International Journal of Mechanical and Materials Engineering (IJMME), Vol. 2 (2007), No. 2,189--199.

EFFECTIVENESS OF THE DEVELOPED INSTRUMENTATION SYSTEM ON THE VEHICLE TRACTIVE PERFORMANCE MEASUREMENT

Ataur Rahman, A.K.M Mohiuddin and Altab Hossain
Department of Mechanical Engineering, Faculty of Engineering,
International Islamic University Malaysia,
53100 Kuala Lumpur, Malaysia.
E-mail: arat@iiu.edu.my

ABSTRACT

The effectiveness of the developed automation system on the vehicle was verified with the validated mathematical model. The vehicle's tractive efforts recorded with the installed *developed automation system* in the range of 40 to 64 % of the vehicle gross weight and 47 to 67% of the vehicle dry weight, represent the high effectiveness of the torque transducer. Furthermore, the recorded vehicle's maximum tractive effort at the slippages in the range of 6 to 12% also represents the higher effectiveness of the developed speed transducer. Integrated developed automation system is considered precise and effective from the recorded tractive effort of 62% of the 6 wheeler drive vehicle's gross weight at 15% slippage.

Keywords: Automation system, Torque transducer, Motion resistance Transducers, Speed transducer, Sinkage transducer, Vehicle performance.

INTRODUCTION

The instrumentation system was developed with design and development of the shafts for the torque and motion resistance transducer. Later on both the shafts were turned to the respective transducer with bonding the strain gauge, and slip ring. Furthermore, the speed transducers for the instrumentation system were made with employing the proximity switch, digital panel meter, and radar sensor. The full description of the developed automation system is provided in the next section. The potential benefits of the developed automation system on the vehicles are extensive especially with regard to better utilization of unprepared low bearing capacity peat terrain for vehicle operation and safety. The purposes of the developed automation system on the vehicle are to control and measure the vehicle tractive performance. The vehicle designed optimization on the low bearing capacity peat terrain based on the investigation of vehicle field tractive performance. The major objective of this study is to justify the effectiveness of employing the automation system on the vehicle with the investigation of the vehicle tractive performance in terms of tractive effort and slippage.

DESCRIPTION OF THE AUTOMATION SYSTEM

The developed automation system was installed on the newly designed vehicle as shown in Figure 1. A rugged and portable industrial computer with built-in 16 Dewe-Module Dewetron's Dewe-2010 PC was used as the central data acquisition system of the measurement apparatus. The DAISY Lab 5.6 software was included in the DEWE-2010 PC data acquisition system to control the data acquisition and provide facilities for monitoring, processing, and storing of both the measured performance parameters by developing a program as shown in Figure 2. The virtual functioning buttons consist of a START/STOP button to initialize or to stop the program, a RECORD/PAUSE button to start to record the displayed data or pause the data recording, and a RESET button to return the initials value of sprocket torque, actual and theoretical speeds of the vehicle to zero. The total data recorded, input file name and current date and time are also displayed. During normal operating conditions, the data collection begins with triggering the virtual STARTbutton and ended with triggering virtual STOP button. Once the program is executed, an input dialog box is prompt to acquire the user on the field

Figure 1: Instrumentation system on the developed vehicle.

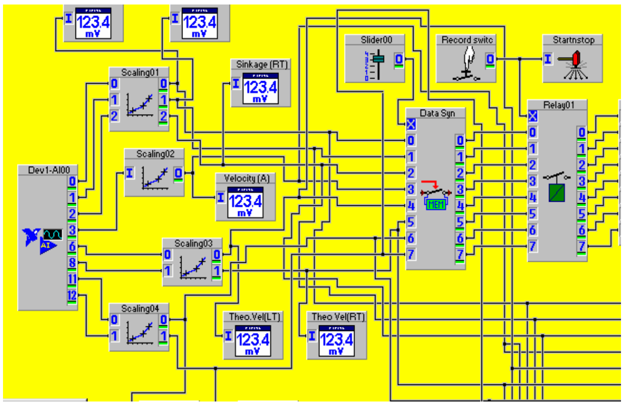


Figure 2. Programming by DasyLab® into the DEWETRON-2010.

operation information, which relates to terrain name, operation name, and experiment number. The key enter is triggered to accept the input on the earlier specified field operation information and to start the data monitoring task at the same time. All acquired information is displayed on the DEWE-2010 PC data acquisition system screen by developing Touch-Screen-Visual-Control-Interface (TSVCI). The main purpose of the developing TSVCI is to make more convenient for the vehicle operator to operate the employed automation system during field testing. Furthermore, it is easier for troubleshooting the default transducer or sensor with viewing the TSVCI at a glance. The virtual RECORD button is used for recording the experimental data. A new file was created every time with triggering the virtual START button and the file was closed with triggering the STOP button. All data were recorded into same file in ASCII format.

Torque Transducer

Figure 3 shows the main drive shaft for torque transducer was designed and developed with considering all the mechanical design aspects. The main drive shaft was turned to torque transducer by bonding KFG-5-120-D16-11-L1M-2S Kyowa, 90 degree rosettes, 120 Ohm, 2.1 gauge factor into the notch of the *designed and developed* driving shafts and mounting a Michigan S4 slip ring at the end of the shaft. The main purpose of the bonding strain gauge into the notch on the shaft at the location between sprocket and radial piston hydraulic motor was in order to measure the strain of the actual shaft. It was installed on the tested vehicle to measure the torque T of the vehicle. The recorded torque was directly converted to the tractive effort F of the vehicle by using the mathematical equation in the program:

$$F = T\left(\frac{2}{D}\right)\left(10^{-3}\right) \qquad (1)$$

In equation (1), F is the tractive effort of the vehicle in kN, T the measured torque of the developed torque transducer in N-m and D the diameter of the driving sprocket of the tested vehicle in m.

