ELECTRONIC SYSTEMS FOR MODERN CONSTRUCTION MACHINES

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SUMMARY

Even under the very severe operating conditions typical for the construction machinery area electronic control systems are beeing used more and more.
Examples of presently used electronic control systems in a big European construction machinery supplier's program of excavators, wheeled loaders and track type vehicles are presented.

1. INTRODUCTION

The customers are always calling for us to come up with improved construction machinery with a wider range of functions, greater economy and simplified operating characteristics.
As a result, the conventional system modules of construction machines, (figure 1) namely the "mechanical", "hydraulic" and "electrical" modules, are becoming more and more problematical.

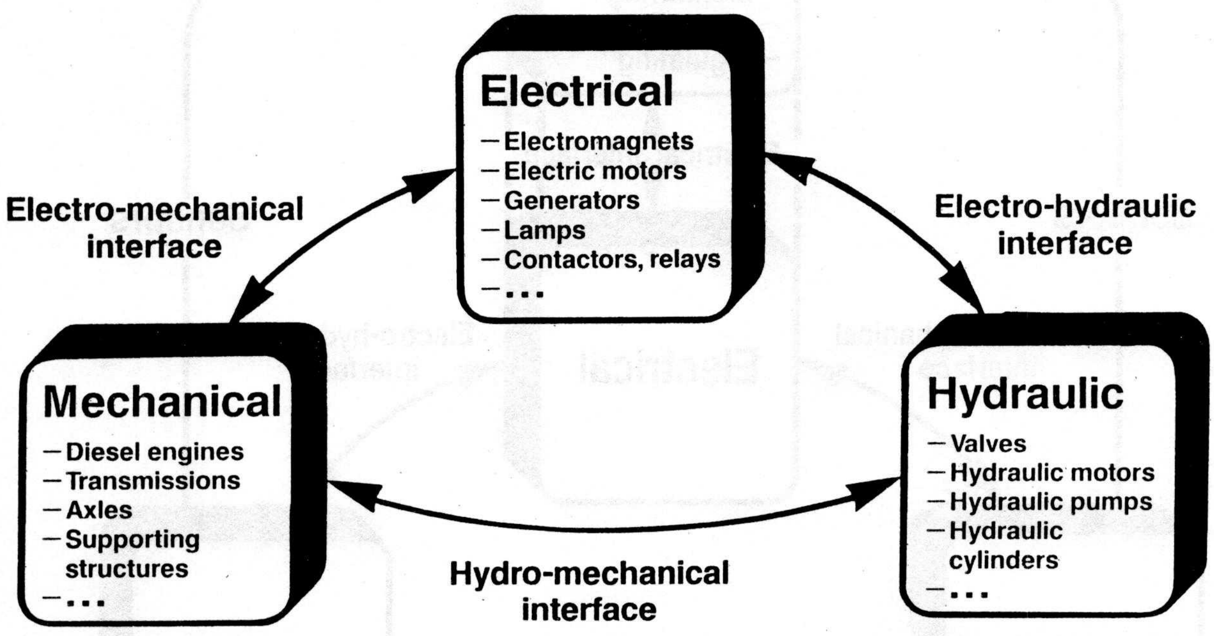


Figure 1 : Conventional system modules of construction machines

On the one hand, these problems are partly due to the fact that the additional machine functions requested by customers increase the complexity of the mechanisms and the hydraulic and electrical systems.

On the other hand, in the field of construction machines there is an increasing number of cases to which conventional solutions are very difficult, if not impossible, to apply.
This is true in the case of earthmoving machines, for example, where there is a requirement to incorporate the diesel engine and mechanical gearboxes together with the hydraulics into a unified control system.
Against the background of the successful application of micro-electronics in the industrial field and above all in the field of automobiles, this has resulted in the increasing use of electronics to solve problems associated with the control of construction machines.
In consequence, there have been developed for the Liebherr construction machinery special electronic systems:

the Litronic systems.

