ARCHYBALD: An hybrid transmission for heavy vehicles

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***Abstract*— This paper describes the technological and innovative project ARCHYBALD. The objective is to design a hybrid powertrain for a heavy vehicle, especially in the military field. Here, we present the different interest of the project for a military vehicle, then the system and its different subsystems and afterwards more especially the mechanical powertrain designed by Nexter Systems.**

Keywords-Powertrain; Hybrid; Military;

I. INTRODUCTION

The reduction of the oil resources, their price increase and their effects of the environment lead the transport industries to innovate and to develop solutions with a low fuel consumption and low air pollution. One solution is to design a hybrid powertrain, which contains the whole of the elements linking up the necessary sources of energy to move the vehicle, with the wheels. The expression "hybrid powertrain" means that there is a mix between multi-source energies. In our case, it is between chemical energy (gasoil) and an electrical source (battery).

The project ARCHYBALD (ARChitectures HYBrides Adaptées aux véhicules Lourds à forte Disponibilité) is funded by the ANR (Agence Nationale de la Recherche)/ADEME (Agence De l'Environnement et de la Maîtrise de l'Energie) in order to design a hybrid powertrain of heavy trucks for:

- Civil applications (bus, dustcart…)
- Military applications (transport of troop…)

The PREDIT (Programme de Recherche Et D'Innovation dans les Transports terrestres) selected the project proposed by the company Nexter, project coordinator, with the industrial partner, BATSCAP and three laboratories: FEMTO-ST (Franche-Comté Electronique Mécanique et Optique – Sciences et Technologies), L2EP (Laboratoire d'Electrotechnique et d'Electronique de Puissance de Lille) and the INRETS (Institut National de REcherche sur les Transports et la Sécurité). The study belongs to the research group MEGEVH (Modélisation Energétique et Gestion d'Energie de Véhicules Hybrides). The project ARCHYBALD began in January 2008 and lasts 36 months.

II. THE CHALLENGES OF A HYBRID POWERTRAIN WITH A HIGH AVAIBILITY FOR A HEAVY VEHICLE

For a few years the transport industry has developed hybrid vehicles, which are compromises between the conventional vehicle with an internal combustion engine and the electric vehicle. The main objectives of a hybrid structure are to reduce the air pollution and the fuel consumption of the internal combustion engine. There are different hybrid powertrain configurations: serial, parallel and serial-parallel.

The aim of the project ARCHYBALD is to design an innovative powertrain for heavy vehicles. The company Nexter also studied a serial hybrid powertrain with the DPE 6x6[1]. Currently the configuration serial-parallel offers the most possibilities. So the project ARCHYBALD chooses to study a serial-parallel hybrid powertrain.

In the military field, the interest of a hybrid vehicle has some differences with the civil field. There are six main advantages to use a hybrid technology in a military vehicle as developed in [1], [2].

- **Sound stealth**: It is a necessity for the security of the military troops to pass unnoticed with their vehicles. The sound stealth can be possible with the electric mode (internal combustion engine stopped).

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- **Availability**: It is the capacity of the vehicle to function with a breakdown. So if the internal combustion engine has broken down, the hybrid vehicle is able to function with the storage elements.
- **Survivability**: It is the capacity to accelerate in order to move quickly during fighting (tactical jump and dodge) or leave quickly the combat zone. It is possible, if the electric motor assists the internal combustion engine.
- **Autonomy**: The use of both energy sources increases the driving time. Moreover the regenerate braking increases the storage elements capacity. Indeed, the vehicle recovers its kinetic energy during its braking and stocks it in the storage elements.
- **Fuel Consumption**: The possibility to manage the different working mode of the internal combustion engine and the possibility to drive in an electric mode reduce the fuel consumption. Moreover the use of the function "Stop&Start" increases the gain. Indeed the vehicle sets in sleep mode as soon as the speed is less than 6 km/h. The alternator and the starter are replaced by one electric motor, which can start the internal combustion engine and load the battery.
- **Air pollution**: It is a necessity to limit the greenhouse gas emissions. But it can also be interested if the vehicle must start with the internal combustion engine in a closed room (boat, plane, garage). It is possible with the function "Stop&Start" and the electric mode.

III. THE TECHNICAL ARCHITECTURE OF THE HYBRID POWERTRAIN

The objective of the project ARCHYBALD is to design a hybrid powertrain with a high availability for a heavy vehicle. The development of this study concerns several partners and each has defined tasks.

