Research of the Snaking Phenomenon to Improve Directional Stability of Remote Controlled Articulated Wheel Tool-Carrier

Marian Lopatka, Tomasz Muszynski

Military University of Technology, Mechanical Faculty, Combat Engineer Equipment Department
Kaliskiego Str. 2, 00-908 Warsaw, Poland
mlopatka@wme.wat.waw.pl

ABSTRACT: Articulated wheel tool-carriers manufactured up to 20-25 tons of total weights are wide available on the construction equipment market and have a lot of unique advantages not accessible on Ackerman steering or truck-mounted equipment such as :

- for weight up to 20 t high cross-country mobility – comparable to heavy military tracked vehicles due to size of wheels;
- excellent manoeuvrability and keeping attachment straight ahead during turning;
- high lift capacity due to heavy axis construction;
- high puling force;
- wide range of tools and attachments due to quick-coupling device;
- high productivity;
- high reliability and durability.

Moreover their steering systems and transmission are easy to automation due to hydraulic control systems. For those reasons they could be useful and cost effective on hazardous areas and robotised construction sites.

There is one unsolved problem, which limits the speed of operation and efficiency of using – they have poor directional stability. During straight movement the articulated tractor deviates from straight line and permanent driver correction is required. The path has oscillation shape so it is called snaking phenomenon. So in the case of remote control the speed is limited to 5-6 km/h. The higher road speed above 30 km/h of driver controlled tractor need an operator aid system that would improve directional stability of articulated tractor too. Designing such system demand perfect knowledge of snaking phenomenon arise reasons.

This paper describes tests and trials conducted on 20 tons articulated wheel loader to get answer how the snaking phenomenon is arisen. Used methods, achieved original results and their analysis are presented. It could be basis for future works on articulated tractor directional stabilisation system.

KEYWORDS: articulated tractor, high speed, identification, remote control, snaking phenomenon, steering system

1. INTRODUCTION

In Akerman steering system thanks the geometry of suspension the stabilising force and moment appear. The steering play lets them acts independent, without the driver attention. This feature has not gets articulated steering system and snaking phenomenon always appears. It is illustrated in fig.1. It shows the travel path of articulated tractor, which is oscillating round the theoretical direction of movement. Lack of directional stability of movement caused by too high speed or too low skill and experience of driver gives growing deviation and finally the machinery is leaving road strip (permitted corridor of movement).

In order to determine all main reason of arising and growing the snaking phenomenon the experimental research was conducted. As the test object was used the loader SL -34 -weight 19,5 t and net engine power 162 kW (manufactured by Huta Stalowa Wola) in two versions of steering system, offered by manufacturer :

Type 1 – with mechanical feedback and gain w = 1/5.5 - applied in machines first generation;

Type 2 – with hydraulic feedback and gain w = 1/3.2 – operating in L-S system with priority valve and amplifier - applied at present by almost all manufacturers of construction machines,

and 2 research systems designed by authors:

Type 3 - direct working with hydraulic feedback and gain w = 1/6.5 - without L-S system and amplifier;

Type 4 - direct working with hydraulic feedback and gain w = 1/16.2- without L-S system and amplifier.

As a gain "*w*" in steering system the inverse of number of steering wheel turns needed to realizing the full turn of frame was called.

After introduction tests [Lopatka] it was affirmed that in all steering systems the oscillations has similar period of vibration – about 2,5-3 s. From the type of steering system is depending only the value of maximum deviation amplitude and driver effort measured as angle of steering wheel revolve.

To eliminate claims that snaking phenomenon is some kind of natural frequencies or that arise because of excising the critical speed – this values was identified.

As a next step the research of steering system acting was conducted and finally the influence of driver on machinery stability was determined.

