

Design, Development and Evaluation of a Digital Tractor Dynamometer

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Abstract: In this study, to measure drawbar pull of agricultural tractors, a digital dynamometer was designed, developed and evaluated based on AT89C52 microcontroller. The microcontroller was programmed using assembly language. The inputs of microcontroller supplied from a kind of S shape electronic loadcell that has 4 resistant strain gauges with Wheatstone Bridge configuration. The amplifier AD524 and an analogue to digital converter ADC0804 were used in electronic parts of the set. During dynamometer calibration the correlation coefficient (R^2) between force and output voltage was 0.99. Ultimately, the laboratory tests and evaluation were performed and the correct performance of set was proved.

Key words: Drawbar pull, loadcell, microcontroller, tractor

INTRODUCTION

Farm Machinery Testing and Evaluating Centers must be equipped to precise tools to measure and evaluate performance parameters so that by accurate data, they can provide a realistic analysis from a special machine function. Due to more accuracy, also convenient utilization of digital measuring systems in comparison to mechanical systems, use of this type of systems to outfit tractors and measure the technical parameters is growing. Study and research works related to tractors traction assessment need accurate strain force measurement. Precise measurement of strain force is impressive in the calculation of functional parameters of drawbar power, such as specific fuel consumption and drawbar tractive efficiency. For accurate measurement of drawbar power, researchers have used different methods.

Safari *et al.* (1999) designed and developed a kind of hydraulic drawbar dynamometer with the capacity 20 kN that its components included: the main cylinder, the secondary cylinder, pressure gauge, needle valve, connector hose, electronic pressure sensor and booster system. The dynamometer was calibrated using a standard strain-testing machine with the capacity of 600 kN. Their results showed that in all replication the coefficient of correlation, R^2 , for the relationship between electronic pulses read from display screen and strain force was equal to 0.99. During the test, the measurement accuracy was 1%. A drawbar dynamometer was also designed and built by Zarif Neshat and Ranjbar (2004). The dynamometer

was able to measure drawbar power of most agricultural implements in category I and II. The dynamometer was formed from both mechanical and electronic parts and able to measure pull and pressure load entered to tractors and agricultural implements. Mechanical part included the main body of loadcell, sub-components of the main body, reactionary segment, ball bearings and other appurtenances, and electronic part included loadcell, the Wheatstone Bridge circuit, data collection mechanism and the mechanism of the data analysis. Designed device was evaluated after laboratory calibration. Test and evaluation results showed that in all replication between the applied force to the dynamometer and output voltage existed a linear relationship with coefficient of correlation $R^2 = 0.99$. In another study, Turner (1993) made a typical hydraulic forcemeter that only able to measure draft of single hitch point implements. This force transducer was not affected by lateral force or moment and support overload up to 40%. Kheiralla and Yahya (2001) used a draft transducer in which Proof Rings were used as a strain sensor to measure drawbar power. Sensitivity of tractor draft transducer was about 13.6 mV per kN and maximum strain load in the set measuring range was 50 kN. Khan *et al.* (2006) developed a digital dynamometer to measure tractor draft. They exerted sensitivity, linearity hysteresis and repeatability tests on the designed device. The dynamometer was able to measure vertical and horizontal tension forces up to 10 and 20 kN, respectively. In another related study, Khan *et al.* (2007) designed a loadcell with an octagonal structure to test the

performance of tractors in the category II and III. The device was able to measure up to 80 kN horizontal forces and 60 kN vertical forces. Results of calibration tests and measurements performed by these researchers were satisfactory. The aim of present study was to design a digital tractor dynamometer using simple and prevalent Integrated Circuits (IC) for use in laboratory experiments.

MATERIALS AND METHODS

After designing a prototype electronic circuit map using ORCAD 9 software for development of a final reliable tractor dynamometer for measurement of agricultural machinery drawbar during November 2007-October 2008 in agricultural machinery laboratory of Shahid Chamran University of Ahvaz, Iran, several sets of trial and error efforts were cared on the different electrical circuits. Because of high accuracy of electronic loadcells, in this study, to measure the draft, a typical electronic loadcell was used as sensor component. The selected loadcell is mad in South Korean with the marketing brand of Bongshin, which has nominal capacity of 5000 kg-N. The device is shown in Fig. 1 and 2. Specification of the loadcell is given in Table 1 extracted from set manual. Secure overload and maximum overload capacity of the set is 150 and 300% of its nominal capacity respectively. Performance of the device is based on the resistance strain gauges connected to each other in the form of Wheatstone Bridge. Changes in resistance value as consequent of strain load emerge as changes in the output voltage. To design digital dynamometer, microcontroller AT89C52 also IC ADC0804 and AD524 were used.

