



Office de la Propriété

Intellectuelle  
du Canada

Un organisme  
d'Industrie Canada

Canadian  
Intellectual Property  
Office

An agency of  
Industry Canada

CA 2800416 A1 2011/12/08

(21) **2 800 416**

(12) **DEMANDE DE BREVET CANADIEN**  
**CANADIAN PATENT APPLICATION**

(13) **A1**

(86) Date de dépôt PCT/PCT Filing Date: 2011/05/30  
(87) Date publication PCT/PCT Publication Date: 2011/12/08  
(85) Entrée phase nationale/National Entry: 2012/11/22  
(86) N° demande PCT/PCT Application No.: IL 2011/000416  
(87) N° publication PCT/PCT Publication No.: 2011/151816  
(30) Priorité/Priority: 2010/05/30 (IL206061)

(51) Cl.Int./Int.Cl. *B60W 30/18* (2012.01),  
*B60K 6/46* (2007.10), *B60W 10/06* (2006.01),  
*B60W 10/08* (2006.01), *B60W 20/00* (2006.01),  
*F16H 61/47* (2010.01), *F16H 61/472* (2010.01),  
*B64F 1/10* (2006.01)

(71) Demandeur/Applicant:  
ISRAEL AEROSPACE INDUSTRIES LTD., IL

(72) Inventeurs/Inventors:  
BRAIER, RAN, IL;  
PERRY, ARIE, IL

(74) Agent: OSLER, HOSKIN & HARCOURT LLP

(54) Titre : CONTROLEUR POUR UN SYSTEME D'ENTRAINEMENT

(54) Title: CONTROLLER FOR A DRIVE SYSTEM

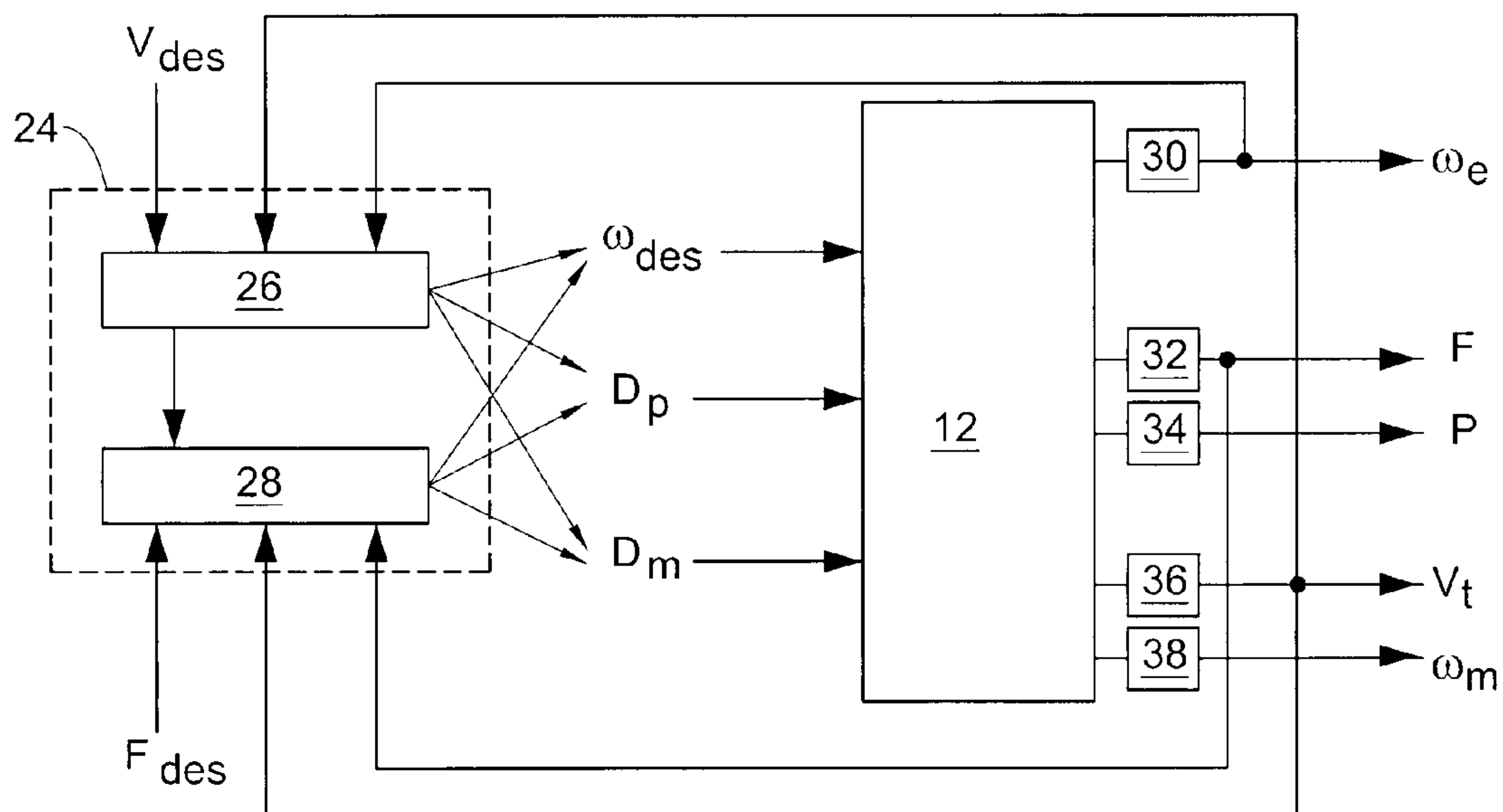


Fig. 2

(57) Abrégé/Abstract:

A primary controller disclosed. The primary controller is configured for controlling operation of a drive system comprising a prime mover, a generator, and a motor, wherein the prime mover is configured to provide energy to the generator, which is configured to drive the motor. The controller comprises a speed controller configured for determining a target speed of the motor dependent on externally-supplied speed input and a torque controller configured for determining a target torque of the motor based on externally-supplied torque input and on parameters of the vehicle. The primary controller is configured to simultaneously determine the target speed and the target torque and to simultaneously control the prime mover, generator, and motor to operate the motor at the target speed and the target torque.

## (12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau(43) International Publication Date  
8 December 2011 (08.12.2011)(10) International Publication Number  
WO 2011/151816 A1

## (51) International Patent Classification:

**B60W 30/18** (2006.01) **B60K 6/46** (2007.10)  
**B60W 20/00** (2006.01) **F16H 61/47** (2010.01)  
**B60W 10/06** (2006.01) **F16H 61/472** (2010.01)  
**B60W 10/08** (2006.01) **B64F 1/10** (2006.01)

(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.

## (21) International Application Number:

PCT/IL2011/000416

## (22) International Filing Date:

30 May 2011 (30.05.2011)

## (25) Filing Language:

English

## (26) Publication Language:

English

## (30) Priority Data:

206061 30 May 2010 (30.05.2010) IL

(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).

## (72) Inventors; and

(75) Inventors/Applicants (for US only): **BRAIER, Ran** [IL/IL]; 8c Emek Haaylon Blvd., P.O. Box 2264, 73142 Shoham (IL). **PERRY, Arie** [IL/IL]; 3 Shabtai Street, 45257 Hod Hasharon (IL).

(74) Agent: **REINHOLD COHN & PARTNERS**; P.O.B. 13239, Tel-Aviv 61131 (IL).

## Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- of inventorship (Rule 4.17(iv))

## Published:

- with international search report (Art. 21(3))

[Continued on next page]

## (54) Title: CONTROLLER FOR A DRIVE SYSTEM

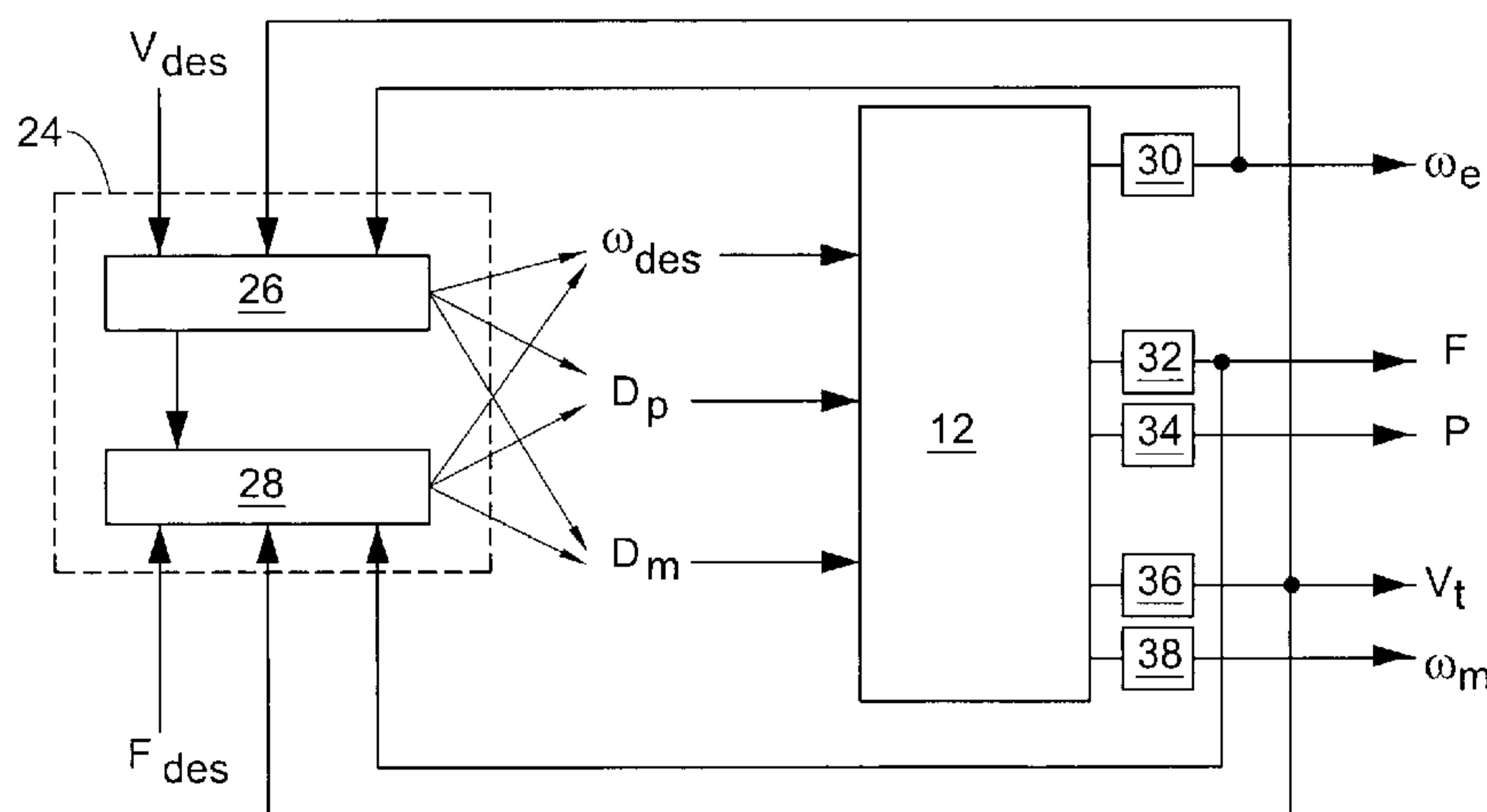


Fig. 2

WO 2011/151816 A1

(57) **Abstract:** A primary controller disclosed. The primary controller is configured for controlling operation of a drive system comprising a prime mover, a generator, and a motor, wherein the prime mover is configured to provide energy to the generator, which is configured to drive the motor. The controller comprises a speed controller configured for determining a target speed of the motor dependent on externally-supplied speed input and a torque controller configured for determining a target torque of the motor based on externally-supplied torque input and on parameters of the vehicle. The primary controller is configured to simultaneously determine the target speed and the target torque and to simultaneously control the prime mover, generator, and motor to operate the motor at the target speed and the target torque.

**WO 2011/151816 A1**



---

- *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))*

## CONTROLLER FOR A DRIVE SYSTEM

### FIELD OF THE INVENTION

This invention relates to vehicles powered by hydraulic drive systems, and more particularly to control systems therefor.

### BACKGROUND OF THE INVENTION

5        Typically, a drive system for a vehicle comprises a prime mover (such as a diesel engine), usually outputting constant power, and which powers a generator, which in turn drives motors in each of the vehicle wheels. System speed of response, maneuverability and varying conditions are usually not of concern. When such a drive system carries a load having multiple degrees of freedom, with resonant frequencies lower than that of the drive system itself, 10        maneuvering of the vehicle is difficult if not impossible.

### SUMMARY OF THE INVENTION

A controller is provided which controls both the vehicle speed and traction force at the same time, by using controllable variable displacement hydraulic motors. This is accomplished by having a speed controller which controls the speed of the vehicle by controlling several 15        system inputs, and a traction force controller to determine the traction force of the vehicle controlling same inputs, as well as based on control of parameters of the vehicle. To accomplish this, each of the two controllers controls the prime mover RPM, the hydraulic pump displacement, and the hydraulic motor displacement to drive the vehicle. The measured RPM of the prime mover is used as feedback for the speed controller, the measured vehicle speed is used 20        as feedback for both the speed controller and the traction force controller, and the measured drive pressure of the hydraulic system of the vehicle is used as feedback for the traction force controller.

Vehicle speed, acceleration and traction force are governed simultaneously by a controller which constantly controls dynamically all vehicle moving parameters, the prime 25        mover speed, the vehicle speed and traction, in real time. The overall system control is accomplished by having a speed controller which controls the speed of the vehicle based on user desired speed input, and a force controller to determine the acceleration to reach the desired

- 2 -

speed and the traction force of the vehicle based on user input and a force envelope, road conditions, parameters of the vehicle, and induced structural limitations, while taking the current speed of the vehicle into account. To accomplish this, each of the two controllers controls the prime mover, the hydraulic pump, and the hydraulic motor to drive the vehicle. The measured 5 RPM of the prime mover is used as feedback for the speed controller, and compared to desired power output. The measured vehicle speed is used as feedback for both the speed controller and the force controller, and the measured acceleration and traction force (which can be measured by any one of several known methods) of the vehicle is used as feedback for the force controller. The invention enables the real time control of hydraulically driven vehicles, utilizing varying 10 governing rules according to the specific requirement and as function of varying conditions, typically impossible today.

According to one aspect of the presently disclosed subject matter, there is provided a primary controller configured for controlling operation of a drive system comprising a prime mover, a generator, and a motor, wherein the prime mover is configured to provide energy to the 15 generator, which is configured to drive the motor, the controller comprising:

- a speed controller configured for determining a target speed of the motor dependent on externally-supplied speed input; and
- a torque controller configured for determining a target torque of the motor based on externally-supplied torque input and on parameters of the vehicle;

20 wherein the primary controller is configured to:

- simultaneously determine the target speed and the target torque; and
- simultaneously control the prime mover, generator, and motor to operate the motor at the target speed and the target torque.

The speed controller may be further configured to determine the target speed dependent 25 on the power output of the prime mover and on the measured actual speed of the motor, with the torque controller being further configured to determine the target torque based on the measured actual speed and the measured actual torque of the motor.

