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(54) Benævnelse: **Fremgangsmåde til overvågning af en robot og robot med overvågningsindretning**

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DESCRIPTION

[0001] The invention relates to a method for monitoring moving parts of an industrial robot and an industrial robot with moving parts. The following measures are known for the realization of a so-called "safe robot":

- Limiting the axis speed by means of software limitation;
- Limiting speeds by restricting the intermediate circuit voltage;
- Monitoring the speed and/or the position via several redundant monitoring channels;
- Collision monitoring by monitoring the driving torques via the motor currents;
- Collision monitoring by separate sensors, e.g., for detecting the approach to obstacles (capacitive, inductive, ultrasound, visual) or contact forces (pressure measuring mats having different physical principles);
- Exclusion from certain parts of the work space by mechanical stops or by software.

[0002] The measures mentioned are in part not reliable as sole measures, but only in conjunction with at least one further monitoring channel, which are complex in some cases. As a rule, therefore, sufficient redundancy is provided by multichannel means, i.e., monitoring and taking several measurements. In addition, redundant monitoring previously includes the fact that identical or related measured quantities are only detected as measurement values by two or more sensors, and the (measured) measurement values are transmitted and processed via separate channels so that only errors of detection, transmission and processing could be eliminated, but not errors of the detected measured quantities or physical quantities themselves.

[0003] US Pat. No. 5,130,632 describes in a safety-technical embodiment where measurement values of a first force sensor are compared with measurement values of a second force sensor in order to be able to detect sensor errors by such a redundant evaluation. In this embodiment, identical measured quantities, namely the force, are detected and no two different measured quantities are used.

[0004] The object of the invention is to improve the monitoring of an industrial robot in order to increase safety.

[0005] According to the invention, this object is achieved by a method of the type mentioned at the outset, which is characterized in that measurement values of at least two different measured quantitiesfibre is detected and at least one of these measurement values is processed to a first measurement result in such a way that can be compared to the measurement value of the other measured quantity or a second measurement result obtained on the basis of this measurement value so that the first measurement result is compared to the measurement value of the other measured quantity or the second measurement result obtained on the basis of this measurement value and that a signal characterizing the comparison result is provided.

[0006] An industrial robot is also provided for the solution, said robot configured by two measuring devices for detecting different measured quantities as measurement values on the movable parts of the industrial robot, at least one processing unit for at least one of the measurement values of the measured quantities for processing this measurement value into a first measurement result comparable to the other measurement value of the other measured quantity or a second measurement result obtained from this measurement value and by a comparison unit for comparing the first measurement result to the measurement value of the other measured quantity or a second measurement result obtained on the basis of this measurement value.

[0007] Measured quantity should contain the physical quantity to be measured, measurement value the immediate result of a sensor and possibly transducer, measurement result the result of a computational, in particular electronic processing of a measurement value, in particular by an output value with the measurement value or a measurement result of another physical quantity derived from this.

[0008] The invention makes use of different or diverse physical measured quantities for the redundant monitoring of a robot, and thus various measured signals or values are made available. This makes possible a better redundant and thus safe monitoring of an industrial robot, primarily by the fact that the robot does not exceed specified speeds in a general or situation-dependent manner, which is important for limiting the overrun traverse during stop and for limiting the kinetic energy, that the robot continues to not exceed predefined acceleration values, which is important for avoiding uncontrolled states of movement in the event of a disturbance in the control, and finally that collisions with obstacles are reliably detected.

[0009] In an extremely preferred embodiment, provision is made here, for example, in addition to monitoring the movement of a robot by means of motor current measurements, that at least one measured quantity is to measure material stresses at parts of the robot or through measuring devices for determining material stresses.

[0010] In particular, it is essential that, by this measurement of material stresses or the formation of a robot such that material stresses are measured thereon, an additional, diverse measuring and processing channel is made available through this, the measuring signal or value of which does not depend on corresponding values in the robot control, such as, for example, the material flow measurement, so that interfering influences do not lead to systematically identical or similar measurement errors in all the various measuring and processing channels. In addition, the measurement value obtained from the material stress can also be used for other purposes.

