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HYBRID HYDRAULICS WITH ACCUMULATOR AS THE FRAME OF THE VEHICLE

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Abstract. This concept of a steel accumulator as the frame of a vehicle is based on the structural capacity as a beam left on an ends closed tubular device when used at the operating pressure. This allows to overcome the major disadvantage of hydraulic accumulators when compared with electric batteries, in terms of w-hour/Kg; this also permits the use of a much needed larger accumulator. Depending on the operating cycle, the main installed power could be far less than 50% of the classical installed power. The accumulator in the frame can also being used as a compressed natural gas container, making much easy the use of CNG in vehicles. The creation of a hydraulic power integrator, power from the accumulator, + the prime mover, and refill the accumulator with the remnant power is a new important concept. Enormous savings on first and operating cost. Vast new markets created for Hydraulics.

Keywords: Fluid power transmission**.** Applicable patents USA 8,079,437; 8,567,544 Japan 5,600,323 Europe pending

THE SYSTEM DESCRIPTION

This system (the DynaDrive) is applicable to all types of terrestrial and aerial vehicles, using any prime mover. The system is especially attractive for Industrial applications. Said prime mover could be any engine or electrical motor. When the prime mover is running, it will be only at a constant speed and optimum torque; a servo valve controlled variable flow hydraulic device is connected to the prime mover via a unidirectional coupling and acts as a **"power integrator"**, receiving hydraulic power from the accumulator, mechanical power from the prime mover, or a combination thereof, supplying the desired flow and required pressure to the hydraulic motors. A second servo valve controlled variable pump on the same shaft that the power integrator, reloads the accumulator with the remnant power, if any, during the whole cycle. The accumulator will be quite large. The braking energy will be returned to the accumulator (75%) as opposed of the 25% available in electrical systems. The whole vehicle is controlled by wire, and uses only one joystick to control speed, direction, acceleration, braking and in some cases including steering. The power integrator acts as an infinite variable transmission, as well as a clutch and an operational brake.

An accumulator, which is an energy storage device, **is also positioned as the load bearing frame of the vehicl**e, reloading when the vehicle is braking and/or when the prime mover is running and there is additional energy from the prime mover, and/or the accumulator is providing the energy. The system allows for the vehicle being run with only the energy from the accumulator.

THE NOVELTY

The Accumulator Impact

Any classic hybrid hydraulic system has a significant handicap: steel accumulators, albeit being much cheaper than electrical batteries, last forever and create little heat, can weigh more than one hundred (100) times the weight of a lead-acid battery per unit of stored energy, and an even worst ratio with more modern batteries. As a result, all or most, accumulators used for present hybrid hydraulic applications are quite expensive, too small for the typical applications, made of fiber, for high pressure and may be usable only for short cycles, mainly for brake energy recuperation and release. Replacing the frame with a **rigid steel accumulator** makes now a Hydraulic **accumulator figuratively weightless**, as it replaces the present frame, makes many parts lighter and eliminates other parts. This accumulator has very little maintenance, and very low cost. This design allows for a much larger accumulator, with a more uniform and lower pressure. Its high weight installation at the bottom of any vehicle makes any vehicle very stable and sometimes adds necessary weight to it.

Energy content:

Piston accumulator	=	0,42	watt-hour/kg	See ref 1
Lead acid battery	=	50		Design News 04/08/2008
Lithium Battery	=	150		
Gasoline	=	12.722		

The above numbers tell a great story about the conundrum confronted by the design of vehicles, whereas the batteries cost and weight limits dramatically its application, when competing with gasoline, which has an enormous energy content. Also this table show how dramatic is the disadvantage of a hydraulic accumulator in terms of weight and volume, and our solution goes a long way to solve it.

Structural Analysis

Material	Modulus of elasticity	Price
Steel	= 200 x10^3 N/mm^2	> US$ 1/Kg
Aluminum	= 69 x10^3 N/mm^2	US$ 3,2/kg
Carbon fiber	= 100 x10^3 N/mm^2	US$ 22/kg

For rigidity and cost, steel is the material of choice for these applications, with the exception for aircrafts.

