合肥工业大学

毕业设计英文翻译原文

学　院　名　称　汽车与交通工程学院

专　业（班 级）　车辆工程（2014 级 1 班）

姓　名（学 号）　2014210558　江曦

指　导　教　师　赵林峰

系（教研室）负责人　张炳力

Modeling and Simulation of Vehicle Steer by Wire System

Sheikh Muhamad Hafiz fahami[1], Hairi Zamzuri[2*] ,Saiful Amri Mazlan[3], and Muhammad Aizzat Zakaria[4]

[1,2,4] UTM-Proton Active Safety Laboratory, Universiti Teknology Malaysia, Kuala Lumpur
(mhfsheikh2@live.utm.my, *hairi@ic.utm.my, maizzat2@live.utm.my)
[3] Malaysia - Japan International Institute of Technology, Universti Teknology Malaysia, Kuala Lumpur
(amri@ic.utm.my)

Abstract— The steer by wire system offer many benefits compare with conventional steering system. By eliminating the mechanical linkage of column shaft between the steering wheel and the front wheel system, it gives more space efficiency, fuel efficiency in term of functionality and at the same time present challenges to the designer. Many researchers have done their control strategy on steer by wire system in past recent years. This paper presents the control strategy for the wheel synchronization and the variable steering ratio.Mathematical modeling was created for steering wheel and front wheel model. The steering wheel and the front wheel system is control using PID controller and introduce a new feedforward variable steering ratio based on under propensity equation method. A simulation was made and compared in order to analysis the system performance.

Index Terms; - Steer by wire system, variable steering ratio, front tire angle, modeling and simulation.

I. INTRODUCTION

Steer-by-wire systems (SBW) are new technology in vehicle system application. In steer-by-wire system, there is no mechanical coupling between the steering wheel and front wheel system as shown in fig. 1.Even though the mechanical coupling between the steering wheel and the front wheel system are eliminated, a steer by wire system expected not only implement same function as conventional mechanical coupling steering system, but it expected to provide advanced steering function. There are several advantage offers by steer by wire system such as no oil leaking, freedom in car interior design, large space in cabin and less injury in car accidents [1].

There are main several requirements for steer by wire system [2]:

(1) Directional control and wheel synchronization. It is required that front wheel follow the driver input command from the steering wheel.

(2) Capability of steering wheel return or free control. The steering wheel should return automatically to the center if the hands of driver remove or release from the steering.

(3) Variable steering ratio. The steering ratio between steering wheel angle and front wheel angle. For example, steering ratio 15:1. By means steering wheel it to 15 degree angle, the front tire wheel should turn to 1 degree angle.

(4) Adjustable variable steering feel. The vehicle driver relies on steering feel to sense the force of road condition with tire to ground contact and maintain control of the vehicle.

Several works has been undertaken to study the modeling and control of steer by wire system. Reza Kazemi et al [4] presented the control strategies of steering wheel using PID controller and Active front steering (AFS) controller for front wheel system. The research focus on an integrated control system of AFS and direct yaw moment control (DYC) by actively controlling the front tire angle, this control system designed using model matching technique [8].Oh S-W et al[6], introduced the steering ratio using feed forward controller. Gradient propensity equation is used to control the steering ratio. The author claim less feedback sensor is use based on vehicle state equation [6]. While in paper [2], the steering ratio is determine based on steering wheel angle and vehicle speed. The author introduced fuzzy logic to control the steering ratio.

These papers focus on directional control and variable steering ratio control strategies. The following section will describe the control methods for directional control strategy by using PID controller and variable steering ratio with the aims to satisfy the steer by wire requirements.

978-1-4673-1310-0/12/$31.00 ©2012 IEEE

A. Steer by Wire System

In conventional mechanical steering system, the column shafts are directly connected to rack pinion gear and tire system as shown in fig. 1a. Existing conventional steering system use hydraulic power steering (HPS) or Electric power steering (EPS) to assist the driver. The advantage of EPS compared to HPS is the system comparatively new technology with less complicated build mechanism, taking less space and more durable.

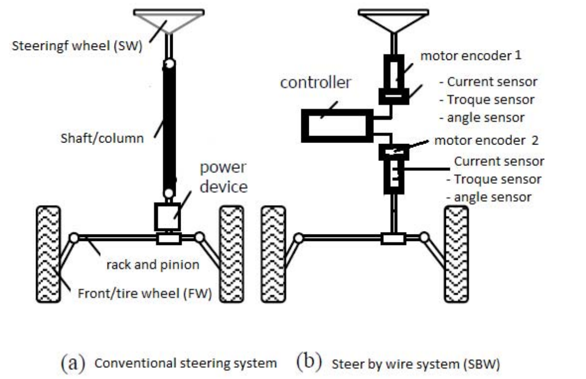


Fig.1 Conventional steering and Steer by wire (SBW)[1]

Fig. 1b show the steer by wire system where the power assist system (i.e. using hydraulic or electric) and column shaft are removed. Sensors and actuators were attached to the steering wheel and the front wheel system. The signal from steering wheel motor encoder is use to observe the rotation angle from driver input. This rotation angle is then converted to electrical signal and wired to an electronic control unit (ECU). The ECU controls the signal and sends it to front wheel actuators for rotating the front wheel parts in the same manner of the steering wheel behavior.

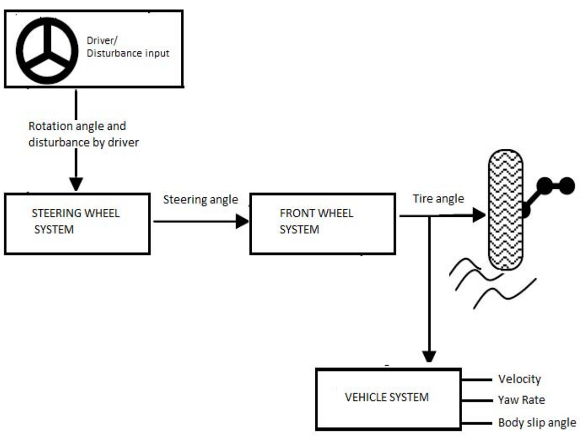


Fig.2 Steer by wire system (SBW) overview [1]

In general, a steer by wire system can be divided into three main subsystems [3]. There are steering wheel, front wheel and vehicle model system as shown in fig. 1b and fig. 2. The steering wheel system contains torque sensor, current sensor, steering angle sensor and motor encoder while front wheel system contains rack pinion gear, angle sensor, motor encoder and other mechanisms that are related. The vehicle model consists of 2 degree of freedom (D.O.F) which is lateral and yaw motion. The model of steering wheel and the front wheel system are model and simulate using parameters as shown in Appendix I

B. Steering Wheel System Modelling

The steering wheel dynamic equation was modelled using mathematical equation based on Newton's law.