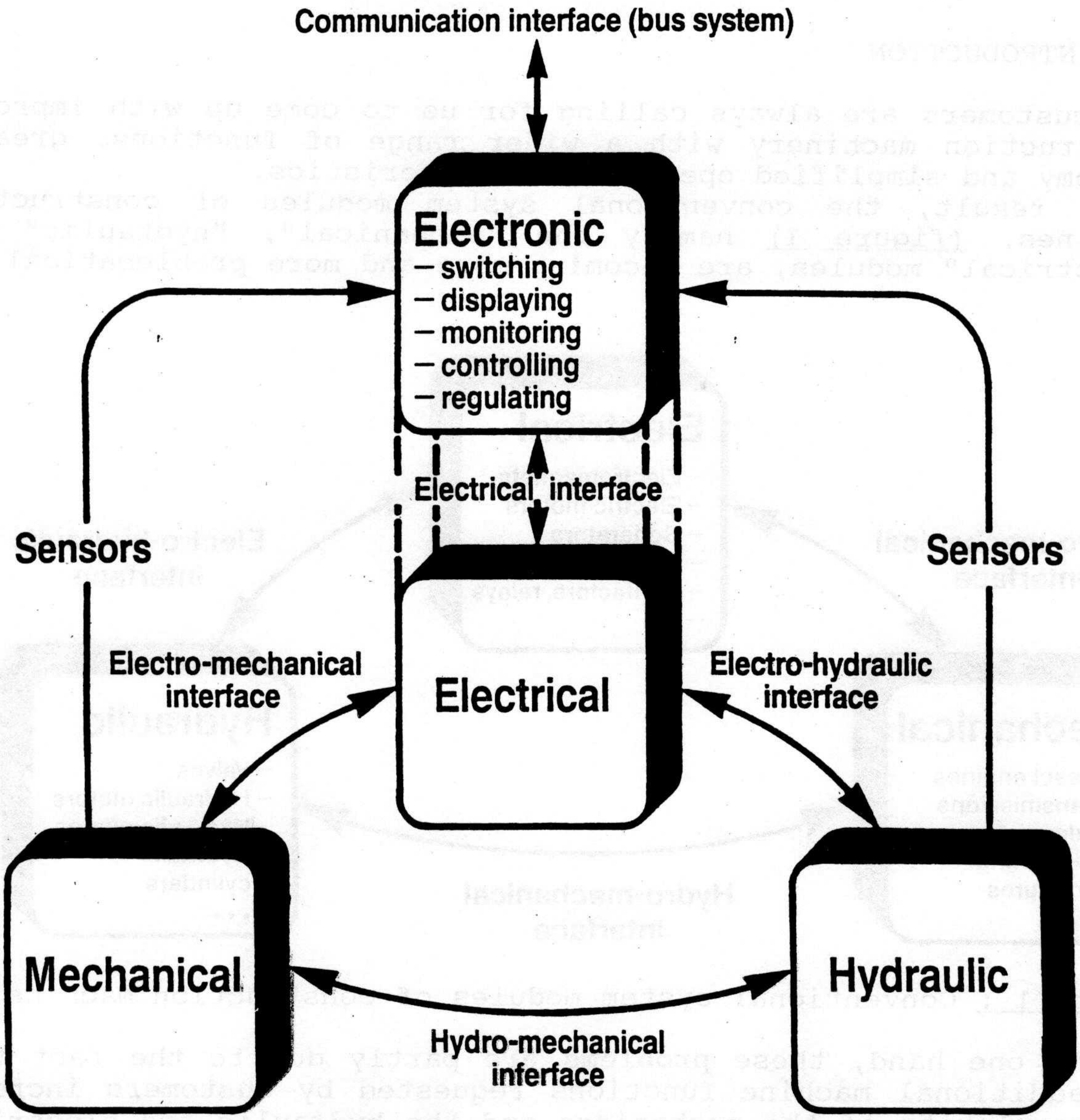


Figure 2 : System modules of the Litronic-generation of construction machines

The range of applications to which Litronic systems are already applied covers nearly all vehicles and products included in the Liebherr construction machinery group's delivery programe.

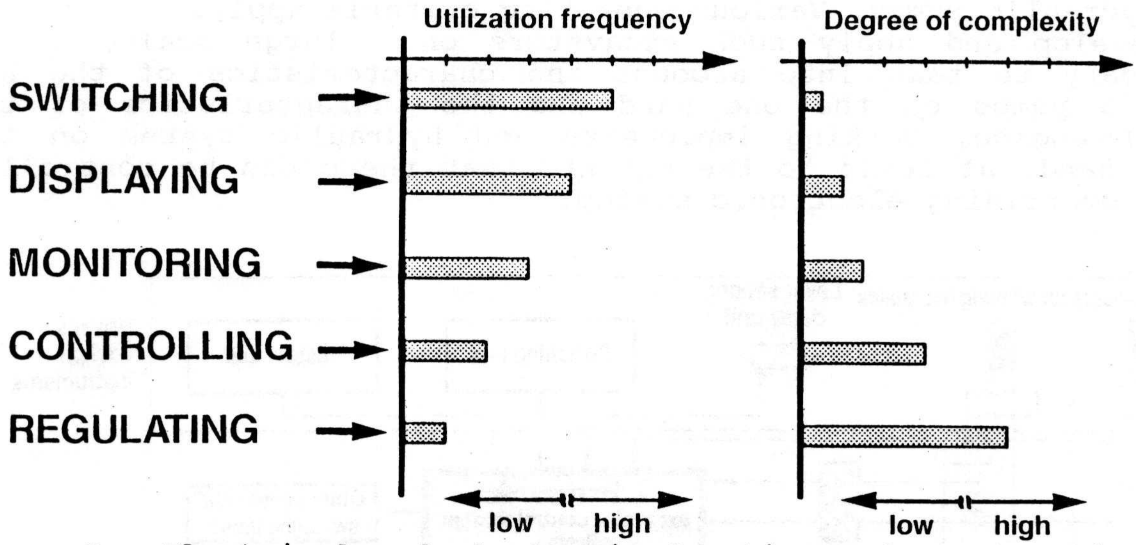


Figure 3 : Electrical and electronic functions of construction machines

As figure 3 shows, the tasks performed by electronic systems in construction machinery relate to the following functions:

- switching,
- displaying,
- monitoring,
- controlling and
- regulating.

It is obvious that low-complexity electrical functions still account for the majority of applications, whereas the more complex electronic functions (like "regulating") are applied rather seldom, when one considers their potential benefits for the system as a whole.
The reason for this is without doubt the fact that electronic systems for construction machines are usually more complex and expensive than conventional systems and are expected to cope with extreme requirements and tough operating conditions.
Consequently, factors such as economy can scarcely be used as the main arguments for employing electronic systems on construction machinery. Instead, the main advantages are

- the ability to achieve new and improved functions, and
- the ability to combine these individual functions to create system functions that were not previously practicable.

In my further presentation examples of beneficial electronic systems and intelligent system applications with a high degree of automatisation will be taken from the following areas:

- excavators,
- wheeled loaders
- bulldozers.

2. LITRONIC IN HYDRAULIC EXCAVATORS

The primary power source of most hydraulic excavators is the diesel engine, and the engine's power output must be put to the best possible use by the hydraulic system and in particular by the hydraulic pumps. Various operating criteria apply.
To develop and apply such excavators on a large scale, it is necessary to take into account the characteristics of the hydraulic pumps on the one hand and the characteristics of the diesel engine, working implements and hydraulic system on the other hand, at least to the extent, that these can be controlled by an overriding electronic system.