According to another aspect of the presently disclosed subject matter, there is provided a primary controller being configured for controlling operation of a vehicle driven by a drive 30 system, the controller comprising:

- a speed controller configured for determining a target speed of the vehicle dependent on externally-supplied speed input; and

- 3 -

- a traction force controller configured for determining target traction force and acceleration of the vehicle based on externally-supplied traction input and on parameters of the vehicle;

wherein the primary controller is configured to:

- simultaneously determine the target speed, acceleration, and traction force; and
- simultaneously control a prime mover, generator, and motor of the drive system to drive the vehicle at the target speed, acceleration, and traction force.

The speed controller may be further configured to determine the target speed of the vehicle dependent on the power of prime mover and on the measured actual speed of the vehicle, with the traction force controller being further configured to determine the target traction force of the vehicle based on the measured actual speed and the traction force of the vehicle.

The measured actual speed of the vehicle may be measured by measuring the angular velocity of wheels of the vehicle.

The primary controller may be configured to:

- influence the speed of the vehicle at least by affecting the speed of the motor; and
- influence the traction force of the vehicle at least by affecting the torque of the motor.

According to both of the above aspects, the torque controller may be further configured to determine the target torque dependent on the target speed.

Further according to both of the above aspects, the externally-supplied speed input may comprise a desired user-supplied desired vehicle speed.

Further according to both of the above aspects, the externally-supplied torque input may comprise information regarding maximum and minimum design torques.

Further according to both of the above aspects, the prime mover may be an engine, the primary controller being configured to control the prime mover at least by affecting its speed.

Further according to both of the above aspects, the primary controller may be further configured to mitigate effects on the prime mover, the motor speed, and the motor torque due to force disturbances (such as slopes, wind, and rolling friction) on the vehicle when driven by the drive system.

Further according to both of the above aspects, the drive system may be configured to drive the vehicle when subject to a load, the primary controller being configured to reduce the resonance of the load during operation of the vehicle subject to the load.

Further according to both of the above aspects, the drive system may be an electric drive system. The prime mover may be selected from the group consisting of a diesel engine, one or

more batteries, and one or more fuel cells. The generator may be an electric generator. The motor may be an electric motor.

Further according to both of the above aspects, the drive system may be a hydraulic drive system. The prime mover may be a diesel engine. The generator may be a hydraulic pump. The 5 primary controller may be configured to control the hydraulic pump at least by affecting its displacement. The motor may be a hydraulic motor. The primary controller may be configured to control the hydraulic motor at least by affecting its displacement.

According to a further aspect of the presently disclosed subject matter, there is provided a primary controller configured for controlling operation of a drive system comprising a prime mover, a generator, and a motor, wherein the prime mover is configured to provide energy to the 10 generator, which is configured to drive the motor, the controller comprising:

- a speed controller configured for determining a target speed of the motor dependent on at least two different input parameters; and
- a torque controller configured for determining a target torque of the motor based on at 15 least two different input parameters;

wherein the primary controller is configured to:

- simultaneously determine the target speed and torque; and
- simultaneously control the prime mover, generator, and motor to operate the motor at the target speed and the target torque.

20 The input parameters can be measured input parameters selected from the group consisting of power output of the prime mover, measured actual speed of the vehicle, measured speed of the hydraulic motor, and measured actual traction force of the vehicle.

The input parameters can be user input parameters selected from the group consisting of user-supplied desired speed, the maximum acceleration by which the desired speed may be 25 reached, user-supplied torque, information regarding a maximum and a minimum design torque, desired motor speed, parameters of the vehicle (e.g., dimensions and weight of the vehicle), and parameters of the actual load maneuvered by the vehicle.

The input parameters can be external input parameters selected from the group consisting of locations other vehicles, slope of the road, wind, and rolling friction.

30 The at least two different input parameters can comprise at least one parameter from each of two or more of the measured input parameters, the user input parameters, and the external input parameters.

According to a still further aspect of the presently disclosed subject matter, there is provided a vehicle comprising a primary controller according to any one of the preceding claims. The vehicle may be configured to tow an aircraft, and may be further configured to receive a landing gear of the aircraft.

## 5 BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, an embodiment will now be described, by way of a non-limiting example only, with reference to the accompanying drawings, in which:

**Fig. 1A** is a schematic illustration of a vehicle having a drive system;

10 **Fig. 1B** is a schematic illustration of the vehicle illustrated in Fig. 1A with a hydraulic drive system;

**Fig. 1C** is a schematic illustration of the vehicle illustrated in Fig. 1A with an electric drive system; and

15 **Fig. 2** is a schematic illustration of a primary controller according to the present invention.

## DETAILED DESCRIPTION OF EMBODIMENTS

As schematically illustrated in Fig. 1A, there is provided a vehicle **10**, which is powered by a drive system **12** designed to drive the vehicle. The vehicle **10** further comprises wheels **14** for moving the vehicle, and a platform **16** for carrying a load, which may be a landing gear (not illustrated) of an airplane, such as a commercial airliner. In addition, a controller (not illustrated in Fig. 1) is provided to control the operation of the vehicle via the HDS **12**.

20 In addition to the above, the vehicle **10** may be an aircraft towing vehicle, and thus be provided with suitable elements therefore. Examples of some of such vehicles and elements are disclosed, for example, in one or more of WO 2008/038270, WO 2008/139437, and WO 2008/139440, the entire disclosures of which are incorporated herein by reference.

25 The drive system **12** comprises a prime mover **18** (such as a diesel engine), a generator **20**, and a motor **22** associated with, and configured to drive, each wheel **14** of the vehicle **10**. (It will be appreciated that although the drive system **12** is described as having one prime mover **18** and one generator **20**, it may comprise several of these elements, for example to provide redundancy.) The drive system **12** is similar to those known in the art. In particular, the prime

- 6 -

motor **18** provides power to the generator **20**, which drives each motor **22**. As mentioned, the motor **22** is functionally connected the wheels **14** to power them.

The platform **16** is connected with a chassis of the vehicle **10** with known spring and damping characteristics as part of the multi degrees of freedom load. These parameters may be measured and/or estimated empirically by any known means. In addition, appropriate connectors, such as springs and/or dampers may be provided between the platform **16** and the chassis of the vehicle **10** in order to provide desired characteristics, depending on the load.

The platform **16** is typically designed to carry a heavy load having multiple degrees of freedom. For example, the vehicle **10** may be configured to tow an aircraft (such as a commercial jumbo-jet), in which case the platform **16** may be designed to carry a landing gear, such as the nose landing gear, of the aircraft.

The vehicle **10** is further provided with a primary controller, one example of which is schematically illustrated in Fig. 2 and designated at **24**. The primary controller **24** comprises a speed controller **26**, configured to determine a target speed (i.e., a speed at which the speed controller calculates the vehicle could operate most ideally, taking into account inputs and calculating as detailed below) of the vehicle, and a force controller **28**, configured to determine target acceleration and target traction force (i.e., acceleration and traction force at which the force controller calculates the vehicle could operate most ideally, taking into account inputs and calculating as detailed below) of the vehicle. (It will be appreciated that while the term “force controller” is used with reference to the specific example of a vehicle, it is equivalent to a torque controller which may be used by a primary controller designed to control operations of an HDS designed to drive something other than a vehicle, such as lifting equipment, an antenna, etc.)

The speed controller **26** is configured to determine the target speed, taking into account several inputs, which may include:

- a user-supplied desired speed ( $V_{des}$ , for example regarding the desired vehicle speed (this may be provided via a computer interface, or by a traditional foot-pedal);
- the maximum acceleration by which the desired speed may be reached;
- the power output of the prime mover **18**; and
- the actual speed of the vehicle **10** (for example by measuring the angular velocity of the wheels of the vehicle).