Using Standard Pipe as the Frame and Accumulator:

P= working pressure in daN/cm^2 S_1 is maximum working load of construction steel in daN/cm^2, **b** is the outside radius and **a** is the inside radius of a pipe or tubing.

P=S_1*log$_e$ (b/a) See ref 2

This is the formula for heavy wall tubing or pipe; heavy wall occurs when the wall thickness is more than 10% of the outside radius.
If maximum working pressure = 140 daN/cm^2, with a maximum admissible steel working load of 828 daN/cm^2 (safety factor 5) any standard pipe schedule 120 complies with these requirements.

TABLE 1

Nominal pipe	**Schedule**	**OD diameter**	**Wall thickness**	**Weight per foot**	
		Inch	Inch	Pounds/ft	Kg/m
6”	120	6,625;	0,562	36,42	54,26
8”	120	8,625	0,719	60,69	90,43
10”	120	10,750	0,844	89,27	133,00
12”	120	12,75	1,000	125,49	187,00
14”	120	14,000	1,094	150,76	224,63
16”	120	16,000	1,219	192,40	286,67
18”	120	18,000	1,375	244,14	363,77
20”	120	20,000	1,500	296,37	441,59

These are the most useful diameters for most of the applications. Standard length is ~40’ (~12.19m)

The longitudinal stress formula for this pipe is:

$$S_2 = P*(a^2/(b^2-a^2))$$ See ref 2

S_2 in all pipes above, is close to 350 daN/cm^2 , about 40% of the radial load at maximum pressure, making this pipe an ideal Beam. It has also a high torque resistance:

Admissible twisting moment is:

$$\boldsymbol{T = S * \pi(b^4 - a^4)/2b}$$ See ref 2.

Example for a 12”pipe shed. 120 T= 12.000*3,416 (1651-834)/12,75= **2.416.080 # inch**
Or **27.831 Kg m** a **Very high torque capacity giving the necessary rigidity to any vehicle.**

The Effect of the Temperature on the Gas Pressure

For the same volume, the formula for the pressure in relation with the temperature is:
(Boyle-Mariotte formula)

$P_1/T_1=P_2/T_2$ where P is the pressure and T is the temperature in degrees Kelvin.

When the temperature variation gets from 10 ^{0}C to 40 ^{0}C during a 24 hour period, the pressure will vary no more than 10%. For harsher climates it will be a different pressure setting for winter or summer.

The efficiency remains almost the same; however, for electric batteries, which are basically a chemical factory, the effect of low and high temperatures is substantial and remains one of the negative points for its application.

THE NOVEL HYBRID HYDRAULIC CIRCUIT

This hydraulic circuit allows for the full efficient use of the power available, as well as the accumulator saved energy, far superior to the present hybrid hydraulic systems and much better than an electric Hybrid, especially for heavy Industrial applications. The engine, radiator, battery, alternator, etc. becomes much smaller (and lighter), depending of the used cycle of the vehicle, and the following parts are eliminated: Gear box, clutch, differential, standard brake, shaft, drive train, mechanical accelerator and many others.

It also cuts down substantially the rotary masses in any application, making the machine much more energy efficient, as those masses require energy to accelerate, energy that later is destroyed. This is an important point, although in our case we get back up to 70% in this energy.

Due to the hydraulic circuit arrangement and the large dimension of the accumulator, the prime mover dimension is no longer sized for the torque needs for acceleration, as in a standard vehicle, but for the average power needed in a specific cycle. For example, take a subway; starting acceleration requires maximum torque, to maintain speed, very little power is required; at deceleration, power is partially reverted to the accumulator. Then it stops for several seconds before restarting. A typical cycle indicates the need of no more than 10% of the present installed power. Imagine the savings in power lines alone, as the power line dimension goes up with the square of the current.

