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MODULAR DRIVE SYSTEMS

Abstract. This article describes some of the modern drive systems primarily designed for use in military technology. The main features of the power-pack type systems are discussed along with their structure. The most important technical parameters are listed on the basis of selected examples of Polish applications. In addition, tables are provided with known examples of implemented applications of modular drive systems in land vehicles: armoured personnel carriers and tanks.

Keywords: modular drive systems, power-pack, engine, transmission, gearbox, tank, military vehicle.

1. INTRODUCTION

Manufacturers of the best known and leading military land vehicles were forced to convert conventional drive systems into power-pack type modular drive systems. One of the reasons for this was the need for fast dismantling of the damaged component and installation of a new one in the shortest possible time, so as not to disrupt the combat momentum, and above all to ensure the safety not only of the vehicle crew, but also of the maintenance personnel.

The newly designed military land vehicles are mostly provided with modular power-pack type drive systems which have a number of advantages, as described later in this paper.

2. FEATURES AND EXAMPLES OF DRIVE SYSTEMS

The power transmission system of a modern military tracked vehicle should make the most of the engine characteristics, and of the torque transferred to the tracks dependent on the resistance to motion of the vehicle. This can be achieved by applying, preferably in an automatic manner, appropriate transmission ratio adapted to travel speed and terrain conditions. Another important task of the drive unit is to enable steering of the vehicle at a turning radius set by the driver, as is the case, for instance, in wheeled vehicles. Currently, the most commonly used design is a drive system with automatic transmission and hydrostatic steering mechanism that ensures controllability both when driving in straight line, as well as when changing direction. Therefore the main task of the designer of a modern tracked vehicle is to develop a power transmission system which should provide:

- any turning radius set by the driver, that radius being independent of changes in ambient conditions, engine speed, engine load or driving resistance;
- good vehicle steerability;
- high efficiency of power transmission;

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- maintaining the set straight driving direction irrespective of changes in track motion resistance;
- optimum utilization of engine performance under varying loads.

Power transmission systems used in modern military vehicles, both wheeled and tracked, may generally be classified into the following groups:

- mechanical;
- hydromechanical;
- electromechanical;
- electrical.

Mechanical drive is the simplest solution, historically the most widely used, easy to operate, but absorbing much of driver's attention while moving over rough terrain or under combat conditions. In order to improve the comfort of operating modern military vehicles, hydromechanical automatic gearboxes are used, and in the case of tracked vehicles, hydromechanical gearboxes with hydrostatic steering mechanisms. Recently there is also renewed interest in electric/diesel or hybrid drives in military equipment. The efficiency of electric drives is high as compared to that of hydromechanical drives [1].

Land vehicles with conventional power transmission systems are now slowly being consigned to history. These systems, despite their undeniable reliability and often uncomplicated design, are supplanted by power-pack type drive systems.

2.1. Conventional drive systems

A conventional drive system (powertrain) is a set of mechanisms designed to drive a vehicle by delivering mechanical energy from the engine to the driving wheels of the vehicle [2].

The system consists of an internal combustion engine connected to the main transmission (gearbox) by means of a shaft. Gear changing is effected manually by operating a lever (with the exception of automatic transmission). Air supply and engine and transmission cooling systems are installed in the vehicle body, usually in the chassis. An excellent example of such design is the Anders Fire Support Vehicle.

FSV Anders is the effect of development work conducted in the years 2008 – 2010 by OBRUM in cooperation with the Military University of Technology (WAT) and Wojskowe Zakłady Mechaniczne S.A. [17,18,19].

Fig. 1 shows the drive system of the ANDERS Fire Support Vehicle. The FSV has a conventional drive system which comprises: HMUN transmission (manufactured by Huta Stalowa Wola S.A.), a hydromechanical drive system, and the engine used in the armoured personnel carrier concept, i.e. MTU 8V 199 TE20 [6-15].

In this case the transmission is connected to the engine by means of an additional shaft, and not directly to the flywheel housing. This is shown schematically in Fig. 1.