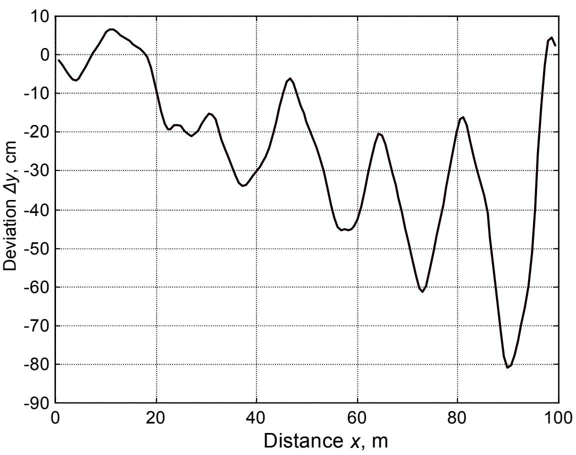

Figure 1. The snaking phenomenon of articulated tractor – speed 28 km/h – steering system – type 2

2. THE NATURAL FREQUENCY

The steering system of articulated tractor always contains 1(in small equipment) or 2 hydraulic cylinders and moved with them 2 masses connected to front and rear part of articulated frame. The oil in the cylinder gives the spring and damping effect. So, such system always has gets natural frequencies.

To find them the simple test was conducted. The steering system was excitated with fast steering wheel revolve and the recorded pressure in cylinder shows the oscillation with natural frequency of system. The results (fig.2) shows that period of vibration is 0,4 s and the frequency is 2,5 Hz. Compared to period 3 s of snaking phenomenon it is clear that they are not connected and snaking phenomenon is not kind of vibration related with natural frequency of steering system.

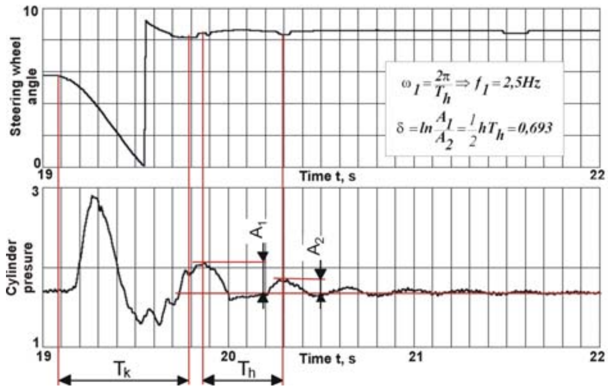

Figure 2. The results of test for indication of natural frequencies in steering system

3. THE CRITICAL SPEED

The critical speed characterize the vehicle mass distribution and lateral tire stiffness. During straight movement any disrupt due to different front and rear tire deformations changing him in some kind of circular movement and centrifugal force is appeared. The value of this force depends on the speed. When the centrifugal force is greater then stabilizing forces from tire stiffness the vehicle is not stable - leaving the strip and driver steering corrections is needed. The maximum value of speed when the vehicle is stable is called critical speed.

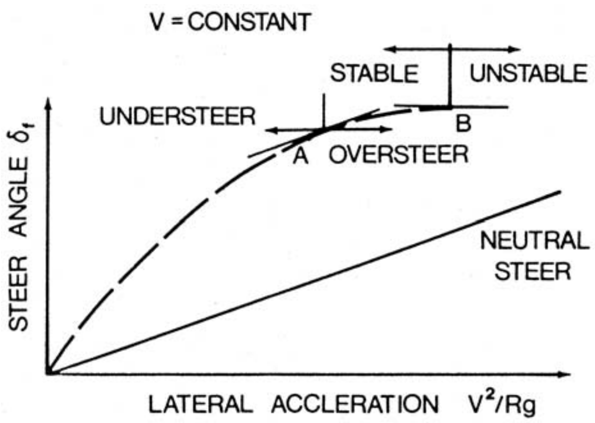

Figure 3. The directional control response characteristics [Wong]

Conducted test shows (fig.1) that tractor is loosing his stability with speed not exceed 28 km/h. Executed mathematical calculations indicated value of critical speed equal 44 km/h but credibility value can be find only in empirical way. To obtain this, the test according to [SAE] was performed. We decided for method 4 – constant speed/variable steer angle test and conducted them at a rate of 28 km/h. How to use the test results to determine the critical speed is demonstrated in fig.3.

According to assumed guidelines, during tests were recorded :

- the change of steering wheel turn angle β;
- the lateral acceleration a_p in the cab.

On the basis recorded dates the directional control response characteristics were plotted – fig.4. It show that the tractor not achieved the critical speed and it is much more higher then developed 28 km/h.