[0011] In particular, the monitoring of material stresses according to the invention indirectly enables the monitoring of reaction load moments and forces as a result of collisions, accelerations and movement speeds (centrifugal force, Coriolis force) which lead to loading of the robot structure and thus to the material stresses to be measured.

[0012] In a preferred manner, material stresses are measured at several points of the robot structure, wherein preferably corresponding measurement transducers are mounted on at least two sides of a robot part, such as a rocker arm or robot arm, but preferably on two sides mounted to each other: upper or lower side and right or left side.

[0013] In a preferred embodiment of the method according to the invention, it is provided that the material stresses are measured by means of at least one measurement transducer, wherein in particular material stresses are measured by means of a strain gauge or else material stresses are measured by means of a fibre optic based pickup. A robot according to the invention is designed in a further development in such a way that the devices for determining material stresses are configured as a measurement transducer, wherein devices for determining material stresses are in turn configured as strain gauges or devices for determining material stress are configured as a piezoelectric or fiber optic pickups. It is, in principle, possible to use different types of measurement transducers, that is, to combine the above-mentioned.

[0014] Since the course of the measured quantity to be measured and thus the measurement values obtained by measurement, in particular of material stresses, can be very complex as a result of the superimposition of forces and torques, the sensor information is preferably evaluated by comparison with reference runs, wherein such reference runs on the one hand can be generated synthetically by calculation via a corresponding mathematical model or on the other hand by recording the real measurement values under known conditions (without interfering influences). In a further preferred embodiment, it is therefore provided that current measurement values or measurement results are compared to reference values, wherein in particular current measurement values or measurement results are measured with reference values and/or tolerances are considered by forming a reference corridor to a reference curve. If the measurement values or measurement results deviate more than is permissible from the corresponding reference curve, an unforeseen event, e.g., a collision with the operator, can be concluded. The permissible limit of the deviation is defined by a tolerance band (reference corridor).

[0015] In this case, provision can preferably be made for stopping the robot in the case of deviations from the expected measurement values or measurement results, wherein in particular, as already indicated above, the measurement of material stresses for monitoring the movement of the robot together with the measurement of other monitoring quantities takes place as redundant monitoring.

[0016] A further development of the robot according to the invention provides that at least one device for determining material stresses is arranged on at least two surfaces each of a robot part.

[0017] In a preferred embodiment, a monitoring device is provided with which at least one device for determining material stresses is connected to robot parts.

[0018] The redundancy in the test for unexpected results is achieved by simultaneous evaluation of the material stresses monitored according to the invention together with at least one further measuring channel, which can be used, in particular, via the position-measuring system in the control, via software-determined positions and/or via speeds or motor torques, which are measured via current sensors in the drive amplifiers.

[0019] If none of the redundant measuring channels indicates an overshoot of the tolerance band, it may be concluded that there is no interference. If at least one of the measuring channels indicates an overshoot, the robot is stopped and put into a safe state by means of a safe logic by closing the brakes and switching the drives in an energy-free manner.

[0020] Further advantages and features of the invention will emerge from the claims and from the following description, in which exemplary embodiments of the invention are explained in detail with reference to the drawings. They show:

Fig. 1 a block diagram for monitoring the movements of a robot.

Fig. 2 a diagram for detecting and evaluating material stresses on a robot part.

Fig. 3 a concrete embodiment example for detecting material stresses on a robot due to a movement about the A1 axis.

Fig. 4 a concrete embodiment for detecting material stresses on a robot due to a movement about the A3 axis.

Fig. 5 a robot, the robot arm of which comes into contact with the shoulder of a person;

Fig. 6 a robot with a schematic representation of the reaction torque on the acceleration of the axis A3;

Fig. 7 a robot with a schematic representation of the centrifugal and Coriolis forces occurring during movement about the vertical axis A1;

[0021] Fig. 1 shows a block diagram for carrying out the method according to the invention for monitoring a robot by means of receiving different, diverse physical measured quantities by means of a redundant measurement system, on the example the use of material stresses in the structure of an industrial robot 1.5.

[0022] During operation of a robot, forces and moments can occur in parts which lead to material stresses within the parts of the robot, which detects via suitable devices, such as strain gauges 8 or also fibre optic sensors (not shown) and thus also can be monitored during the operation of the robot with regard to the deviation of predetermined value sequences or to predetermined or expected value sequences.

