



(51) International Patent Classification:
H02M 7/537 (2006.01)

(21) International Application Number:
PCT/US2011/045073

(22) International Filing Date:
22 July 2011 (22.07.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/367,133 23 July 2010 (23.07.2010) US

(71) Applicant (for all designated States except US): **FMC TECHNOLOGIES, INC.** [US/US]; 1803 Gears Road, Houston, Texas 77067 (US).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **NICHOLS, Bradley W.** [US/US]; 177 Cotton Gin Lane, Slatillo, Mississippi 38866 (US).

(74) Agents: **STALFORD, Terry J.** et al.; Fish & Richardson P.C., P.O. Box 1022, Minneapolis, Minnesota 55440-1022 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,

HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: DRIVE CONTROLLER FOR A VIBRATORY FEEDER

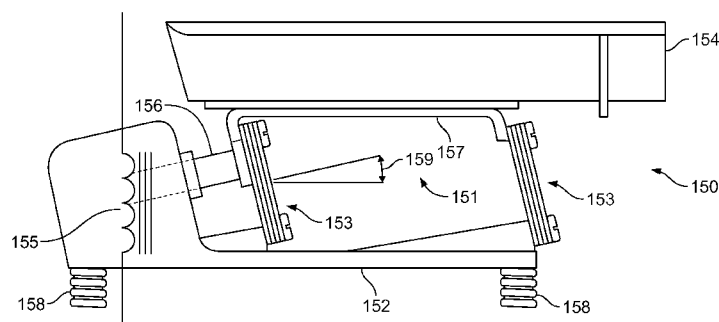


FIG. 1

(57) Abstract: A vibratory feeder includes a vibrator and a variable frequency drive. The vibrator includes an inductor coil and an armature. The inductor coil, when energized by a current, attracts and displaces the armature to perform mechanical work. The variable frequency drive powers the vibrator and includes an inverter, current-blocking device, and capacitor. The inverter includes a DC bus and generates a relative sine wave current including positive half-cycles energizing the inductor coil and negative half-cycles whereby the inductor coil is de-energized. The current-blocking device is connected in series with the inductor coil and blocks current to the inductor coil during the negative half cycles. The capacitor is connected in parallel with the DC bus and captures a portion of a counter EMF resulting from de-energizing the inductor coil during negative half-cycles. The capacitor discharges the captured portion of the counter EMF to reenergize the inductor coil during subsequent positive half-cycles.



DRIVE CONTROLLER FOR A VIBRATORY FEEDER

CLAIM OF PRIORITY

This application claims priority to U.S. Patent Application Serial No.
5 61/367,133 filed on July 23, 2010, the entire contents of which are hereby incorporated
by reference.

TECHNICAL FIELD

This present disclosure relates to vibratory feeders, and, more particularly, to
systems, methods, and apparatus for a drive controller for electromagnetic vibratory
10 feeders.

BACKGROUND

A vibratory feeder is a device that uses vibration to “feed” material to a process
or machine. Vibratory feeders can use both vibration and gravity to move material. In
some applications, material to be conveyed may cling to or gather on the walls of the
15 delivery trough, funnel, or passage. Gravity alone may not be sufficient to coax the
material down the delivery passage. In some instances, the feed tray will need to be
vibrated to assist delivery of the material down the conveyor. Vibratory feeders can
offer an efficient, cost-effective means to maintain free flow of product from bins,
hoppers and chutes.

20 One example of a vibratory feeder is a pill bottling system. A large batch of
pills is dumped into the top of the vibratory feeder. Gravity will pull the pills toward
the bottom of the feeder where they can exit one at a time so that they can be counted.
Once the correct number is in the container, the feed is stopped until a new bottle is
placed in position. In this way bottles can be filled automatically by machine with the
25 correct number of pills in each bottle. The vibration in the vibratory feeder ensures that
pills keep moving towards the exit into the bottle without congesting the opening of
the feeder. Other examples of vibratory feeders include vibratory feeders used in
construction, mining, aggregates, glass, cement, chemical, wood products, steel
industries, and other heavy industrial settings. For instance, in an automated cement
30 mixing operation, irregular loads of raw material, such as gravel, can be fed into a
vibratory feeder which then delivers the load to subsequent machines and processes at

a steady rate. Vibratory feeders can take many shapes, sizes, and orientations and can feed bulk material, loaded in an uncontrolled fashion, at a controlled and steady rate.

SUMMARY

In one aspect, the disclosure encompasses an improved vibratory feeder including a vibrator including an inductor coil and an armature. The inductor coil, when energized by a current, can attract and displace the armature in a first direction to perform mechanical work. The vibrator can further include a variable frequency drive adapted to power the vibrator, the variable frequency drive including an inverter including a DC bus and adapted to generate a relative sine wave current, including a first positive half-cycle and a second negative half-cycle, where the inductor coil is energized during the first half cycle and de-energized during the second half cycle. The variable frequency drive can further include a current-blocking device connected in series with the inductor coil, the current-blocking device blocking current to the inductor coil during the second negative half cycle, and a capacitor connected in parallel with the DC bus and adapted to capture at least a portion of a counter EMF resulting from de-energizing of the inductor coil during the second half-cycle. The capacitor can further discharge the captured portion of the counter EMF to reenergize the inductor coil during subsequent first half-cycles.

