Article citation info:
Tarkowski S. Dynamic Testing for ATV Vehicles in Linear Motion. The Archives of Automotive Engineering - Archiwum Motoryzacji. 2016; 73(3): 119-132, http://dx.doi.org/10.14669/AM.VOL73.ART8

DYNAMIC TESTING FOR ATV VEHICLES IN LINEAR MOTION

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Summary

This article presents the results of the acceleration and deceleration testing of ATV vehicles under maneuvers in linear motion. When measuring lags the braking technique was taken into consideration. The maneuver was performed using three different combinations of the brake use. The first combination involved the use of the rear breaker exclusively, the second involved the use of front brake exclusively and the third the use of brakes for both axles simultaneously. Four vehicles of completely different technical characteristics (capacity and engine power, vehicle weight) were used. The measurements were carried out on dry surfaces of varying adhesion coefficient: asphalt and gravel. The maneuvers were performed to the extreme, i.e. with maximum possible force pressure on the brake levers and the maximum throttle opening. MEREX recorder was used to record the data. The results are represented as graphs (function of time) and tables (maximum parameter value for each maneuver). The results of research supplement specialist knowledge utilized in the process of road accidents reconstruction for vehicles of this type.

Keywords: ATV, quad, acceleration, deceleration

1. Introduction

Over the last several years the growing popularity of all-terrain vehicles (ATV), which are commonly referred to as quads, could be observed. ATVs are vehicles that can move in virtually any type of terrain. According to the definition formulated by the American National Standards Institute (ANSI), ATV type vehicle is an off-road vehicle equipped with low pressure tires, in which the steering is similar as in a motorcycle (i.e. "astride"). The vehicles of this type also equipped with a motorcycle type handlebar [7]. The Polish nomenclature also used terms such as "wszędołaz" or "quad" to identify vehicles of this type.

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ATVs can be used in a variety of ways. Due to its usability and sturdiness in the field they are often used as a tool by the Forest Service, border protection services or the military. Their wide range of optional equipment makes it possible to use them in agriculture, mountain rescue and by road traffic control or sanitary services. ATVs are also very often used for recreational purposes. This particular are of use may raise particular concern in the context of traffic safety. In recent years there has been a decrease in prices of this type of vehicles – the cheapest versions can be purchased for as much as PLN 3 000. The wide availability and relatively low price of the vehicles can be regarded as a key factor in the rise of the number of ATV users. The available statistics do not provide the full picture regarding the actual numbers of ATV users due to the imprecise legal references under which the ATV was registered before Poland signed the accession treaty with the EU.

First ATV vehicles appeared on the Polish market in the mid-90s. The legal situation at that time was not suitable to unanimously classify the vehicles and assign them to a specific group. Due to that fact they used to be registered as agricultural tractors, motorcycles, mopeds or as other motor vehicles. It was only after the implementation of approval regulations to Polish legislation that ATVs begun to be registered as motor vehicles. According to the amended regulations [5], [6] ATVs are motor vehicles of subtype specified as light quadricycles or quadricycles other than light. According to [5] light quadricycle is a vehicle whose unladen weight does not exceed 350 kg – not including the weight of the batteries if it is an electric vehicle. Additionally, the maximum design speed of a quadricycle cannot exceed 45 km/h and its engine cylinder capacity 50 cm^3 – with a spark-ignition engine. If the vehicle is equipped with a different type of internal combustion engine or electric engine, the maximum power must not exceed 4 kW. Quadricycles (other than light) are vehicles of unladen weight not exceeding 400 kg or 550 kg – for vehicles designed to carry goods (not including the mass of batteries in the case of electric vehicles). The maximum net engine power of the engine for such vehicle does not exceed 15 kW.

Establishing the precise number of ATVs is further hampered by the fact, that a great deal of them have not been registered at all, because of their use (at least theoretically) outside public roads. ATVs – similar to cars – have four wheels, but in comparison to cars their use is characterized by a much higher risk levels. The wheelbase and track width is substantially smaller than in the car, because of the weight proportions (vehicle/driver), the height of the mass center of a laden ATV in comparison to unladed substantially increases. From the viewpoint of stability and steerability this is a drawback and is potentially dangerous (ATVs are very unstable and easy to roll over) [2]. This feature a major disadvantage and reduces the safety level the vehicle use. ATVs are often fitted with powerful engines, which, combined with their low weight and high center of gravity may pose a problem for the users and be potentially dangerous – especially for unexperienced drivers. Regardless, driving an ATV does not require special licensing. Driving a light ATV requires at least an AM license. Driving a quadricycle requires a driver license of B1 category or higher [6].

