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COMPARISON OF MEASUREMENT METHODS FOR VEHICLE ACCELERATION

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Abstract: Two vehicle acceleration measurement methods for determination of time needed to achieve a velocity of 100 km/h are presented: a) based on the acceleration measurement with Analog Devices iMEMS accelerometers, b) based on a length measurement using signals from Antilock Braking System sensors. The measurements done in real conditions showed a very good agreement.

Keywords: vehicle acceleration measurement, ABS sensors, accelerometers.

1. INTRODUCTION

The measurement of vehicle acceleration is a very important characteristic for every vehicle because it is directly connected with the torque and the power of engine. Our particular interest is determination of time that a car needs to speed up from 0 to 100 km/h, and realisation of the compact, robust and accurate measuring instrument for that measurement.

This paper describes two methods of vehicle acceleration measurement. In the first method acceleration is directly measured by the Analog Devices iMEMS accelerometers, while the second method is based on distance measurement by analysing the output of Antilock Braking System (ABS) sensors. The point of each method is to calculate the speed of the vehicle so we can define the moment when the vehicle starts to accelerate and the moment when the vehicle has achieved the speed of 100 km/h.

Measurements in real conditions were done using the car Honda Civic by obtaining the data needed for both methods at the same time, so the results can be matched to each other. For data acquisition a National Instruments PCI-6014 card is used, and the used software is developed using the package National Instruments LabVIEW 7.1.

2. USED METHODS OF MEASUREMENTS

The measurement of vehicle "so called" acceleration from 0 to 100 km/h (i.e. time) is based on the detection of moment when a car reaches a speed of 100 km/h (to calculate elapsed time from the beginning). Therefore, in this experiment we implemented two methods of vehicle acceleration measurement by which a speed of the vehicle is measured constantly:

- Acceleration measurement method
- Distance measurement method

Each method has to measure speed of the vehicle constantly so we can calculate the time that car needs to accelerate from 0 to 100 km/h. In Table 1, average accelerations for some car types are pointed out, expressed in m/s^2, as well as in ratio to g ($1g$ = 9,81 m/s^2), which is more often case in literature; in the last row an associated travelled distance is written.

Table 1. Average acceleration from 0 to 100 km/h for some cars

Car type	Formula 1	Sport car	Fast car	Family car
t/s	3	5	10	15
$\bar{a}$ /(m/s^2)	9,3	5,6	2,8	1,9
$\bar{a}$ /g	0,94	0,57	0,28	0,19
s/m	41,7	69,5	139	208,5

We can see from the values in Table 1 that an average acceleration over $1g$ is hard to obtain, even for Formula 1, while an average family car accelerates at about 2 m/s^2. This is valuable information for the needed dynamic range in the application of an integrated accelerometer.

2.1. Acceleration measurement method

The speed of a vehicle basically can be calculated from its acceleration (in the direction of moving, which is horizontal) through equation:

$$v = v_0 + \int_0^t a \, \mathrm{d}t \, , \tag{1}$$

where in our case $v_0 = 0$ km/h. The accuracy of the measured speed is influenced by the errors in acceleration measurement, because with the constant absolute error of the acceleration measurement, the absolute error of speed grows with the time of integration. This case is shown in Fig. 1.

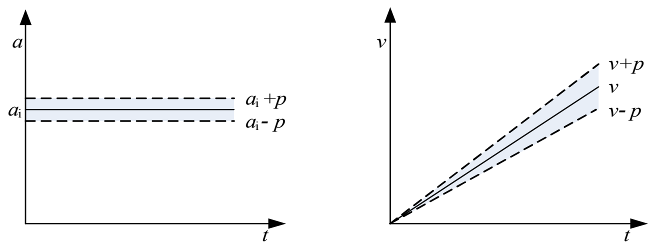

Fig. 1. Absolute error of speed grows up when we integrate acceleration with constant absolute error

