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AN "HIGH MANEUVERABILITY" SOLUTION FOR POWERING HEAVY DUTY TRACKED TRACTORS WITH CAR COMMON RAIL DIESEL ENGINES

Leonardo Frizziero and Luca Piancastelli
ALMA MATER STUDIORUM University of Bologna, Department of Industrial Engineering, viale Risorgimento, Bologna, Italy
E-Mail: leonardo.frizziero@unibo.it

ABSTRACT

Even in heavy duty tracked vehicle, just like tracked tractors, it is possible to implement Electronic stability control (ESC) system. This is a computerized technology that improves the safety of a vehicle's stability by detecting and reducing loss of traction (skidding). The use of software for the Electronic Stability may render controllable also inherently unstable vehicles. This can be a revolution for heavy tracked tractors where the unstable dual drive transmission can be used. This very simple transmission system with its extremely high efficiency reduces weight, room and fuel consumption. As for the aircrafts, artificial stability improves handling, giving to the driver the possibility to reach the ultimate dynamic and static limits of the unstable vehicle. The overall performance of the tractor is then enhanced. The possibility to use two engines instead of one, far from being a complication, makes it possible to use of the shelf market solution box for engines and gearboxes. Automotive derived CRDIDs (Common Rail Direct Injection Diesel) can be used instead of specialized heavy duty direct injection diesel engines. This paper demonstrates both the feasibility and the durability of this solution. The TBO (Time between Overhaul) of an automotive CRDID used in a heavy duty vehicle is evaluated. Finally an ad hoc transmission is proposed for the very limit case of a 2,000HP (1,500 kW) powerplant.

Keywords: powering tracktors, common rail diesel

INTRODUCTION

Starting from a good car engine is always a good idea, since they are mass produced in millions of items. This fact helps to lower the costs and to improve the result, by allowing huge development programs. In addiction trillions of hours are run by several different users in completely different conditions. In this way statistical reliability data are available. The use of these engines has also the advantage of the worldwide availability of cheap and spare parts. The modern diesel engine has the highest thermal efficiency of any standard internal or external combustion engine due to its very high compression ratio. Marine low-speed diesel and up-to-date automotive Common Rail Direct Injection Diesel (CRDID) share a thermal efficiency that exceeds 50%. In 1997, Alfa Romeo marketed the turbo CRDID in a passenger car, the model "156". In racing BMW won the 24 Hour Nürburgring race with the 320d, powered by a two-liter, four-cylinder CRDIDI. The combination of high-performance with better fuel efficiency allowed the team to make fewer pit stops during the long endurance race. "The vast majority of Europe’s new cars remain powered by gasoline or diesel motors. Diesel cars account for 55% of all new registrations, gasoline cars for 42%; all other technologies - hybrids, electrics, gas and ethanol-fueled vehicles - combine to make up the remaining 3%."[1]. High power is needed in heavy wheeled and tracked duty vehicles. For this "market" the limited availability of Power units and transmissions greatly reduces affects the designer choice. Development of these engines is limited by the number and new designs are rare. In many cases transmissions can be traced back to WWII. Just to have an idea the first common rail truck was marketed by Renault only in 1999, with a delay of two years from the first cars. This fact is due to the production number of trucks compared with the one of the cars. In 2010, 239 millions of light- European Union stock of light-vehicles reached the 239 millions. In the same year, the EU heavy vehicle stock was of only 35 millions [1]. Extremely heavy duty vehicles are, in most cases, tracked. The engine availability for new designs is very limited and the availability of transmission-types is even lower. Many of these transmissions may be traced back to WWII. Modern CRDIDs have High Pressure fuel Pumps (HPP) which supplies fuel constantly at high pressure with a common rail to each injector. Each injector has a solenoid/piezoelectric actuator operated by an Electronic Control Unit (ECU), resulting in an extremely accurate control of injector opening times that can be varied on many control conditions, such as engine speed and loading, altitude, temperature and humidity. This provides engine extremely accurate engine control. It is perfectly possible to control the engine speed with the accuracy of 1/10 rpm with excellent performance and fuel economy. This fact opens new perspectives in the possibility of powering these extremely heavy duty vehicles with more than one engine. The multiengine option was already adopted with success in "sport cars" like the Mercedes A190 Twin (1999). The maintenance level of these modern CRDIDs is extremely reduced with limited scheduled maintenance and build-in, predictive On Board Diagnosis (OBD) systems. OBD controls the emissions and the efficiency of the engine, providing a tool to avoid unnecessary maintenance and improving the engine availability and reliability. This paper introduces new concepts to adapt car engines to these high-powered vehicles. In the first part of this paper, steering of tracked vehicles is introduced, since the steering is an important part of the transmissions. Then, a few available engines from the automotive market are introduced. Finally a very simple solution for the installation of car CRDIDs on heavy duty tracked vehicles is discussed.

