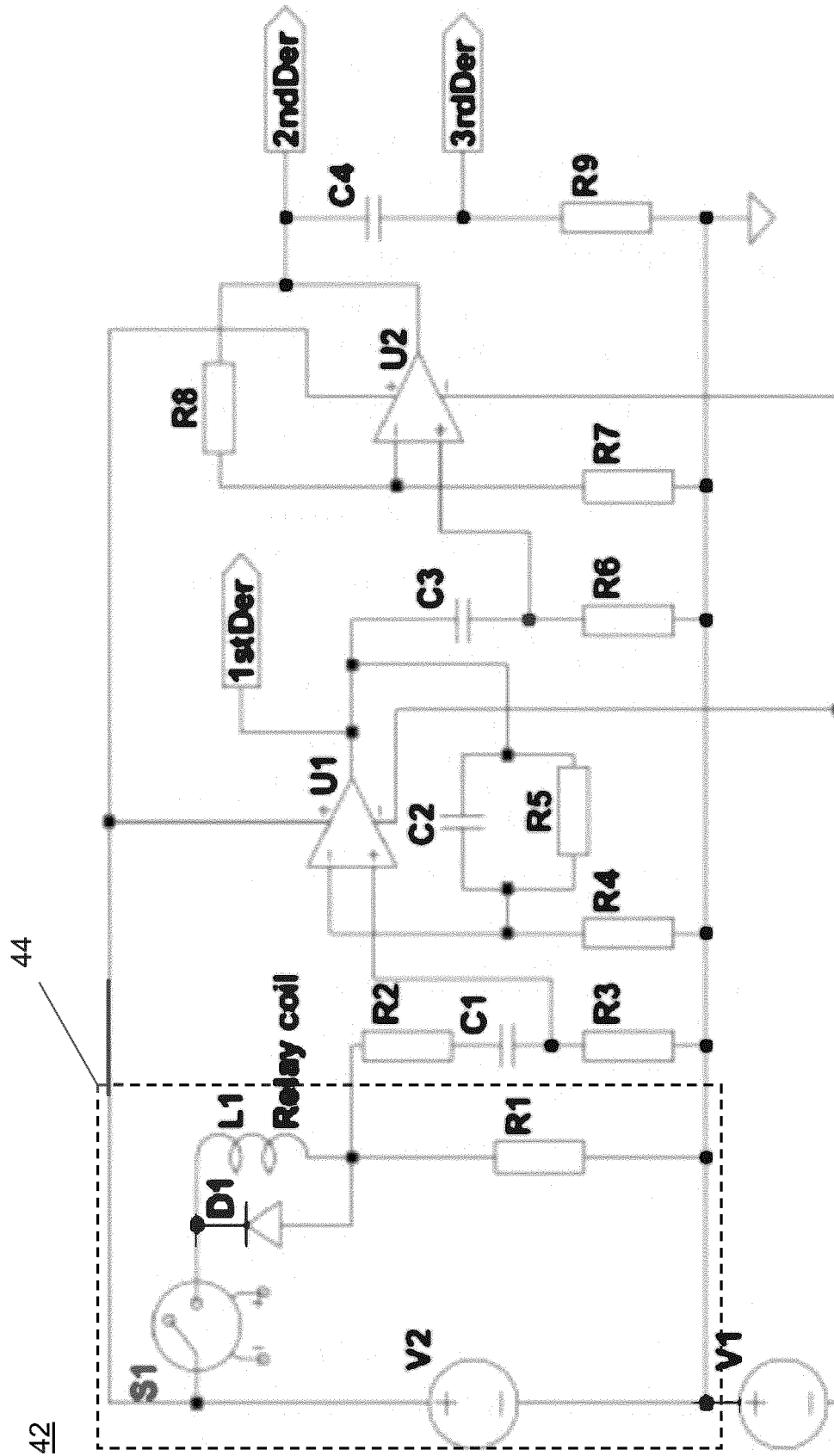


Fig. 6

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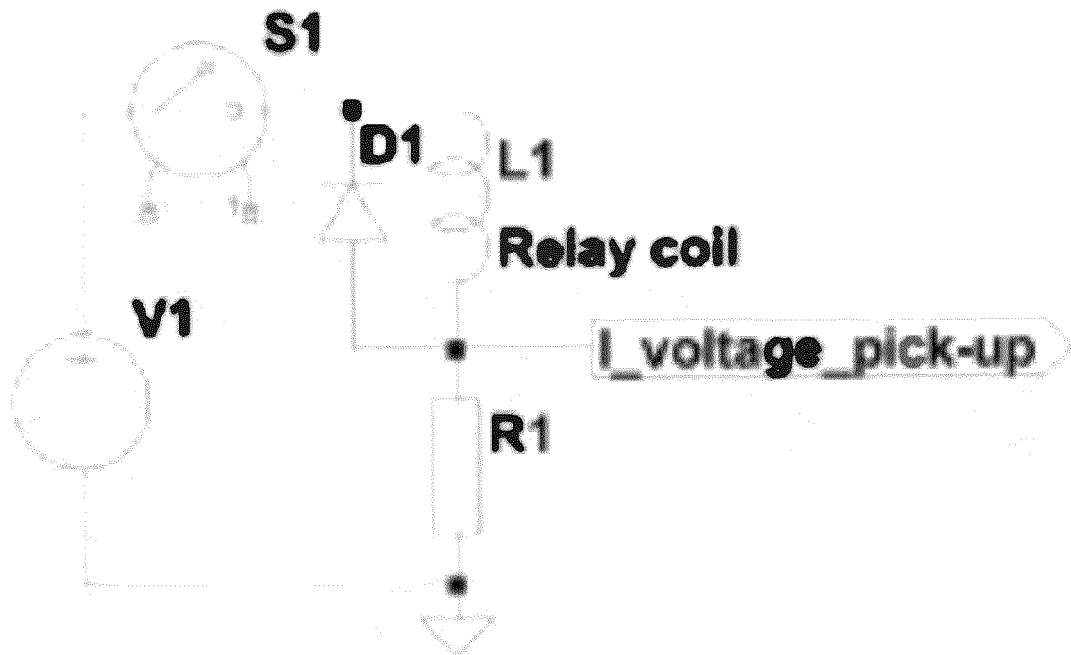


Fig. 7

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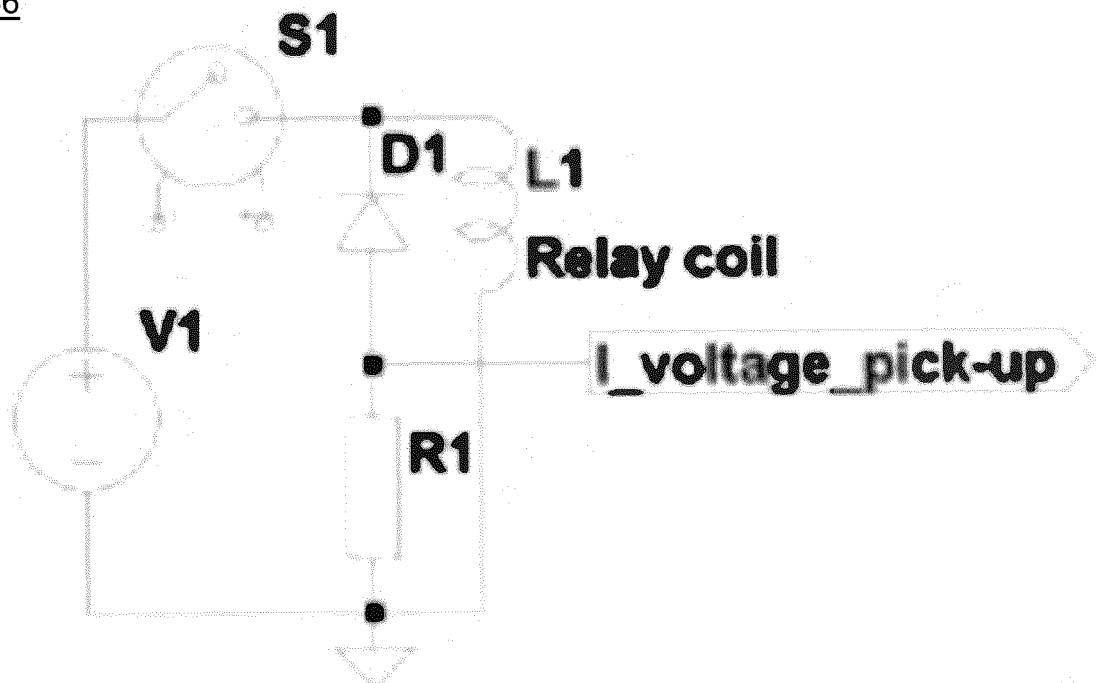


Fig. 8



EUROPEAN SEARCH REPORT

Application Number

EP 22 15 5770

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A, D	WO 2020/020555 A1 (BSH HAUSGERAETE GMBH [DE]) 30 January 2020 (2020-01-30) * page 10, lines 8-16; figure 3a * -----	1-8	INV. H01H47/00
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TECHNICAL FIELDS SEARCHED (IPC)

H01H

The present search report has been drawn up for all claims

1

Place of search

Munich

Date of completion of the search

30 June 2022

Examiner

Simonini, Stefano

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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