Comparison between Hydraulic and Electrical motors

As opposed to the major disadvantage than an accumulator has over an electrical battery, electric motors have major disadvantages compared to hydraulic motors, especially in weight and cost.
In hydraulic motors, a typical working pressure is about 300 daN/cm2 or higher. On the other hand, the magnetic forces in an electrical motor depend and are limited by the steel magnetism which is = 1,6 Tesla. The formula for magnetic attraction is:

F (daN/cm2) = B (tesla) ^{2}/0.25 See ref 1

Or Fmax=10daN/cm2.

In practice, it is very difficult to get this yield and numbers around 1 daN/cm2 are common, thus enormous weight gain and cost by the use of hydraulic motors as opposed to electrical ones.

Typical power to weight ratio: **Hydraulic motors 9 Kw/Kg Electrical motors 0.45 Kw/kg**
Ratio 1:20 See ref 1.

The Use of a Unidirectional Coupling

Connecting the shaft of the prime mover to the power integrator via a unidirectional coupling, allows for the use of the vehicle with only the accumulator energy when the engine is not running, and there is enough pressure and energy left. Normally the accumulator pressure might be higher than the pressure needed, so the secondary swash plate pump will recharge the accumulator with that extra energy and, at the same time, regulate the speed of the main shaft.

PRODUCTION

One or more heavy wall steel pipe with both ends capped will be the frame of any vehicle for Industrial applications. To it, we attach all the off-the-shelf needed parts. The end result, a vehicle in its multiple applications, that **is less costly to produce, to operate (major energy savings) and to maintain, compared**

with classical and even modern present applications. By using well known parts, we do what's called piggy-back engineering, creating a collaborative team with vendors and manufacturers.

As an example, you have a yard hustler, whereas we create a frame with two pipes, eliminating the clutch, drive train, both differentials and its structure. We install four slow speed radial motors on each back wheel and a much smaller engine, and radiator with an unheard installation design flexibility.

The most interesting issue is that all of the needed parts are already available off the shelf in the open market, with many vendors and manufacturers for each one, such as servo valve controlled swash plate pumps, high and low speed wheel motors, all kind of prime movers, from diesel, gas, CNG, electrical motors, etc. Other needed parts as pressure transducers, piston accumulators, fuses, PLC, oil coolers and filters, cabs, controls, etc., are also available off the shelf. There is no part to develop to make this solution viable.

THE MARKET

The market entails many large industries and applications, with numerous players in each, including, city Vans, school buses, yard Hustlers, garbage trucks, taxis, bulldozers, post office &delivery vans, airplane tractor, airport buses, tramway, underground, city buses, automobiles, military applications, and many others.

The biggest impact is realized on applications where the cycle analysis shows a much lower average power compared with the maximum installed power, together with 8 hours or more in operation.

Let's take a bulldozer; when it starts pushing, the load becomes higher and higher, until the end of the cycle; the it goes back completely unloaded and restarts going forward with little initial load. My estimate is that it requires an engine with less than 40% of the present load.

Each application entails numerous new economical and operating benefits for each product. Some of them are different than others; it will require a deep knowledge of that particular market and its application, to be able to take advantage of all the benefits brought about by this hydraulic design.

For example, in military applications, the energy savings, being quite substantial, are extremely important, because the cost of Diesel in the battlefield is several times the cost at the pump.

In any of its applications, the cost of higher torque at the wheels is very low, allowing the use of much larger diameter wheels which in many cases have several advantages such as comfort, operations on rough terrain and safety, increasing dramatically the benefits for some applications.

We need also to mention the airplane applications. When any vehicle requires acceleration, this is when the maximum torque and power is required. Using a hybrid solution, having two sources of power to do so, the main prime mover becomes much smaller.

