COMMONWEALTH OF AUSTRALIA

THE PATENTS ACT 1952-1969

CONVENTION APPLICATION FOR A PATENT

We, MITSUBISHI DENKI KABUSHIKI KAISHA
of 2-3, Marunouchi 2-chome, Chiyodaku, TOKYO, JAPAN.

hereby apply for the grant of a Patent for an invention
entitled: "CONTROL SYSTEM FOR CONTROLLING DYNAMIC BRAKING
OF ELECTRIC MOTOR VEHICLE"

which is described in the accompanying complete specification.
This application is a Convention application and is based on the
application(s) numbered: 2718/80

for a patent or similar protection made in JAPAN

on 14th January, 1980

My/Our address for service is care of GRIFFITH, HASSEL & FRAZER,
Patent Attorneys, of 323 Castlereagh Street, Sydney 2000, in the
State of New South Wales, Commonwealth of Australia.

DATED this 13th day of January, 1981

MITSUBISHI DENKI KABUSHIKI KAISHA
By their Patent Attorneys:

of GRIFFITH, HASSEL & FRAZER
Fellows, Institute of Patent Attorneys of Australia

TO: THE COMMISSIONER OF PATENTS
INSTRUCTIONS

(a) Insert No. if available
(b) Insert full name(s) of applicant(s)
(c) Insert title of invention
(d) Insert full name(s) of declarant(s) who must be PERSON or PERSONS, NOT a corporate body. (see head note).
(e) Insert address(es) of declarant(s).

Delete entirely if applicant is corporation body.
Delete entirely if applicant is person or persons.

In support of the application No. (a) made by (b), MITSUBISHI DENKI KABUSHIKI KAISHA

for a patent on an invention entitled (c).
"CONTROL SYSTEM FOR CONTROLLING DYNAMIC BRAKING OF ELECTRIC MOTOR VEHICLE"

1. (d) Takeshi Kitsuregawa
of (c) 2-3, Marunouchi 2-chome, Chiyodaku, TOKYO, JAPAN.

do solemnly and sincerely declare as follows:

1. (g) I am authorised by the abovementioned applicant for the patent/patent of addition to make this declaration on its behalf.

2. The basic application(s) as defined by Section 141 of the Act was/were made in the following country or countries on the following date(s) by the following applicant(s) namely:—

in (i) JAPAN on (j) 14th January, 1980 by (k) MITSUBISHI DENKI KABUSHIKI KAISHA

in (i) on (j) 19 by (k) MITSUBISHI DENKI KABUSHIKI KAISHA

in (i) on (j) 19 by (k) MITSUBISHI DENKI KABUSHIKI KAISHA

3. (m) Shinzo Hirao and Junichiro Kaneda
of (n) MITSUBISHI DENKI KABUSHIKI KAISHA, 80, Aza Nakano, Minami Shimizu, City of

Amagasaki, Hyogo Prefecture, JAPAN.

I declare the actual inventor(s) of the invention and the facts upon which the applicant(s) is/are entitled to make the application are as follows:—

—as regards entitlement under Section 34 of the Act:—(o).

The applicant is the assignee of the said invention from the said inventors.

—as regards entitlement under Part XVI of the Act:—(q).

4. The basic application(s) referred to in paragraph 2 of this Declaration was/were the first application(s) made in a Convention country in respect of the invention the subject of the application.

Declared at Tokyo, JAPAN this 25th day of December 1980
MITSUBISHI DENKI KABUSHIKI KAISHA

(r) By Takeshi Kitsuregawa

Takeshi KITSUREGAWA,
Managing Director

GRIFFITH, HASSEL & FRAZER Box 2133, G.P.O. SYDNEY 2001 AUSTRALIA
1. A control system for controlling the separately excited dynamic braking of an electric motor vehicle comprising an electric traction motor including an armature and a field winding, a dynamic braking resistor connected across the armature to form a closed loop dynamic braking circuit, first current adjusting means for holding a field current supplied to the field winding at predetermined constant magnitudes stepwise in accordance with speed ranges of an electric motor vehicle, a parallel combination of a resistor and second current adjusting means, and switching means responsive to the field current required for the electric traction motor to induce thereacross a voltage enough to maintain a constant magnitude of a dynamic braking current flowing through the closed loop dynamic braking circuit and less in magnitude than an output current from the first current adjusting means to be closed to connect the parallel combination of the resistor and second current adjusting means across the field winding thereby to cause the second current adjusting
means to control continuously the field current for the
application of the separately excited dynamic braking to
the electric motor vehicle.
COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952-69

COMPLETE SPECIFICATION

(ORIGINAL)

FOR OFFICE USE:

Application Number:
Lodged:

Class

Int. Class

66192/81

Complete Specification Lodged:
Accepted:
Published:

Priority:

Related Art:

TO BE COMPLETED BY APPLICANT

Name of Applicant: MITSUBISHI DENKI KABUSHIKI KAISHA

2-3, Marunouchi 2-chome, Chiyodaku,
Address of Applicant: TOKYO, JAPAN.