Tracked vehicles steering solutions

Steering a tracked vehicle is very different from steering a wheeled vehicle. In a typical four wheeled car, the front two wheels can be pivoted to point the vehicle. The power is delivered to the traction wheels via differential gear(s). This type of transmission allows the radial velocity difference between the wheels to be accounted for, and the wheeled vehicle can theoretically turn without any slippage or skidding. With a few exceptions, like the universal carrier and tetrarch, tracked vehicles have to rely on skid steering. If one track is moving faster than the other, the forward and rearward sections of the tracks slip laterally over the ground and the vehicle turns. The ideal track steering mechanism is simple, continuous, efficient and additive; this means that, when transitioning to a turn, the mean track velocity remains the same. Tests have shown that additive steering works better when the vehicle is in deep mud or sand, since keeping both tracks moving helps prevent the tracked vehicle from getting stuck. In addition the ideal tracked vehicle steering mechanism should make driving in a straight line easy. Neutral steering should also be allowed, that is, that the tracked vehicle can turn within its own length. Additionally, the energy from the slowed track should be transferred to the sped up one in a regenerative way.

Traditional track steering

The most obvious way to steer a tracked vehicle is to have a single engine-transmission driving both tracks, and to slow down one side or the other with brakes. A clutch system is added so that the power is first disconnected from the inside track and then the brake is applied. This is called "clutch and brake" steering. Clutch and brake steering is subtractive and non-regenerative. A tracked vehicle that is driving downhill turns the opposite direction of the driver's intent as the steering clutch is engaged. In fact the track on the side of the turn speeds up due to the loss of engine braking. The situation will be rectified once the brake engages. The clutch and brake systems can achieve wide turn radii only by engaging the clutch instead of the clutch+brake, with imprecise resulting turn. Finally, neutral steer is not possible. A few tracked vehicles use a single engine a separate transmission for each track. To turn the vehicle one track is put in a higher gear ratio than the other. Since this solution is too bulky and complex, there is usually a single gearbox for both tracks, but each final drive has a double epicyclic reduction gearbox. By engaging one of the epicyclic elements with a band brake the final reduction ratio of the drive sprocket is reduced, producing a turn. By disengaging all the brakes, the steering mechanism goes into neutral. This geared steering is almost always used with an auxiliary clutch and brake system. There are negligible efficiency (<1%) and weight penalties (1-2%) for having and additional epicycle into the final drives. This system is not additive. As long as the clutch and brake system is not activated, it is regenerative. It is continuous as it uses band brakes and epicyclic gearing. In its most common form, it only provides a single radius of wide turns in addition to the auxiliary clutch and brake system for very tight turns. Normally the single radius of turn provides a compromise between "high" and low speed driving; being too tight for the former and too narrow for the latter. There is no smooth transition between turning and not-turning.

In Controlled Differential Steering (CDF or Cletrac) the output from the transmission runs through a differential gear. The steering brakes are still present. When one of the brakes is engaged, the differential diverts the power to one track or the other for steering. In Cletrac systems the power is diverted through a series of idler gears. CDF has a small efficiency penalty (1-3%) on the system because of the additional gearing. CDF is additive and regenerative, as one track speeds up while the other slows down. Both tracks are energized at all times during a turn, so the system is also continuous. At top efficiency this system produces a turn of a single radius. However, with reduced efficiency, turns of greater radius can be achieved by slipping the brake. An important problem of CDF comes from the differential. As the tracked vehicles the tank hits a patch of uneven ground, more power will be diverted to the track with less resistance on it. For this reason, a CDF equipped tracked vehicle has the tendency to "self-steer" in off-road conditions. This behavior requires continuous corrections by the driver. A differential locking system may be added to reduce this tendency.