Amplifier AD524: The main segment of amplifier part is a 16 pins IC with dual supply voltage that has 3 pins with the output gains of 10, 100 and 1000 as well as a common pin with adjustable gain. In all use conditions, the output signal is extracted from pin 9 and 10. AD524 is a precise amplifier and is best suited where high accuracy and low tolerance are needed.

Analog to digital converter ADC0804: This converter is a CMOS 8-bit integrated-circuit in a 20 pins package with power supply 5-volt. ADC0804 is used with ctenoid resistors. ADC0804 analog to digital converter has an output port that can connect to the data buses. The IC is most used in mechanisms based on microprocessors.

Calculations and equations: Equation (1) was used for calculation and final test of dynamometer sensitivity. The equation shows the relationship between changes in output voltage and changes in applied force (Sabzposhan, 2007).



Fig. 1: A view of bongshin loadcell

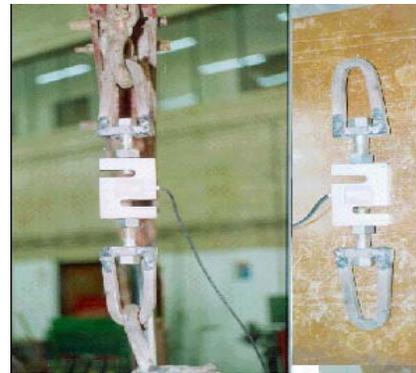


Fig. 2: Loadcell and grabs under load

Table 1: Specification of bongshin loadcell

Parameter	Specification	Unit
Nominal capacity	5000	Kg-N
Nominal output	2.9992	mV/V
Input impedance	350.5	Ohm
Output impedance	351.6	Ohm
Power supply	10 (DC)	V
Maximum power supply	15 (DC)	V
Load type	Pull and pressure	-
Secure overload	150	%
Maximum overload	300	%

$$S = \frac{\Delta V_{out}}{\Delta F} \quad (1)$$

where, S is sensitivity of the device, ΔF is force changes and ΔV_{out} is tensiometer output voltage changes.

Gain of the amplifier circuit (G) was calculated from Eq. (2):

$$G = \frac{V_{Out}}{V_{In}} \quad (2)$$

where, V_{out} and V_{in} is output voltage from and input voltage to circuit.

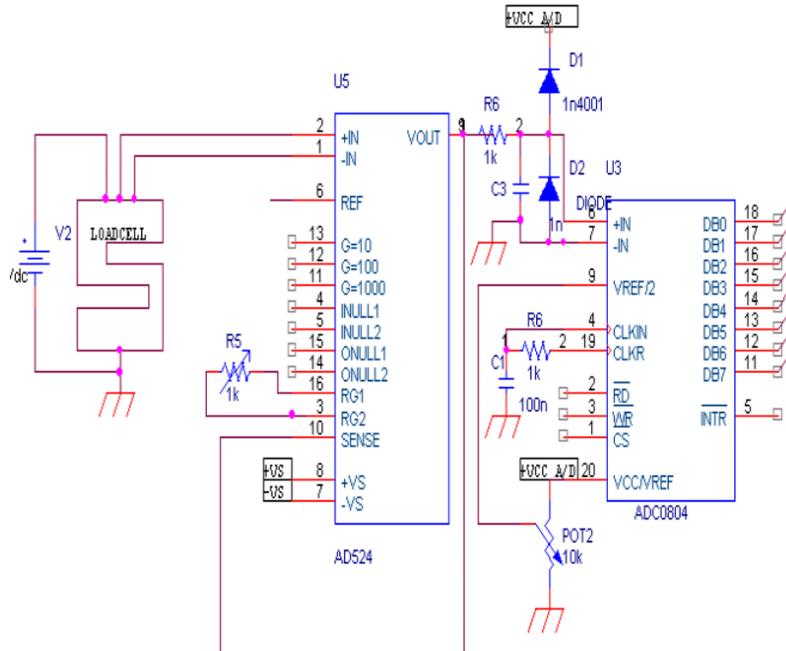


Fig. 3: Technical and electrical circuit map of the set

RESULTS AND DISCUSSION

Final technical and electronic circuit map designed by the ORCAD 9 software is shown in Fig. 3. As mentioned in the earlier, eventually, the set in addition to electronic loadcell was designed based on the four major electronic components, including: amplifiers, analog to digital converter, microcontroller and display unit. Results for the selected IC were satisfactory. After several steps of reform exerted in the program written for IC AT89C52, the program satisfied research needs.