The force controller **28** is configured to determine the target acceleration and traction force, taking into account several inputs, which may include:

- 7 -

- a user-supplied traction input ( $F_{des}$ , this may include maximum and minimum design vehicle traction forces provided in advance by a designer);
- parameters of the vehicle (e.g., dimensions and weight of the vehicle);
- parameters of the actual load maneuvered by the vehicle
- 5     • the actual speed of the vehicle **10**;
- the target speed determined by the speed controller **26**;
- the actual traction force of the vehicle **18**.

The primary controller **24** is configured to determine the target speed, acceleration, and traction force simultaneously, and to control the prime mover **18**, generator **20**, and motors **22** simultaneously to implement the target values. For optimal vehicle performance, the primary controller **24** may direct operation of the drive system **12** such that the power output of the vehicle **10** (i.e., traction force  $\times$  speed) is as close as possible to that of the prime mover **18** at all times.

In order to implement the target values, the primary controller **24** is configured to affect 15 the power output of the prime mover **18**, and the operations of the generator **20** and motors **22**.

In addition to the above, the primary controller **24** may be configured to detect and mitigate the effects of external forces which are due to disturbances on the vehicle **10**. These disturbances may include slopes of the road on which the vehicle travels, the effect of wind on the vehicle and/or the load, and the effects of rolling friction of the vehicle and the towed load.

According to one example, which is illustrated in Fig. 1B, the drive system **12** is a 20 hydraulic drive system (HDS). The prime mover **18** may be any suitable prime mover, such as a diesel engine. The generator **20** may be a variable displacement hydraulic pump **20a**, and the motors **22** may be variable displacement hydraulic motors **22a**. According to such an arrangement, the power output of the prime mover is related to its speed, and the hydraulic pump 25 supplies hydraulic fluid to the hydraulic motors.

It will be appreciated that, as is well known, the speed of the vehicle **10** is associated with the speed of the hydraulic motor, and the traction force thereof is associated with the torque of the hydraulic motor thereof.

The primary controller **24** may be further configured to maintain system stability by 30 reducing the resonant frequencies of the load, so that it does not approach the system bandwidth of the drive system **12**. If the resonance of the load were to approach or lower than that of the system bandwidth of the drive system **12**, control of the vehicle **10** would be lost and difficult to regain.

- 8 -

By analyzing the load dynamics, vehicle and drive system dynamics, and control system dynamics, the system state space may be defined by the following twelve variables:

$X_1 = X_p$ (platform displacement)	$X_2 = X_1^* = V_p$ (platform velocity)
$X_3 = X_t$ (vehicle displacement)	$X_4 = X_3^* = V_t$ (vehicle velocity)
$X_5 = \omega_e$ (engine speed RPM)	$X_6 = P$ (hydraulic system pressure)
$X_7 = D_p$ (pump displacement)	$X_8 = X_7^* = D_p^*$ (Pump displacement rate)
$X_9 = D_m$ (motor displacement)	$X_{10} = X_9^* = D_m^*$ (Motor displacement rate)
$X_{11} = P_{c1}$ ( $D_p$ control pressure)	$X_{12} = P_{c2}$ ( $D_m$ control pressure)

The system is further defined by the following variables:

5 System inputs .....  $\omega_{des}$  (desired speed);  $eV_p$ ;  $eV_m$  (pump & motor control)  
 System outputs .....  $V_t(X_4)$ ;  $\omega_e(X_5)$ ;  $P(X_6)$ ;  $P_{c1}(X_{11})$ ;  $P_{c2}(X_{12})$   
 System disturbance (fast) .....  $F_{load}$   
 System disturbance (slow) .....  $F_{disturb}$  ( $F_{roll} + F_{slope} + F_{wind}$ )  
 Constant parameter (in control loop) .....  $F_{preload\ pump}$  (pump spring preload)  
 10 Constant parameter (in control loop) .....  $F_{preload\ motor}$  (motor spring preload)

The state space equations are as follows (it will be appreciated that  $X_5^*$  is the first input,  $X_{11}^*$  is the second input, and  $X_{12}^*$  is the third input to the system):

$$X_1^* = X_2$$

$$15 \quad X_2^* = -(K_p/M_p)X_1 - (B_p/M_p)X_2 + (K_p/M_p)X_3 + (B_p/M_p)X_4 - F_{load}/M_p$$

$$X_3^* = X_4$$

$$X_4^* = D_{m0}(r/RM_t)X_6 + P_0(r/RM_t)X_9 - (B_m/M_t)X_4 - (B_p/M_t)X_4 - (K_p/M_t)X_3 + (K_p/M_t)X_1 + (B_p/M_t)X_2 - F_{disturb}/M_t$$

$$X_5^* = -(K_e/J_e)X_5 - (D_{p0}/J_e)X_6 - (P_0/J_e)X_7 + (K_e/J_e)\omega_{des}$$

$$20 \quad X_6^* = D_{p0}(\beta_e/V_0)X_5 + \omega_{e0}(\beta_e/V_0)X_7 - (C_t\beta_e/V_0)X_6 - D_{m0}(r/R)(\beta_e/V_0)X_4 - \omega_{m0}(\beta_e/V_0)X_9$$

$$X_7^* = X_8$$

$$X_8^* = (A c_p K_{pump}/M_p c_p)X_{11} - (B c_p/M_p c_p)X_8 - (K c_p/M_p c_p)X_7 - (K_{pump} F_{prep}/M_p c_p)$$

$$X_9^* = X_{10}$$

$$X_{10}^* = (A c_m K_{motor}/M_m c)X_{12} - (B_m/M_m c_m)X_{10} - (K_m/M_m c)X_9 - (K_{motor} F_{prem}/M_m c)$$

$$25 \quad X_{11}^* = K_e(\beta_e/V_0)eV_p - A c_p(\beta_e/V_0 K_{pump})X_8 - (C + K_p)(\beta_e/V_0)X_{11}$$

$$X_{12}^* = K_e(\beta_e/V_0)eV_m - A c_m(\beta_e/V_0 K_{motor})X_{10} - (C + K_p)(\beta_e/V_0)X_{12}$$

- 9 -

where:

$B_p$  = damper damping

$C_t$  = total hydraulic system leakage

$F_{\text{disturb}}$  = summation of all disturbing forces

5  $F_{\text{load}}$  = force due to the load

$K_p$  = damper stiffness

$M_p$  = mass of the load

$M_t$  = mass of the vehicle

$V_0$  = volume of hydraulic fluid

10  $\beta_e$  = bulk modulus of hydraulic fluid

$\omega_{\text{des}}$  = desired speed of prime mover

$D_{m0}$ ,  $D_{p0}$ ,  $\omega_{e0}$ ,  $\omega_{m0}$ , and  $P_0$  are system operating point values

$R$  is the gear ratio

$R$  is the wheel radius

15  $J_e$  and  $K_e$  are diesel engine inertia and control gain constant

$K_{\text{pump}}$ ,  $K_{\text{motor}}$ ,  $K_m$ ,  $K_p$ ,  $F_{\text{prep}}$ , and  $F_{\text{prem}}$ , are pump and motor controller parameters

$M_m$ ,  $M_p$ ,  $B_m$ ,  $c_m$ ,  $c_p$ , are pump and motor controller piston parameters

In addition, the state space is defined as follows :

Governing equations:	$X^* = AX + Bu$	$Y = CX + Du$		
State variables:	$X: n \times n$	$u: m \times 1$	$Y: 1 \times 1$	
State matrices:	$A: n \times m$	$B: 1 \times m$	$C: 1 \times n$	$D: 1 \times m$

20

By utilizing the above description of the system state space notation,  $y=f(u)$ ,  $D_p$ ,  $D_m$ , and  $\omega_{\text{des}}$  are used as a basis for the primary controller 24 inputs to operate the vehicle 10 by controlling  $\omega_e$ ,  $V_t$ , and  $P$  as system outputs. Any known numerical computing environment, for example as sold under the name MATLAB® (with or without Simulink®), can be used to 25 develop an open loop transfer function  $G(s)$ .

