

WHITE PAPER
STEERING INTO THE FUTURE

A safe Steer-by-Wire for mobile machinery

Parker



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Introduction 3
Standards and Regulations 4
System Structure/Architecture 5
Functional Safety 6
Hydraulic-free Cabin 6
Performance Improvements 7
Automation 7
Energy Efficiency Benefits 7
Conformity Assessment Body 7
Conclusion 8
Discussion. 8

INTRODUCTION

Mobile machinery is a type of machinery with a huge variety. A mobile machine often has a very specific use. It can be digging, lifting goods, harvesting trees, rock drilling and so on. Most of them need the ability to steer, also most of them are wheeled.

Since mobile machinery is often heavy vehicles, some steering force- or torque amplifying system is needed. Traditionally, the steering systems are realized using a hydraulic system as force/torque amplifier. Hydraulics have the benefi ts of being cost effective, power dense and available on the machines.

Most machines use a hydraulic orbitrol unit for controlling the steering wheels. It consists a pump with a rotary valve and a torsion spring.

The operator then only needs to turn the steering wheel against the torque the torsion spring yields. This is a pure hydromechanical system. The steering cylinder(s) are actuated with the orbitrol as the control unit.

Over the years, orbitrol steering has become a de facto standard in mobile machinery. This, by itself is convincing saying the orbitrol solution has many benefits. It is a proven and reliable system. But, there are disadvantages with the orbitrol steering system. A Steer-by-Wire system where the hydromechanical connection between the steering wheel and the steering cylinders is substituted with electronics enables easier installation, increased comfort for the operator, and a machine able to be automated. These advantages come together with high energy efficiency.



STANDARDS AND REGULATIONS

There are two type of regulations a steering system for mobile machinery is affected with in the European Union (EU). Those are

1. The Machine Directive
2. Rules of Local Transport Agencies

All machines put on the European market needs to comply with the Machine Directive. Standard committees have worked out standards which are compatible with the Machine Directive.

These standards are a helping guidance for compliance with the Machine Directive. There are different levels of standards

A-type (basic safety standards),

B-type (generic safety standards), and

C-type (machine safety standards).

Typically, OEMs use the C-type standards which cover their applications. C-type standards then refers to B-type and A-type standards. Most C-type standards applicable to mobile machinery refers to the C-type standard ISO 5010:2019 on steering system matters.

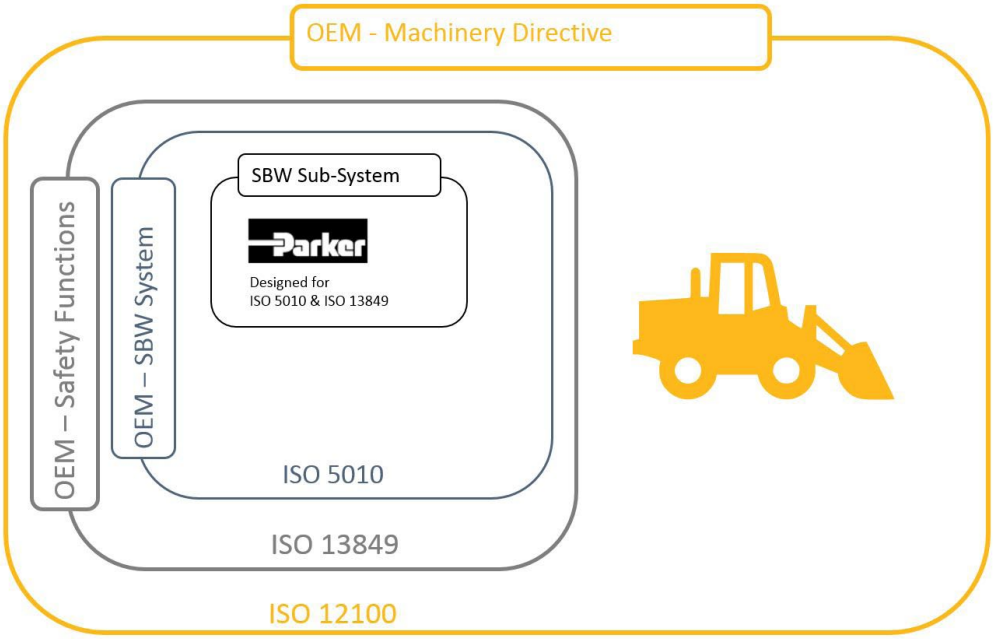


Figure 1 Machine Directive and standards applied on a vehicle

In ISO 5010:2019 there are specific requirements for conventional orbitrol steering and steer-by-wire systems. For example, the standard distinguishes between the maximum vehicle speeds

