Proceedings of the 74th Internationale Tagung LAND.TECHNIK
November 22-23, 2016, Cologne, Germany

Comfort Evaluation Criteria for Pitching Vibration Damping of Agricultural Tractors

Dr. **Thomas H. Langer**, MSc **Kaspar Holm-Petersen**, Danfoss Power Solutions, Nordborg, Denmark
Dipl.-Ing. **Dirk Metker**, CLAAS Selbstfahrende Erntemaschinen GmbH, Harsewinkel, Germany

Abstract

The market of agricultural machinery continuously increases its demands for better comfort and higher safety for the end user. This poses a challenge for OEM's in order to develop new suspension and damping techniques and, indeed, how to quantify good ride comfort. The standardized method to evaluate comfort is utilizing ISO 2631-1, but due to the frequency weighting filters include in this standard, it does not capture the effect of pitching vibration damping.

In this paper, a comfort evaluation criterion for pitching vibration damping of agricultural tractors is presented. The aim is to quantify ride comfort when developing solutions for damping of pitching vibrations in order to compare different strategies.

The new criterion was utilized during development of active pitch damping by operating the electro-hydraulic hitch valve of an agricultural tractor. The ISO 5008 Smooth Track and asphalt road served as boundary conditions for the development work.

The developed criteria shows good correlation with the subjective comments from a number of test drivers.

Introduction

The business segment of agricultural tractors represents a highly competitive field, where almost all manufacturers due to customer demand of low fuel consumption and strengthened emission standards perform quite equally concerning efficiency. Then two factors are left in the competitive game; intelligent features and good operator comfort. One of the cornerstones of operator comfort is the tractors vibration attenuation performance in order to reduce the vibration exposure on the operator.

Most agricultural tractors with inflatable tires are facing the problem of low frequency oscillations during transit operations. The first natural order of many tractors are pitching due to relative short wheelbase and high inertia. The pitching movement, Fig. 1, typically occur at a frequency of approximately 1Hz and the amplitudes can increase to an intensively levels if the oscillations are not damped. Often, the operator has to decrease travel speed to reduce the oscillations[1]. The pitching oscillations not only result in discomfort; the need of decreasing speed reduces productivity and the presence of the oscillation contribute to higher fatigue of the tractor chassis and a potential risk to loose directional control of the vehicle due to variation of road contact of the steering tires.

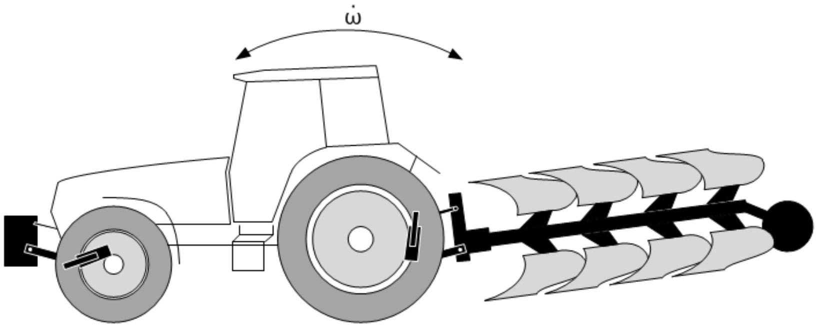


Figure 1: Pitching movement of an agricultural tractor with front weight and plough.

In general, two paths exist to reduce vibration exposure; 1) by introducing additional degrees of freedom in terms of dedicated suspension systems[2,3,4,5] or; 2) damping of vehicle oscillations by engaging the existing actuators like the rear hitch of a tractor[6,7,8,9], which is simpler, reduce maintenance and is less costly than a dedicated suspension system. Independent of the technical solution, whether it is a dedicated suspension system or based on the tractor hitch, whether it is passive, semi-active or active, the crucial question is of course how well do the dampening work – or in other words; how much is the comfort improved.

ISO 2631-1 sets the standard on how to evaluate comfort in terms of whole-body vibration (WBV)[11] and the method is also recognized by the European Directive EC/2002/44 that contains directions for work related vibration exposure and defines an action value and a limit value for the eight-hour daily exposure to WBV for the human operator[12]. Utilizing EC/2002/44 and ISO 2631-1 for evaluation for oscillation damping of pitch movement poses some challenges; EC/2002/44 only consider translational accelerations evaluated in the seat. Hence, the resulting longitudinal acceleration resulting from the pitching movement will be highly dependent on seat position, cabin and seat suspension. Another challenge by applying ISO 2631-1 is the defined frequency weighting filter, which primarily pass acceleration in the range of 1-4Hz. Hence, for a vehicle with a low natural first order below 1Hz, the transients will not be captured. Low frequency oscillations below 1Hz is not damaging to the human body, but can cause motion sickness and therefore still comfort related. In order to quantify ride comfort when developing and benchmarking solutions for damping of pitching oscillations an evaluation method is needed.

