A motor drive circuit comprises positive and negative input terminals (1, 2) for connection of the motor circuit to a DC supply, a DC link filter (3) connected between the input terminals (1, 2); an electric motor having at least two phases, a plurality of motor drive sub-circuits, each connected to a respective phase of the electric motor and which each control the flow of current into or out of the respective phase of the motor that has been drawn from the supply though the DC link filter (3), and a switching means (7) provided in the electrical path between the DC link filter and the electric motor drive sub-circuits, the switching means (7) being movable between a closed position in which it connects the DC link filter to the motor drive sub-circuits, and an open position which isolates the DC link filter from the motor drive sub-circuits.
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MOTOR DRIVE CIRCUIT

This invention relates to a motor drive circuit which is especially, but not exclusively, suited to use in an electrical power-assisted steering (EPAS) system for a vehicle.

EPAS systems are known of the kind comprising an electric motor connected through a gearbox to act on a steering mechanism of the vehicle. For example, the gearbox may provide a connection between the motor and a steering column shaft, or directly onto a portion of a rack and pinion mechanism forming part of the steering mechanism.

The electric motor is used to assist a driver in applying torque to the steering mechanism, by applying an assistance torque of the same sense, to make it easier to turn the steering wheel, for example during parking manoeuvres. Thus, operation of the motor may assist in rotating the steering column shaft, or moving a portion of the steering rack mechanism. Of course, the motor may be connected to any part of any typical steering mechanism as long as it can provide an assistance torque to aid the driver in turning the steering wheel.

The motor, which may be a multi-phase brushless star-connected permanent magnet motor, is controlled by motor control means comprising control and drive circuits, which is operative to supply a current from a power supply to the motor phase windings. The phase windings of the motor are connected at a star point. Each phase is connected to a common supply rail which connects in turn to a positive terminal of the power supply by a top transistor, and to a negative supply rail which connects to a negative terminal by a bottom transistor, the two transistors defining an arm of a multiple arm bridge. This bridge forms
the drive circuits, while the control circuits are provided by a microprocessor or digital signal processor or analogue signal processing or some combination thereof. The microprocessor is operative in response to signals from a torque sensor provided on the steering column to measure the torque applied by the driver, from a motor rotor position sensor providing information about motor speed and direction and optionally from signals corresponding to current flowing in the motor bridge or power supply. This information can be used in combination with the torque sensor signal and/or column position sensor signal to determine which phase winding should be energised and when. The microprocessor produces control signals which are used by a bridge driver to energise the transistors of the drive circuits to cause current to flow in a desired motor phase.

To prevent noise from the motor being passed to the DC supply terminals, a DC link filter is provided between the terminals and the motor phases. The purpose of this filter is to smooth out or filter out any high frequency noise that may be produced. It typically comprises a capacitor connected between the supply rails, and may also include one or more inductors connected in series in each rail between the terminals and the motor phases.

A problem with this electrical power-assisted steering system is that a fault occurring in the motor drive or control circuits can cause an error condition which is unacceptable in a vehicle steering system, where safety is critical.

For example, suppose that a top transistor in one arm of the bridge is energised in error while a bottom transistor in another arm of the bridge is also energised in error. This fault would result in a phase of the motor
becoming permanently energised and cause the motor to become permanently attracted to a particular position, tending to clamp the steering column in position and resist rotation. This would be readily apparent to the driver, and is clearly undesirable. This situation could occur if the bridge driver is at fault, or if a short circuit occurs across the drive stage transistors, or if a short circuit occurs across the DC link supply.

One known solution to this problem is to provide a clutch between the motor and the steering column. The clutch, typically a dog or friction clutch, is normally engaged but in the event of a fault being detected, the clutch is operated to disengage the motor from the steering column. However, the clutch is costly and bulky, and additional test procedures must also be incorporated to check that the clutch can still be disengaged should it be necessary to do so, which again adds to the cost and is time-consuming.

Another solution is to provide a means for isolating the motor drive stage from the motor in the event of a failure, for example by providing a relay between the drive stage transistors and the phase connections to the motor. Yet a further solution is to use a relay to isolate the motor phases from the star point of the motor. Both of these solutions remove the drive current from the motor but are not without their problems and inherent disadvantages. Over time the contact resistance of a relay may deteriorate, perhaps reducing their operational speed, and they are also costly as well as bulky items to add to a motor.