From a wide range of Analog Devices iMEMS accelerometers, for this application we selected a high precision accelerometer on single IC chip ADXL203 [1, 2]. It can measure both dynamic and static acceleration in dual independent and perpendicular axis, in a range of $\pm 1{,}7g$ with the sensitivity of approximately (1000 mV)/g, which is equal to 102 mV/(m/s^2). The basic parts of that accelerometer are a polysilicon surface-micromachined sensor and signal conditioning circuitry to implement an open-loop acceleration measurement architecture (Fig. 2). The output signal is analogue voltage proportional to acceleration, while for $a = 0$ m/s^2 (i.e. zero acceleration) output is nominally equal to one half of the supply voltage.

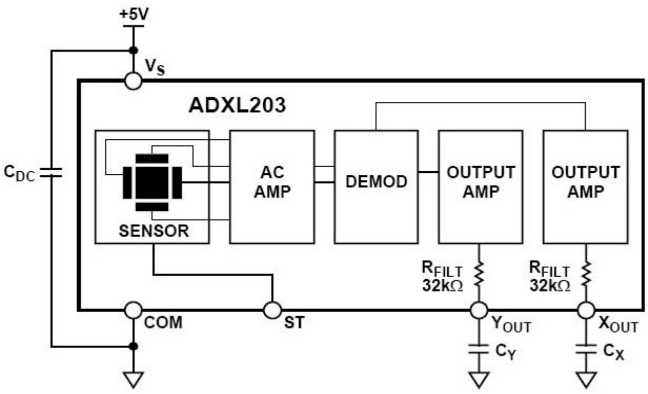

Fig. 2. Functional block diagram of ADXL203 accelerometer

Earth gravity affects acceleration measurement with this method. Basically, a car accelerates in direction parallel with Earth surface (direction of interest), and perpendicular on Earth gravity direction. If the axe of the sensor is not the same to the direction of interest, which can arise during a normal acceleration of a car or due to an incorrect mounting of the sensor itself, an error can arise. Thus, if the corresponding angle is α, the accelerometer will measure the sum of the component of the car acceleration ($a\cos\alpha$) and the component of Earth gravity ($g\sin\alpha$). In that case, the measured value of acceleration is:

$$a_{\mathrm{m}} = a\cos\alpha + g\sin\alpha\,, \tag{2}$$

and the associated relative error can be calculated as:

$$p_{\mathrm{ra}} = \frac{(a\cos\alpha + g\sin\alpha) - a}{a} \cdot 100\%\,. \tag{3}$$

In Table 2 the relative errors of measured acceleration, calculated by (3) for some chosen values of a and α, are pointed out.

Table 2. Relative error of measured acceleration p_{r}

α	$p_{\mathrm{r}(a=2\ \mathrm{m/s^2})}$	$p_{\mathrm{r}(a=4\ \mathrm{m/s^2})}$	$p_{\mathrm{r}(a=6\ \mathrm{m/s^2})}$	$p_{\mathrm{r}(a=8\ \mathrm{m/s^2})}$
0°	0 %	0 %	0 %	0 %
0,2°	1,7 %	0,9 %	0,6 %	0,4 %
0,4°	3,4 %	1,7 %	1,1 %	0,9 %
0,6°	5,1 %	2,6 %	1,7 %	1,3 %
0,8°	6,8 %	3,4 %	2,3 %	1,7 %
1,0°	8,5 %	4,3 %	2,8 %	2,1 %

Error rises proportionally with the angle α and inversely proportionally with the car acceleration a. This is not a small problem for our vehicle acceleration measurement application, because the expected average value of car acceleration is not even 5 m/s^2 and the angles up to 1° are rather small.

For this vehicle acceleration measurement application we developed all necessary hardware and software. Fig. 3 shows the test board with the mounted two accelerometers ADXL203 and the regulated power supply. Only one accelerometer is enough for the measurement purposes; however, two accelerometers are used for the control and development purposes. The obtained results are presented in section 3.