However, in the case of an airplane, we need to add not only the power to accelerate the mass, but also the energy to gain elevation rapidly. The power required to become airborne is many times the one needed to cruising speed. A Hybrid solution with many small propellers on the wings, manned by hydraulic motors and the accumulator as the main structure could create a new type of airplane commuter applications.

We can also mention here a railroad application. One problem with railroads is that the locomotives have too few wheels to accelerate a train and require a large amount of torque to do so; the power to maintain cruising speed is much smaller. If we install in every car the motive power with this system, which could be maybe 50 HP, and so create cars with two or four traction wheels per car, completely eliminating the expensive locomotives. The train is created by Wi-Fi controlling each car and making much easier to move cargo and much lower cost, each car has its own destination, and can be combined with different trains.

Drawings

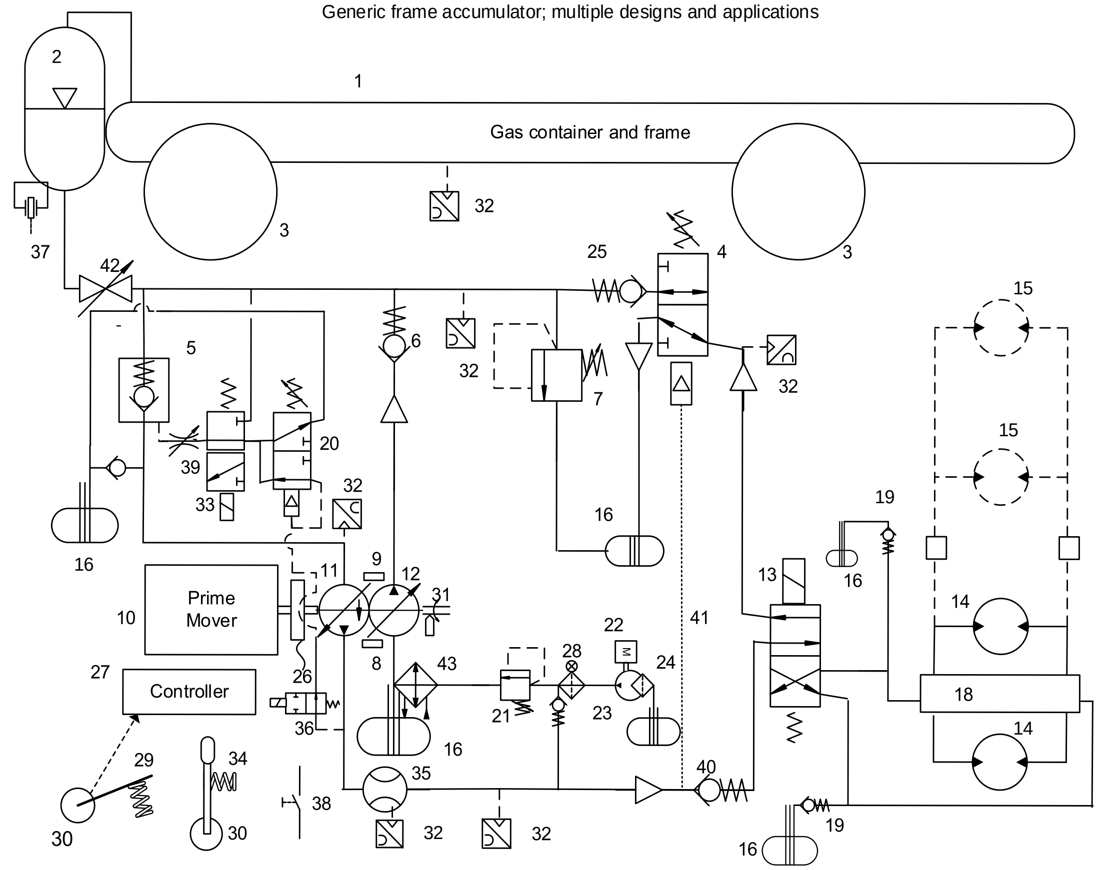
FIG. 1 is a schematic illustration of hybrid hydraulic system schematics in accordance with one aspect of the invention; FIG. 2 is a schematic side view of a commercial van, using a hybrid hydraulic system in accordance with one aspect of the invention; FIG. 3 is a top view of the van shown in FIG. 2 of the drawings; and

FIG. 4 is a view of a cutaway of the van along line A-A in FIG. 2 of the drawings.