Double (Wilson, Maybach) and triple (Merrith-Brown, Merrith-Maybach) differential systems are an evolution on the controlled differential system. In these systems there are two input shafts leading to the steering unit. One input shaft is from the transmission, while the other comes "directly" and independently off the engine. The power is then provided to the steering mechanism even if the tracked vehicle is in neutral. This gives the tracked vehicle, the ability to turn about on its own axis (neutral steer). Double and triple differential systems also output different turn radii depending on which gear the vehicle is in. The steering brakes are still added to achieve different turn radii.

Double and triple differential systems are still very efficient, but less than CDF or geared steering due to the friction from all the additional gears. These systems have a tendency to self-steer when they hit uneven terrain, however a differential locking system may be added to reduce this tendency.

In Double Differential with Hydrostatic/Electric Steering Drive there are two inputs to the steering mechanism; one leading from the gearbox, and the other leading from a variable-displacement hydrostatic pump or a variable-speed electric motor. This system offers all the advantages of the double/triple differential system, except instead of having one or two discrete turn radii per gear ratio, it provides a smoothly variable range of turn radii based on the displacement ratio of the hydrostatic pump or on the speed of the electric motor. In addition, the pump/motor torque reduces the tendency of the vehicle to self-steer on uneven terrain through a cross-action resistance in the differential. Due to the low efficiency of the hydrostatic motor, the hydrostatic steering drives are substantially less efficient than purely mechanical double or triple differentials. In the case of the electric motor, it depends on the efficiency of the electric motor, which is always a compromise with dimensions of motor and controller. This solution offers the best control and it is widely used in modern tracked vehicles especially in the double differentials version. These highly specialized transmission systems are produced in small numbers and their availability on the market is consequently reduced.

Dual drive inherent instability

The most obvious way to drive the tracks at different speeds is to have an engine for each track. To turn the vehicle, it is sufficient to increase the speed of one engine and decrease the speed of the other. This steering method has not been successful, although some very early tracked vehicles and Ferdinand Porsche's various mechanical abortions did use this method of steering.

In a few dual drive electric hybrid vehicles (Porsche Tiger, IS-6...); the energy was recovered from the slowing track by running the electric motors in reverse to act as generators and then giving that power to the motor of the speeding up that. This made the hybrid dual drive steering regenerative (up to 65%). However larger motors were required to handle the additional power.

If the transmissions have reverse gearing, dual drive provides infinitely variable turn radii and allows neutral steer. It is very mechanically efficient, since there is no power flow from the transmission to the steering mechanism. Unfortunately, dual drive tracked vehicles are inherently unstable. This means that they are poor at manually driving in straight lines. In fact it is difficult to balance manually the speed of both engines. Also the tracked vehicle will tend to veer if it hits irregular terrain, being the two drive sprockets not cross-linked.

