



with a bigger swash angle command to the variable displacement pump. However, as soon as the engine speed reaches the saturation speed $n_s (n_s is a function of Q_r)$ it is not possible to increase the swash angle of the pump anymore, as it is at its maximum. In comparison in throttle control (OC), NC, and PC in partial pilot actuation (Q_r) the flow to the actuator is more influenced by a reduction in engine speed, especially in throttle control system with constant displacement pumps.

Both behaviors have their benefits. The limited engine speed influence on the oil flow of the LS systems makes working with changing engine speeds easier. On the other hand, the significant influence of the prime mover speed on the actuator flow with the open center systems (throttle control (OC), NC and PC) allows for a higher fine control resolution at reduced speed.

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CHAPTER

Machine Control Concepts

Detlef Hawlitzek



Life today cannot be imagined without electronics in motor vehicles and mobile working machines. Many necessary and convenient functions could not be implemented without electronic systems. The requirements on mobile working machines, e.g., construction machines, municipal vehicles, or agricultural machines, have changed very much over the last years. The demand for continuously increasing productivity while at the same time increasing the driving comfort by means of state-of-the-art display and operating systems keeps facing the manufacturers with new challenges. As compared to electronics in consumer goods or in "normal" industrial use, e.g., in packaging machines or conveying systems, there are considerably higher requirements regarding use in mobile applications, to ensure sufficient operating reliability in all work situations.

4.1 Requirements and Trends

Mobile working machines and plants are often tailored to specific applications and thus provide optimized functions. Since they can therefore not easily be replaced by other machines, high availability and reliability are of utmost priority. The integration of system diagnosis (in hardware and software) which enables the operating staff to quickly localize faults minimizes downtime. This can be supported by the use of dialogue units (HMI = Human Machine Interface). These dialogue modules provide the machine operator with

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clear information and messages adapted to the operating situation, either as text or as graphics. Incorrect operation of the machine is also prevented this way. For the machine operator the dialogue units have to be clearly visible and easily accessible, so the best possible mounting locations on the machine have to be selected. The requirements for a clear, ergonomic design permanently withstanding the hard conditions in field applications are increasing.

4.1.1 Electronics and Hydraulics

Increasingly harder regulations on emission such as TIER 4 (final) have made the demand for energy efficient solutions grow worldwide. In these solutions, the electronics in conjunction with work function and traction drive control plays an important role. The interaction of these components helps reduce diesel consumption and thus stack emissions of mobile working machines. Energy efficient hydraulics with high user-friendliness will also contribute its share. That means that the further electrification of hydraulics as well as the integration of hydraulics in networked systems of mobile working machines will be a challenge in the future. Besides, the increasing use of electric drives in mobile working machines as a replacement for hydraulic functions makes the use of intelligent efficient control units necessary. This trend continues through hybrid vehicles to completely electrically driven vehicles, such as compact sweeper vehicles.

4.1.2 **Safety**

Almost all mobile working machines have functions that may endanger persons and material. Therefore, every manufacturer has to comply with the general regulations for a safe machine design. Given that these regulations and standards are defined for a broad range of different machines, they cannot be precisely adapted to the function of a mobile working machine. Therefore, there is an increasing number of product standards which are tailored to specific requirements. In certain applications like vehicle lifts, clearly defined product standards have been in place for a long time. The employers' liability insurance associations also often have clear requirements towards manufacturers of machines. For this reason, there is an increasing demand for certified electronic assemblies for mobile vehicles. So-called safety control units can be used in applications where components with different performance levels (Pl) to EN 13849 [4] or SIL to EN 62061 [5] are needed. The safety concept of these control units monitors all internal and external functions and reliably switches off in case of an error. For safe data transmission the CANopen safety protocol can be used in the network. Practical: transmission is carried out together with the "non-safe" data on the same bus cable; no additional bus cable is required.

4.1.3 Driver Assistance Systems

There is an increasing demand for so-called assistance systems to support safe machine operation. They can, for instance, monitor the working area of a mobile working machine



for foreign objects. Examples are 2D/3D sensors. On a photoelectric basis they detect objects in the detection range and in the result transmit size and distance of the detected objects to the downstream control unit (Figures 4.1 and 4.2).

