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Creation and Reliability Analysis of Vehicle Dynamic Weighing Model

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Abstract: In this paper, it is modeled by using ADAMS to portable axle load meter of dynamic weighing system, controlling a single variable simulation weighing process, getting the simulation weighing data under the different speed and weight; simultaneously using portable weighing system with the same parameters to achieve the actual measurement, comparative analysis the simulation results under the same conditions, at 30 km/h or less, the simulation value and the measured value do not differ by more than 5 %, it is not only to verify the reliability of dynamic weighing model, but also to create possible for improving algorithm study efficiency by using dynamic weighing model simulation. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Weighing sensor, ADAMS, Dynamic weighing, Simulation.

1. Introduction

With the development of highways in China, overweigh in the proportion of the reason of traffic accidents, jam, roads and bridges damage have risen [1]. Static weighing method is an inefficient traffic weighing method and reasons why weighing accuracy can't be improved significantly [2] are the time tire force by the weighing platform is short, so that signal sampling is insufficient. Also the interferential force acting on the weighing platform is multiple, such as speed, vibration the vehicle itself, inertial force and so on [3]. The technology to improve vehicle weigh-in-motion accuracy is forced on neural network [4-6], digital low-pass filter [7], data fusion technique [8]. These algorithm research based on weighing output signal mainly use statistical analysis of measured data not only time-consuming, but also has difficulty to popularize as limitation in vehicle model. To this end, a new method is proposed this paper by using ADAMS software based on the actual structure of weighing sensor and modeling principle, getting the weighing data with different parameters and. Reliability of the vehicle weigh-in-motion model is verified through the contradistinction with the actual test data. This dynamic model can provide lots of reliable data for dynamic weighing algorithm and offers the possibility of improving research efficiency with the superiority of variable parameters and multiple choice of vehicle model.

2. Creation and Simulating of Dynamic Weighing Model Based on ADAMS

2.1. Dynamic Weighing System

The portable dynamic weighing sensor system, which is installed weighing sensor and bridge approach on the smooth ground, when the vehicle longitudinal axis pass through the weighing platform with a constant speed, its bar center remain the same as before, according to the torque balance principle, adding the front and rear axle' weighing are the vehicles total weighing [10].

When the vehicle onto the weighing platform, dynamic weighing system is a multi-degree of freedom vibration system consisting of the vehicle, the weighing sensor and the ground. Fig. 1 is a schematic diagram of dynamic weighing.

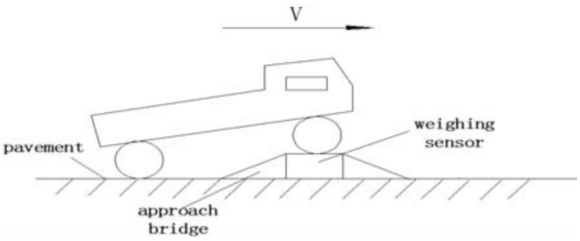


Fig. 1. Schematic diagram of simple side weigh.

2.2. Mathematic Model of Weighing System

Fig. 2 (a) shows the dynamic model of weighing sensor [11], where M is mass of the vehicle axle, K1, C1 is the stiffness and damping of vehicle tire, m is the mass of weighing sensor, K, C is the stiffness and damping of the sensor. When the tire move onto the weighing platform, y(t) is the displacement of the weighing platform. As a rigid body, it is not vibration when the vehicles move onto the weighing platform instantaneous, so the weighing model can be simplified by shown as Fig. 2 (b).

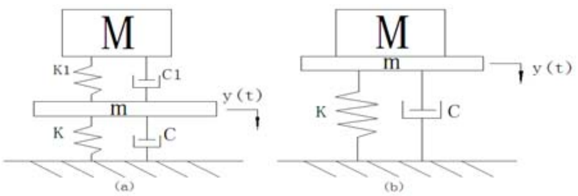


Fig. 2. Dynamic model of weighing sensor.