Actual Inventor: Shinzo Hirao and
Junichiro Kaneda.

Address for Service: Griffith, Hassel & Frazer,
323 Castlereagh St.,
SYDNEY N.S.W. 2000 AUSTRALIA

Complete Specification for the invention entitled: "CONTROL SYSTEM FOR CONTROLLING DYNAMIC BRAKING OF ELECTRIC MOTOR VEHICLE"

The following statement is a full description of this invention with the best method of performing it known to me/us:-

- 1 -
This invention relates to improvements in a control system for controlling the dynamic braking of an electric motor vehicle.

Conventional control systems for controlling the separately excited dynamic braking of the electric motor vehicle have comprised the DC traction motor including an armature connected across a dynamic braking resistor and a field, and the motor-generator externally driven to deliver a three-phase AC to the thyristor exciter. The thyristor exciter has been controlled in current phase to excite separately and control the field of the traction motor. The exciter has had an output capacity greater than a resistance loss due to the field of the traction motor.

Also as, the traction motor, a DC series motor has been, in many case, employed under consideration of the acceleration characteristic thereof developed in the power running mode of operation. In this case a field current through the field winding required for the separately excited dynamic braking has been nearly equal in magnitude to a dynamic braking current through the armature resulting in an extremely high magnitude. Accordingly the thyristor exciter has been extremely high in capacity and therefore the associated motor-generator have been of the high current and output type. As a result, conventional control systems such as described above have been disadvantageous in that they increases in dimension, weight and cost.
Accordingly it is an object of the present invention to provide a new and improved control system for controlling the separately excited dynamic braking of an electric motor vehicle which system is economic and decreased in dimension, weight and cost without the necessity of employing a motor-generator and a thyristor exciter previously required.

The present invention provides a control system for controlling the separately excited dynamic braking of an electric motor vehicle comprising an electric traction motor including an armature and a field winding, a dynamic braking resistor connected across the armature to form a closed loop dynamic braking circuit, first current adjusting means for holding a field current supplied to the field winding at predetermined constant magnitudes stepwise in accordance with speed ranges of an electric motor vehicle, a parallel combination of a resistor and second current adjusting means, and switching means responsive to the field current required for the electric traction motor to induce thereacross a voltage enough to maintain a constant magnitude of a dynamic braking current flowing through the closed loop dynamic braking circuit and less in magnitude than an output current from the first current adjusting means to be closed to connect the parallel combination of the resistor and second current adjusting means across the field winding thereby to cause the second current adjusting means to control continuously the field current for the application of the separately excited dynamic braking of the electric motor vehicle.

Preferably, each of the first and second current adjusting means may comprise thyristor chopper means.
The present invention will become more readily apparent from the following detailed description taken in conjunction with the accompanying drawing in which:

Fig. 1 is a circuit diagram of a conventional control system for controlling a separately excited dynamic braking of an electric motor vehicle;

Fig. 2 is a circuit diagram of one embodiment according to the dynamic braking control system of the present invention;

Fig. 3 is a graph illustrating the braking force-to-speed characteristics;

Fig. 4 is a Table indicating by way of example, the manner in which the arrangement shown in Fig. 2 controls a current supplied to the field winding shown in Fig. 2 and a field current therethrough; and

Fig. 5 is a circuit diagram of one portion of a modification of the present invention.

Fig. 1 shows a conventional control system for controlling a separately excited dynamic braking of an electric motor vehicle. The arrangement illustrated comprises an armature M of an electric traction motor connected across a dynamic braking resistor BRe to form a closed loop dynamic braking circuit, and a field winding MF thereof connected across a three-phase thyristor full-wave rectifier or exciter EXRf subsequently connected to a three-phase motor-generator MG.

The arrangement comprises further a pantograph Pan, a disconnector L, resistors R1 and R2 and an electric motor MGM connected in series to one another in the named order. The electric motor MGM forms a motor portion of the motor-
generator MG and includes a field winding MG MF connected in series thereto and also connected to ground. The resistor R2 is further connected across a starting contactor MGM.

