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Research Paper

New methodology for accelerating the four-post testing of tractors using wheel hub displacements

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Durability tests of tractor prototypes need substantial financial and time commitments. The duration and cost of tests could be reduced using accelerated tests able to reproduce on the structural part of the tractor, the same damage produced on the tractor during its real life but over a reduced time period. It has been recently demonstrated how it is possible to speed up the tests using automotive proving grounds. However a complete prototype with all its components is necessary to perform tests on proving grounds, but to test only the structural durability is possible the use of a 4-post bench. A 4-post bench is able to reproduce a specific vehicle response, with the possibility of applying fatigue editing techniques to remove the non-damaging portions of the load signals. These techniques are usually applied to load signals measured with strain gauges during tests on proving grounds. However, strain gauge installations and data validation of the acquired signals are time-consuming. Here a new method, able to calculate the displacements on the wheel hub starting with acceleration measurements, applying fatigue editing techniques and defining drive files to command the actuators of a 4-post bench is described. The method proposed has an acceleration factor for the test of 5.3 together with a more rapid procedure to fit the transducers and to analyse the data obtained from the accelerometers compared to those obtained from the strain gauges.

1. Introduction

The tractor producers are increasingly trying to reduce the time-to-market whilst increasing product reliability (Hughes, Jones, & Burrows, 2005; Strutt & Hall, 2003). One of the more onerous activities in the approval process of new vehicles is durability approval. This activity consists in the application of a load sequence, able to reproduce a damage equivalent to that obtained during the real use by customers, to the whole vehicle or to a specific component (Oelmann, 2002).

In agricultural vehicles these tests can be performed on a bench, on tracks with bumps or by field tests. A bench is usually used for early stage prototypes, the tracks with bumps for advanced prototypes and the field test as final verification before the vehicle is released onto the market. The field tests are preferable due to the possibility of reproducing the real use of the machine, but recently the

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Nomenclature

a	acceleration
A	Fourier transform of the acceleration
d	displacement
$\mathcal{F}$	Fourier transform
$\mathcal{F}^{-1}$	inversion of the Fourier transform
FFT_{filt}	FFT (fast Fourier transform) filter
n_i	cycle number of the loading history
PD	pseudo-damage
RF	reduction factor
S_i	load amplitude
T	Tukey window function
T_m	duration of the measured signal
T_e	duration of the edited signal

producers have been reducing the amount of field testing because of difficulties in the control and reproducibility of the tests and to the strong dependence on weather and field conditions which do not easily fit in with development programming. Recently a method able to reproduce the real loads on tractors has been successfully defined using automotive proving grounds permitting tests to be accelerated by a factor of 3 (Mattetti, Molari, & Sedoni, 2012). To perform this test is necessary for a tractor prototype to be completed with all the components. However, to test the structural durability of the tractor it is useful to verify only the structural part of the tractor using a 4-post bench, without waiting for all the components. Four-post benches consist of 4 hydraulic actuators installed to reproduce a specific dynamic response on the vehicle. The drive files used to command the actuators are calculated from the signals reproduced from system identification techniques (Kelly, Kowalczyk, & Oral, 2002). Four-post benches have been used for many years in the automotive sector for different uses such as durability assessment and suspension tuning (Dodds, 1974; Kowalczyk, 2002; Londhe, Kangde, & Karthikeyan, 2012). In the agricultural sector 4-post benches have been used only to reproduce the vibrations transmitted to the driver (Anthonis, Vaes, Engelen, Ramon, & Swevers, 2007; Hostens, Anthonis, Kennes, & Ramon, 2000).

The advantages of using a 4-post bench with respect to the proving grounds are numerous; it can be used continuously in any weather condition, tests are repeatable and fatigue editing techniques can be used. Editing techniques have been used to modify strain gauge signals reproduced at the bench by removing portions of the signal not likely to cause damage (El-Ratal, Bennebach, Lin, & Plaskitt, 2002). Although there are three types of fatigue editing technique (Abdullah, 2009; Conle & Topper, 1979; Lubinski, Guynn, Simms, & Woerner, 2001), only editing in the time domain can be used for a 4-post test because it maintains the synchronicity of the different signals. Fatigue editing techniques are more frequently used on external loads applied to components to define a test valid not only for the vehicle under examination but also for similar vehicles. To perform the procedure the damage is calculate using a pseudo stress-life curve which differs with respect to the real curve for the material but has the same damage exponent (Ledesma, Jenaway, Wang, & Shih, 2005).

As the vertical wheel hub loads in a vehicle are proportional to the vertical displacements caused by the road surface (Awate, Panse, & Dodds, 2007) a method to directly derive the drive files using proving ground digitised profiles tailored for a specific vehicle has been developed (Scime, 2011). Although the procedure permits drive files to be defined without any measurement, it requires time consuming preparatory work to convert the roughness of the road surface into displacements of the wheel hub and it does not permit the use of fatigue editing techniques. It is therefore necessary to measure the vertical displacements of the wheel hub during drive tests on proving grounds. These displacements can be measured with specific laser sensor (Gillespie, Sayers, & Segel, 1980) or more simply calculated through a double integration of the vertical accelerations of the wheel hub measured by accelerometers. However, due to the small zero output acceleration bias in the accelerometer signals, the integrated signals have a drift (Han, 2010) which is usually deleted using a high pass filter (Halfpenny, Hussain, McDougall, & Pompetzki, 2010). The roll-off and the phase delay caused by the IIR (infinite impulse response) and FIR (finite impulse response) filters on the signal, distort the not damaging portions making fatigue editing impossible (El-Ratal et al., 2002).

The objective of this paper is the definition of a methodology to integrate the accelerations measured on the wheel hub by removing the signal drift and allowing the application of fatigue editing techniques on the signals to be used to calculate the drive files, allowing a 4-post bench test to be carried out.

2. Materials and methods

A four wheel drive tractor with 80 kW PTO (power take off) power and a mass of 3500 kg was used for the test. The tractor was instrumented with 4 monoaxial accelerometers (Measurment Specialities 4630 with full scale of ±50 g, Measurement Specialities Inc., Hampton, Va) and two half-bridge strain gauges (HBM K-216.61-2064, HBM, Marlboro, MA), calibrated to measure the axle forces. The measured channels are reported in Table 1 and the position of some transducers is shown in Fig. 1, the others not shown were in similar positions on the other semi-axles.

Table 1 – Measured channel list.

Channel	Measured channel
1	Axle left hand front (LHF) vertical load
2	Axle right hand front (RHF) vertical load
3	Axle left hand front (LHF) vertical acceleration
4	Axle right hand front (RHF) vertical acceleration
5	Axle left hand rear (LHR) vertical acceleration
6	Axle right hand rear (RHR) vertical acceleration