DEVELOPMENT OF AN ELECTRONIC JOYSTICK STEERING (STEER-BY-WIRE) DEVICE FOR DISABLED DRIVERS

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1. SPECIAL FEATURES OF JOYSTICK STEERING

1.1 Two-handed operation with two separate joysticks

Steering a vehicle with only one hand calls for a great deal of concentration and is too tiring. Even if steering is controlled with only one hand, it is also possible to use the other for controlling the vehicle. Since disabilities may differ greatly from person to person, steering devices need to be designed as flexibly as possible. It is important to be able to adjust the required settings for operating and steering the vehicle on both joysticks independently to suit the nature and severity of the disability.

Joysticks are installed on both sides of the driver, and they are operated by turning them to the left and right. By using both hands in this way, driving is less tiring and it is easier to maintain control of the vehicle. Operation with two joysticks is also a prerequisite for a redundant design of the system.

1.2 Force feedback

For the sake of simplicity, feedback of the forces associated with steering has not been integrated into existing vehicles that have been converted to joystick steering, but steering mechanisms of this type are extremely difficult to master at high speeds. With normal mechanical steering mechanisms – with or without power-assisted steering – any abrupt manoeuvres require a considerable amount of force on the steering wheel. But the driver is already aware of the effects this pressure will have and is therefore not surprised by the reaction of the vehicle. The case is very different with joystick steering without force feedback: even at high speed it is possible to steer the vehicle sharply with very little effort, and this can lead to extremely dangerous manoeuvres.

With force feedback, the driver also receives additional information about the lateral acceleration that has taken place. This makes it considerably easier to keep the vehicle in the proper lane when negotiating a bend. This feature is especially important for joystick steering mechanisms that are designed on the basis of a specific concept.

Force feedback also tells us in a subtle, though by no means less significant, way about the road-holding properties of the tyres, and thus about the cohesion properties of the road surface. To ensure safe driving behaviour it is important that the dynamic range is clearly indicated for each cohesion coefficient.

Steering forces when the vehicle is not in motion or is moving slowly also provide us with information about the cohesion properties of the road surface. Vibrations in the steering mechanism allow us to deduce how uneven or damaged the road surface is.

1.3 Speed-related steering ratio expressed as lateral acceleration in proportion to steering lock

People who suffer from muscular diseases often have a very limited range of movement, and for this reason the ease of operation afforded by a joystick needs to be applicable for all speeds. Thanks to the speed-related steering ratio, the vehicle can be steered accurately at high speeds, yet is also easy to park when it is moving very slowly.

The prerequisite for a variable steering ratio is a steer-by-wire concept without a mechanical connection between the joysticks and the vehicle’s wheels. A speed-related steering ratio is practically impossible to achieve on a purely mechanical basis.

1.4 Speed-related force feedback support

As with modern power-assisted steering, the force feedback is low during manoeuvres at low speeds, but the driver does not lose his or her feeling for steering.