The strain of the shaft was turned into voltage with developing Wheatstone-Bridge Circuit. Figure 4 shows the employed wiring configuration of the Wheatstone bridge with the 9 pin D-sub male connector. The purpose of the mounting of S4 Michigan Scientific slip ring was to each end of the rear drive shafts to provide the strain gages cable transmission continuity from the rotating drive shaft. The strain gauge circuitry from each side of the drive shaft was wired in series to a common DEWE-2010 Data Acquisition System. Transducer was designed for a torque range of 0 to 2136 N-m and a sensitivity of 0.00021 mV(kN^{-1})(V^{-1})

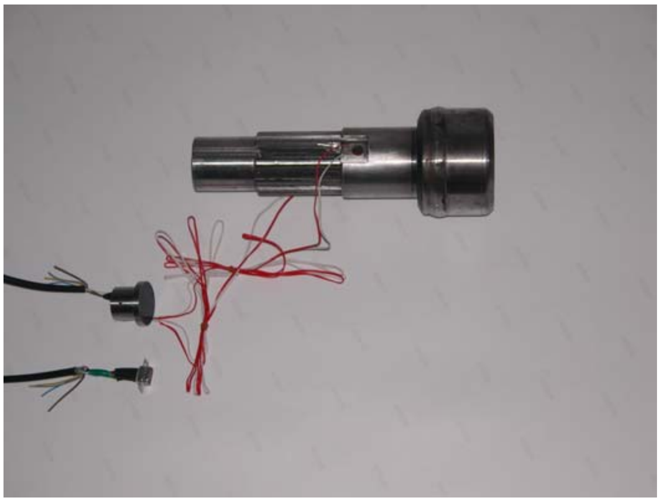


Figure 3: Developed torque transducer

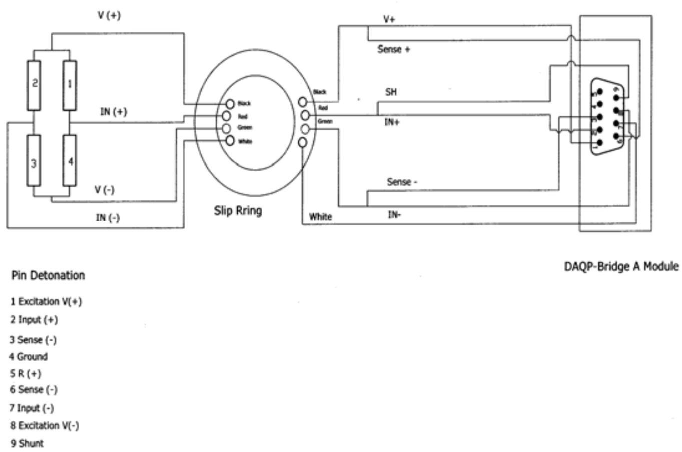


Figure 4: Torque transducer electrical wiring system

The circuit sensitivity can be measured by using the following equation of James and William (1978):

$$S_c = \frac{\Delta E}{\ell} = \frac{V}{\ell}\frac{r}{(1+r)^2}\left(n\frac{\Delta R}{R}\right) \quad (2)$$

where, $\frac{\Delta R}{R} = S_a\ell_a + S_t\ell_t + S_s\gamma_s$

In Equation (2), n is the number of active arms employed, $S_t\ (= S_g)$ the gauge factor, V the output circuit voltage in mV, r $\left(i.e, r = \frac{R_2}{R_1}\right)$ the resistance ratio for the circuit.

The plotted calibration reading for both of the torque for both sprocket torque transducers were highly correlated. The linearity equation for the right track transducer was found as follows:

$$V_R = (2\times10^{-3})(T) \quad \text{and} \quad R^2 = 0.98 \quad (3)$$

In Equation (3), V_R is the output voltage of right track torque transducers Wheatstone circuit in mV and T the vehicle's torque in Nm. In the same way the calibration equation was found for the left track transducer as follows:

$$V_L = (2\times10^{-3})(T) \quad \text{and} \quad R^2 = 0.99 \quad (4)$$

In Equation (4). V_L is the output voltage of right and left track torque transducers Wheatstone circuit in mV and T the vehicle's torque in Nm. The obtained calibration equation was later programmed into the DEWE-2010 Data Acquisition System to give direct readout of the vehicle torque of the sprocket in Nm.

The relationship between the applied load and the measured load based on the output reading of the torque transducer is expressed as follows:

$$T_m = (1.0003)(T_a) \quad \text{and} \quad R^2 = 0.99 \quad (5)$$

In Equation (5), T_m and T_a are the measured and applied torque, respectively. The transducer is rated to give measurement accuracy of 0.03% error. This factor was used for computing and documenting the measured output torque by the transducer. The torque transducer had been given more reliable measurement but sometimes the data appeared in negative which might be high voltage fluctuation on the circuit.

Velocity Transducer

The developed of velocity transducer was installed on the tested vehicle to measure the theoretical velocity and the actual velocity of the vehicle. The purpose of measuring the actual and theoretical velocity was to obtain the slippage under the track during dynamic motion. The slippage of the vehicle under the track during dynamic motion was calculated based on the following equation:

$$i = \left(1 - \frac{V_a}{V_t}\right)(100\%) \quad (6)$$

In Equation (6), *i* is the slippage in percentage, V_a the actual velocity in km/h, and V_t the theoretical velocity in km/h.

The velocity transducer of the vehicle is consisted with the RVSII velocity sensor and the Omron E2E-X5-ME1 proximity sensor. Velocity Radar sensor was used to measure the actual speed of the vehicle from their reflection. The unit consisted of transmitter/receiver assembly. It used the Doppler radar affect from a 24.125 GHz microwave emission to generate a frequency signal that is proportional to ground speed. This actual speed transducer is capable to measure the vehicle travel speed in the range of 0.53 to 107 km/hr. The velocity radar sensor was calibrated by clamping sensor bracket with the tractor. The sensor and its bracket were mounted with tractor at 682.6 mm height from the ground and $30^0 \pm 5^0$ angle with the ground surface. The DEWE-2010 Data Acquisition System was used with the radar sensor to measure the sensor's circuit output voltage readings.

