Tractor accelerated test on test rig

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Abstract

The experimental tests performed to validate a tractor prototype before its production, need a substantial financial and time commitment. The 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 real life in a reduced time. These tests were usually performed reproducing a particular harsh condition a defined number of times, as for example using a bumpy road on track to carry out the test in any weather condition. Using these procedures the loads applied on the tractor structure are different with respect to those obtained during the real use, with the risk to apply loads hard to find in reality. Recently it has been demonstrated how, using the methodologies designed for cars, it is possible to also expedite the structural tests for tractors. In particular, automotive proving grounds were recently successfully used with tractors to perform accelerated structural tests able to reproduce the real use of the machine with an acceleration factor higher than that obtained with the traditional methods. However, the acceleration factor obtained with a tractor on proving grounds is in any case reduced due to the reduced speed of the tractors with respect to cars. In this context, the goal of the paper is to show the development of a methodology to perform an accelerated structural test on a medium power tractor using a 4 post test rig. In particular, several proving ground testing conditions have been performed to measure the loads on the tractor. The loads obtained were then edited to remove the not damaging portion of signals, and finally the loads obtained were reproduced in a 4 post test rig. The methodology proposed could be a valid alternative to the use of a proving ground to reproduce accelerated structural tests on tractors.

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Key words: durability, accelerated test, tractor, 4-post rig.

Journal of Agricultural Engineering 2013; XLIV(s2):e76
doi:10.4081/jae.2013.s2.e76

Introduction

Recently the competitiveness between different tractor manufacturers has increased in particular with reference to the increasing of the reliability (Strutt and Hall, 2003) and to the reduction of the time-to-market similarly to the automotive trend (Hughes *et al.*, 2005). One of the development steps more involved in this tendency is the durability approval due to the high time-consumption (Oelmann, 2002). This development phase consists of an application of a load sequence, representative of the real use of the machine, to the whole vehicle or to a specific component (Garcia *et al.*, 2010). The load sequence reproduces in the structure a damage equivalent to that obtained by the farmer's use in the whole life of the tractor. A detailed measure of the real loads on a similar machine during the customer usage, a removal of the not damaging cycles (Lee *et al.*, 2005), and the reproduction of the load cycle obtained on a tractor prototype are therefore necessary.

The reproduction of the load cycle on a real field is difficult, not only due to the dependency on weather conditions, but also for the reduced occurrence of the applied loads and, as a consequence, a long time necessary to reproduce the entire cycle. To overcome these problems, particular tracks with defined bumps were designed, but despite a reduction of the test time they have not permitted an accurate reproduction of the load cycles (Mattetti *et al.*, 2012). In the recent years different studies have been performed to improve the feasibility of these tests (Thomas *et al.*, 1999; Renius, 1977; Kim et al, 2006; Kim *et al.*, 2006). One of these methods involved the use of proving grounds, special tracks with different types of pavements that are possible to meet during the real car driving (Ensor and Cook, 2007). The use of proving grounds permits a

reduction of the testing time due to a high occurrence of the stress and due to the high occurrence of higher damaging events with respect to the field. The use of the proving grounds have permitted to reproduce a load cycle of a medium power tractor with an acceleration factor of about three (Mattetti *et al.*, 2012). This acceleration factor is around three times, lower with respect to the usual one obtained for cars (Braccesi *et al.*, 2005), due to the lower speed of the tractor and the difficulties in the reproduction of the horizontal loads. Other problems related to the use of the proving grounds are the weather conditions and the necessity to change the drive after some hours. To further increase the acceleration factor of the tests a 4 post test rig could be used. This rig is provided by hydraulic cylinders, transducers and control systems used to replay the load cycle on the vehicle. The reproduction of the load cycle on the 4 post test rig could reduce the time of the proving ground tests due to the possibility to perform these tests in the lab without a driver on the tractor (Ledesma *et al.*, 2005). The goal of the paper is the definition of a methodology to reproduce the load cycles necessary for the durability approval also in a 4 post test rig with an acceleration factor higher with respect to that obtained with only proving grounds.

Table 1. Measured channels list

Channel	Measured channel	Hand
1	Lift arm load	Left
2	Lift arm load	Right
3	Top link load	-
4	Lower arm axial load	Left
5	Lower arm axial load	Right
6	Vertical front axle load	Left
7	Vertical front axle load	Right
8	Vertical front axle acceleration	Left
9	Vertical front axle acceleration	Right
10	Vertical rear axle acceleration	Left
11	Vertical rear axle acceleration	Right

Materials and methods

The methodology was applied to a 80 kW power tractor. In the tractor the transducers indicated on Table 1 were fitted to measure the load on the lift arm, on the top link, on the lower arm, on the vertical front axle; and the accelerations on the vertical front and rear axle.

The test schedule has been defined in Mattetti *et al.*, (2012) to reproduce the loading cycle derived from the signals obtained during tests on field. In particular the test schedule was composed of a combination of different proving grounds (PG) travelled a defined number of times and two field operations (FO), also repeated a defined number of times. The signals correspondent to the channels 1-7 reported on Table 1 were edited to reproduce a part of the test schedule on the 4 post test rig. The editing was obtained using the software nCode GlyphworksTM (). In particular the editing was realised splitting the signals into temporal windows in which the pseudo-damage was calculated according to:

$$PD = \sum_i n_i S_i^4$$

where:
S_i: load amplitude derived from rainflow matrix;
n_i: cycle number counted in a generic time history;
with S_i and n_i calculated using the rainflow algorithm (Downing and Socie, 1982; Rychlik, 1987).