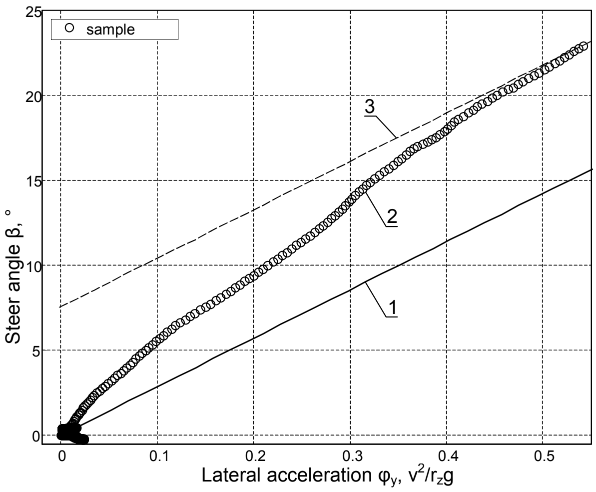

Figure 4. The directional control response characteristics of loader SL-34 at a rate 28 km/h :1 neutral characteristic, 2 real characteristic, 3 parallel line to neutral

Moreover it indicates that from critical speed point of view the loader at speed 28 km/h is stable and has got understeer characteristics. So, one may say that snaking phenomenon is not related to critical speed of vehicle.

4. THE STEERING SYSTEM OPERATION

Changing of movement direction and steering of articulated equipment is realized by turns of articulated frame with hydraulic cylinders of steering system. Each turn is related with pressure and flow changing. To know how it operates and what phenomena takes part during steering such signals as :

- pressure in both cylinder chambers;
- steering wheel angle;
- turns of articulated frame or
- length of steering cylinders;

should be measured.

In first steep the resistance of steering was determined. As a measure of resistance the pressure difference between active and passive cylinder chamber was used.

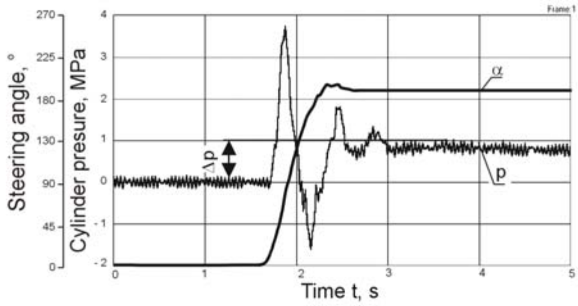

Figure 5. The steering wheel angle and pressure during steering on hard surface – loader is stand still

Example of recorded signals during steering on firm surface is shown in fig.5. It indicated that after steering the system is not stable. In active chamber of cylinder after steering the pressure is higher then in passive chamber about 0,8 MPa and it correspond to the steering resistance moment equal 4 kNm. This is a residual steering moment and it appears because of oil compression in active chamber of cylinder. This moment is trying continuing the steering process but the resistance is too high. The value of this moment is depending on steering resistance and velocity of frame turning.

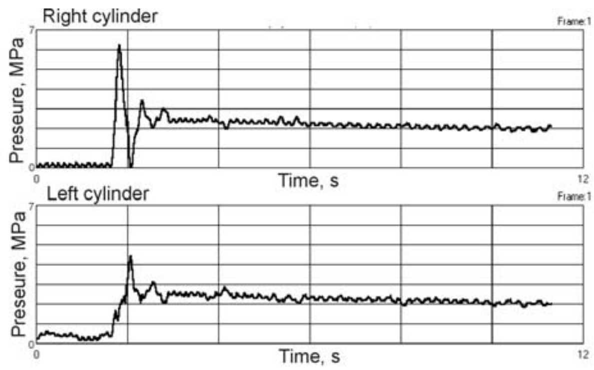

Figure 6. The pressure in both active and passive chambers of steering cylinders during tractor movements

When the tractor is moving the steering resistance is lowering and this residual steering moment is caused the turn of articulated frame up to time when the pressure in both chambers are equal fig.6. In these times the length of active cylinder is growing about 1-1,5 mm – fig.7. It correspond the turns of articulated frame about $\Delta\beta$ = 2,7°. To compensate it the driver must makes revolves of steering wheel on about 9 deg.. If he do not do it the tractor would achieve the permissible deviation Δy_{max} = 0,35 m according to [ISO], after 22 m.

