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(54) **Method of detecting and controlling the torque of a three-phase motor and device to carry out the method**

(57) A method of detecting and controlling the torque of a three-phase motor is disclosed, comprising the following steps: effecting a first detection of the torque value delivered by said motor at the actuation unit (2) of said motor, or externally thereto; effecting a second detection (5) of the torque value delivered by said motor, downstream said actuation and upstream the motor terminals, through processing means using as input signals the voltage signals of each phase and the current signals of at least two of said phases; comparing said torque values with predetermined torque thresholds; commanding the interruption of the electric power to said motor when said torque values exceed said threshold limits.

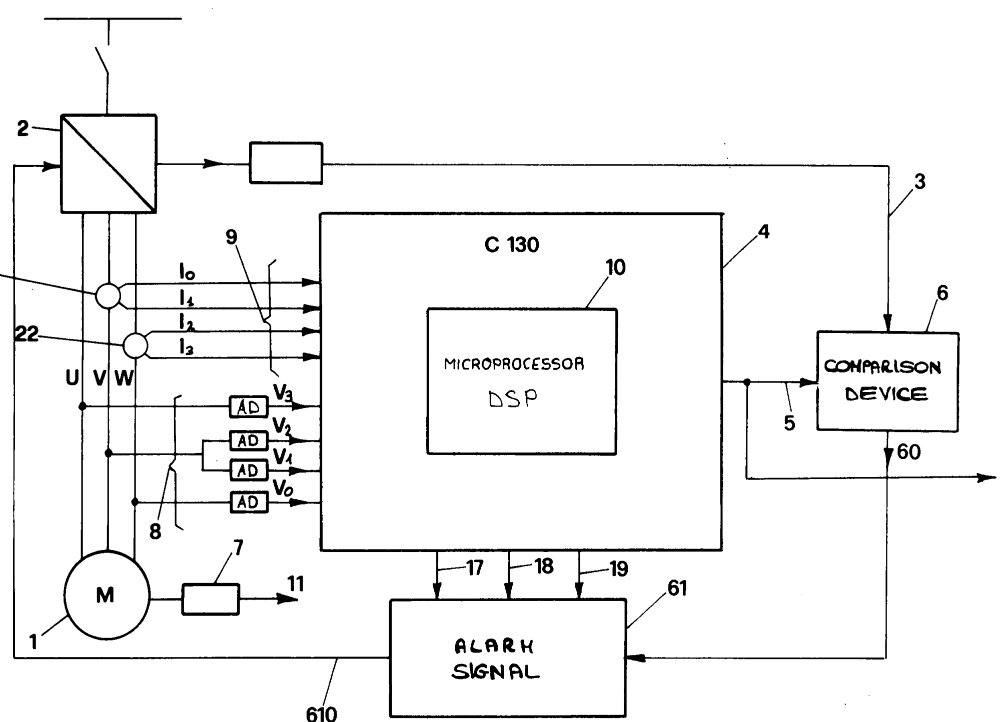

FIG.1

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Description

[0001] The present invention relates to a method of detecting and controlling the torque of a three-phase motor and a device adapted to carry out the method. The method is particularly adapted to be used in systems where it is necessary to monitor the instantaneous value of the torque delivered by the motor.

[0002] In some applications actuators with variable speed motors are used wherein, for safety reasons, it is necessary to use a system of detecting the torque physically and functionally separated from the circuits controlling operation of said motor.

[0003] A typical application of actuators with variable speed motors consists of cableways for passenger transportation. In order to guarantee the maximum operative safety of these equipments, strict regulations require to monitor separately the instantaneous value of the delivered torque relative to the value detected by the motor actuating device.

[0004] Cableways are known where traction is carried out by direct current motors whose shaft transfers mechanically the motion to a traction sheave driving the cable.

[0005] In this kind of equipments the torque value is taken separately by measuring the direct current feeding the motor at the armature which is proportional to the value of the torque delivered by said motor.

[0006] This latter outer detection according to the prior art is easily carried out by measuring shunts allowing to obtain a voltage value proportional to the current and therefore to the delivered torque.

[0007] Both torque values detected as above described are transmitted to two monitoring devices causing the equipment to stop by intervention on the motor actuation and the brakes if said values exceed predetermined threshold values.

[0008] Use of direct current motors however involves a number of inconveniences inducing the operators in this field to use three-phase alternate current motors of synchronous or asynchronous kind replacing the direct current motors.

[0009] Indeed, use of direct current motors, more particularly for cableways, involves a number of drawbacks cited herein below.

[0010] The first drawback consists in that the direct current motors require rather heavy maintenance in view of the provision of sliding members requiring a frequent cleaning for a correct operation.

[0011] Another drawback consists of the reactive power and current irregularities produced by the converters used to feed the direct current motor.

[0012] A further drawback consists in that the direct current motors have high rated speeds.

[0013] For these reasons in systems where low operative speeds are required, such as for cableways, it is necessary to use mechanical reduction units to be arranged between the motor shaft and the traction sheave of the equipment, so as to allow a sufficiently high speed of the direct current motor even when the equipment cable moves at the minimum speed.

[0014] This requirement however involves installation of cumbersome and expensive mechanical units.