The open loop transfer function is solved in order to obtain the dynamic behavior of the system (i.e., its dominant poles). At the same time, a parameter and order of magnitude analysis is performed in order to eliminate insignificant elements and neglect fast responding dynamics, thus simplifying state matrices  $A$ ,  $B$ , and  $C$ . For example, pump and motor valve control system 30 may be designed such that they are fast enough so that their dynamic responses and related swashplate (pump and motor) movements are fast relative to input servo-valve voltage and can be regarded as pure gain.

- 10 -

Likewise, slow-changing disturbance loads (e.g., wind and slope) and control piston spring preload coefficient (pump and motor) may be disregarded.

As further illustrated in Fig. 2, the speed controller **26** and force controller **28** control the displacement of the hydraulic pump **20a** ( $D_p$ ), the displacement of the hydraulic motor **22a** ( $D_m$ ), and the desired speed of the prime mover **18** ( $\omega_{des}$ ), which are implemented via the HDS **12**. This affects, *inter alia*, the actual speed of the prime mover **18** ( $\omega_e$ ), the traction of the vehicle (F), the pressure of the HDS (P), the velocity of the vehicle **10** ( $V_t$ ), and the speed of the hydraulic motor ( $\omega_m$ ). It will be appreciated that the vehicle may be supplied with one or more instruments to measure these values, for example a prime mover speed sensor **30**, a vehicle traction sensor **32**, an HDS pressure sensor **34**, a vehicle velocity sensor **36**, and a motor speed sensor **38**. Each of these may be provided for example as is known in the art.

In particular, the speed controller **26** may be configured to determine the target speed and/or to determine how to control the displacement of the hydraulic pump **20a** ( $D_p$ ), the displacement of the hydraulic motor **22a** ( $D_m$ ), and the desired speed of the prime mover **18** ( $\omega_{des}$ ), based on the power output of the prime mover (which is predictably related to the actual speed  $\omega_e$  thereof) and the measured actual speed of the hydraulic motor  $\omega_m$ . In addition, the force controller may be configured to determine the target torque and/or to determine how to control the displacement of the hydraulic pump **20a** ( $D_p$ ), the displacement of the hydraulic motor **22a** ( $D_m$ ), and the desired speed of the prime mover **18** ( $\omega_{des}$ ), based on the measured actual speed of the hydraulic motor  $\omega_m$  and the measured traction of the vehicle F (which relates to the torque of the hydraulic motor **22a**).

According to another example, which is illustrated in Fig. 1C, the drive system **12** is an electric drive system. The prime mover **18** may be any suitable prime mover, such as a diesel engine. The generator **20** may be an electric generator **20b**, and the motors **22** may be any suitable types of electric motors **20b**. It will be appreciated that the speed and torque of the electric motors **22b** may be controlled in any suitable way, depending on the type of electric motor provided, as is well known.

An open loop transfer function for the electric drive system may be determined similar to as described above, *mutatis mutandis*.

It will be appreciated that the example illustrated in Fig. 1C comprises more than one electric generators **20b**, each of which drives one or more electric motors **20b**, as indicated by solid lines. In such a case, each electric generator **20b** may be further connected to the electric motors **22b** which are driven by one or more other electric generators, as indicated by dashed

- 11 -

lines. Thus, if one of the electric generators **20b** should fail, one or more of the others can be automatically configured to drive the electric motor(s) **22b** which had previously been driven by the failed electric generator. Thus, the drive system **12** is provided with a redundancy. The vehicle may comprise a single prime mover **12** as illustrated, or more than one (e.g., one 5 associated with each electric generator **20b**).

Providing an electric drive system as disclosed herein may have several advantages. For example, such a system facilitates operating the vehicle **10** at slow speeds. In the event that the vehicle is an airplane towing vehicle, this allows for pushback operations to be performed by the vehicle **10**. In addition, the drive system **12** is afforded a high degree of control, which helps 10 protect the nose landing gear of the airplane, which is typically the element thereof to which the vehicle **10** applies direct force, from damage due to high loads.

It will be appreciated that by providing a primary controller **24** which operates as described above allows multiple inputs to be used to determine multiple outputs simultaneously.

Those skilled in the art to which this invention pertains will readily appreciate that 15 numerous changes, variations and modifications can be made without departing from the scope of the invention *mutatis mutandis*. For example, the primary controller may be configured for use, *mutatis mutandis*, with any type of system driven by an HDS and subject to a multi-degree of freedom load, such as construction and/or lifting equipment, antennas, etc.

**CLAIMS:**

1. A primary controller configured for controlling operation of a drive system comprising a prime mover, a generator, and a motor, wherein the prime mover is configured to provide energy to the generator, which is configured to drive the motor, the controller comprising:

- 5 • a speed controller configured for determining a target speed of the motor dependent on externally-supplied speed input; and
- a torque controller configured for determining a target torque of the motor based on externally-supplied torque input and on parameters of the vehicle;

wherein the primary controller is configured to:

- 10 • simultaneously determine the target speed and the target torque; and
- simultaneously control the prime mover, generator, and motor to operate the motor at the target speed and the target torque.

2. The primary controller according to Claim 1, wherein:

- 15 • the speed controller is further configured to determine the target speed dependent on the power output of the prime mover and on the measured actual speed of the motor; and
- the torque controller is further configured to determine the target torque based on the measured actual speed and the measured actual torque of the motor.

3. The primary controller according to any one of the preceding claims, wherein said torque controller is further configured to determine the target torque dependent on the target speed.

20 4. The primary controller according to any one of the preceding claims, wherein said externally-supplied speed input comprises a desired user-supplied desired vehicle speed.

5. The primary controller according to any one of the preceding claims, wherein said externally-supplied torque input comprises information regarding maximum and minimum 25 design torques.

6. A primary controller according to any one of the preceding claims, wherein said prime mover is an engine, said primary controller being configured to control the prime mover at least by affecting its speed.

30 7. A primary controller according to any one of the preceding claims, being further configured to mitigate effects on the prime mover, the motor speed, and the motor torque due to force disturbances on the vehicle when driven by the drive system.

- 13 -

8. A primary controller according to Claim 7, wherein said disturbances are selected from the group including slopes, wind, and rolling friction.

9. A primary controller according to any one of the preceding claims, wherein said drive system is configured to drive the vehicle when subject to a load, said primary controller being configured to reduce the resonance of the load during operation of the vehicle subject to said load.

10. A primary controller according to any one of the preceding claims, wherein said drive system is an electric drive system.

11. A primary controller according to Claim 10, wherein said prime mover is selected from the group consisting of a diesel engine, one or more batteries, and one or more fuel cells.

12. A primary controller according to any one of Claims 10 and 11, wherein said generator is an electric generator.

13. A primary controller according to any one of Claims 10 through 12, wherein said motor is an electric motor.

14. A primary controller according to any one of Claims 1 through 9, wherein said drive system is a hydraulic drive system.

15. A primary controller according to Claim 14, wherein said prime mover is a diesel engine.

16. A primary controller according to any one of Claims 14 and 15, wherein said generator is a hydraulic pump.

17. A primary controller according to Claim 16, being configured to control the hydraulic pump at least by affecting its displacement.

18. A primary controller according to any one of Claims 14 through 17, wherein said motor is a hydraulic motor.

19. A primary controller according to Claim 18, being configured to control the hydraulic motor at least by affecting its displacement.