Enhanced stability for unstable tracked vehicles and dual drive

Stability system is successfully installed in cars since 1997, when Mercedes Benz developed the ESP (Electronic Stability Program). The car system uses 4 sensors on wheels to measure rotational speeds, a 3D sensor to measure accelerations, velocities and angles, the throttle position and the steer angle. An ECU (Electronic Control Unit) measures the car slip and, in case of necessity, cuts the throttle and the direction by breaking each wheel in a proper way. The objective is to reduce the error on desired direction inputted by the driver via the steering wheel. The control system is a digital PID (Proportional Integrative Derivative) control. The ESP is superimposed on an ABS (Antilock Braking System) that avoid wheel blockage. This system works very well in many conditions and turns off when adherence is too low or control is beyond recovery leaving to the driver a normal car. For every car model a proper tuning is to be made. Normally a car simulator calculates the optimum values to be inputted into the ECU, then standard experimental tests are performed on special test paths that were designed for the specific application of the ESP/ABS. These systems are difficult to implement on a tracked vehicle in uneven terrain. This is due to the extremely variable conditions that, in most cases, turn the ESP off, leaving the driver to steer manually the vehicle. Brake efficiency on tracked vehicle is also reduced by vehicle inertia and the track-soil friction. For the electronic stability program a dual drive is highly recommended since it can control independently the velocity of the two tracks. Single track velocity can be easily achieved by the CRDID ECU. The diesel braking capability reduces the necessity to use an external brake enhancing the endurance of the brake and reducing is thermal sizing. The unstable behavior of the dual-drive tracked-vehicles greatly improves the response of the system. However, the tracked vehicle system is highly not linear. In this case an Improved Electronic Stability Program (IESP) based on a fuzzy logic algorithm may be the best choice [5]. The IESP may use the same hardware (sensors/actuators) of a standard ESP (Mercedes-Benz™); only the control system is completely different. It is sufficient a software upgrade to convert a car from ESP to IESP. The IESP reads the driver steering angle and the dynamic condition of the vehicle and selectively acts on throttle and track-engine speed in order to put the vehicle on the required direction even during a sudden and complete loss of adherence. The fuzzy logic advantage is the capability of self-tuning. Once the inertia data of the vehicle are introduced into the software, the fuzzy control system does not need any further tuning. On the contrary the standard ESP, which is based on a traditional PID control system, needs to be adapted to every car model and the tuning differs from sedan, cabriolet and 2 volumes of the same car. The traditional ESP tuning process is long and expensive and experimental tests are required. Traditional ESP cannot recover direction from a spin and cannot control the car direction after a tyre burst. The only known limit of the IESP proposed in [5] is small oscillations in very limit condition. This oscillation affects not only the yaw axis, which is normal, but also the pitch and the roll giving the impression to the driver of an unstable and unsafe handling. However, this “unsafe felt” l behaviour takes place in a condition very close to the physical limit of the vehicle dynamic. In this case these oscillations may be a good warning to the driver to behave more properly. “Physic cannot be fooled” as Richard Feynman said about the famous Shuttle accident. As for the aircrafts, artificial stability improves handling, giving to the driver the possibility to reach the ultimate dynamic and static limits of the unstable vehicle. The overall performance of the vehicle is then enhanced. The extremely simplified solution of the dual drive transmission with its extremely high efficiency reduces also the fuel consumption.

Problems of CRDID automotive to tracked vehicle conversions: power settings

The interest of the automotive firms in tracked vehicle is limited. So the conversion should be made by small firms able to deal with small numbers. An important aspect is mechanical reliability. Automotive CRDIDs are highly reliable. Statistically, the problems are really very few and they are related to the beginning of the serial production, to accessories or to mistakes of the automatic quality control system. These events are very rare and they are well known both to the manufacturer and to the maintenance people. For tracked-vehicle-CRDIDs they can be easily avoided. In order to improve reliability and durability, in tracked-vehicle CRDID the maximum rpm may be reduced from the automotive maximum. In fact, automotive CRDIDs are already derated since the maximum rpm is reduced by 15% to avoid catastrophic failures with an extremely high confidence level. The second very important aspect is the maintenance. The tracked-vehicle engines are much more controlled than the automotive ones, where the common driver never takes a look at the engine. Often maintenance is not made for 100,000 km. That means more than 3,000 h. In this period only the lubricant and coolant levels are controlled by a fuel station operator. These men change also filters substitution when strictly necessary. The maximum rpm reduction means more mean average pressure. This fact increases the mechanical and thermal stress at the same power level. The result is a reduced power output, a reduced power-to-mass ratio and a less efficient propulsion system.

High performance automotive conversions

Table-1 summarizes a few special parts developed for racing CRDID. In the racing field the stringent requirements on engine mass and the necessity to achieve high power output to be competitive with spark ignition engine boost the research activity.

Table-1. Special parts available.