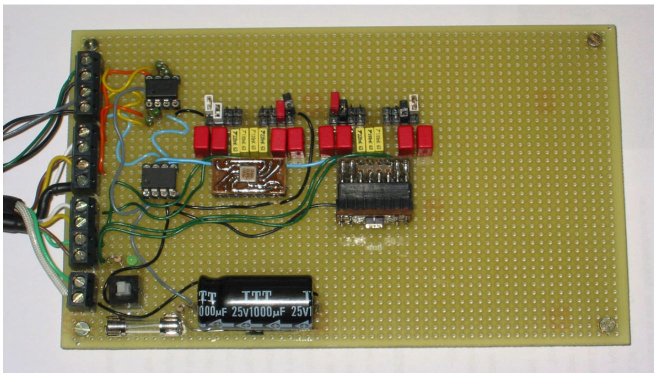

Fig. 3. Test board with installed accelerometers ADXL203

2.2. Distance measurement method

Based on the distance measurement, this method works on the same principle as a car tachometer. The definition of the speed is described with the known equation:

$$v = \frac{\mathrm{d}s}{\mathrm{d}t}\,. \tag{4}$$

For distance measurement we used signals from ABS sensors that are already installed in our test car. ABS is a system that prevents tire blocking and improves the performance of car brakes. The system consists of the ABS speed sensors mounted on every wheel, a control unit that processes signals from speed sensors, and a device that controls brake forces. The ABS speed sensor (Fig. 4) consists of a gear pulser attached to the wheel and an electromagnetic sensor that generates sinusoidal signal of frequency proportional to the wheel rotating speed.

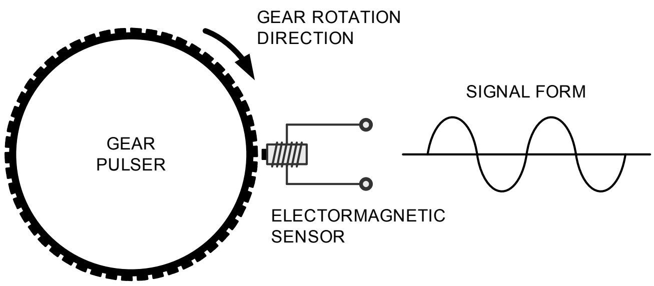

Fig. 4. ABS speed sensor block diagram

On our test vehicle, the gear pulser generates 50 periods of sinusoidal signal per one cycle of the wheel [3]. This signal can be used for the car speed determination during its acceleration, because by counting the number of periods we can calculate the travelled distance, and the speed can be determined as the derivative of the measured distance. However, the system firstly needs to be calibrated before we can use it in the car acceleration measurement. The scope of the calibration is to measure, as precisely as possible, the diameter of the rear wheels, so we can calculate the number of sinusoidal periods generated when a car pass a distance of one meter. This is very important because the diameter of the wheel is the function of the tyre pressure and temperature. The calibration procedure is described by the drawings shown in Fig. 5.

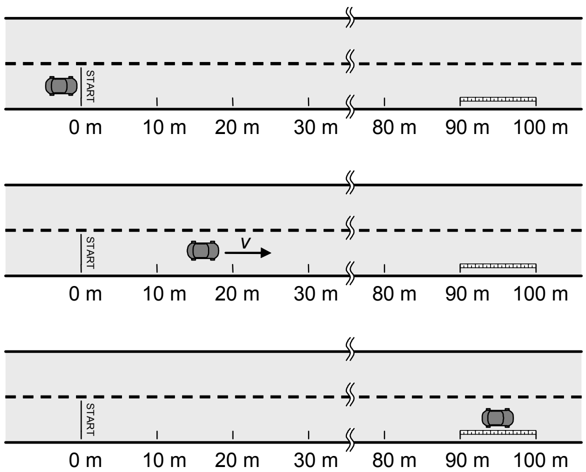

Fig. 5. ABS sensor calibration procedure

For the calibration in the real conditions we used a straight 100 m road, and for the distance measurement a 10 m construction meter. The car was positioned on the beginning line and the recording of the ABS sensor signal was started. Then the car was accelerated to the speed of about 50 km/h and stopped within 100 m from the start. The typical results obtained during the described measurements are shown in Fig. 6.