Presently, no separate statistics are carried out that would constitute a basis for establishing the actual number of accidents involving the vehicles of this type [11], [12], however the increasing number of press reports on the subject may suggest that they are increasingly often [8], [9], [10], [13], [14], [15]. It may be assumed that the number of accidents with ATVs (especially serious) will continue to rise. Specialist literature on the subject used when assessing road accidents (inter alia [3] [4]) does not provide any quantitative data that could be the basis for reconstructing the course of events for road traffic accidents involving ATVs. In the light of the increasing number of this type of vehicles and the number of events connected to their use, that in injuries of both the users and members of the public, this may pose a serious problem in future. Similar situation was observed before – as in the case of motorcycles, whose substantial number appeared in the country in the 90s of the 20th century. Since then, there has been a steady increase in the number of accidents involving two-wheelers, at the same time accident reconstruction experts did not have any publications which could be the basis for describing the behavior of motorcycles in such situations. In view of the above it seems necessary to provide tools in the form of a set of parameters that could be utilized when assessing accidents with the involvement of ATVs. Considering the above it has been decide to tackle the issue.

The aim of the research described in this paper was to determine the maximum values for acceleration and deceleration for some ATV maneuvers in linear motion on different types of surfaces.

2. Research Methodology

The study was conducted on linear and horizontal measurement sections of asphalt and gravel surface (in both cases the surface was dry). The testing area is shown in Figures 1 and 2. The following was measured: acceleration in longitudinal axis during the quad run-up to the speed of 30 km/h as well as during braking and deceleration from this speed. For this purpose, MEREX device was used which was equipped with three accelerometers monitoring the longitudinal, lateral and vertical axes. The measuring resolution of the device is equal to 0.01 m/s^2, and the sampling frequency is 10 Hz. The device was also equipped with a GPS chip. The data (with the exception of data on the vehicle location and its instantaneous speed) were displayed onscreen as well as stored in the internal memory of the device. The view of the recording device shown in Figure 3. The recording device was not equipped with a system for compensating the vehicle body inclination angle for the accuracy of measurement. Thus, in order to reduce the measurement error it was on the steering wheel (the method of attaching the measuring device is shown in Figure 4. None of the tested vehicles was provided with a built-in speedometer. For the purpose of controlling the instantaneous speed of the vehicles during the test drive a Tom Tom device equipped with a GPS device and a display was used (Figure 3). Due to the accuracy of the device, as a part of the procedure, it was necessary to perform test drives in order to enable the driver, after reaching the set vehicle speed of 30 km/h, to maintain it for 2 seconds minimum, prior to applying the brake and starting deceleration.

The measurements were taken at short intervals, which allowed to maintain a similar temperature of the braking system friction elements for each trial. Due to the design of the brake system and the expected impact of the applied braking technique on the lag value, the braking technique was taken into consideration during the testing (with front brake, rear breaker and both simultaneously). In order to provide a possibly high repeatability of testing conditions, the test runs were performed by one drive. It was a man whose body weight amounted to approximately 100 kg (including clothing and helmet) and whose height was approximately 190 cm. His task involved performing the planned maneuvers with the application of maximum possible force pressure on the brake levers (during braking) and the maximum throttle opening (during run-up). When testing the acceleration of vehicles equipped with manual transmission, it was assumed to perform the maneuver without any change of gears.