In a further aspect, the disclosure encompasses a method for providing power to a inductor coil of an electromagnetic vibratory feeder. Operation of the vibratory feeder can be initiated by supplying a first amplitude of a relative sine wave current to the inductor coil, the relative sine wave including a positive half-cycle and a negative half-cycle, where the inductor coil is energized by the first amplitude during an initial instance of the positive half cycle. Current can be blocked to the inductor coil using a diode connected in series with the inductor coil during negative half-cycles, subsequent to the initial instance of the positive half cycle, of the relative sine wave current, the inductor coil de-energizing during negative half-cycles of the relative sine wave current. At least a portion of a counter EMF induced in the inductor coil during de-energizing of the inductor coil during negative half-cycles of the relative sine wave current can be captured in a capacitor connected in parallel with a DC bus supplying the relative sine wave. The portion of the counter EMF stored in the capacitor can be discharged to the inductor coil during instances of the positive half-cycle subsequent to

the first instance of the positive half cycle, wherein the subsequent instances of the positive half-cycle have a second amplitude, the second amplitude less than the first amplitude.

In a further aspect, the disclosure encompasses an electrical circuit including an inductor coil adapted, when energized by a particular current, to attract and displace an armature contributing to vibration of a vibrating machine. The circuit can further include an inverter including a DC bus, the inverter adapted to generate a relative sine wave current, including a positive half-cycle and negative half-cycle, wherein the inductor coil is energized during the first half cycle and de-energized during the second half cycle. A current-blocking device connected in series with the inductor coil can be adapted to block current to the inductor coil during the second negative half cycle. A capacitor connected in parallel with the DC bus can be adapted to capture at least a portion of a counter EMF resulting from de-energizing of the inductor coil during the second half-cycle and discharge the captured portion of the counter EMF to reenergize the inductor coil during positive half-cycles.

The concepts above can include one or more or none of the following features. A delivery channel of a vibratory feeder can be connected to the vibrator and adapted, when vibrated by the vibrator, to convey material from a first position to a second position on the delivery channel. The mechanical work can include the vibration of the delivery channel. The armature can retract in a second direction, opposite the first direction, during de-energizing of the inductor coil. The inverter can include a plurality of insulated gate bipolar transistors (IGBTs) adapted to produce a pulse-width-modulated voltage output adapted for use in generating the relative sine wave current. The relative sine wave current can be generated by combining a pulse-width-modulated voltage output with a carrier signal of a particular frequency. The carrier signal can have a frequency of at least 4 kilohertz. The inductor coil can alternately discharge and reenergize based on the particular frequency of the carrier signal. The variable frequency drive can be powered by a three-phase AC power source. The mechanical work performed as a percentage of energy consumed to generate the relative sine wave current is greater than or equal to 80%. The current-blocking device is a diode. The relative sine wave current can include a half-wave rectified current. The inverter can be further adapted to vary a frequency of the relative sine wave current in response to a control signal.

The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

5

DESCRIPTION OF DRAWINGS

FIGURE 1 illustrates an example vibratory feeder.

FIGURE 2 is a circuit diagram of an example vibratory feeder system including a variable frequency drive.

FIGURE 3 is an example signal diagram showing performance of a vibratory
10 feeder system, such as the system shown and described in connection with FIGURE 2.

FIGURE 4 is an example flowchart of operations of an example vibratory frequency drive system.

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

15

An improved controller for providing power to a vibratory feeder device is described. The new controller can include a variable frequency drive (VFD) working in conjunction with a diode to provide half-wave rectified current to the electromagnetic feeder coil. Although examples in the present disclosure may describe the use of a diode for providing half-wave rectified current and for blocking
20 current in one direction, other current-blocking devices may also be used and are within the scope of the present disclosure. When the diode blocks the current flow in one direction (i.e., during a second half-cycle), a field collapse can occur in the feeder coil, resulting in a reverse electromagnetic field (reverse or counter EMF). In traditional electromagnetic vibratory feeders, the repeated field collapse of the feeder
25 coil is lost in the form of heat at the feeder coil and the controlled heat sink. In some instances, the feeder coil can exhibit a poor power factor due to high counter EMF generated in the coil in connection with field collapse within the coil. The collapse of the field in the coil can occur while the transistor switches (e.g., insulated-gate bipolar transistors (IGBTs)) of the VFD are active, allowing the field collapse to charge a
30 capacitor attached to the DC bus of the VFD. The energy associated with the field collapse can then be reused in subsequent half-cycles to re-build the field in the feeder coil. This potential energy stored in the capacitor is not consumed, but passed from

the inductor to capacitor and back each half-cycle. Consequently, reusing the energy from the field collapse, stored in the capacitor, to reenergize the coil in subsequent cycles can reduce overall power consumption in the vibratory feeder. Less current is required to be supplied to the feeder coil to energize the coil in light of the contribution
5 of the energy contributed by the capacitor. In some instances, the improved controller can reduce overall energy consumption by more than 50%.