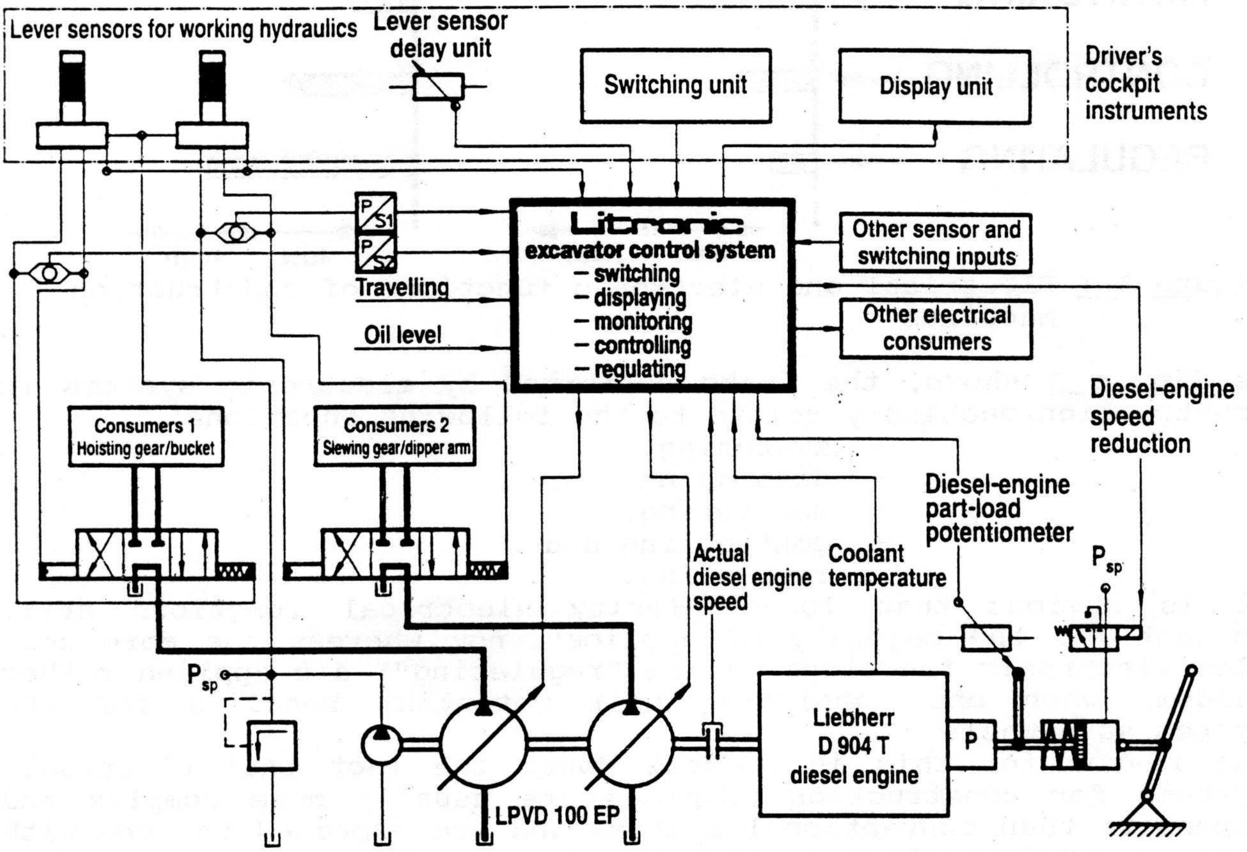


Figure 4 : Litronic excavator control system (block circuit diagram)

As figure 4 shows, the driveline of such an excavator consists of the diesel engine, which drives a double hydraulic pump with electro-proportional control.
The oil flow from the double pump is fed to the consumers via the control valve blocks.
The control valve blocks are hydraulic pilot-controlled, with the pilot pressure shared by means of two pressure measuring elements that form part of the excavator's electronic control system.
A system laid out in this way allows the excavator to perform many useful functions, such as
- controlling the flow in relation to requirements by dividing the available energy between the various consumers,
- lever sensors for the working hydraulics with adjustable time

lags and automatic drops in the diesel engine speed during working pauses,
- an economy mode as well as stepless adjustment of the diesel engine's speed to the respective requirements of the operator,
- electronic underspeed control of the diesel engine, either in full load- or in part-load operation, to optimize the exploitation of the diesel engine's output power,
- protection of the diesel engine and of the hydraulic system against overload conditions
- monitoring of the entire system parameters by means of a functional operating and monitoring unit, with audible and visual warning systems and automatic protective mechanisms.

As far as excavators and most other earthmoving machines are concerned, the most important function is the electronic underspeed control for the diesel engine.
The principle of this is shown in figure 5.

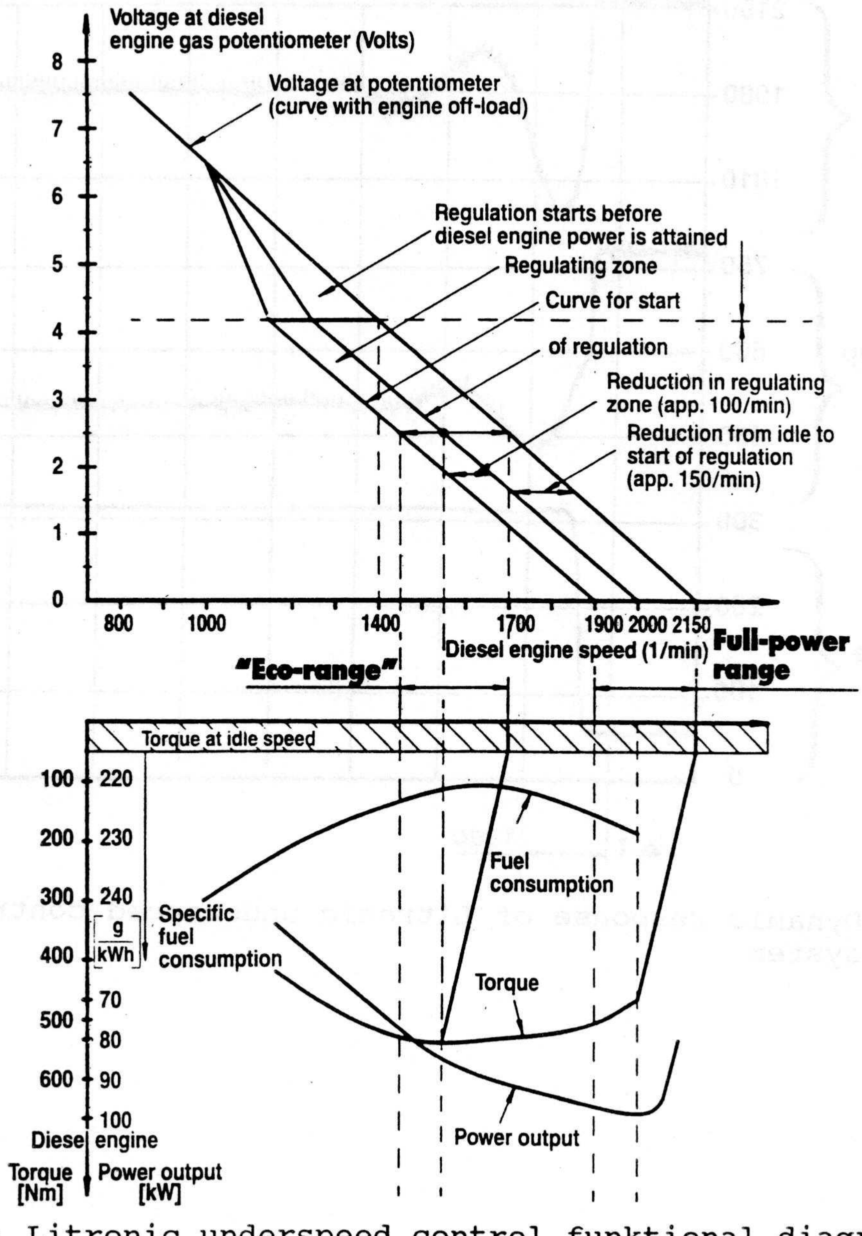


Figure 5 : Litronic underspeed control funktional diagram

The three axes in this diagram show the voltage at the diesel engine's gas potentiometer (and thus the desired value for diesel engine speed), the actual diesel engine speed and the associated diesel engine characteristics: torque, output power and specific fuel consumption.
Also included are two examples of excavator work ranges (namely the full-power range and the "eco"nomy range).
It is obvious, that in the full power range the total engine power can be transformed into usefull hydraulic power.
It is also obvious, that in the economy-range at the diesel engine speed of approx. 1550 1/min to 1700 1/min the fuel consumption is reduced by approximately 15 percent (caused by less speed an less specific fuel consumption) in relation to operating the excavator in the full power range.