Proposed Evaluation Criteria

The proposed evaluation method for pitch oscillation damping is based on the methodology of ISO 2631-1 by summarizing the pitch oscillations in terms of the root-mean-square acceleration after applying a 5Hz low pass filter:

$$\dot{\omega}_{RMS,y} = \left[\frac{1}{T}\int_0^T \dot{\omega}_{y(5Hz)}^2(t)dt\right]^{1/2}$$

The method is suitable for evaluation of a tractor that drives through a defined track with a given speed and recording the time signal for a well-defined period *T*.

This method has a number of advantages; as rotational acceleration is considered, the mounting of the accelerometer can be placed anywhere on the tractor chassis. Second, the evaluation method is similar to the one in ISO 2631-1 for which a good correlation with subjective ride comfort experience exists[12,13,14]. Third, by only applying a low pass filter, the method is suitable for tractors with low first natural order pitching.

Experimental Setup

In order to demonstrate the usage of the proposed evaluation method, it has been applied for an implementation project of active hitch damping on an agricultural tractor. The tractor in concern is the CLAAS Xerion 5000, Fig. 2, and the electro-hydraulic hitch control system is delivered by Danfoss consisting of dedicated double acting hitch valves, PVBZ-HD, pressure sensors and a MC024 controller which is operated through the CLAAS Electronic on-Board Information System (CEBIS), Fig. 3. All communication is established through the CAN bus. For evaluation purpose a Honeywell 6DF-1N6-C2-HWL accelerometer that utilizes CAN communication is mounted to a rigid part of the chassis.

Figure 2: CLAAS Xerion 5000 with test plough rear and front weight.

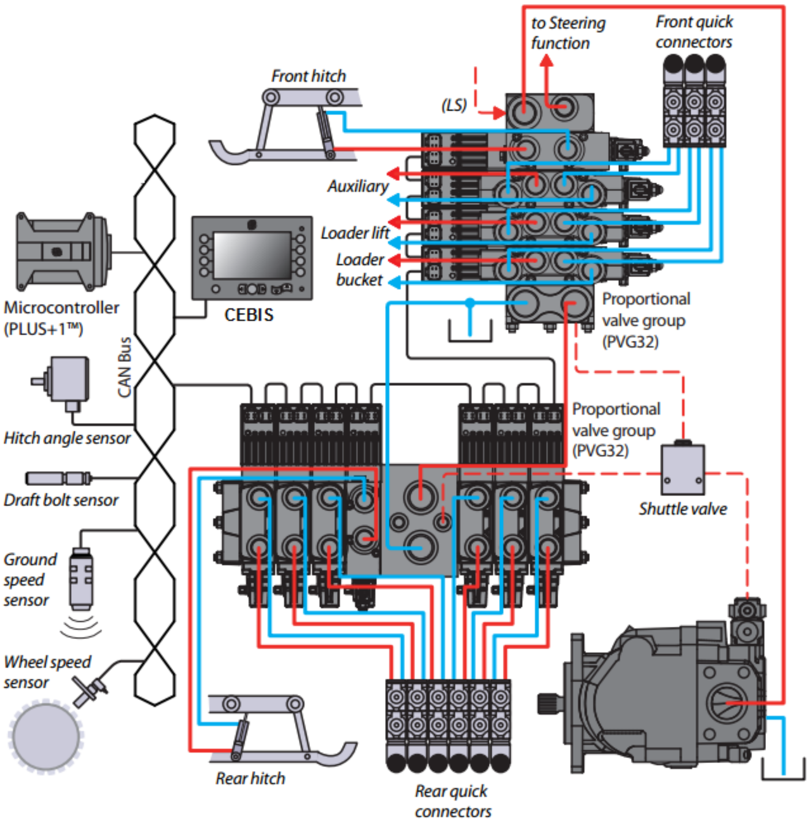


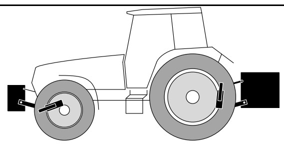
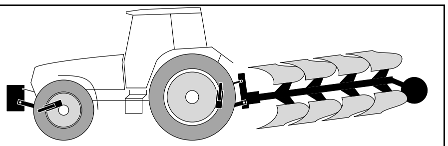
Figure 3: Hitch control system implemented on CLAAS Xerion 5000. Further details can be found in [15].