A vibratory feeder can include a trough, or other delivery channel, as well as a vibrator, such as shown in FIG. 1. In the example illustrated in FIG. 1, an electromagnetic feeder 150 is shown as a two mass system, including trough side mass
10 members 151 connected to a base mass 152 through spring banks 153. The trough side mass members 151 include a trough 154, an electromagnetic armature 156, and a mounting bracket 157 (which can connect one side of the spring banks 153 to the trough 154 and electromagnetic armature 156). The base mass 152 can include the electromagnetic coil (and core) 155 along with attachments for the remaining ends of
15 the spring banks 153, with mounts for isolation springs 158 (which can isolate dynamic vibration forces produced by the feeder from its mounting support).

The vibrator can be implemented as an electromagnetic, electromechanical, pneumatic, electric rotary, or other vibrator. In an electromagnetic vibrator, feeder, or other device, such as that shown in the example of FIG. 1, an electromagnetic coil 155
20 is energized to produce a magnetic field within the coil 155. When the electromagnetic vibratory feeder 150 is on, a current flows through the electromagnetic coil 155 of the vibratory feeder 150 to create a pulsating magnetic flux that repeatedly attracts the armature 156 of the vibratory feeder 150 and deflects the springs 153, pulling the trough 154 in a first direction (in this example, back and
25 downward) based at least in part on the mounting angle 159 of the springs 153. Conversely, when the current flow through the electromagnetic coil 155 of the electromagnetic feeder 150 is diminished, the energy stored in the springs 153 is released, moving the trough 154 in a second, opposite direction (in this example, forward and upward). As the cycle is repeated, the angular vibration created will cause
30 material contained in the trough 154, such as small packages, products, gravel, sand, or other material, to progress along a length of the trough 154 to an end of the trough.

To repeatedly energize and de-energize the coil 155, a relative sine wave current can be provided, for example, by an inverter of an VFD, thereby alternately

engaging and disengaging the armature by generating and collapsing a magnetic field within the coil 155. The electromagnetic coil 155 can, in some cases, be an inductor of significant size requiring a significant field to attract the armature of the electromagnetic feeder. In conventional, (e.g., SCR-based) control schemes, the energy captured in the coil 155 would flow off as counter EMF and have to dissipate as heat loss in order for the field to fully release and the armature 156 to retract. However, in the present, improved vibratory feeder drive control, the counter EMF is used to charge a capacitor which is used to assist in powering subsequent cycles energizing the coil 155.

In some instances, power can be supplied to the feeder coil of a vibratory feeder or vibrator using a VFD and controller. A VFD can be used to provide more up-to-date digital integration for use with modern day control systems. A VFD can be used with a three-phase power source to assist in balancing a plant's line loads without concern for feeder balancing throughout their plants. Additionally, a pulse-width modulated control can be used to eliminate power factor and harmonic affects on plant electrical systems. The adjustable frequency nature of a VFD can allow a feeder to be used in both high and low frequency applications.

In one example, an improved VFD and control can be used to improve the efficiency of a vibratory feeder. The VFD can vary the frequency of signals controlling a vibratory feeder device. Indeed, in some instances, the frequency of a signal controlling the energizing and de-energizing of an electromagnetic coil can be controlled by a control signal such as a feedback control signal. The VFD can accept a single- or three-phase voltage source. The DC bus settings and IGBT enable patterns of the VFD can remain capable of generating a three-phase output. Two legs of the output of the VFD can be used to drive the electromagnetic feeder coil of the vibratory feeder. A diode can be placed in series with the coil. Additionally, at least one capacitor can be connected to the DC bus of the VFD. In some instances, the capacitor is integrated in the VFD itself, although in other instances, the capacitor can be external to the VFD.

Through the use of a diode with the VFD controller, counter EMF resulting from de-energizing of the coil can be recaptured by charging the capacitor connected in parallel to the DC bus to increase the efficiency of the vibratory feeder. The energy from the captured counter EMF stored in the capacitor can then be discharged during

the next half-cycle back into the coil of the feeder. Each half-cycle, the energy to build the field in the coil, is passed between the inductor (coil) and the capacitor. While a small amount of energy may be lost to heat in the improved vibratory feeder controller described, for example through the diode, the core of the magnet when it is induced, and/or the IGBTs and other small transient losses, a significant portion of the energy in the counter EMF can be captured and reused, rather than being lost to heat as in traditional vibratory feeders, thereby significantly improving power efficiency of the feeder.

In one example of the improved vibratory feeder system 200, including a VFD, diode, and coil, for example as illustrated in FIG. 2, can salvage substantially all of the counter EMF of the coil. In FIG. 2, an inverter built from a plurality of IGBT switches I1-I6 and powered by a three-phase AC power source can fire a pulse-width-modulated (PWM) output in such a pattern to generate a relative sine wave. The relative sine wave can be generated, for example, by combining a PWM output with a carrier signal of a particular frequency. For instance, the carrier frequency can include frequencies greater than 4000 hz. The frequency of the carrier signal can dictate the frequency of the relative sine wave, and control the frequency of a vibratory feeder armature's movement relative the coil to thereby realize low and high frequency feeder applications. Accordingly, in some examples, the frequency of the relative sine wave can be varied through use of the VFD to thereby also control the operation frequency of the vibratory feeder. The diode D92 permits current output from the VFD to travel in only one direction to the feeder coil 205. During de-energizing of the coil 205, counter EMF resulting in the coil 205 is collected by a capacitor CAP1 in parallel with a DC bus of the controller.