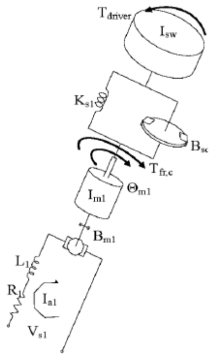


Fig.3 Steering wheel system diagram [4]

In steering wheel system, the input to the system are the steering angle (θ_{sw}) and driver torque (T_{driver}). While motor torque (T_{m1}) and torque friction (T_{frc}) will react as a disturbance. The output of the system is the steering motor current (i_{a1}) and steering motor angular displacement (θ_{m1}). (B_{sc}) is steering column damping, (k_{s1}) lumped torque stifness, (I_{sw}) steering lumped inertia, (R_1) motor electrical resistance, (L_1) motor electrical inductance,(I_{m1}) lumped inertia motor and (k_{b1}) steering motor emf. The mathematical equations of the steering wheel system subsystem are given below:

Steering angle:

$$\ddot{\theta}_{sw}=\frac{1}{Isw}[T_{driver}\text{-}\ T_{frc}\text{-}B_{sc}\dot{\theta}_{sw}\text{-}k_{s1}\theta_{sw}+B_{sc}\ \dot{\theta}_{m1}+k_{s1}\theta_{m1}]\quad(1)$$

Current of steering Motor:

$$\dot{\imath}_{a1}=\frac{1}{L1}\,[-R_1 I_{a1}-k_{b1}\dot{\theta}_{m1}+\theta_{sw}]\qquad(2)$$

Steering Motor angular displacement:

$$\ddot{\theta}_{m1}=\frac{1}{Im1}[\text{-}k_{s1}\theta_{m1}\text{-}B_{m1}\dot{\theta}_{m1}\text{-}B_{sc}\dot{\theta}_{m1}+k_{s1}\theta_{sw}+B_{sc}\dot{\theta}_{sw}+T_{m1}](3)$$

Consequently, the state equation of the steering wheel system is given as:

$$\dot{x}(t) = A_{sw}x\ (t) + B_{sw}u\ (t)\qquad(4)$$

$$y\ (t) = C_{sw}x\ (t) + D_{sw}u\ (t)\qquad(5)$$

$$x\ (t) = [\ \theta_{sw}\ \dot{\theta}_{sw}\ \ \theta_{m1}\ \dot{\theta}_{m1}\ i_{a1}\ ]\qquad(6)$$

And u(t) is considered as the input of the steering wheel subsystem, and parameter states are:

$$u\ (t) = [T_{driver}\quad \theta_{sw}\quad]\ .^{T}\qquad(7)$$

$$A_{sw}=\begin{bmatrix} 1 & 0 & 0 & 0 & 0\\ \frac{-k_{s1}}{I_{sw}} & \frac{-B_{sc}}{I_{sw}} & \frac{K_{s1}}{I_{sw}} & \frac{B_{sc}}{I_{sw}} & 0\\ 0 & 0 & 1 & 0 & 0\\ \frac{k_{s1}}{I_{m1}} & \frac{-B_{sc}}{I_{m1}} & \frac{-K_{s1}}{I_{m1}} & \frac{-(B_{sc}+B_{m1})}{I_{m1}} & 0\\ 0 & 0 & 0 & -K_{b1}/L_1 & (-R_1/L_1) \end{bmatrix}$$

$$B_{sw}=\begin{bmatrix} 1 & 0 & 0 & 0 \\ (1/I_{sw}) & 0 & (-1/I_{sw}) & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & (-1/I_{m1}) \\ 0 & (1/L_1) & 0 & 0 \end{bmatrix}$$

$$C_{sw}=\begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$D_{sw}=0$$

C. Front Wheel System Modelling

Fig .4 shows the front wheel model.

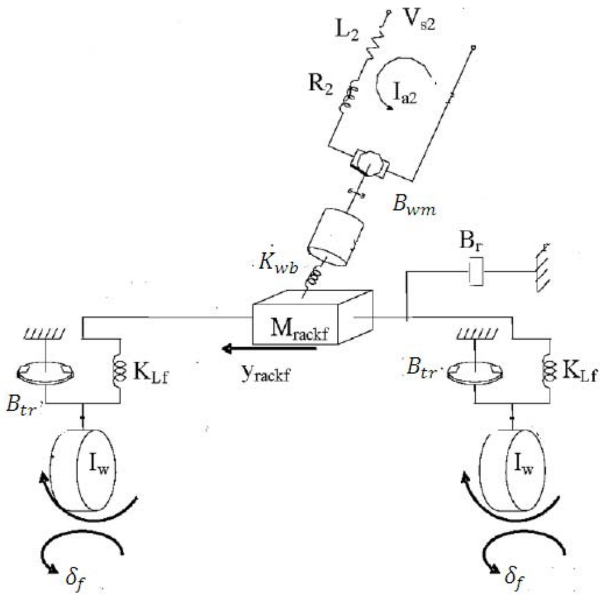


Fig.4 Front tire wheel system diagram [4]

The mathematical equations of the front tire wheel subsystem are written as follows:

Front motor current

$$\dot{i}_{a2} = -\frac{R_2}{L_2} i_{a2} - \frac{K_{wb}}{J_{wm}} T_{m2} + V_{s2} \quad (8)$$

The Torque of Front motor

$$\dot{T}_{m2} = \frac{K_{wb}}{L_2} i_{a2} - \frac{B_{wb}}{J_{wm}} T_{m2} - \frac{\theta_{m2}}{C_{wm}} \quad (9)$$

The Rack force;

$$\dot{y}_{rack} = -\frac{b_r}{m_r} y_{rack} - \frac{\theta_{m2}}{C_{wm*}g_{mr}} - \frac{g_r}{C_{tr}} v_{tr} \quad (10)$$

and Front tire angle;

$$\dot{\delta}_f = -\frac{B_{tr}}{jt}\delta_f + \frac{v_{tr}}{C_{tr}} \quad (11)$$

Front Angular displacement motor

$$\dot{\theta}_{m2} = \frac{T_{m2}}{J_{wm}} + \frac{y_{rack}}{mr*g_{mr}} \quad (12)$$

Tierod velocity

$$\dot{v}_{tr} = \frac{y_{rack}}{m_{r*}g_r} - \frac{v_{tr}}{jt} \quad (13)$$

Consequently, the state equation of the front tire wheel system is given as:

$$\dot{x}(t) = A_{ftw}x(t) + B_{ftw}u(t) \quad (14)$$

$$y(t) = C_{ftw}x(t) + D_{ftw}u(t) \quad (15)$$

where state model is given as:

$$x(t) = [\, i_{a2} \;\; T_{m2} \;\; y_{rack} \;\; \delta_f \;\; \theta_{m2} \;\; v_{tr} \,]^T \quad (16)$$

The steering motor angular displacement (θ_{m1}) is considered the input of the front wheel system. The mathematical model in states matrix forms are:

$$u(t) = [\theta_{m1}] \quad (17)$$

$$A_{ftw}=\begin{bmatrix} \frac{-R_2}{L_2} & \frac{-K_{wb}}{J_{wm}} & 0 & 0 & 0 & 0 \\ \frac{K_{wb}}{L_2} & \frac{-B_{wm}}{J_{wm}} & 0 & 0 & \frac{-1}{C_{wm}} & 0 \\ 0 & 0 & \frac{-b_r}{M_r} & 0 & \frac{-1}{C_{wm*}g_{mr}} & \frac{-g_r}{C_{tr}} \\ 0 & 0 & 0 & \frac{-(B_{tr})}{jt} & 0 & \frac{1}{C_{tr}} \\ 0 & \frac{1}{J_{wm}} & \frac{-1}{g_{mr*}M_r} & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{g_{r*}M_r} & \frac{-1}{jt} & 0 & 0 \end{bmatrix}$$

$$B_{ftw}=\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \quad C_{ftw}=\begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}, \quad D_{ftw}=0$$

D. Controller Design

1) Directional control and Wheel Synchronization

Fig. 5 shows the block diagram for the control structure of the steer by wire system (SBW). It is includes the steering wheel system, the front wheel system and the controller. Two PID controllers were used for steering wheel and front wheel system. Based on the fig. 5, when the driver holds and turn the steering wheel, an adjustable angle is created by the motor of the steering wheel system, the PID controller for will adjust the steering angle to a desired angle by calculate the error. This angle will substitute in to the front wheel system and feedback to the PID controller.