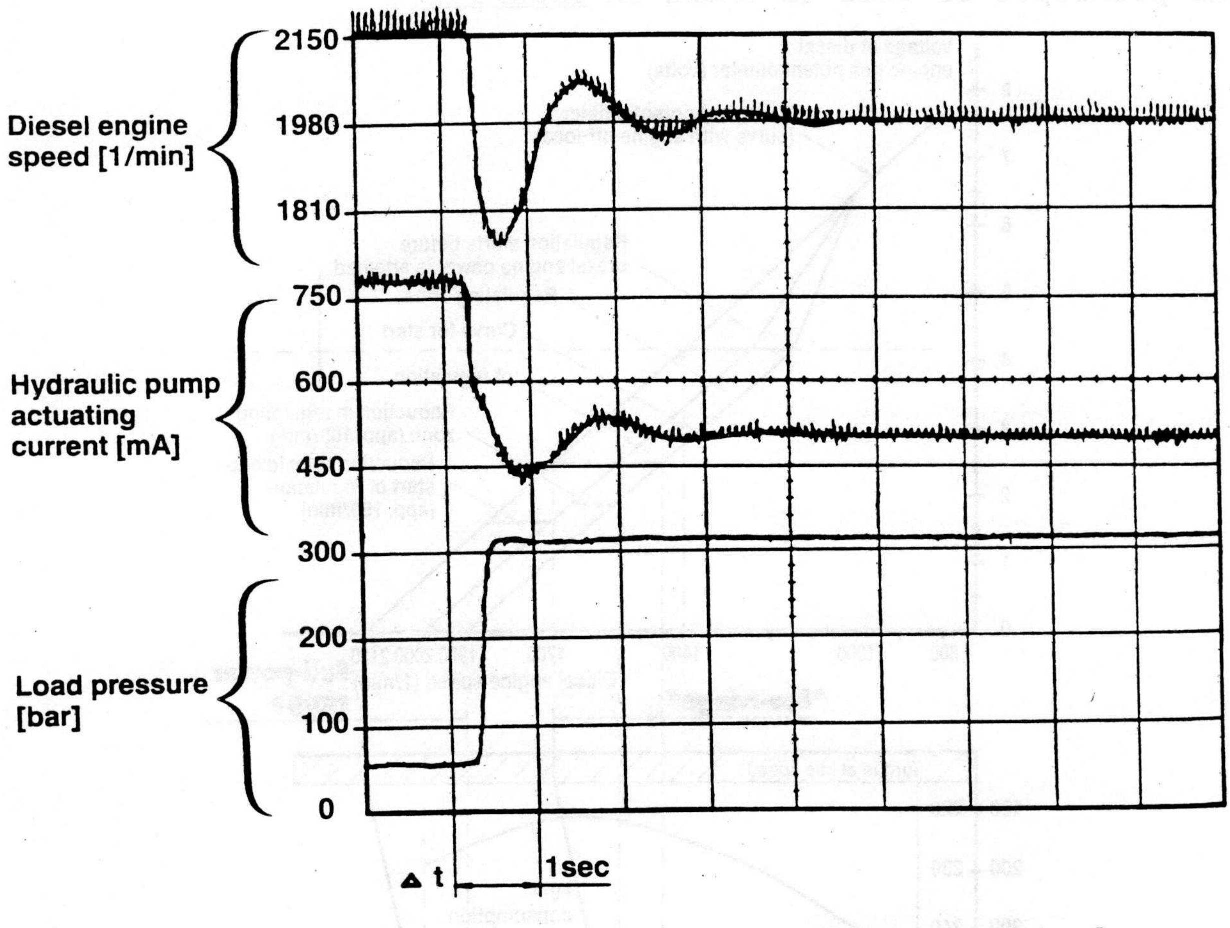


Figure 6 : Dynamic response of Litronic underspeed control system

Figure 6 shows how the Litronic load regulator responds when the load suddenly jumps from 50 bar to 320 bar in the full power range.
The rating of the double hydraulic pump is more than double the power of the diesel engine, and must be regulated down to the same value as the diesel engine's output power by the regulator within the shortest possible time.
This high installed pump rating ensures that each of the two hydraulic pumps can accept the full output power of the diesel engine as and when required, thus permitting each of the two consumer circuits to convert the full diesel power into excavating power.

3. LITRONIC IN WHEELED LOADERS

To increase the effective ratio range of hydrostatically or hydrodynamically driven wheeled loaders, the larger types have a multi-ratio mechanical gearbox on the output side of the stepless hydraulic transmission (hydrodynamic converter or hydrostatic transmission).
During the work phases, the wheeled loaders always move in the lowest gears and change their speed by varying their engine speed and using the stepless hydraulic transmission.

Shift direction / Travel situation	1st → 2nd gear	2nd → 1st gear
On flat road	+	−
Uphill	+	insignificant whether + or −
Downhill	+	−

+ : Change of speed on shifting tends to accelerate vehicle
− : Change of speed when shifting tends to decelerate vehicle

Figure 7 : Wheeled loader transmission shift modes

By using multi-ratio power shift mechanical gearboxes it is possible to vary the mechanical transmission ratio while the wheeled loader is in motion and under load.
However, if no steps are taken to adapt the output speed of the stepless hydraulic transmission to the input speed of the mechanical power shift gearbox, the rigidity of the driveline can lead to a jerky shift.
Whereas a transmission jerk with an accelerative effect has scarcely any disturbing results, a jerk with a retardative effect can, depending on travel speed, be severe enough in extreme situations (snow, wet road etc.) to lock the wheels.
Since such situations must be avoided for safety and refinement reasons, the task of the electronics is to delay the transmission jerk when shifting (for example downshifts at too high travel speed or at driver errors) so that a smooth shift is obtained in all driving situations.
Furthermore, it is the task of the power shift electronics, at the driver's option, either

- to permit semi-automatic driving with manual gear selection, or
- to permit fully automatic driving with gears selected automatically according to speed and load.