Turning to FIG. 3, signal diagrams 300 are shown illustrating the behavior of each of DC bus voltage 355, load voltage 305, line current 310, load current 315, PWM output 320, and diode effects 325, 330 during operation of an example vibratory feeder control circuit, such as the circuit illustrated and described in connection with FIG. 2. As shown in FIG. 3, the first cycle of power energy is drawn from the DC bus and energizes the coil. During the next half-cycle the current 315 is blocked 325 by the diode allowing the field in the coil to collapse. Reactive energy stored in the inductor charges the capacitor (at 335) through the close switch(es) (e.g., IGBTs) as they fire their standard pattern. The capacitor does not discharge (e.g., 340) until the

next half-cycle when current is again permitted to flow by the diode. When the capacitor discharges, the energy fills the inductor again along with the real power required to perform work, which is drawn off the DC bus causing the feeder to stroke.

As seen in FIG. 3, when the vibratory feeder is first started, the current
5 required to energize the coil in the first half cycle is higher than in subsequent cycles. This is a consequence of the introduction of the stored counter EMF captured in the previous half cycle by the capacitor. This cycle then repeats itself only drawing enough energy (current 310 from the VFD) needed to reenergize the coil in cooperation with the energy discharged by the capacitor, as well as compensate for
10 system losses and the energy needed for the mechanical work. In some instances, the improved VFD control system can improve system power efficiency (i.e., Efficiency = Mechanical Work / Real Energy Consumed) and realize power efficiency of 85% or higher.

In some instances, operation of the improved VFD system can include one or
15 more of the following steps, as illustrated in FIG. 4. The VFD inverter can switch IGBTs to generate a relative sine wave current to the feeder coil at 402. In response to this current, during a first, positive half-wave, a field is created in the coil of the magnet causing phase shift due to resistance of current flow in the inductor. In some instances, the line current can be required to be equivalent to load current due to total
20 power requirement of the system. The magnet (resulting from the energized coil) then draws the armature to the coil, performing mechanical work. As the sine wave current enters the second, negative half-cycle, a diode, coupled in series with the coil, blocks current flow switching off the flow of energy to the coil at 404. At this moment, potential energy is captured inside the coil that will flow-off as counter EMF as the
25 coil de-energizes. When the diode cutoff is reached, the capacitor charges with the energy from the counter EMF from the coil at 406 and does not discharge again until the potential shifts and current flow returns. As the sine wave re-cycles to positive, and the direction of current flow changes, the field in the feeder coil is to be energized again to re-attract the armature. In cycles following the first, power-up cycle, the
30 capacitor, now storing energy from the captured counter EMF of the previous half-cycle, discharges the stored energy back into the coil at 408, thus requiring less energy from the incoming line to re-energize the coil. This cycle can then repeat itself with the line current remaining relatively low by virtue of the contributions of the capacitor,

thereby still providing the needed energy required to mechanically operate the system. The cycle repeats until the VFD is shut off and the IGBTs stop operating. At shut off, the unit, including the coil and/or capacitor, dissipates excess and stored energy either in loss from the coil and/or from the capacitor.

5 Although this disclosure has been described in terms of certain implementations and generally associated methods, alterations and permutations of these implementations and methods will be apparent to those skilled in the art. For example, the system described herein can include other or additional components to perform the described techniques and still achieve the desirable results. Other
10 variations are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A vibratory feeder comprising:
 - a vibrator including an inductor coil and an armature, wherein the inductor coil, when energized by a current, attracts and displaces the armature in a first direction to perform mechanical work;
 - a variable frequency drive adapted to power the vibrator, the variable frequency drive including:
 - an inverter including a DC bus and adapted to generate a relative sine wave current, including a first positive half-cycle and a second negative half-cycle, wherein the inductor coil is energized during the first half cycle and de-energized during the second half cycle;
 - a current-blocking device connected in series with the inductor coil, wherein the current-blocking device blocks current to the inductor coil during the second negative half cycle; and
 - a capacitor connected in parallel with the DC bus and adapted to capture at least a portion of a counter EMF resulting from de-energizing of the inductor coil during the second half-cycle and discharge the captured portion of the counter EMF to reenergize the inductor coil during subsequent first half-cycles.
2. The vibratory feeder of claim 1, further comprising a delivery channel connected to the vibrator and adapted, when vibrated by the vibrator, to convey material from a first position to a second position on the delivery channel.
3. The vibratory feeder of claim 2, wherein the mechanical work includes vibration of the delivery channel.
4. The vibratory feeder of claim 1, wherein the armature retracts in a second direction, substantially opposite the first direction, during de-energizing of the inductor coil.

5. The vibratory feeder of claim 1, wherein the inverter includes a plurality of insulated gate bipolar transistors (IGBTs) adapted to produce a pulse-width-modulated voltage output adapted for use in generating the relative sine wave current.