For a constant travelling speed, the sensor output voltage readings were recorded by using the DEWE-2010. At the same time, the tractor's travelling time was recorded by using a stop watch for the actual travelling speed of the tractor. The procedure was repeated for getting the output voltage reading of the sensor from the DEWE-2010. The velocity radar sensor was connected with a 9 pin D-sub male connector. This connector was connected to a 9 pin D-sub female connector on the first DAQx-V analogue voltage input signal conditional module on the Dewe-2010 PC Instrument.

The plotted calibration reading of the radar sensor was highly correlated. The linearity equation is expressed as follows:

$$V_a = 3.57(V) \quad \text{and} \quad R^2 = 0.94 \quad (7)$$

In Equation (7), V_a is the actual velocity in km/h and V is the output measured voltage of the radar sensor in volt/volt. The relationship between actual velocity and measured velocity is best expressed by the following equation:

$$V_m = 0.9952 V_a \text{ with } R^2 = 0.9711 \quad (8)$$

In Equation (8), V_m is the measured output velocity in km/hr and V_a the actual velocity in km/hr. The transducer is rated to give measurement accuracy of 0.48% error. This factor was used for computing and documenting the measured actual velocity by the transducer.

The radar sensor made it possible to obtain corresponding results, but problems existed at the beginning of tests, in particular, because the low velocity was closed to the radar's lower acquisition limit (Benoit et. Al., 2002).

Omron E2E-X5ME1 proximity sensor with an instrumented 25 teeth sprocket was used to measure the theoretical speed of the vehicle. The theoretical speed-sensing units are located at the end of the both rear sprocket driving shaft for measuring the vehicle theoretical speed. The sprocket is fixed to the end of the rear sprocket driving shaft while the proximity inductive sensor is mounted by a special made mounting bracket at the side of the each track frames and just top of the instrumented sprocket. The proximity inductive sensor delivers a pulse as the gear tooth of the rotating sprocket passes to its magnetic sensing element. The measured pulses are initially converted to give rear sprocket rotational speed and then the theoretical speed. Theoretical speed-sensing unit can generate an output signal of 0.556V per km/hr. All the computed data will be displayed in real-time on the touch screen panel of the 2010-Dewetron. The equation that was developed based on the selection of the frequency setting range for the E2E-X5ME1 proximity switch in the DEWETRON-2010, the number of revolutions of the driving sprocket and the pheriperical distance of the consecutive teeth of instrumented sprocket is expressed as follows:

$$V = 5.56(v) + 7.89 \tag{9}$$

In Equation (9), V is the velocity of the vehicle in km/hr and v the output voltage of the proximity switch. The low number of teeth on the crown of the sprocket caused a stepped curve, which presented problems during the calculation of slippage, in particular at the beginning. The same results also presented by Benoit *et. al.*, (2002).

Engine Speed Measuring Transducer

The engine speed measurement was conducted by using a speed transducer. The objective of the engine speed measurement was to fix the vehicle traveling speed. The speed transducer which comprised with a K3GN-NDC-FLK DC24 digital panel meter, an OMRON E2E-X1C1 proximity switch, and a 24DC volt battery pack. The proximity switch was used to sense the number of rotating pulse the engine flywheel per minute and the digital panel meter was used to record the rpm of the engine flywheel. The purpose of the using of speed meter transducer on the vehicle was for fixing up the engine speed in order to get the desired vehicle speed.

Motion Resistance Transducer

The R_0 motion resistance is the whole of the forces being opposed to the movement of a vehicle. The motion resistance of the vehicle is the sum of the internal resistances result from the friction forces specific to the running gear and the external resistances result from the interaction of the tracks and the environment, such as the slope of the soil or its state. Therefore, the equation of the motion resistance,

$$R_0 = R_i + R_e \tag{10}$$

The objective of the motion resistance tests was to measure R_0 then to determine R_i and R_e. The sum of resistance R_0 was the force necessary to draw the test vehicle. A second draws the tested vehicle in neutral at a constant speed using slings connected to a motion resistance transducer. The collected data by the data logger based on the motion resistance transducer were the values of R_0 force.

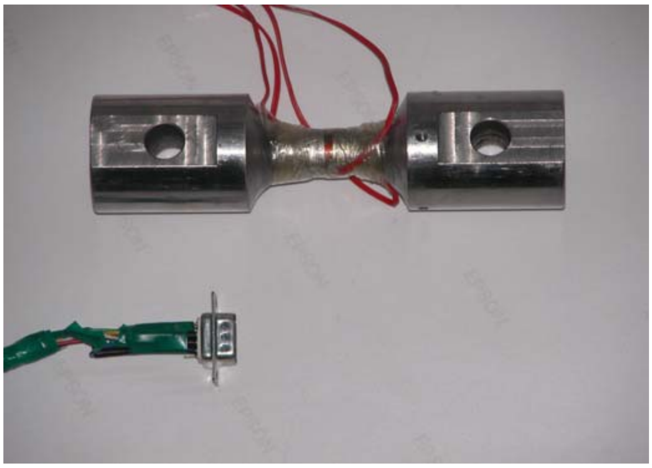


Figure 6: Developed motion resistance transducer.

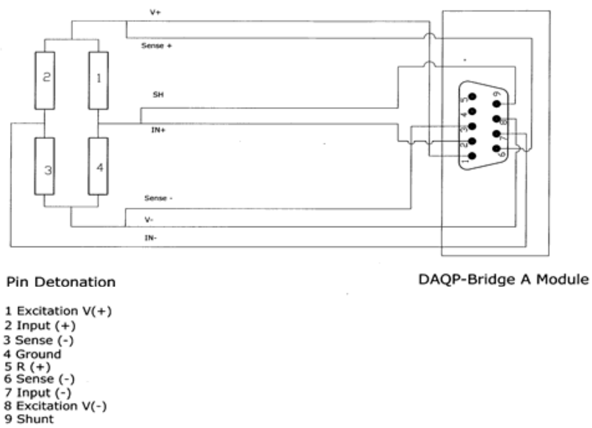


Figure 7: Electrical Circuit Layout

Figure 6 shows the shaft for motion resistance transducer was design and developed with considering all the mechanical design aspects. The shaft was turned into motion resistance transducer by bonding 4 pieces of Kyowa KFG5120C16-L1M2R stain gauges on the shaft. It was designed for a load range of 0 to 29.43 kN and a sensitivity of 0.0002 mV(kN^{-1})(V^{-1})]. Figure 7 shows the employed electrical wiring configuration of the motion resistance transducer with 9 pin D-sub male connector. The motion resistance was not conducted due to the anchoring problem of the auxiliary vehicle on the road side.