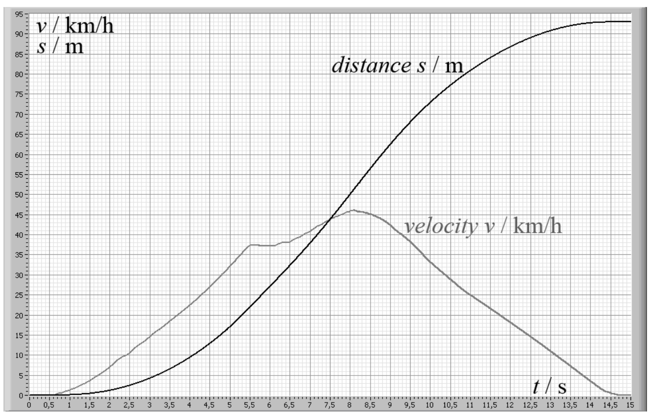

Fig. 6. The result of one ABS sensor calibration measurement

From the results of calibration, the following constant can be calculated:

$$k_{\mathrm{ABS}} = \frac{N}{s}, \tag{5}$$

where N is a number of periods generated by the ABS speed sensor, and s is the travelled distance. Altogether 8 calibrations were made, and the results are presented in Table 3, with the calculated mean values of ABS constant and their standard deviations for rear left and right wheel, respectively.

Table 3. Results of ABS speed sensors calibration of rear wheels

ABS speed sensor	Rear left	Rear right
$\bar{k}_{\mathrm{ABS}}/(\mathrm{m}^{-1})$	28,520	28,489
Std. deviation / (m^{-1})	0,018	0,026
Relative std. deviation	0,06 %	0,09 %

We can see that the standard deviation is less than 0,1 %, which makes the result even better than expected, and shows that the accurate calibration of sensors is possible. With the error in the determination of the travelled distance less than 0,1 m, this calibration procedure can be done with a relative error less than 0,1 %, which is a very good result.

3. MEASUREMENT RESULTS OBTAINED USING TWO METHODS

3.1. Data acquisition and analyses

All software needed for this application is developed using the software package National Instruments LabVIEW 7.1 [4, 5]. The data acquisition program was developed to record all signals from the accelerometers and the ABS speed sensors during the acceleration measurement, so they can be stored on the hard disk for further analysis [6].

Program for signal processing and data analyses calculates the car speed from the recorded data of both methods. The signals from accelerometers are filtered with the low-pass filter and then integrated to get the car speed graph. Fig. 7 shows the typical results obtained by the acceleration measurement method when the car accelerates from 0 km/h to about 120 km/h.

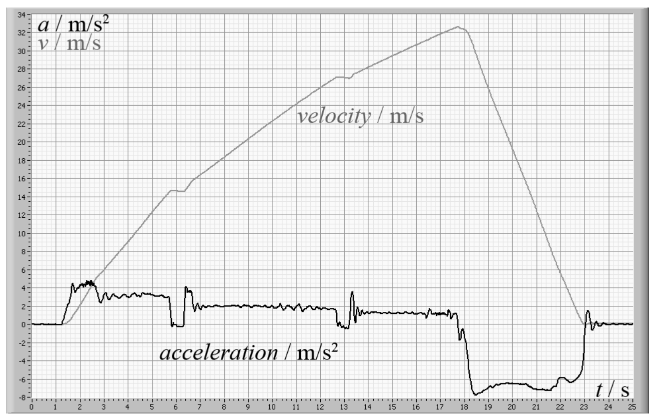

Fig. 7. Typical results of acceleration measurement method

Concerning the distance measurement method, the signals from ABS speed sensors are also filtered, but with the adaptive filters in order to remove the noise from the signals as much as possible, so that the sinusoidal periods can be counted. The amplitude of the signal from ABS speed sensor is proportional with the frequency of the signal, which is proportional to the car speed. So when the car starts to move, the amplitude of the signal can be smaller than the noise that comes from the car ignition system. That is the reason why the counting procedure cannot clearly recognize a few periods of the ABS speed sensor signal at the beginning of car's movement. Eventually, from the counted periods we get the data (graph) of the travelled distance, from which, as derivative, follows the data (graph) of the car speed. The signals' processing, filtering and analysing is rather complex and time consuming for the used experimental set-up.