[0015] Use of actuators comprising three-phase motors either of 'synchronous or asynchronous kind with variable frequency, allows to overcome the above-mentioned drawbacks.

[0016] More particularly, the synchronous or asynchronous three-phase motors require a reduced maintenance and have a greater reliability relative to the direct current motors.

[0017] Moreover, the synchronous or asynchronous motors with high number of poles fed at variable frequency may be used at considerably lower speed in comparison with the direct current motors.

[0018] This allows to carry out the direct mechanical connection between the motor shaft and the traction sheave without requiring mechanical reduction units for the low-speed operation.

[0019] Use of alternate current motors of the synchronous or asynchronous kind and their control by actuators, such as static converters, allows to reduce the reactive power absorbed by the network and to keep the phase angle cos φ as much close to 1 as possible to meet the limits fixed by the energy provider.

[0020] Moreover, such technique allows to reduce emission of current harmonics thus reducing the transients caused thereby.

[0021] Also for this kind of motors, when used in cableways for passenger transportation, there is the duty to monitor the value of the delivered torque separated from that detected by actuation of said motor.

[0022] The detection of the torque in this configuration is however difficult, relative to the direct current motors, because the motor phase current is no more proportional to the delivered torque, because a portion of said current supports the flux of the magnetic field at the magnetic gap.

[0023] It is an object of the present invention to overcome such a limitation.

[0024] More particularly a first object of the invention is to provide a method of measuring and controlling the torque of a three-phase motor in equipments where the detection of the torque separated from the circuits controlling the actuation of said motor is required.

[0025] Another object of the invention is to provide a control device carrying out such a method thus allowing to use alternate current motors in the equipments where it is installed.

[0026] The foregoing objects are obtained through a method of detecting and controlling the torque of three-phase motors that, according to the main claim, is characterized by comprising the following steps:

- effecting a first detection of the value of the torque delivered by said motor at the actuation unit of said motor, or outside it;
- effecting a second detection of the value of the torque delivered by said motor, downstream said actuation and upstream the motor terminals, through processing means using as input signals the voltage signals of each phase and the current signals in at least two of said phases;
- comparing said torque values with predetermined torque thresholds;
- emitting alarm signals and causing interruption of electric supply to said motor when said torque values exceed said threshold limits.

[0027] According to a preferred embodiment said method is carried out by a control device of the motor torque wherein the first detection is effected at the actuation unit according to known methods, and the second detection is effected downstream the actuation and upstream the motor terminals, through a torque detection device wherein the acquired voltage and current signals are numerically processed to supply an output signal of a value proportional to the torque delivered by the motor.

[0028] The device of the invention provides that said torque detection device is connected to an alarm-signalling device providing to send an interrupt command to the motor actuation when the torque value exceeds some predetermined limits or when the torque variation gradient exceeds the inputted limit.

[0029] Moreover, a comparator device is also provided, comparing the two torque signals outgoing from the actuation and said torque signalling device. Such a comparator device is electrically connected to the alarm-signalling device.

[0030] According to a different embodiment the method also provides a step of detecting the motor speed through a bidirectional incremental encoder keyed to said motor allowing to obtain also a speed control.

[0031] The foregoing objects and advantages will be better understood by the description of a preferred embodiment given as an illustrative but not limiting example with reference to the accompanying sheets of drawings in which:

- Figure 1 is a block diagram of the device of the invention;
- Figure 2 shows the torque detection device being part of the torque measuring and controlling device of the invention; and
- Figure 3 is a diagram of a simplified model of asynchronous motor used in the device of the invention.

[0032] With reference now to said figures of the drawings and more particularly to Figure 1, one can see that the alternate current motor 1 is connected to a three-phase line U, V, W supplied by an actuator 2 generally consisting of an inverter supplying as output a three-phase voltage with variable frequency.

[0033] The actuator 2 comprises also known calculation means of the torque supplied at any time to the motor 1 using for the calculation the voltage and current parameters of the three-phases U, V and W.

[0034] A signal 3, thereby calculated and proportional to the torque, goes out from actuator 2 to enter a comparator device 6, where it is compared with another torque measure obtained as explained hereinafter.

[0035] On the three-phase line U, V and W connecting the actuator 2 to the motor 1, the voltage of the three-phases U, V and W are taken through external resistors arranged between each phase and the corresponding terminal of the torque detection device 4, which actually is an electronic board for instance of the type G 130, and are acquired by the board through differential amplifiers; in practice through differential amplifiers AD with high input impedance, two line voltage values between two pairs of phases are acquired, and the ohmic values of the external resistors are adapted as a function of the motor-feeding voltage. More particularly the voltage V_1-V_0=W-V and the voltage V_3-V_2=U-V are detected and sent to the inputs of the torque detection device 4. The four voltages V_0, V_1, V_2, V_3 are generally indicated as first inputs 8.

[0036] The currents of the two phases U and W are detected through Hall effect current transducers adapted to detect correctly and with galvanic insulation currents with variable frequency in a wide field, from the continuous component up to high frequency components.

[0037] On the board the load resistors of the transducers are installed on tags, with an ohmic value adequate for the correct operation of the transducer and each board. The board is adapted to supply stabilised voltages at +15 Vcc and -15 Vcc generally required to feed the transducers.