The 100m smooth version of ISO 5008[16] serves as boundary condition, Fig. 4. The test track is suitable for repetitive tests and often applied for suspension system evaluation[5,17]. The track is as well a part the standard road for evaluation of seat for approval of agricultural and forestry vehicles[18].

Figure 4: ISO 5008 Smooth Track.

The travel speed for all tests is kept constant at 17.5km/h. All test are conducted according to the recommendations by the EN 1032 standard for vibration test of mobile machinery[19].
The active oscillation damping is tested for two different implement configurations of the tractor, Tab. 1. Both configurations are tested with and without applied damping minimum five (5) times in order to determine a statistical mean. The data is post analyzed by a MATLAB script.

Table 1: Different implement configuration of the tractor.

Configuration		
Front implement mass [kg]	3.400	1.800
Front tire inflation pressure [bar]	2.0	1.0
Rear implement mass [kg]	6.260	2.200
Rear tire inflation pressure [bar]	2.0	1.2

Results

The root-mean-square pitch acceleration for the two implement configurations are shown in Tab. 2 without active damping (AD) enabled and with AD enabled for both front and rear hitch. For the heavy rear implement a reduction of 25% is obtained with active damping enabled, and for the plough due to the higher mass moment of inertia contribution a reduction of 32% is obtained.

Table 2: Comparison of pitching oscillation with and without active damping.

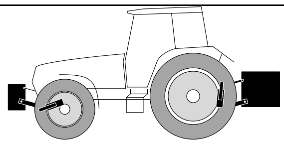
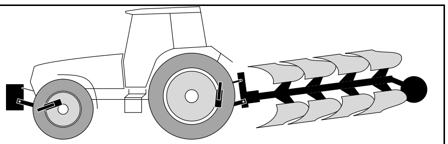
Configuration				
Samples $\dot{\omega}_{RMS,y}$ [rad/s^2]	w/o AD	with AD	w/o AD	with AD
#1	0.386	0.305	0.431	0.289
#2	0.429	0.301	0.416	0.277
#3	0.452	0.295	0.431	0.282
#4	0.392	0.298	0.412	0.284
#5	0.384	0.313	0.418	0.281
Mean	**0.409**	**0.303**	**0.422**	**0.283**
Reduction		*25%*		*32%*

Fig. 5 shows the recorded pitch acceleration in time domain for one measurement with and without active damping for the tractor with the plough implement. It is observed that the amplitudes with active damping in general are smaller. A FFT analysis of the data will reveal a dominant frequency of 1Hz.

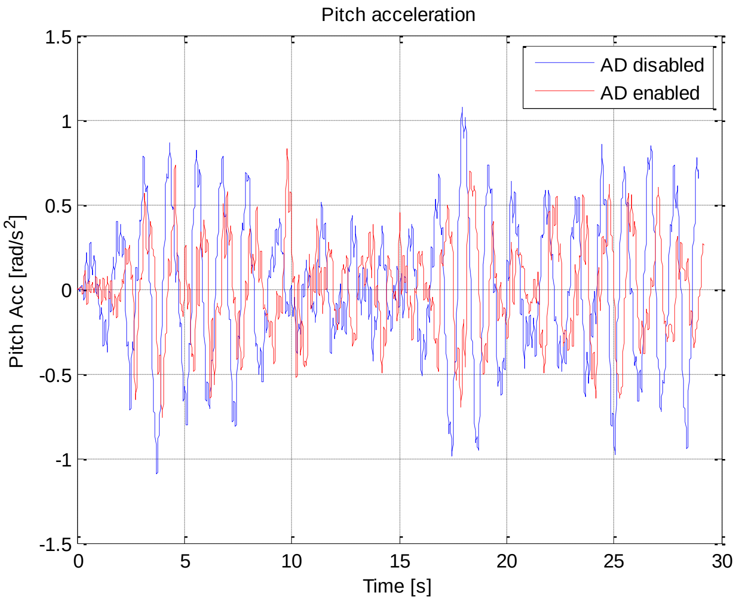


Figure 5: Comparison of pitch accelerations for plough implement.

The improvement of ride comfort in terms of reduction of the root-mean-square pitch acceleration, Tab. 2, is in accordance with the subjective improvement reported by several CLAAS test drivers. In addition to above, high speed test at on-road conditions have been carried out with the same set of control parameters for the active damping and showed a reduction of pitch oscillations of 25%.

