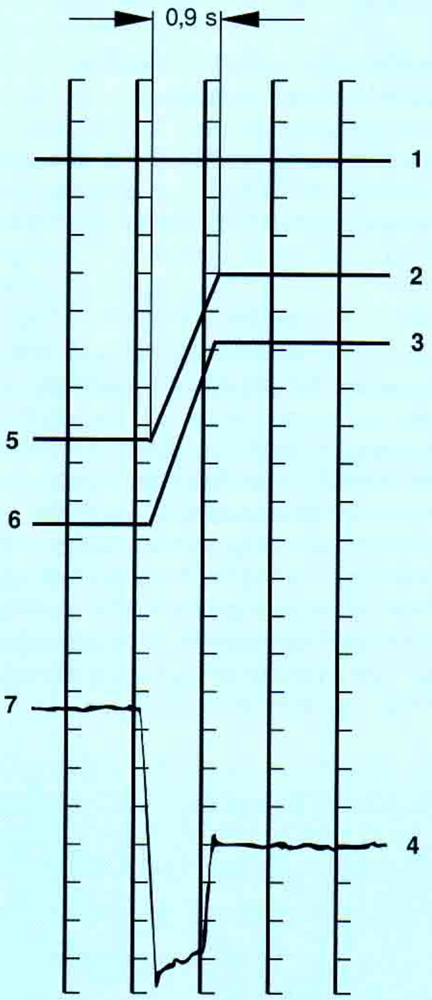

1 Throttle open
2 Command speed 3500 rpm
3 Actual speed 3350 rpm
4 Torque
5 Actual speed 5700 rpm
6 Command speed 5700 rpm
7 Torque 310 Nm

Diagram 9: *Speed and torque curves with engine connected.*

The axial piston units which had been running since 1983 and were checked after a running time of 7500 hours. A visual check showed no apparent wear. This was only to be expected, as the functioning of the test rig had not shown any degradation.

On first commissioning, the decision had been made that the main components should receive a basic overhaul after 10 000 hours. This corresponds to approximately 5 years operating time.

6 Low loss controls in a hydraulic ring main system with imposed pressure

Low loss power take off from a ring main system with imposed pressure is best achieved with a rotary drive in which the output device can be "swivelled over centre". Utilising such devices, a four quadrant drive is possible in open circuit configuration.

However, fixed displacement units can also be connected to such systems. For this, it is necessary to make certain changes to the circuit as can be seen in *figure 55.* A fixed displacement unit (1) is coupled to a tacho-unit (2) in a conventional manner. The speed information is achieved by flow control (3) and the directional control by means of directional valve (4). Between the pressure line and the main actuator, a 4 way proportional valve (5) (which is piloted via the tacho-unit circuit) is installed. The proportional valve now controls the pressure difference at the secondary unit dependent upon the external torque applied to the unit, so that the pre-set speed set by the flow control can be maintained. The pressure difference between the system pressure and the actuator pressure is generated at the proportional valve.

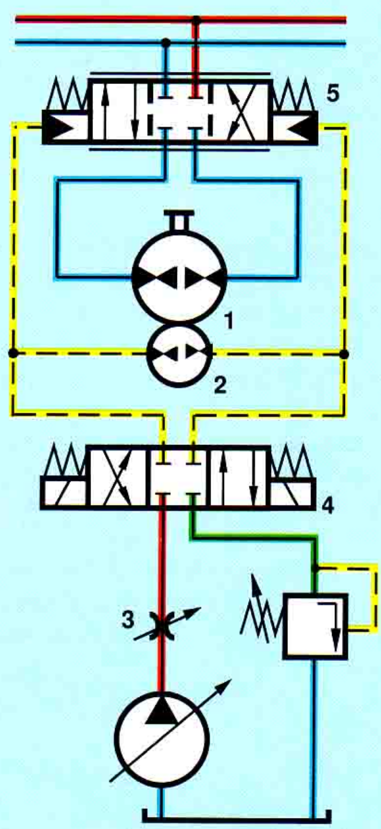

Fig. 55:
Fixed displacement unit in a system with impressed pressure

Regenerative braking operation is also possible with this circuit. The losses are, however, higher than with a variable unit having over-centre control, due to the existence of the throttling valve in the energy flow line.

