ISSN: 1231-4005
e-ISSN: 2354-0133
ICID: 1134110
DOI: 10.5604/12314005.1134110

ABS SYSTEM USE IMPACT ON BRAKING TORQUE IN AVIATION BRAKE

Zbigniew Skorupka

Institute of Aviation, Landing Gear Department
Krakowska Av. 110/114, 02-256 Warsaw, Poland
tel.: +48 22 1883885
e-mail: zbigniew.skorupka@ilot.edu.pl

Abstract

ABS (Anti-Locking) systems improve performance and safety of the braking systems. Use of ABS is now factory standard in both commercial and military aviation. ABS system in its origin was designed in order to prevent wheels from slipping and locking on the low friction surfaces such as ice. By preventing wheel, locking ABS system helps in not losing control over the vehicle during difficult braking conditions.

In Aviation ABS, systems were introduced quite early as mechanical systems but their common usage is connected with computer and electronic systems development in 1970's. In aircraft, ABS systems are responsible for safety of braking by preventing phenomena described above and for preventing landing with engaged brakes what is common in military and in big commercial aviation. In modern aviation ABS systems use is both safety and economical feature resulting in visible profits during airplane lifetime.

Other question is efficiency of the process i.e. braking torque value. Braking torque is the most important parameter of brake from exploitation point of view. It is directly connected with braking distance as well with amount of force needed to achieve assumed braking parameters for the mechanical vehicle. Stability of braking torque is important in order to get optimized characteristics of the braking process itself. Most of the brake characteristics and efficiency calculations were based on assumption that braking torque should be stable during braking process.

In this paper author would like to investigate ABS use impact on braking torque, which by definition is not stable in anti-lock equipped systems. Author will base on literature sources as well as on results of laboratory tests made during development of ABS system for 2700 kg take off mass airplane made in Landing Gear Laboratory of Warsaw Institute of Aviation in which author works on daily basis.

Keywords: *transport, motor vehicle, brake, brake design, brake tests, ABS tests, Anti-Lock system*

1. Introduction

In every moving vehicle, efficient braking is essential for safe operation. Unfortunately braking on slippery surfaces such as water, mud or ice can result in blockade (locking) of wheel, what can cause loose of traction control and great increase in braking distance. Such behaviour can result in accidents, fatal not only not only to the vehicle's crew or passengers but also to the people or property around it. In order to prevent that kind of situations Anti-Lock system (ABS) was introduced [1]. Gabriel Voisin designed first mechanical ABSs in 1929 for aviation use due to great speeds and dangerous conditions during landing phase of the aircraft. Because mechanical ABS systems were complicated and unpractical their usage was limited and finally abandoned (Fig. 2).

In 1959, first ABS system was used in motorcycle in order to prevent it from falling on the ground during heavy braking on wet surface. This system was a success, but common use of the ABS system in road vehicles started in 1970's when electronic control was introduced. Up until now ABS system, become standard feature in cars and soon in motorcycles.

In aviation, Anti-Lock systems are obligatory in large commercial machines and are desired addition in military airplanes. In aviation, ABS is responsible for two functions: one is to maintain traction during hard surface conditions and second is to prevent touchdown with locked wheels. Unless traction control is obvious from safety point of view, the anti-lock prevention during touchdown needs some explanation.

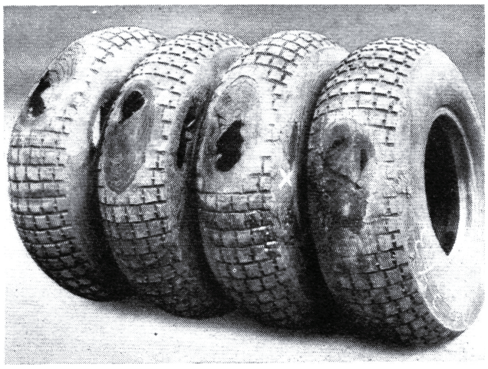

Fig. 1. Destroyed aircraft tyres due to locked wheels touchdown (source: [3])

During touchdown phase of landing, some of the pilots have bad habit of engaging the brakes before airplane touches the ground in order to decrease of the braking distance. Landing with applied brakes cause immediate wheels lock what leads to tyre damage (Fig. 1) (in extreme, tyre can burst during touchdown) and total loose of traction during the most dangerous manoeuvre in flight operation. Of course, it can also destroy brake itself making safe stop virtually impossible.