The motor-generator MG is connected to three-phase inputs to the full-wave rectifier or exciter EXRF and include a field winding GF connected to three-phase output thereof through an automatic voltage regulator AVR.

A high voltage collected by the pantograph Pan is applied to the electric motor MGM through the disconnector L and the series resistors R1 and R2. This results in the motor-generator MG generating a three-phase alternating current at a low voltage. The three-phase current from the motor-generator MG is applied to the automatic voltage regulator AVR which, in turn controls the field winding GF to maintain a constant voltage across the latter. The three-phase current from the motor-generator MG is also applied to the thyristor exciter EXRF which, in turn, full-wave rectifies the current while undergoing the phase control. Then an full-wave rectified current from the exciter EXRF is supplied to the field winding MF to excite the latter separately and controllably.

An voltage EM induced across the armature M of the traction motor is proportional to both a magnetic flux ⦨ produced by its field winding MF and the number of rotation n in unit time of its armature M as expressed by

\[ EM = k\phi n \]  

(1)

where k designates a constant. If the saturation of the magnetic flux is disregarded then the induced voltage EM is proportional to both a field current IF (see Fig. 1) and
a speed $V$ of an associated electric motor vehicle and therefore may be expressed by

$$EM = kIFv \quad (1')$$

where $K$ designates a constant.

On the other hand, a dynamic braking current $IM$ (see Fig. 1) flowing through the closed loop dynamic braking circuit is determined by both a fixed magnitude of resistance $RB$ exhibited by the dynamic braking resistor $BR_e$ and the induced voltage $EM$ across the traction armature $M$ and may be expressed by

$$IM = EM/RB \quad (2)$$

If the dynamic braking current $IM$ is controlled to a constant magnitude independently of the speed $V$ then the dynamic braking resistor $BR_k$ has a capacity $P$ in kilowatts expressed by

$$P = IM^2RB \quad (3)$$

Therefore the capacity $P$ is constant. Accordingly the braking current $IM$ is controlled to a constant magnitude.

To this end, it is required to control the voltage $EM$ induced across the traction armature $M$ to a constant magnitude as seen from the expression $(1')$. This results in the necessity of controlling the field current $IF$ to be reversely proportional to the speed $V$ as apparent from the expression $(1')$ or the following expression $(4)$:

$$IM = EM/KV \quad (4)$$

on the assumption that $EM$ is held constant.

In a conventional process of controlling the dynamic braking effected by the arrangement of Fig. 1, the capacity of the traction motor $M-MF$ or an output capacity $Pe$ of the thyristor exciter $EXR_f$ might be expressed by
\[ P_e = E_e \cdot I_{\text{MAX}} > I_{\text{MAX}}^2 \cdot R_F \] (5)

where \( E_e \) designates an output voltage developed on the DC side of the thyristor exciter \( \text{EXRf} \), \( I_{\text{MAX}} \) a maximum magnitude of the field current \( I_F \) and \( R_F \) designates an internal resistance of the field winding \( MF \) of the traction motor. In other words, an exciting capacity is formed of the product of the maximum magnitude \( I_{\text{MAX}} \) of the field current and the output or exciting voltage \( E_e \) considering a time constant resulting from inductances of the particular system for exciting the field current. That exciting capacity is greater than a resistance loss \( I_{\text{MAX}}^2 \cdot R_F \) exhibited by the field winding \( MF \) of the traction motor.

Previously the traction motor has comprised, in many cases, a DC series motor in view of the acceleration characteristic developed in the power running mode of operation. Under these circumstances, the exciting or field current \( I_F \) for excited dynamic braking has had a magnitude generally equal to that of dynamic braking current \( I_M \) through the armature \( M \) resulting in a necessary flow of high current. Accordingly, the use of a separately excited dynamic braking system has led to the disadvantages that the thyristor exciter \( \text{EXRf} \) becomes extremely high in capacity which is attended with increases in dimension, weight and cost thereof. Further since the motor-generator forming an exciting source supplies also the exciting current \( I_F \) with a high magnitude to the field winding, the same has been of a high current and a high output type resulting in additional disadvantages that the motor-generator \( MG \) and the automatic voltage regulator \( \text{AVR} \) increase in dimension, weight and cost.
Fig. 2 shows one embodiment of a control system for controlling the separately excited dynamic braking of an electric motor vehicle in accordance with the present invention. The arrangement illustrated comprises a pantograph Pan, a high speed circuit breaker HB, a disconnector L, a series reactor FL connected in series to one another in the named order. The pantograph Pan slidably contacts an overhead line OHL and the series resistor FL is connected to a parallel capacitor FC subsequently connected to ground to form a filter with the capacitor FC.

