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APPARATUS AND METHOD FOR EXPERIMENTAL RESEARCH ON THE DYNAMICS OF TRACTOR–FRONT LOADER SYSTEMS

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Summary. The paper presents a complex measurement installation developed for experimental research on the dynamics of tractor–front loader systems, in order to allow analysis of the dynamic behaviour of the system in various travel situations, on horizontal tracks or on slopes (transport, braking, acceleration), as well as analysis of the actual working process of the loader (bucket penetration into the manipulated material, lifting of the filled bucket and discharging of the bucket). The developed installation allows for simultaneous measurement and recording of the values of 11 parameters, followed by the computer aided processing of the obtained data.

Key words: tractor-front loader dynamics; experimental research; measurement installation; data processing

INTRODUCTION

The constructive and operational improvement of tractors as mobile self-propelled agricultural means allowed the mounting or coupling of equipment, hence rendering tractors exploitable in agriculture as well as in other branches of economy (forestry, communal works, construction works, etc.). Consequently, tractors equipped with front loaders and adequate instruments are successfully used in loading and unloading of a wide range of products and materials.

Although the first front loaders have been developed over 60 years ago, to date only few studies have been recorded concerning the dynamic behaviour of the tractor–front loader system, as the principal interest of research has been focused mainly on the constructive and functional optimisation of these systems and the development of working elements for the manipulation of a widest possible variety of materials [Czybora 2003].

The development of calculations of the tractor carriage and its front axle under the influence of various types of agricultural equipment mounted on or coupled to it allows for the completion of varied theoretical [Popescu and Czybora 2001, 2004, Czybora 2003] and experimental research [Czybora 2003], based on the measurement, recording and processing of dynamic strain on the front axle of the tractor subjected to the influence of the front loader.

MATERIALS AND METHODS

As theoretical research studied the evolution of the dynamic and kinematic parameters of the systems in dependence on the bucket lifting height [Popescu, and Czybora 2001, Czybora 2003, Popescu and Czybora 2004], and experimental research was carried out by measuring the modification of parameters in time, a data processing algorithm was developed for determining parameter modification in dependence on the lifting height [Czybora 2003].

In order to carry out experimental research on the dynamics and kinematics of tractor-front loader systems (U-650 wheel tractor and the IF-65 front loader, both of Romanian make) the paper presents a modern measurement installation for measurement recording and processing of data collected by sensors, which allowed for the simultaneous measurement of 11 quantities: 3 forces (axle loads and driving/braking force on wheels), 4 hydraulic pressures (2 in the arm actuating cylinders and 2 in the bucket actuating cylinders), 2 motions (arm and bucket cylinder piston rod strokes) and 2 accelerations (horizontal acceleration of the tractor and vertical acceleration of the loader arm).

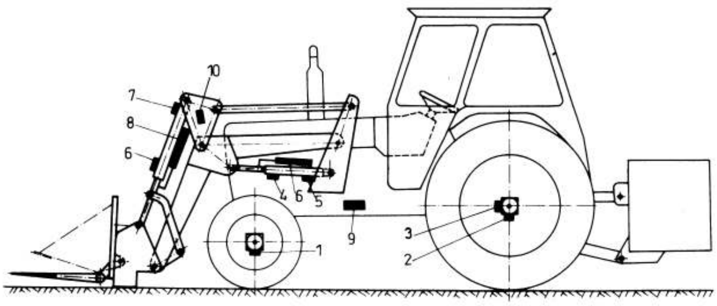

Fig. 1. Sensors mounting diagram on the tractor-front loader system

In order to achieve the above-mentioned objectives of experimental research, the following quantities were determined directly (Fig. 2): the normal (vertical) load on the front axle (with DMS-sensor 1); the normal (vertical) load on the rear axle (with DMS-sensor 2); the driving or braking force on the tractor rear wheels (with DMS-sensor 3); the stroke of the loader arm lifting cylinder rod (with inductive displacement transducer 6); the stroke of the bucket overturning cylinder rod (with inductive displacement transducer 8); the forces in the arm lifting cylinder rod (with pressure transducers 4 and 5); the forces in the bucket overturning cylinder rod (with pressure transducers 6′ and 7); the horizontal acceleration of the tractor (with acceleration transducer 9); the vertical acceleration of the loader arm (with inductive acceleration transducer 10);

Some kinematic and dynamic parameters were determined indirectly: the lifting height of the bucket was determined based on the stroke of the arm hydraulic cylinder, and the bucket charge based on the pressure in the arm cylinder. For this the dependency equations of the parameters were deduced and introduced into the data processing programmes of the measurement installation.

The load on the front axle was determined with DMS-sensors [Hoffmann 1987]. The oscillating axle of the front axle 1 (Fig. 2) is subjected to bending by the force transmitted by the tractor body 2 to rod 3 of the front axle. The four DMS-sensors R_1, R_2, R_3 and R_4 were mounted in a complete bridge and connected to measurement instruments.