[0038] The two current transducers 21 and 22 with their load resistors may be considered equivalent to two shunts series connected to the two phases, with signal terminals:

+U and -U (positive voltage on +U for current Iu with direction entering the motor)
+W and -W (positive voltage on +W for current Iw with direction entering the motor).

[0039] Therefore the two transducers connected to the phases U and W supply the current signals I_0, I_1, I_2, I_3 generally indicated as second inputs 9 which are applied to the corresponding inputs of the board 4 (G130) as shown in Fig. 2.
[0040] The entire sequency of acquiring the instantaneous values of current and voltage and therefore of processing and emitting the consequent instantaneous torque value, in the case of the embodiment, is effected every 113 microseconds, that is approximately 9000 times per second. This allows to obtain significant indirect values, although a high speed of detecting the instantaneous value of the torque and other quantities is maintained.
[0041] The analogue signals of current and voltage are required in 10 bits numerical values plus the sign, therefore with a resolution of about 1/1000 of their full scale value and most part of the calculations are carried out on 16 bits codified internal numerical values.
[0042] The method of processing the signals received by the transducers and subsequently the method of calculating the torque and the auxiliary numerical values will be the described herein after.
[0043] The voltage and current analogue signals are processed by electronic analogue circuits with operational amplifiers in the following way.

Signal Va of line voltaqe V-W:

[0044] Board terminal V_0: connected to the resistor connected to phase W.
[0045] Board terminal V_1: connected to the resistor connected to phase V.
[0046] A differential amplifier, present in the torque detection device 4, supplies the internal alternate signal: $Va = 0.25 \times [V_1(V) - V_0(W)]$
[0047] Va is positive for a voltage V greater than voltage W.
[0048] The direction of the rotational vector Va of the signal Va is taken as axis X reference for the phase equivalent circuit of the motor used for the calculations.
[0049] The generic vector A is generally represented by the compound number $A = A_x + j\,Ay$, where:

A_x = axis X component, oriented from left to right
Ay = axis Y component, oriented up from down

[0050] In the specific case therefore one obtains: $Va = Va + j\,0 = Va$

Signal vX of line voltage U-V:

[0051] Board terminal V_2: connected to the resistor connected to phase V.
[0052] Board terminal V_3: connected to the resistor connected to phase U.
[0053] A differential amplifier supplies the internal alternate signal: $vX = 0.25 \times [V_3(U) - V_2(V)]$
[0054] vX is positive for voltage U greater than voltage V
[0055] The rotational vector vX is oriented 120° anti-clockwise relative to Va.

Signal Vb of voltage in quadrature with Va:

[0056] A summing amplifier, always belonging to the device 4, supplies the internal signal:

$$Vb = -2/\sqrt{3}x[vX + Va/2]$$

[0057] It is assumed that the detected line voltages consist of high frequency components, that will be removed by suitable filters, and sinusoidal components "useful" at the motor-feeding frequency. The "useful" components of three line voltages have a sinusoidal development, keep an identical module and the regular phase displacement of 120° to each other. The same hypotheses are used for the motor alternate currents, with the assumption that in every instant it behaves in the same way on the three phases.
[0058] On the basis of these hypotheses, the useful sinusoidal component of the signal Vb is in phase quadrature relative to the useful sinusoidal component of the signal Va.
[0059] In the chosen reference system X-Y one then obtains $Vb = 0 - j\,Vb$

Relations between (Va, Vb) detected and (Vx, Vy) of the reference system X-Y:

[0060] Having defined the rotational vector V of the voltage of the phase equivalent circuit as: $V = Vx + j\,Vy$
the following correspondence is obtained: $Vx = Va$ $Vy = -Vb$

Current signal Ia of phase U:

[0061] Board terminal I_0: connected to terminal +U of the current transducer at phase U.
[0062] Board terminal I_1: connected to terminal -U of the current transducer at phase U.
[0063] A differential amplifier, belonging to the device 4, supplies the internal alternate signal: $I_a = 3/2 \times [I_1(-U) - I_0(+U)]$
[0064] I_a is positive when the current of phase U entering the motor is positive (from motor to source).
[0065] If the motor is a three-phase load resistor, in the system of axes X-Y the rotational vector would be:

$$Ia = 0 - j\,Ia$$

Current signal iY of phase W:

[0066] Board terminal I_2: connected to terminal +W of the current transducer at phase W.
[0067] Board terminal I_3: connected to terminal -W of the current transducer at phase W.
[0068] Another differential amplifier, still belonging to device 4, supplies the internal alternate signal: $iY = 3/2 \times [I_3(-W)-I_2(+W)]$
[0069] iY is positive when the current of phase W entering the motor is positive (from motor to source).
[0070] If the motor is a three-phase load resistor, in the system of axes X-Y the rotational vector iY would be oriented 60° anti-clockwise relative to axis X.