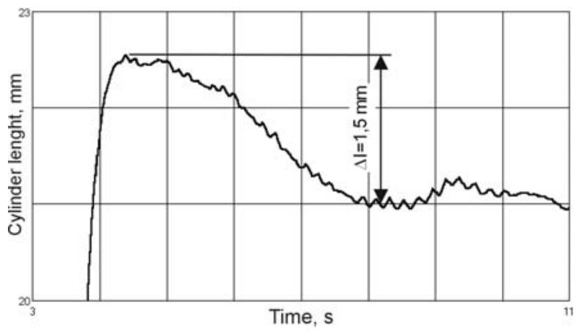

Figure 7. The changing of steering cylinder length as e results of residual steering moment acting

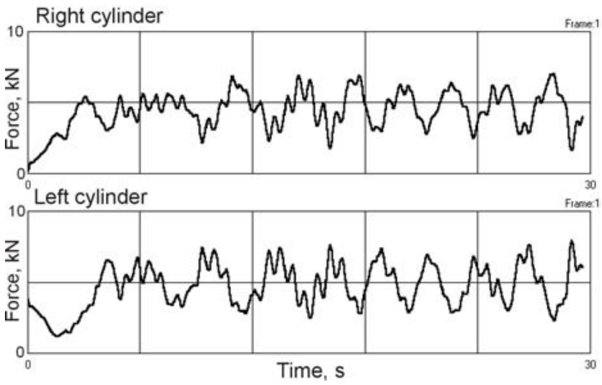

Figure 8. The forces in steering cylinders calculated from the pressure

The pressure measure permitted to determine forces in both – left and right cylinders – acting on articulated frame – fig.8. It shows that the frame is continually stretched – each cylinder develop the mean force about 5 kN amplitude oscillation is about 2-3 kN. This mean that joint is stretched by force about 10 kN and in this steering system has not gets any plays.

5. THE SNAKING PHENOMENON GAIN REASONS

For comparison of working efficiency of studied steering system arrangements, the time delay between signal from sensor of hydraulic steering cylinder length and signal from sensor of steering wheel turn angle was used. Analysing obtained results (fig.9,10) it is possible to affirm, that in standard arrangement the time delay is equal $\Delta t \approx 0,45$ s and it is higher then in arrangement with L-S system, where the delay is kept on level $\Delta t \approx 0,35$ s. One should pay attention that in L-S type arrangement although the signal time delay is decreased, the snaking phenomenon is more intensive and vehicle can loss their stability of movement (fig.1). This is due to considerably larger gain of steering system improving manoeuvrability and raising work efficiency during typical tasks as well as lowering the number of turns of steering wheel indispensable for realization of working cycle and the same the operator's effort.

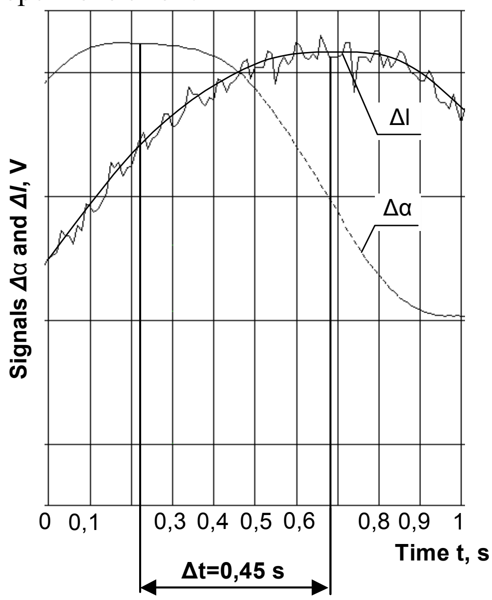

Figure 9. Time delay between steering wheel angle and cylinder length – steering system – Type 1

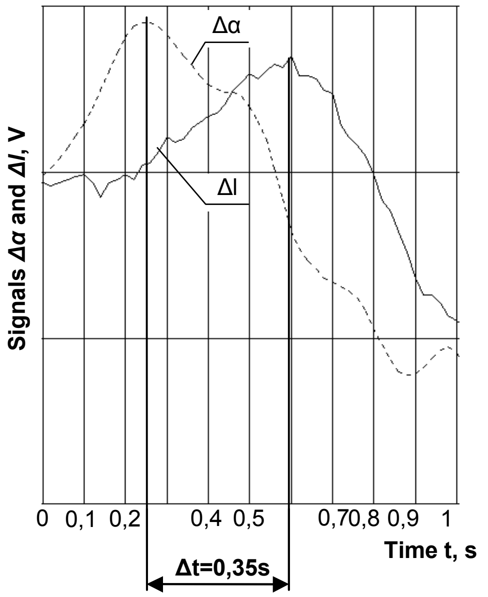

Figure 10. Time delay between steering wheel angle and cylinder length–steering system–Type 2

The growth of gain in steering system as well as growth of signal delay is the mine causes of increasing the snaking phenomenon. However in essential his scale depends on operator's skill and predisposition.