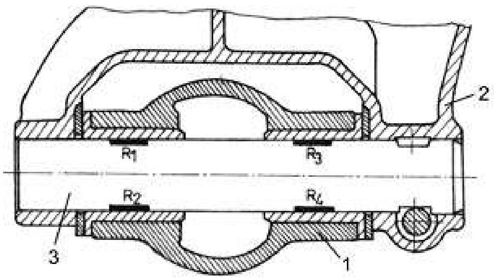

Fig. 2. DMS-sensors mounting diagram on the oscillating bolt of the front axle for the measurement of the vertical load on the tractor front axle

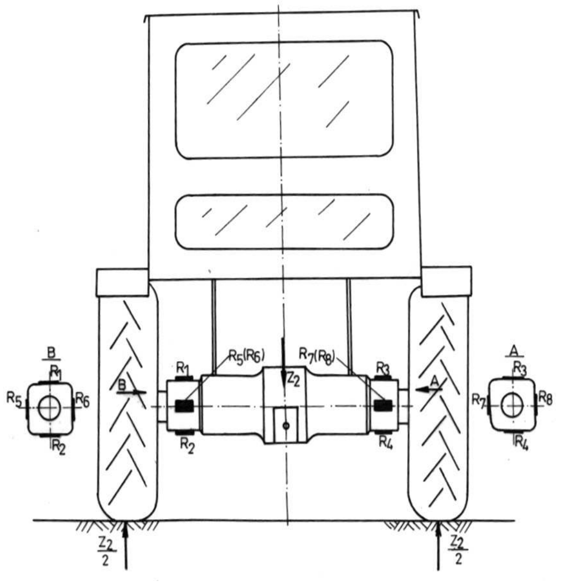

Fig 3. DMS-sensors mounting diagram on the rear axle casing for the measurement of the vertical load and of the driving/braking force

The load on the rear axle was determined with DMS-sensors [Hoffmann 1987]. For this purpose the DMS-sensors R_1, R_2, R_3 and R_4 were mounted on the rear axle casings (Fig. 3). The casing of the rear axle is subjected to bending by the normal forces $Z_2/2$, which act upon the axle from the wheel side. DMS-sensors R_1, R_2, R_3 and R_4 are mounted in complete bridge and connected to measurement instruments.

The tangential forces (driving or braking force) of the driving (rear) axle were determined with the horizontally mounted DMS-sensors R_5, R_6, R_7 and R_8 (Fig. 3). Under the action of the forces acting on the rear axle stemming from the wheel tangential forces, the axle casing is subjected to bending in the horizontal plane.

The pressure in the hydraulic cylinders was determined by the mounting of pressure transducers of P11/50-2000 type (manufactured by HBM – Darmstadt/Germany) on to both connecting pipes of the cylinders. This type of pressure transducers has an elastic membrane the deformation of which (proportional to the pressure) is measured with an inductive displacement transducer.

The stroke of the hydraulic cylinder rods was determined with W 100 type inductive displacement transducers, manufactured by HBM (Hottinger Baldwin Messtechnik)-Darmstadt.

The horizontal acceleration of the tractor and vertical acceleration of the loader arm were determined with inductive transducers with seismic masses of type B-12 (manufactured by HBM).

The dynamic and kinematic experimental data transmitted by the sensors and transducers were collected according to the measurement linkage of Figure 4. For this purpose a DAO 2400 system (manufactured by Microstar Laboratories USA) was used, available at the National Institute for Agricultural Machines (INMA) of Bucharest. This system has 16 analogical inputs, 16 digital outputs and a testing frequency of 120 kHz. A 3B 18/3820 ANALOG DEVICES type amplifier ensured an amplification of the quantities. The energy source was a lead plate battery and 12 V voltage. The data collection software allowed for the filtration of the signals obtained by the DMS-sensors and transducers, as well as determination of the minimum, maximum and mean values of the signals.

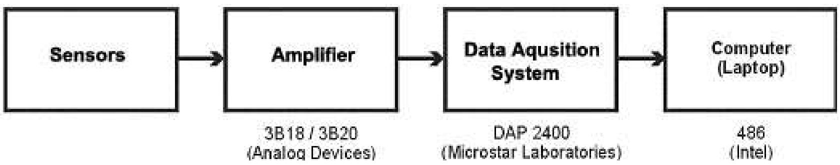

Fig. 4. Data collection and processing equipment diagram

The DAP system is installed on a 486 DX 4 LAPTOP containing the data collection software, using the specific DALP language. The data collection and processing equipment was grouped on a plate mounted on the left fender of the tractor (Fig. 5).

RESULTS A CONCLUSIONS

Following the processing of the collected data the time-related variations of the 10 measured dynamic and kinematic quantities were plotted for various working situations of the loader, corresponding to the testing programme [Czybora 2003].

The software of the computer allowed for a variation establishment of certain quantities in dependence on others, for the analysis of the dynamic behaviour of the loader in various working situations.

As indicated at the gauging of the sensors for the measurement of the axle forces, the origin of measurement for the static load of the U 650 wheel tractor was Z_{10}=12 100 N for the front and Z_{20}= 23 900 N for the rear axle.