Suppose the moment time t = 0, the full weight of the vehicle is instant effect on the weighing platform entirely, that is, a unit step signal u(t) effect on the sensor, by Newton's laws of motion and vibration theory [12]:

$$(M+m)\frac{d^2y}{dt^2}+Ky(t)+c\frac{dy}{dt}=Mgu(t), \quad (1)$$

2.3. Kinematic Analysis and Algorithm Rules of ADAMS

Mechanical systems simulation model is built this paper. There are several motion connectors between mechanical part and ground, component and ground, can be represented by algebraic equations with generalized coordinate system. The kinematic constraint equations can be obtained as follow, where nh is the number of constraint equations of motion connectors:

$$\theta^k(\mathrm{q})=[\theta_1^k(\mathrm{q}),\theta_2^k(\mathrm{q}),...,\theta_{nh}^k(\mathrm{q})]^T=0, \quad (2)$$

The position, speed, acceleration and constraint forces of zero degree of freedom (DOF) system is considered and analyzed in ADAMS. Then constraint equations of the system can be determined as follows.

$$\theta(\mathrm{q},\mathrm{t}_n)=0, \quad (3)$$

where t_n represents the position at the any moment in process of simulation, Which can be derived by Newton-Raphson iterative method of the constraint relations:

$$\theta_{qj}\Delta q_j+\theta(\mathrm{q}_j,\mathrm{t}_n)=0, \quad (4)$$

$\Delta q_j = q_{j+1} - q_j$ means J-th iteration. The speed and acceleration at t_n can be solved with linear algebraic equations and ADAMS software provides two solving Method: CALAHAN method and HARWELL method. The former one runs faster and HARWELL can deal with the redundant constraints.

2.4. Modeling Based on ADAMS

According to Fig. 2, we can complete the vehicle dynamic weighing simulation model with the weighing sensor dynamics model. It's weighing sensor system parameters are shown in Fig. 3 as accordance with the actual system size.

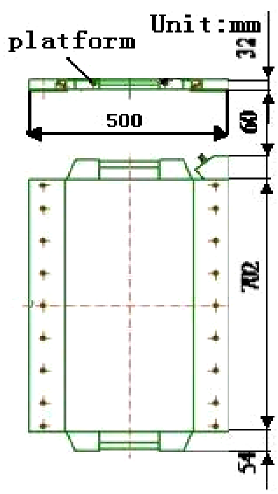


Fig. 3. Size of weighing sensor for portable axle load scale.

Weigh-in-motion model constitutes with automobile tires, simple vehicle body, front and rear axles, road and weighing sensor. Process of model creating simplifies bracket and backing; defining constraint points, setting the spherical constraint and bridge be connected directly with ground, imported the ANSYS to be flexible, based on the actual 60Si2Mn spring steel, setting elastic modulus E=2e11pa, density DENS=7.85e3 kg/m³ and Poisson's ratio μ=0.3. We mesh by solid45 to replace the rigid weighing platform (Fig. 4). In consideration of the difference of damping device and suspension structure of each kind of vehicle, we direct connect the front and rear axles with spring to simplify automobile shock absorber [13]. Under the accuracy premise, vehicle and ground are set rigid body to ensure the running of software unrestricted. Combined with the principle vehicle characteristics and processes modeling and simulation of the actual weighing, established based on the vehicle dynamic weighing ADAMS model, and shown in Fig. 5. Fig. 6 shows the interface of parameters of different speed and tire contact.

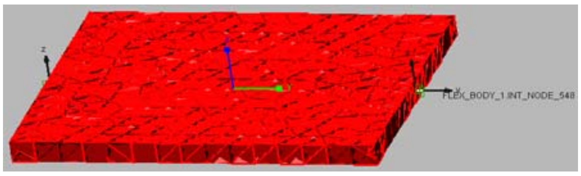


Fig. 4. Flexible body of weighing sensor.

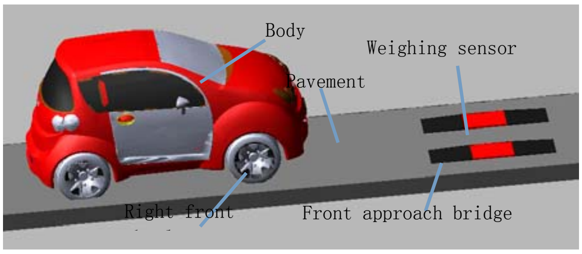


Fig. 5. Model of vehicle weigh-in-motion.