Engine	Crankshaft	Ti Alloy rods	Aluminum Alloy Crankcase	Light Crankcase	camshaft	Journal bearings
Audi V12tdi	x	x				x
Audi V8tdi	x	x				x
Fiat 2000jtd	x	x	X	x		x
Peugeot 1600 HDI						x
Fiat 1300jtd			X	x		x
SmartCDI	x				x	x

Available CRDID from the automotive market

A few CRDIDs from the automotive market are known to the authors: their performances are summarized in Table-2.

Table-2. CRDIDs from the automotive field.

Engine	Automotive Power (HP)	Naked mass (kg)	Ultimate power (HP)	Crankcase	Length (mm) x Height (mm) x Width (mm)
Audi V12tdi	500@4,000rpm	220	900@5,200rpm	CGI	980x560x712
Audi V8tdi	327@4,000rpm	195	600@5,200rpm	CGI	890x560x712
Fiat 2000jtd	190@4,500rpm	114	250@5,200rpm	Cast Iron	858x507x687
Peugeot 1600 HDI	115@3,800rpm	92	200@5,000rpm	All. alloy	790x472x607
Fiat 1300jtd	95@4,400rpm	105	200@6,000rpm	Cast Iron	693x432x572
SmartCDI	54@4,400	63	100@5,200rpm	All. alloy	495x404x542

A few comments are needed on the ultimate power concept. Automotive engines have the advantage of torque at low rpm. It is the torque that moves the wheels through the transmission. A common optimization point

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for CRDIDs in the European automotive market is the motorway optimum speed point. This means low rpm, highest gear and standard velocity, for example 2,000rpm, 6th speed and 120km/h. This condition is particularly unfavorable for the CRDID, since the crankshaft speed is very low, this means relatively low oil pressure and problems of pistons and journal bearing cooling. For the journal bearings the peripheral velocity can be low and insufficient minimum oil thickness may take place. The peak pressure in the combustion chamber in the indicator cycle is near the TDC (Top Dead Center), usually in the range from 0 to +18° After TDC (ATDC). Inertia loads are very low and they subtract a little amount of the pressure loads induced by piston and rod at the TDC (Top Dead Center). The peak pressure load on piston and crank assembly are then at the maximum possible. In aerial vehicles this low torque low rpm point is not needed, since no motorways are available for these vehicles. In the automotive field the optimization is aimed to best efficiency during transient. This result is obtained through optimum compactness of the TC, the installation and the aftercooler. Minimum sizing or undersizing is fundamental. Short ducts, small volumes are used so have immediate throttle response, more room and lower costs. This is a big advantage, since room is precious in tracked vehicles. Piping, fittings, heat exchangers are usually too small or of insufficient quality to be used in heavy duty vehicles. The other important aspect is the rpm and load range. In the case of tracked-vehicles the used range is from 50% to 100%. Intake and exhaust manifold are usually replaced and all the parts not strictly necessary are removed. The engine "naked" of Table-2 is the engine without accessories and turbocharger. The SFC are similar, with the exception of the one derived from the Smart CDI, that has, in this case, the maximum relative increment of output power. This is paid by a small penalty in SFC (Specific Fuel Consumption). In a few cases also the crankshaft and the camshafts are replaced. The head is also tuned up, with larger valves, polished ducts and re-worked swirl-ducts. The intake duct valves are also set in a fixed position for maximum power. Additional treatments are made were necessary for improved wear resistance. Just as a first approximation the output power of a tracked-vehicle conversion can be evaluated with (1).

$$P_{\max} = \frac{T_{\max Auto}\, e\, \pi\, n_{\max}}{30} \quad (1)$$

Where $T_{maxAuto}$ is the maximum torque of the automotive engine, **e** is a factor that takes into account that the conversion from Euro 6 to the much less stringent requirements of heavy duty vehicles makes it possible to eliminate several pressure drops in the air-exhaust system of the engine. With the use of SCR (Selective Catalytic Reduction) ***e*** can be around 1.15 (15% increase in torque) in many engines. Table-3 summarizes the values calculated with (1) and the ultimate values (racing field).

Table-3. Summary of results of (1).

