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Overcoming design challenges of electro-hydraulic steering systems

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Abstract

Electro-hydraulic steering solutions on agricultural machinery offers several benefits to the farmer. GPS-controlled auto-guidance reduces overlap for certain field operations improving the productivity and saving the farmers money. It is also a cornerstone in the controlled traffic farming philosophy and not at least it reduces the human effort during long work hours. Variable steering ratio further improves the operator comfort; studies have demonstrated a 16% reduction in average workload and a 6% productivity increase during front loader operation. Four-wheel steering including a new evolution of electro-hydraulic steering with a virtual steering axis sets new standard for manoeuvrability of agricultural machines.

Electro-hydraulic steering systems however poses a challenge to the engineering teams developing, deploying and testing these solutions. Besides all the functional development, electro-hydraulic steering is also associated with safety concerns, which enquires OEMs to conduct risk assessments, develop safety functions and choosing components to obtain the needed approval for on-road driving.

This paper will discuss some of the benefits of electro-hydraulic steering and some examples of safety functions needed for a virtual steering axis system.

Why Electro-Hydraulic Steering

Electro-hydraulic steering provides several opportunities for improved productivity, operator comfort and operability of modern self-propelled agricultural machines.

The most well-known utilization of electro-hydraulic steering is GPS-controlled auto-guidance of mainly agricultural tractors. Utilizing GPS indications to assist the operator has shown productivity improvements of 11% but utilizing the GPS signal in a closed loop control of the steering has shown up to 17% productivity increase [1]. Productivity is not the only reason for farmers to invest in auto-guidance on their tractors and other agricultural machines; it also relief the operator from concentrating mainly during planting season. A study from North America has shown that auto-guidance reduce awkward postures of the operator by 6% [2] which helps reducing risk for lower back pains [3].

With the introduction of electro-hydraulic steering new ideas to utilize the additional steering valve has entered the market; variable steering ratio; the operator can select a higher steering gain that reduces the number of steering-wheel turns from lock-to-lock. This improves the comfort during headland turns and operating front loaders. Studies have shown, that an increased steering gain (called Quick-Steer) reduces muscle activity by 16% compared to conventional steering during loader operations [4].

An electro-hydraulic steering architecture also facilitates alternative user interfaces like mini-wheels and joysticks. Adding an additional steering wheel to e.g. a tractor [5] increases the applications. In the recent years, joystick steering has become a popular option in wheel loaders within the construction market as it offers a symmetric posture improving the comfort and reducing the risk of lower back pains [2]. A general study has shown that joystick steering reduces upper body muscle activity by 65% compared to a conventional mid-centred steering wheel [4]. Additionally, joystick steering also eliminates the steering wheel column, which improve the visibility significantly as seen in new combine harvesters [6]. Same benefits apply to other machines with headers, like forage harvester, sugar beet and potato harvesters.

Four-wheel steering has been known from telehandlers and some few tractor models for years and typically offers 3 static steering modes: 1) front wheel steering, 2) four-wheel steering and 3) crab steering. However, with an independent electro-hydraulic steering valve for the rear axle, features like hill drift compensation and moderated crap steering becomes possible [7,8].

Electro-hydraulic trailer steering provides benefits in terms of less footprint and fewer damaged crops for spraying and fertilizing [9].

Design Challenges

Even though there are a lot of added value by use of electro-hydraulic steering systems, it also comes with some challenges for the design engineers. One example can be the need for additional pump flow which might affect pump sizing and layout. Another is making the right choice on steering input device (joystick, steering wheel, mini-wheel). However, most of the challenges is how to design a safe system. For vehicles driving at higher speeds and especially driving on public roads, a risk assessment will typically reveal the need of a high safely level. For a four-wheel steering machine, this can be solved with a mechanical lock-out. However, this is not convenient for the operator and does not provide a smooth transition between steering modes and on-road and off-road driving modes. In the following, a couple of safety functions will be presented for multi-axis steering systems as examples on how to solve meet the safety requirements and ensure operability, comfort and productivity. The multi-axis vehicle steering is adding steering functionality to have steering on one or more steering axis. Any possible steering mode can be achieved by commanding a virtual axis position (VAP) and a virtual axis angle (VAA), Fig. 1. The system holds seven safety function specifically the for multi-axis functionality on top of other safety functions already a part of safe electro-hydraulic steering products by Danfoss [10].