[0023] The industrial robot of Fig. 1 has a robot base 2, converter 3 arranged on this, a carousel 4 arranged on the base 2, rotatably about the vertical first robot axis A1, an articulated robot rocker arm 5 pivotable about the horizontal second axis A2, an articulated robot arm 6, on the free end of which facing away from the rocker arm 4 and pivotable about a further horizontal robot axis A3, on whose free end, facing away from the robot arm 5, a robot hand 7 is arranged. Strain gauges 8 are arranged on rocker arm 4 and robot arm 6.

[0024] A robot 1 is shown and additionally a monitoring circuit 11 as a block circuit diagram. The monitoring device 11 has a monitoring unit 12 for monitoring the elongations of the robot structure, a monitoring unit 13 for monitoring the position of robot parts, taking into account the time sequence and thus the speed, and finally a monitoring unit 14 for monitoring the motor current from the converters 3 and thus the drive torque.

[0025] In a comparison unit 15 as part of the monitoring device 11, the measurement values or measurement results measured by the units 12, 13, 14 are compared to model values of a model 16. If the measurement values deviate from predetermined values or a predetermined course, a safe switching-off of the robot takes place via a switching device 17.

[0026] Fig. 2 shows a diagram for the detection and evaluation of material stresses on a robot part.

[0027] In the case of a robot, for example, acceleration moments and also collisions (deceleration, negative acceleration) result in reaction load moment M according to

$$M = J * q\_dd, \qquad (1),$$

wherein J is the moment of inertia and q_dd is the angular acceleration about an axis (step A of Fig. 2).

[0028] This load moment, according to

$$\sigma = M / W, \quad (2),$$

wherein W is the resistance moment, leads to stresses on the robot structural elements σ (step B).

[0029] These stresses, in turn, operate according to Hook's law

$$\varepsilon = \sigma / E \quad (3)$$

[0030] Elongations ε on the robot part, wherein E is the elastic modulus that can be detected or measured by strain gauges (step C).

[0031] The measurement values of the elongations ε can now be further processed in such a way that the measurement values of the elongation and thus stress measurements are comparable to other measurement values of other measured quantities, for example, motor current measurement values (step E). In a further step F, a comparison is made to such a further measured quantity F', and, in the event that both indicate an error, a dangerous situation or the like, a safe switching-off is made (step G). In addition or alternatively, it can be provided that there is an evaluation of the elongations, i.e., comparison to a reference elongation sequence (step E') and, when the comparison shows that the measurement result falls out of the reference elongation sequence or reference corridor, a safe switching-off is also performed (step G).

[0032] Fig. 3 shows that a strain gauge 8 is arranged on one side (the right or left side of the robot rocker arm 5) for detecting the load moments of the robot rocker arm during movement of the same (and the following robot elements) around the vertical axis A1.

[0033] On the other hand, Fig. 4 shows that the corresponding strain gauge 8 is arranged on the upper side (or on the lower side) of the rocker arm 5 for detecting the reaction or stress moments of a movement about the first horizontal axis A2.

[0034] Figs. 5 to 7 show concrete embodiment examples of the method according to the invention and of a robot according to the invention with moving parts and the monitoring of the machine or of the robot 1 by means of the detection of the physical measured quantity of the material stress. Furthermore, a person 9 is shown schematically in Fig. 5.

[0035] If, for example, a robot arm 6 strikes the shoulder of a person from the top, as shown in Fig. 5, or if it strikes another object from above, this results in increased bending moments in the robot arm 6 and thus material stresses in the latter, which can be measured by means of measuring strips 8 on the robot arm 6, in particular by measuring strips 8 arranged on the underside and on the upper side of the arm. Correspondingly, when the robot arm 6 is laterally striking against a person or an object, in which case measurement strips 8, preferably arranged on the right and left of the robot arm 6, are provided for measuring the material stresses. If the robot arm 6 strikes with its front side or with a tool connected to it in the direction of the extent of the robot arm 6 against a resistance, such as against a person, bending moments and thus material stresses arise in particular in the rocker arm 4.