FIGURE 1

Hybrid Hydraulic schematics with the frame as accumulator

Generic frame accumulator; multiple designs and applications



DETAILED DESCRIPTION OF THE OPERATION

One preferred embodiment of the system is illustrated in FIG. 1 of the drawings. It should be appreciated that the embodiment shown in FIG. 1 of the drawings is representative of a hydraulic schematics, and variations and modifications may be made.

FIGS. 2, 3 and 4 of the drawings comprise illustrations in schematic format of a vehicle sample application incorporating one preferred embodiment of the system on a commercial van. It should be understood that this is for illustration purposes only and the scope of it is not in any way limited by the use of this example. Furthermore, the system may be used on many types of vehicles as well as vehicles having different types of prime movers, including electric motors and internal combustion engines (ICE).

With reference to FIG. 1 of the drawings, there is shown a preferred embodiment of one hydraulic circuit. FIG. 1 of the drawings shows schematically an accumulator 1, the gas container, which simultaneously comprises and operates as the load bearing frame of the vehicle on which it may be installed. An oil and gas accumulator 2 is also provided and this accumulator may be separate from the accumulator 1, but both gas sides connected, or could be installed inside the accumulator 1. The accumulators 1 and 2 may in certain embodiments be combined into a single accumulator, or accumulator 2 may be the whole frame of the vehicle, with oil and gas inside.

A prime mover 10 is provided which is, for example, an electric motor or an internal combustion engine. The prime mover 10 is connected via a unidirectional coupling or a clutch 26 to a unidirectional variable power

integrator 11 which integrates the prime mover 10 and the hydraulic system (to be described) for optimal energy usage. The prime mover 10 is also connected along the same shaft to a unidirectional variable charge pump 12. This unidirectional coupling 26 allows for the operation of the system when the prime mover 10 is not running, just using the energy stored in the accumulator.
The power integrator 11 is controlled by a servo valve 9, while the charge pump 12 is controlled by a servo valve 8. Both of the servo valves 8 and 9 receive the appropriate signals from a controller 27 which receives input from the system and controls energy deployment based on such input. The accumulator 2 has an electronic oil level indicator 37 that signals the amount of oil in the accumulator 2 to the controller 27. If the amount of oil in the accumulator 2 is large, the signal from the controller 27 to start the system will not launch the prime mover 10, but rather utilize stored energy in the accumulator 2. If, however, the signal from the accumulator 2 indicates a low amount of oil in the accumulator 2, the prime mover 10 will automatically be started at a set rpm, so that sufficient flow will be available to propel the vehicle.

Once the prime mover 10 is activated and starts running, the power integrator 11 and the pump 12 will have zero flow initially. The pump 12 will flow immediately after, charging the accumulator 2 and 1, with the available torque generated from the prime mover 10, via check valve 6, taking oil from the tank 16. Note that FIG. 1 shows several tanks with reference numeral 16. However, there is generally only one tank 16. Multiple representations of the tank 16 are shown for simpler understanding.

The power integrator 11, once it receives a signal to go to a certain flow, will take oil from the tank 16, via check valve 17, and send such oil to the hydraulic motors 14 (and 15 if so built) via flow meter 35, check valve 40, solenoid valve 13 (only one version shown) and controlling block 18. The block 18 may have several functions including that of relief valve, differential control effect, ABS, flow sharing, and the like. The flow of oil will be the same independent of the pressure. There are two anticavitation valves 19 that could be part of the block 18 that go to tank 16, in order to avoid vacuum to occur.

