

PATENT SPECIFICATION

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(54) IMPROVEMENTS IN OR RELATING TO SYNCHRONOUS ELECTRIC MOTOR CONTROL ARRANGEMENTS

(71) We, KABUSHIKI KAISHA
DAINI SEIKOSHA, a Japanese company,
of 31-1, 6-chome, Kameido, Koto-ku,
Tokyo, Japan, do hereby declare the
invention for which we pray that a patent
may be granted to us, and the method by
which it is to be performed, to be
particularly described in and by the
following statement:

This invention relates to synchronous
electric motor control arrangements and
more specifically to control arrangements
for driving a synchronous electric motor by
A.C. of variable frequency derived from a
variable frequency A.C. source.

Conventional practice when driving a
synchronous electric motor from a variable
frequency A.C. source which provides a
variable frequency A.C. output the
frequency of which determines the speed of
the motor, is to supply the A.C. to the motor
at the same amplitude (voltage) at all
frequencies. A control arrangement of this
nature is in principle expected always to
drive the motor synchronously with the
frequency of the output from the A.C.
source regardless of deviations in motor
load and torque, and to change the motor
speed solely in response to changes in the
output frequency from said A.C. source.
However, such conventional driving
apparatus has the defect that it is liable to
produce excessive temperature rise in the
motor and even burning of the windings as a
result of power loss due to the ohmic
resistance component in the motor
windings, for the ohmic power loss in the
motor increases with current increase in the
windings and serious current increase can
be caused by decrease in the impedance of
the windings when the frequency of the
variable frequency A.C. supplied to the
motor is reduced to a low value in order to
run the motor slowly.

The relations of the speed v of a
synchronous motor to the current I through
its windings and to its power consumption P
are shown by the following equations:

$$I = E / (R + \omega L) \quad (1)$$

where L and R are, respectively, the motor
winding inductance and its ohmic
resistance, E is the power supply voltage, I is
the motor current, and $\omega = Kv$, K being a
constant. The power consumption P is given
by:

$$P = I^2 R + I^2 \omega L \quad (2)$$

As will be seen from these equations, as
the motor speed decreases the current I
becomes large and accordingly the power
loss $I^2 R$ relative to the total power
consumption increases.

This can cause excessive heat generation
and even burning of the motor windings.
Moreover frequent starting and stopping of
the motor may make the situation worse by
causing excessive storing of heat generated
in frequency periods of low speed running.
Because of these effects a synchronous
motor which may have to run at low speeds
and/or be frequently started and stopped
and/or to be subjected to large variations of
load and torque, has to be low rated to be
safe from over-heating and damage and this,
of course, involves the use of motors and
associated control apparatus of larger
capacities and therefore more expensive
than would be the case if these effects were
not present. The present invention seeks to
overcome or reduce the foregoing defects
and disadvantages.

According to this invention a
synchronous electric motor control
arrangement for driving a synchronous
electric motor at variable speed from a
source of AC voltage of variable frequency
includes a circuit providing an output of the
same frequency as that from said source but
of controllable voltage, means for applying
AC voltage from said source to the input of
said circuit, means for applying output
voltage from said circuit to said motor to
drive the same and automatic control means

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for controlling the output voltage supplied from said circuit to the motor so as to increase said voltage with increase in the frequency from the AC source and consequent increase in motor speed and to decrease said voltage with decrease in said frequency and speed.

Said automatic control means may include a speed/voltage converter driven by the motor, or they may include a frequency/voltage converter connected to receive the variable frequency from the AC source.

The variable frequency AC source may be connected to the synchronous motor through a power amplifier the output voltage of which is controlled by a control voltage from a source the voltage of which is in turn controlled by output voltage from the speed/voltage converter or the frequency/voltage converter as the case may be.

Preferably the control effected by the automatic control 'means' is such as to result in at least approximately constant motor torque over its working range of speed.

The invention is illustrated in and further explained in connection with the accompanying drawings, in which:

Figure 1 is a simplified block diagram of one embodiment of the invention;

Figure 2 is a simplified block diagram of another embodiment of the invention; and

Figure 3 is an explanatory graphical figure.

Like references denote like parts in Figures 1 and 2.