Fig. 1. Asphalt surface – a place of research

Fig. 2. Ground surface – a place of research

Fig. 3. MEREX recording device (on the left side) and Tom Tom device (on the right side)

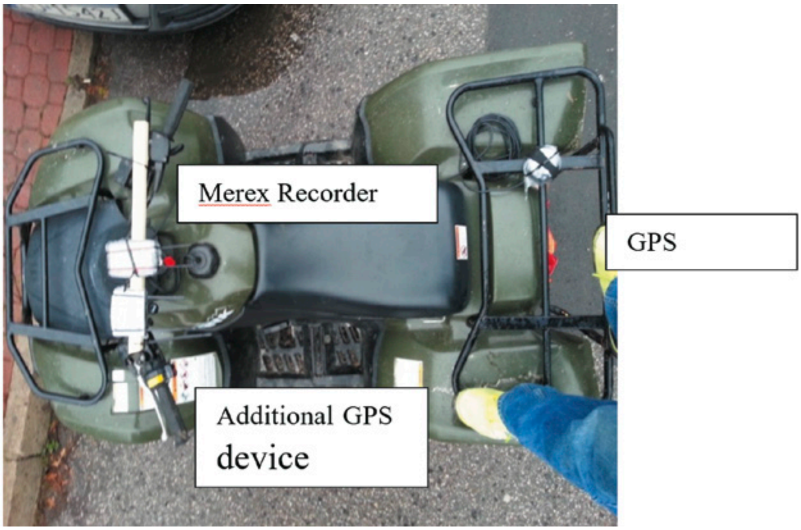

Fig. 4. The disposition method of measuring devices on the sample vehicle

3. The Subject of Testing

The testing made involved the use of four vehicles: Kymco MXU with cylinder volume of 150 cm^3, Suzuki Ozark with cylinder volume of 250 cm^3, Yamaha Grizzly with cylinder volume of 350 cm^3 and Arctic Cat with cylinder volume of 400 cm^3. In the further sections of the study will be referred to as "vehicles 1–4." They were vehicles of different class and purpose. They varied according to technical parameters, such as engine capacity or curb weight. Also the differences in the design of braking system for particular vehicles were crucial from the point of view of the research, as well as the type of torque conversion generated by the driving unit to the wheels. Detailed specifications of the tested vehicles are presented in Table 1. Only in two cases the producers specified the engine power. No information on the maximum torque of tested vehicles was obtained. None of the tested vehicles was approved nor was registered.

The vehicle 1 was powered by an air-cooled, four-stroke, single-cylinder engine with a displacement of 149 cc, equipped with an automatic continuously variable transmission (CVT). The curb weight of the run vehicle was 185kg (without driver). Power was transmitted through a chain to the rear wheels. The vehicle was equipped with two drum brakes on the front axle and a single, ventilated disc brake on the rear axle. During the test run the vehicle was equipped with off-road tires: 21/7-AT11 – front and 22/10-AT9 – rear. The general view of vehicle 1 is shown in Figure 5

Fig. 5. Vehicle 1

The vehicle 2 was powered by an air-cooled, four-stroke, single-cylinder engine with a displacement of 243 cc,. It was equipped with a semi-automatic transmission with reverse gear and five forward gears (CVT). The run vehicle curb weight was 194 kg (without driver). The power was transmitted to the rear wheels by the means of a drive shaft. The vehicle was equipped with two disc brakes on the front axle and a single drum brake on the rear axle. During the test run the vehicle was equipped with off-road tires: 22/7-AT11 – front and 22/10-AT9 – rear. The general view of vehicle 2 is shown in Figure 6.

Fig. 6. Vehicle 2

The vehicle 3 was powered by an air and oil cooled, four-stroke, single-cylinder engine with a displacement of 348 cc,. It was equipped with an automatic, five-speed gearbox of Ultramatic type. The curb weight of the ready to run vehicle was 243kg (without driver). The power was transmitted to two or four wheels by the means of a drive shaft. The vehicle was equipped with two disc brakes on the front axle and a single drum brake on the rear axle. During the test run the vehicle was equipped with off-road tires: 25/7-AT11 – front and 25/10-AT9 – rear. The general view of vehicle 3 is shown in Figure 7.

Fig. 7. Vehicle 3

The vehicle 4 was powered by an air and oil cooled, four-stroke, two-cylinder engine with a displacement of 366 cc,. It was equipped with an automatic, five-speed gearbox with an additional off-road gear. The curb weight of the ready to run vehicle was 316kg (without driver). The power was transmitted to two or four wheels by the means of a drive belt. The vehicle was equipped with a single disc brakes on each axle. During the test run the vehicle was equipped with off-road tires: 25/8-AT11 – front and 25/10-AT9 – rear. The general view of the vehicle 4 is shown in Figure 8.