1.5 High degree of flexibility with respect to installation and adaptation to each driver’s specific requirements

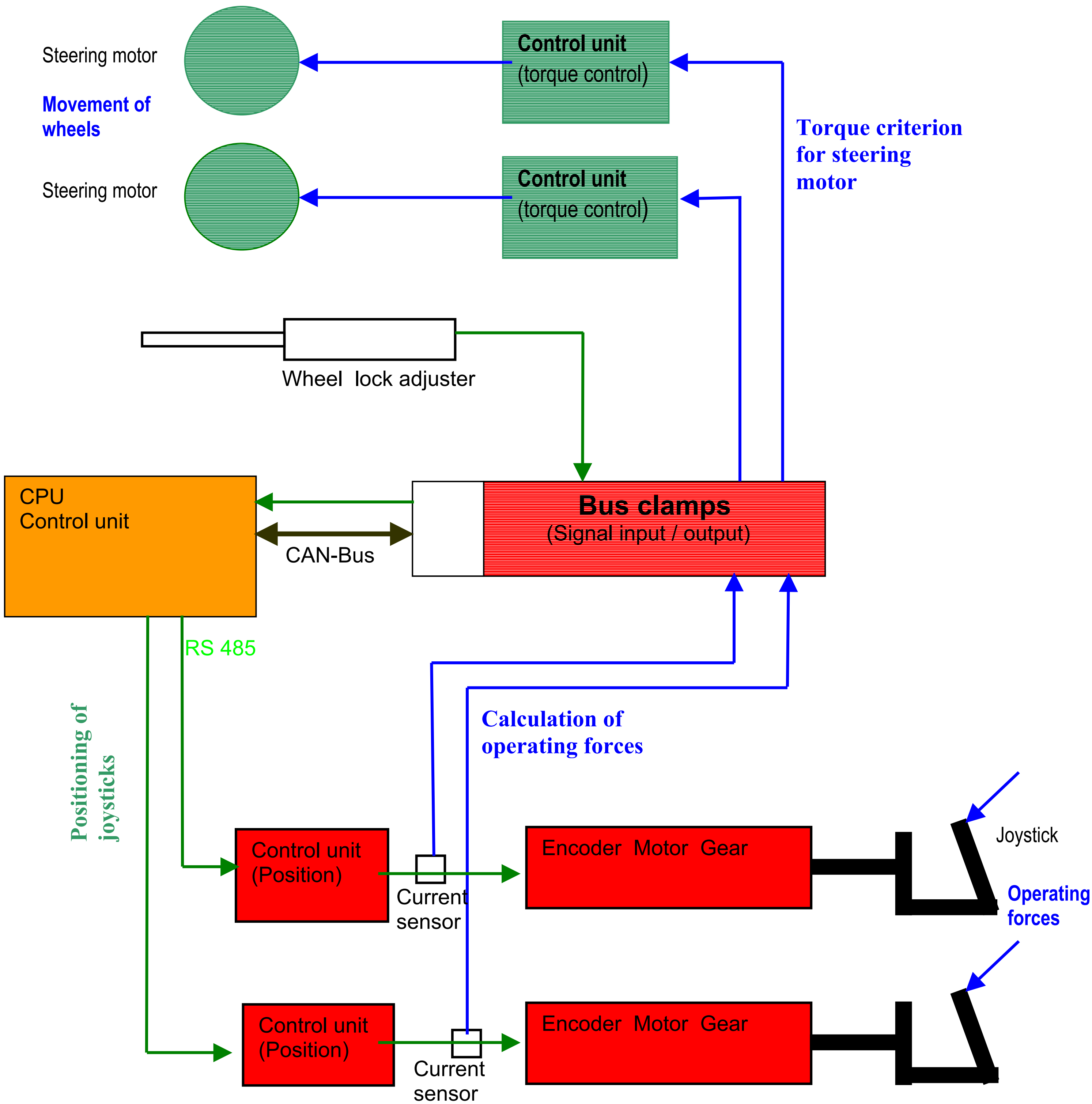
Thanks to the elimination of mechanical steering, it is possible to install joysticks at any suitable location in the vehicle. The operating forces on the joysticks can be adjusted to suit the degree of disability of the driver.

2. TECHNICAL IMPLEMENTATION

The diagram below depicts an overview of the system in simplified form. As far as possible, the system has been developed with tried-and-tested industrial components and with sub-systems that have been purchased as complete units.

The fundamental measurable variables are the operating forces on the joysticks, which are used for calculating the torque criteria for the steering motors, and the degree of lock which is a relevant criterion for determining the position of the joysticks. The various sub -systems and components are described in greater detail below.

Figure 1.



2.1 Steering motors with gears

The two steering motors are based on electric power-steering devices from vehicles of the MG-F type (2001 model). Electric power-steering devices are currently being installed to an ever-increasing extent in smaller cars.