1. <=10 km/h
2. <20 km/h
3. >=20 km/h

Naturally, the safety requrements increase with maximum design speed. Many mobile machines are designed for speeds faster than 20 km/h, that is why the Parker Steer-by-Wire valve is ready for compliance with the ISO 5010:2019 standard. A major implication for machinery designed for higher speeds is the requirement of a secondary steering system which is automatically engaged in case of a failure of the primary system. However, since the ISO 5010:2019 standard covers the steering function of the vehicle the OEM needs to do the validation of the complete steering system installed in the machine. The relations between the Machine Directive and the compatible standards can be seen in Figure 1.

Some mobile machines are used on public roads and some are not. The machines which are used on road, need to be approved by National agencies. These rules can vary between countries. However, the standard ISO 5010:2019 is basically the guiding principle within the EU.

SYSTEM STRUCTURE/ ARCHITECTURE

An example of Steer-by-Wire system, see Figure 2, and related components from Parker can be used in machines that requires single fault tolerance.

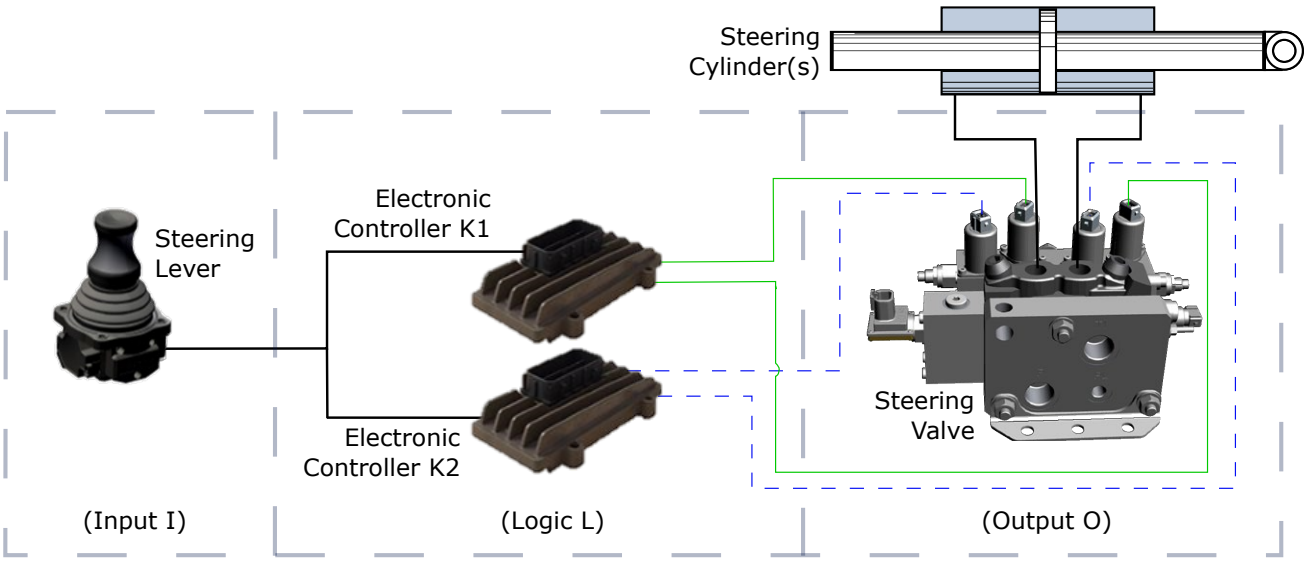


Figure 2 Overview of the Parker Steer-by-Wire system

The system can be split into three connected subsystems; input (I), logic (L), and output (O), see Figure 2.

The input (I) subsystem is either a steering wheel, or a joystick, see Figure 3, using a single fault resistant way of transmitting an operator steering command to the logic (L) subsystem. The single fault tolerance can be implemented using a voting scheme together with multiple sensors.

The logic (L) subsystem can be implemented with two parallel mobile hardened SIL 2 compliant control units, IQAN-MC41FS, see Figure 4. The importance of using safety controllers is an implication from the standard ISO 13849. The input from the input device is read by both controllers independently. Cross monitoring is implemented between the two control units.

An innovative approach in the output subsystem (O), is the SBW110 valve (see Figure 5) that is controlled by two individual pilot circuits. The pilot circuits consist of fail-safe pilot valves. In the SBW110 valve the pilot circuit with highest actuation pressure takes command of the spool. Single fault resistance is achieved by controlling these two circuits in an intelligent way which allows for a straight forward detection of a failure in any of the pilot circuits.