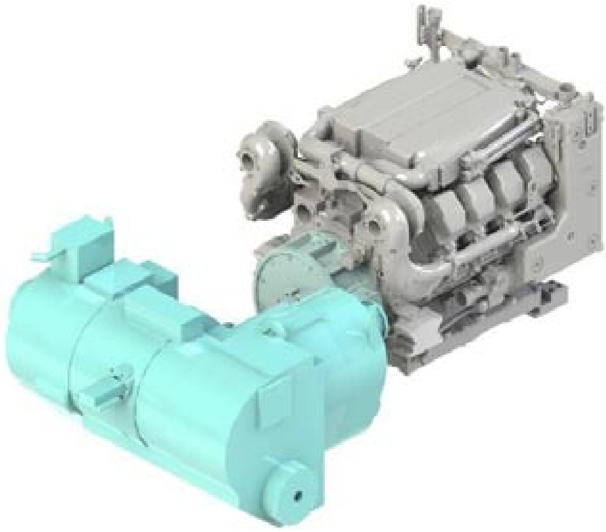


Fig. 1. Conventional drive system of the ANDERS Fire Support Vehicle [17,18]

This design has several disadvantages:

- assembly and disassembly of the drive system is very cumbersome and time-consuming;
- the outer dimensions and weight of the complete drive system are much higher than those of a modular power-pack [2,5].

Table 1 below lists the basic dimension and weight specifications of the drive system of FSV.

Table 1. Weight and dimensions of the drive system of FSV Anders [18,19]

Weight (kg)	1725
Length (mm) Width (mm) Height (mm)	2014 1887 983
No. of gears	4 forward gears, 1 reverse gear

2.2. Modular drive systems

Modular drive systems, called power-pack type systems, are ready for installation, previously set up on assembly stations, the main components being an internal combustion engine and main transmission, the characteristics of which have been carefully tailored so that their torques overlap and the vehicle to which the drive system is dedicated achieves the best possible driving parameters. Power-pack combines all driven units on one frame forming a functionally complete structure. The drive system is mounted on the frame together with all appurtenances, including the fuel, oil and air filters, exhaust silencer and cooling system with hydrostatic pumps, hydraulic motors and radiator fans. An excellent example of a modular drive system is the Puma Infantry Fighting Vehicle shown below in Fig. 2. The vehicle constitutes a novel weapons system which had substantially strengthened the German armed forces. The vehicle carries three crew members in one air-conditioned compartment (commander, driver, gunner) and up to six landing party soldiers in the rear of the vehicle where a rear exit hatch is located. A tight separation of the drive compartment from the crew compartment reduced noise by 90% as compared to Marder 2 [3] (down to 95 dB) [4].

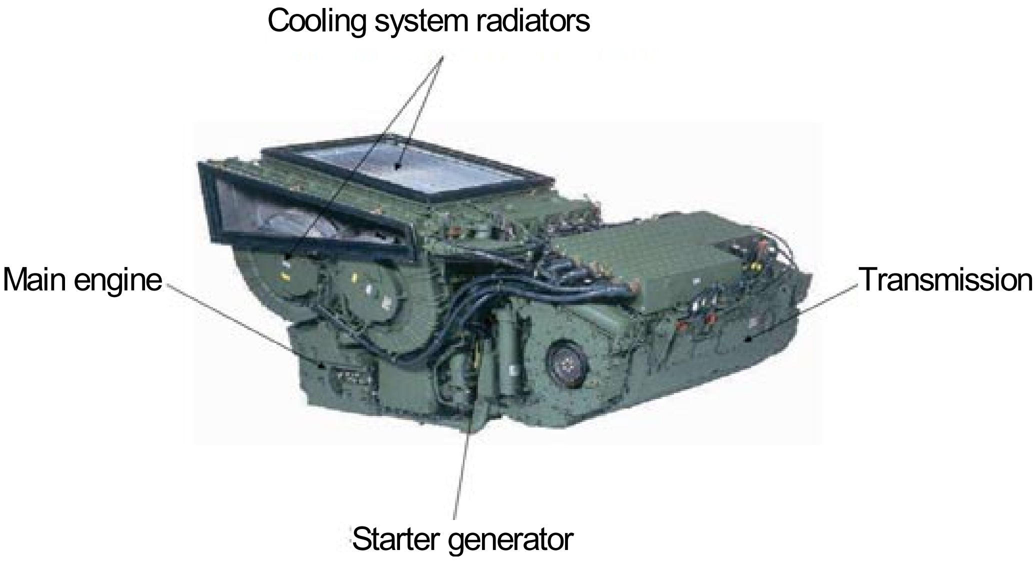


Fig. 2. Complete drive system of IFV Puma [4]

IFV Puma is powered with a 10-cylinder MTU (HPD) 890 engine. This engine is compact and lightweight. Despite this it produces an output of 1100 hp. The new HPD type engine is the key unit in the general concept of the Puma vehicle. Reduced space requirements for the drive system also contribute to lower vehicle weight, which enables putting on a heavier armour [5].