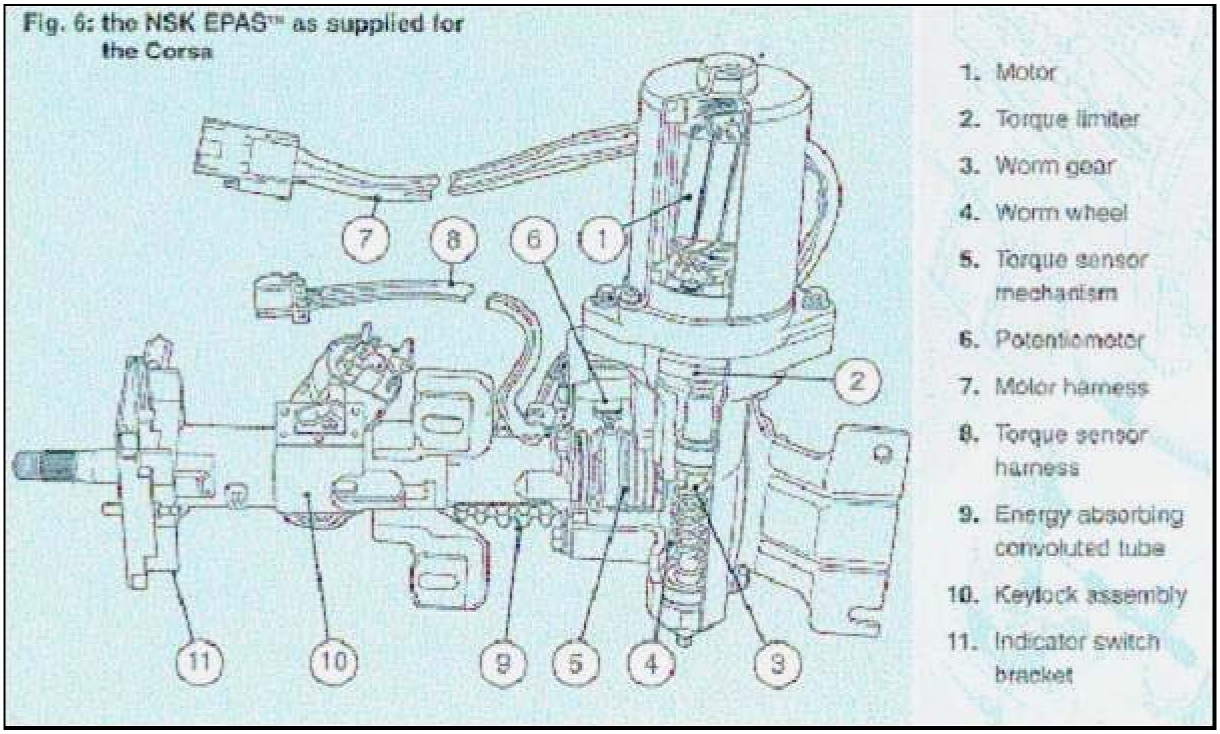


Figure 2: A steering column of an electric power-steering device with worm gearing, torque sensor and electromagnetic motor harness as borrowed from Opel Switzerland for study purposes.

For safety reasons, two motors are used in the concept that has been developed. Thanks to the electromagnetic harness, it is possible for each of the motors to be separated individually and mechanically from the steering system in the event of any malfunctions. The load on the steering motors is very low since the hydraulic power steering remains active in the modified vehicle. For the further development of the vehicle, two complete power-steering units are used as depicted above.

The motor drive unit is located beneath the dashboard in the interior of the vehicle.

Figure 3.

A special casing was made for the transmission, while the worm gearing corresponds to the original.

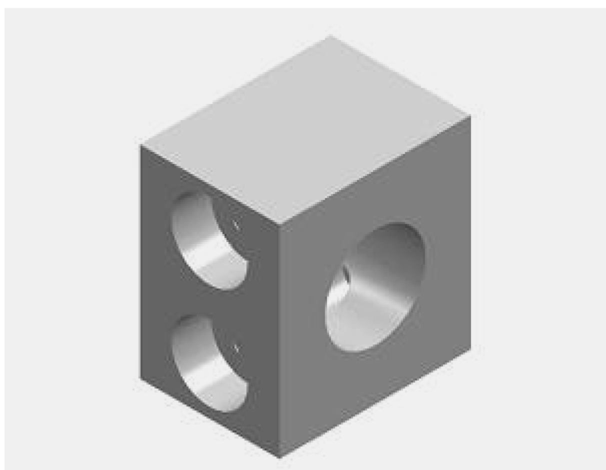


Figure 4: A CAD drawing was prepared for the design of the special casing, which was produced by an external supplier. Here it was essential to calculate the spacing of the borings as precisely as possible in order to secure correct clearance of the toothed wheels.

The original steering shaft is used without any modification whatsoever, and this means that its stability is not reduced. This is especially beneficial from the point of view of approval of the vehicle for use on the road. The toothed gear wheel is affixed to a sheath that is vacuum-formed onto the shaft and secured with a welding spot. The tooth wheel itself is affixed to the sheath by means of a press fit and a wedge. Since both motors produce the same torque in normal operating mode and drive the same worm wheel, a pure torque is generated on the steering shaft without lateral forces. This means that the steering shaft is not placed under any greater load than when steering with a steering wheel.