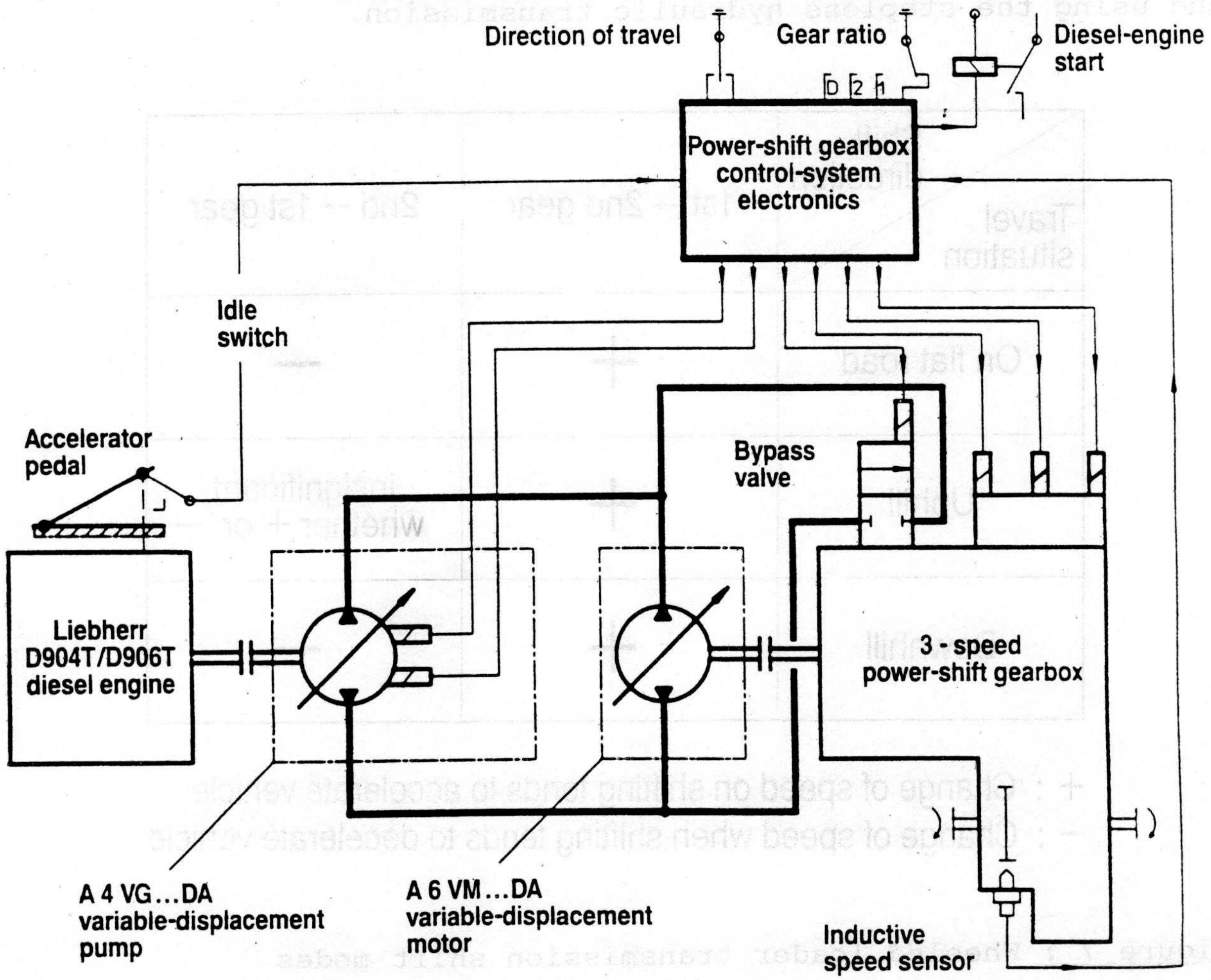


Figure 8 : Control system electronics for L531 - L551 power-shift gearboxes (block circuit diagram)

Figure 8 shows a simplified block schematic of the driveline for the Liebherr L531, L541 and L551 wheeled loaders.
The Liebherr diesel engine drives a swashplate-type axial-piston pump with an automotive control system.
The oil at high pressure which is generated by the pump is supplied to an axial piston type motor, also with an automotive control system, which in turn drives the 3-speed power shift gearbox.
The hydraulic motor, and thus the hydrostatic transmission, can be short-circuited or decoupled by means of a bypass valve.
This transmission system attenuates shift jerks by using the bypass valve to reduce the high pressure in the hydraulic transmission during gear shifts, and restoring it by means of a ramp function when the shift has been completed.

A slightly simplified method has been adopted for the Liebherr L510 wheeled loader.