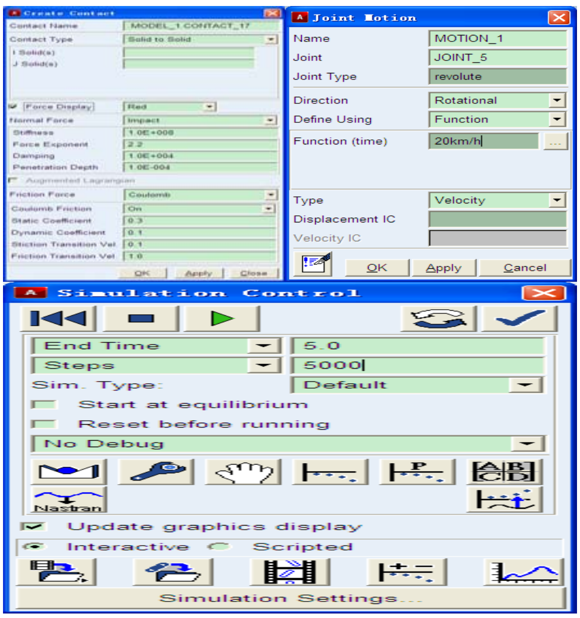
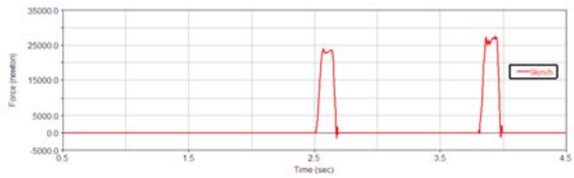


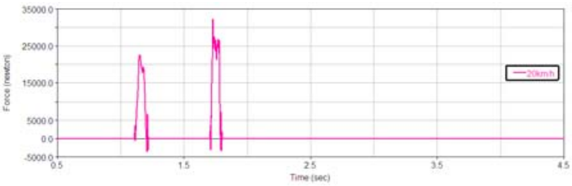
Fig. 6. Parameter settings.

2.5. Simulating and Result

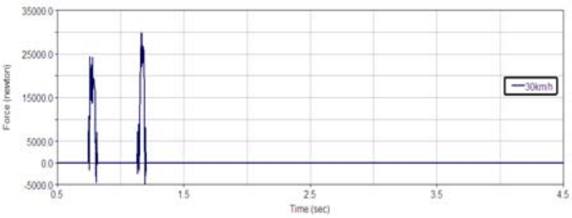
According to the model of the weighing, the rata are 9 km/h, 20 km/h, 30 km/h, the simulation under the quality of 10t can obtained by the left side of the load sensor signal contact force curve shown in Fig. 7.



(a) Weighing signal at 9 km/h



(b) Weighing signal at 20 km/h



(c) Weighing signal at 30 km/h

Fig. 7. Output signal of simple side simulation.

The Fig. 7 shows, it is exposed to the impact when the vehicle moves onto the bridge, and showing attenuation phenomena. The higher the speed, the steeper ascent axle signal, the lower axle sensor signal is gentle, middle signal stabilized, it can be directly treated as axle load weighing true value. After the vehicle acceleration, sensor is subjected to increasing disturbance factors, signaling complex, dynamic measurement error increases [14], resulting in the decreased accuracy. A large number of simulation data show that: when the car rear axle wheels is in contact with the ground left bridge, it will generate additional inertial impact, leading to the rear axle peak signal is greater than the former. Signal attenuation happens since the car runs over the platform, and as acceleration of the speed, the ascent of axle load signal becomes more precipitous, while the middle signal tends to stable at low speed, which can be regarded as the real weight signal. Interferential factor increases and weighing signal becomes more and more complicated as speed accelerates, resulting dynamic error increases [13]. Lots of simulating data proves that an additional impact force will generates at the moment rear wheels start to touch with pavement, that makes peak signal of rear axle bigger than front. The repeated experiments, finishing the simulation model to obtain the weighing data in Table 1.

Table 1. Alex weighs of model simulation.