The pilot valves uses a unique fail-safe design ensuring the actuation pressure to be at a low and safe level given no current on the pilot valve. The SBW110 is monitored using sensors for pressure, temperature and spool position.

Beyond the system and component designs there are also aspects to consider regarding production. Quality systems and processes are implemented at Parker specifically to minimize risk of errors in production and assembly. Inspections, tests, and automation are measures taken as outcomes from process FMEA.



Figure 3: Input device with multiple signals, Tactile Feedback Device (TFD), used with a steering wheel, or a joystick



Figure 4: Safety controller IQAN-MC41FS

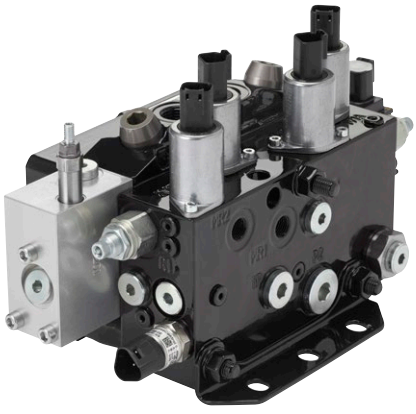


Figure 5: The SBW110 mobile Steer-by-Wire valve

FUNCTIONAL SAFETY

The safety of a system that depends on automatic protection operating correctly in response to its inputs, or failure in a predictable manner is often referred to as functional safety. The system should be designed to properly handle potential human errors, hardware failures and operational or environmental stress. Standards exist for guidance in this area to comply with the machine directive.

A Steer-by-Wire system typically includes electronic control device(s), micro controllers, or ECUs. The functional safety requirements of such a control system, including the hydraulics, are described in the standard ISO 13849. This standard defines the concept of Performance Levels, PL. The PL is a discrete measure to specify the ability of safety-related parts of control systems to perform a safety function under foreseeable conditions. There are mainly three properties of a system combined to determine the achieved PL:

1. Meantime to dangerous failure of components, MTTFd
2. Structural arrangement of the parts, Category
3. Diagnostics coverage, meaning the ratio between the failure rate of detected dangerous failures and the failure rate of total dangerous failures, DC

Studying C-type standards for mobile machinery applications with speed above 20 km/h often yield a PLr, required Performance Level, of PLd for off road and PLe for on road applications.



HYDRAULIC-FREE CABIN

Traditionally, hydraulics has been used in most mobile machinery. Both implements, and traction have used hydraulics. A driver has been the power density, and the pleasant handling of overloads. Also, the controls have been hydraulic. Pilot circuits including hydraulic joysticks were used. No electric control units were used. Most of this is still true today. However, the trend has been to use more and more electrohydraulic valves in the pilot circuits, both for implements as well as for hydrostatic traction systems.

This is a natural step in the evolution, and among the benefits which come with the electrohydraulic components are

- Less hydraulic noise in the cabin
- Easier installation
- Enables advanced controls

Steering systems are lagging behind in this trend. Most mobile machines still use the classical orbitrol steering units, meaning still hydraulics but no electronics in the cabin. Actually, the full steering flow passes the orbitrol in the cabin compared to only the pilot flow in the case of hydraulic joysticks.

A reason to why the steering system has not changed much over the years is probably the concern of safety. The orbitrol system is a proven concept and the task of designing, verifying, and validating, a new system with an electronic control system is cumbersome for an OEM. Parker Steer-by-Wire components simplify for the OEM to fulfill the applicable standards.

PERFORMANCE IMPROVEMENTS

The steering function in mobile machinery is often used in different situations. For example, transporting, and during operation such as grading or digging. Steer-by-Wire technology removes unwanted jerk and allows signal conditioning on the command signal. Further, features such as progressive steering can be easily implemented. The steering effort is also independent from the actual hydraulic system, meaning the effort to steer with the TFD or joystick is determined only by the device itself.



AUTOMATION

Steer-by-Wire is an enabler for automation. Since the SBW110 valve can be controlled by the IQAN-MC41FS modules, all features built-in the IQAN toolchain can be used to actuate the steering. For example, semiautomatic motions, and return to position algorithms can be implemented on the vehicle ECU and sent as commands to the steering system.

The IQAN software tools have support for interaction with external software tools, for example Matlab/SIMULINK and AMEsim. With these features IQAN can be a part of a model based work flow where models and algorithms are developed in, for example, Matlab/SIMULINK.