Referring to Figure 1, a variable-frequency oscillator 1 supplies its output to a power amplifier 2 the output from which drives a synchronous motor M. Block 3 represents a variable voltage power source the output voltage of which is varied in response to a control voltage supplied to a control terminal of said source 3. The output of source 3 is fed to power amplifier 2 and controls its output voltage. Block 4 is a speed/voltage converter which converts the speed of revolution of the motor M into a voltage dependent thereon and feeds this voltage as control voltage to the control terminal of the variable voltage power source 3. The power amplifier 2 supplies output A.C. power of the same frequency as the output from oscillator 1 to the synchronous motor M as the driving power thereof, but the voltage at which this power is supplied is varied in dependence on the frequency because of the speed-dependent control voltage supplied from the converter 4. Accordingly, the lower the speed of the synchronous motor M, the lower becomes the voltage of the driving electric power thereto, and in this way excessive increase

of motor current due to decrease in the impedance of the winding of the motor with consequent increased power loss which might otherwise cause excessive motor heating or possible damage to the motor winding is eliminated or reduced to a safe amount. Increase of motor speed above a lower range of speed produces an increase of the voltage of the electric power supplied to the motor and thus serves to reduce the decrease in motor torque which would otherwise be caused by decrease of motor current due to increase of the impedance of the motor winding. The result is that the synchronous motor is protected against the danger of excessive heating or burning of its winding at low speeds and accordingly, for given conditions of operation, a motor of lower capacity may be used than would be possible (with equal protection) with conventional practice. In other words the motor may be higher rated than would be otherwise acceptable. Further, the output voltage control of the power amplifier 2 is made by controlling the output voltage of the variable voltage power source 3 without causing any substantial power loss in the output circuit of said amplifier 2, so that heat generation in that circuit due to power loss can be made small and the load on the said amplifier 2 can be much decreased.

In the embodiment of Figure 2, the variable frequency source again feeds into the motor-driving power amplifier 2 and the output voltage of said amplifier is again controlled by the variable-voltage power source 3. However, in place of the speed/voltage converter 4 of Figure 1 there is a frequency/voltage converter 5 which converts the frequency of the output from the source 1 into a control voltage which is fed to the control terminal of the variable-voltage power source 3 and controls the voltage of its output to the power amplifier 2.

As will be seen the output voltage driving the motor M and supplied from the power amplifier 2, is again dependent on the speed of the motor because the said motor is a synchronous one. Accordingly, the embodiment of Figure 2 provides the same advantages as the embodiment of Figure 1 as regards protection of the motor against overheating and possible damage at lower speeds, maintenance of adequate torque at higher speeds, reduction of power loss in the output circuit of amplifier 2 and reduction of load on said amplifier, and ability safely to use a high-rated and therefore small and relatively cheap motor for given conditions. The embodiment of Figure 2 has the additional practical advantage that there is no motor speed detector and no need to include in the control system any device actually driven by the motor itself.

Figure 3 graphically represents the relation of the power consumption of the motor M and the power loss in the power amplifier 2 to the speed of motor M when the latter is operated at constant torque in an apparatus as shown in Figure 1 or in Figure 2.

5 In Figure 3 curve *a* is a curve of power consumption of motor M. The power consumption is reduced to a minimum value of P_{min} when the motor speed approaches zero and increases approximately linearly to a maximum value of P_{max} at a maximum speed V_{max} , while the motor torque is kept constant. The minimum power consumption P_{min} is nearly equal to the ohmic resistance loss I^2R caused by the flow of a current I through the internal ohmic resistance R of the motor winding. In an "ideal" motor, 10 P_{min} would be zero and in a practical case this loss would be acceptably small. Curve *b* represents power consumption in the power amplifier 2. When the motor M is running at its highest speed V_{max} with maximum power consumption P_{max} , the power consumption of the amplifier 2 is very small almost nothing but, as the speed of the motor M decreases, this power loss gradually increases to a maximum value of $P_{max} - P_{min}$ near zero motor speed. The reason for this is 15 that a constant torque from the synchronous motor M requires a constant motor current I and, if the voltage for the power amplifier were to be kept constant in order to keep a constant current I , the said power amplifier would be forced to consume the remaining large power when the motor consumes little power because it is running at low speed, and to consume little power when the motor is running at high speed and with high power consumption. Straight line *c* represents the power loss in the power amplifier 2. As the 20 source voltage for the power amplifier decreases along curve *a* in response to reducing speed of the synchronous motor M, the power amplifier 2 does not have to consume the whole power remaining when the motor is running at low power consumption and low speed but has only to consume a little power, which is almost equal to the ohmic loss I^2R .