A pilot line 41 extends to a pilot operated three way, two position valve 4. When the pressure on line 41 reaches a certain value, the valve 4 will open the output of the hydraulic motors 14 and 15 to tank 16. On a braking generating mode, the valve 4 sends the output flow of the motors 14 (and motors 15) via check valve 25 and valve 42 to the accumulator 2. If the accumulator 2 reaches a certain pressure, oil is discharged back to the tank 16 via relief valve 7 or to the inlet of the pump 11. The valve 42 is just a service valve that isolates the accumulators 1 and 2 for safety purposes. The safety and/or auxiliary brakes are not represented here.

If the output pressure of power integrator 11 reaches a certain threshold, a pilot line goes through solenoid valve 36 (two way, two position) to the pilot valve 20, which is a three way, two position valve. The output of valve 20 goes through solenoid valve 33, a three way, two position valve, and controlled orifice 39 to open a pilot operated check valve 5. This action connects the high pressure accumulator to the suction of the power integrator 11, to allow for an elevated pressure at the output of the power integrator 11, obtaining higher accelerations of the vehicle with a much smaller engine (50% or less). The main output flow of power integrator 11 is controlled by said power integrator 11 and recharge pump 12. Any over speed of the prime mover 10, detected via speed sensor 31, causes the pump 12 to send the extra energy back to the accumulator 2 and 1, and in so doing, has the effect of maintaining a constant speed at the common shaft.

When the prime mover 10 is not running because enough energy is stored in the accumulator 2 (+1), the running mode for this situation will now be described. The solenoid valve 36 is energized, closing the pilot line to the pilot operated valve 20. The solenoid valve 33, a three way, two position valve, is energized opening the accumulator 2 via check valve 5 to the inlet of power integrator 11. The speed of the vehicle, given by the output flow of the power integrator 11, will be controlled by the swash plate position of the power integrator, and the set rpm of the system, via charge pump 12.

A pedal 29, or a joystick 34, command a position sensor 30 that transmits signals to the controller 27 with information as to what speed is desired, and what acceleration or braking rate is required. Internal controls in the controller 27 may be programmed in order to limit both the acceleration and braking or deceleration rate to a given maximum. A switch 38, which is an on-off switch, may be provided to allow for reverse operation when needed.
Either the pedal 29 or the joystick 34 go to zero output when released. If, at that point, prime mover 10 is running, it will continue running only until the accumulator 2(+1) is full, loading it via charge pump 12 and associated servo control valve 8. In that condition, the power integrator 11 is not creating any output flow for moving the vehicle acting as the operating brake and the vehicle is hence at a standstill. If the joystick 34 is supplied with an auxiliary sensor, then such a joystick may also be able to additionally control steering. This is

not applicable, of course, to vehicles running on rails, but all the other functions would be available.

Several pressure transducers 32 are provided in the system in order to allow for the controller 27 to know the instantaneous pressure in several parts of the hydraulic circuit, and react properly thereto for both the operation as well as the safety of the vehicle.

Some auxiliary hydraulic functions may also be present in the system. Thus, a charge pump 23 may be provided and comprises a low flow, low pressure pump powered by a small electric motor 22. The charge pump 23 could also be powered by the main shaft of prime mover 10, mounted after or beyond the position of the charge pump 12. A strainer 24 associated with the tank 16 facilitates the flow to the inlet of the pump 23, while the output of pump 23 goes to a filter 28, relief valve 21, cooler 43, and back to tank 16.