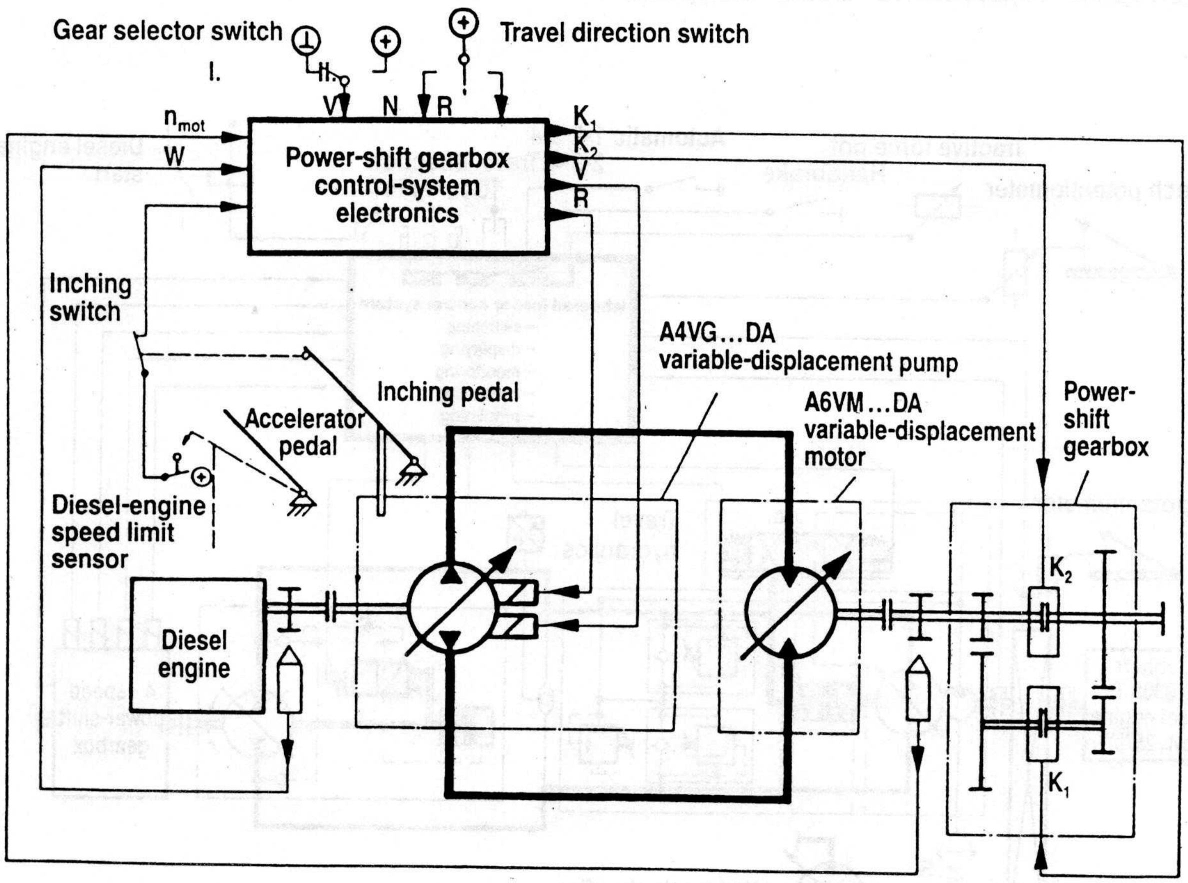
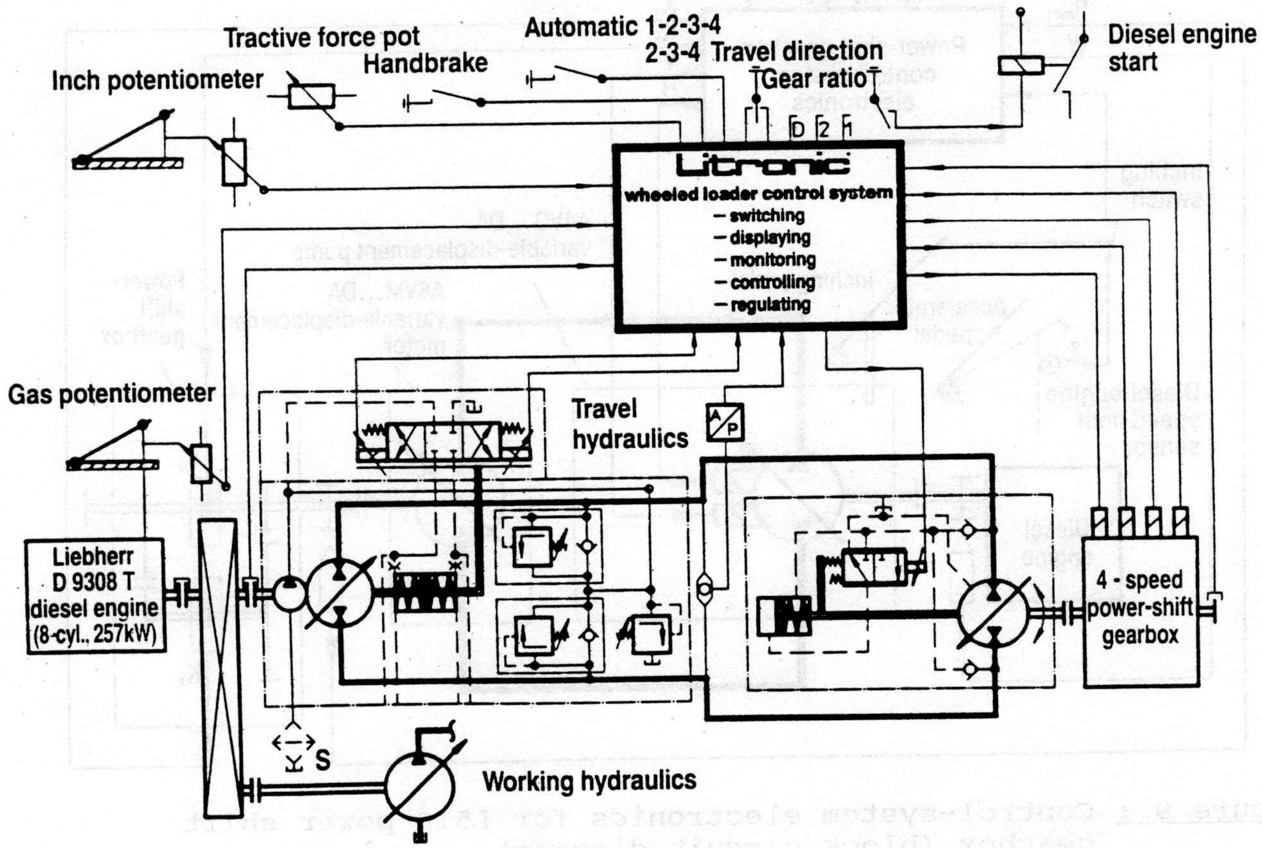


Figure 9 : Control-system electronics for L510 power shift gearbox (block circuit diagram)

Using an ingenious principle, that is to say permitting downshifts to the next lower gear (for example from II to I) only when the accelerator pedal is fully or almost fully depressed, this new principle enables the conventional hydrostatic transmission with its automotive hydraulic adjustment system to be left unchanged, and uses a special electronic control system

- to determine the correct shift point
- to control the shift sequence and duration, and
- to inhibit shifts when operating conditions are inappropriate.

The automatic version of the shift system described here differs from the semi-automatic version in that the gear shift commands are generated automatically when certain road speeds are reached. The automatic version achieves a standard of behaviour when in motion comparable to an automobile with automatic transmission. The solution described here thus makes it possible to use digital switching logic as a means of greatly increasing the refinement of the wheeled loader when in motion, without making the hydraulic equipment more complex.