In order to recognize the possibility of snaking phenomenon limitation by means of gain limit as well as signal delays, two direct working research systems was designed - Type 3 and Type 4.

As a result of L-S arrangement elimination, the transmission time and delay was shortened in designed steering systems up to Δt=0,05 s.

Table 1.

The efficiency of works comparison for selected hydraulic steering systems of SL-34 articulated loader at rated speed 27 km/h

Steering system	Gain in steering system	Signal time delay	Average deviation amplitude
Type 1	1/5,5	0,45 s	27,4 cm
Type 2	1/3,2	0,35 s	58,4 cm
Type 3	1/6,5	0,05 s	18,0 cm
Type 4	1/16,25	0,05 s	8,1 cm

Although the signal time delay in steering system was considerable decrease (tab.1), the snaking phenomenon was limited in considerably smaller range. It should be taken in consideration that the smallest deviations from theoretical track, appear in arrangement with the smallest gain. On this bases the conclusion can be made that the operator is one of sources triggering the snaking phenomenon – limitation of possibility of his influences by gain decrease - stabilize the movement of machine, and the growth of steering system gain led to losing of stability and leaving the traffic lane.

This is completely in agreement with car research results described in [Chaczaturow] as driver behaviour. When the driver is high concentrated because of narrow corridor of travel – his reaction period is equal about 2,5-3 s.

So, in this way the main snaking phenomenon frequency is a driver excitation frequency. At this high speed of tractor movement it is a maximum velocity of driver reaction on sensed deviations.

6. DEVIATION SENSING DELAY

Because of sensed by driver lateral deviations limits their reaction and stability of movement, the research to determine possibility of improvements this sensing was conducted. In this order three position markers were situated on machine and the motion path was recorded with the digital video camera.

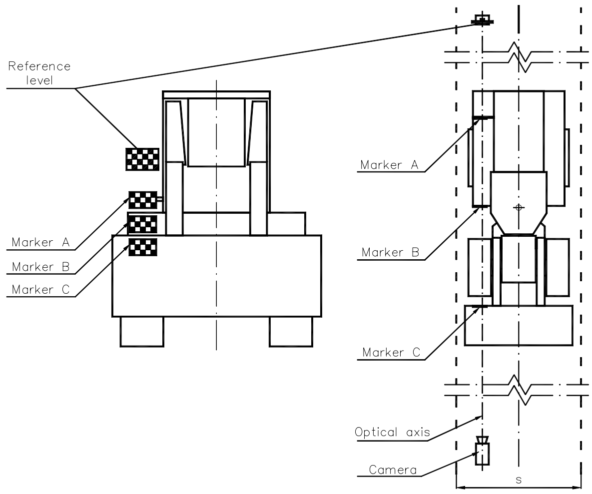

Figure 11. Diagram of loader markers movement path measurement system

Two markers (A and C) were intended to marking the motion paths of the front and rear of machine (located in distance 2,5 m from joint), and third (B) – showed the operator inclination – it was fixed in axis of the joint (fig.11). They possess measuring mesh which make up white and black squares side length 5 cm, arranged in figure "chessboard ". Both the pattern and the size of elements were well-chosen on the ground of earlier conducted tests – their goal was achievement maximum legibility as well as possible to obtainment measuring accuracy, depended from resolution of recording system.

The position and distance of recording camera were carefully chosen too, in order to assure the indispensable sharpness in whole measuring range.
The analysis of registered courses of motion paths obtained with video recording method (fig.12) shows, that the rear part of machine in relation to the front gets about 30% larger values of maximum side deviations. It results mainly from lower stiffness of rear axis tires working with almost 2-times lower inflation pressure than in front one.
The character of registered courses is completely consistent bat it should be noted that deviation sensed by operator (marker B) is delayed about 0,5 s in comparison with the movement of front of machine (marker C).
This delay explains why the hydraulic system improvements – 9-times reducing delay in steering system – are limiting deviation only 3-times. Time delay in sensing of deviation is comparable to delay in commercial steering systems.