Without any means to isolate the motor from the drive stage the phase windings are still connected together and also still connected to the drive stage. As a result of this an electrically conducting path could still be
present around the bridge (i.e. through two short circuited transistors and two phase windings). Then, on rotation of the motor shaft drive due to rotation of the steering column, a back EMF is produced in one or more of the windings. As a result of this EMF and the complete electrical path around the bridge, a substantial current can flow through the motor phase windings which produces a torque in the opposite sense to the rotation of the motor shaft. This resisting torque is highly undesirable because in this case, not only is steering assistance lost due to disconnection of the power supply, but a resisting torque is then applied which makes turning the steering column difficult.

Another problem encountered in such a system is a short circuit to earth across the DC link filter. This is especially problematic where the capacitor is an electro-lytic component as a short can cause a catastrophic failure to occur.

Any device placed in the motor current path needs to be capable of carrying the motor current, breaking the high current inductive loads that may be present, and maintaining a low contact resistance.

These problems are, of course, not unique to applications in electric power steering systems.

In accordance with the present invention, we provide a motor circuit comprising:
positive and negative input terminals for connection of the motor circuit to a DC supply,
a DC link filter connected between the input terminals;
an electric motor having at least two phases,
a plurality of motor drive sub-circuits, each connected to a respective phase of the electric motor and which each control the flow of current into
or out of the respective phase of the motor that has been drawn from the
supply through the DC link filter,
and a switching means provided in the electrical path between the DC link
filter and the electric motor drive sub-circuits, the switching means being
movable between a closed position in which it connects the DC link filter
to the motor drive sub-circuits, and an open position which isolates the
DC link filter from the motor drive sub-circuits.

This motor circuit ensures that any short circuits of the motor phases to
ground or one of the supply voltages will not cause a short across the DC
link filter, and so prevent a catastrophic failure of the DC link filter. In
addition, it removes one of the possible short circuit paths that may cause
the motor to enter a braking mode of operation, which could present a
safety hazard.

The motor may comprise a high reliability motor. By this we mean that
the motor, including its phases windings and any associated connections,
has a very low probability of failure in a mode which may cause motor
braking.

Thus, the switching means together with the high reliability motor
ensures, if a fault condition arises, that the motor does not provide a
resisting torque to the movement of the steering column the switch means
will isolate the motor from the DC supply so that no current flows in the
phase winding. This means that no clutch is required.

The switching means may include means for operating the switch within a
predetermined period of time from detecting a fault. A separate fault
detection means may be provided which sends signals to the switching
means when a fault is detected. The predetermined period may correspond
to instantaneous operation, or within a time set by regulations. For example, the switching means may operate within 200 milliseconds or perhaps less. Such fault detection means are well known in the art of fault protection.

Preferably, the switching means comprises a switch or relay which is connected in series between an output of the DC link filter and the inputs to the motor drive sub-circuits. Alternatively, the switching means may comprise a semi-conductor device, such as a transistor.

One of the input terminals may be grounded, with the DC link filter connecting the other terminal to this ground. In that case, the switch means may be located in the electrical path between the side of the DC link filter connected to the non-grounded terminal and the motor drive sub-circuits.

An additional switching means may be provided between at least one of the DC supply terminals and the DC link filter. In an application in which one of the input terminals is connected to ground, the switch may be between the other terminal and the input to the DC filter. In an automotive application, this is typically the negative terminal.

When this switch is opened along with the other switch means the DC link filter will be completely isolated from both sources of power, i.e. the DC supply and the motor. This also prevents the possibility of reverse polarisation of the capacitors in the DC link during reverse battery conditions.

The invention is applicable to a wide range of motor types and sizes. In a preferred embodiment, the electric motor comprises a 3-phase motor
which has its phases connected in a star formation. It may alternatively be
connected in a Wye (or delta) formation.

The motor drive sub-circuits may each comprise a switch which can be
opened and closed to electrically connect the motor phase to one of the
input terminals through the DC link filter. Each phase of the motor may be
connected to two such sub-circuits, each one connected to a different
one of the input terminals. The motor drive sub-circuits may be arranged
in such a manner that they cannot fail in such a way that they short each
other out, i.e. by providing an independent circuit for each phase.

The motor may form part of an electric power assisted steering system in
which its function is to apply an assistance torque to a steering column or
other steering component to assist a driver of a vehicle in turning the
wheel.

There will now be described a preferred embodiment illustrating the
various aspects of the invention, with the aid of the following drawings,
in which:-

Figure 1 is a detailed schematic of an electric motor and a drive circuit in
accordance with a first embodiment of the present invention; and

Figure 2 shows a motor and an alternative embodiment of a drive circuit
to which the present invention is applicable.