The steering wheel, steering column and operating devices on the steering column assembly remain fully functional. The play of the gear bearings is adjusted with washers (steering shaft) and external screws (worm gear).

Figure 5: Steering column with the two steering motors and fully functional steering wheel

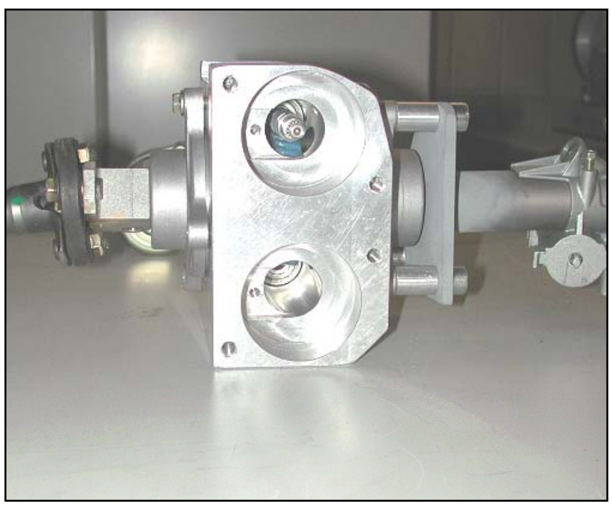


Figure 6: Load transmission to the steering shaft takes place via a non-inhibiting worm gear

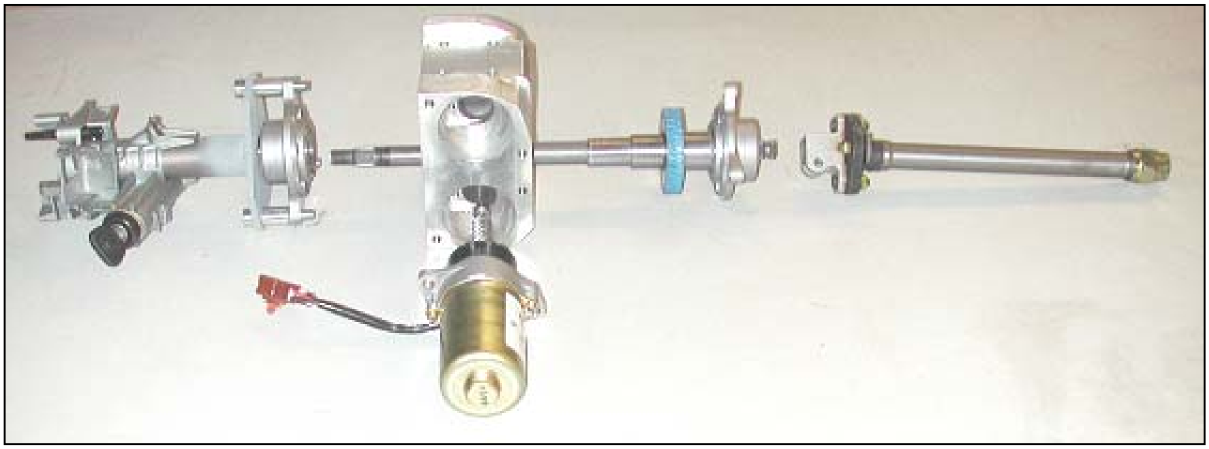


Figure 7: The steering column assembly is affixed to the gearbox casing together with the left end plate. In the middle, steering shaft with press-fitted sheath for the bearing seats and worm wheel

2.2 Control unit of steering motors

The torque control of the steering motors is effected with low losses with the aid of pulse-width modulation. In the conceived joystick steering system, two steering motors are used that each have their own control unit. After conducting tests with electric control units, we are currently developing our own basic model, which foresees control via four (MOSFET) transistors with analog signals.

2.3 Positioning of steering lock

Here an industrial potentiometer is used. A working temperature up to 100°C and protection category IP 65 guarantee safe use on the underbody of the vehicle near the engine. For a comprehensive safety system, the use of two independent potentiometers is essential, but for the test vehicle we decided to do without a redundancy at this stage.