[0036] As already explained with reference to Fig. 2, and as can be seen from Fig. 5, during the acceleration or deceleration of robot axes, moments occur according to the formula,

$$M\_q_i = q_i\_dd*J$$

wherein M_qi is the reaction moment to the acceleration of the axis i, as shown in Fig. 5 the axis A3, q_i_dd is the angular acceleration of the axes i and J is the moment of inertia. These moments lead to material stresses, which can be detected by means of suitable measuring transducers, such as, in particular, strain gauges or fibre optic transducers.

[0037] In Fig. 6, it can be seen that with constant movement of the robot, centrifugal force and Coriolis forces correspondingly

$$F\_Zentrifugal = m \cdot (\overline{q\_d})^2 * r$$

or the Coriolis force,

$$F\_Coriolis = 2 * m * (\overline{qd} \times \overline{s-d}),$$

wherein F_Zentrifugal is the centrifugal force, m is the mass, $\overline{q\_d}$ is the angular velocity, r is the radius, F_Coriolis is the Coriolis force, and $\overline{s\_d}$ is the translatory velocity.

[0038] The sensors, which detect the resulting material stresses, provide a constant image of the structural load during operation of the robot. The measurement values obtained can be further processed and used in a plurality of ways, in particular online, for monitoring and safety purposes, in order to permanently compare the measurement values with predetermined guide values or to compare limit values in order to ensure safety of the man-machine system in which movements, namely speeds and accelerations, are held in a tolerable range and/or a successful stopping when a robot part strikes a human being.

[0039] Fig. 7 thus shows, in a diagram, in which the location of a robot part is plotted over time, a reference curve R for a predetermined movement of the robot or of a robot part. The reference curve R is assigned a tolerable range as reference corridor S. Furthermore, Fig. 4 shows a measurement curve M, which shows the actual location of the robot part during an operation over time. In the range X, the measuring curve M moves from the reference corridor S and thus displays an impermissible movement or collision with unexpected measurement values. The robot can then be switched off, for example.

REFERENCE LIST

[0040]

1	Industrial robot
2	Robot base
3	Inverter
4	Rocker arm
5	Robot rocker arm
6	Robot arm
7	Robot hand
8	Strain gauges
9	Person
11	Monitoring device
12	Monitoring unit
13	Monitoring unit
14	Monitoring unit
15	Comparison unit
16	Model
17	Switching device
M	Measurement curve
R	Reference curve
S	Reference corridor
X	Range

PATENTKRAV

1. Fremgangsmåde til overvågning af dele af en industrirobot (1), hvorved måleværdierne for to forskellige målte størrelser detekteres, og i det mindste én af disse måleværdier bearbejdes i et første måleresultat, **kendetegnet ved, at** måleværdier bearbejdes i et første måleresultat, således at det er sammenligneligt med måleværdien for den anden målte størrelse eller et andet måleresultat, der er opnået på basis af måleværdien, **ved, at** det første måleresultat sammenlignes med måleværdien for den anden måle- størrelse eller det andet måleresultat, som er opnået på basis af måleværdien, og **ved, at** der tilvejebringes et signal, som karakteriserer resultatet af sammenligningen.

2. Fremgangsmåde ifølge krav 1, **kendetegnet ved, at** materialespændinger i dele af maskinen måles som i det mindste én målt størrelse.

3. Fremgangsmåde ifølge krav 2, **kendetegnet ved, at** materialespændingerne måles ved hjælp af mindst én måletransducer (8).

4. Fremgangsmåde ifølge krav 2 eller krav 3, **kendetegnet ved, at** materialespændingerne måles ved hjælp af en strain-gauge (8).

5. Fremgangsmåde ifølge et hvilket som helst af kravene 2 eller 3, **kendetegnet ved, at** materialespændingerne måles ved hjælp af piezo-elektriske eller lysleder-baserede sensorer.

6. Fremgangsmåde ifølge et hvilket som helst af kravene 2 til 5, **kendetegnet ved, at** materialespændingerne måles ved hjælp af måletransducere (8), der er positioneret på mindst to overflader af en robotdel.

7. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** aktuelle måleværdier for målte størrelser eller måleresultater sammenlignes med referenceværdier.

8. Fremgangsmåde ifølge krav 7, **kendetegnet ved, at** aktuelle måleværdier for målte størrelser og/eller måleresultater sammenlignes med referenceværdier, idet der tages højde for tolerancer.