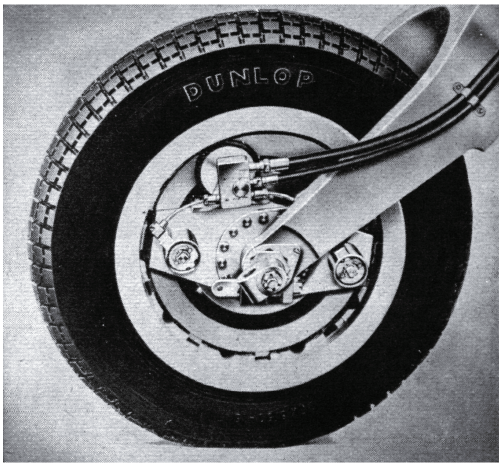

Fig. 2. Dunlop Maxaret mechanical ABS system in aircraft wheel (source: [2])

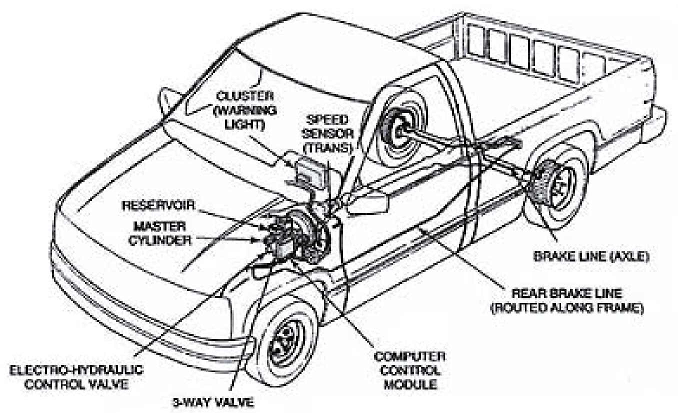

Fig. 3. The example of the ABS system used in modern cars (source: Internet)

Operation principle of Anti-Lock system is based on wheel rotation control. Set of sensors monitor wheel rotation while control system checks wheels movement. If any of the wheels stop rotating or difference between speeds of the wheels is too great, control system release brake of locked wheel (in simpler ABS systems there is no control which wheel is locked so all brakes are disengaged). When speed of the locked wheel starts to rise, control system enables normal braking.

Typical ABS system (Fig. 3) for hydraulic brakes consists of electronic control system (ECU), wheels speed transducers, servo valves for brake operation.

Nowadays ECU part of ABS system is a fast computer programmed with algorithm developed during laboratory testing. Algorithm can be fixed or learning. Fixed one is set to most common conditions obtained during tests both laboratory and made on vehicle. Algorithm is fixed and needs to be changed by the programmer. Learning algorithm, on the other hand, is present in laboratory and enables learn function during vehicle tests, what can be useful when ABS system should "know" how to interact with habits of specific operator.

One of the questions is what happens with brake efficiency when ABS is operational and how it affects average braking torque (moment) which is measure of brake efficiency. It is necessary to remember that in order to stop the vehicle on the desired distance, braking torque has to be optimal, stable and repeatable in every working condition of the brake [5].

In this article author will show comparison between braking torque in brake with ABS system engaged and disengaged. Presented figures are results of laboratory tests made at Institute of Aviation Landing Gear Laboratory.

3. Braking torque measurement and test equipment used.

All of the brake tests were made in Landing Gear Laboratory of Institute of Aviation in Warsaw using test stand designed for aviation grade equipment tests.

Mentioned test stand is used to test full-scale brakes in life like conditions. These tests give knowledge of full brake design performance and behaviour. Usually, full-scale tests are made after model tests in order to exclude material variable form brake tests. Full-scale tests are required to evaluate brake design and to prove its efficiency and reliability. Full-scale tests can be performed using test stands such as M3T (Fig. 4, 5 and Tab. 1) located in Landing Gear Laboratory in Institute of Aviation in Warsaw.