A modular drive system is characterized by:

- ability to rapidly replace the entire system in case of failure and to repair the faulty system and bring it to full working condition - replacement of the drive system takes about an hour, which is of paramount importance under combat conditions;
- automatic gear change ensures optimum utilization of the power and torque of the engine;
- control system extends failure-free operation time of the drive system;
- steering using a steering wheel.

3. STRUCTURE OF THE MODULAR DRIVE SYSTEM

As expected and in line with clients' requirements, designers of leading engine manufacturers, e.g. MTU Friedrichshafen GmbH [6] or Scania Engines [7], compete in upgrading the designs in this rapidly evolving field. Currently two main types of modular power-pack drive systems are installed in land vehicles of leading manufacturers (e.g. IFV Puma, CV90, IFV Dardo, PT-91M, etc.): L-shaped configuration (Fig. 3) and U-shaped configuration (Fig. 5).

3.1 L-shaped power-pack drive system

In this arrangement the engine is positioned perpendicularly to the transmission, which leaves room for locating the driver station in the front part of the vehicle body. The place is separated from the engine by means of a steel partition. This location of the driver allows for better visibility of the travel path, while the crew compartment is provided with more space for equipment or extra ammunition. Installation of the drive system in front of the vehicle enables locating disembarking hatches in the rear part of the vehicle, as is common in IFVs [8,9].

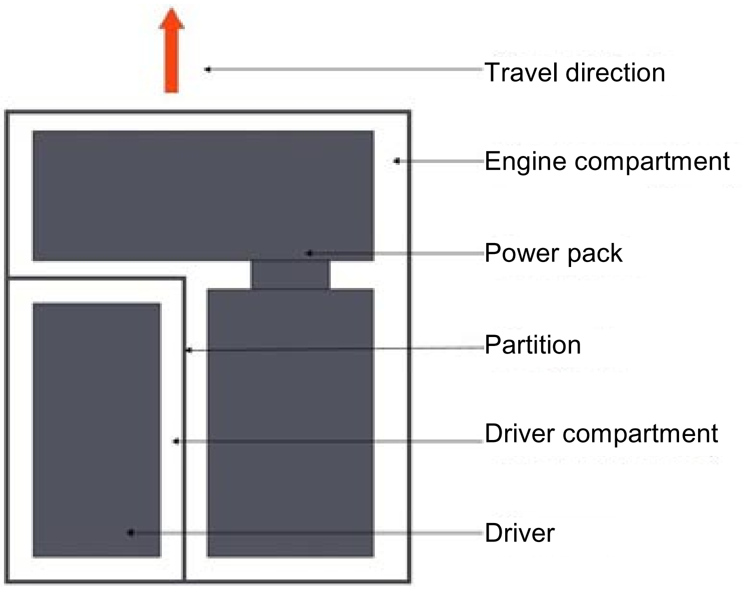


Fig. 3. Schematic view of the L-shaped modular power-pack drive system

A Polish example of such system is the power pack created as a concept of the Infantry Fighting Vehicle. It is, however, at an initial stage of development, therefore it lacks some components on the common frame, e.g.: cooling system, etc.

The conceptual design of the Infantry Fighting Vehicle [14] was created in 2012 at OBRUM Gliwice.

Fig. 4 shows a drive system designed for the infantry fighting vehicle. The engine used for this vehicle is MTU 8V 199 TE20 [6,15].

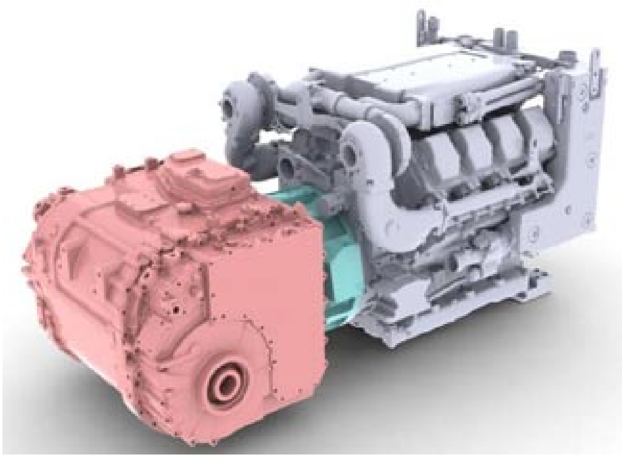


Fig. 4. Power-pack – MTU 8V 199 TE20 engine with X300 transmission [16]

Table 2. Basic specifications of the MTU 8V 199 TE20 engine [6-15]

Output (kW)	530
Maximum torque (Nm)	2700 (@1500 rpm)
Maximum rpm	2530 rpm
Weight (kg)	1135

The X-300 transmission is manufactured by Allison Transmission [12,16]. An additional power take-off can be mounted on the transmission. Characteristic of this transmission, and its greatest advantage, is its low weight.