Current signal Ib in quadrature with Ia:

[0071] A summing amplifier of the device 4 supplies the internal alternate signal:

$$Ib = -2/\sqrt{3x[iY+Ia/2]}$$

[0072] The signal Ib is in quadrature relative to the signal Ia.
[0073] In the chosen reference system X-Y one has:

$$Ib=-Ib+j0$$

Relations between (Ia, Ib) detected and (Ix, Iy) of the reference system X-Y:

[0074] Having defined the rotational vector I of the voltage of the phase equivalent circuit as: $I = Ix + j\,Iy$
the following correspondences are obtained: $Ix = -Ib$ $Iy = -Ia$

Transposition of analogue signals Va, Vb, Ia, Ib into numerical values:

[0075] The torque detection device 4 is fed by a microprocessor 10 of the type DSP for the numerical processing, receiving directly on 4 inputs the 4 voltage analogue signals and on other 4 inputs the signals with sign-inverted voltage.
[0076] The DSP converts the signals by means of stages ADC into the following 10 bits numerical values with sign:

$$V_\alpha = Va = Vx$$

$$V_\beta = Vb = -Vy$$

$$I_A = Ia = -Iy$$

$$I_B = Ib = -Ix$$

METHOD OF CALCULATING TORQUE AND AUXILIARY NUMERICAL VALUES

[0077] The microprocessor DSP provides to carry out the routines for calculating the various quantities according to the stored programme, using the main relations indicated below.

[0078] The calculation method substantially uses a simplified model of the asynchronous motor shown in Figure 3, consisting of a single-phase circuit with the following elements:

a) Resistance RS and inductance LS series connected to the stator-phase circuit. These quantities show the effects of the ohmic losses in the stator copper (not in the rotor copper) and the losses reducing the magnetic useful flux to the magnetic gap due to the stray fluxes.

b) Resistance R_{iron}, inductance L_{flux} and resistance R_{torque}, parallel connected. They represent the ohmic losses in the iron, the useful flux produced at the magnetic gap and the power transferred to the rotor respectively; a portion thereof is due to the ohmic losses R_c in the rotor copper, the remaining part R_p is the mechanical useful power generated by the motor.

[0079] The values of RS, LS, R_{iron} are calculation constants; they are obtained starting from values of some main parameters of the motor that are programmed at the start and kept in a board-permanent memory.

1 - Calculation of module of voltage V feeding the phase equivalent circuit

[0080] The module of voltage V is obtained by adding the squares of the two components in quadrature:

$$V_{RMS} = \sqrt{(V_\alpha^{\ 2} + V_\beta^{\ 2})}$$

2 - Calculation of the electric angle φ of voltage V and stator pulsation WEL_φ

[0081] The electric rotational angle φ of the stator voltage, developing with time is calculated by the formula:

$$\mathrm{FI} = \mathrm{arcocos}\ (V\alpha\ /\ V_{RMS})$$

[0082] Then the following values are calculated:

$$\mathrm{SIN}\ \varphi = \sin(\mathrm{FI})$$

$$\mathrm{COSFI} = \cos(\mathrm{FI})$$

[0083] The stator pulsation is calculated as derivative of the rotational angle FI:

$$\mathrm{WEL\_}\varphi = d\ \mathrm{Fi}\ /\ dt$$

3 - Calculation of the active and reactive motor power

[0084] In the phase equivalent circuit with voltage V = Vx + jVy and current I = Ix + jly, one has:

$$P_{ATT} = \text{active power} = Vx \times Ix + Vy \times Iy$$

$$P_{REA} = \text{reactive power} = Vy \times Ix - Vx \times Iy$$

[0085] Given the preceding relations between the components X, Y and the measured components:

$$P_{ATT} = V_{\alpha} \times I_A - V_{\alpha} \times I_B$$

$$P_{REA} = - (V_{\alpha} \times I_A + V_{\beta} \times I_B)$$

[0086] They correspond to the orthogonal components of the non-rotary vector of the apparent power:

$$A = P_{ATT} + j\ P_{REA}$$

4 - Calculation of the active and reactive components of the current

[0087] IA and IB are alternate quantities that may be represented with two vectors orthogonal to each other, rotating with a speed proportional to the pulsation WEL_φ making one revolution in one period. From these two alternate quantities two continuous quantities may be obtained, that is the active component $I_{\_ATT}$ of the current (in phase with the feeding voltage V) and the reactive component $I_{\_REA}$ (in quadrature with voltage V).

[0088] This is obtained with a demodulation of IA and IB synchronous with the rotational angle FI of the voltage, according to the relations:

- Active current: $I_{\_ATT} = SIN_{\varphi} \times I_A - cos_{\varphi} \times I_B$
- Reactive current: $I_{\_PEA} = - COS_{\varphi} \times I_A - SIN_{\varphi} \times I_B$

[0089] The two values represent the module of two vectors orthogonal to each other, non-rotating, whose vectorial sum is the vector I of the stator current.

[0090] As reference for the direction of the vectors, it is assumed that the stator voltage vector V is oriented along the axis Y, that is in the form: $V = j\ V_{RMS}$

[0091] Consequently, the non-rotating current vector takes the form:

$$I = I_{\_REA} + j\ I_{\_ATT}$$

5 - Calculation of the stator voltage drops

[0092] The phase equivalent circuit provides for a resistance RS and an inductance LS series connected.

[0093] The values of RS and LS are programmed at start, kept in a board permanent memory, and then suitably normalized and limited to avoid use of excessive values.