Engine	**Automotive Power** (HP)	**Calculated with (3) HP**	**Ultimate power** (HP)
Audi V12tdi	500@4,000rpm	692	900@5,200rpm
AudiV8tdi	327@4,000rpm	420	600@5,200rpm
Fiat 2000jtd	190@4,500rpm	290	250@5,200rpm
Peugeot 1600 HDI	115@3,800rpm	138	200@5,000rpm
Fiat 1300jtd	95@4,400rpm	137	200@6,000rpm
SmartCDI	54@4,400	84	100@5,200rpm

So, even with this extremely simplified method, the results are acceptable, with the exception of the FIAT 2000jtd. It should be noted that tests are to be carried out and "weak" components should be detected. It is a good rule not to remove a working engine from the brake just to send it to the wrecking yard. Failure in CRDIDs may be tricky; in fact thermal fatigue may reveal the damage at the successive start up. As it can be seen the available commercial CRIDIDs are in the range of 168HP for the dual "SmartCDI" up to the 1,384HP of the dual "AudiV12tdi".

CRDID durability

The maintenance schedule is influenced by the “weariness” parameter. Historically TBO has been expressed in “hours”. The term “hours” has always been different from case to case. In some cases it meant the total number of revolutions of the crankshaft measured by a device installed on the crankshaft. Another parameter is the lubricant consumption rate. When this rate overcomes the limit given by the manufacturer, the engine should be overhauled. In F1 racing cars the engine durability is also affected by the number of times a certain engine speed has been overcome. This is not the case of CRDID where overspeed is controlled by the FADEC (Full Authority Digital Electronic Control). The availability of the FADEC with OBD (On Board Diagnosis) makes it possible to improve the TBO criteria with a more sophisticated algorithm. The result is an on-line indication of the residual engine life for proper TBO scheduling.

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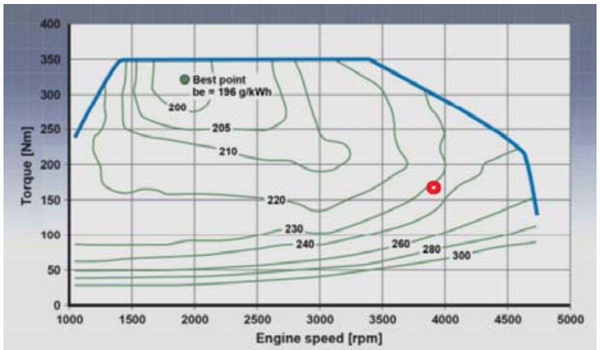

Figure-1. SFC [gr/kWh] of OM 651 DE22 [6]; 196 g/kW=42.6% efficiency.

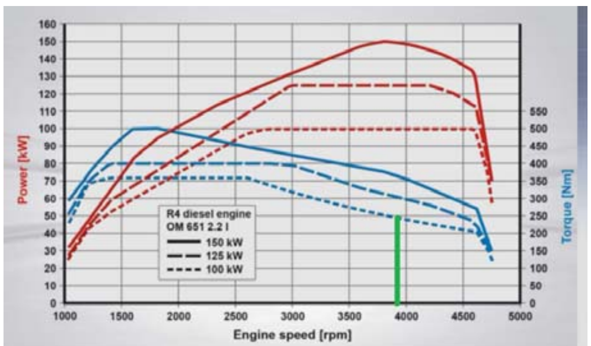

Figure-2. Power and torque curves for main OM 651 variants [6].

Heavy duty CRDID durability (TBO) based on Load Factor (LF) and Power Factor

Just for explanatory reasons, since fuel consumption is not significantly affected by the engine size, kW CRDID was chosen. Just as an example, from Figures 1 and 2 it is possible to obtain Table-1.

Table-1. Typical fuel consumption at average power settings.

Fuel consumption	
Max (100%-100 kW)	20.91 lxh
Max continuous (92%-92 kW)	18.47 lxh
Off road (73% 73 kW)	14.05 lxh
Road (60% 60 kW)	11.55 lxh

The values calculated in Table-1 are just for explanatory reasons; the true data of the engine should be supplied by the Manufacturer.