The reactor FL is also connected to a two-phase thyristor chopper device including two first thyristor choppers CH1 and CH2 interconnected in parallel to the filter reactor FL and connected to respective smoothing reactors MSL1 and MSL2. The smoothing reactors MSL1 and MSL2 are then connected together to the junction of an armature M and a field winding MF of a DC series motor through a field resistor MFRe. The field winding FM has a magnitude internal resistance RF and is connected to ground and the DC series motor serves as a traction motor for an electric motor vehicle (not shown).

The armature M of the traction motor is connected a dynamic braking resistor BRe having a fixed magnitude of resistance RB to form a closed loop dynamic braking circuit as in the arrangement of Fig. 1. The field winding MF is connected across a series combination of a field weakening contactor WFK and a field weakening resistor WFRe which is, in turn, connected across a second thyristor chopper FCH.

Further the choppers CH1 and CH2 are connected to ground through respective flywheel diodes DF1 and DF2.
A high voltage on the overhead line OHL is connected by the pantograph Pan and supplied to the first thyristor chopper device CH1 - CH2 through the components HB, L and FL. The first thyristor choppers CH1 and CH2 convert the high voltage applied thereto to pulsed currents through the control of the rate of conduction thereof. The smoothing reactors MSL1 and MSL2 and the flywheel diodes DF1 and DF2 are operative to smooth those pulsed currents resulting in a smoothed output current IA. The smoothed output current IA flows through the field resistor MFR. and then is supplied to the field winding MF of the traction motor M-MF serving as a load. Since the internal resistance RF of the field winding MF is extremely low, the output current IA from the thyristor choppers CH1 and CH2 may be still high with the rate of conduction thereof rendered minimum. Under these circumstances, the field resistor MFR is effective for reducing the current IA to the required magnitude.

It is noted that the thyristor chopper device CH1 - CH2 is also used to drive the traction motor M-MF in the power running mode of operation and is not additionally provided in order to control the dynamic braking in accordance with the present invention. The thyristor chopper device CH1 - CH2 undergoes the phase control to maintain the output current IA at predetermined constant magnitudes stepwise in accordance with a plurality of speed ranges, in the example illustrated three speed ranges of an associated electric motor vehicle and regardless of any variation in voltage on the overhead line OHL.

When put in its closed position, the field weakening contactor WFK electrically connects the parallel combination
of the field weakening resistor $WF_{Re}$ and the second thyristor chopper $FCH$ across the field winding $MF$ therethrough. Under these circumstances, a field current $IF$ flows through the field winding $MF$ and is controlled by the second thyristor chopper $FCH$ in the manner as will be described later.

The control of the dynamic braking effected the arrangement of Fig. 2 will now be described in detail with reference to Fig. 3 wherein there is illustrated a braking force $TB$ in Kg plotted in ordinate against a speed $V$ in Km/h of the associated electric motor vehicle in abscissa. Curve IM$\text{Const}$ depicts the braking force-to-speed characteristic developed when a maximum dynamic braking current or an armature current flows through the dynamic braking resistor $B_{Re}$ independently of the speed of the electric motor vehicle. The three speed ranges as described above involve a low speed range between speeds $V_1$ and $V_2$, a moderate speed range between speeds $V_2$ and $V_3$ and a high speed range between speeds $V_3$ and $V_4$. The first thyristor chopper device $CH_1$ - $CH_2$ controls stepwise the output current $IA$ to be maintained at its magnitudes $IA_1$, $IA_2$ and $IA_3$ in the low, moderate and high speed ranges respectively.

Where the electric motor vehicle has a speed $V$ in the low speed range or between the speeds $V_1$ and $V_2$, the second thyristor chopper $FCH$ controls continuously the field current $IF$ through the control of the conduction thereof after one portion of the output current $IA$ from the first chopper device $CH_1$ - $CH_2$ has been shunted through the resistor $WF_{Re}$ by closing the contactor $WFK$. This is because the traction motor induces thereacross a voltage or a braking
force required for ensuring the characteristic shown at curve IMconst in Fig. 3.

It is noted that the second thyristor chopper is disabled at a speed less than the magnitude Vl and also that the dynamic braking current IM is required not to be greater than a maximum magnitude permitted by the dynamic braking resistor BRe.