The same problems occur in a cylinder control in the same type of system, as the the most effective solution involving steplessly changing the piston area is technically not possible. Three possible cylinder controls are shown in *figure 56*. At the bottom, a flow coupled system is illustrated with control being achieved via the swivel angle of the pumps. Energy recovery is possible when the cylinders are being retracted. This energy is returned to the electrical power lines. In the centre, a system is shown with flow coupling by means of proportional valves. These take their power from pressure compensated pumps. The power loss here is dependent upon the pressure drop across the proportional valves. In the partial load condition, with high performance devices, this can be extremely high.

The most expensive, but at the same time the system with the lowest losses, is the system with pressure coupling and "hydraulic transformers" at the top of the page. In this circuit, the losses are dependent upon the efficiency of the transformers. This solution is, however, only economic when high powers and large units are to be employed, e.g. on very large excavators. As the cylinders are retracted, the potential and kinetic energies are stored in the accumulators in the common pressure line. The cooling power which must be installed is very much less than with throttling control.

The hydraulic transformer consists of a fixed displacement unit which is directly coupled to a standard unit for secondary control as shown in *figure 57*.

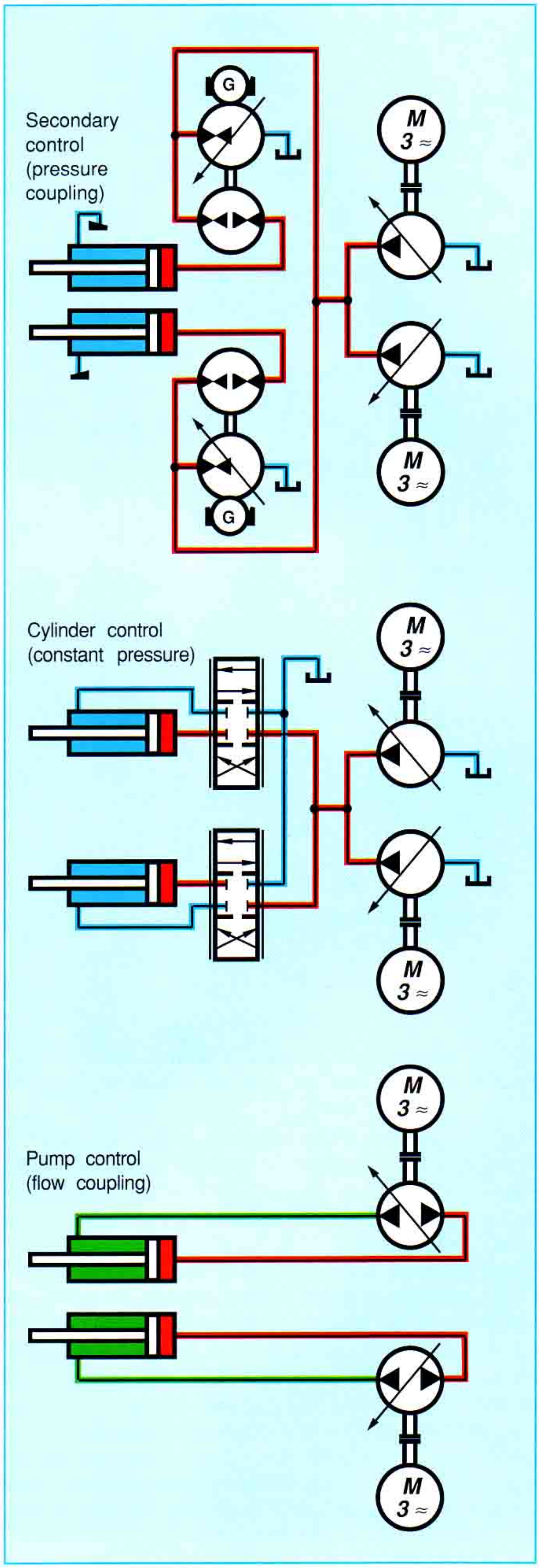

Fig.56: *Linear hydraulic drives.*

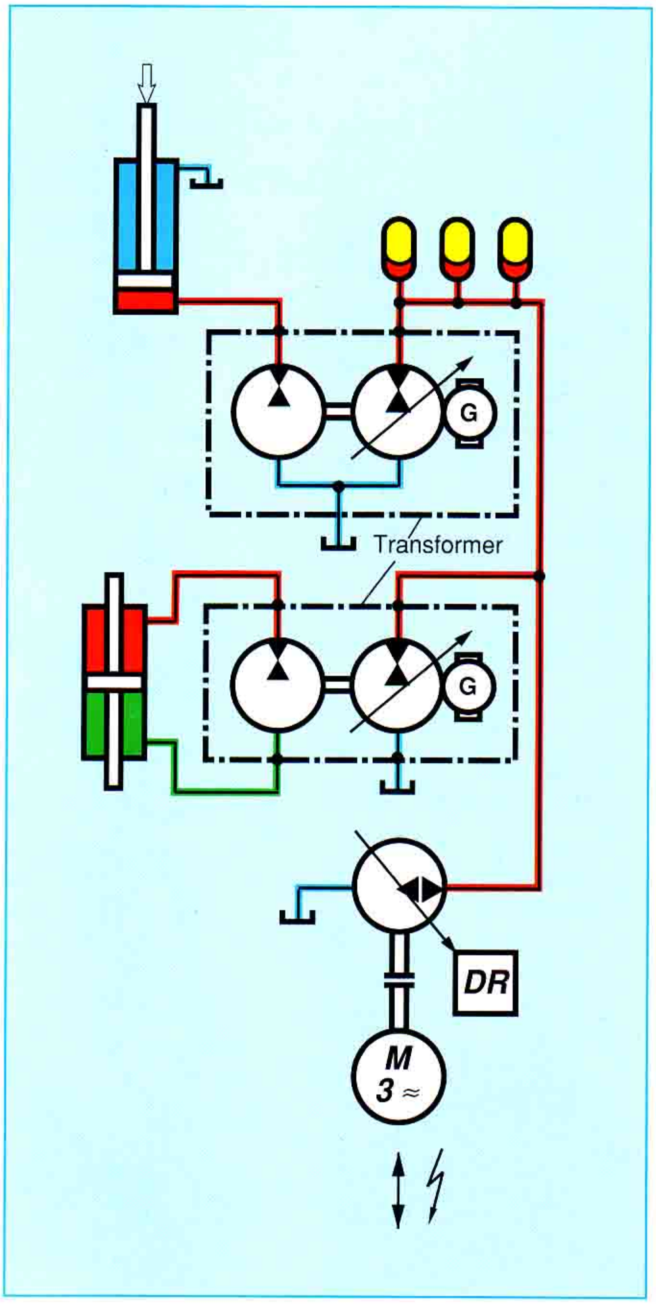

Fig. 57: *Cylinder control with hydraulic transformer*

Fig. 57 shows two possible cylinder circuits for connecting cylinders to a system with imposed pressure. These show a single acting cylinder with load in one direction and a double rod cylinder with alternating loads.