5

6. The vibratory feeder of claim 1, wherein the relative sine wave current is generated by combining a pulse-width-modulated voltage output with a carrier signal of a particular frequency.

10

7. The vibratory feeder of claim 6, wherein the carrier signal has a frequency of at least 4 kilohertz.

8. The vibratory feeder of claim 6, wherein the inductor coil alternately discharges and reenergizes based on the particular frequency of the carrier signal.

15

9. The vibratory feeder of claim 1, wherein the variable frequency drive is powered by a three-phase AC power source.

10. The vibratory feeder of claim 1, wherein the mechanical work performed as a percentage of energy consumed to generate the relative sine wave current is greater than or equal to 80%.

20

11. The vibratory feeder of claim 1, wherein the current-blocking device is a diode.

25

12. A method for providing power to a inductor coil of an electromagnetic vibratory feeder, the method comprising:

initiating operation of the vibratory feeder by supplying a first amplitude of a relative sine wave current to the inductor coil, the relative sine wave current including a positive half-cycle and a negative half-cycle, wherein the inductor coil is energized by the first amplitude during an initial instance of the positive half cycle;

blocking current to the inductor coil using a diode connected in series with the inductor coil during negative half-cycles, subsequent to the initial instance of the positive half cycle, of the relative sine wave current, wherein the inductor coil de-energizes during negative half-cycles of the relative sine wave current;

capturing, in a capacitor connected in parallel with a DC bus supplying the relative sine wave current, at least a portion of a counter EMF induced in the inductor coil during de-energizing of the inductor coil during negative half-cycles of the relative sine wave current; and

discharging the portion of the counter EMF stored in the capacitor to the inductor coil during instances of the positive half-cycle subsequent to a first instance of the positive half cycle, wherein the subsequent instances of the positive half-cycle have a second amplitude, the second amplitude less than the first amplitude.

13. The method of claim 12, wherein the relative sine wave current is generated by a variable frequency drive.

14. The method of claim 12, wherein the relative sine wave current includes a half-wave rectified current.

15. The method of claim 12, wherein the inductor coil is re-energized, at least in part, by instances of the positive half-cycle subsequent to the first instance of the positive half cycle.

16. The method of claim 15, wherein discharging of the portion of the counter EMF stored in the capacitor supplements re-energizing of the inductor coil by the instances of the positive half-cycle subsequent to the first instance of the positive half cycle.

5

17. The method of claim 12, wherein energizing the inductor coil generates a magnetic field, the method further comprising attracting and displacing an armature of the vibratory feeder using the magnetic field.

10 18. The method of claim 12, wherein energizing and de-energizing the inductor coil using the relative sine wave current generates a pulsating magnetic field used to vibrate the vibratory feeder.

19. An electrical circuit comprising:

15 an inductor coil adapted, when energized by a particular current, to attract and displace an armature contributing to vibration of a vibrating machine;

an inverter including a DC bus and adapted to generate a relative sine wave current, including a positive half-cycle and negative half-cycle, wherein the inductor coil is energized during a first half cycle and de-energized during a second

20 half cycle;

a current-blocking device connected in series with the inductor coil, wherein the current-blocking device is adapted to block current to the inductor coil during the second negative half cycle; and

a capacitor connected in parallel with the DC bus and adapted to

25 capture at least a portion of a counter EMF resulting from de-energizing of the inductor coil during the second half-cycle and discharge the captured portion of the counter EMF to reenergize the inductor coil during positive half-cycles.

20. The electrical circuit of claim 19, wherein the inverter is adapted to generate a first instance of the positive half-cycle of the relative sine wave current to initially energize the inductor coil, the first instance of the positive half-cycle having a first amplitude, and generate subsequent instances of the positive half-cycle, subsequent to the first instance, each of the subsequent instances of the positive half-cycle having an amplitude lower than the first amplitude.

21. The electrical circuit of claim 19, wherein the inverter is further adapted to vary a frequency of the relative sine wave current in response to a control signal.