For example, if the field current IF is controlled to its magnitude IF4 at the speed V3 of the electric motor vehicle then the current IM through the closed loop M-BRe as described above may be expressed by

\[ IM = \frac{K_1 \cdot V_3 \cdot \phi(IF4)}{BRe} \]

where K1 designates a constant. On the other hand, a corresponding braking force TB3 may be expressed by

\[ TB3 = K_2 IM \cdot \phi(IF4) \]

where K2 is a constant. The constants K1 and K2 are determined by the characteristics of the traction motor M-MF. In the actual control the object of the control is a braking force required for the speed V to be controlled and accordingly, a braking force required at the speed V3 has a magnitude TB3 as seen in Fig. 3. As a result, the second thyristor chopper FCH controls the field current to a magnitude IF4. In Fig. 3, IF1, IF2, IF3 and IF4 designate magnitudes of the field current controlled by the second thyristor chopper FCH and gradually decrease in the named order.

From Fig. 3 it is seen that when the braking force TB required at the speed Vl ranges from its magnitude TB11 to TB12, the field current IF is controlled to range from its
magnitude IF3 to IF4. Also when the braking force required at the same speed V1 ranges from its magnitude TB12 to TB13, the field current is controlled over a range of from its magnitude IF2 to IF3. For the braking force not smaller than its magnitude TB13 the field current is controlled in a range of from IF2 to IF1.

Under these circumstances the output current IA is stepwise controlled to the magnitudes IA1, IA2 and IA3. In short the output current IA3 is set to be somewhat greater than the field current IF3 and the output current IA is changed from its magnitude IA3 to IA2 when the field current IF increases from its magnitude IF4 to IF3. Similarly the output currents IA2 and IA1 are set to be greater than the field currents IF2 and IF1 respectively.

The foregoing may be collected substantially as shown in Fig. 4 wherein there is illustrated a Table indicating the shares and ranges of the output and field currents IA and IF in order to control those currents at the speed V1. The required braking force TB is sorted into a low range greater than TB11 and smaller than TB12, a moderate range greater than TB12 and smaller than TB13 and a high range greater than TB13 as shown in the uppermost row of the Table. The field current IF is higher than IF and less than IF3, higher than IF3 and less than IF2 and higher than IF2 and less than IF1 in the low, moderate and high ranges respectively as shown in the second row of the Table. The output current IA from the thyristor chopper device CH1 - CH2 is maintained to IA3, IA2 and IA1 in the low, moderate and high ranges respectively as shown in the third row. In the fourth row, a maximum range
in which the second thyristor chopper FCH can control the field current is sorted into \( \Delta I_{F1} = I_{A3} - I_{F4} \), \( \Delta I_{F2} = I_{A2} - I_{F3} \) and \( \Delta I_{F3} = I_{A1} - I_{F2} \) in the low, medium and high ranges respectively.

The output current \( I_{A} \) from the thyristor chopper device CH1 - CH2 can be set to such magnitudes \( I_{A1} \), \( I_{A2} \) and \( I_{A3} \) that \( \Delta I_{F1} \), \( \Delta I_{F2} \) and \( \Delta I_{F3} \) are equal to one other. Under these circumstances the second thyristor chopper FCH has a control capacity reduced to one third that obtained with the output current \( I_{A} \) fixed to its constant magnitude \( I_{A1} \). The setting of the output current \( I_{A} \) to a constant magnitude corresponds to the arrangement of Fig. 1 because the motor-generator MG shown in Fig. 1 delivers to the field winding MF its output voltage maintained constant. Thus the second thyristor chopper FCH can much decrease in both dimension and weight which is attended with the extremely high effect in view of its cost.

A modification of the present invention illustrated in Fig. 5 is different from that shown in Fig. 2 only in that in Fig. 5 a series combination of an AC breaker ABB, a traction transformer MTr, a full-wave rectifier Rf (which may comprise a thyristor or a semiconductor diode bridge) and a high speed circuit breaker HB is connected between the pantograph Pan and the filter reactor FL (not shown in Fig. 5). The arrangement shown in Fig. 5 is equally applicable to electric motor vehicles of the AC type.

It is theoretically possible to control the field current \( I_{F} \) by the thyristor chopper device CH1 - CH2 alone. As described above, the field current may not decrease even...
with a minimum conduction rate of the thyristor chopper
device CH1 - CH2 because the field winding MF of the traction
motor is low in internal resistance. Under these circumstances
the field resistor MFRe is required to be of a high resistance
resulting in the disadvantage that the resistor MFRe has a very
high current capacity. According to the present invention,
however the control of the field current through the traction
motor can be accomplished by shunting and controlling one
portion of the field current with the second thyristor chopper
controlled in rate of conduction. Accordingly the field
resistor MFRe is required only to have an extremely low
magnitude of resistance.