When the single acting cylinder at the top of the illustration is extended, a speed signal is given to the tacho-unit which in turn acts as a speed control for the cylinder. The fixed displacement unit acts as a pump, the pressure output of which is dependent upon the load on the cylinder. The variable unit matches its displacement to the cylinder loading and the pressure available in the power line working under secondary control, so that the signalled speed of the cylinder is achieved. When the cylinder is retracted under load, the function of the transformer is reversed. The variable unit works as a pump and delivers fluid back into the pressure line. At the same time, the speed set at the tacho-unit once more acts as a speed control for the cylinder. The energy recovered can either be stored or transferred to other actuators. The tacho-unit may be either electrical or hydraulic in this circuit.

The reversal of the cylinder movement can either be achieved by reversing the direction of rotation of the transformer or by reversing the swivel angle of the output device of the transformer. As reversing the swivel angle is much faster than reversing the complete transformer, this is much to be preferred. A further advantage is that the unit need not run in the low speed range where friction and wear are at their peak values.

Fig. 58 shows the design of a hydraulic transformer using standard swashplate axial piston units. The design requires neither input not output drive shafts as the drive shafts are coupled together via a coupling. The tacho-unit is connected to the through shaft of on of the units. If required, the through shaft of the fixed displacement unit can be used to drive a second actuator. An extra load can thus be powered in a simple manner from this point.