Table-2. Typical 1 hour long "heavy duty cycle".

Power setting	**Time** (min)	**Duration** (%)	**Fuel burned** (l)	**Fuel burned** (kg)
100	0.6	1	0.2	0.18
92	6	10	1.85	1.55
73	41.4	69	10	8.37
60	12	20	2.3	1.92
Total	60	100	14.35	12.02

Table-2 summarizes a typical 1 hour long "heavy duty cycle". From Table-1, it is possible to calculate an approximated fuel consumption of 14.35 l (12.02 kg). In a very simplified durability model, an engine has a lifetime that can be measured in weight of fuel burned. You can run that mass of fuel through the engine in a short time period if you are extracting large amounts of power, or you can take much more time to burn the same amount if you only extract small amounts of power. The Load Factor (LF) represents the relationship between fuel burned and the number of hours you are taking to burn it. At max continuous power, the fuel burned would have been 20.91l. Hence the LF can be calculated (2).

$$LF = \frac{Fuel_{Burnt}}{Fuel_{\max ratedpower}} = \frac{14.35}{20.91} = 0.68 \qquad (2)$$

The typical small car load factor is 0.44. It is then possible to calculate the load factor ratio LF_{ratio} (3).

$$LF_{ratio} = \frac{0.68}{0.44} = 1.54 \qquad (3)$$

A small car used for typical automotive light duty will go for 250,000 km without rebuild when properly maintained. At the average speed (city car) of 28 km/h, this means a TBO=8,930 h. On a pure LF basis the aircraft engine will last 3,700 h (4).

$$TBO_{heavy\_vehicle} = \frac{TBO_{automotive}}{LF_{ratio}^2} = \frac{8930}{(1.54)^2} \approx 3800\,[h] \qquad (4)$$

The basic concept is that the LF reduces the life with a quadratic law. However in an heavy duty

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conversion, it is possible to increase the power output of about 15% (1). The TBO of the automotive conversion will be then 2,470h (5).

$$TBO_{heavy\_vehicle} = \frac{TBO_{automotive}}{LF_{ratio}^2 P_{ratio}^3} = \frac{8930}{(1.54)^2 (1.15)^3} \approx 2470\,[h] \quad (5)$$

The durability (TBO) of the automotive conversion is then satisfactory.

Dual drive powerpack

Since the output power and torque is halved, the availability of commercial transmission for the "dual type system" is larger than the single gearbox one. In addition to the common automatic gearboxes, several other, more modern options are available. From the F1 field robotized gearbox (like the Selespeed from Ferrari) or dual clutches are available. Typically the robotized gearboxes are available up to 600Nm, while the commercial "dual clutch" gearboxes reach 750Nm. For the robotized units it is possible to choose the type of clutch. This is the reason why it can be considered the best choice for our application, where a torque converter is highly appreciated. In the case of CRDIDs, the practical limitation is 6,000 rpm, due to the common rail injection system inherent limits. Commercial high power Direct Injection Diesel run at about 2,000 rpm. Their torque value should be divided by a factor ranging from 2.5 up to 3.0 for a direct comparison with automotive derived CRDIDs. For this reason an automotive CRDID of 600Nm may be compared with a 1,800Nm classical heavy duty diesel engine. The higher speed of the automotive CRDID makes it possible to reduce the size of the gearbox and to further increase the dual drive weight advantage. Only the Final Reduction will be slightly larger due to the increased reduction ratio. Figure-3 shows the dual drive power pack for a 1200HP-V16 engine derived from the FIAT 2000jtd.

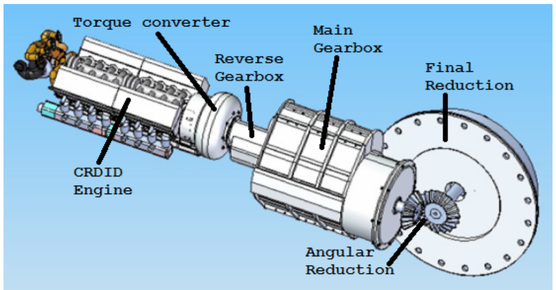

Figure-3. V16-1,000HP@4,500 rpm powerpack assembly.