Fig. 8. Vehicle

4. Testing Methodology

The acceleration and deceleration tests recorded, apart from the vehicle speed, the course of acceleration and deceleration as a function of time. The analysis of results provided the maximum values of acceleration and deceleration – as achieved during particular test runs. Subsequently the mean values were calculated and standard deviation determined. The results presented in this report represent the average value of maximum acceleration and deceleration – as achieved by individual vehicles. The collected data were assigned to each of the maneuvers carried out (acceleration, deceleration) as well as to each technique used to facilitate braking, i.e.:

- braking with the rear brake (hereinafter referred to as "A")
- braking the rear brake (hereinafter referred to as "B")
- braking with the use of both brakes simultaneously (hereinafter referred to as "C")

Table 1. Technical details of vehicles

Vehicle Number		**1**	**2**	**3**	**4**
Brand		Kymco MXU 150	Suzuki Ozark 250	Yamaha Grizzly 350	ArcticCat TRV 400
engine capacity [cm^3]		149.4	243	348	366
engine type		4-stroke, 1 cylinder	4-stroke, 1 cylinder	4-stroke, 1 cylinder	4-stroke, 2 cylinders
power [HP]		11	N/A	N/A	17
Weight of vehicle in running order: (kg)		185	194	243	316
tire size	front	21/7-10	22/7-AT11	25/7-12	25/8-10
	rear	22/7-10	22/10-AT9	25/10-12	25/10-12
brake type	front	2*drum	2*disc	2*disc	1*disc
	rear	1*disc	1*drum	1*drum	1*disc
transmission type		automatic	manual	manual	automatic
power transmission system		chain	drive shaft	drive shaft	drive belt
drive type		2x4	4x4	4x4	4x4

5. Test Results

The results for acceleration tests on asphalt and dirt are presented in Table 2. The average value of the maximum acceleration of the test vehicle on asphalt remained within the range of 2.10-4.13 m/s^2. The lowest acceleration values were obtained for vehicle 1, which was equipped with an engine capacity of lowest capacity and automatic transmission. The highest acceleration values on asphalt were obtained by vehicle 3 equipped with manual transmission. This vehicle was not powered with a highest capacity moto (of tested vehicles). The obtained result could be related to the ratio of vehicle's engine power to its total weight ratio during the test run – however due to the incomplete set of data on the power of the engines for all the vehicles it is not possible. Because of this, it seems advisable to relate the test results to the construction of power transmission systems and the adopted testing program that assumed no change to a higher gear in vehicles with a manual transmission (vehicles 2 and 3).

Table 2. Acceleration test results

measu-rement no.	Asphalt Surface Acceleration a_{max} [m/s²]				Asphalt Surface Acceleration a_{max} [m/s²]			
	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4
1	2.20	2.39	3.97	2.68	3.03	2.59	3.73	3.15
2	2.24	2.43	4.10	2.48	3.25	2.74	3.92	3.09
3	2.03	2.38	4.16	2.64	3.37	2.63	3.67	3.28
4	2.15	4.01	4.36	2.68	2.11	2.53	3.36	2.59
5	2.60	3.95	4.23	2.33	2.61	2.57	3.74	3.33
6	1.76	3.93	4.34	2.44	2.15	2.57	3.81	3.34
7	1.95	2.39	4.01	2.87	3.11	2.62	3.34	3.93
8	2.19	2.38	4.10	3.09	3.68	2.28	3.33	3.67
9	1.75	2.16	3.86	3.19	3.88	2.43	3.86	4.06
	2.10	2.89	4.13	2.71	3.02	2.55	3.64	3.38
	0.264	0.808	0.167	0.291	0.624	0.131	0.234	0.451

In the case of the test run performed on the dirt road the average acceleration value remained within the range of 2.55-3.64 m/s². The lower limit of the range specified for this type of surface was of a higher value than in the case of asphalt surface, whereas the upper value was lower than in the case of asphalt surface. The lowest acceleration values were achieved by vehicle 2, whilst the highest by vehicle 3. Comparing the results obtained by individual vehicles on the tested surfaces it can be seen that the vehicles equipped with automatic transmission achieved higher values of acceleration on dirt surface than on asphalt surface (vehicles 1 and 4). In the case of vehicles equipped with manual transmission the acceleration values for dirt surface were lower in comparison to those achieved for asphalt surface. This was related to the traction loss during acceleration as observed during vehicle test runs on dirt surface. In the case of vehicles with automatic transmission no traction loss was observed on dirt surface – a gear upshift took place instead.