9. Fremgangsmåde ifølge krav 8, **kendetegnet ved, at** der tages højde for tolerancer ved dannelse af en referencekorridor for en referencekurve.

10. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** robotten standser i tilfælde af afvigelser fra forventede måleværdier og/eller måleresultater.

11. Industrirobot (1), omfattende to måleindretninger til bestemmelse af forskellige målte størrelser som måleværdier på bevægelige dele af industrirobotten, **kendetegnet ved** mindst én bearbejdningsenhed (12, 13, 14) for mindst én af måleværdierne for de målte størrelser med henblik på at bearbejde denne måleværdi til et første måleresultat, der er sammenligneligt med den anden måle-

værdi for den anden målte størrelse eller et andet måleresultat, som er opnået på basis af denne måleværdi, og ved en sammenligningsenhed (15) til sammenligning af det første måleresultat med i det mindste måleværdien for den anden målte størrelse eller et andet måleresultat, der er opnået på basis af denne måleværdi.

12. Industrirobot ifølge krav 11, **kendetegnet ved** måleindretninger til bestemmelse af materialespændinger.

13. Industrirobot ifølge krav 12, **kendetegnet ved, at** indretningerne til bestemmelse af materialespændinger er udformet som målesensorer.

14. Industrirobot ifølge krav 12 eller krav 13, **kendetegnet ved, at** indretningerne til bestemmelse af materialespændinger er udformet som strain-gauges (8).

15. Industrirobot ifølge et hvilket som helst af kravene 12 til 14, **kendetegnet ved, at** indretningerne til bestemmelse af materialespændinger er udformet som lysleder-baserede sensorer.

16. Industrirobot ifølge et hvilket som helst af kravene 12 til 15, **kendetegnet ved, at** der i hvert tilfælde er anbragt mindst én indretning til bestemmelse af materialespændinger på mindst to overflader af en robotdel.

17. Industrirobot ifølge et hvilket som helst af kravene 12 til 16, **kendetegnet ved** en overvågningsindretning (11), til hvilken mindst én indretning er forbundet med henblik på bestemmelse af materialespændinger på maskindele i industrirobotten.

18. Industrirobot ifølge krav 16 eller krav 17, **kendetegnet ved, at** overvågningsindretningen (11) omfatter enheder til overvågning af i det mindste udvidelser i industrirobottens maskinstruktur samt en yderligere målt størrelse.

19. Industrirobot ifølge et hvilket som helst af kravene 16 til 18, **kendetegnet ved, at** overvågningsindretningen (11) omfatter en sammenligningsindretning (15) til sammenligning mellem strømmåleværdier og/eller måleresultater med forudbestemte modeller for robotbevægelser (16).

20. Industrirobot ifølge et hvilket som helst af kravene 18 og 19, **kendetegnet ved, at** overvågningsindretningen (11) omfatter en koblingsindretning (17) til udkobling af industrirobotten.

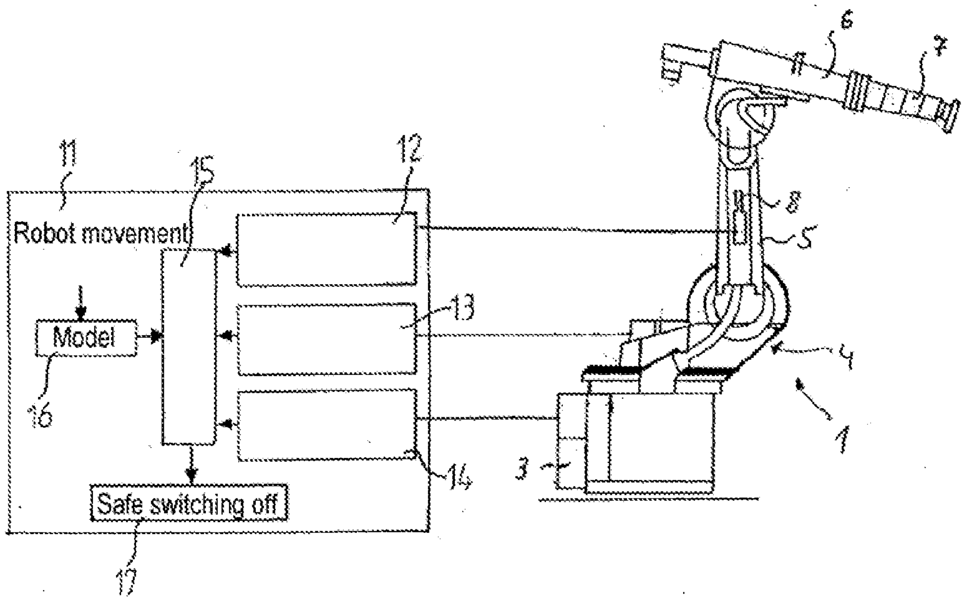
11
Robot movement
15
12
13
Model
16
14
Safe switching off
17
6
7
8
5
4
1
3