Table 3. Basic specifications of the X-300 transmission [12,16]

Weight (kg)	950
Length (mm) Width (mm) Height (mm)	2014 1887 983
No. of gears	4 forward gears 2 reverse gears

3.2 U-shaped power-pack drive system

In this arrangement the engine is parallel to the transmission. The units are connected by means of an intersecting axis intermediate gear, usually having a 1:1 ratio. The power-pack is U-shaped, and therefore it is often mounted in the rear part of the chassis. There is less load on the front of the vehicle, which improves driving performance in marshy terrain.

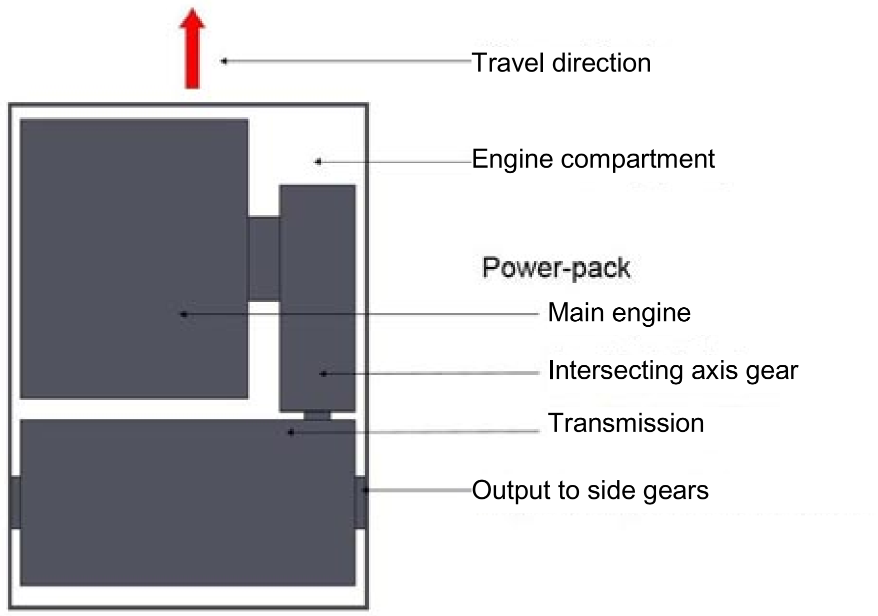


Fig. 5. Schematic view of the U-shaped modular power-pack drive system

Fig. 6 shows a modular drive system installed on the PT-91M tank designed for the Malaysian army based on PT-91 tank with conventional drive system.

PT-91M is driven by a power-pack consisting of French transmission ESM-350 [2] weighing 1750 kg (Fig. 7) and S-1000 engine [2,13] manufactured by PZL WOLA S.A. (Fig. 8). The ESM-350 transmission was adapted specifically to this tank version. The ESM-350 transmission has an additional power take-off [10,11], usually mounted on the gearbox or engine housing, which enables delivering the driving force to external devices. This enables driving a shaft or a hydraulic pump.

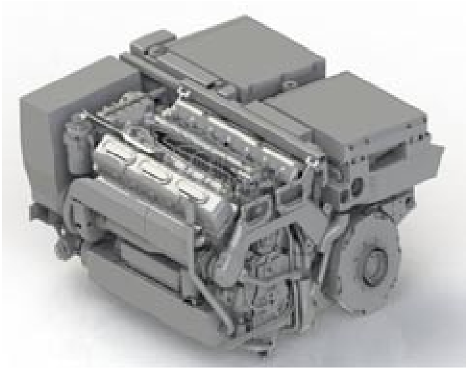


Fig. 6. Power-pack fabricated for the Malaysian army [12,13]

Fig. 7. Renk ESM350 transmission [2]

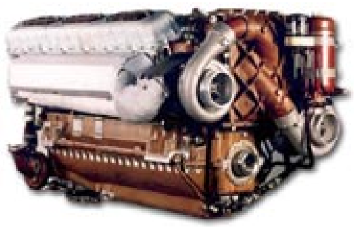


Fig. 8. WOLA S1000 engine [13]

Table 4. Basic specifications of the S1000 engine [13]