Sequence	speed (km/h)	Real weigh (kg)	Left front axle weigh (kg)	Left rear axle weigh (kg)	Right front axle weigh (kg)	Right rear axle weigh (kg)	Total weigh (kg)	Relative error (%)
1	9	10000	2306	2522	2443	2553	9824	-1.76
2	20		2201	2456	2246	2741	9644	-3.56
3	30		2145	2478	2176	2644	9443	-5.57
4	9	14000	2970	3847	3143	4196	14156	1.11
5	20		2878	3845	2789	3741	13253	-5.33
6	30		2671	3746	2716	3532	12665	-9.54
7	9	20000	4613	5495	3947	6201	19152	-4.24
8	20		3784	5211	3585	5466	18046	-9.77
9	30		3558	5085	3412	5494	17549	-12.26

Table 1 shows interferential factors sharp increase as the speed increase, and loss of weighing signal is severe at the same weigh. while the same speed, the larger the vehicle load, weighing when weighing sensor action by the front axle needs more time to reach steady state, when the rear axle weighing, weighing platform suffered interference increasing, more intense vibration, the more signal loss axle.

3. Reliability of Actual Dynamic Test

3.1. System Collecting

Weighing sensor would the vehicle axle pressure sensor signal into an analog voltage signal, through the amplifier, the high speed sampling acquisition card converts it into a digital signal and transmitted to the computer through the USB interface, the signal is stored, filtered, analysis and operated by the computer, ultimately get the total weight and vehicle speed of each axle. Amplifier AD622 has response speed, signal transmission rata is 1.2 V/μs. Acquisition card conversion precision is 14-bit, two channel analog channels are selected sampling frequency 25 kHz. This dynamic performance can be to meet the system requirements for signal acquisition and transmission.

Fig. 8. Experimental site of vehicle weigh-in-motion.

After the acquisition card initialization, can be set the sampling frequency, sample the channel parameters and methods, write multithreaded data collection procedures, began the real time data collection. Fig. 8 is a schematic diagram of the experimental site collection.

To determine the linear relationship between the system input and output, when the data is collected consummately, the system should be calibrated experiments [15]. Calibration car load of about 1.4 t, load limit 0.5 t, respectively, for the two way system with a ton weighing standard weights were calibrated [16]. Average values as the measurement result, to eliminate the deviation to bring the instantaneous value of the display. Specific data are shown in Table 2.

Table 2 Experimental data of No.1 system calibration.

Standard weights W (kg)	No.1 data Y11 (mV)	No.2data Y22 (mV)	Average Y1 (mV)
0	431.1	432.1	431.6
25	444.7	445.5	445.1
50	458.0	458.8	458.4
75	471.4	472.4	471.9
150	512.3	513.0	512.6
300	593.6	594.1	593.8
400	647.5	648.7	648.1
500	702.1	702.8	702.4
600	756.5	756.9	756.7
800	865.7	865.6	865.6
1000	974.8	974.1	974.5

Method of least squares fitting process to obtain a linear relationship between the output voltage and the weight of the system:

$$Y1=0.5429*W+431.1884, \tag{5}$$

$$Y2=0.5441*W+422.1117, \tag{6}$$

Fig. 9 shows the fitting curve of input-output measured data. Linearity error of weighing system is less than 2 mV; two weighing system linearity are 0.4 %, resolution of two groups is 1.84 kg and 1.83 kg respectively. The relationship 2 mV should corresponds to 4 kg is deduced by coefficient of (5) and (6), that meets the design requirements of weigh-in-motion accuracy.

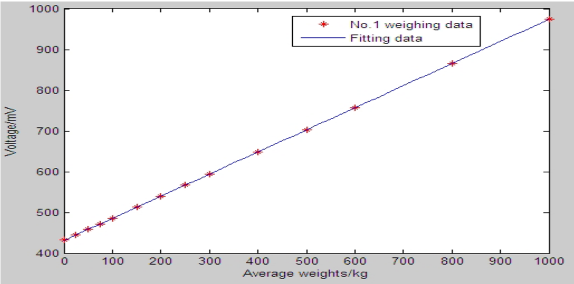


Fig. 9. Input-output curve fitting of No. 1 system.

3.2. Repeatability

Choose 500 kg standard weights, putting onto weighing sensor every 15 min, experiment data is shown in Table 3.

Table 3. Experimental data of repeatability.