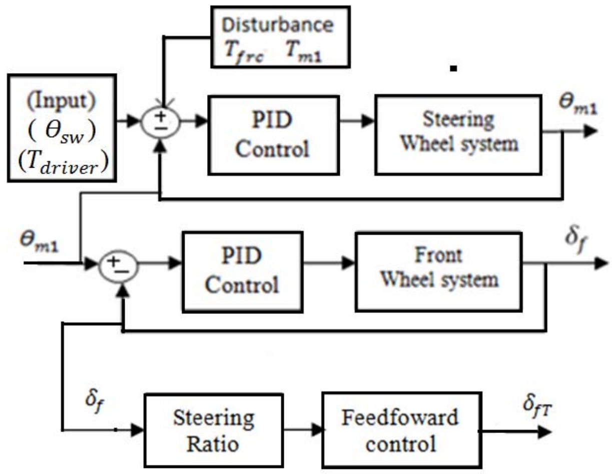


Fig.5 Control structure SBW system diagram

II. VARIABLE STEERING RATIO

The steering ratio is one of the main advantages in advanced vehicle steering system. The ratio is referred to the amount of turn in steering wheel to the amount of degree of the front tire angle. An advantage of steering ratio is that the driver applies a small force on steering wheel, which will result in large steering force at the front wheel. Thus will reduce the amount of steering wheel turn compared to the tire angle. In conventional steering system, the steering ratio is set between 12:1 and 20:1 depending to the manufacturer.

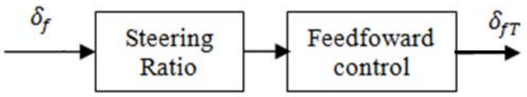


Fig.6 Variable steering ratio diagram

Feedback sensors from the front tire wheel angle and vehicle speed were used as a input to the steering ratio algorithm in order to control the tire angle. Fig. 6 shows the implementations of the variable steering ratio. The concept of the variable steering is to improve maneuverability by adjusting the tire angle based on vehicle speed. If the vehicle speed is increased, smaller steering ratio will use while in vehicle at stop condition (i.e in parking) a higher ratio will use. By using this method, the maneuverability and stability can be improved [6]. A feed forward control is used to control the steering ratio based on understeer gradient equation.. Equations (18) present the understeer gradient equation. An improvement was made based on paper [6], by adding the characteristics of the initial front tire angle and the steering ratio to the control strategies and it is present in equation (20). Equation below shows the improvement of the understeer gradient equation.

$$K=\frac{R}{V^2}\left(\delta_f - 57.3\frac{(a+b)}{R} \right) \tag{18}$$

$$K = [(W_f/C_f) - (W_r/C_r)] \tag{19}$$

$$\delta_{fT} = \left(\frac{(a+b)\frac{\delta_f}{\delta_{ratio}}}{(V^2K+(a+b)} \right) + \frac{\delta_f}{\delta_{ratio}} \tag{20}$$

Where;

δ_{ratio} = steering ratio

δ_{FT} = Front tire angle (with steering ratio)

V = vehicle speed

δ_f = Front tire angle without steering ratio

K= adjustable gain

a = distance of front tire to vehicle COG

b = distance of rear tire to vehicle COG

R = radius of COG path

W_f= weight of front wheel

W_r= weight of rear wheel

C_f = total front cornering stiffness

C_r = total rear cornering stiffness

III. SIMULATION AND RESULTS

To investigate the effectiveness of the proposed control algorithm, a computer simulation based on Matlab software were conducted and output responses are compared with passive system.

Wheel Synchronization Controller

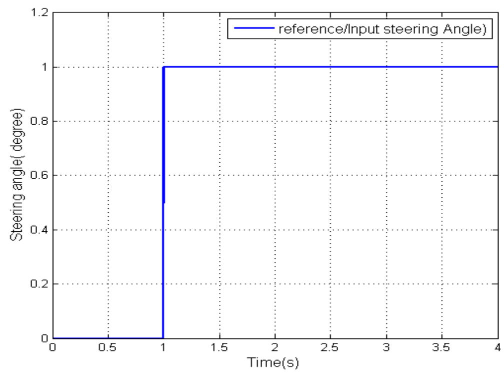


Fig 7: Input steering angle

To simulation the robustness of the system, two scenarios were conducted, case 1 without disturbance input and case 2 with a disturbance inputs. The input to the system is a steering angle (θ_{sw}) simulated as a step response, as shown in fig. 7 and driver torque (T_{driver}) = 4Nm. The torque friction (T_{frc}) and the torque motor (T_{m1}) = 2Nm, react as disturbance input, where torque friction (T_{frc}) is created using random noise. Fig. 8 and fig 9 shows the output response for the steering motor angular displacement (θ_{m1}) and the front tire angle (δ_f) without disturbance input, however fig.10 and fig. 11 with disturbance input to the system.

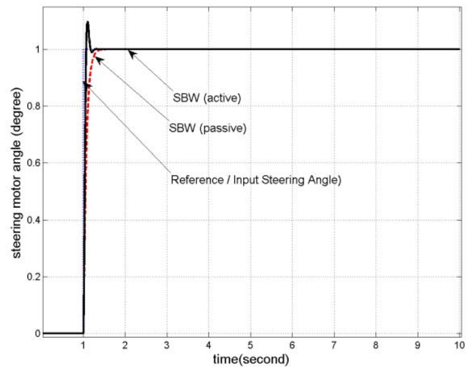


Fig 8: Steering motor angular displacement (θ_{m1} case 1)

Based on fig. 11, the front tire angle (δ_f) response is unstable due to the used of open loop system (without using controller), however by using PID controller the system is stable even there are exist disturbances at the input to the system..