After analyze and a comparative study, the different partners of the project decided to develop a serial-parallel hybrid powertrain. They also decided to design it to be integrated in the military vehicle: the VBCI.

The technical architecture is composed of three main elements. At first there is the storage system. It is developed by the INRETS and it has the particularity to couple two elements: batteries and supercapacitors (BATSCAP). Then there are two electric machines and theirs converters developed by FEMTO-ST. They must be compact and high-yield. The mechanical transmission is designed by Nexter Systems. It combines different energy generated by the engine and the electric machines. The entire vehicle is modelized by the L2EP. The architecture proposed to adhere to the specifications is represented on Fig. 1.

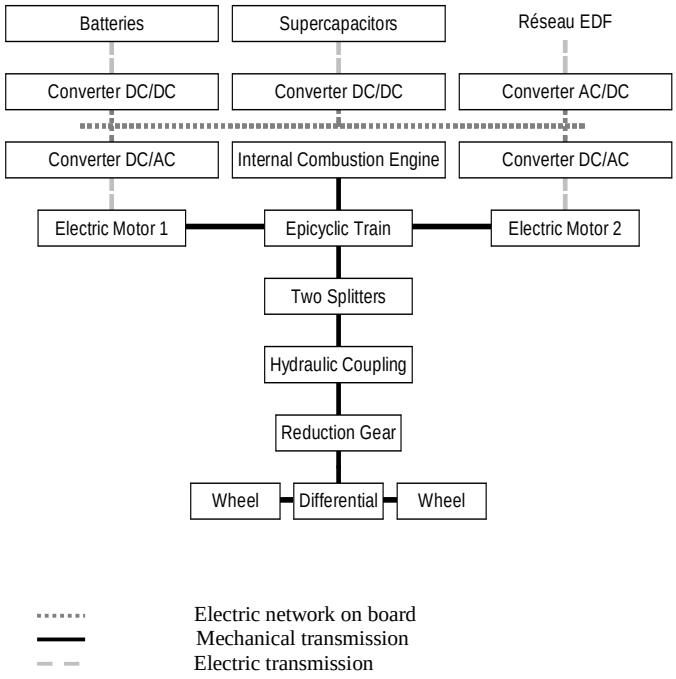

Figure 1. Technical architecture of the powertrain ARCHYBALD

The architecture is composed of four main subsystems [2], [3], [4], [5].

A. The mechanical transmission

The mechanical transmission and the motors have replaced the gearbox. The main element is a Ravignau gear train developed by Nexter Systems [3]. It can combine three energy sources to move the wheel. At the output both splitters are placed to have a ratio four-speed transmission. Then the hydraulic coupling transmits the engine torque with progressiveness. The reduction gear is an epicyclic gear in order to reduce the speed. The differential permits the good functioning from the vehicle if there is a speed difference at the wheel in the bend.

B. The electric architecture

The power network connected two electric motors, batteries, supercapacitors, a cooling system for the electric equipment, a low voltage network (power supply for the vehicle) and the workshop electric network to reload the storage elements. The control network is set up of four electronic control and checking units (Engine, energy storage, power storage, batteries), a calculator of in-car energy management, a detector of the insulation defect of the power network circuit. The equipment of this control network is feeded by a direct low voltage 28V.

There are two possible architectures: a mono-bus or a double-bus. There are three main advantages to use the double-bus: redundancy (if a equipment failed, the system can still run), the sharing of power and the reduction of the charge of the feeders and the volume diminution of the converters.

C. *The energy storage elements*

There are both storage elements: Batteries and supercapacitors. The batteries stock energy in electro-chemical form and the supercapacitors stock quickly energy and so the power delivers is more important than with the batteries. The goal of the studies led by INRETS is to show that supercapacitors can be used to protect the batteries against overcurrent in order to increase batteries time life.

D. *The electric machines*

Both electric machines have the same specifications: the power is 70 kW, the maximum torque is 1000 Nm, 2000 Nm in transient state and the maximum speed is 4000 rpm. The electric machines are designed to take up four challenges: compacity, efficiency, cost and hard environment.

IV. THE RAVIGNAU GEAR TRAIN

The vehicles designed by Nexter Systems have the particularity to need high torque at low speed and to have to move at high speed (near 100km/h).