No.1 /mV	No.2 /mV	No.3 /mV	No.4 /mV	No.5 /mV
702.5	702.3	702.6	702.5	703.4
No.6 /mV	No.7 /mV	No.8 /mV	No.9 /mV	No.10 /mV
702.6	702.7	702.5	702.4	702.6

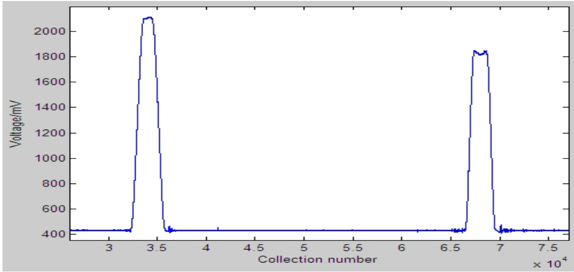
Data above demonstrate system repeatability is within 0.5 %.

4. Reliability Analysis Between Simulation and Actual

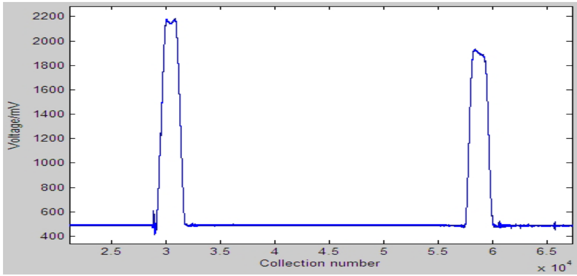
In order to verify system reliability, simulation data and actual data is contrasted with the same parameters. Original signals gained by left weighing sensor at different speed are shown in Fig. 10.

It is worth mentioned, contact-impact factor and friction factor between pavement and wheel, wheel and weighing sensor are empirical parameters. Flexible platform becomes more sensitive, and contrasting with actual signal, simulation signal fluctuates largely, with shape and tendency identical. Comparison of actual experiments and model simulation is as follow.

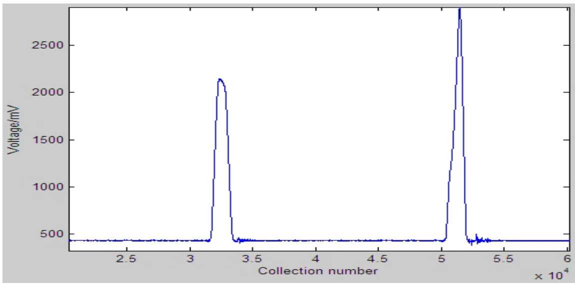
From Table 4 we can observe that the maximum error between actual data and simulation data is below 5 %, with the regular pattern and tendency identical. This result can be confirmed further that if these parameters vehicle model set can close to the actual material as much as possible, weighing signals weigh-in-motion model get will be more reliable. In addition, vehicle weigh-in-motion model created this paper is based on many imaginary, with consummating under continuous process of debugging.



(a) weighing signal at 9 km/h



(b) weighing signal at 20 km/h



(c) weighing signal at 30 km/h

Fig. 10. Output signal of actual experiments.

5. Conclusions

A vehicle weigh-in-motion system is built based on portable axle load scales by ADAMS this paper. The relative error between simulation data and measured data is below 5 % with the same parameter under 30 km/h, which meets the demand of actual data collection and reliability of system is verified. Dynamic vehicle model created by ADAMS can provide lots of reliable data for dynamic weighing compensation algorithm with the superiority of variable parameters and multiple choice of vehicle model, which can reduce labor intensity, thus the great academic value and economic value can be foreseen. With consummating this model constantly, interference factor such speed, road conditions and vibration can be used to research the influence for weighing accuracy, establishing a theoretical basis.

Table 4. Compare of actual experiments and model simulation.

Sequence	Speed (km/h)	Left front axis weigh (kg)	Left rear axis weigh (kg)	Right front axis weigh (kg)	Right rear axis weigh (kg)	Total weigh (kg)	Actual weigh (kg)	relative error (%)	Measured /Simulation relative error (%)
1	8.7	2546	2296	2579	2474	9895	10056	-1.60	0.72
2	20.4	2591	2207	2788	2006	9592		-4.61	-0.54
3	28.6	2477	2125	2745	2031	9378		-6.74	-0.69
4	9.1	2486	3574	3014	4612	13686	13971	-2.04	-3.32
5	19.4	2248	3785	2816	4179	13028		-6.75	-1.70
6	31.2	2064	4287	2471	3974	12796		-8.41	1.04
7	10.1	3974	4292	4268	5788	18322	19276	-2.95	-4.33
8	19.7	3453	5612	3448	5074	17587		-8.76	-2.55
9	29.1	3207	6074	3379	4216	16876		-12.45	-3.84

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