Fig.1

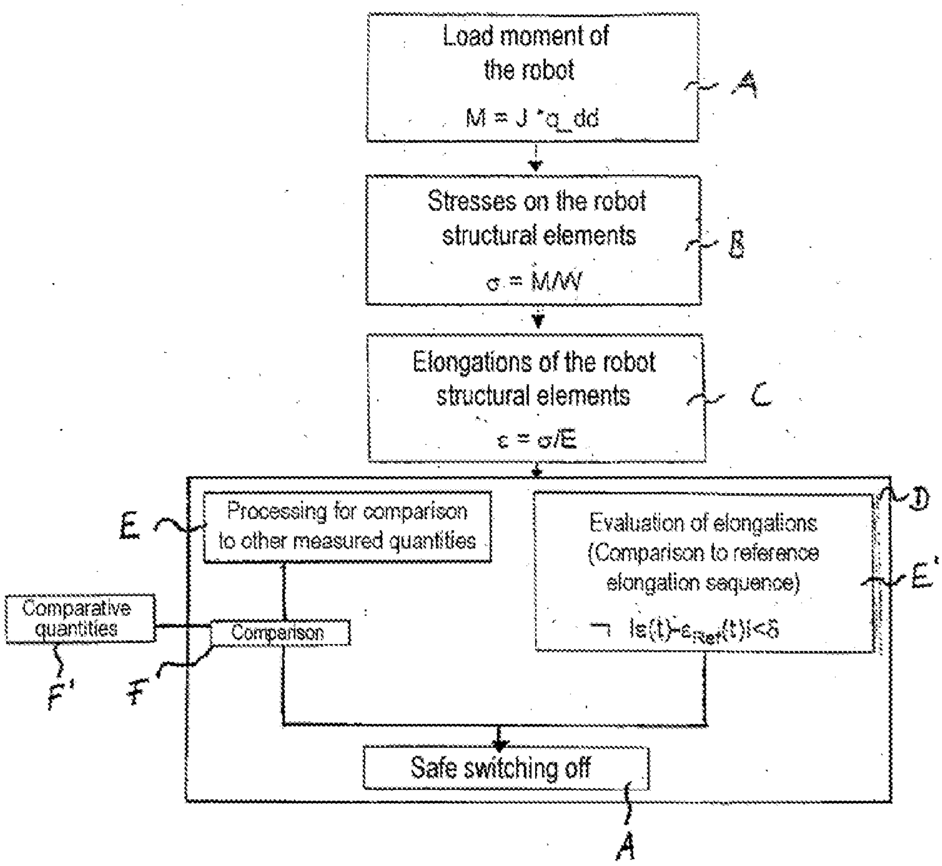
Load moment of the robot
M = J *q_dd
A
Stresses on the robot structural elements
σ = M/W
B
Elongations of the robot structural elements
ε = σ/E
C
D
E
Processing for comparison to other measured quantities
Evaluation of elongations (Comparison to reference elongation sequence)
¬ |ε(t)-ε_Ref(t)|<δ
E'
Comparative quantities
Comparison
F'
F
Safe switching off
A