Figure 1 illustrates a part of an electrical power-assisted steering (EPAS)
��统 for use in a vehicle which incorporates an electric motor. The
drive circuit comprises a pair of input terminals 1,2 for connection to the
positive and negative supply rails of the vehicle. A DC link filter 3 is connected between the two terminals 1,2. It comprises two capacitors U1 and U2 connected in parallel between the two input terminals, with an inductor connected in series with one of the capacitors U2. An output of the DC link filter 3, taken from between the inductor L1 and capacitor U2 is fed to a rail 4 which carries current to several motor drive sub-circuits. The sub-circuits are connected as a three phase bridge, with each phase of the bridge comprising a motor drive sub-circuit having a transistor M1-M6 connected to one of the rail 4 or to ground 5. A top transistor M1 is connected between the first end of a respective phase winding (R,Y,B) and the positive supply rail 4, and a bottom transistor M2 is connected between the first end of the respective phase winding and the negative supply rail 5. Each of the transistors is shown as a single power transistor, which may be of the FET or bi-polar type. The transistors are energised or de-energised by an electronic drive circuit 6.

In the electrical circuit between the DC link filter and the rail 4 supplying the motor drive sub-circuits is a switch means 7. This comprises a semiconductor switch in the form of a transistor M9 with an intrinsic diode D3 connected across its source and drain terminals. During normal operation the power dissipation of the device can be reduced by enhancing the device channel to avoid the voltage drop that would otherwise result from the current passing through the intrinsic diode D3.

In the event that a DC link short circuit fault is detected which would lead to incorrect operation of the electric motor, the switch means 7 is opened so that rail 4 is not shorted to rail 5. The bridge rectification of the transistors M1-M6 and the intrinsic diode D3 ensures that the motor current cannot flow from rail 4 to rail 5.
An alternative arrangement is shown in Figure 2 of the accompanying drawings. This is identical to that shown in Figure 1 apart from the addition of a further semi-conductor switch means 8 in the electrical path from the input terminal to the DC link. Switch 8 comprises two transistors M7 and M8 and respective intrinsic diodes D1 and D2. Switch 8 works in tandem with switch 7 such that they both open and close at the same time. They are normally both closed but in the event of a failure they are both opened to give complete isolation of the DC link filter.
1. A motor circuit comprising:
   positive and negative input terminals for connection of the motor circuit to a DC supply,
   a DC link filter connected between the input terminals;
   an electric motor having at least two phases,
   a plurality of motor drive sub-circuits, each connected to a respective phase of the electric motor and which each control the flow of current into or out of the respective phase of the motor that has been drawn from the supply through the DC link filter,
   and a switching means provided in the electrical path between the DC link filter and the electric motor drive sub-circuits, the switching means being movable between a closed position in which it connects the DC link filter to the motor drive sub-circuits, and an open position which isolates the DC link filter from the motor drive sub-circuits.

2. A motor circuit according to claim 1 in which the motor comprises a high reliability motor.

3. A motor circuit according to any preceding claim in which the switching means comprises a switch or relay which is connected in series between an output of the DC link filter and the inputs to the motor drive sub-circuits.

4. A motor circuit according to claim 1 or 2 in which the switching means comprises a semi-conductor device, such as a transistor.

5. A motor circuit according to any preceding claim in which one of the input terminals is grounded, with the DC link filter connecting the
other terminal to this ground, and in which the switch means is located in the electrical path between the side of the DC link filter connected to the non-grounded terminal and the motor drive sub-circuits.

6. A motor circuit according to any preceding claim in which an additional switching means is provided between at least one of the DC supply terminals and the DC link filter.

7. A motor circuit according to claim 6 when dependent on claim 5 in which the further switch means is provided between the non-grounded terminal and the input to the DC filter.

8. A motor circuit according to claim 7 in which the further switch means is opened and closed at the same time as the switch means.

9. An electric power assisted steering system which includes a motor circuit according to any preceding claim.
Fig. 1

SUBSTITUTE SHEET (RULE 26)
A. CLASSIFICATION OF SUBJECT MATTER

INV. H02H 7/122

According to International Patent Classification (IPC) or to both national classification and IPC:

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02H H02M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C

See patent family annex

Date of the actual completion of the International search: 19 December 2006

Date of mailing of the international search report: 28/12/2006

Name and mailing address of the ISA/Authorized officer:
European Patent Office, P B 5818 Patentlaan 2 NL - 2280 HV Rijswijk
Tel (+31-70) 340-2040, Tx 31 651 epo nl, Fax (+31-70) 340-3016

Segaert, Pascal
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