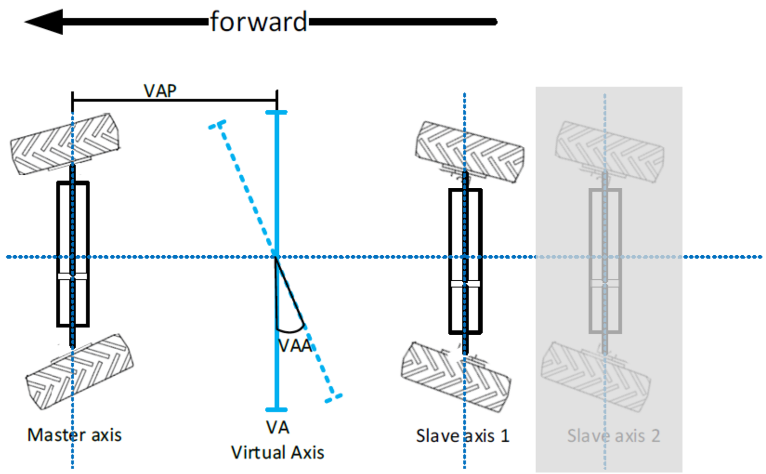

Fig. 1: Multi-axis steering variables; VAP and VAA [11].

Example 1 – Safe vehicle speed dependent VAP limit

The received VAP set-point is limited in accordance with a programmable safe VAP range envelope, Fig. 2. This may be useful in advanced multi-axis steering modes where VAP can be changed dynamically during multi-axis operation and where there is no expectation to the VAP set-point. In such cases, a safe VAP envelope can be configured.

The safe VAP range is configurable as a three-piece linear characteristic as shown in Fig. 3. The software performs linear interpolation to calculate the limited VAP set-point which is used by the multi-axis control algorithm.

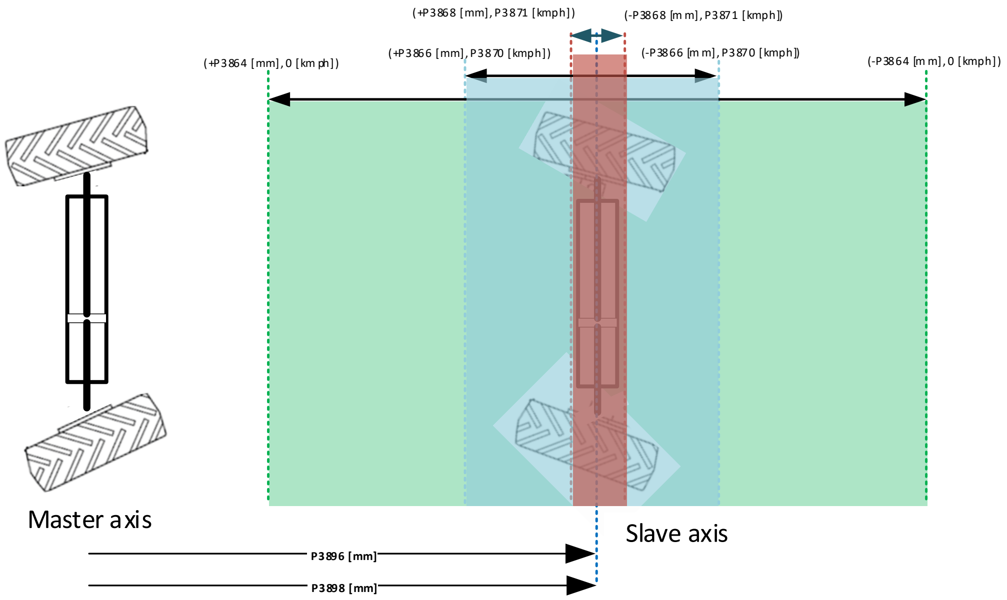

Fig. 2: Safe vehicle speed dependent VAP limit operation [11].