Normally, both axial piston units are selected to have the same displacement. However, as these are standard units, any required combination of units can be selected to suit the application, the operating pressure of the fixed displacement unit and the operating conditions. This means effectively, that the transformer can be operated either as a pressure transformer or as a flow transformer. As no external mechanical connections to the transformer are required, the design of the overall unit can be simplified as may be seen in *Fig. 59*.

The drive shafts of the two units may be connected to a common drive flange fixed to the housing and which also carries the gear drive to the tacho. As the pistons operate in opposite directions, bearing loads are substantially reduced. This also has a beneficial effect on the bearing life.

In addition, the axial dimensions (and also the manufacturing costs) are considerably reduced. Any reduction in manufacturing costs must also have a considerable influence on the range of applications of the unit, making it more economic for lower powered applications.

If, however, the application of a hydraulic transformer is not possible on economic grounds, the cheaper circuit shown in *figure 60* can be employed.

Once more, the cylinders are operated from a system with imposed pressure on to which a number of units are connected.

The units can operate either as generators or motors.

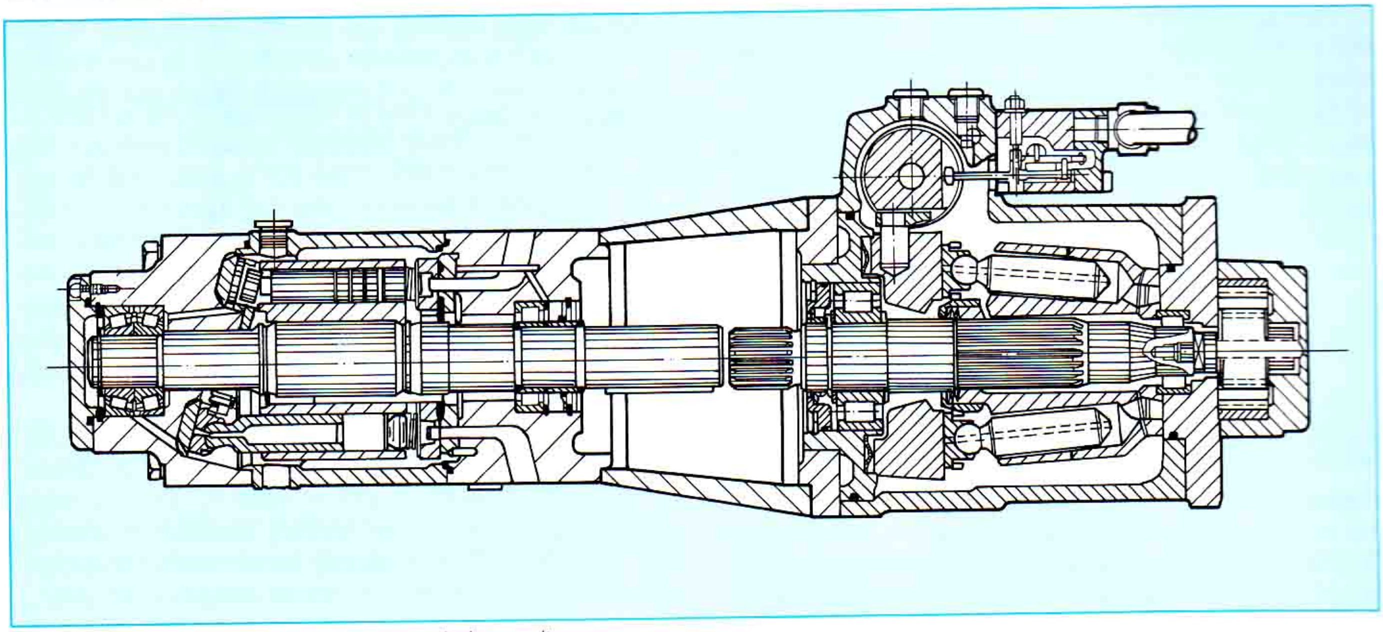

Fig. 58: *Hydraulic transformer with swashplate units*

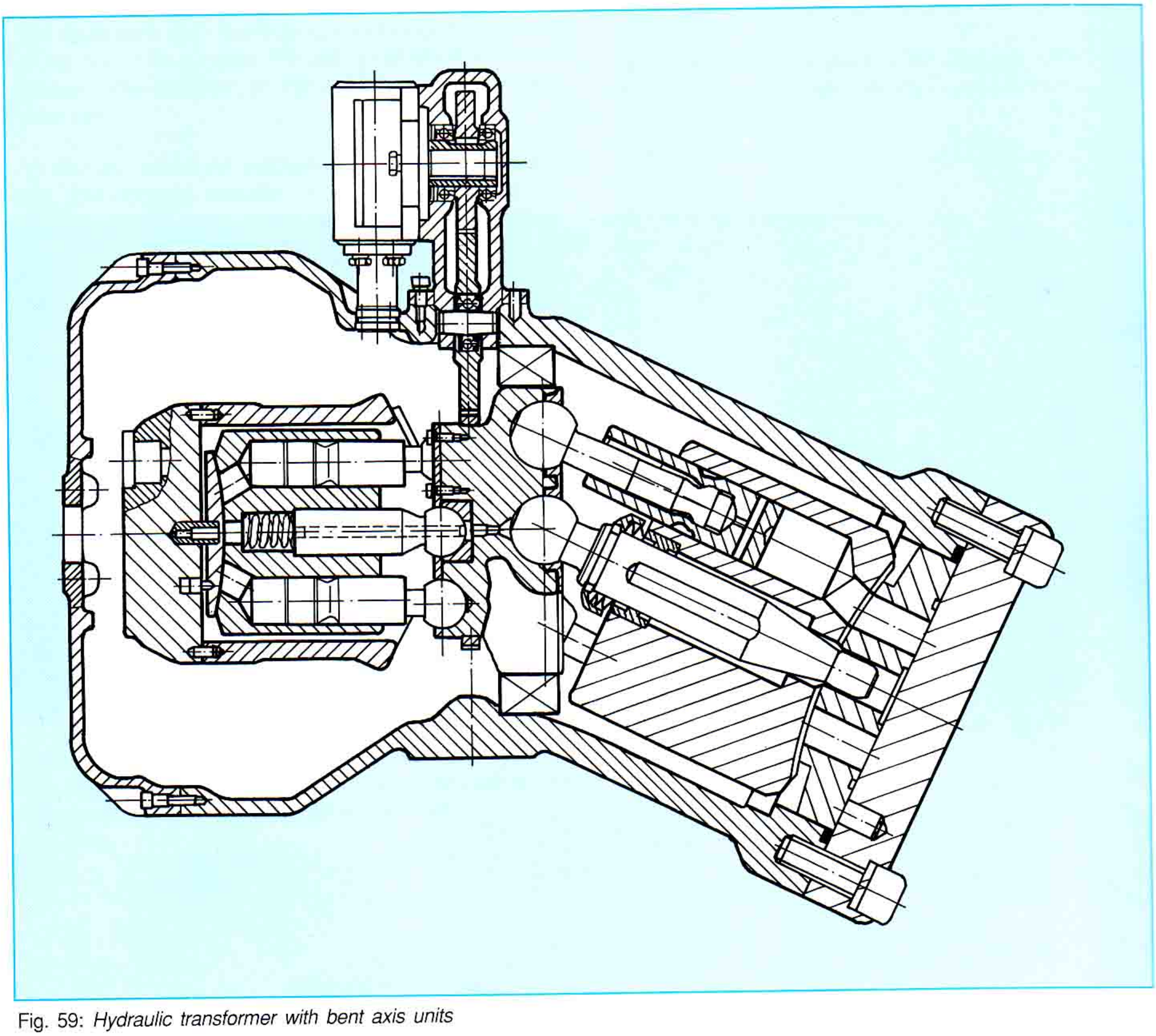

Fig. 59: *Hydraulic transformer with bent axis units*

An internal combustion engine drives an axial piston unit with a mooring type control (mooring control means a two quadrant drive system). A metering pump is also driven by the engine to control the speed of the cylinders. The speed of the cylinders is controlled as a function of engine speed and of the swivel angle of the metering unit. If the pressure at the actuator side(V) is lower than the system pressure(H) when the cylinder is extending, the metering unit acts as a motor and drives the engine. If the pressure is higher, the metering unit acts as a pump and the extra power is taken from the engine.

When the cylinder is retracted, the process is reversed. Energy is recovered as the engine only needs to make up the difference in pressure between (V) and (H) on the diagram. The engine is driven when the pressure (V) on the actuator side is higher than that on the system side (H). If pressure on the actuator side rises to the level of the maximum permissible value, a pressure switch operates the directional valves to unload the annulus side of the cylinders to tank. This has the effect of reducing the pressure by the ratio of cylinder areas.