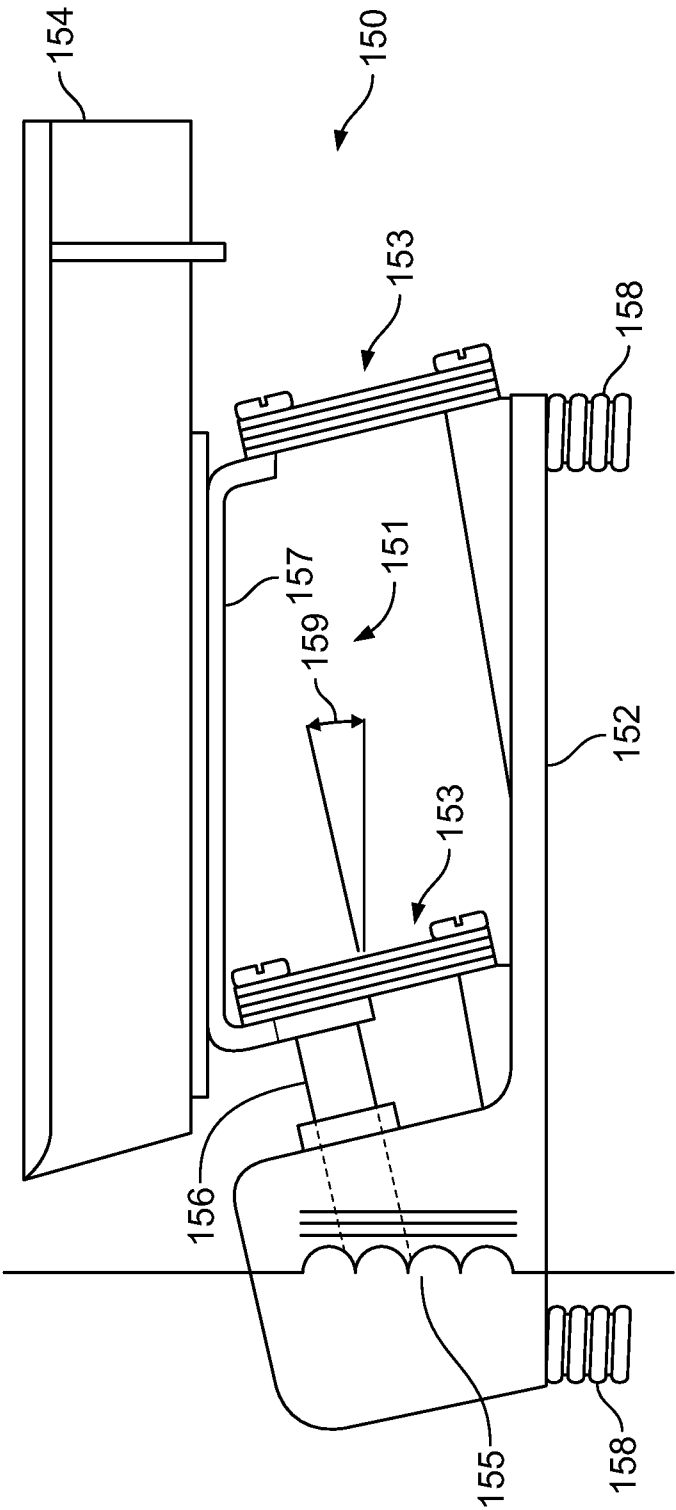


FIG. 1