To test linearity of dynamometer responds, using a crane machine and rams, different strain loads was exerted to dynamometer. After each tests, the output voltage of the instrument was measured by a laboratory voltmeter. Data was prepared in a graph produced in Fig. 4. Data obtained from the experiment was analyzed using computer software and then best-fit line was produced. The results proved a high degree of linearity between output voltage and force applied with coefficient of correlation $R^2 = 0.99$. The relationship between output voltage and measured force obtained as equation: $Y = 0.0006X + 0.0219$.

Set calibration: According to Eq. (1), after each calibration test, sensitivity of the device was calculated. Combined loadcell and amplifier sensitivity was obtained 0.693 kg per mV with tolerable approximation that proved proper function of device. Considering that force gauge

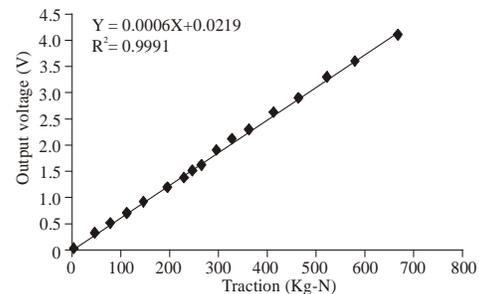


Fig. 4: Dynamometer response

calibration test was done in gain 100 that calculated according to Eq. (2), dynamometer sensitivity was obtained equal to 6.9. In the loadcell manual, nominal, secure overload and maximum overload capacity was expressed equal to 5,000, 7,500 and 15,000 kg-N, respectively. In this study to calculate the maximum working range of devices, loadcell secure overload was used. According to it, the maximum output voltage was calculated equal to 0.05519 volt. Since the maximum input voltage to analog to digital converter is equal to 5 volt, amplifier gain was calculated and regulated equal to 96. As mentioned, the analog to digital converter (ADC0804) is an 8-bit IC and this means that only able to display 256 modes. Thus, each of the 256 modes is representative of 19.5 mV. In other words, for 19.5 mV change in output of dynamometer, display unit output

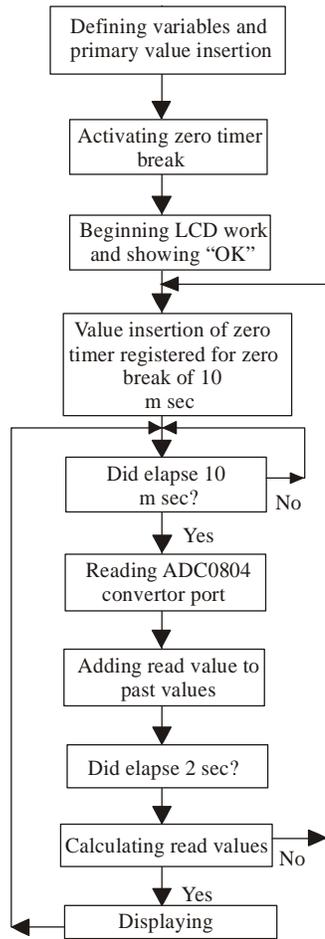


Fig. 5: Program flowchart of digital dynamometer

increases 1 unit. Finally, the device was calibrated so that each unit displayed on display screen represented $7500/25 \approx 29$ kg-N. Burned program in microcontroller 8052 record a sample of strain force each 10 m.sec. Display unit figure change every 2 sec. Therefore, each figure represents the average of the 200 sample. The final program algorithm of the set is given in Fig. 5.

CONCLUSION

The final test results showed that despite simplicity of circuit design and performance as well as low cost of the set, devices had satisfactory final function, accuracy

and linearity. Use of several simple circuits causes to measurement set has a small bulk so that total electronic parts can be put in a small box for use of operator. Another strong point of the device is utilization of a loadcell based on the resistance strain gauges that provides very high accuracy. Also wide working range of devices provides ability of force measurement for variety of implements and tractors.

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