The first chopper device CH1 - CH2 and the second
chopper FCH are also used in the power running mode of operation.
This eliminate the necessity of employing field current
adjusting means peculiar to the dynamic braking, that is
to say, a high capacity motor-generator and a high capacity
thyristor exciter such as a full-wave thyristor rectifier
previously required to be used with the dynamic braking. In
this respect, the present invention exhibits the great effect
in view of the dimension, weight and cost.

While the present invention has been described
in conjunction with the three step control of the output
current IA from the thyristor chopper device it is to be
understood that the output current IA may be controlled in
either two steps or a multi-step including four or more steps.
The larger the number of the steps in which the output current
IA is stepwise controlled the smaller the control capacity of
the second thyristor chopper will be.
Also while the present invention has been illustrated and described in conjunction with an electric motor vehicle controlled by a chopper device it is to be understood that the present invention is equally applicable to electric motor vehicles of the AC type. In the latter case, an AC thyristor type Ward-Leonard system having a thyristor bridge connected thereto is substituted for the chopper device CH1 - CH2 shown in Fig. 2.
The claims defining the invention are as follows:

1. A control system for controlling the separately excited dynamic braking of an electric motor vehicle comprising an electric traction motor including an armature and a field winding, a dynamic braking resistor connected across the armature to form a closed loop dynamic braking circuit, first current adjusting means for holding a field current supplied to the field winding at predetermined constant magnitudes stepwise in accordance with speed ranges of an electric motor vehicle, a parallel combination of a resistor and second current adjusting means, and switching means responsive to the field current required for the electric traction motor to induce thereacross a voltage enough to maintain a constant magnitude of a dynamic braking current flowing through the closed loop dynamic braking circuit and less in magnitude than an output current from the first current adjusting means to be closed to connect the parallel combination of the resistor and second current adjusting means across the field winding thereby to cause the second current adjusting means to control continuously the field current for the application of the separately excited dynamic braking to the electric motor vehicle.

2. A control system for controlling the separately excited dynamic braking of an electric motor vehicle according to claim 1 wherein each of the first and second current adjusting means comprises thyristor chopper means.

3. A control system for controlling the separately excited dynamic braking of an electric motor vehicle according
to claim 1 wherein the first current adjusting means comprises an AC thyristor type Ward-Leonard system having a thyristor bridge connected thereto.

4. A control system for controlling the separately excited dynamic braking of an electric motor vehicle substantially as described in conjunction with Figures 2 to 4 or 5.

Dated this 13th day of January, 1981.

MITSUBISHI DÔNKI KABUSHIKI KAISHA
By their Patent Attorneys
GRIFFITH, HASSEL & FRAZER.
FIG. 1

IA_1 > IA_2 > IA_3
IF_1 > IF_2 > IF_3 > IF_4

FIG. 3
<table>
<thead>
<tr>
<th>REQUIRED BRAKING FORCE TB</th>
<th>( TB_{11} &lt; TB &lt; TB_{12} )</th>
<th>( TB_{12} &lt; TB &lt; TB_{13} )</th>
<th>( TB_{13} &lt; TB )</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIMITS OF FIELD CUR IF</td>
<td>( IF_4 &lt; IF &lt; IF_3 )</td>
<td>( IF_3 &lt; IF &lt; IF_2 )</td>
<td>( IF_2 &lt; IF &lt; IF_1 )</td>
</tr>
<tr>
<td>OUTPUT CUR FM CH1 &amp; CH2</td>
<td>( IA_3 )</td>
<td>( IA_2 )</td>
<td>( IA_1 )</td>
</tr>
<tr>
<td>MAX CONT LIMITS OF FCH</td>
<td>( \Delta IF_1 = IA_3 - IF_4 )</td>
<td>( \Delta IF_2 = IA_2 - IF_3 )</td>
<td>( \Delta IF_3 = IA_1 - IF_2 )</td>
</tr>
<tr>
<td>REMARK</td>
<td>( IA_1 &gt; IA_2 &gt; IA_3 )</td>
<td>( IF_1 &gt; IF_2 &gt; IF_3 &gt; IF_4 )</td>
<td></td>
</tr>
</tbody>
</table>

**FIG. 4**

**FIG. 5**