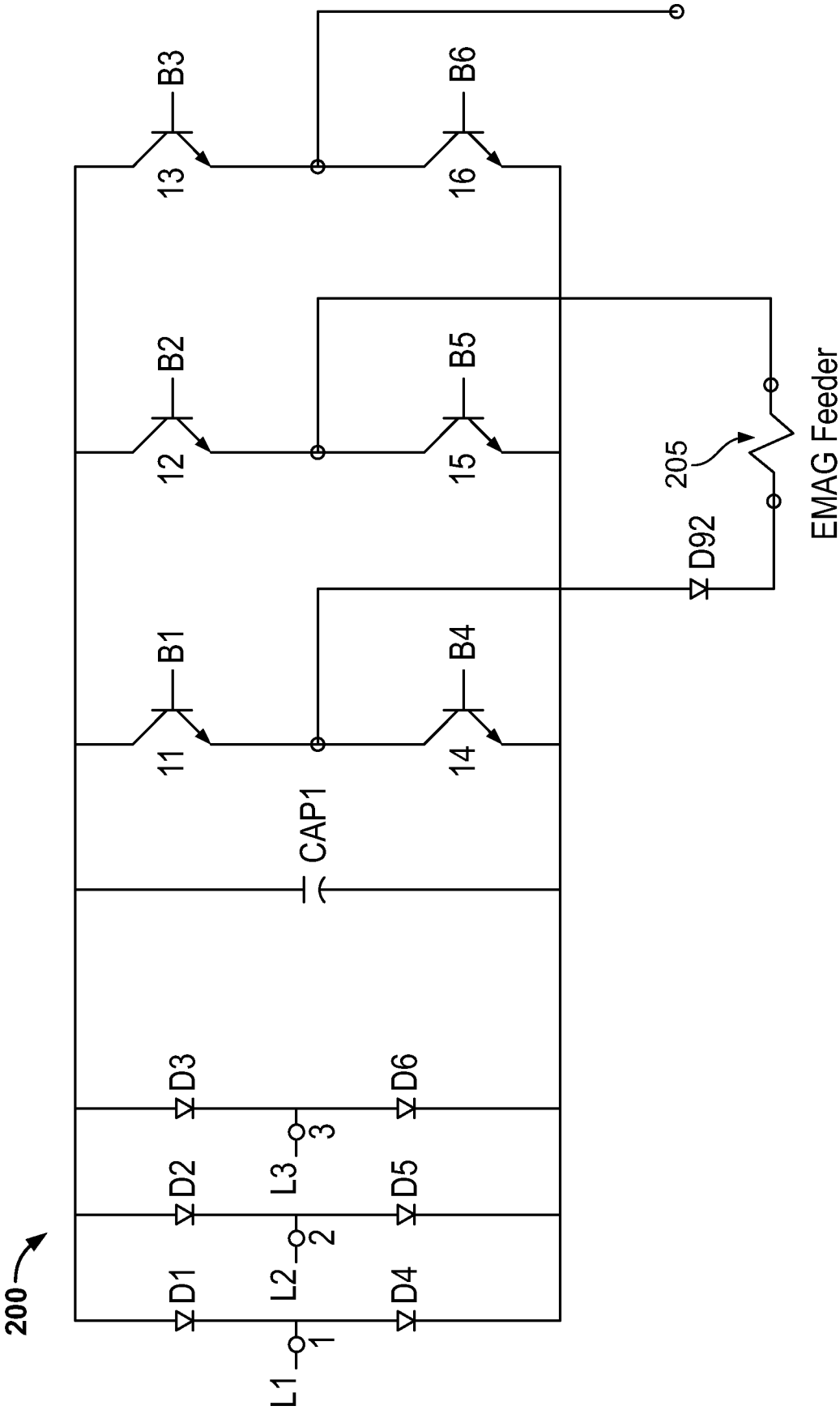
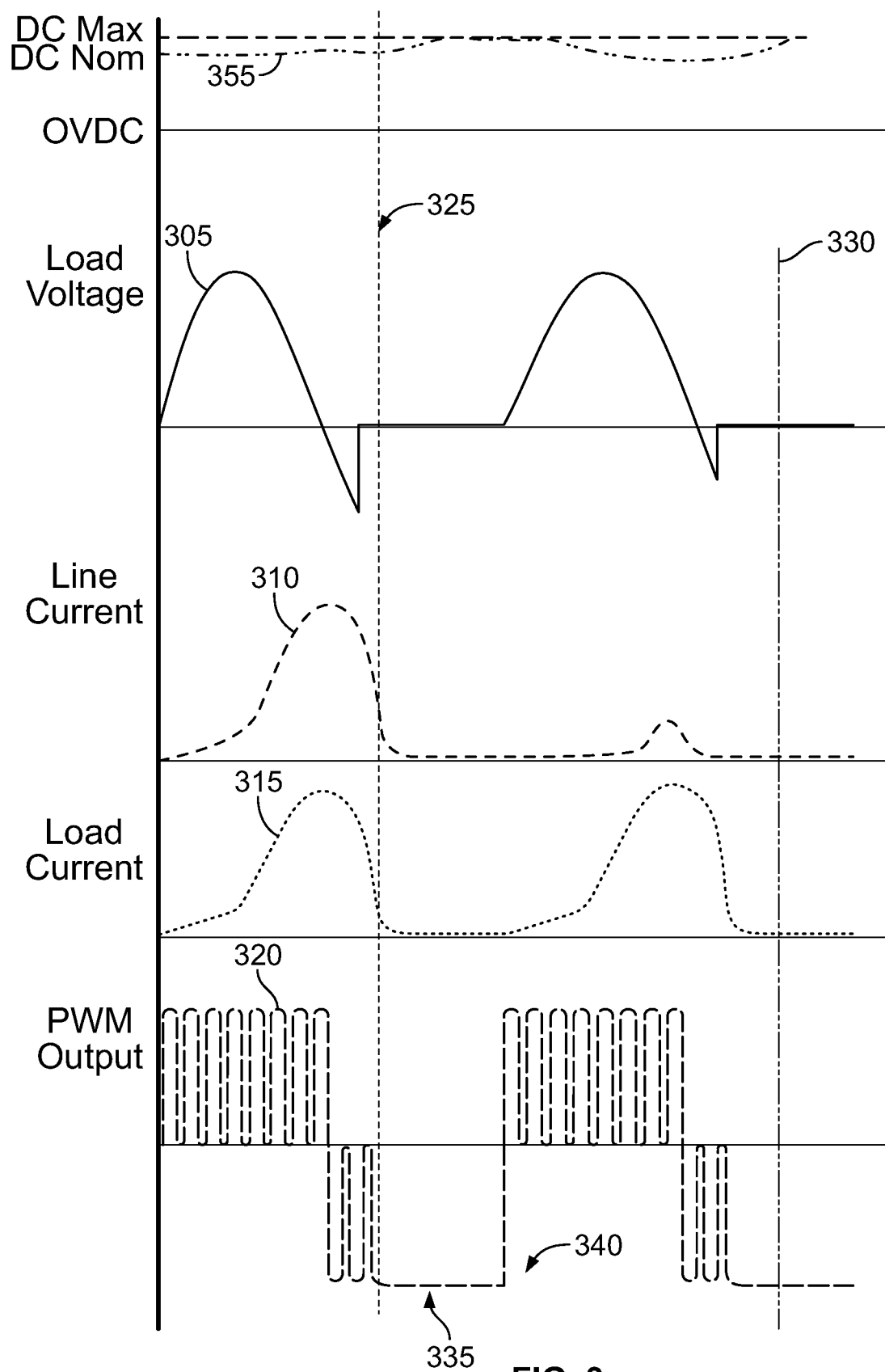