The signals were edited removing the less damaging portions, and maintaining a damage higher than 95% of the total damage. The removal of some portions of the signal introduces unwanted spikes that modify the frequency content of the signal and could damage the rig. For this reason the not continuous windows were connected with half-sine joining functions. Once defined the windows of the force signals, the correspondent windows of the acceleration signals were composed to be reproduced in the 4 post test rig. From the acceleration the drives of the hydraulic cylinders of the 4 post test rig were obtained to reproduce the load cycle on the different channels (Kelly *et al.*, 2002).

Results

The signals of one test condition with the deleted parts highlighted are reported in Figure 1. The deleted parts of the signals are in preponderance in the starting and final parts of the signals.

The edited signals have a similar trend with respect to the measured ones with the only difference being the duration of the signal. In Figure 3 the power spectrum densities are compared, in particular the two trends are very similar due to the fact that the editing does not introduce anomalous peaks.

The tractor could be tested on the 4 post test rig for a reduced duration with respect to the different tests on proving grounds (PG) and on

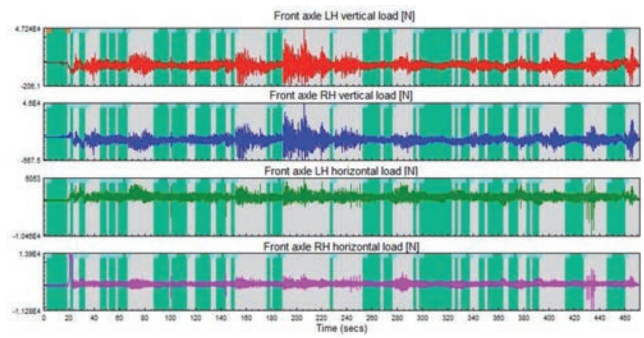
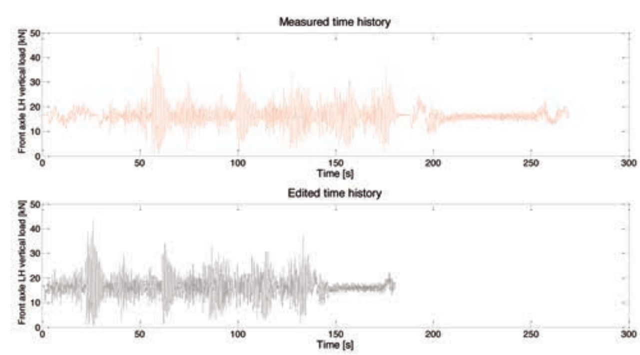


Figure 1. Editing of the signals: the green parts are the not damaging part of the signals.



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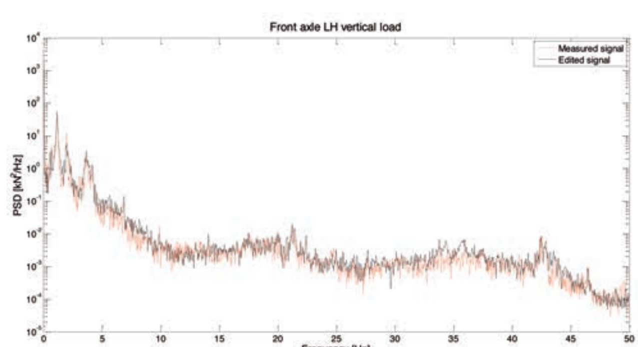

Figure 3. Comparison between the Power Spectrum Density of the measured signal and the edited one.

Table 2. Reduction factor for each test condition.

Testing condition	Duration of the tests without/with the combination with the test on 4 post test rig [s]	Reduction factor [%]
PG test condition 1	181	33
PG test condition 2	270	41
PG test condition 3	373	11
PG test condition 4	373	9
PG test condition 5	368	8
PG test condition 6	**370**	**15**
FO test condition 1	42	69
FO test condition 2	49	78

field (FO). The reduction factor for each test condition with respect to the time necessary on PG and on FO are reported on Table 2.

Testing condition Duration of the tests without/with the combination with the test on 4 post test rig [s] Reduction factor [%] PG test condition 1 181 33 PG test condition 2 270 41 PG test condition 3 373 11 PG test condition 4 373 9 PG test condition 5 368 8 PG test condition 6 370 15 FO test condition 1 42 69 FO test condition 2 49 78

The two field operations are the activities with the highest reduction coefficients due the higher portion of not damaging signals. But the two field operations are the activities with the higher influence on the total time of the test. The using of the 4 post test rig permits a reduction of the total time of the test into only 500 hours instead of the 1100 hours obtained by Mattetti *et al.* (2012) with the use of PG and FO only.

Furthermore the test on the 4 post test rig can be performed without interruption due to the change of the driver or unfavourable weather conditions as for the proving ground and field work tests.

Conclusions

In the paper a methodology to perform accelerated structural tests on a tractor has been presented. In particular, starting from a test schedule composed of a combination of proving grounds and field works, tests on a 4 post test rig have been performed to reduce the total time of the test. The use of the 4 post test rig permits a reduction of the total time of the test in only 500 hours instead of the 1100 hours obtained with the use only of proving grounds and field works. The total acceleration factor with the 4 post test rig was about 6.

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