Sinkage Transducer

The sinkage is considered as the vertical displacement of the vehicle due to the load. The purpose of the sinkage measurement is to provide safety of the vehicle from sink as the peat soil is very much problematic soil. It is noted that the surface layer which is called the surface mat of the peat considered as the load supporting segment of the terrain. The thickness of the surface mat was found 12 to 17 cm from the earlier field sinkage testing by Ataur *et al.* (2004). So, if the vehicle sinkage is $z \geq 12\,cm$, the vehicle is assumed to sink. Therefore, the vehicle could protect from sink by measuring the sinkage by using sinkage transducer. The sinkage transducer was developed by mounting three pieces of *Ultrasonic sensor* model 401.426, ranged between 10.16 to 101.6cm on the rear frame of the vehicle. But, unfortunately, two of the sensors were damaged by hitting a root on the field. So, it was not possible to collect the data on vehicle sinkages.

VEHICLE FIELD TESTING

The vehicle was tested by using the employed automation system on three different fields: *Field Type* I (moisture content 59.85%), *Field Type* II (moisture content 68.79%), and *Field Type* III (moisture content 81.06%). The automation system was tested by executing the developing programmed with DASY Lab 5.6 into the DEWE-2010 on the field, and the speed was set to the K3GN-NDC-FLK DC24 digital panel meter for getting the expected traveling velocity of the vehicle. Then, a preliminary run on the field was performed for ensuring the expected function of the instrumentation system of the vehicle.

RESULTS AND DISCUSSIONS

The calibrated parameters for the instrumentation system in the statistical analysis were considered to be highly significant only if the probability level is less than 0.01 (i.e or $Pr < 0.01$) and significant only if the probability level is less than 0.05 (i.e or $Pr < 0.05$).

The vehicle tractive effort and slippage were investigated for two different loading conditions of 18 and 25 kN at two traveling speeds of 6 and 10 km/h. The obtained experimental data vehicle tractive performance was later used to validate the mathematical models.

Torque Transducer

The regression and the ANOVA on the sprocket torque transducers calibration data are summarized in Table 1 and 2. Table 1 shows that the regression model is highly significance at significant level of $P_r<0.01$. For the sprocket torque transducers, t-values 122.36 for the right track and 122.34 for the left track are higher than t^*_{61} (0.01) =2.607. This implies that the torque has significant effect on the output voltage. Based on the standard error estimated values of 0.0001 for the right track and 0.0001 for the left track and the R-square values of 0.993 for the right track and 0.994 for left track can be concluded that the applied torque and the measured output voltage are strongly correlated. Table 2 shows that the applied torque has significant ($P_r<0.01$) effect on the output voltage. Neither the mode nor the interaction between the mode and the applied torque has significant effects on the output voltage. The insignificant effect of the mode indicates that there is no significant hysteresis effect on the output voltage during ascending and descending of the torque on the torque transducer.

Figure 8 shows the *typical* graph of the 25 kN vehicle's tractive efforts that were recorded by the data logger with the execution of the torque transducer on the fields at speed of 6km/h and 10km/h, respectively.

For the vehicle weight of 18 kN

- The maximum tractive efforts were found 8.9 kN at speed of 6 km/h and 11.5 kN at speed of 10 km/h on *Field type* I. Therefore, the traction coefficients of the vehicle are 0.49 at speed of 6 km/h and 0.64 at speed of 10 km/h.
- The maximum tractive efforts were found 11.7 kN at speed of 6 km/h and 12.05 kN at speed of 10 km/h on *Field type* II. Therefore, the traction coefficients of the vehicle are 0.65 at speed of 6 km/h and 0.67 at speed of 10 km/h.
- The maximum tractive efforts were found 10.7 kN at speed of 6 km/h and 11.75 kN at speed of 10 km/h on *Field type* III. Therefore, the traction coefficients of the vehicle are 0.59 at speed of 6 km/h and 0.65 at speed of 10 km/h.

Table 1. Regression analysis for sprocket torque transducer

Source	df	SS		F value		P value		R-square	
		Left Track	Right Track	Left Track	Right Track	Left Track	Right Track	Left Track	Right Track
Model	1	0.233	0.235	14972.20	14972.00	0.0001**	0.0001**	0.993	0.994
Error	61	0.001	0.0012						
Total	62	0.234	0.233						
Parameter		Parameter Estimated		T for H_o Parameter =0		$P_r > \|T\|$		Standard Error Estimated	
Torque		0.0002	0.0002	122.36	122.34	0.0001**	0.0001**	0.0001	0.0001

** Highly significant at probability level 1%

Table 2 ANOVA on the torque of the sprocket

Source	df	Anova SS		F value		Pr >F	
		Left Track	Right Track	Left Track	Right Track	Left Track	Right Track
Torque	21	0.4521	0.443	147.76	146.97	0.001**	0.001**
Mode	1	0.0002	0.0002	2.39	2.38	0.1256	0.1321
Torque*Mode	19	0.0018	0.0017	1.31	1.31	0.2078	0.210
Error	84	0.0063	0.0061				
Total	125	0.458	0.447				

Mode: loading and unloading, ** Highly significant at probability level 1 %

For the vehicle weight of 25 kN

- The maximum tractive efforts were found 9.9 kN at speed of 6 km/h and 11.25 kN at speed of 10 km/h on *Field type* I. Therefore, the traction coefficients of the vehicle are 0.40 at speed of 6 km/h and 0.45 at speed of 10 km/h.
- The maximum tractive efforts were found 11.5 kN at speed of 6 km/h and 12.3 kN at speed of 10 km/h on *Field type* II. Therefore, the traction coefficients of the vehicle are 0.42 at speed of 6 km/h and 0.49 at speed of 10 km/h.
- The maximum tractive efforts were found 11.6 kN at speed of 6 km/h and 12.8 kN at speed of 10 km/h on *Field type* III. Therefore, the traction coefficients of the vehicle are 0.47 at speed of 6 km/h and 0.51 at speed of 10 km/h.