20. A primary controller being configured for controlling operation of a vehicle driven by a drive system, the controller comprising:

- a speed controller configured for determining a target speed of the vehicle dependent on externally-supplied speed input; and
- a traction force controller configured for determining target traction force and acceleration of the vehicle based on externally-supplied traction input and on parameters of the vehicle;

wherein the primary controller is configured to:

- simultaneously determine the target speed, acceleration, and traction force; and
- simultaneously control a prime mover, generator, and motor of the drive system to drive the vehicle at the target speed, acceleration, and traction force.

5 21. The primary controller according to Claim 20, wherein:

- the speed controller is further configured to determine the target speed of the vehicle dependent on the power of prime mover and on the measured actual speed of the vehicle; and
- the traction force controller is further configured to determine the target traction force of the vehicle based on the measured actual speed and the traction force of the vehicle.

10 22. A primary controller according to Claim 21, wherein the measured actual speed of the vehicle is measured by measuring the angular velocity of wheels of the vehicle.

23. A primary controller according to any one of Claims 20 and 21, being configured to:

- influence the speed of the vehicle at least by affecting the speed of the motor; and
- influence the traction force of the vehicle at least by affecting the torque of the motor.

15 24. The primary controller according to any one of Claims 20 through 23, wherein said traction force controller is further configured to determine the target traction force dependent on the target speed.

25. The primary controller according to any one of Claims 20 through 24, wherein said 20 externally-supplied speed input comprises desired vehicle speed.

26. The primary controller according to any one of Claims 20 through 25, wherein said externally-supplied traction input comprises information regarding maximum and minimum design vehicle traction forces.

27. A primary controller according to any one of Claims 20 through 26, wherein said prime 25 mover is an engine, said primary controller being configured to control the prime mover at least by affecting its speed.

28. A primary controller according to any one of Claims 20 through 27, being further configured to mitigate effects on the speed and traction forces due to force disturbances on the vehicle.

30 29. A primary controller according to Claim 28, wherein said disturbances are selected from the group including slopes, wind, and rolling friction.

- 15 -

30. A primary controller according to any one of Claims 20 through 29, wherein said vehicle is configured to carry a load, said primary controller being configured to reduce the resonance of the load during operation of the vehicle subject to said load.

31. A primary controller according to any one of Claims 20 through 30, wherein said drive system is an electric drive system.

32. A primary controller according to Claim 31, wherein said prime mover is selected from the group consisting of a diesel engine, one or more batteries, and one or more fuel cells.

33. A primary controller according to any one of Claims 31 and 32, wherein said generator is an electric generator.

34. A primary controller according to any one of Claims 31 through 33, wherein said motor is an electric motor.

35. A primary controller according to any one of Claims 20 through 30, wherein said drive system is a hydraulic drive system.

36. A primary controller according to Claim 35, wherein said prime mover is a diesel engine.

37. A primary controller according to any one of Claims 35 and 36, wherein said generator is a hydraulic pump.

38. A primary controller according to Claim 37, being configured to control the hydraulic pump at least by affecting its displacement.

39. A primary controller according to any one of Claims 35 through 38, wherein said motor is a hydraulic motor.

40. A primary controller according to Claim 39 being configured to control the hydraulic motor at least by affecting its displacement.