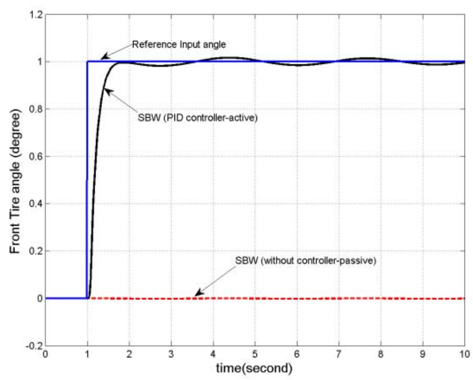


Fig 9: Front Tire angle (δ_f case 1)

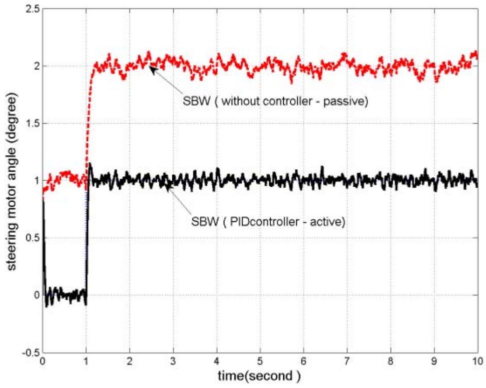


Fig 10: Steering motor angular displacement (θ_{m1} case 2)

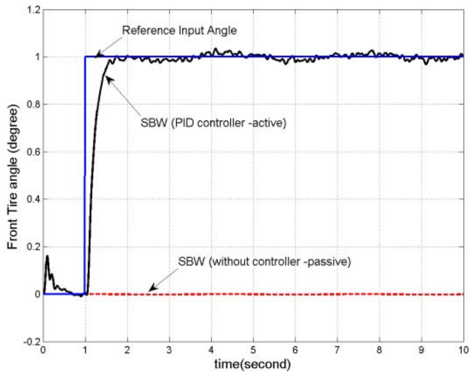


Fig 11: Front Tire angle (δ_f case 2)

A. Variable Steering Ratio

A simulation is conducted by applying steering ratio of 15:1, steering angle input as fig. 7 and a random noise disturbance input friction torque (T_{frc}) was applied and torque of motor (T_{m1}) = 2Nm. In variable steering ratio, at high speed the tire angle is stiff and at lower speed the tire angle is increased to provide easy maneuverability.

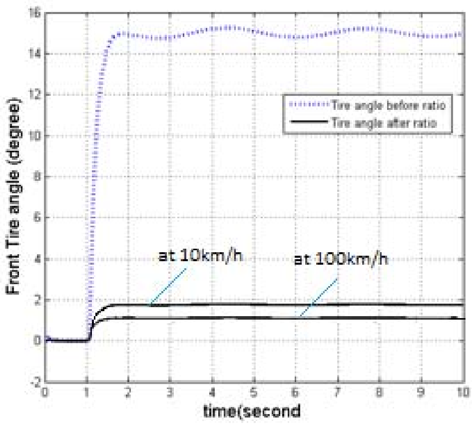


Fig 12: Front Tire angle (δ_{fT})

From fig 12, it can been seen, the front tire angle (δ_{FT}) response are varies at low and high speed and fig 13 shows the relationship between of the front tire angle (δ_{FT}) against the vehicle speed.

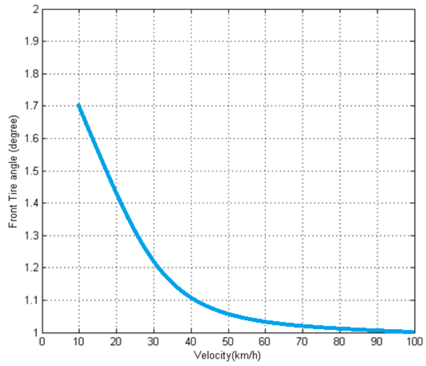


Fig 13: Front tire angle (δ_{FT}) against Vehicle Speed (V)

IV. CONCLUSION

In this paper, mathematical model and control strategy for a steer by wire system was proposed. From the simulation, it can been conclude that by using the PID controller, the front tire angle (δ_{FT}) is stable even disturbance and torque are applied. Based on the results, the controller is able to reduce the disturbance error. In variable steering ratio, the proposed feed forward control is suitable to use due to less sensor use and simple control strategy with constant steering ratio. From the simulation result, the variable steering ratio is achieved, where by using the proposed control strategy, the front tire angle (δ_{FT}) is increased and proportional to the vehicle speed. Thus the proposed control strategy improved maneuverability and stability of the system. For future work, a yaw rate and body slip angle will be investigate to include into the system for in order to improvement the maneuverability and stability

ACKNOWLEDGEMENT

This work is collaboration between Proton Sdn Bhd and Universiti Teknologi Malaysia. The works is also supported by Ministry of Higher Education under FRGS research grant (vote no: 7808.4F053)

APPENDIX I

BIL	Steer ByWire System Parameter		
	Items	***Values***	***units***
K_{s1}	Lumped torque stifness(SM)	*3500*	Nm/rad
I_{sw}	Steering Lumped Inertia(SM)	0.0079	Kgm2
B_{sc}	Steering column damping(SM)	0.136	Nmsec/rad
I_{m1}	Internia of steering motor(SM)	0.0021	Kgm2
K_{b1}	Steering motor emf constant(SM)	0.35	V-s/rad
L_1	Motor electical inductance (SM)	0.002	H
R_1	Motor electrical resistance (SM)	4.6	Ohm
R_2	Motor electical resistance (FM)	5.0	Ohm
L_2	Motor electical inductance (FM)	0.002	H
K_{wb}	Motor torque constant (FM)	2	Nm/rad
J_{wm}	Motor moment inertia (FM)	0.0079	Nm/rad
B_{wm}	Motor resistance coefficien (FM)	1.0	Kgm2
C_{wm}	Motor shaft compliance (FM)	0.4	Nm/s
b_r	Resistance rack (FM)	25	Nm/rad
m_r	Mass rack (FM)	2.0	Kg
g_{mr}	coloumn pinion radius (FM)	0.015	m
g_r	length ratio steering arm (FM)	4.5	m
C_{tr}	Compliance of tie rod (FM)	0.2	rad/Nm
B_{tr}	resistance of tie rod (FM)	0.004	Nms/rad
j_t	Inertia of tire (FM)	1.36	Kgm2
δ_{FT}	Front tire angle (with ratio)	-	degree
T_{driver}	torque of driver	[0,4]	Nm
T_{frc}	torque friction	Random	Nm
T_{m1}	steering motor torque	[0,2]	Nm
V_s	voltage source	-	V
θ_{m1}	Angular displacement of steering motor	-	degree
i_{a1}	Current of steering motor	-	ampere
i_{a2}	Current of front motor	-	ampere
T_{m2}	Torque of front motor	-	Nm
y_{rack}	Rack force	-	Nm
θ_{m2}	Angular displacement of front motor	-	degree
V_{tr}	Tie rod velocity	-	Km/h
V	Vehicle speed	[10,100]	Km/h

REFERENCES

[1] Ba-Hai Nguyen and Jee-Hwan Ryu, "Direct Current Measurement Based Steer By Wire Systems for Realistic Driving Feeling, IEEE International Symposium on Industrial Electronics (ISIE 2009), Seoul Olympic Parktel, Seoul,Korea July 5-8, 2009

[2] Y.Tau,"Vehicle Steer-by-Wire System Control" SAE Technical Paper No. 2006-01-1157.