Autonomous driving has become a hot topic in the mobile market. Steer-by-wire is almost a necessary component to access the steering actuation in such an environment.

Safety is of equal importance when it comes to automation. The OEM can focus on safety of the algorithms and signaling.

ENERGY EFFICIENCY



The Steer-by-Wire valve, SBW110, is a state of the art closed center load sensing (LS) valve. Compared to many existing steering systems there is potential of substantial energy efficiency improvement.

- Pressure margin can be lowered
- No open center flow (if currently open center is used)
- Leakage is expected to be lower

CONFORMITY ASSESSMENT BODY

Compliance to the standards, in this case ISO 5010:2019 and ISO 13849, is a self-certification process. There are so called “Conformity Assessment Bodies (CAB)” assigned by the EU who can express report on compliance.
For conviction of standard compliance Parker has used the Research Institute of Sweden (RISE) which is CAB.

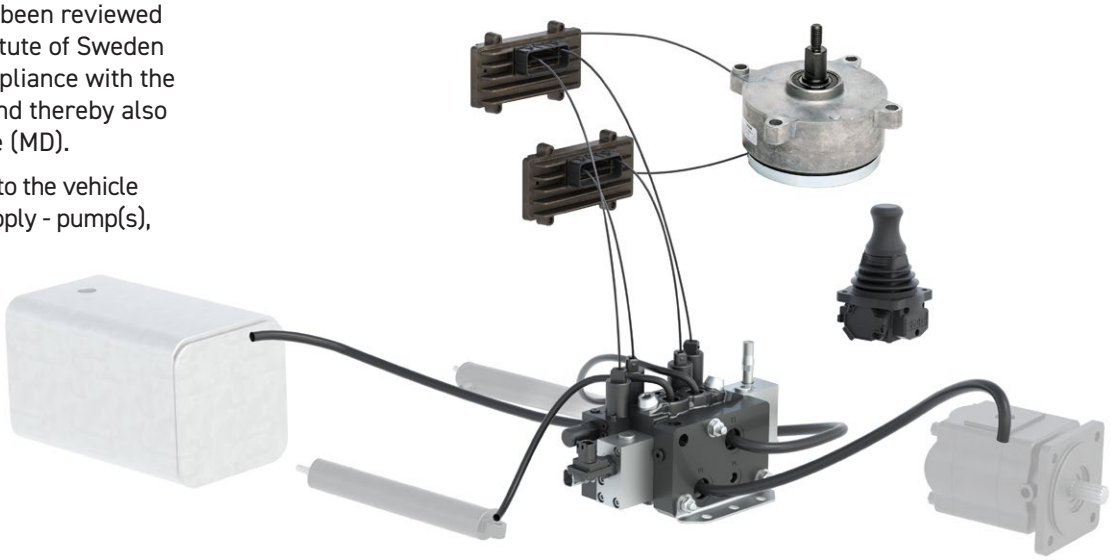
PARKER STEER-BY-WIRE SYSTEM

Parker has developed components for a Steer-by-Wire system including input device, TFD steering sensor or joystick, controllers and directional control valve. It has been a concurrent engineering process where the parts are linked together. The components are individually suitable in any Steer-by-Wire system with safety related data available. The system and components has been reviewed by the Research Institute of Sweden (RISE) to ensure compliance with the relevant standards and thereby also the machine directive (MD).

The system interface to the vehicle is hydraulic power supply - pump(s), electric supply to TFD or joystick and controller units, warning alerts in case of a system abnormality, and hydraulic connections to the steering cylinder(s).

The complete system has been verified and validated on a test machine inhouse at Parker to prove the performance under similar conditions experienced by an OEM.

Parker has a long history in the market of mobile valves and conventional joystick steering systems where an orbitrol is the primary steering unit. The main difference to Steer-by-Wire is the safety aspects that comes when removing the orbitrol as the primary steering unit.



CONCLUSION

Installation and serviceability are simplified by hydraulic-free cabin. No hydraulic connections meaning only an electric interface between the cabin and the chassis. Steer-by-Wire supports the trend of automation in the mobile market with its electronic signal interface. A major advantage with the Steer-by-Wire for a machine operator is less fatigue and more precise and conforatble control. Parker has developed a Steer-by-Wire valve for the mobile market and speeds exceeding 20 km/h using ISO 5010:2019 and ISO 13849. Together with the Steer-by-Wire input devices, TFD steering sensor and/or joystick, and SIL 2 compliant IQANMC4xFS controller, a system compliant to ISO 5010:2019 can be achieved.



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