The next stage testing comprised of brake tests. The results of this part of testing and the maximum lag values a_{Hmax} achieved by the vehicles are shown in Tables 3-6.

Braking with the use of brakes on both axles simultaneously resulted in the highest values of deceleration during test runs on all surface types. In the case of these vehicles, as it the case of similar testing carried out for motorcycles [1], it could be observed that the maximum value of braking deceleration depends on the breaking technique and is achieved when braking with the use of two brakes simultaneously. In the case of vehicle 4 such relation was not observed. This may be due to the braking system design for this particular ATV, where a single disc brake was used for each axle. The highest deceleration value was recorded for vehicle 1 braking with the use of both brakes simultaneously. In the case of this vehicle the highest deceleration values (of all vehicles tested) were achieved on both tested surfaces. For this braking technique on dirt surface similar deceleration value (to vehicle 1) was achieved by Vehicle 3. In the case of this vehicle, the deceleration obtained on asphalt surface was approximately 0.8 m/s² lower than for vehicle 1. Deceleration values for other ATVs braking with the use of both brakes at the same time were lower than for those described above. For vehicles 2–4 the difference between the maximum deceleration value obtained on asphalt and dirt surface compared for different braking techniques did not exceed 0.5 m/s². In the case of vehicle 1, on dirt surface, the recorded acceleration recorded value was lower than that achieved on asphalt surface by approximately 0.9 m/s² (in the case of emergency braking with the front brake and both brakes simultaneously).

Table 3. Vehicle 1 deceleration test results

Vehicle 1	Asphalt Surface			Dirt Surface		
	lag a_{Hmax} [m/s²]			lag a_{Hmax} [m/s²]		
measurement no.	brake "A"	brake "B"	brake "C"	brake "A"	brake "B"	brake "C"
1	5.45	3.22	7.76	3.83	2.82	6.29
2	5.50	3.09	6.99	4.76	2.23	5.88
3	5.27	3.42	6.78	4.41	3.21	6.55
	5.41	3.24	7.18	4.33	2.75	6.24
	0.12	0.17	0.52	0.47	0.49	0.34

Table 4. Vehicle 2 deceleration test results

Vehicle 2	Asphalt Surface			Dirt Surface		
	lag a_{Hmax} [m/s²]			lag a_{Hmax} [m/s²]		
measurement no.	brake "A"	brake "B"	brake "C"	brake "A"	brake "B"	brake "C"
1	4.47	3.20	4.97	4.46	2.96	5.49
2	5.46	2.88	5.34	4.23	3.07	4.66
3	4.81	3.08	5.23	4.37	3.23	6.67
	4.91	3.05	5.18	4.35	3.09	5.61
	0.50	0.16	0.19	0.12	0.14	1.01

Table 5. Vehicle 3 Deceleration Test Results

Vehicle 3	Asphalt Surface			Dirt Surface		
	lag a_{Hmax} [m/s²]			lag a_{Hmax} [m/s²]		
measurement no.	brake "A"	brake "B"	brake "C"	brake "A"	brake "B"	brake "C"
1	5.12	3.63	6.09	4.92	3.23	6.26
2	5.29	3.70	6.25	4.78	2.79	7.01
3	5.15	3.52	6.74	4.86	2.90	5.45
	5.19	3.62	6.36	4.85	2.97	6.24
	0.09	0.09	0.34	0.07	0.23	0.78

Table 6. Vehicle deceleration 4 test results

Vehicle 4	Asphalt Surface			Dirt Surface		
	lag a_{Hmax} [m/s²]			lag a_{Hmax} [m/s²]		
measurement no.	brake "A"	brake "B"	brake "C"	brake "A"	brake "B"	brake "C"
1	5.17	5.40	4.70	4.83	5.57	5.43
2	6.25	5.24	5.91	5.52	4.93	5.04
3	5.17	5.71	5.66	4.53	5.19	4.36
	5.53	5.45	5.42	4.96	5.23	4.94
	0.62	0.24	0.64	0.51	0.32	0.54

Table 7 summarizes the average values as based on the maximum acceleration and deceleration values achieved in the tests.