Fig. 8 shows the typical results (non corrected) of the car acceleration measurements from 0 to 100 km/h, obtained by the two methods previously explained in subsections 2.1 and 2.2. The black line represents the results obtained from the acceleration measurement method, and the grey line from the distance measurement method.

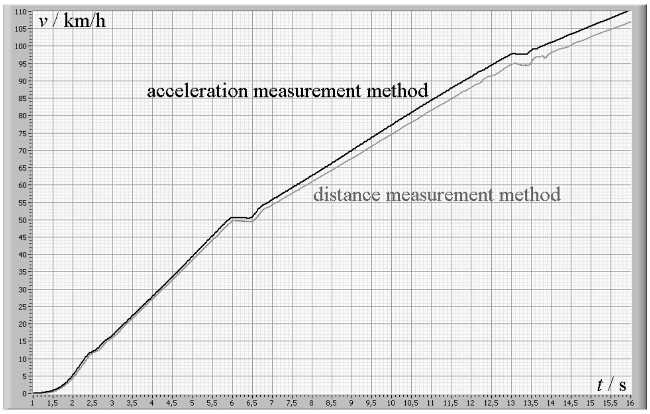

Fig. 8. Acceleration measurement results of both methods (without correction)

We can see that the black line is slightly over the grey line, and similar curves were obtained in all repeated measurements. The one reason for such behaviour is the Earth gravity influence on acceleration measurement method. On the other hand, the problem with the distance measurement method is the accurate determination of the periods (of the generated signal) at the beginning of movement due to the small rotating speed of the wheel. Therefore, to compare two methods of measurement some reference model (or value) is needed.

3.2. Reference model and corrections

The analysis of the obtained results showed that the differences between them are up to 0,3 s for time determination needed to accelerate from 0 to 100 km/h (as it can be seen from the results in Table 5). There are some systematic effects that need to be recognized.

The error that arises in the acceleration measurement method is due to the changing of the angle of the car to the horizontal surface during the acceleration, which has a direct consequence on the position of the mounted accelerometer. In other words, an angle α and associated error, which can be calculated by (3), appears in the measurements. Because it is hard to dynamically measure angle α, to correct this error we used a fact that the distance measurement method is not sensitive to the change of angle, and by comparing these two curves it is possible to calculate a corrective factor k_a by which a speed graph from the acceleration measurement method should be multiplied. Table 4 shows the results of such calculation, and from five repeated measurements follows a mean value of k_a equal to 0,9678 with a relative standard deviation of only 0,18 %. The value of k_a could be different for different types of cars, but also depends on the set-up of the accelerator sensor within the car.

Table 4. Results of the determination of factor k_a

No.	k_a
1	0,9683
2	0,9705
3	0,9668
4	0,9660
5	0,9673
Mean value	0,9678
Std. deviation	0,0017
Relative std. deviation	0,18 %

After the correction factor k_a is applied on all measurement results obtained by acceleration measurement method, the differences between the speed graphs are rather small (Fig. 9).