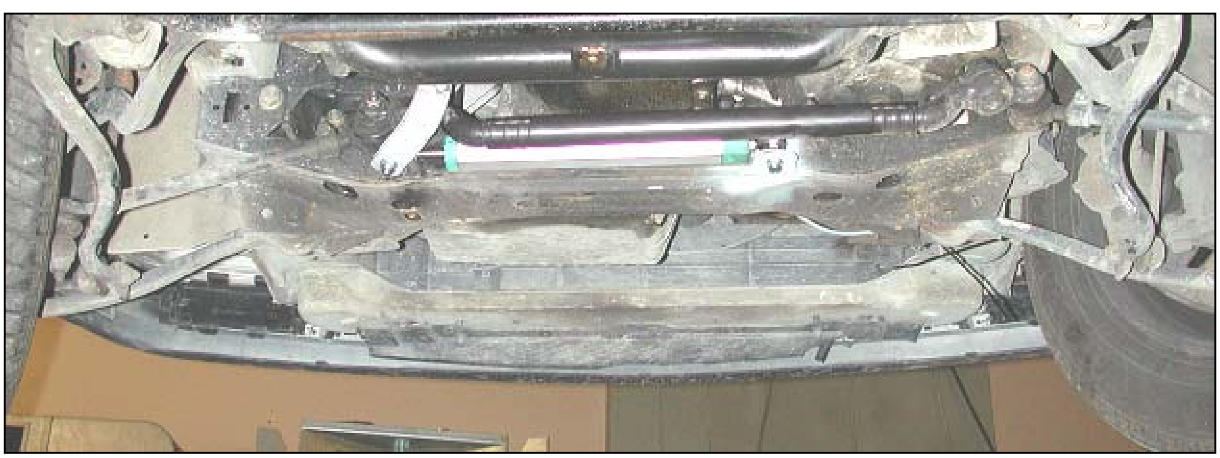


Figure 8: Potentiometer at full lock, photographed with the engine casing removed

For geometrical reasons, the path on the potentiometer is not linear to the angle of lock. In order to obtain a defined steering parameter field, it is necessary to identify the correlation of the angle of lock and the electrical resistance of the potentiometer.

In order for an interruption in the power supply or signal feed to be correctly detected, a resistor is installed before and after the potentiometer. In the event of an interruption, a signal of 0 or 12V is indicated – levels that cannot be achieved unless a disturbance has occurred.

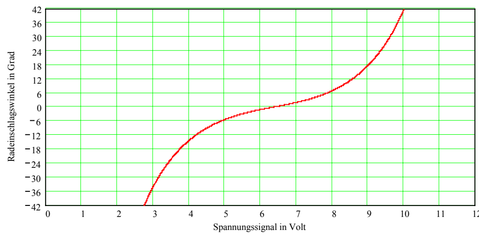


Figure 9: Angle of wheel lock to voltage signal with a constant power supply of 13V

2.4 Joystick units

These comprise a joystick and its bearings, gears, motor, encoder, motor control unit, two sensors for measuring current, and a rotation angle adjuster. Both joysticks are identical in construction. The motor is necessary with a concept for force feedback, the gears permit the use of a light, high-r.p.m. motor, the encoder records the number of revolutions and the position of the motor. It is possible to obtain a given position with the aid of the control unit by comparing the target and current values.

The sensors measure the power consumption of the motor that is required for maintaining the set position. They also measure the power consumption of the joystick within the control unit. Duplicate measurement of current reveals errors, and the joystick concerned can be deactivated. The rotation angle adjuster informs the control unit about the absolute position during the initialisation stage prior to departure.

Figure 9: Joystick positions: upright, to the left and to the right

Joystick

The joystick was made especially for this application. It has a broad adjustment range so that it will be possible to find the ideal position in later practical trials. A special feature here is that the rotation point may be at hand height or below or above it.