[0094] From the value of inductance LS the value of the inductive impedance XLS is calculated by the relation: XLS = LS x WEL_φ namely inductance times stator pulsation

[0095] The stator impedance ZS takes therefore the form: ZS = RS + j XLS

[0096] In the reference system chosen for the non-rotating vectors, the voltage drop DV due to the stator impedance takes the value: DV = DVx + J DVy,
where:

$$DVx = I_{\_REA} \times RS - I_{\_ATT} \times XLS$$

$$DVy = I_{\_ATT} \times RS + I_{\_REA} \times XLS$$

[0097] The "useful" voltage VF, obtained from V subtracting the voltage drop DV, then becomes:

$$VF = V - DV = - DVx + j\ (VRMS - DVy)$$

[0098] Indeed the system calculates these quantities:

$$XX = -DVx \qquad \text{VF component along axis X}$$

$$YY = -DVy$$

$$Y = (VRMS + YY) \qquad \text{VF component along axis Y}$$

$$VF = \sqrt{(XX^2 + y^2)} \qquad \text{VF module}$$

[0099] The "useful" voltage vector VF results therefore phase displaced for an angle DE relative to the feeding voltage vector V. The angle DE is calculated as follows:

$$COSDELAY = Sen(DE) = XX / VF$$

$$DE = Arcosen(COSDELAY)$$

[0100] (The calculation uses the function Arcocos(DE) and the sum of a fixed phase displacement).
[0101] From this SINDE = sen(DE) and COSDE = cos(DE) are calculated.

6 - Calculation of "torque" and "magnetization" currents

[0102] The stator current I, up to now divided into the active component in phase with the feeding voltage ($I_{\_ATT}$ on the axis of vector V), and reactive component in quadrature ($I_{\_REA}$ orthogonal to V) may be divided in a similar way into two components in phase and quadrature with the "useful" voltage represented by the vector VF:

a) The component Ig, in phase with VF, represented by a vector Iq parallel to VF.
Being in phase with VF, the component Iq supports the active power due to two effects:

- The losses in iron, having as a model the resistance R_{iron} fed by voltage VF and therefore crossed by current: $Iqo = VF / R_{iron}$
- The "useful" power transformed into mechanical power at the motor axis, therefore supported by the "torque" current: $I_{torque} = Iq - VF / R_{iron}$.

b) The component Id, in quadrature with VF, supporting the useful flux of the magnetic field at the magnetic gap (FLUX). It has as a model an inductance and produces the flux FLUX = VF / WEL_φ.

[0103] The components Iq and Id are calculated starting from the components $I_{\_ATT}$ and $I_{\_REA}$ and the phase angle DE between VF and V.
[0104] The calculation is effected as follows:

$$IQ = I_{\_ATT} \times COSDE + I_{\_REA} \times SINDE \qquad \text{Component Iq}$$

$$ID = I_{\_REA} \times COSDE + I_{\_ATT} \times SINDE \qquad \text{Component Id}$$

$$ACCU = IQ - VF / R_{iron}$$

Component I_{torque}

[0105] (Actually, the last relation uses the value of the programmed parameter GMU = 1 / R_{iron}).

7 - Estimation of flux at the magnetic gap

[0106] The useful flux at the magnetic gap FLUX is bound to voltage VF and pulsation WEL_φ, according to the simplified relation:

$$VF = FLUX \times WEL\_\varphi, \text{ da cui: } FLUX = VF / WEL\_\varphi.$$

[0107] In view of the proportionality between the mechanical torque C and the motor slip S = (We - Wm) / We, where We is the electric pulsation WE_φ and Wm is the mechanical pulsation of the rotor, the following relations on the active powers exchanged at the rotor are obtained:

$$P_{rotor} = P_{mechanical} + P_{rotor\ copper}.$$

[0108] In the asynchronous motor these powers and pulsations are bound by the relations: P_{rotor} = VF × ACCU Product by rotor current ACCU and phase voltage VF Protor / We = $P_{mechanical}$ / Wm = C Expressions of the motor mechanical torque.

$$(VF / WEL\_\varphi) \times ACCU = C$$

[0109] The ratio (VF / WEL_φ) represents the useful flux at the magnetic gap FLUX which is therefore given by:

$$FLUX = VF / WEL\_\varphi.$$

[0110] Indeed, the calculation of the useful FLUX is carried out with an algorithm allowing to take into account the time constance regulating the quick flux variations and to limit the flux calculated value within the range of reasonably possible values:

a) For values of the pulsation WEL_φ lower than a fixed threshold (frequency in the order of 5-10 Hz, speed much lower than the rated one), the flux calculated value is limited so as not to go below 80% its rated value nor to exceed 150%.

At very low speed, the calculations made with very reduced voltage values may cause an underestimation of the flux and therefore of the torque. Since at such speed and pulsation, in almost all the applications, the flux is kept close to the rated value, the minimum value of 80% is reasonable and reduces the risk to calculate a torque value considerably lower than the actual one.

b) For higher values of pulsation WEL_φ, the upper limit is maintained at 150%, while the lower limit is reduced to 25% of the flux rated value, because frequently at high speed the motor is de-fluxed to avoid an excessive increase of voltage.