This assembly was made starting from an engine that is designed starting from four FIAT 2000 multijet heads. This engine outputs a maximum torque of 1, 800Nm@2, 000rpm. This is the design point for the transmission. A torque converter with a maximum torque output of 4, 000Nm@2, 000rpm was installed. The reverse gearbox and the main gearbox follow. The final reduction was divided into two parts: an angular one with conical gears and a traditional epicyclic reduction. The total length the engine is 1,600mm while the whole assembly is 3,200mm. The width of the assembly is less than 750mm, so the overall width of the dual system is less than 1, 500mm. The dual system is shown in Figure-4.

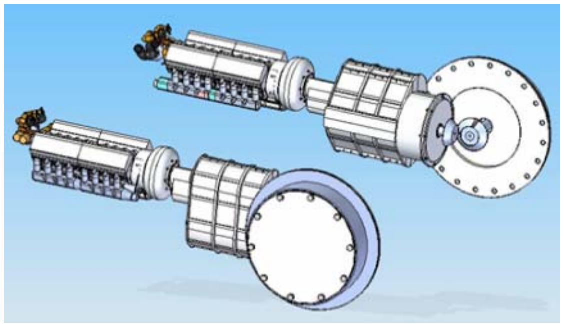

Figure-4. Dual drive 2, 000HP transmission.

The Fuller type gearbox is designed for robotized control. The steering can be then achieved by adjusting the speed of the two transmission to the desired effect (Figure-5).

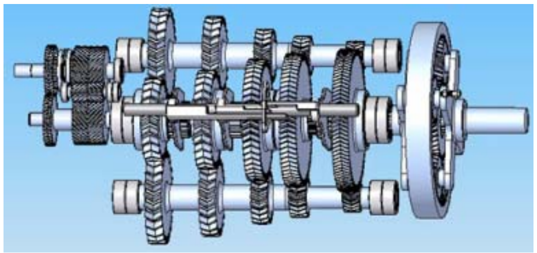

Figure-5. Fuller type gearbox.

The robotized gearbox system uses a hydraulically run, computer-operated system. The hydraulic system operates the gear selection. As the engine starts up the hydraulic system comes up to pressure. The gearbox is controlled by buttons or by the mode selected by the driver for the computer. For example: road, terrain, mountain, slow. Effectively, it is a robotized manual gearbox. Gear changes are made by the computer system which also controls the CRDID speed. When the gear is changed, the electronic unit controls the gearbox and the CRDID. Two actuators are used - one controlling the gear engagement and the other the gear selection. The G-ECU (Gearbox Electronic Control Unit) communicates with the FADEC CRDID that controls the engine. The G-ECU system calls on information from the position of the accelerator pedal, the road speed, engine speed, and the power requirements being indicated by the driver. All that's needed to change gear is a simple nudge on the joystick - forward to move up a gear and backwards to change down or to rely on computer controls in one of the "automatic drive" modes. The input-velocity of the engine and the output velocity of the gearbox are synchronized electronically by measuring the relative speed of the shafts. The engine speed is then modified to reach the required value. As it is reached the shift takes place. No built-in mechanical synchronization is then needed. The

Fuller type gearbox makes it possible to share the torque through two different shafts. This is possible with a suitable arrangement of gear teeth in such a way to make the meshing stiffness more constant during tooth meshing. The angular reduction should use helicoid or Gleason gears instead of the straight one shown in Figure-4.

CONCLUSIONS

The implementation of a dual drive inherently unstable heavy duty tracked vehicle is introduced in this paper. This vehicle has to use a computerized control system to achieve the stability. This solution makes it possible to reach the limit of the vehicle with full safety of the vehicle crew. The dual drive solution, not only makes it possible to reach extremely high power and torque level with very compact powerpacks, but also improves the overall efficiency of the system. Automotive to heavy duty conversions of CRDIDs is also proposed and durability of automotive engines is evaluated. Automotive engines with native OBD make it possible to reduce maintenance and to enhance vehicle availability.

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