25 The control device 4 or 5 of Figure 1 or 2 and the variable voltage source 3 for the power amplifier 2 of those Figures, may take any of a variety of forms known per se. However, a convenient construction for the embodiment of Figure 2 includes, for the source 3, a switching regulator regulating the voltage from a standard supply source 30 and, for the device 5, a frequency/voltage

converter controlling said switching regulator in dependence on the frequency (from source 1).

WHAT WE CLAIM IS:—

1. A synchronous electric motor control 65 arrangement for driving a synchronous electric motor at variable speed from a source of AC voltage of variable frequency, said arrangement including a circuit providing an output of the same frequency as that from said source but of controllable voltage, means for applying AC voltage from said source to the input of said circuit, means for applying output voltage from said circuit to said motor to drive the same, and 70 automatic control means for controlling the output voltage supplied from said circuit to the motor so as to increase said voltage with increase in the frequency from the AC source and consequent increase in motor speed and to decrease said voltage with decrease in said frequency and speed.
 2. An arrangement as claimed in claim 1 wherein the automatic control means include a speed/voltage converter driven by the motor. 75
 3. An arrangement as claimed in claim 1 wherein the automatic control means include a frequency/voltage converter connected to receive the variable frequency from the AC source. 80
 4. An arrangement as claimed in claim 2 or 3 wherein the variable frequency AC source is connected to the synchronous motor through a power amplifier the output voltage of which is controlled by a control voltage from a source the voltage of which is in turn controlled by output voltage from the speed/voltage converter or the frequency/voltage converter as the case may be. 85
 5. An arrangement as claimed in any of the preceding claims wherein the control effected by the automatic control means is such as to result in at least approximately 90 constant motor torque over its working range of speed.
 6. Synchronous motor control arrangements substantially as herein described with reference to the 95 accompanying drawings. 100
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Figure 3 graphically represents the relation of the power consumption of the motor M and the power loss in the power amplifier 2 to the speed of motor M when the latter is operated at constant torque in an apparatus as shown in Figure 1 or in Figure 2.

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The control device 4 or 5 of Figure 1 or 2 and the variable voltage source 3 for the power amplifier 2 of those Figures, may take any of a variety of forms known per se. However, a convenient construction for the embodiment of Figure 2 includes, for the source 3, a switching regulator regulating the voltage from a standard supply source and, for the device 5, a frequency/voltage

converter controlling said switching regulator in dependence on the frequency (from source 1).

WHAT WE CLAIM IS:—

1. A synchronous electric motor control arrangement for driving a synchronous electric motor at variable speed from a source of AC voltage of variable frequency, said arrangement including a circuit providing an output of the same frequency as that from said source but of controllable voltage, means for applying AC voltage from said source to the input of said circuit, means for applying output voltage from said circuit to said motor to drive the same, and automatic control means for controlling the output voltage supplied from said circuit to the motor so as to increase said voltage with increase in the frequency from the AC source and consequent increase in motor speed and to decrease said voltage with decrease in said frequency and speed.
2. An arrangement as claimed in claim 1 wherein the automatic control means include a speed/voltage converter driven by the motor.
3. An arrangement as claimed in claim 1 wherein the automatic control means include a frequency/voltage converter connected to receive the variable frequency from the AC source.
4. An arrangement as claimed in claim 2 or 3 wherein the variable frequency AC source is connected to the synchronous motor through a power amplifier the output voltage of which is controlled by a control voltage from a source the voltage of which is in turn controlled by output voltage from the speed/voltage converter or the frequency/voltage converter as the case may be.
5. An arrangement as claimed in any of the preceding claims wherein the control effected by the automatic control means is such as to result in at least approximately constant motor torque over its working range of speed.
6. Synchronous motor control arrangements substantially as herein described with reference to the accompanying drawings.

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