Table 7. The average values for acceleration and deceleration

	Asphalt Surface				Asphalt Surface			
	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4
acceleration	2.10	2.89	4.13	2.71	3.02	2.55	3.64	3.38
braking A	5.41	4.91	5.19	5.53	4.33	4.35	4.85	4.96
breaking A	3.24	3.05	3.62	5.45	2.75	3.09	2.97	5.23
breaking C	7.18	5.18	6.36	5.42	6.24	5.61	6.24	4.94

6. Conclusion

When analyzing the maximum acceleration for ATVs it is not advisable to relate this parameter to the engine capacity and its performance (power and torque) directly. In this case, it is required to pay specific attention to the ratio of power to the vehicle total weight (including the driver's weight), as well as the design of the used powertrain and its efficiency. Unfortunately, not all manufacturers of ATVs provide the parameters for the maximum power and torque values for engines installed in their machines. For the analysis of acceleration maneuver – specifically for dirt surface – it was observed that the wheels of vehicles with manual transmission tend to lose traction more often in comparison to vehicles with automatic transmission – due to which their actual acceleration assumes lower values. During the test runs, it was also observed that the maximum acceleration value for the vehicle equipped with off-road tires and automatic transmission is higher on dirt surface than on asphalt.

The testing carried out has shown that the braking technique of ATV-type vehicles may affect the maximum deceleration value – as in the case of motorcycles. However, when taking this parameter into account during accident analysis, attention should be paid to the particular solution used for the ATVs braking system design, as this can affect the maximum deceleration value. For the tested vehicles 1–3, in which the front axle was fitted with a dual brake (drum or disc) greater maximum deceleration values were recorded when braking with the use of the front brake – as compared to braking with the rear brake only (as with motorcycles). In the case of vehicle 4, which was fitted with the same braking system on both axles (single disc), the maximum deceleration values were similar – regardless of the braking technique. In the case of the vehicle 1, where the rear axle was fitted with a single brake disc, the axle was not equipped with a differential. Other vehicles, with each axle fitted with a single brake, were equipped with a differential. The used braking system designs may thus impact the maximum deceleration value, as well as the difference in deceleration in the function of applied braking technique.

Also the type of used tires may affect the maximum deceleration value. For the tested vehicles that were equipped with off-road tires, during braking with the use of both brakes simultaneously, a reduction in braking efficiency was observed in relation to the expected result, calculated with the use of the "classic method" for this type of surface (including the value of the friction coefficient $\mu = (0.8 \div 0.9)$, assumed for dry asphalt surface, deceleration calculated on the basis of the elementary relationship would equal to $(7.8 \div 8.8)$ m/s2. In the case of braking with the use of the same technique on dry dirt surface, the braking performance was slightly higher than the expected performance calculated using the "classic method" (including the value of the friction coefficient $\mu = (0.5 \div 0.6)$, assumed for dry dirt surface, deceleration calculated on the basis of the relationship would equal to $(4.9 \div 5.9)$ m/s^2. In addition, in the case of vehicles of 2 and 3 it was observed that the maximum deceleration value achieved on dirt surface was comparable to that obtained on asphalt surface. For vehicles 1 and 4 the deceleration values recorded on dirt surface were lower than those recorded on asphalt surface. Taking into account the present state of knowledge it is impossible to precisely and clearly explain the differences in the behavior of the tested vehicles on these roads. It may be assumed that this is related to the transmission system design and the adopted testing methodology. In this context, it seems appropriate to conduct further research on the topic.

When analyzing accidents involving ATVs on different surfaces as well as taking into consideration the time-spice ratio analysis, it is possible, with extreme caution, to estimate possible deceleration value, taking into account the road-tire interaction (for off-road tires specifically). They provide better traction on dirt surface than road tires. It is possible to form a statement that in the case of off-road tires the maximum deceleration value for braking carried out by using both brakes at the same time is comparable for both tested surface types.

The full text of the article is available in Polish online on the website http://archiwummotoryzacji.pl.

Tekst artykułu w polskiej wersji językowej dostępny jest na stronie http://archiwummotoryzacji.pl.

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