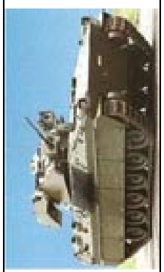
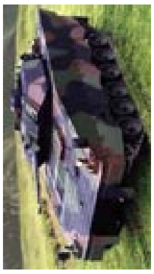
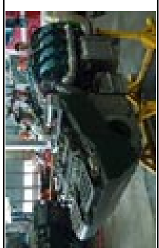
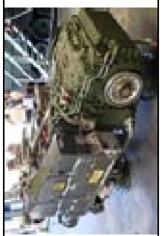
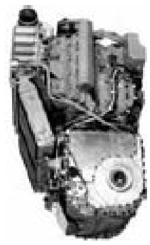
Output (kW)	736
Maximum torque (Nm)	4300 (@1500 rpm)
Maximum rpm	2200 rpm
Weight (kg)	1100

Table 5. Basic specifications of the power-pack of PT-91M tank [9]

Weight (kg)	3610
Length (mm) Width (mm) Height (mm)	2014 1887 983
No. of gears	8 forward gears; 3 reverse gears
PTO (kW)	200

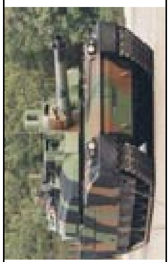
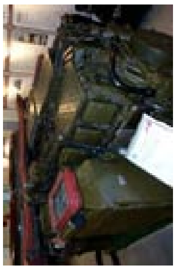
4. EXAMPLES OF POWER-PACKS USED IN INFANTRY FIGHTING VEHICLES OF WESTERN MANU

Table 6. Examples of power-packs used in infantry fighting vehicles of western manufacture

Vehicle	CV90	PUMA	DARDO	MARDER 1-A5	WARRIOR 2000
					
Power-pack			not available		
Crew	3 +7	3 +6	3 +6	3 +7	3 +7
Weight (kg)	up to 40,000	31,500 t (level A) 43,000 (level C)	23,000 (combat)	28,200 (combat)	25,400
Engine	Scania V8 14 litre (or 16 litre)	MTU V10 892	6-cylinder Iveco–Fiat 8260	MTU MB Ea-500	Perkins V-8 Condor Diesel
Output (kW)	808	1073	512	600 hp	550
Output/Weight (hp/t)	20.2	34.1 (level A) 25 (level C)	22.6	21.3	23.5
Max. speed (km/h)	70	70	70	75	75
Driving range	900	600	500	520	660
Manufacturer	Sweden	Germany	Italy	Germany	United Kingdom
Development	upgrades	upgrades	upgrades	upgrades	upgrades

5. EXAMPLES OF POWER-PACKS USED IN TANKS OF WESTERN MANUFACTURE

Table 7. Examples of power-packs used in tanks of foreign manufacture

Vehicle	Merkava 3/4 	Mitsubishi Type-90 	Leopard 2-A6 	AMX-56 Leclerc 	Challenger II 
Power-pack		Not available			
Crew	4	3	4	3	4
Weight (kg)	64,000/65,000	50,200	62,300	54,500	62,500
Engine	AVDS-1790-9AR / GD833	Mitsubishi 10ZG (2-stroke)	MTU MB873 KA501	UDV8X-1500	CV12 Perkins Condor
Output (kW)	1500	1500	1521	1496	1200
Output/Weight (hp/t)	19.67/23.07	30	24.1	27.52	19.2
Max. speed (km/h)	55	70	72	72	59
Driving range	500	400	550	550/650	450
Manufacturer	Israel	Japan	Germany	France	United Kingdom
Development	upgrades	new project	upgrades	upgrades	upgrades

6. CONCLUSIONS

- Modern modular power-pack type drive systems replace conventional drive systems.
- Many armies (users of land vehicles) upgrade their equipment and replace conventional drive systems with power-packs.
- Dimensions of conventional drive systems are often much larger than those of modular power-pack type systems.
- Choice between the L- and U-shaped power-pack takes place at the beginning of the design work, when decisions are made during the drawing up of Tactical and Technical Guidelines which system will be optimal for the given type of vehicle.
- Gear changing in the power-pack is automatic, which ensures optimum utilization of the power and torque of the engine.
- In the case of failure of the modular drive system, the entire system can be replaced quickly. It is then repaired to retain full operability.
- Replacement of the modular drive system takes about an hour, which is of paramount importance under combat conditions. Short replacement time improves the safety of the vehicle crew and of the maintenance personnel.
- Automatic control system applied in power-packs extends failure-free operation time of the drive system.
- Steering a vehicle with a power-pack is by means of a steering wheel, which improves driving ergonomics.

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