[3] Li Qiang and He Ren, "Modeling and Simulation Study of the steer by Wire System Using Bond", IEEE International Symposium on Industrial Electronics (ISIE 2009), Seoul Olympic Parktel, Seoul,Korea July 5-8, 2009

[4] Reza Kazemi et al "Yaw Moment Control of the passenger Car via Steer by Wire system" ASME- International mechanical Engneering Congress& Exposition (IMECE 2011) ,Denver,Colorado USA, Nov 11

[5] F.Tahami and H.Afshang, " A Fractional Order Model for Steer-by-Wire System", IEEE IECON 2009 the 35th Annual Conference of the IEEE Industrial Electronics Society, Nov. 2009, Porto, Portugal.

[6] Oh S-W, Chae H-C,Yun S-C,Han C-s " The design of controller for the steer by wire system",JSME Int Journal.Ser. Cmech Systems, Mach ElemManuf, Japan, vol 47,pp.896-907,2004.

[7] S.Wook, " The development of and advanced control method for SBW system to improve the vehicle maneuverability and stability" SAE International Congress and Exhibition 2003.

[8] Masao nagai,Motoki shino, and Feng Gao, " Study on integrated control Of active front steer angle and direct yaw moment" JSAE, Society of Automotive Engineers of Japan, Inc and Elsevier Science B.V, JSAE Review 23 (2002) 309-315

[9] Julien Coudon, et. Al, " A New Reference Model for Steer-By-Wire Application with Embedded Vehicle Dynamic", IEEE American Control Conference, 2006

[10] Abe, M., Vehicle dynamics and control for improving handling and Active safety:from four wheel steering to direct yaw moment control Proc.Inst. Mech. Engr. Vol. 213, Part K, pp. 87-101 (1999)

[11] S. C. Chang, "Synchronization in a steer by-wire vehicle dynamic System"International Journal of Engineering Science 45 (2007) 628-643.

Active Steering Wheel, a new solution to implement active steering functionality into a vehicle

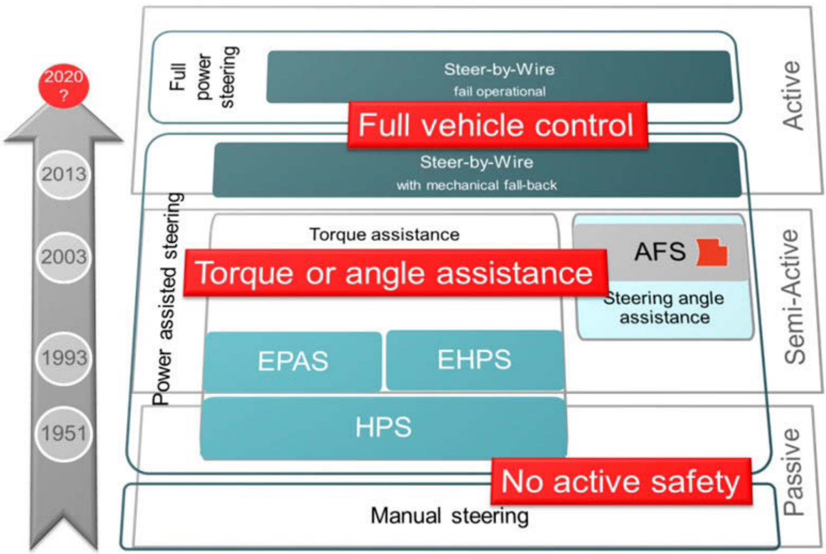
Roland Grimm, Director Electronics, Safety System, TAKATA AG

P.E. Pfeffer (Ed.), *5th International Munich Chassis Symposium 2014,* Proceedings,
DOI 10.1007/978-3-658-05978-1_35

Development of Steering Systems

Since motorized vehicles are on the road, they all have an element to steer the vehicle. At the beginning it was a pure mechanical connection steering wheel – steering column – steering gear – front axle – front wheel. In the 50's of last century the first systems of steering assistance were developed and introduced into the market. A hydraulic system supported the driver to turn the steering wheel with lower torque, so especially steering at low speed became more convenient. To reduce the fuel consumption of the vehicles the hydraulic system was replaced by electrical systems in the 90's. Beside torque assistance, almost 10 years ago angle assistance was introduced to steering systems.

In 2013, Nissan launched the first steer-by-wire vehicle with a mechanical fall-back system. That means, there is a clutch available which would shortcut in an event of system failure the steer-by-wire system and realizes a mechanical connection between steering wheel and front wheels.

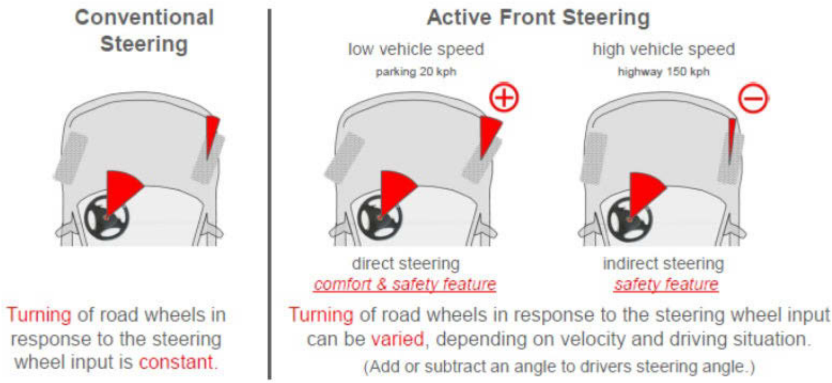


Picture 1: Development of Steering Systems over the past 60 years

Where does the journey go? When will we have a pure steer-by-wire system without mechanical feedback and what will be the advantage of such a system?

Active Steering functionality

Active steering describes a steering system in a vehicle where the ratio between the driver's steer inputs and the angle of the steered road wheels may be continuously and intelligently altered. Active steering technology was introduced in 2002 in Germany and Japan almost at the same time by two different OEM's. At lower speeds, this technology reduces the amount that the steering wheel must be turned – improving performance in situations such as parking and other urban area traffic manoeuvres. At higher speeds, the performance is such that the normal increased responsiveness from speed is avoided and it provides improved directional stability.



Picture 2: Functionality of an active steering system

But an Active Steering System is not only useful for parking manoeuvres; it can also be used to improve the chassis behaviour of the complete vehicle. Fast lane changes, extreme steering manoeuvers can be supported in a way that the vehicle remains in a more controlled situation.

In addition, all interactions which are actually done by ESC systems can be supported by an Active Steering System more agile. Side wind correction, lane keeping, braking on roads with different friction.

TAKATA solution “Integration into steering wheel”

The central component of active front steering is a superposition gear, driven by an electric motor and embedded in the steering system. At all active steering systems on the market this central component mounted in the steering column or in the front axle. The TAKATA active steering system is mounted directly in the steering wheel.