8 - Calculation of the motor torque

[0111] According to the relations above indicated, the mechanical torque delivered by the motor (TORQUE) is calculated on the basis of the product between flux at the magnetic gap (FLUX) and the "torque" component I_{torque} (ACCU) of the current:

$$TORQUE = FLUX \times ACCU$$

[0112] This torque value is then normalized and expressed with the value C%, as a percentage of the motor rated torque C_{nom}, that the system calculates starting from the programmed motor plate parameters: rated mechanical power and rated speed.

$$C\% = 100 \times TORQUE / Cnom$$

[0113] Such a value is indicated with reference 5 in Fig. 1 which is the signal coming out from the torque detection device 4 to enter the comparator device 6.
[0114] The signal relating to the torque value 5 is also sent to other devices not shown in Fig. 1, such as display and control devices.
[0115] The torque signal 3 coming from actuator 2 and the torque signal 5 coming out from torque detection device 4 are inputted into the comparator device 6 just comparing the two signals to detect which is their deviation.
[0116] If the deviation of the values of the torque signals 3, 5 exceeds a predetermined limit, the comparator device emits a signal 60 reaching the alarm- signalling device 61 which in turn emits a signal 610 reaching and blocking actuator 2.
[0117] The torque detection device 4 is also provided with means monitoring their maximum driving or breaking steady-state torque and the maximum torque gradient.
[0118] As to monitoring the maximum driving or breaking steady-state torque, the board emits the alarm, taking from +24 V to 0 V the voltage of the output terminal 17 dedicated to this function, if the instantaneous value of the (driving or breaking) torque exceeds a programmed threshold value kept in a board permanent memory.
[0119] On the contrary, as to monitoring the maximum torque gradient, the board emits another alarm signal when the torque undergoes a too intense and rapid variation. More particularly, in the case of the embodiment, the alarm is emitted through the signal 18 when the difference between the torque instant value and the value recorded one second before exceeds a threshold value inputted by a dedicated parameter.
[0120] The alarm is stored and remains active up to a manual reset command, transmitted to a board ON/OFF input.
[0121] The monitoring operations of maximum torque and maximum gradient undergo the automatic testing procedure at start. When the test command is received at start on the corresponding ON/OFF input 21, the board replaces the measured torque value with a fixed value, programmed through a stored parameter. The width of such a value and the rapid torque variation cause the monitoring intervention and emission of alarms, that will be checked by external circuits.
[0122] The torque monitoring procedure may undergo a manual test; in this case the operator may select at will a torque value through the man - machine interface connected to the board through the input 16 and check the behaviour of the monitoring routines of the board at the selected torque value.
[0123] According to the described embodiment, the invention provides also for monitoring the maximum speed which is actuated through collection of signals 11 coming from an encoder 7 coupled to the motor 1.
[0124] If the speed value detected by the encoder exceeds a programmed threshold value, the board 4 emits a signal 19 which is received by the alarm-signalling device 61 causing the motor-locking-effect by blocking the actuator 2.
[0125] The used encoder is of the incremental and bi-directional type.
[0126] The torque detection and controlling device comprises also display and data input means, indicated by numeral 15, comprising for instance a computer connected to the torque detection device 4 through a serial bi-directional communication line 16, for example of the type RS485.
[0127] The device 4 is also provided with an output 12 emitting a signal proportional to the motor speed and connected to a speed analogue indicator 14.
[0128] An analogue indicator of the calculated torque indicated with numeral 13 is also provided.

Claims

1. A method of detecting and controlling the torque of a three-phase motor **characterized by** comprising the following steps:

    - effecting a first detection of the torque value delivered by said motor at the actuation unit (2) of said motor, or externally thereto;
    - effecting a second detection (5) of the torque value delivered by said motor, downstream said actuation and upstream the motor terminals, through processing means using as input signals the voltage signals of each phase and the current signals of at least two of said phases;
    - comparing said torque value with predetermined torque thresholds;
    - commanding interruption of electric power to said motor when said torque values exceed said threshold limits.

2. The detection and control method according to claim 1), **characterized by** comprising also a step of detecting the speed of said motor.

3. The detection and control method according to claim 1), **characterized in that** the torque value in said second detection step is obtained through an algorithm providing for the mathematical processing of the numerical voltage and current values using a simplified model of said motor.

4. The method according to claim 3), **characterized in that** said simplified model provides for using constants consisting of approximated values of resistance and inductance of the phase circuit of the stator of said motor and of the approximate resistance associated to the ohmic losses in the magnetic gap of said motor.

5. A device for the second control of the torque of a three-phase motor (1) fed by an alternate voltage with variable frequency comprising an actuation unit (2) of said motor electrically connected to a power supply line (L) and provided with at least an output signal (3) of a value proportional to the torque delivered by said motor, **characterized by** comprising also

   - a torque detection device (4) electrically connected to the line between said actuation unit and said motor, provided with signal processing means (10) and an output (5) to transmit the torque value detected through said processing means;
   - a monitoring central unit (6) electrically connected to said outputs and interfaced with said actuation to command each stop according to the torque signal values coming from said outputs.

6. The torque control device according to claim 5), **characterized by** comprising speed detecting means (7) associated to said motor.