FIG. 2

**FIG. 3**

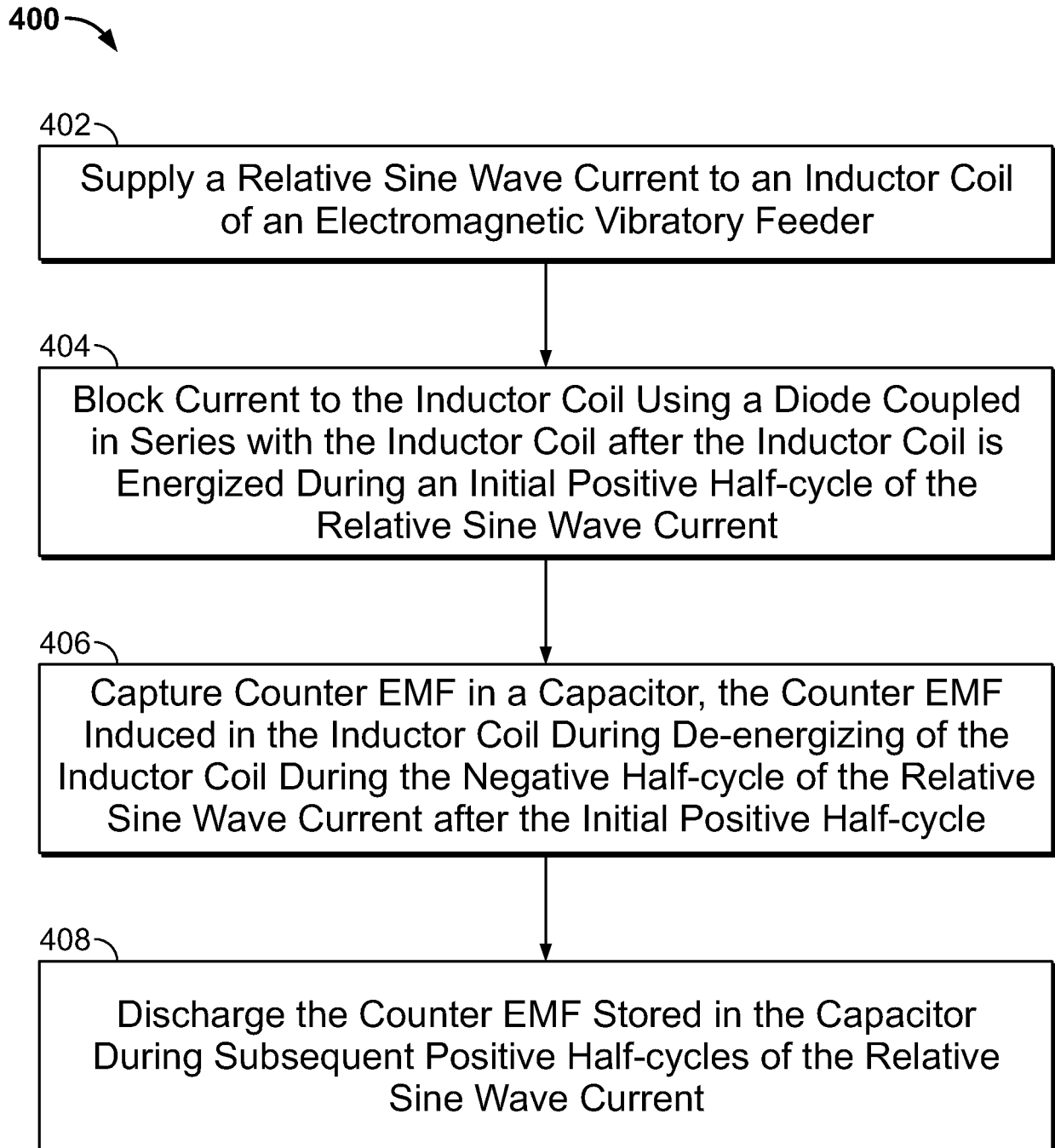


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 11/45073

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H02M 7/537 (2011.01)

USPC - 363/131

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)

USPC: 363/131

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 IPC(8): H02M 7/537 (2011.01); USPC: 363/131,56.01,120,33; 222/52
 (keyword limited; terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PubWEST(USPT,PGPB,EPAB,JPAB); Google Scholar

Search Terms: sine, sinusoidal, capacitor, diode, igbt, vibrator, carrier, pm, pulse width, emf, variable drive, inverter, move, convey, coil, inductor, feeder.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,675,955 B2 (NASSER-MOGHADDASSI et al.) 13 January 2004 (13.01.2004), entire document, especially; FIG 1, 15a, 15b, 17a, 18, col 1, ln 26-58, col 2, ln 48-67, col 3, ln 1-45, col 4, ln 34-41, col 7, ln 18-53, col 10, ln 15-28, col 11, ln 39-47, col 13, ln 8-45, col 14, ln 10-67, col 15, ln 29-42, col 15, ln 51-67, col 16, ln 1-18.	1-21
A	US 6,116,408 A (POUNDS) 12 September 2000 (12.09.2000), entire document.	1-21
A	US 5,074,403 A (MYHRE) 24 December 1991 (24.12.1991), entire document.	1-21

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23 November 2011 (23.11.2011)

Date of mailing of the international search report

07 DEC 2011

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

Lee W. Young

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774