The variation of the tractive efforts of the vehicle on the different field was found for the different speed and the different loading conditions. The reason for the increase of tractive effort could be due to the higher rate of loading. For the peat with higher moisture content, the higher the rate of loading the greater the peat reaction will be. This is due to the hydrodynamic effect arising from the water movement within the peat (MacFarlane, 1969, and Wong et al., 1982).
The vehicle's tractive efforts with the installed *developed automation system* were found in the ranged of 40 to 64 % of the vehicle gross weight and 47 to 67% of the vehicle dry weight, indicate the best tractive performance of an off-road tracked vehicle on an unprepared peat terrain. Therefore, it could be concluded that the *developed torque transducer* was quite effective for the automation system.

Velocity Transducer

The regression on the actual velocity transducer calibration data is summarized in Table 3 . The regression results on the actual velocity showed that the regression model is highly significance at significant level of P_r<0.01. For the actual velocity transducer, t-value 27.398 higher than t^*_{17} (0.01) =2.576. Hence the null hypothesis has been rejected. This implies that the independent variable of vehicle traveling speed has significant effect on the dependent variable of output voltage. Based on the standard error estimated value of 0.0091 and the R-square values of 0.98 can be concluded that there were high relationships between the vehicle traveling speed and measured output voltage of the actual velocity transducers. Figure 9 shows the *typical* graph of the 25 kN vehicle *s*lippages that were recorded by the data logger with the execution of the velocity transducers on the fields at speed of 6km/h and 10km/h, respectively.

Table 3. Regression analysis for actual velocity transducer

Source	Df	SS	F -value	P-value	R-square
Model	1	31.87012	750.638	0.0001**	0.9779
Error	17	0.72178			
Total	18	32.59			
Parameter	Estimate	T for H0: Parameter=0	$P_r > \|T\|$		
V_a	0.2498	27.398	0.0001		

** Highly significant at probability level 1 %

For the vehicle weight of 18 kN

- The maximum slippages were found 12% at speed of 6 km/h and 11.05% at speed of 10 km/h on *Field type* I. Therefore, the vehicle slippage decreases 0.23% with increasing the vehicle traveling speed from 6 to 10 km/h.
- The maximum slippages were found 13.8% at speed of 6 km/h and 13% at speed of 10 km/h on *Field type* II. Therefore, the vehicle slippage decreases 0.20% with increasing the vehicle traveling speed from 6 to 10 km/h.
- The maximum slippages were found 15% at speed of 6 km/h and 13% at speed of 10 km/h on *Field type* III. Therefore, the vehicle slippage decreases 0.50% with increasing the vehicle traveling speed from 6 to 10 km/h.

For the vehicle weight of 25 kN

- The maximum slippages were found 15% at speed of 6 km/h and 13% at speed of 10 km/h on *Field type* I. Therefore, the vehicle slippage decreases 0.50% with increasing the vehicle traveling speed from 6 to 10 km/h.
- The maximum slippages were found 14% at speed of 6 km/h and 13.7% at speed of 10 km/h on *Field type* II. Therefore, the vehicle slippage decreases 0.075% with increasing the vehicle traveling speed from 6 to 10 km/h.
- The maximum slippages were found 15.2% at speed of 6 km/h and 13.9% at speed of 10 km/h on *Field type* III. Therefore, the vehicle slippage decreases 0.33% with increasing the vehicle traveling speed from 6 to 10 km/h.

The variations of the slippages of the vehicle were found is mainly for changing the vehicle traveling speed from 6 to 10 km/h as shown in Figure 10. But, vehicle loading conditions changing is significantly not affect on the vehicle slippage. This is due to the fact that the tearing off the terrain surface increased the shear displacement of the vehicle on the field is mainly for vehicle traveling speed which could increase the vehicle tractive effort and decrease the vehicle slippage of the vehicle (James et. al., 1978, Radforth, 1958 and Wong 2001).

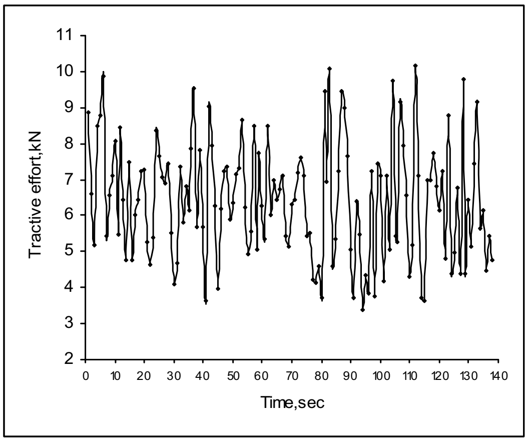
The conclusion could be further supported by the general formula of the tractive effort computation as given by Bekker (1969):

$$F = 2B \int_0^L \tau \, dx \quad (11)$$

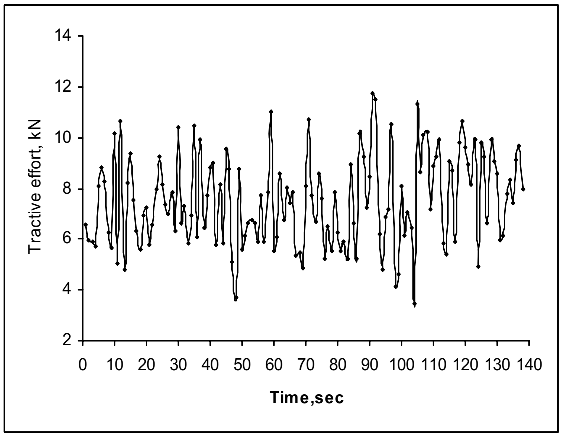
where, $\tau = \tau_{\max} \left(\frac{j_x}{K_w} \right) \exp\left(1 - \frac{j_x}{K_w} \right)$,

$\tau_{\max} = (c + \sigma \tan \varphi)$ and $j_x = ix$

In Equation (11), F is the tractive effort in kN, τ the shearing stress in kN/m^2, j_x the shear displacement in m, τ_{max} the maximum shear stress in kN/m^2, c the cohesiveness in kN/m^2, φ the internal friction angle in degree, i the slippage in percentage, and x the part of the vehicle ground contact length in m.