The powertrain proposed by Nexter Systems uses a Ravignau epicycle gear train to fit these needs and to enable to hybrid a vehicle according to the needs of the militaries (see §II).

A. *Why a Ravignau epicycle gear train is used?*

Usually, the Ravignau gear train is used in the automatic gearbox. It has a good compactedness and enables to have five reduction ratios whereas a simple epicycle gear train has only three. For this kind of application, the reduction ratios of the Ravignau gear trains are chosen by commanding the opening and the closing of brakes and clutches.

For the ARCHYBALD application, the mechanism has any brake and clutch. The idea is to have a continuous variation transmission by commanding the speed of the two electric motors. Each electric motor is coupled at one of the gear of the train. Thus, we can choose the speed of the engine regardless of vehicle speed, subtract or add energy in the transmission.

B. *Architecture of the Ravignau gear train*

The architecture of the powertrain is as follow:

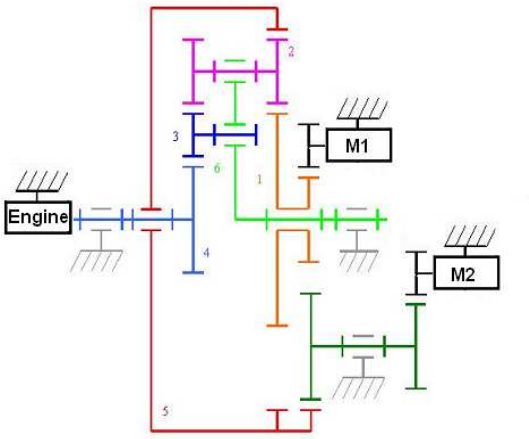

Figure 2. Ravignau gear train

This architecture was chosen to have the maximum of multiplication of the engine torque. This enable to fit the need of high torque at low speed.

C. *Working*

We can define two working modes: a full hybrid mode and an electric mode.

1) *Full hybrid mode*

The working of system was defined so that the internal combustion engine works in an area of good consumption (called Z).

For that, the continuous variation of ratio between the engine and the output of mechanism is made by adapting the torque and the speed of the two electric motors: a circulation of electric energy occurred between the two motors.

Four cases are possible:

- Case 1: A working point of the engine, included in Z, exists such as the power absorbed by one of the motor is equal to the power generated by the other.
- Case 2: The need of power of the vehicle is greater than maximum power of engine. The electric motors are piloted to reach the maximal power of engine, and energy, coming from batteries, is added in the system by one of the electrical motors
- Case 3: A working point of the engine, included in Z, exists if power is absorbed by the system (loading of batteries). One of the electrical motor absorbs more energy than the other generates
- Case 4: It is not possible to working in the good consumption area of the engine but an improvement of the fuel consumption is possible.

The cases 1, 3 and 4 fit the needs of autonomy, fuel consumption and air pollution develop in §II.

The case 2 fits the need of survivability.

2) *Electrical mode*

It is possible to work with the electric motors only. This electric mode is very interesting for the army because it fits the needs of:

- **Sound health**: the vehicle can move with the engine shut down
- **Availability**: The vehicle continues to function whereas the internal combustion engine has a failure.
- **Fuel Consumption and air pollution:** The engine can be shut down during the waiting phase thanks to the function stop and start of the mechanism.

D. *Commands*

Initially, we though that the Ravignau gear train could be driven by commanding independently the engine and the two

electric motors. In reality, the mechanism is a system with two independent inputs and two outputs.

Commands are being developed by the L2EP to take into account this particularity. The control of the three motors must be link for the system does not lock.

E. The sizing

The Ravignau gear train is composed of toothed wheels, transmission shafts and a ring gear.

A toothed wheel is defined geometrically by a module, a pitch diameter and a width. The values of these features have been determined in order to respect the kinematic formula and the strength of materials. In fact the toothed wheel must withstand at the bending stresses and the contact stresses. In order to compute them, we have used the ISO standard 6336-2006 called "Calculation of load capacity of spur and helical gears" [6]. This method provides dimension in order to reduce the wear and so that the gear not break. So it introduces requirements of the value of the three dimensional characteristics.

The diameters of the transmission shafts are sized for the maximal torsional constraint. As concerning the ring gear, it is sized thanks to the strength materials.

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