<u>Figure 10 :</u> Litronic wheeled loader control system (block circuit diagram)

After the description of this two electronic transmission control principles, a system will be presented, which far exceeds the normal bounds of present stage of series applications.
That is to say the use of a microprocessor control system for the whole driveline management task of large wheeled loaders, such as the Liebherr L561 machine.
The objective when developing this wheeled loader control system was to use electronics to control and regulate all the functions relevant to travel movement, for management of the powershift gearbox and for a tractive-force limiting system controllable by the driver.
The driveline consists of a Liebherr V8 diesel engine, a hydrostatic transmission with electronic-proportional control of the variable hydraulic pump and motor and an output-side mechanical 4-speed power shift gearbox.
In this form, the driveline fullfills the following functions:

1) Automatic electronic travel control (forward, reverse and inching) with proportional electrical control of the hydraulic pump and of the hydraulic motor
2) Electronic underspeed control for the diesel engine
3) Electronic maximum pressure limiting (pressure cut-off)
4) A driver-operated potentiometer to regulate tractive force between 20% and 100% of the wheeled loader's maximum tractive force
5) Manual gear selection with electronic synchronizing of the hydraulic transmission and the mechanical power shift gearbox
6) Automatic gear selection with no action needed on the driver's part

These functions can be summed up as offering the following advantages:

- Improved power utilization, using an automatic electronic travel controller and using an electronic underspeed controller for the diesel engin's output power
- Variable pressure setting in the travel hydraulics, to adapt tractive force to suit actual ground conditions
- Avoidance of wheelspin and therefore of excessive or premature tyre wear
- Full control of gear shifts by the microprocessor, so that the driver's workload is reduced (no need to shift the 4-speed gearbox)
- No wear at the shift clutches in the gearbox, and reduced loads on the entire driveline as a result of the electronical synchronised gear shifts

4. LITRONIC IN CRAWLER TRACK VEHICLES

The new Litronic machines family for crawler-track dozers is a further example of how effectively and beneficially mechanical, hydraulic, electrical and electronic elements can be integrated.
When developing this new range of dozers, the objective was to position them right at the top of their class in terms of performance and weight, to give them a modern appearance suggestive of their advanced technical features and to achieve a definite improvement in the efficiency and operating life of components and therefore of the system as a whole.
In addition, the use of the electronic diesel engine underspeed control was intended to convert the installed engine power into higher dozing force and to effect a definite improvement in the vehicle's straight-line running by means of electronic track synchronizing.
The dozer models developed with these objectives in mind are also equipped with full hydrostatic transmissions to the crawler tracks, and therefore possess all the acknowledged advantages of their predecessors, such as:

- straightforward, stepless control over the entire speed range
- high manoeuvrability and power-on turning
- no-wear steering, with point-turn facility
- no-wear braking and reversing.

In addition to these features, it has so far always been difficult to ensure straight-line running of hydrostatic-transmission dozers regardless of load.
The reason for this is to be sought in different rates of internal oil leakage in the travel hydraulic at different operating conditions, and also in production tolerances in the characteristics of the pumps and motors used.
It is obvious that this problem does not admit of an easy solution if only conventional hydro-mechanical transmission principles are at the designer's disposal.

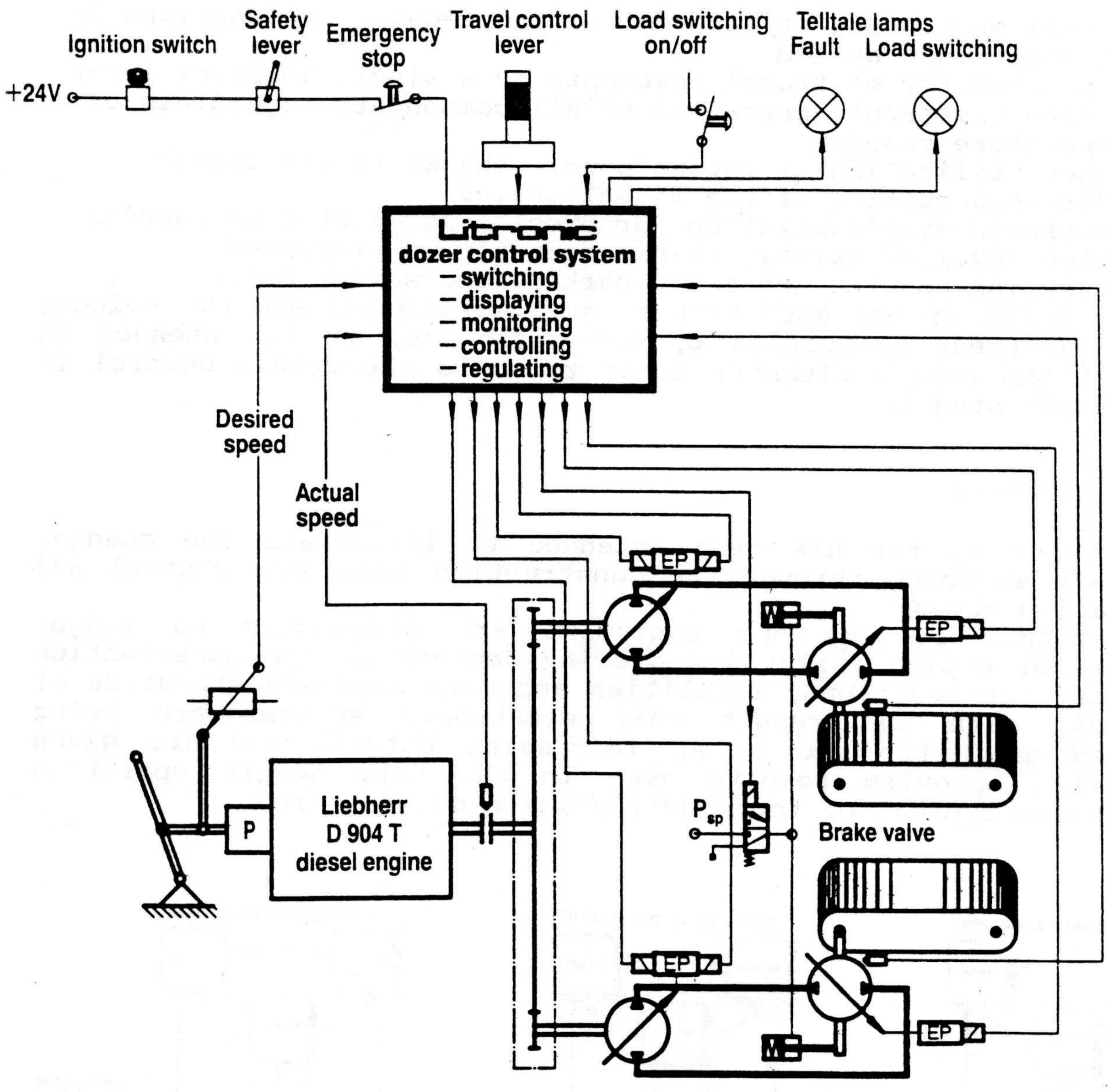


Figure 11 : Litronic dozer control system (block circuit diagram)