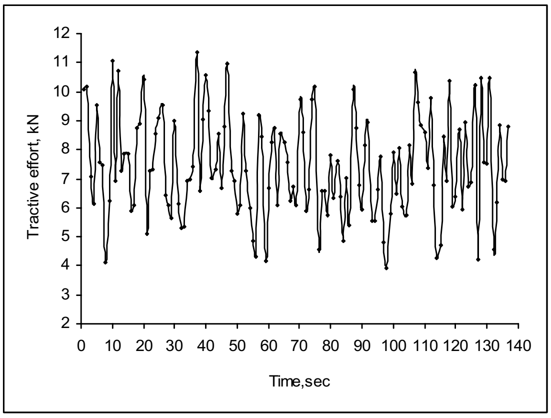


(a) Vehicle tractive effort at traveling of 6km/h

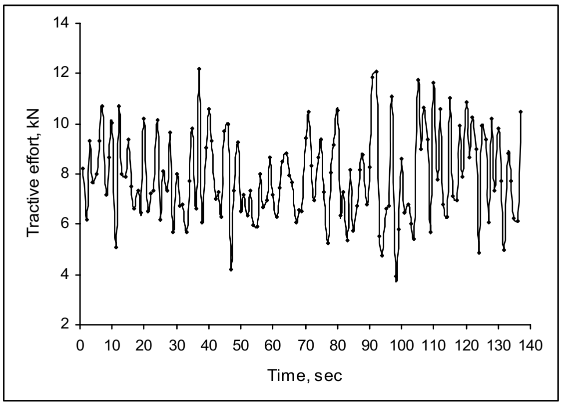


b) Vehicle tractive effort at traveling of 10km/h

(i) *Field Type* I

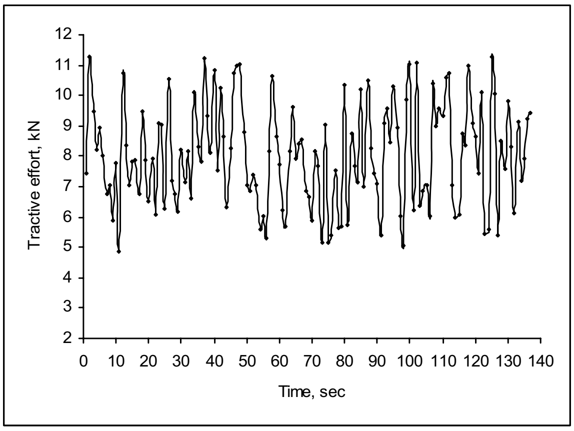


(a) Vehicle tractive effort at traveling of 6km/h

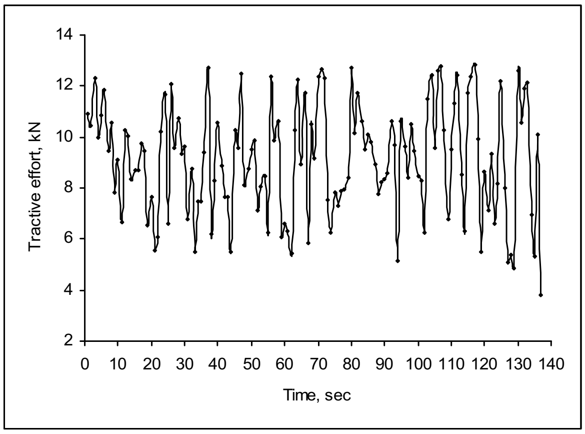


b) Vehicle tractive effort at traveling of 10km/h

(ii) *Field Type* II



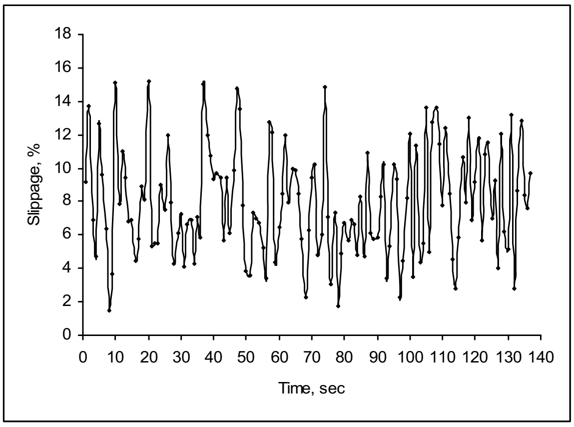
(a) Vehicle tractive effort at traveling of 6km/h



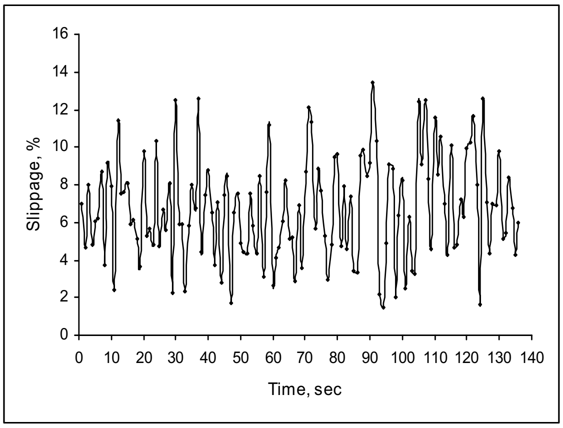
b) Vehicle tractive effort at traveling of 10km/h

(iii) *Field Type* III

Figure 8: *Typical* tractive effort of 25 kN vehicle for straight motion.