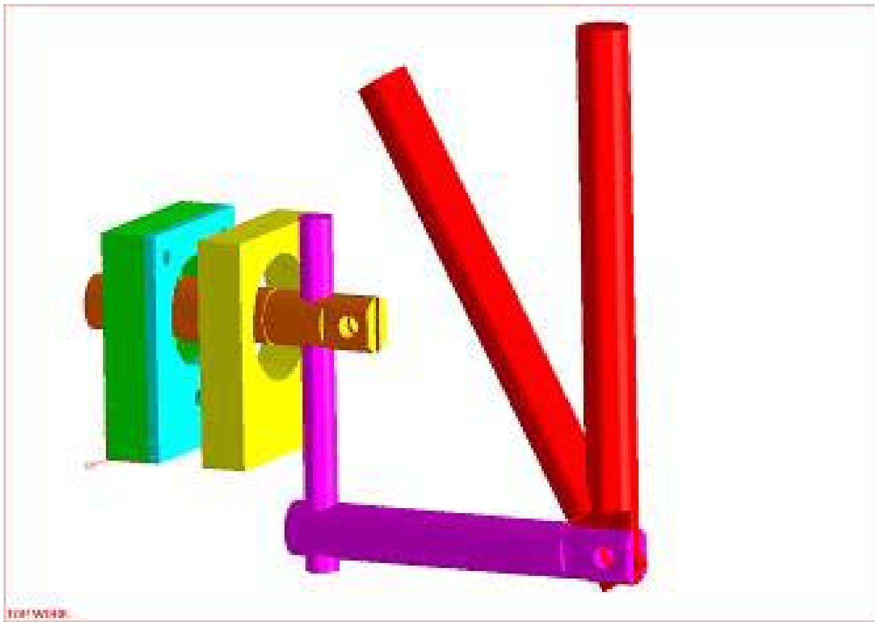


Figure 10.

Joystick bearings

Due to duplication here, the gear shaft is not subjected to either axial or radial forces, but rather is only loaded with torque. The joystick bearings have a sliding fit.

Motor, transmission and encoder unit and control device

The motor, transmission and encoder may be combined with one another as desired and have been purchased here in the form of a preassembled unit. The transmission comprises four shafts and has a high ratio of 238:1. Given the torque level, a ratio of around half this level would be sufficient, and would also offer the significant advantage of lower mechanical frictional resistance following the initiation of torque on the joystick side (more precise registration of triggered torque), but it would also mean longer delivery deadlines.

The control devices are made by the same manufacturer and assume the positioning parameters of each joystick motor. Communication between the central control unit and the joystick devices is secured via an RE 485 interface.

Current sensors

The sensors measure the power consumption of the steering and joystick motors. This information is used by the central control unit for verifying the correct operation of the various sub-systems. These sensors generate a voltage signal proportional to the current conduction, the current direction determines the polarity signs of the voltage signal. The power supply of +/- 15V has to be provided with the aid of a small DC/DC voltage converter. The measurement range of the sensors is used more effectively in that the live cable is fed through the sensor a number of times.

Rotation angle adjusters

These are constructed like a rotary potentiometer, but are significantly more expensive due to their higher degree of precision.

2.5 Power supply

The steering system is operated electrically. The power supply is secured via two batteries and by an alternator when the engine is running. Each of these three independent power sources is also sufficient on its own for the operation of the joystick steering system. If the alternator should cease to function, this is indicated by a control lamp that is already installed in the basic version of the vehicle.

The batteries are used alternately for starting the motor, and therefore have to be highly reliable in terms of operating efficiency. Any decrease in capacity is indicated by a control lamp (the relevant criterion here is the battery voltage under load, measured at the time of start-up of the motor). If a battery suffers any other kind of damage, it is not possible to start the motor, since it is only possible to switch to the other starter battery following a successful start-up of the motor.

The electronic components require different voltages that have to be generated via the 12V network on board the vehicle. The bus clamps have to be supplied with 24V and 5V respectively, while the sensors need -15V and +15V. Voltage transformers are used for this purpose.

Figure 11: The power relays (up to 1,000 amps) for switching the batteries are visible on the left, while the power diodes for separating the batteries are shown on the right.

2.6 Industrial control unit, bus clamps and drive programs

A PC control unit manufactured by Mikrap AG is used as the industrial unit. Communication to the bus clamps is secured via a data bus. Data transfer to the control devices of the joystick motors and loading of the driving programmes are secured via an RS 485 interface. 36 input/output signals are required for the control and monitoring of the steering system.

Figure 12: The central control unit and bus clamps for preparing the input and output clamps are located in the glove compartment.