41. A vehicle comprising a primary controller according to any one of the preceding claims.

42. A vehicle according to Claim 41, being configured to tow an aircraft.

43. A vehicle according to Claim 42, being configured to receive a landing gear of the aircraft.

1/2

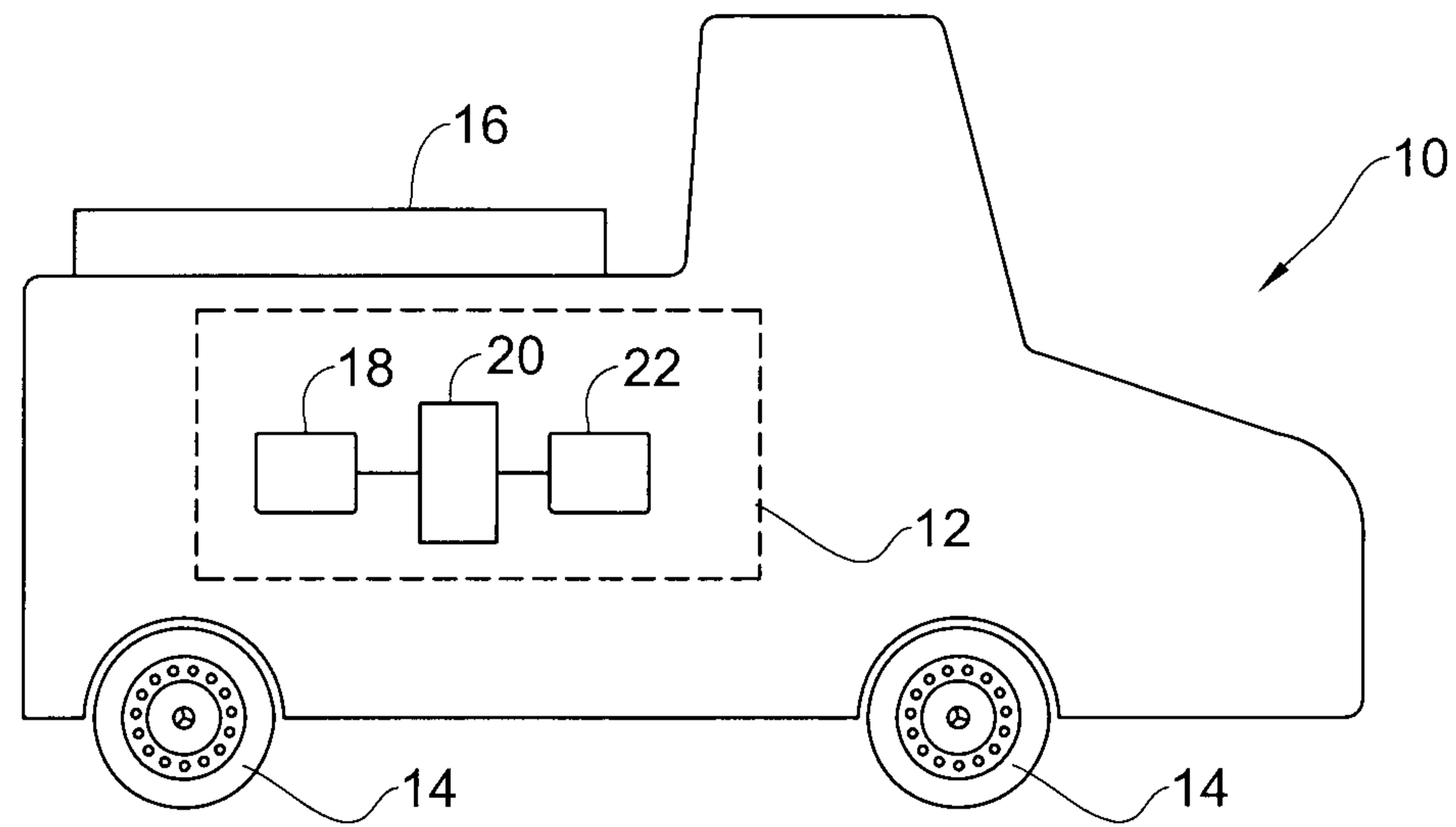


Fig. 1A

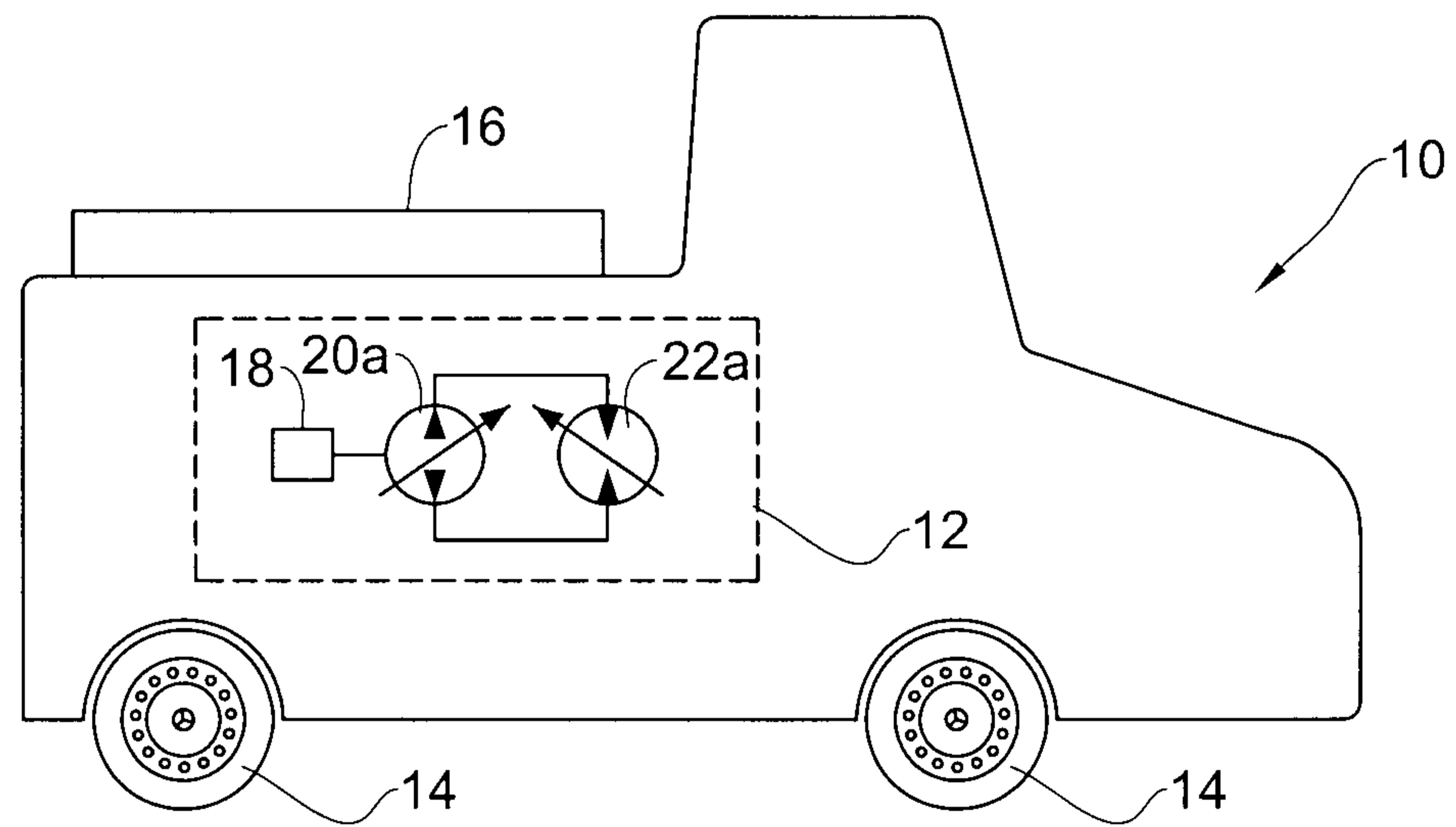


Fig. 1B

2/2

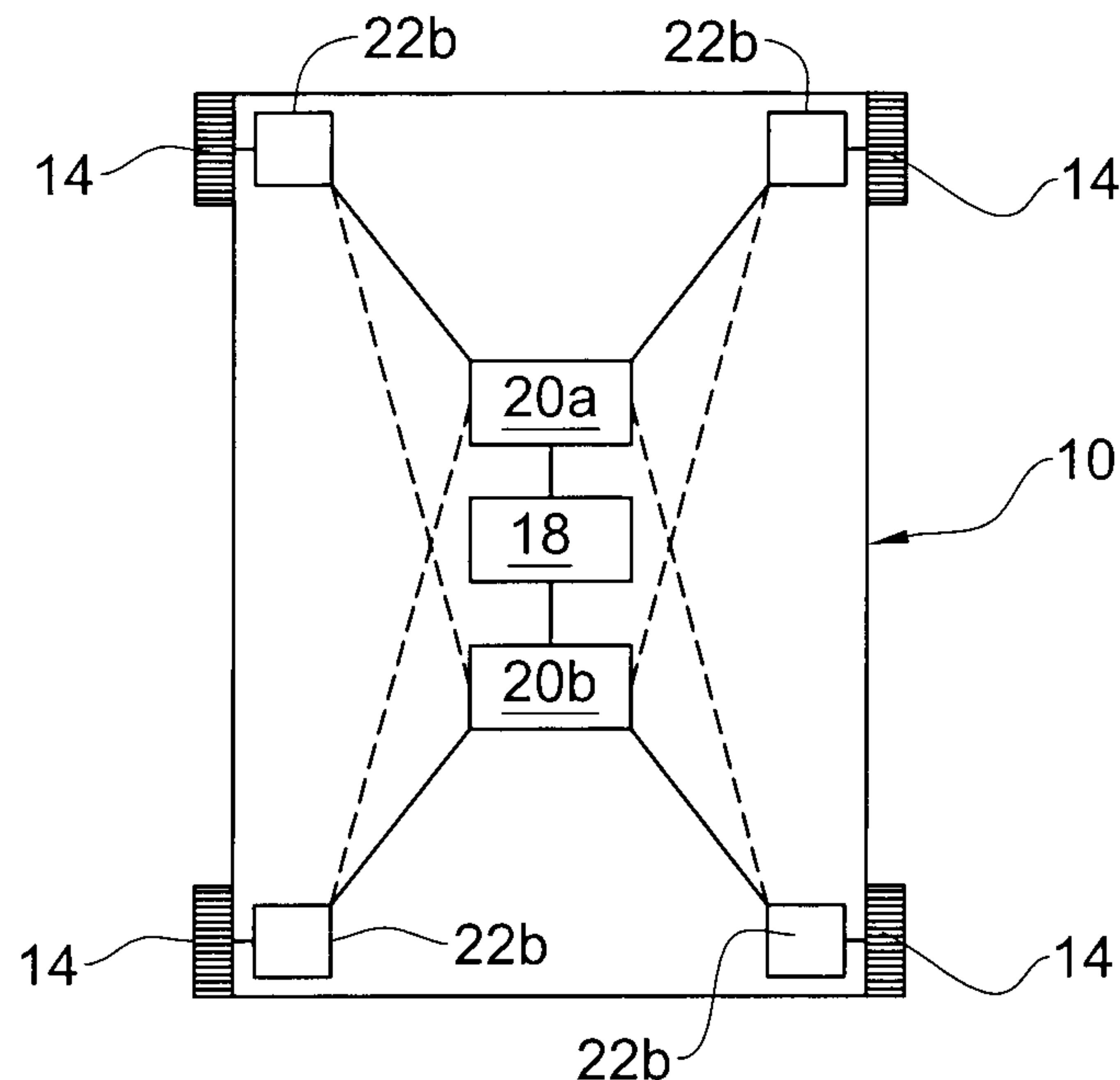


Fig. 1C

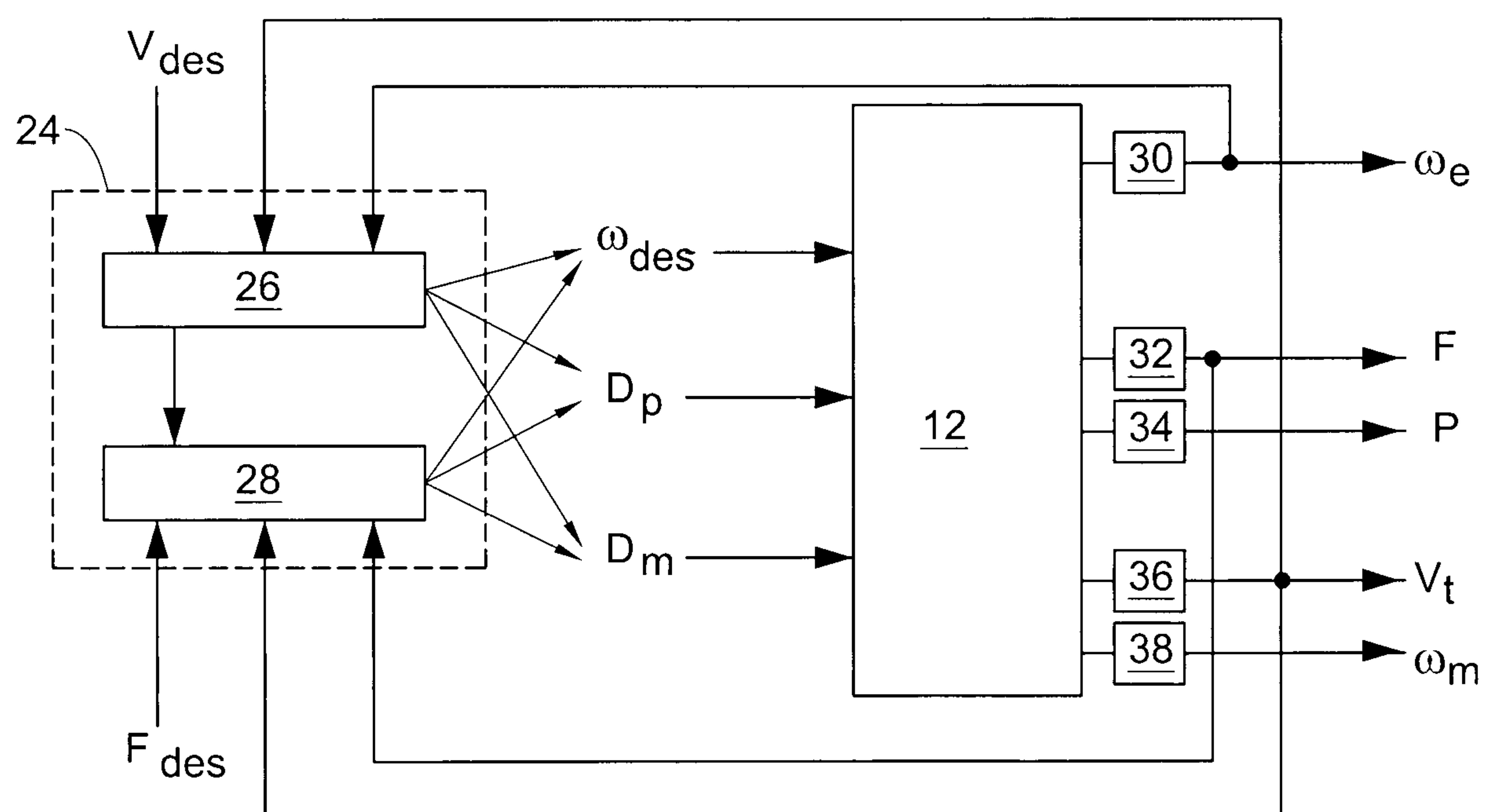


Fig. 2

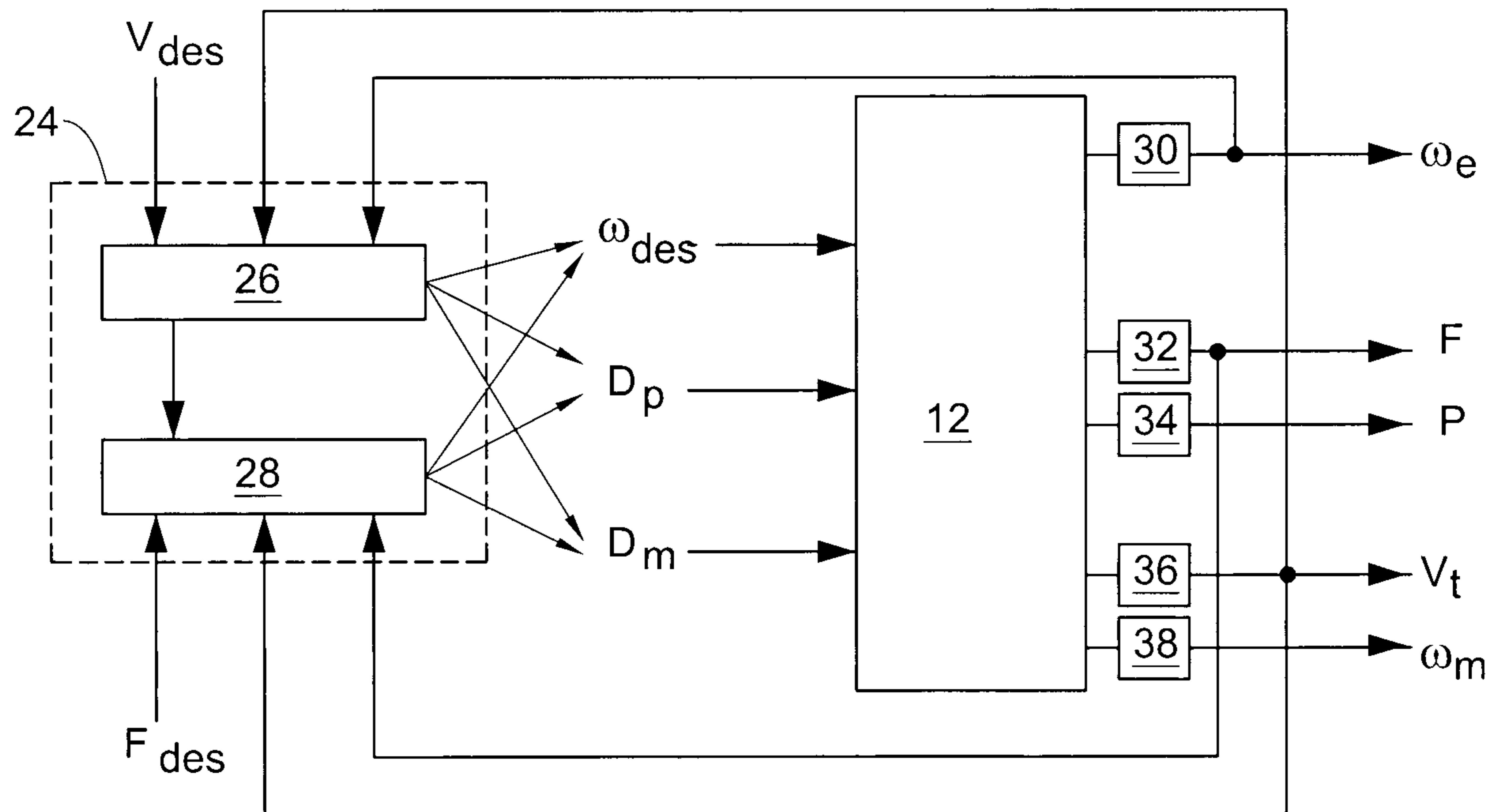


Fig. 2