If more energy is returned to the system than the hydraulic accumulators can accommodate, the axial piston unit with pressure control and the mooring control feature then drives the engine with up to 30% of its power rating. Only after this time is it necessary to convert the extra energy into heat.

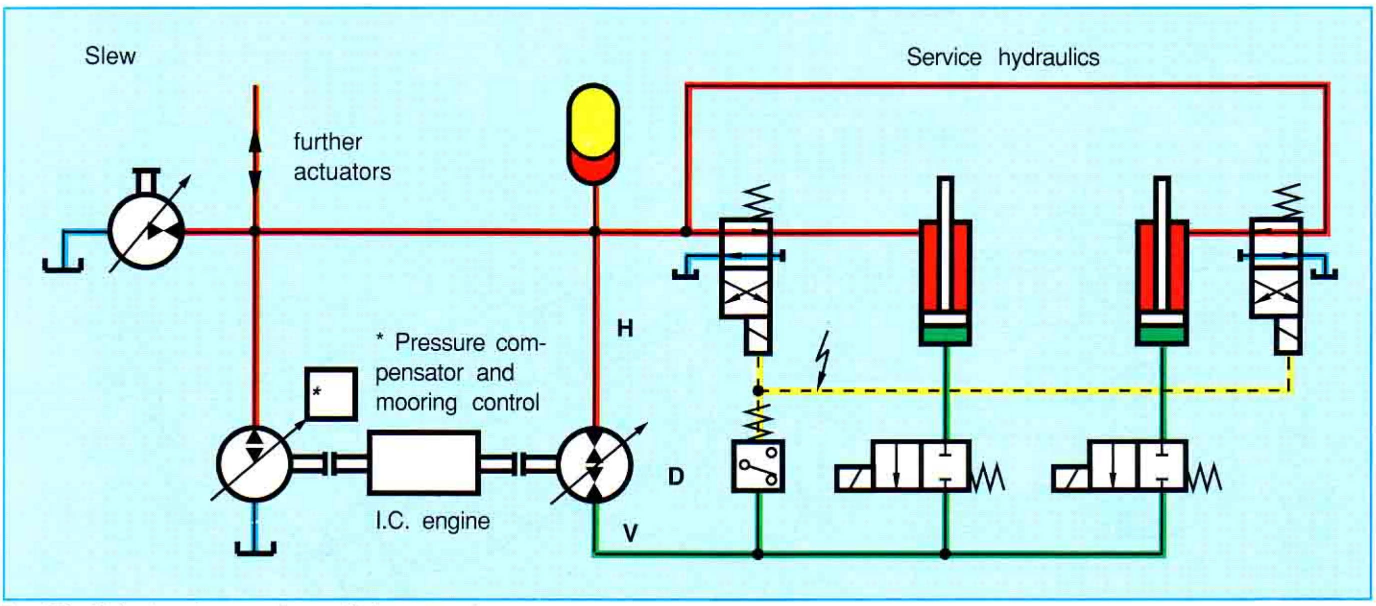

Fig. 60: *Cylinders in a system with impressed pressure*

6.1 A cylinder drive for an oil well pump

A well known characteristic of underground oil wells are the so-called "nodding donkeys", hard at work pumping the oil from deep in the earth. The "nodding beams" of these machines, which are connected to the pump rods, are electrically driven via a belt drive, a gearbox, and a connecting rod. The weight of the pump rod is partially counterbalanced by a counterbalance weight. The velocity of the pump rod changes with the angle of the connecting rod in a sinusoidal manner throughout the cycle.

The need for greater flexibility in meeting the varying operating conditions cannot easily be achieved with this type of drive. In view of this, a direct hydraulic drive utilising a hydraulic cylinder was offered *(Fig.62)*. The hydraulic cylinder drives directly on to the pump rod and , with the exception of the short reversal time, remains constant throughout the stroke.

The conditions under which a crude oil pump must work are dependent upon many factors including the viscosity of the fluid to be pumped, the quantity of water and sand present, the condition of the bore hole and the gas pressure.

