

CLAIMS

1 1. A method for detecting the displacement amplitude X of a reciprocating
 2 armature of an alternating current, linear motor or linear alternator for controlling
 3 the reciprocation of the armature, the motor or alternator having a stator including
 4 a coil with a pair of coil terminals and wound around a ferromagnetic core with air
 5 gaps, the motor or alternator also having magnets fixed to the armature and
 6 positioned for reciprocating through the gaps, the motor or alternator also having
 7 a motor constant α , an equivalent resistance R_{dc} representing resistive losses in
 8 the coil, an equivalent resistance $\Delta R_{external}$ representing induced losses in
 9 structures surrounding the motor or alternator and an equivalent resistance R_s
 10 representing losses due to eddy currents and hysteresis induced by motion of the
 11 magnets with the coils open circuited, wherein the method comprises:

- 12 (a) sensing the amplitude of alternating voltage V_{appl} at the coil terminals;
- 13 (b) sensing the amplitude of alternating current I through the coil terminals;
- 14 (c) sensing the phase angle ϕ_{pf} between said voltage and said current;
- 15 (d) calculating I_m according to the equation

$$I_m = I - \frac{V_{appl}}{R_s}$$

- 16 (e) calculating $(V_{ind})_I$ according to the equation

$$(V_{ind})_I = V_{appl} \cos \phi_{pf} - (R_{dc} + \Delta R_{external}) I_m$$

- 18 (f) calculating $(V_{ind})_L$ according to the equation

$$(V_{ind})_L = V_{appl} \sin \phi_{pf} - L \omega I_m$$

- 20 (g) calculating the displacement amplitude X according to the equation

$$X = \frac{1}{\omega \alpha} \sqrt{(V_{ind})_I^2 + (V_{ind})_L^2}$$

21 wherein ω is the radian frequency of V_{appl} .

- 1 2. The method according to claim 1 and further comprising:
 - 2 (a) determining a motor or alternator armature displacement amplitude X_c at
 - 3 which the armature or a structure fixed to the armature collides with a
 - 4 stationery structure;
 - 5 (b) selecting and storing a motor or alternator armature displacement
 - 6 amplitude X_{max} that is less than X_c ;
 - 7 (b) repeatedly performing said calculation of the displacement amplitude X ;
 - 8 and
 - 9 (c) limiting the displacement amplitude of the motor or alternator to maintain a
 - 10 displacement amplitude $X \leq X_{\text{max}}$.

- 1 3. A method for detecting the displacement amplitude X of a reciprocating
 - 2 armature of an alternating current, linear motor or linear alternator for controlling
 - 3 the reciprocation of the armature, the motor or alternator having a stator including
 - 4 a coil with a pair of coil terminals and wound around a ferromagnetic core with air
 - 5 gaps, the motor or alternator also having magnets fixed to the armature and
 - 6 positioned for reciprocating through the gaps, the motor or alternator also having
 - 7 a motor constant α , an equivalent resistance R_{ac} representing resistive losses in
 - 8 the coil and losses due to eddy currents and hysteresis induced by motion of the
 - 9 magnets with the coils open circuited, and an equivalent resistance $\Delta R_{\text{external}}$
 - 10 representing induced losses in structures surrounding the motor or alternator,
 - 11 wherein the method comprises:
 - 12 (a) sensing the amplitude of alternating voltage V_{appl} at the coil terminals;

- 13 (b) sensing the amplitude of alternating current I through the coil terminals;
 14 (c) sensing the phase angle Φ_{pf} between said voltage and said current;
 15 (d) calculating $(V_{ind})_I$ according to the equation

$$16 \quad (V_{ind})_I = V_{appl} \cos \Phi_{pf} - (R_{ac} + \Delta R_{external})I$$

- 17 (e) calculating $(V_{ind})_L$ according to the equation

$$18 \quad (V_{ind})_L = V_{appl} \sin \Phi_{pf} - L\omega I$$

- 19 (f) calculating the displacement amplitude X according to the equation

$$X = \frac{1}{\omega\alpha} \sqrt{(V_{ind})_I^2 + (V_{ind})_L^2}$$

- 20 wherein ω is the radian frequency of V_{appl} .

- 1 4. The method according to claim 3 and further comprising:

- 2 (a) determining a motor or alternator armature displacement amplitude X_c at
 3 which the armature or a structure fixed to the armature collides with a
 4 stationery structure;
 5 (b) selecting and storing a motor or alternator armature displacement
 6 amplitude X_{max} that is less than X_c ;
 7 (b) repeatedly performing said calculation of the displacement amplitude X ;
 8 and
 9 (c) limiting the displacement amplitude of the motor or alternator to maintain a
 10 displacement amplitude $X \leq X_{max}$.