Fig. 4. M3T test stand for full scale brake testing with mounted airplane landing gear (source: IoA)

Fig. 5. M3T test stand with automotive brake and wheel mounted during tests. (source: IoA)

Tab. 1. M3T Technical Data

M3T TECHNICAL DATA		
N°	**Parameter name**	**Parameter value**
1.	Maximal weight of tested object including mounting parts	3T
2.	Maximal vertical force during the tests	118 kN
3.	Maximal buffer pressure	1.96 MPa
4.	Drum maximal rotational speed	800 rpm
5.	Drum maximal peripheral speed	211 km/h (58.6 m/s)
6.	Drum exterior diameter	1400 mm
7.	Drum width	530 mm
8.	Buffer force	0 – 22.2 kN

For tests which results are base for this article M3T test stand was expanded with pneumatic push (Fig. 6) where ABS equipped aviation wheel was mounted. Wheel and brake was taken from 2500 kg take off mass airplane.

Presented test stand can record number of parameters such as braking moment, braking force, wheel speed, temperature and hydraulic pressure.

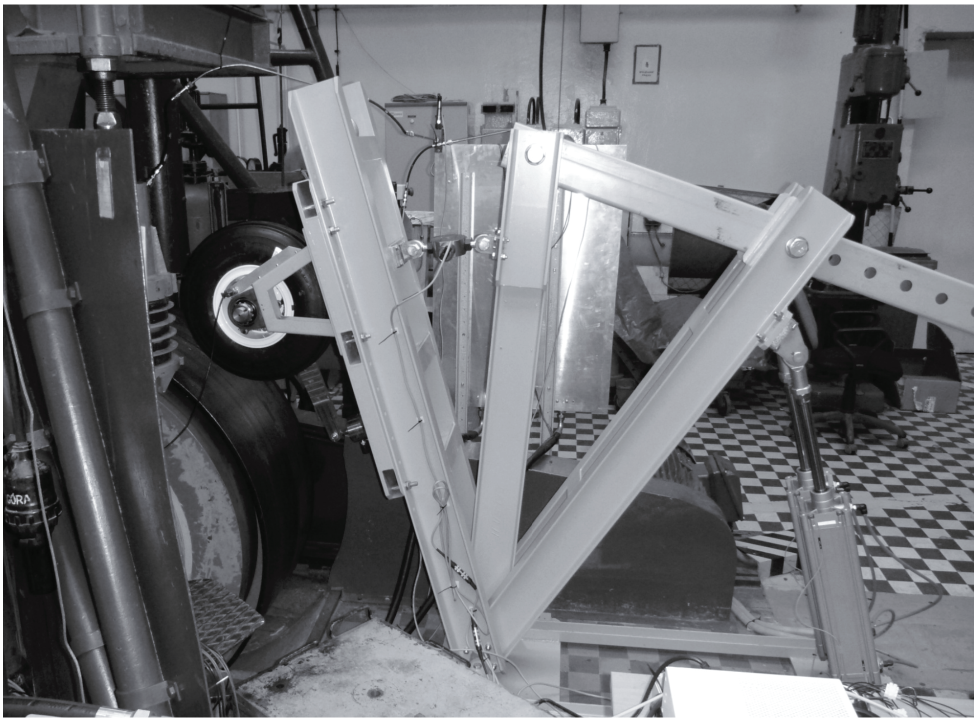

Fig. 6. M3T test stand adds on for ABS system tests (source: IoA)

4. Braking torque curves

During tests, two sets of parameters were used. Main difference was use of two different pushing forces (5 kN and 11 kN) and two surface treatments (slippery – drum covered with oil and non-slippery – dry, bare steel drum surface). These sets were necessary to estimate ABS characteristics during braking in different weather conditions for two masses of aircraft.

Results from the brake tests are shown in the Tab. 2 and on the graphs below (Fig. 7-10).