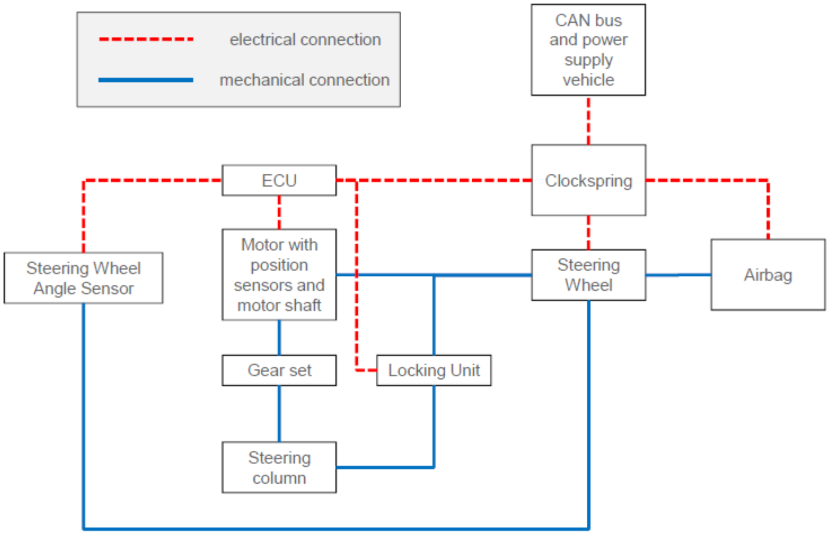
Picture 3: Market solutions and TAKATA’s solution

The take rate of the available Active Steering Systems is low as it is a luxury option. So an integration of this system in the area of the steering column or front axle requires a big change in the vehicle front part. That means a high variance at the OEM in an early phase of the assembly process. Bringing the functionality into the steering wheel offers the possibility to the OEM to put the variance at the end of an assembly process. It is attractive for the OEM to assemble either a leather wrapped steering wheel or a steering wheel with heating or an Active Steering Wheel into the car.

The integration of the Active Steering System into the steering wheel reduces total weight and costs because parts of the steering wheel itself are used for this system. Of course the integration into the steering wheel also has challenges like acoustics, EMC issues, weight increase of the steering wheel and thermal management only to mention some of them.

System Design

In the block diagram below the main components of the Active Steering Wheel are shown.



Picture 4: System Design Active Steering Wheel

The Electrical Control Unit (ECU) receives the signal of the Steering Wheel Angle Sensor, mechanically connected to the steering wheel. That is the so-called requested angle from the driver. Beside of this signal the ECU is connected to the vehicle CAN-bus via the Clockspring and gets relevant signals from the vehicle e.g. vehicle speed, yaw rate, etc. The ECU calculates the requested angle position of the electrical motor and turns the motor accordingly. By turning the motor, an angle is superposed to the steering column, in addition to the steering wheel angle. In other words, in addition to the steering column angle rotation by the steering wheel angle, the motor angle additionally turns the column.

This ECU must fulfil all requirements according ISO 26262 because the Active Steering Wheel is rated as an ASIL D product. The position of the motor is monitored continuously by the ECU.

All calculations are done with a dual core microprocessor. If one of the numerous diagnosis signals indicates a failure or an implausible value of the sensors the ECU forces the Locking Unit to lock the system. In case of a deviation between calculated and actual motor position the system will be mechanically locked via the Locking Unit. In this case, the Active Steering Wheel behaves like a normal Steering Wheel, i.e. has a fixed mechanical steering ratio.

System Components

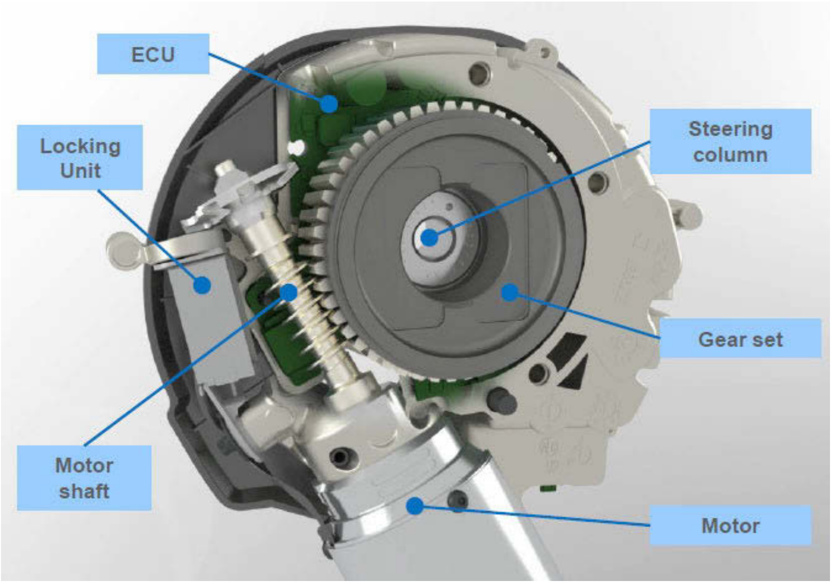
Active Steering Unit

The Active Steering Unit is placed in the middle on in the 6 o'clock spoke of the steering wheel. It is important that the centre of gravity of the Active Steering Wheel is always in the vertical line with the steering column, preventing it to turn by itself under the influence of gravity.

Picture 5: The Active Steering Unit in the Steering Wheel

The Active Steering Unit itself consists of a housing which is mechanically connected to the armature of the steering wheel. The motor is fixed into the housing and has a helical motor shaft. The motor shaft itself drives the helical gear set which is directly mounted on the steering column.

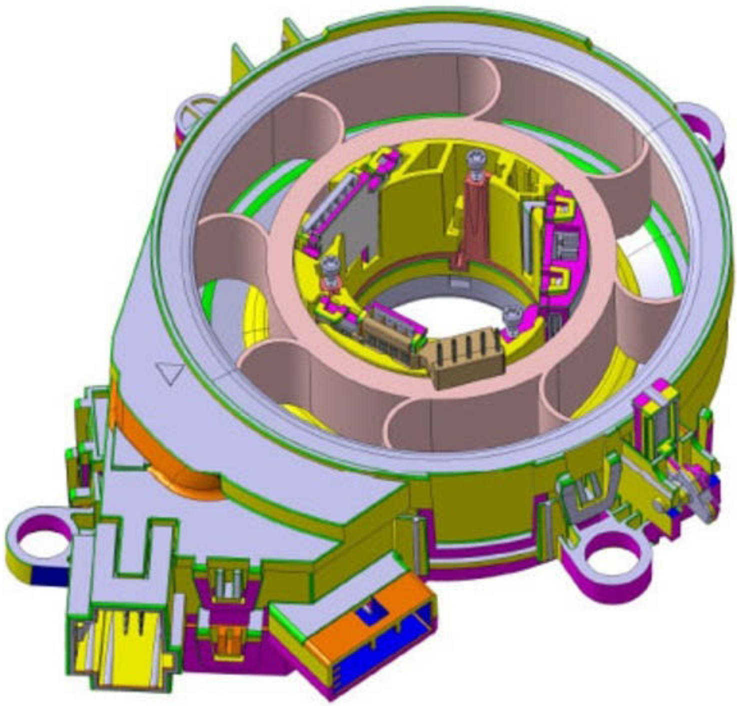
The gear set is not self-locking so a locking unit is necessary to lock the system in case of power supply loss. The Electrical Control Unit is mounted in the housing of the Active Steering Unit. At every start of the system the ECU controls the proper function of the system.