Fig. 2

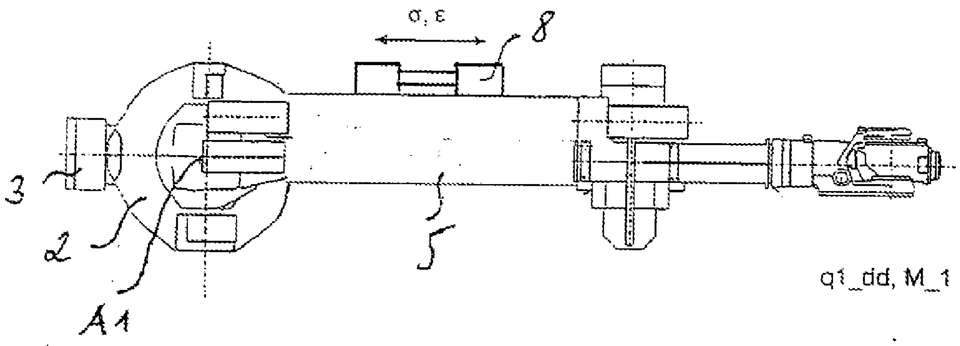

Fig. 3

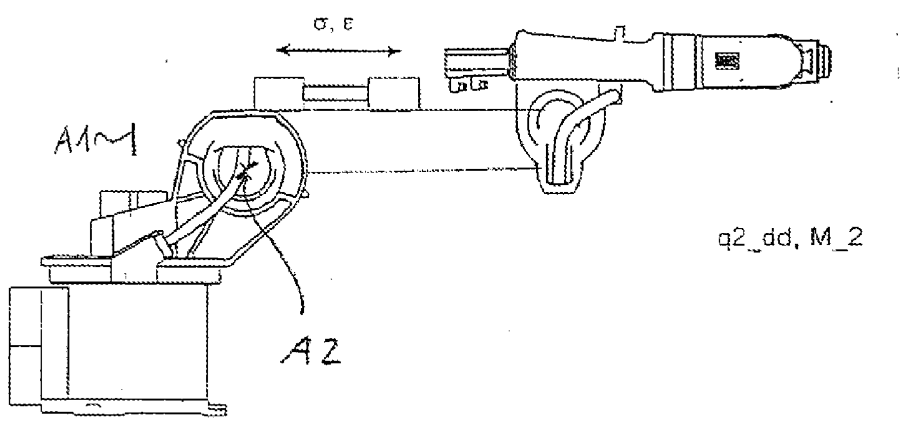

Fig. 4