7. The torque control device according to claim 6), **characterized in that** said speed detecting means comprise an incremental bi-directional encoder (7).

8. A torque detection device (4) for a three-phase motor using a control device according to any of claims 5) to 7), **characterized by** comprising:

   - first inputs (8) detecting the voltage and associated to each phase of said motor operatively connected downstream said actuation and upstream said motor;
   - second inputs (9) detecting the current and associated to at least two of said phases operatively connected downstream said actuation and upstream said motor;
   - processing means (10) of the signals coming from said first and second inputs to calculate the torque delivered by said motor;
   - at least an output (5) to said central monitoring unit (6) to emit said calculated torque signal.

9. The torque detection device (6) according to claim 8), **characterized in that** said signal processing means (10) comprise a digital signal processor (DSP).

10. The torque detection device (6) according to claim 8), **characterized by** comprising third inputs (11) detecting the speed of said motor.

11. The detection device according to claim 8), **characterized by** comprising an output (12) providing a signal proportional to the instant value of the speed of said motor.

12. The torque detection device (6) according to claim 8), **characterized by** comprising analogue indicators (13) of said calculated torque.

13. The torque detection device according to claim 10), **characterized by** comprising speed analogue indicators (14).

14. The torque detection device according to claim 8), **characterized by** comprising data display and input means (15) by the operator.

15. The torque detection device according to claim 14), **characterized in that** said data display and input means (15) are connected to said processing means through a serial bi-directional communication line (16).

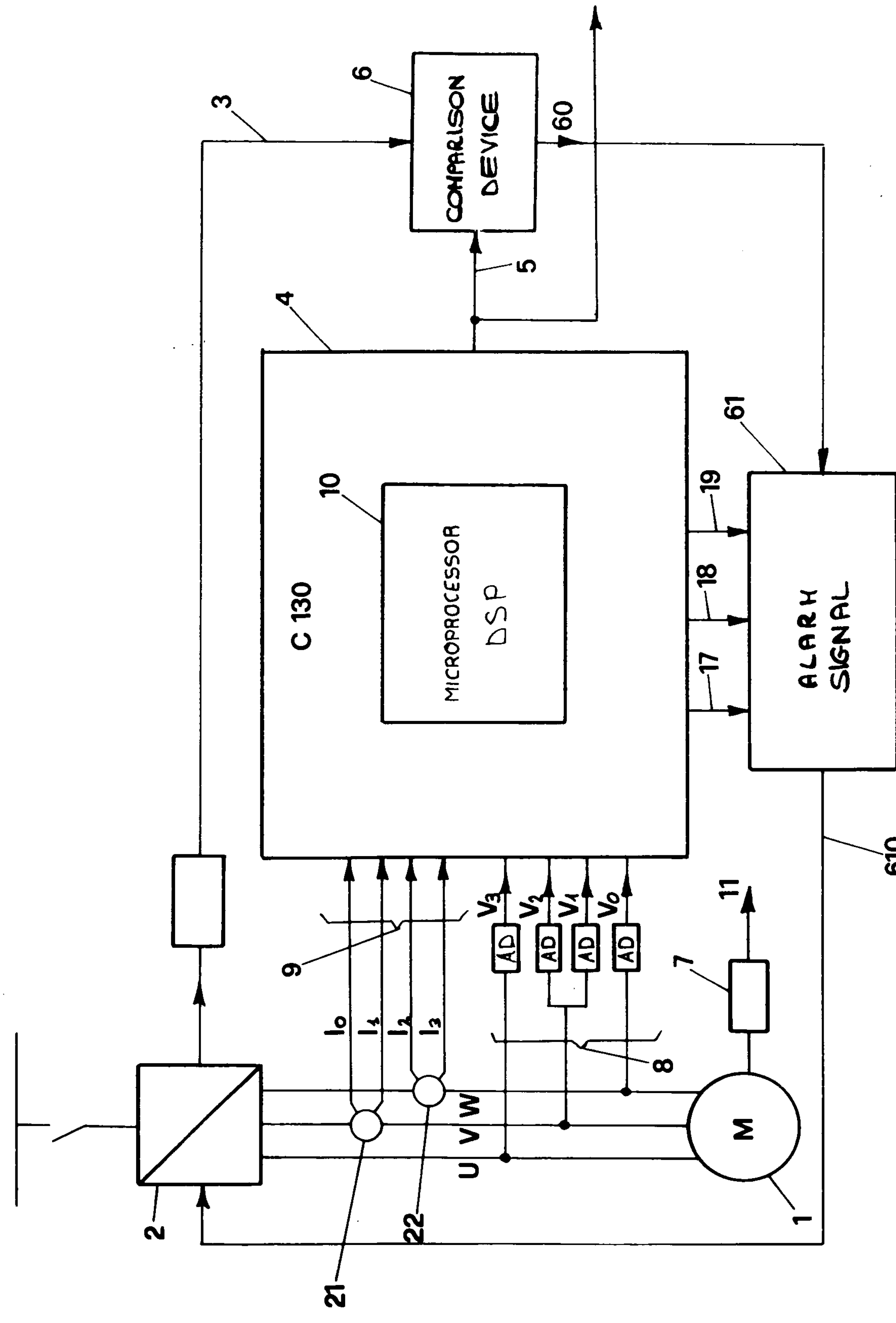
16. The torque detection device according to claim 15), **characterized in that** said serial bi-directional communication line is of the type RS485.