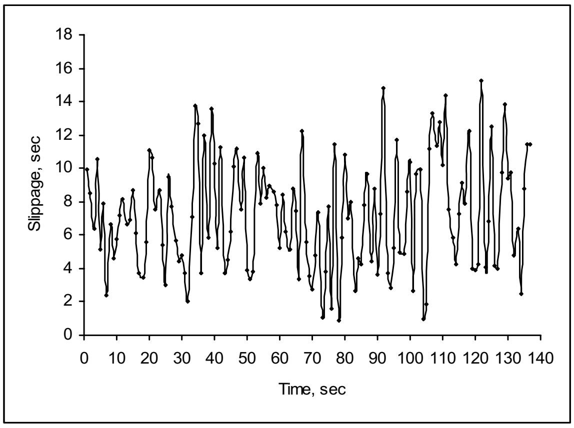


a) Vehicle slippage at traveling speed of 6 km/h

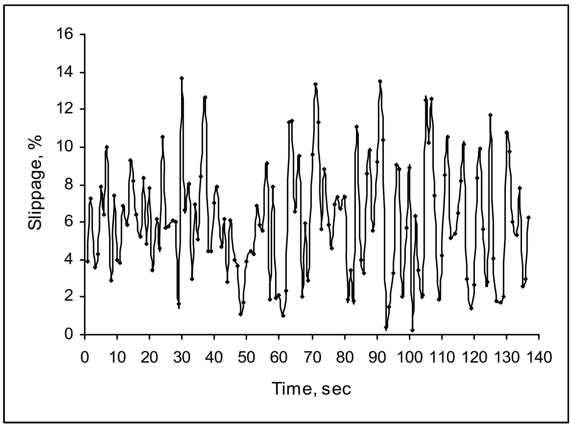


b) Vehicle slippage at traveling speed of 10 km/h

(i) *Field Type* I

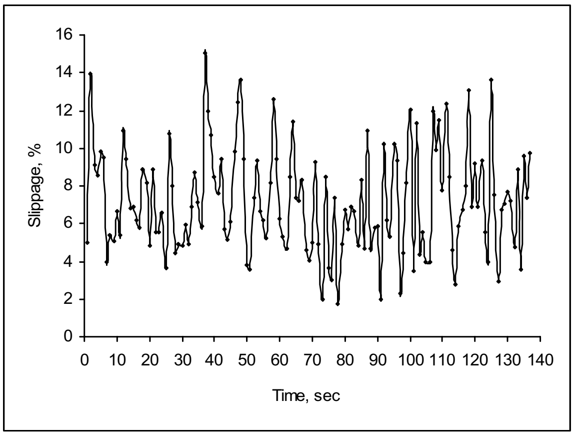


a) Vehicle slippage at traveling speed of 6 km/h

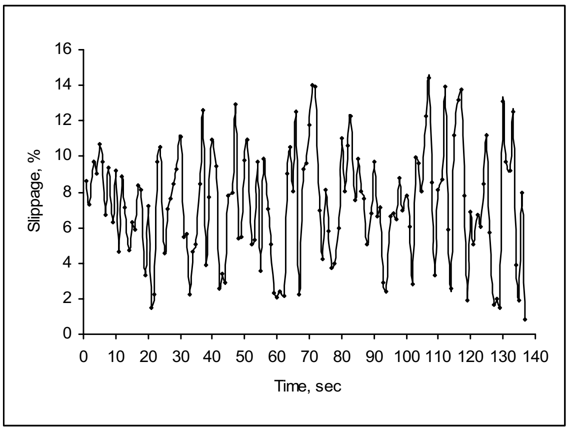


b) Vehicle slippage at traveling speed of 10 km/h

(ii) *Field Type* **II.**



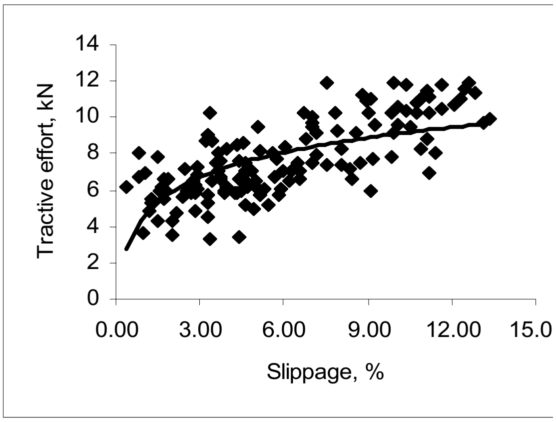
a) Vehicle slippage at traveling speed of 6 km/h



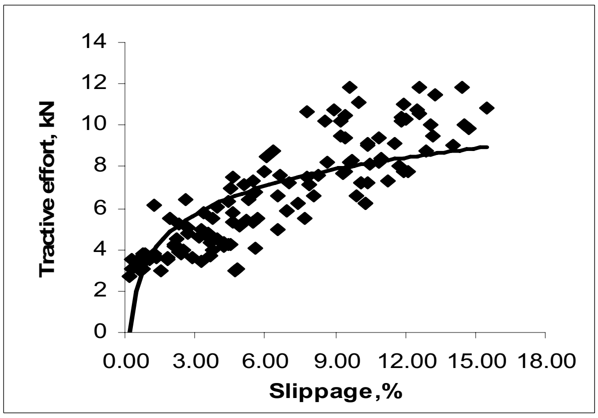
a) Vehicle slippage at traveling speed of 10 km/h

(iii) *Field Type* **III**

Figure 9 : *Typical* slippage for the vehicle of 25 kN during straight motion.