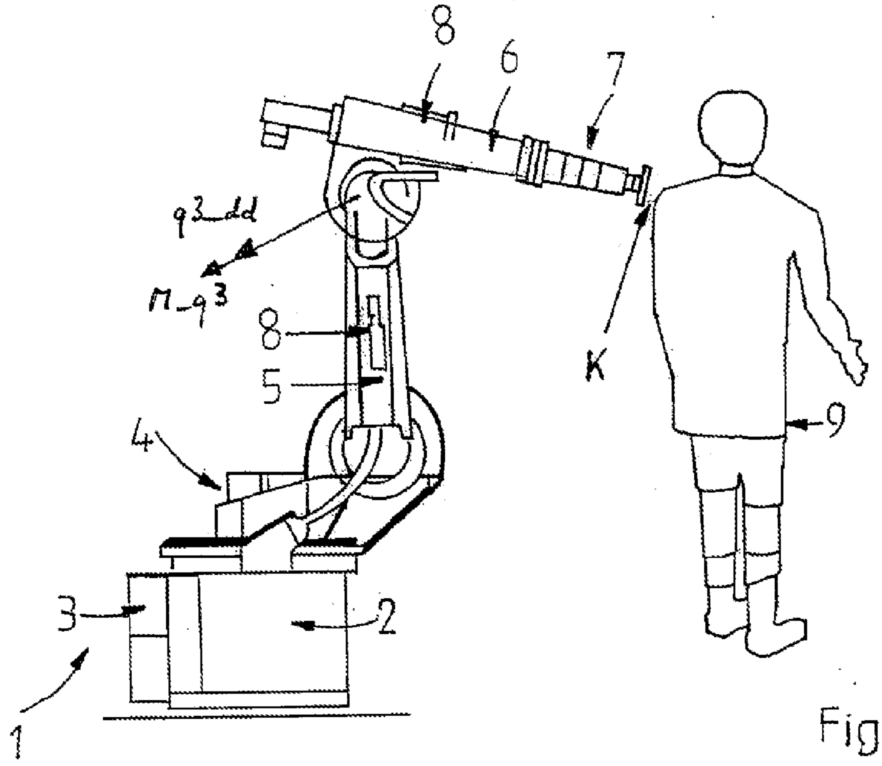

Fig.5

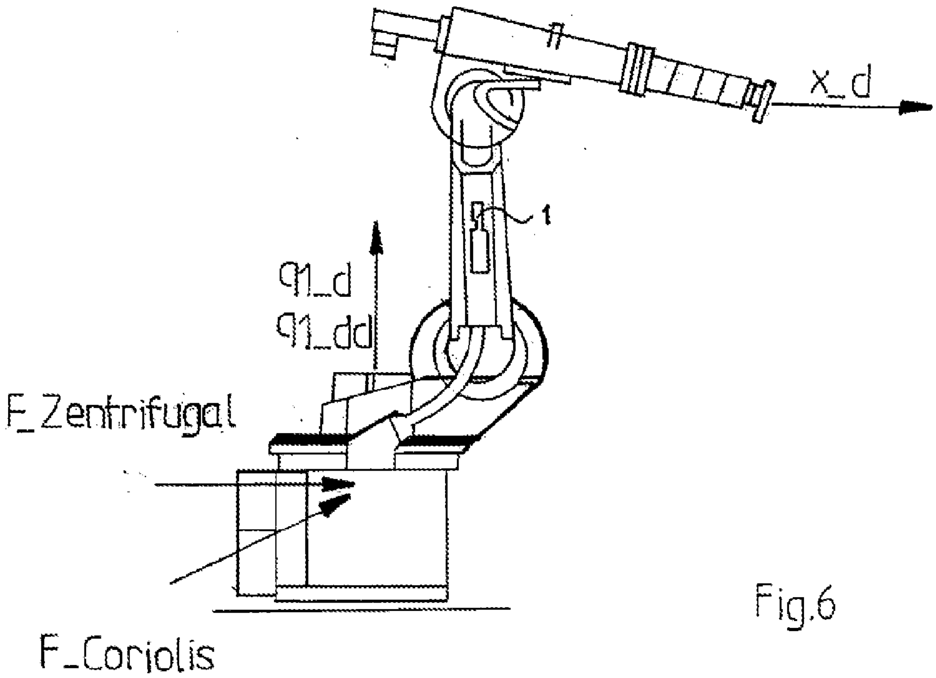

Fig.6

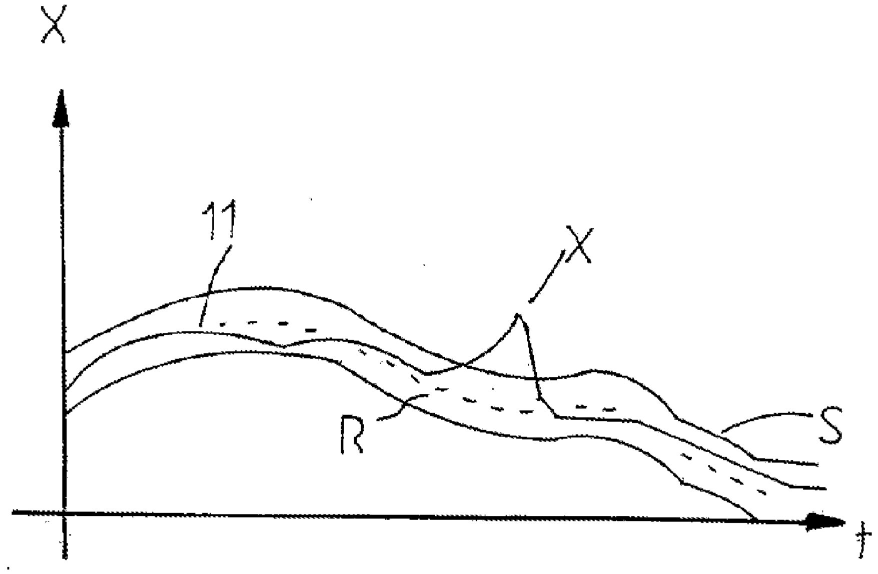

Fig. 7