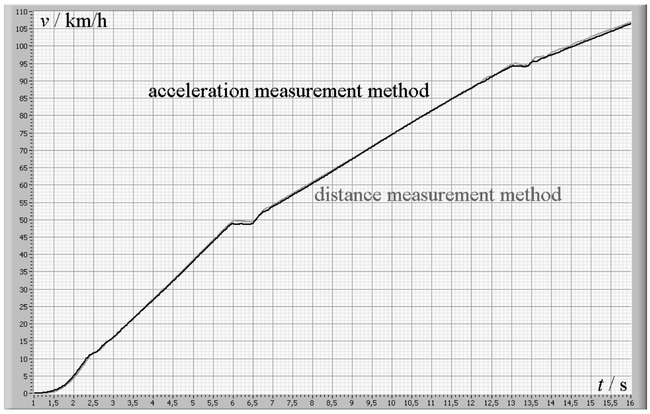

Fig. 9. Car speed graphs after correction

Now we are able to calculate the needed time interval for acceleration from 0 to 100 km/h for every set of measured data. If we denote in index letter "*a*" for the acceleration measurement method, letter "*s*" for the distance measurement method, and numbers "1" and "2" for the beginning (0 km/h) and end (100 km/h), respectively, the following equations can be written:

$$\Delta t_a = t_{a2} - t_{a1}\,, \tag{6}$$

$$\Delta t_s = t_{s2} - t_{s1}\,. \tag{7}$$

Furthermore, even if we are able to calculate the needed time intervals by using (6) and (7) for two methods, we need some reference value for comparison. After examining the obtained results of measurements, it was found that the acceleration measurement method is more precise when we need to define the time of car acceleration beginning, while the distance measurement method is more precise when we need to define the time when the car reaches a speed of 100 km/h. The reason for that is that the signals generated by ABS sensors at the beginning of moving are not clear sinusoid and it is harder to count the number of periods. Therefore, it seems reasonable to define the reference time interval using the "start" moment from the acceleration measurement, and the "stop" moment from the distance measurement, i.e. to establish the reference model by the following equation:

$$\Delta t_{as} = t_{s2} - t_{a1} \,. \tag{8}$$

Now we can compare two methods of measurements to the reference model, and the results of time interval determinations for all five repeated measurements, according to the relations expressed in (6) to (8), are presented in Table 5; the relative errors are calculated as follows:

$$p_{\mathrm{r}ta} = \frac{\Delta t_a - \Delta t_{as}}{\Delta t_{as}} \cdot 100\,\% \,, \tag{9}$$

$$p_{\mathrm{r}ts} = \frac{\Delta t_s - \Delta t_{as}}{\Delta t_{as}} \cdot 100\,\% \,. \tag{10}$$

Table 5. Results of the calculation of the time interval needed to accelerate from 0 to 100 km/h for reference model and both methods

No.	$\Delta t_{as}/\mathrm{s}$	$\Delta t_a/\mathrm{s}$	$p_{\mathrm{r}\,ta}$	$\Delta t_s/\mathrm{s}$	$p_{\mathrm{r}\,ts}$
1	13,63	13,69	0,44 %	13,47	–1,17 %
2	12,93	13,17	1,86 %	12,87	–0,46 %
3	13,56	13,62	0,44 %	13,51	–0,37 %
4	13,25	13,32	0,53 %	13,14	–0,83 %
5	12,71	12,77	0,47 %	12,69	–0,16 %

It is interesting to observe that, in the used set-up and the performed analysis and corrections, the time interval Δt_a is always greater than Δt_s, and for repeated measurements these differences could be as high as 0,3 s. Almost the same situation is when comparing Δt_a and the reference value Δt_{as}, but the differences are slightly smaller. Since the times t_{a1} and t_{s1} represent the intervals between the beginning of the data acquisition and the beginning of the car movement for two methods, respectively, it was found that for all measurements $t_{a1} < t_{s1}$. In contrast, the obtained results for the "stop" moments showed that $t_{a2} > t_{s2}$. Average relative error of the acceleration measurement method is 0,75 %, and for the distance measurement method -0,60 %.

4. CONCLUSION

The comparison of two methods of car acceleration measurements showed their very good agreement, and the achieved accuracy in the measurement of time needed for a car to accelerate from 0 to 100 km/h is at the order of the tenth of a second. These initial results give a good basis for further improvements.

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