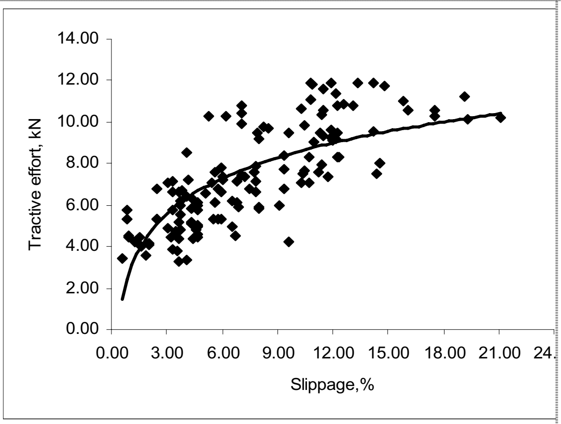


a) Vehicle slippage at traveling speed of 6 km/h

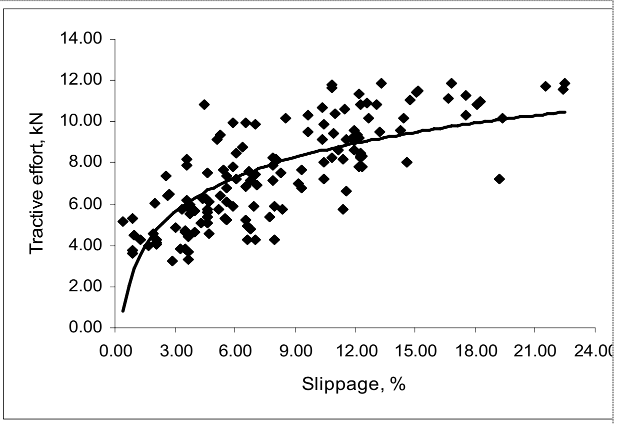


b) Vehicle slippage at traveling speed of 10 km/h

(i) *Field Type* I

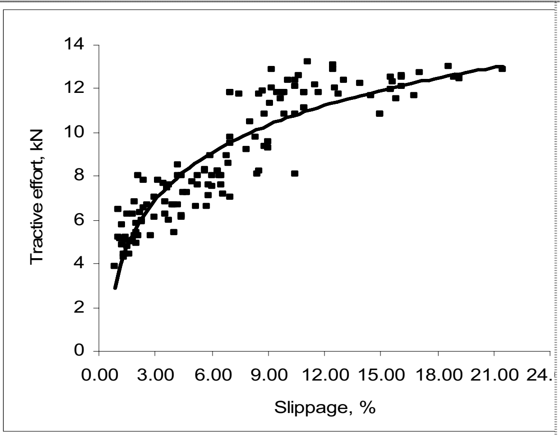


a) Vehicle slippage at traveling speed of 6 km/h

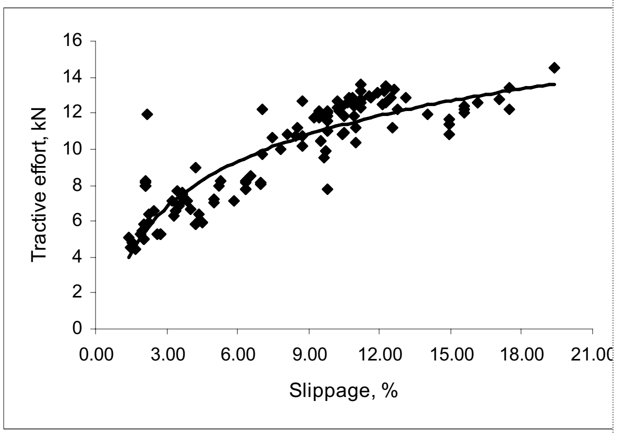


b) Vehicle slippage at traveling speed of 10 km/h

(ii) *Field Type* II



a) Vehicle slippage at traveling speed of 6 km/h



b) Vehicle slippage at traveling speed of 10 km/

(iii) *FieldType* III

Figure 10: *Typical* tractive effort vs slippage of 25 kN vehicle during straight motion.

CONCLUSIONS

The following conclusions could be drawn based on the discussion of this paper:

- Tractive effort of the vehicle was considered as the actual value as the recorded value was the average value of both of the tracks on the respective time and point.
- Recorded readings of the radar sensor were accounted as soon as speed of the vehicle was found at set value.
- Slippage of the vehicle were computed by taking the average theoretical velocity based on the recorded rpm of the proximity switches and the recorded reading of the radar sensor.
- Vehicle design could be considered as optimized based on the recorded tractive effort in the range of 40 to 64% of the vehicle gross weight.
- Maximum tractive effort of the vehicle was recoded at the maximum slippage in the range of 6 to 12%.
- Integrated developed automation system could be considered as precise and effective with considering the tractive effort 62% of the 6 wheeler drive vehicle at 15% slippage.
- Tractive effort of the tracked vehicle in the range of 40 to 64% of the vehicle gross weight is justified the highly effectiveness of the employed automation system.

REFERENCES

1. Ataur, R., Azmi, Y., Zohadie, M., Ahmad, D and Ishak, W. 2004. Mechanical Properties in Relation to Vehicle Mobility of Sepang Peat Terrain in Malaysia. *Journal of Terramechanics*, Elsevier Science, Vol.41, No.1, pp.25-40.
2. Bekker, M.G., 1969, *Introduction to terrain-vehicle systems*, Ann Arbor, MI: University of Michigan Press.
3. Benoit O, Gotteland Ph. DECART: Experimental device for trafficability characterization. In: Proceedings of the International Symposium PARAM 2002. Paris, France, September; 2002.
4. James, W.D and William, F. R. 1978. *Experimental stress analysis*. USA:McGraw-Hill, Inc.
5. MacFarlane, I. C. 1969. *Muskeg Engineering Handbook*. University of Toronto Press,Toronto.
6. Radforth, N. W. 1958. The significance of density as a physical property in peat deposits. Journal of Terramechnics, 2 (3), pp.81-88.
7. Wong, J.Y. 2001. *Theory of Ground Vehicles*, (Third Edition), New York: John Willey & Sons, Inc.
8. Wong, J. Y. J., Radforth, R., and Preston-Thomas, J. 1982. Some further studies on the mechanical properties of muskeg in relation to vehicle mobility. Journal of Terramechanics, 19(2), pp.107-127.