FIGURE 2

Application example
Delivery Van
Hybrid Hydraulics with the frame as accumulator

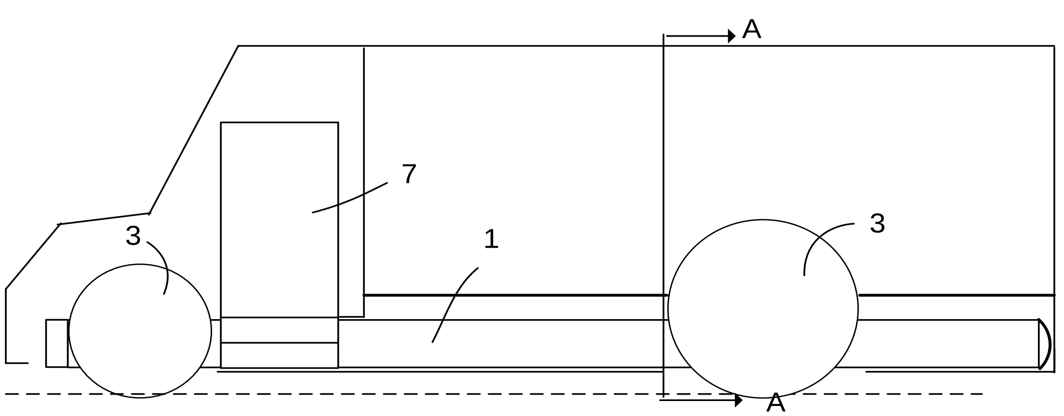


FIGURE 3

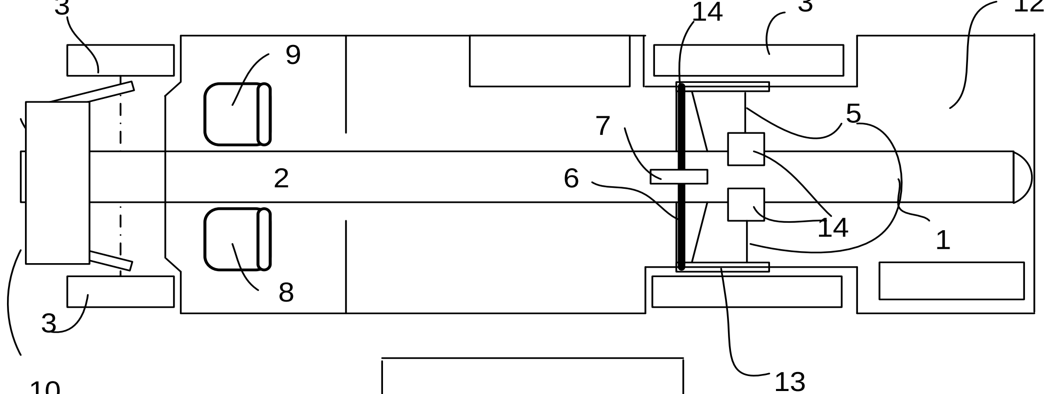


FIGURE 4

A-A cutaway

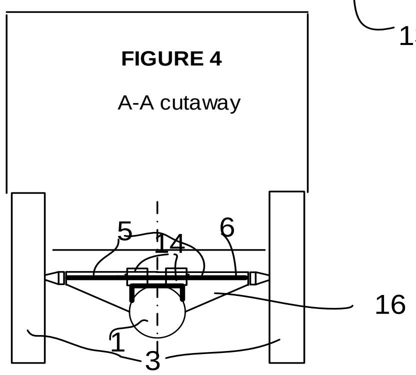


FIG. 2 of the drawings schematically illustrates a side view of a van incorporating the hydraulic drive system described. FIG. 2 shows a van including wheels 3. Front wheels 3 contain an ABS system 45, and an accumulator 1 as the frame of the van. In FIG. 3 of the drawings, the van is shown in top view, and includes a power unit 4, including in it a prime mover 10, power integrator 11, charge pump 12 and other hydraulic and electrical paraphernalia, floor 2, an accumulator 1 and 2 (which may be separate, combined into one unit or only 2 is the frame), CNG or Diesel tank 51, and hydraulic drive motors 14 and 15. Hydraulic drive motors 14 and 15 are associated with the wheels 3. Also shown in this figure are the driver seat 8, the passenger seat 9, compensation bar 6 and shock absorber 7. The van includes a transmission shaft.

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