Conclusion

In this paper, a comfort evaluation method for pitching oscillation damping of agricultural tractors is proposed and demonstrated in a full scale implementation of active damping of the electro-hydraulic hitch control. The method turns out to be a suitable way of quantifying ride comfort in terms of pitch oscillations. The method can be applied of all mobile machines for evaluation of pitch oscillations, it is easy to instrument and the data analysis is straight forward; most data acquisition software package facilitate the needed filters and calculations. The evaluation method, though, is sensitive to the duration, and the dynamics is sensitive to tire inflation pressure and travel speed. Hence, it is recommended to follow the guidelines by EN 1032, apply cruise control and be strict on timing for any benchmark test.

Bibliography

[1] Rahmfeld, R., and Ivantysynova, M.: An Overview about Active Oscillation Damping of Mobile Machine Structure, International Journal of Fluid Power 5 (2004), 5–24.

[2] Ma, X.Q., Rakheja, S., and Su, C.-Y.: Damping requirement of a suspension seat subject to low frequency vehicle vibration and shock, Journal of Heavy Vehicle Systems 47 (2008), 133–156.

[3] Hansson, P.-A.: Optimization of agricultural tractor cab suspension using the evolution method, Computers and Electronics in Agriculture (1995) 35–49.

[4] Koslik, B., Rill, G., von Stryk, O., and Zampieri, D.E.: Active Suspension Design for a Tractor by Optimal Control Methods (1998), Technische Universität München and Universität Augsburg.

[5] Langer, T.H., Christensen, B.B., Mouritsen, O.Ø., and Hansen, M.R.: Optimization of Front Axle Suspension System of Articulated Dump Truck, In Proceedings of the First Joint International Conference on Multibody System Dynamics (2010), Lappeenranta, Finland.

[6] Hansen, M.R., Andersen, T.O., Conrad, F., and Nielsen, B.: Electro Hydraulic Hitch Control, In Proceedings of the 18th International Conference on Hydraulics and Pneumatics (2003), Praque, Czech Republic.

[7] Andersen, T.O., Hansen, M.R., and Conrad, F.: Robust Control of Oscillations in Agricultural Tractors. In Proceedings of IMECE 2003, Washington, USA.

[8] Andersen, T.O., Hansen, M.R., and Conrad, F.: Active Damping of Oscillations in Off-Road Vehicles, In Proceedings of 8th Scandinavian Intl Conference on Fluid Power (2003), Tampere, Finland, pp. 1073–1085.

[9] Andersen, T.O., Hansen, M.R., and Nielsen, B.: An Approach to Specifying the Dynamic Performance of a Hitch Valve on an Agricultural Tractor, In Proceedings of IMECE 2004, Anaheim, USA.

[10] ISO 2631-1 Mechanical vibration and shock Evaluation of human exposure to whole-body vibration Part 1: General requirements (1997), International Organization for Standardization.

[11] Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002 on the minimum health and safety requirements regarding exposure of workers to the risks arising from the physical agents (vibration) (2002), European Parliament.

[12] Wikström, B.-O., Kjellberg, A., and Dallner, M.: Whole-body Vibration. A comparison of different methods for the evaluation of mechanical shocks, International Journal of Industrial Ergonomics 7 (1991), 41–52.

[13] Els, P.S.: The applicability of ride comfort standards to off-road vehicles, Journal of Terramechanics 42 (2005), 47–64.

[14] Jönsson, P.: Procedure for the Reduction of the Effect of Transient Whole Body Vibrations, Doctoral Thesis, Luleå University of Technology (2005).

[15] 11036124 Hitch Control System Description, Danfoss Power Solutions, August 2015.

[16] ISO 5008 Agricultural wheeled tractors and field machinery - Measurement of whole-body vibration of the operator (2002), International Organization for Standardization.

[17] Caffaro, F., Cremasco, M.M., Preti, C., and Cavallo, E.: Ergonomic analysis of the effects of a telehandler's active suspended cab on whole body vibration level and operator comfort, International Journal of Industrial Ergonomics 53 (2016), 19–26.

[18] Commission Delegated Regulation (EU) No 1322/2014 of 19 September 2014 supplementing and amending Regulation (EU) No 167/2013 of the European Parliament and of the Council with regard to vehicle construction and general requirements for the approval of agricultural and forestry vehicles (2014), European Parliament).

[19] EN 1032 Mechanical Vibration - Testing of mobile machinery in order to determine the vibration emission value (2003), European Committee for Standardization.