- 1 5. A freezer comprising a free piston Stirling cooler mechanically linked to and
 2 driven by a reciprocating armature of an alternating current, linear motor, the
 3 linear motor having a stator including a coil with a pair of coil terminals and wound

4 around a ferromagnetic core with air gaps, the motor also having magnets fixed to
 5 the armature and positioned for reciprocating through the gaps, the motor also
 6 having a motor constant α , an equivalent resistance R_{dc} representing resistive
 7 losses in the coil, an equivalent resistance $\Delta R_{external}$ representing induced losses
 8 in structures surrounding the motor and an equivalent resistance R_s representing
 9 losses due to eddy currents and hysteresis induced by motion of the magnets with
 10 the coils open circuited, the freezer having a motor controller comprising:

- 11 (a) a voltage sensor connected to the coil terminals and configured for
- 12 sensing the amplitude of an alternating voltage V_{appl} at the coil terminals;
- 13 (b) a current sensor connected in series with a coil terminal and configured for
- 14 sensing the amplitude of an alternating current I through the coil terminals;
- 15 (c) a phase detector circuit connected to the coil terminals and configured for
- 16 sensing the phase angle ϕ_{pf} between said voltage and said current;
- 17 (d) a microcomputer circuit configured for
- 18 (i) calculating I_m according to the equation

$$I_m = I - \frac{V_{appl}}{R_s}$$

- 19 (ii) calculating $(V_{ind})_I$ according to the equation

$$(V_{ind})_I = V_{appl} \cos \phi_{pf} - (R_{dc} + \Delta R_{external}) I_m$$

- 21 (iii) calculating $(V_{ind})_L$ according to the equation

$$(V_{ind})_L = V_{appl} \sin \phi_{pf} - L \omega I_m$$

- 23 (iv) calculating the displacement amplitude X according to the equation

$$X = \frac{1}{\omega \alpha} \sqrt{(V_{ind})_I^2 + (V_{ind})_L^2}$$

24 wherein ω is the radian frequency of V_{appl} and

- 25 (v) limiting the displacement amplitude $\mathbf{X}$ of the motor to less than a
 26 selected and stored maximum displacement amplitude.

1 6. A freezer comprising a free piston Stirling cooler mechanically linked to and
 2 driven by a reciprocating armature of an alternating current, linear motor, the
 3 linear motor having a stator including a coil with a pair of coil terminals and wound
 4 around a ferromagnetic core with air gaps, the motor also having magnets fixed to
 5 the armature and positioned for reciprocating through the gaps, the motor also
 6 having a motor constant α , an equivalent resistance $\mathbf{R}_{ac}$ representing resistive
 7 losses in the coil and losses due to eddy currents and hysteresis induced by
 8 motion of the magnets with the coils open circuited, and an equivalent resistance
 9 $\Delta\mathbf{R}_{external}$ representing induced losses in structures surrounding the motor or
 10 alternator, the freezer having a motor controller comprising:

- 11 (a) a voltage sensor connected to the coil terminals and configured for
 12 sensing the amplitude of an alternating voltage $\mathbf{V}_{appl}$ at the coil terminals;
 13 (b) a current sensor connected in series with a coil terminal and configured for
 14 sensing the amplitude of an alternating current $\mathbf{I}$ through the coil terminals;
 15 (c) a phase detector circuit connected to the coil terminals and configured for
 16 sensing the phase angle Φ_{pf} between said voltage and said current;
 17 (d) a microcomputer circuit configured for

- 18 (i) calculating $(\mathbf{V}_{ind})_I$ according to the equation

$$19 \quad (V_{ind})_I = V_{appl} \cos \phi_{pf} - (R_{ac} + \Delta R_{external})I$$

- 20 (ii) calculating $(\mathbf{V}_{ind})_L$ according to the equation

$$21 \quad (V_{ind})_L = V_{appl} \sin \phi_{pf} - L\omega I$$

- 22 (ii) calculating the displacement amplitude $\mathbf{X}$ according to the equation

$$X = \frac{1}{\omega \alpha} \sqrt{(V_{ind})_I^2 + (V_{ind})_L^2}$$

- 23 wherein ω is the radian frequency of V_{appl} and
- 24 (iv) limiting the displacement amplitude X of the motor to less than a
- 25 selected and stored maximum displacement amplitude.