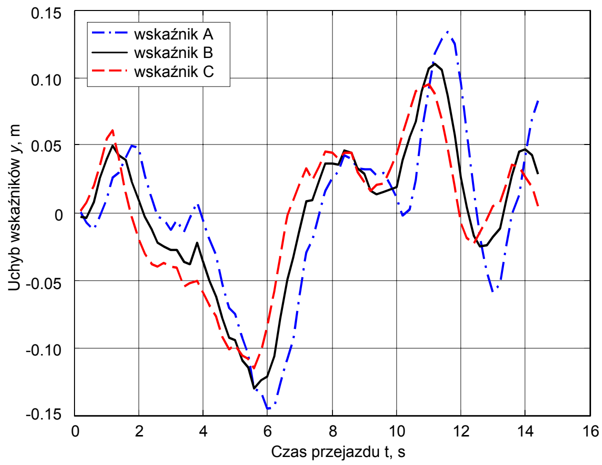

Figure 12 Recorded articulated loader markers movement paths

Dislocation the driver's seat (or future remote control sensors) from current position (close to frame joint) to the front of tractor - can be essential to accelerate the operator's reactions and to improve the stability of articulated machine movement.

7. INITIAL TURNS OF FRAME

Because in articulated tractor the driver fulfil the controller function it is necessary to determine his accuracy of operation. For this reason the simple test was conducted. After starting of movement the operator should adjust the frame in straight position and this angle of frame turning was measured to obtain error of adjustment. Example of test results is demonstrated in fig.13.

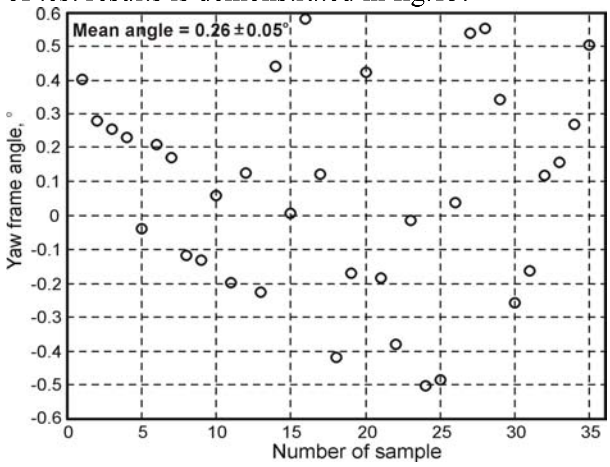

Figure 13. Initial turns of articulated frame – the driver mistake

It shows that the frame always has initial turn angle because of driver mistakes – error depends of his skill and experience and can reach 1 deg. This initial frame angle causes quick leaving the traffic lane and necessity driver acting.

8. CONCLUSIONS

Conducted at MUT research shows that main reasons of arising the snacking phenomenon are :

- residual steering moment and
- initial turns of articulated frame.

This phenomenon is gained by:

- time delay in hydraulic steering system –it is depend on established technical solution;
- time delay in deviation sensing – it is depend on dislocation of driver or remote control sensor/indicator;
- high gain in hydraulic steering system;
- low experience of driver.

The most important conclusion is that in articulated tractors the stabilising function of steering system is fulfilled by driver – however effects of his efforts are depend on signal time delay and gain used in arrangement, and sensed stimulus. Taking this in consideration the stabilising systems - aided the driver is possible to design and limitations of deviations and snaking phenomenon during remote control operation can be achieved.

9. ACKNOWLEDGEMENTS

The authors like to thank Polish Ministry of Science and Informatisation (Grant no.T00345346) for the financial support

9. REFERENCES

[Chaczaturow] Chaczaturow A.: Dinamika sistemy doroga – szina – awtomobil – woditiel. Maszinostrojenie. Moskwa 1976

[ISO] ISO 5010 –1994-02. Steering for off-road, rubber-tired machines

[Lopatka] Lopatka M.J., Muszynski T., Przychodzien T.: Research of High Speed Articulated Wheel Tool-Carrier Steering Systems. 9 ISTVS Conference, New Port 2003

[Wong] J.Y. WONG: Theory of ground vehicles. John Wiley & Sons, Inc. Toronto 1998

[SAE] Standard SAE J266. Steady-state control test procedures for passenger cars and light trucks. 1996