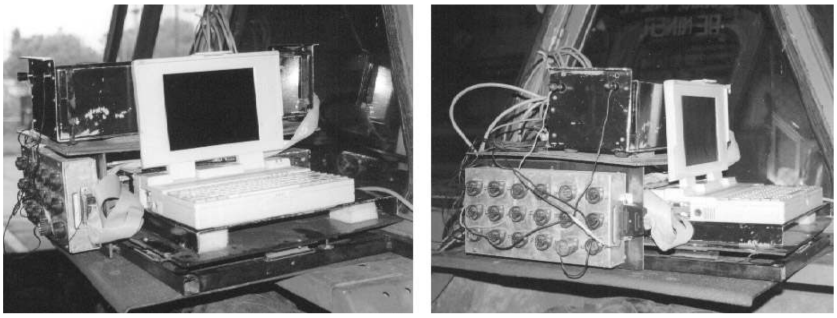

Fig 5. Experimental measurement data collection and recording apparatus mounted on the tractor fender

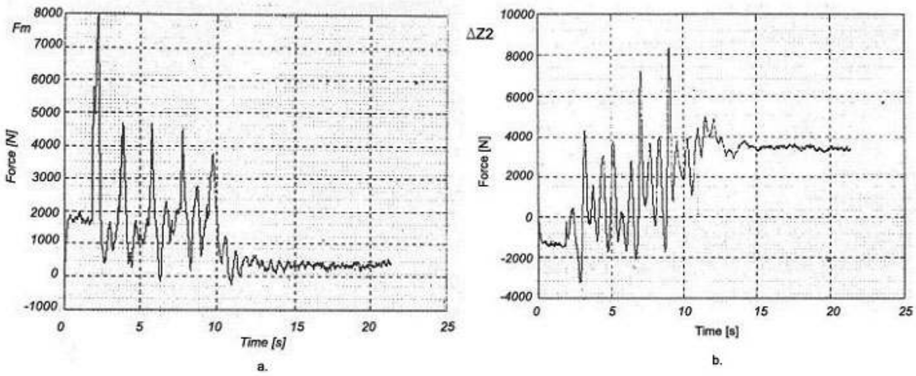

Fig. 6. Time related variation of the driving force F_m on the wheels (a) and of load ΔZ_2 on the rear axle (b) at starting from the spot of the tractor in the 3^{rd} gear, with the maximum bucket load (7000 N)

Research under dynamic circumstances (transport) was carried out in two situations:

– starting from the spot and acceleration of the system, with the bucket loaded with various charges and at various heights;
– braking of the system with maximum braking decceleration applied to various initial velocities, with the bucket loaded with various charges and at various heights.

For illustration Figure 6 shows the curves of the characteristic parameters at starting from the spot with maximum bucket load and at maximum rotation speed of the traction engine (n = 1950 rpm). It can be noticed that at the start of the system the driving force on the wheels F_m (Fig. 6a) oscillates with high frequency and reaches top values of F_m = 8000 N. Then steady values occur, required for overcoming the rolling resistances of the tractor.

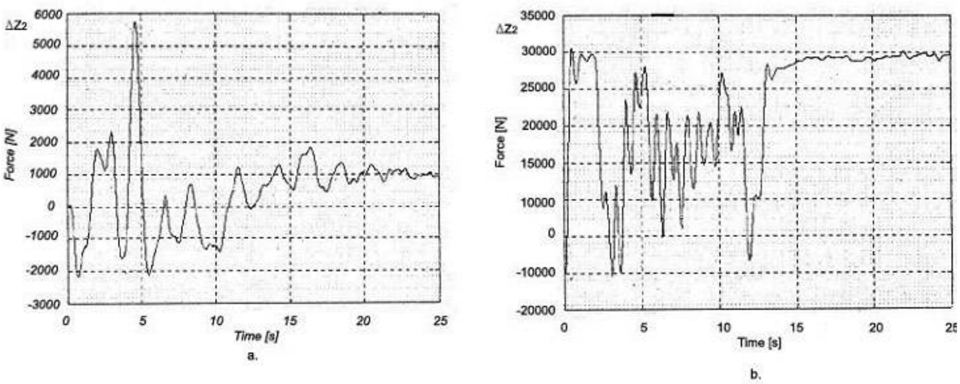

Fig. 7. Variation of load ΔZ_2 on the rear axle (a) and of ΔZ_1 on the front axle (b) at tractor braking in the 3rd gear, with the maximum charge of the bucket (7000 N) at height 400 mm

Corresponding to the non-steady starting process (by the coupling on the tractor) loads with high variations occur, which after about 13 sec become steady. High-frequency vibrations are caused also by the variations of the driving force, as well as by the longitudinal vibrations of the tractor body (induced by the elasticity of the tyres).

Figure 7 exemplifies the time-related variation of the load on the front (ΔZ_1) and rear axle (ΔZ_2), corresponding to maximum braking in the 3rd gear (about 8 km/h) with maximum bucket load (7000 N) at a height of 400 mm.

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