The most important element of the 3D sensor system is a photonic mixer device (PMD) whose function is based on the time-of-flight principle. A modulated light source illuminates the detection zone with invisible infrared light. The PMD sensor that is coupled with the modulation source receives the reflected light and measures the phase shift between the transmitted and received signals. This allows to precisely determine

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FIGURE 4.2 Example 3D- and 2D camera.

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FIGURE 4.3 Typical applications for distance measuring in the field.

the time-of-flight of the light and thus the distance to the object. The PMD sensor has an integrated active extraneous light suppression and operates extremely reliably even in bright sunlight.

This technology is well-known in the automotive range and is also used in latest generation mobile phones.

Typical applications are collision avoidance, obstacle detection, line guidance, autonomous driving, object recognition, or area surveillance (Figure 4.3).

For similar applications without such high requirements such as requirements on precision, sensor systems on the basis of ultrasonic or radar can be used.

4.1.4 Logging of Operational Data

Another requirement: because machine manufacturers and operators want to operate their machines as efficiently as possible and want to reduce downtime to a minimum, operational data logging is becoming increasingly important. System states and machine data have to be saved for statistic evaluation and documentation. This happens via electronic memory components on the machine, with remote access to these data from any location at any time being an additional requirement. So, further technologies are needed allowing access to these data via Internet or via GSM modem. That way manufacturer as well as operator can read and monitor machine states at any time. This not only ensures the optimum operation of the machine, but also increases predictive service management.

4.1.5 Networking

Legislation's requirements concerning safety keep increasing and customers have continuously higher functional requirements to be met by machine manufacturers so the complexity of systems also increases. As a result, the demand for compact and efficient control units that can be combined depending on their functionality keeps getting stronger. Connectivity is therefore a big issue when talking about networked systems. This facilitates the use of bus systems which connect the individual control units for the purpose of data exchange. They allow a remote and intelligent arrangement of the control units in use. So, it is possible to place the control units in the machine where sensors and actuators are mounted. This has the further advantage that control units can be more compact. Another advantage is the considerable reduction of wiring which additionally helps to save weight. In addition, the components must be easy to handle for mounting and in case of service. This is achieved by the mechanical design as well as easy and clear integration during programming. Finally, the components and devices used must withstand the extreme mechanical, climatic, and electric requirements. All requirements have one goal: to produce reliable and competitive machines.

4.2 Controller and Sensors

Mobile working machines nowadays are used worldwide. Climatic and geological conditions play an important role in the construction of the machinery. On the other hand, they should not affect the functionality of a mobile working machine. The extreme mechanical stress caused by impacts and shocks as well as the use at low and high ambient temperatures require a careful selection of the electronic components. Given that the devices are often exposed to dirt, moisture, and water in the applications, high protection ratings and specially selected housing materials are necessary. Furthermore, the electrical interference affecting the entire system or individual components must also be taken into account. A wide supply voltage range and adapted protection measures allow reliable operation of the devices even in cases of large voltage fluctuations caused by the battery/ generator system and high conducted interference.

4.2.1 Requirements

Modern control units and I/O extensions for mobile working machines meet the required manufacturers' specifications (Figures 4.4-4.6).

Extensive climatic tests take place to meet the specifications of the extended temperature range of -40° C to $+80^{\circ}$ C (-40° F to 176° F), as well as extensive mechanical tests for vibration and shock resistance. Intensive electric tests following different standards are as self-understood as certification for road traffic or TÜV approvals concerning functional safety. In addition, the machine manufacturer expects data from applicationspecific sensors and actuators to be processed by the control units. For this purpose, control units offer multifunctional inputs and outputs. These inputs can be configured by software as digital, analog, frequency, resistance, or ratiometric input signals, while

FIGURE 4.4 Controllers and displays.



the outputs can be parameterized as digital, PWM (see <u>Section 4.2.2</u>), or analog output signals. In addition, extensive diagnostic possibilities enable the detection of excessive current, wire break or short-circuit; they can be evaluated by means of the programming software. Signalling elements indicate the function state of the control unit. This can be extremely helpful for troubleshooting.