Picture 6: Main components of the Active Steering Unit

Clockspring Module

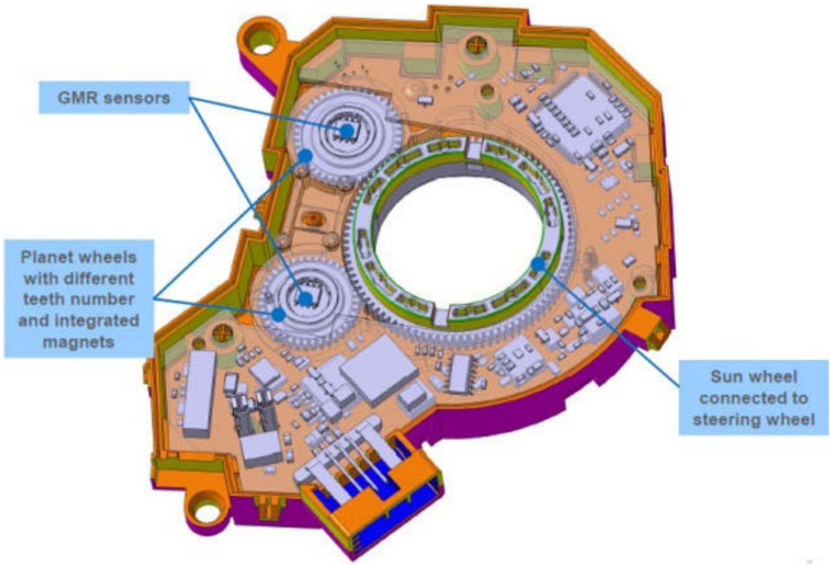
The power to the system is supplied via the Clockspring Module. Although normal driving behaviours normally draw currents around 5A, misuse cases can draw up to 40A. Therefore, the design of the Clockspring has to be adapted.



Picture 7: Clockspring Module

Inside of the Clockspring Module eight flexible flat cables connect the rotor with the stator. Six are used for the power supply of the Active Steering Unit and two of them are used for the normal signals of switches, airbag deployment, horn signal, etc.

On the back side of the Clockspring Module a Steering Angle Sensor is attached. The Steering Angle Sensor basically consists of a planetary gear set where the sun wheel is mechanical attached to the steering wheel. The two planet wheels have different number of teeth and an integrated Magnet inside. Two GMR sensors determine the direction of the magnetic field and a microcontroller calculates the absolute steering angle out of these signals.



Picture 8: Steering Angle Sensor

System Performance Tests

To validate the System Performance of the Active Steering Wheel almost twenty test benches were built up at TAKATA Berlin. Torque and High Speed turning has to be applied to the Active Steering Wheel and to the steering column at the same time

Picture 9: System Test Benches for Active Steering Wheel

Table 1: Active Steering Wheel Test Equipment

<table>
<tr><td>STB01</td><td>System test bench with Temperature / Humidity</td><td rowspan="12">All round Test stand with ability to test in Dual load</td></tr>
<tr><td>STB02</td><td>System test bench with Temperature / Humidity</td></tr>
<tr><td>STB03</td><td>System test bench with Temperature</td></tr>
<tr><td>STB04</td><td>System test bench with Temperature</td></tr>
<tr><td>STB05</td><td>System test bench</td></tr>
<tr><td>STB06</td><td>System test bench</td></tr>
<tr><td>STB07</td><td>System test bench with Temperature</td></tr>
<tr><td>STB08</td><td>System test bench with Temperature</td></tr>
<tr><td>STB09</td><td>System test bench with Temperature</td></tr>
<tr><td>STB10</td><td>System test bench with Temperature</td></tr>
<tr><td>STB11</td><td>System test bench</td></tr>
<tr><td>STB12</td><td>System test bench</td></tr>
<tr><td>CTB01</td><td>Component Test bench</td><td>Related to Component test Gear/Mechanics</td></tr>
<tr><td rowspan="4">CTB03</td><td rowspan="4">Component Test bench</td><td>Related to Component test Gear test</td></tr>
<tr><td>- Efficency</td></tr>
<tr><td>- Pretension</td></tr>
<tr><td>- Idle Torque</td></tr>
<tr><td rowspan="4">HDTB</td><td rowspan="4">High Dynamic Test bench</td><td>Related to System tests</td></tr>
<tr><td>- Step Response</td></tr>
<tr><td>- Rotational Fatigue</td></tr>
<tr><td>- System-Input Vibration</td></tr>
<tr><td>NVH</td><td>Noise / Vibration Test bench</td><td></td></tr>
<tr><td>DTB01</td><td>3x Durability Test bench</td><td rowspan="2">Related to Component test Gear test on System level</td></tr>
<tr><td>DTB02</td><td>3x Durability Test bench</td></tr>
</table>

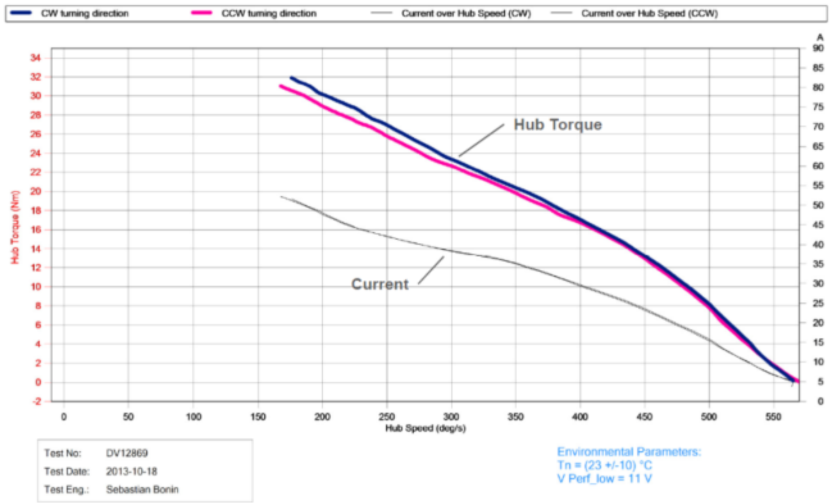
System performance

The quality of an Active Steering System can be defined by several parameters. In this presentation, the focus is on the system performance itself. That means how powerful, how fast is the system. In addition, these tests represent the so-called release-testing, being a short test program conducted for each sample, before it is officially released.

Obviously, the Active Steering Wheel has to meet requirements like noise behaviour, EMC behaviour, high/low temperature, vibration, etc. as well.

Dynamic Performance

Picture 10 shows the Dynamic Performance of the Active Steering Wheel, indicating the torque and angular speed that the system can superpose to the steering column. The motor efficiency, the complete gear set as well as the motor control electronic and software are the main influence parameter on the Dynamic Performance.