Figure 11 shows the schematic layout of the redesigned driveline as a block diagram.
The diesel engine drives the two pumps, which have electronic-proportional control, through a splitter gearbox. The hydraulic pumps run in closed circuits and supply oil at high pressure to two hydraulic motors, which also have electronic-proportional control.
The principal functions of the driveline in this form are:

- Continuously variable speed regulation
- Electronic steering control right down to point turns
- No-wear electronically controlled hydrostatic braking
- Diesel engine load limiting (with priority for the working hydraulics)
- Synchronizing of the two hydraulic motors (and thus the crawler tracks) for accurate straight-line movement.
  The functions outlined above result in the following advantages for the electronically controlled dozer:

- Central monitoring of all control and regulating functions in the electronic system
- Simple control of travel movements by a single joystick lever
- Precise electronic operation of all components regardless of temperature changes
- Higher utilization of engine power, thanks to electronic underspeed control of the diesel engine
- Electronic synchronization for precise straight-line running
- A high level of safety, thanks to built-in overspeed protection and the automatic parking and safety brake

On the basis of the good results so far obtained and the welcome given to these principles by our customers, it is intended to convert the entire Liebherr dozer range to electronic control in successive stages.

5. CONCLUSION

This paper so far has been intended to illustrate the changes that are sweeping through the construction machinery control and regulation areas.
Conventional systems and equipment are frequently no longer capable of coping fully with growing demands in the construction industry for additional facilities and more accurate standards of control, with the result that electronic systems are being adopted gradually but to an increasing extent, and are given steadily improving results even in the very severe operating conditions typical of the construction machinery area.

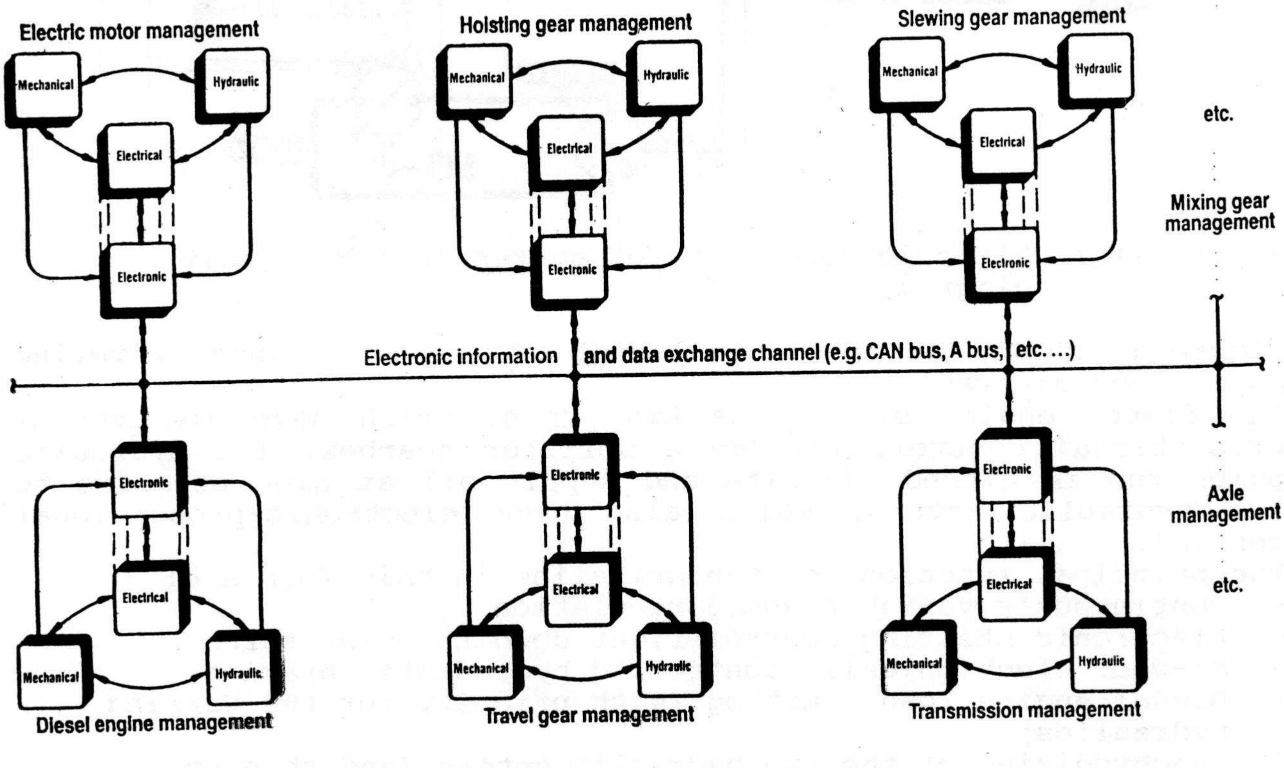


Figure 12 : Construction machinery with distributed intelligence (block circuit diagram)

Whereas many current developments are still largely concerned with individual electronic systems at various points on the construction machine (isolated solutions), there are already clear signs that further stages in the process of integration involving the components and systems distributed through the vehicle or plant will culminate in a single networked, overall system.
The new degree of freedom afforded by the Litronic systems, with the straightforward exchange of electronic data between individual functional systems at various points, makes joint use of operating system parameters from other installed systems possible by way of the communication interface mentioned earlier and a "data bus", so that the entire equipment's performance and efficiency benefits.
The development and use of electronic data exchange systems of this kind began in the automobile and commercial vehicle areas some years ago (the first examples being the CAN bus, the A bus etc.), and is certain to penetrate the construction industry as microelectronics are used increasingly.
In the years to come, we will therefore be called upon to undertake still further intensive development work in the field of construction machinery electronics, so that we can firstly develop complete, optimized systems for each type of machine and secondly offer our clients in the construction industry new generations of products with added benefits as a result of the Litronic concept.