To this are added the problems of pumping very heavy oils. The pumping operation occurs when the pump rod is rising . On the down stroke, the pump chamber is filled. If the down stroke occurs faster than the pump can fill properly, poor filling will occur. These problems are particularly acute in new boreholes where conditions are completely unknown. Flexibility is therefore paramount. Mechanical drives operate at the same speed in each direction - they have no choice. The maximum cycle rate therefore depends on the maximum downward speed. Under certain circumstances, this can be very slow. The hydraulic drive permits independent selection of very slow downward speed and the correct pumping speeds. This means that the lower cycle times can be achieved under otherwise identical conditions.

A further advantage is that the stroke of the hydraulic unit can be varied by simply resetting limit switches. This can be done to reduce production from the field without the necessity of stopping the pump which would otherwise lead to the bore silting up.

When the drive was designed, the possibility of recovering the potential energy of the pump rod during the downward motion could not be overlooked.

Fig. 61: *Nodding Donkey Pump*

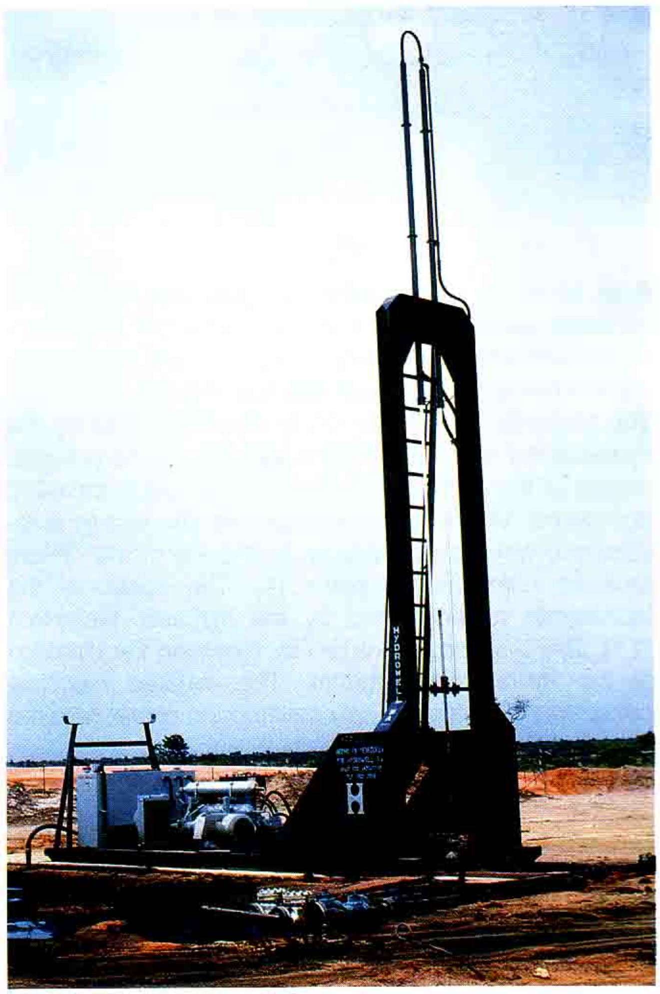

Fig. 62: *Oil well pump with cylinder drive*

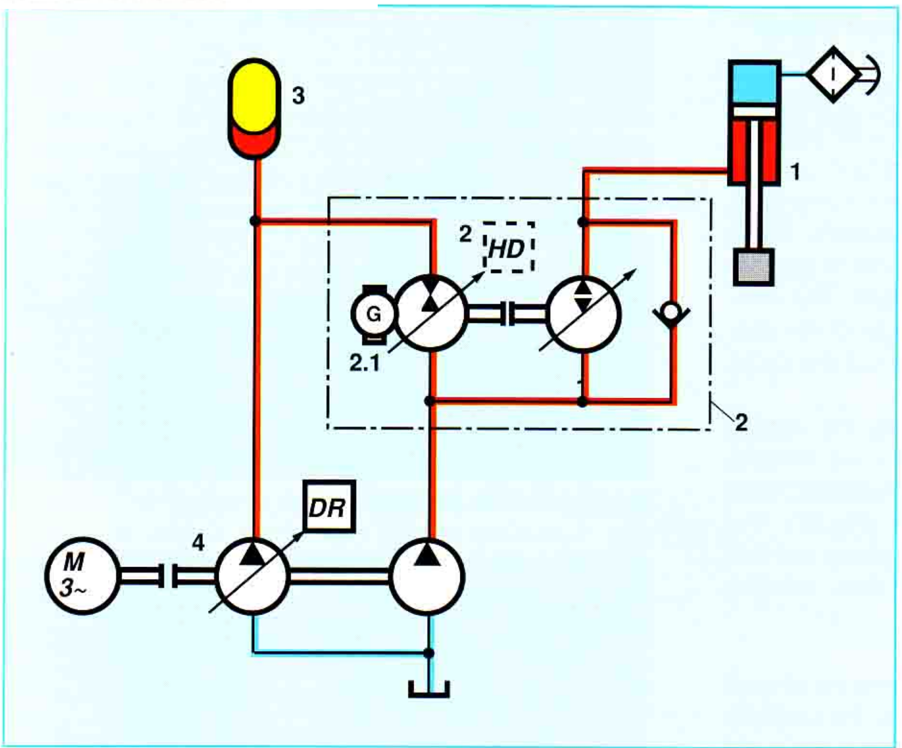

Fig. 63: *Drive scheme with hydraulic transformer*