17. The torque detection device according to claim 8), **characterized by** comprising outputs (17) signalling the maximum torque delivered by said motor.

18. The torque detection device according to claim 8), **characterized by** comprising an output signalling the maximum torque gradient (18) delivered by said motor.

19. The torque detection device according to claim 8), **characterized by** comprising an output (19) signalling the maximum rotational speed of said motor.

20. The torque detection device according to claim 8), **characterized by** comprising auxiliary self-diagnosis inputs with manual (20) and/or automatic (21) command to control the operation of said detection device.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DSP
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FIG.1

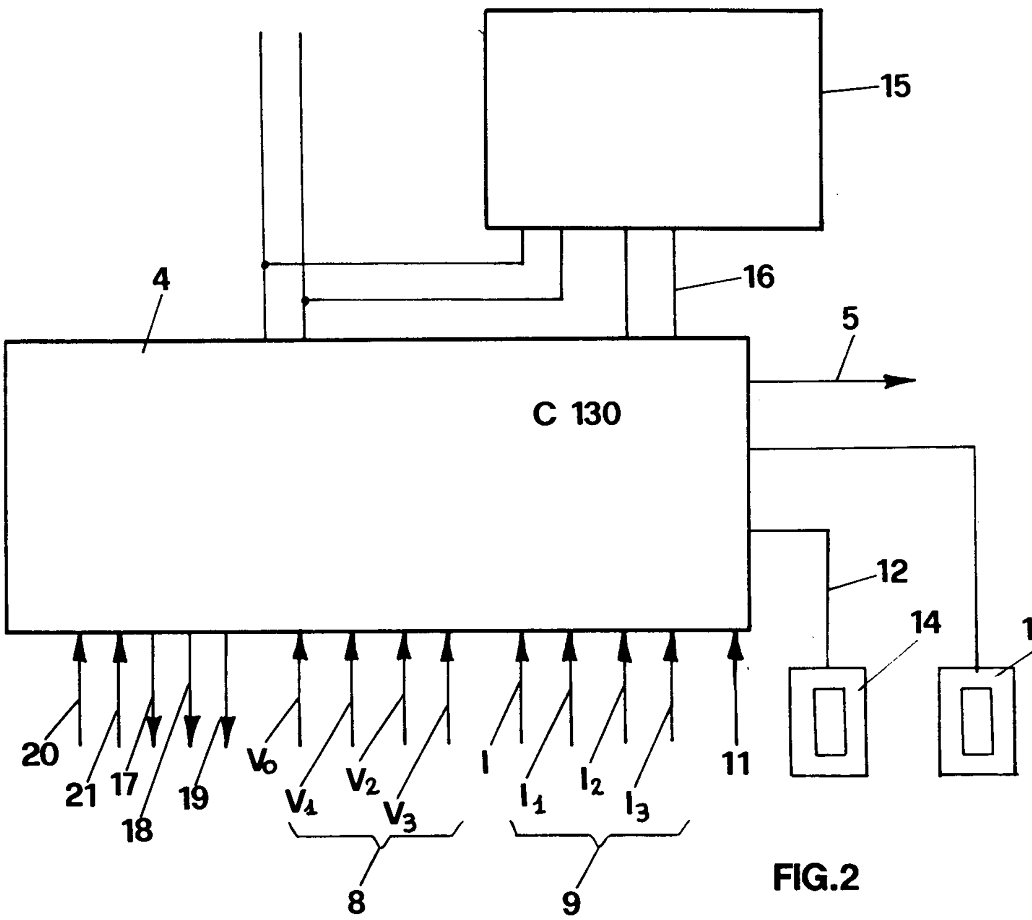
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FIG.2

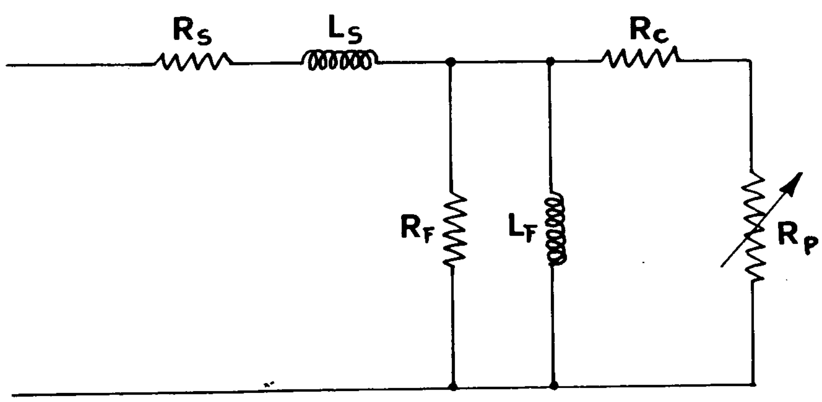
R_S
L_S
R_C
R_F
L_F
R_P

FIG.3

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EUROPEAN SEARCH REPORT

Application Number
EP 03 02 1611

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B61B
H02P
B66B
B66D
G01L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	16 December 2003	Chlosta, P

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