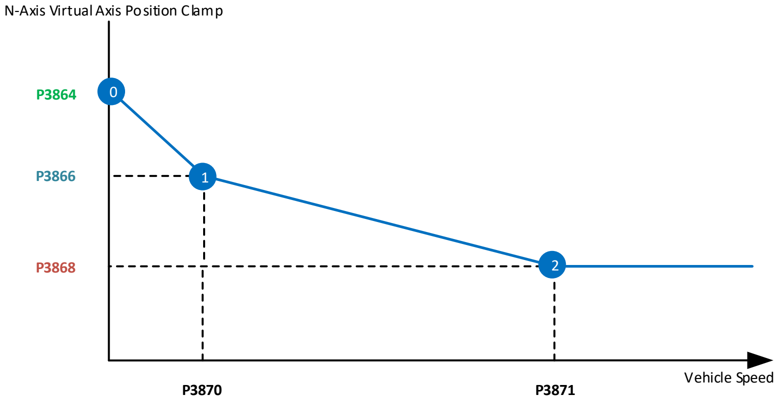

Fig. 3: Safe vehicle speed dependent VAP range envelope [11].

Example 2 - Safe vehicle speed dependent VAP change rate

This safety related control function operates on the output of safety related control function on the previous safety function. A VAP set-point change is limited in accordance with a programmable 'safe VAP change rate' -range shown in Fig. 4. This may be useful for advanced multi-axis steering modes where the VAP set-point can be changed dynamically during multi-axis operation. In such cases, a safe VAP change rate range can be configured while allowing some freedom to the generation of the VAP set-point. The safe VAP change rate range is configurable as a three-piece linear characteristic. The software performs linear interpolation to calculate the limited VAP set-point change rate limit at any vehicle speed.

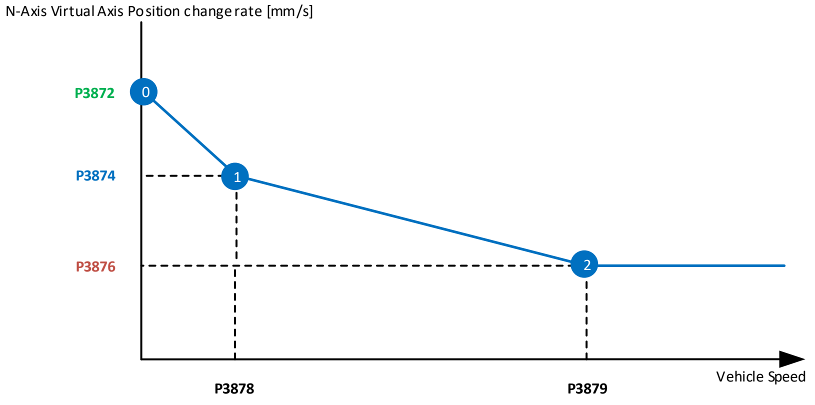

Fig. 4: Safe vehicle speed dependent VAP range envelope [11].

Summary

Both safety functions described above together with five additional safety functions are needed to avoid hazardous events, like roll-over as an example. Together with a safe architecture more detailed described in [11], electro-hydraulic steering can be implemented to provide higher productivity, operability and comfort reducing mechanical lock-outs, that operators tend not to use, or provide a risk to the operator due to many egresses and ingresses of the cabin.

Danfoss has broad portfolio of safe electro-hydraulic steering products together with redundant wheel angle sensors to support any electro-hydraulic steering design. The components and safety functions are developed to match high performance level requirements for OEM identified safety functions.

For more details, please refer to danfoss.com.

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