If all of these requirements are gathered together, it becomes apparent, that a system under the secondary control with energy recovery from a hydraulic transformer would provide the optimum solution *(Fig.63)*.
The single acting cylinder (1) is driven upwards by the hydraulic transformer (2) which also returns the potential energy to the accumulator (3) when the rod is travelling downwards. On the next upward stroke, this energy is re-used and any losses made up by the electrically driven, pressure compensated pump (4). The speed of the transformer is determined by the hydraulic tacho-unit (2.1). The cylinder is reversed by reversing the direction of the hydraulic transformer. The installed electrical power was 55 kW. This only covered the power required to pump the oil or approximate 50% of the power required during the pumping stroke.

The complete installation is shown in *figure 64.* The hydraulic transformer can be seen in the foreground. It consists of 2 tandem units - a total of four axial piston units type A4VSO125HD. To the right, on the through shaft of one of the units, can be seen the tacho-unit —a 6,5 cm^3 gear pump. The manifold with the controls for direction and speed are mounted on the bellhousing.

All components are easily accessible and understood and have simply and easily fulfilled the requirements of:

- long life working on a 24 hour basis
- extreme reliability under adverse conditions and widely varying temperatures
- simple operation and maintenance.

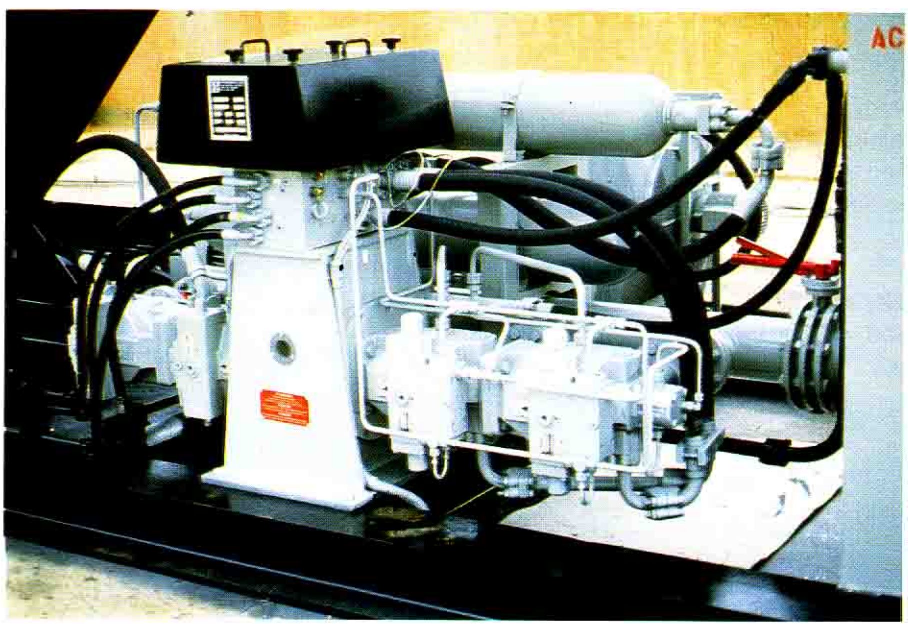

Fig. 64 *Power unit for an oil well pump*