The driving program is currently being developed. It will be divided into the following sub-programs:

Initialisation: The positions of the joysticks are not yet defined immediately after system start-up, and these need to be called up with the aid of the external rotation angle adjuster. If the position of the joysticks does not coincide with the steering lock, e.g. if the wheels have been turned after the system was switched off, they will automatically move into the right position.

Battery management: Control of batteries when under load.

Movement of joysticks: The position of the joysticks primarily depends on the current wheel lock and the travel speed. The target positions are stored in a multiple parameter field. The variability of the steering ratio is defined using the values contained in this field.

Movement of wheels: The operating forces on the joysticks are measured with the aid of the power consumption of the joystick motors, and the desired steering torque is calculated from a second field on the basis of the current steering ratio, travel speed and individual settings. To generate the steering torque, a corresponding PWM signal is sent to the control units of the steering motors.

3. SUMMARY

There has long since been a need for vehicles specially designed to meet the requirements of people with differing degrees of disability, especially for those with severe disabilities such as muscular diseases. However, existing vehicles for the disabled are already very difficult to steer in normal circumstances, but in extreme situations they are practically impossible to keep under control.

The Institute for Automotive Engineering at the Automotive Technology department of the College of Engineering and Architecture in Biel is convinced that it is possible to equip such vehicles with easily manageable joystick steering that is safe in all traffic situations, if certain principles of vehicle engineering are observed. The concept of force feedback must not be ignored, and it should also be possible to improve the degree of steering precision at high speed using a speed-related steering ratio.

In view of these considerations, a joystick steering system suitable for disabled drivers was developed within the framework of a degree course, after which work commenced on the construction of a test vehicle.

A comprehensive project aimed at developing this steering system up to the level of small-scale serial production is currently in progress.

An electronically controlled vehicle operating system that meets the high demands of people with severe muscular disabilities can of course fairly easily be adjusted for use by people with multiple sclerosis, cerebral palsy, paraplegia, etc. By realising a fully electronic steering system in a vehicle that has been modified for use by disabled people, we can gain valuable findings in the highly-promising area of steer-by-wire technology, and disabled road users will be able to benefit from less stringent regulations governing the approval of special vehicles for use on the road.

Joystick steering is exclusively electric/electronic. For two-handed operation, one joystick is installed for each hand. Connection between the joysticks and the vehicle's wheels, as well as between the joysticks themselves, is effected using a system comprising sensors, actuators and control units.

Doing away entirely with the mechanical transfer of steering forces means that immense technical efforts are required in order to fully guarantee safe operation (redundant design, monitoring of certain components with error messages), but on the other hand we are able to achieve a previously unattainable degree of flexibility with respect to installation of the joysticks, as well as make the use of a speed-related steering ratio possible in the first place. It is possible to modify system parameters extensively merely by changing software settings, and this means that adaptation to suit the specific needs of people with disabilities is greatly simplified.

Thanks to force feedback and a freely programmable, speed-related steering ratio it is possible to ensure safe control of the vehicle even with the short response times of a joystick. The vehicle may also be operated by drivers who do not have disabilities, by using the steering wheel and pedals in the normal way.

Four electric motors are used in this fully electrical system: two of these supply power for steering the wheels, and the other two are used for adjusting the positions of the joysticks and securing the feedback of steering forces.

The proper functioning of the steering motors is monitored via the power consumption. If for some reason the effective power consumption does not match the theoretically anticipated level, the motor concerned may be mechanically separated from the steering supply using an electromagnetic harness, while the vehicle can still be safely brought to a halt using the remaining steering motor. The steering motors transfer their force via a worm gear to the unmodified steering shaft.

The joysticks are self-made and are equipped with moveable electric motors which, together with the control unit, are manufactured within the industry. By measuring the power consumption of the joystick motors, the response on the joysticks is registered precisely. Should one joystick cease to function, it would still be possible to bring the vehicle to a halt using the other.

The “brain” of this system is an industrial control unit which detects signals from sensors, calculates output levels and assumes control over the four electric motors. It also monitors the correct functioning of the various components and activates a simplified emergency program if the need arises.

The vehicle’s power supply is secured by two batteries that perform the same functions. These are used alternately for starting up the motor and their status is monitored automatically when they are under load. The construction of the prototype has almost been completed. Before it can be tested on the road, however, a certain amount of programming needs to be carried out, and solutions have to be found to a few remaining problems.