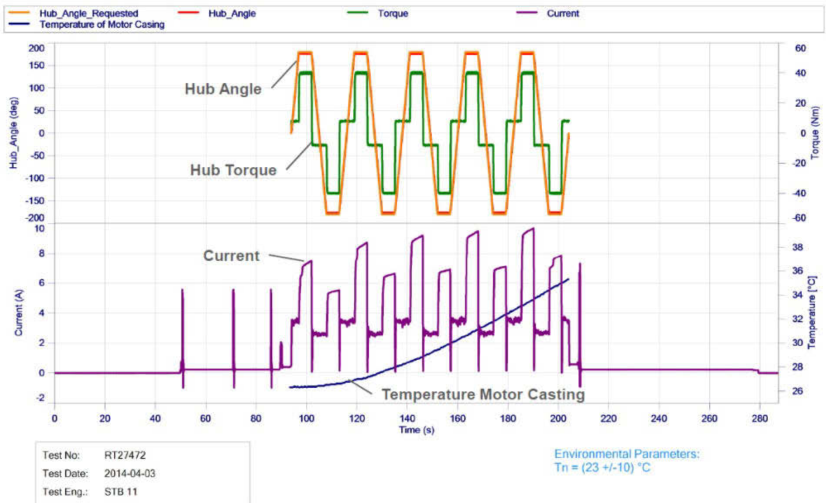


Picture 10: Dynamic Performance Active Steering Wheel

The system must support hub torques up to 70 Nm. Normal driving manoeuvres are far below this value. But we have to consider also some misuse cases which can happen e.g. turning the front wheels against a curb. On torque values higher than 70 Nm the Active Steering Wheel will be locked automatically and has then to withstand hub torque up to 260 Nm.

Parking cycle

Picture 11 shows the Parking Cycle Test with the Active Steering Wheel. In this test, 5 cycles of steering wheel hub turns with a maximum hub torque of 40 Nm are conducted by the system.

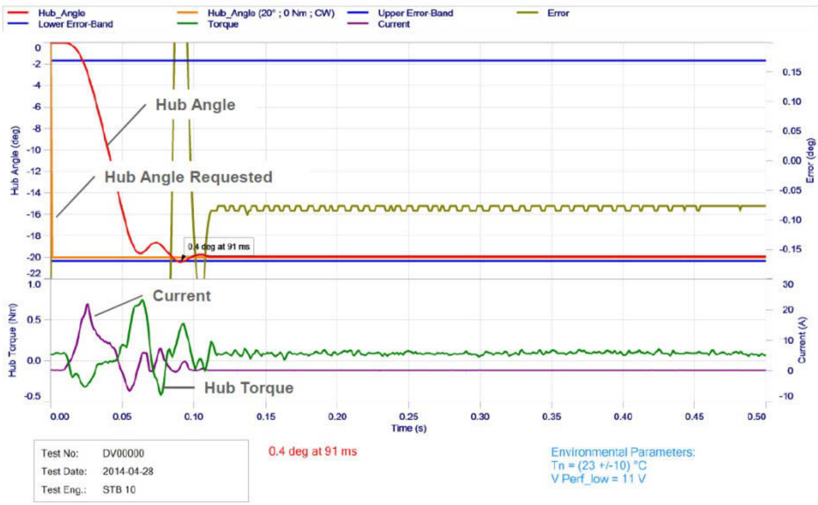


Picture 11: Parking Cycle Active Steering Wheel

The total current during the Parking Cycle Test rises up to 10A and the temperature of the motor housing increases by 10°C.

Step Response

Picture 12 shows the Step Response Test with the Active Steering Wheel. In this test you measure the response time of the complete system on a 20° stepwise change of the requested hub angle. The requested angle is applied electrically to the system and the real hub angle is measured. The system has to react fast but smoothly damped.

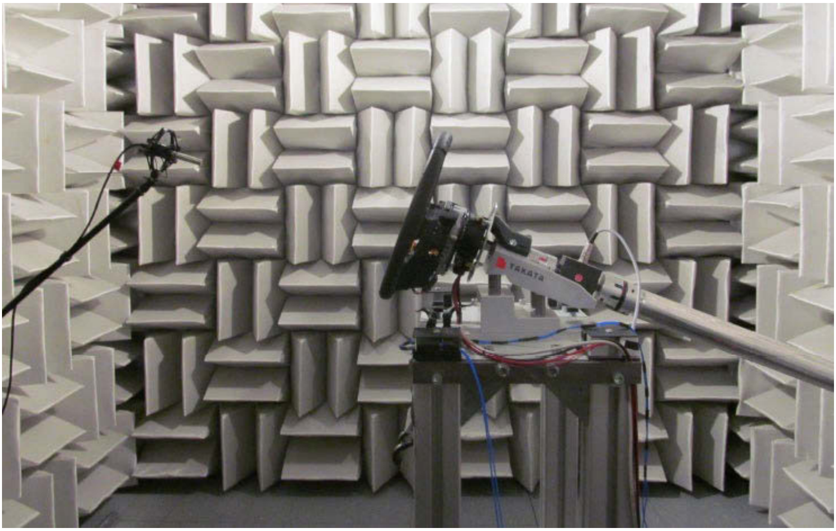


Picture 12: Step Response of the Active Steering Wheel

Picture 12 diagram shows the Active Steering Wheel response to the requested step within less than 100 msec. The maximum of the total current is in the range of 20 A.

NVH Behaviour

Beside of all mechanical requirements the Active Steering Wheel has also to meet requirements concerning noise. The TAKATA solution brings the active elements closer to the driver because they are integrated in the steering wheel and not somewhere in the steering column or front axle area. Therefore the NHV behaviour of the complete system has to be considered intensively. Like the mechanical efficiency of the Active Steering Wheel the NVH behaviour is not only influenced by mechanics itself but also by the complete control of the motor



Picture 13: Active Steering Wheel in the TAKATA NVH chamber at Berlin

Vehicle Evaluation

Even if more than hundred tests (mechanical tests, electrical tests and NVH tests) are done on component level, the final quality assessment of the Active Steering Wheel has to be done in the vehicle itself.

The so-called "good steering feeling" is difficult to specify within test specifications and the fingers, the hands and the ears of an experienced driver are much more sensitive than any test bench ever. Therefore TAKATA trained vehicle test engineers together with the customer to assess the quality and the performance of the Active Steering Wheel by driving the vehicles on test tracks.

Assembly Line

Picture 14: Assembly line Active Steering Wheel

The assembly line of the Active Steering Wheel was built up in Aschaffenburg, Germany and has already passed the run@rate. Beside of the high accuracy of adjustment processes a main focus was given to several test station. The performance of each sample will be measured in terms of torque and hub speed and also the noise behavior of each produced part will be monitored.

A close teamwork between engineering and operations was the key factor for the success.

Summary

With the Active Steering Wheel, TAKATA offers an innovative solution to implement active steering functionality. This is an opportunity for the OEM to adapt active steering functionality very flexible to different platforms, vehicle lines and continents.

Nevertheless, some challenges had to be met during the development. Extremely high awareness on all NVH related issues was necessary. Material studies to find the optimal material for every single component were executed. Buildup of specialized test equipment was mandatory to validate the performance of the system. Development according functional safety norms (ISO 26262) was a must to get an approval for an ASIL D product.

The Active Steering Wheel is not only a product for convenient driving but it is also a component to adapt the chassis behaviour, as seen by the driver. Moreover, it is a component of an active safety system.

Last, but not least, the Active Steering Wheel consists of all components that are required for Steer by Wire. Whether the market will push towards a Steer-by-Wire System instead of an active Steering Wheel? Time will tell.