Tab. 2. Selected tests summary data

N^o	Test N^o	V_s [km/h]	V_f [km/h]	M_{havg} [Nm]	M_{hmax} [Nm]	$t_{h(max-30)}$ [s]	F_{doc} [kN]	ABS status	Drum surface
1	0220	143	30	620	991	11.25	11.34	OFF	Non-slippery
2	0221	141	30	495	759	15.74	5.15	OFF	Non-slippery
3	0222	140	30	831	1489	10.21	5.15	ON	Non-slippery
4	0223	134	30	365	1287	26.81	5.23	ON	Slippery
5	0224	127	30	674	1702	9.56	11.36	ON	Slippery
6	0225	138	30	588	1391	11.43	11.33	OFF	Slippery

Braking time t_h was calculated in range of speeds V from V_{max} to V_f, which were the range of ABS operation. Range of speeds was the same in all of the calculation for ABS enabled and disabled tests in order to achieve direct comparison of tests results. Braking torque M_h value both maximal M_{hmax} and average M_{havg} was estimated in the same speeds range as time. Pushing force F_{doc} was stable in every test, and it is shown as reference.

As it can be seen in the Tab. 2 and on the graphs above for non-slippery surface, there is almost no change of braking torque characteristics over braking time. ABS enabled test shown few system excitations, which were irrelevant for all of the process. Comparison between braking torque values in both cases shown braking torque improvement in ABS enabled tests, it could happened due to better friction pads arrangement in this test as well as for different hydraulic pressure applied in both of the tests.

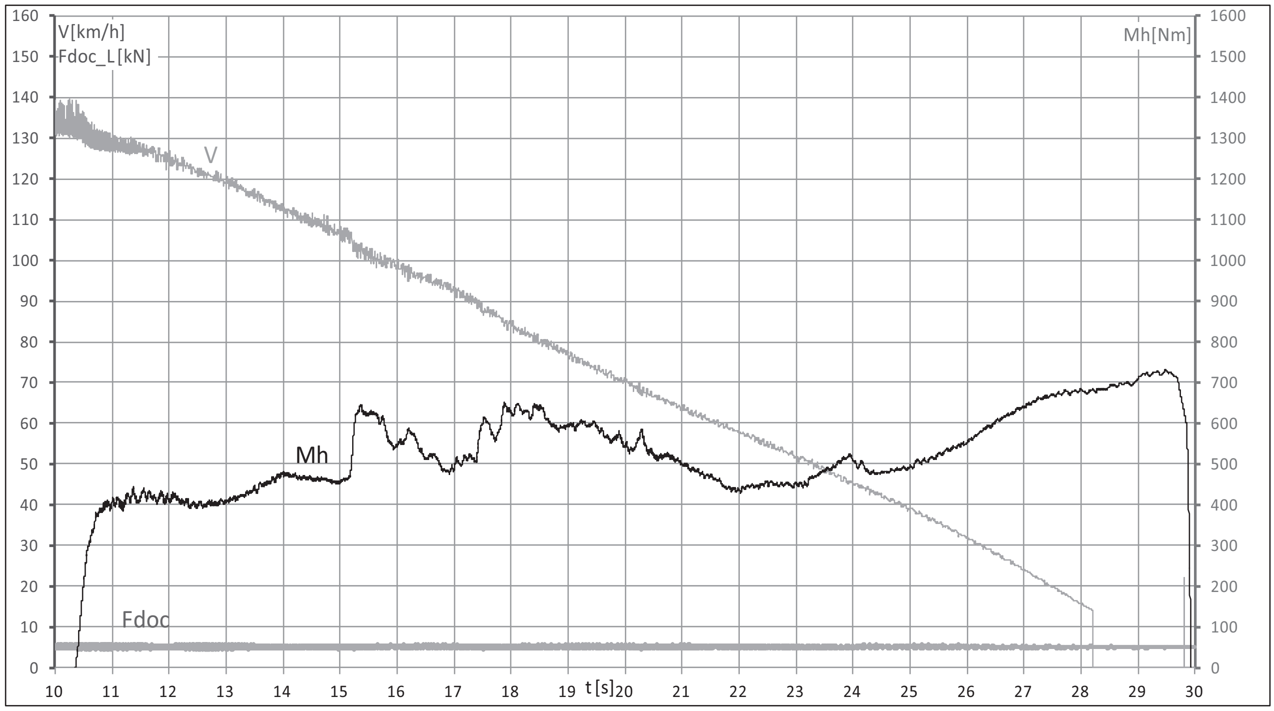

Fig. 7. Test 221, ABS-off, non-slippery surface, pushing force 5 kN

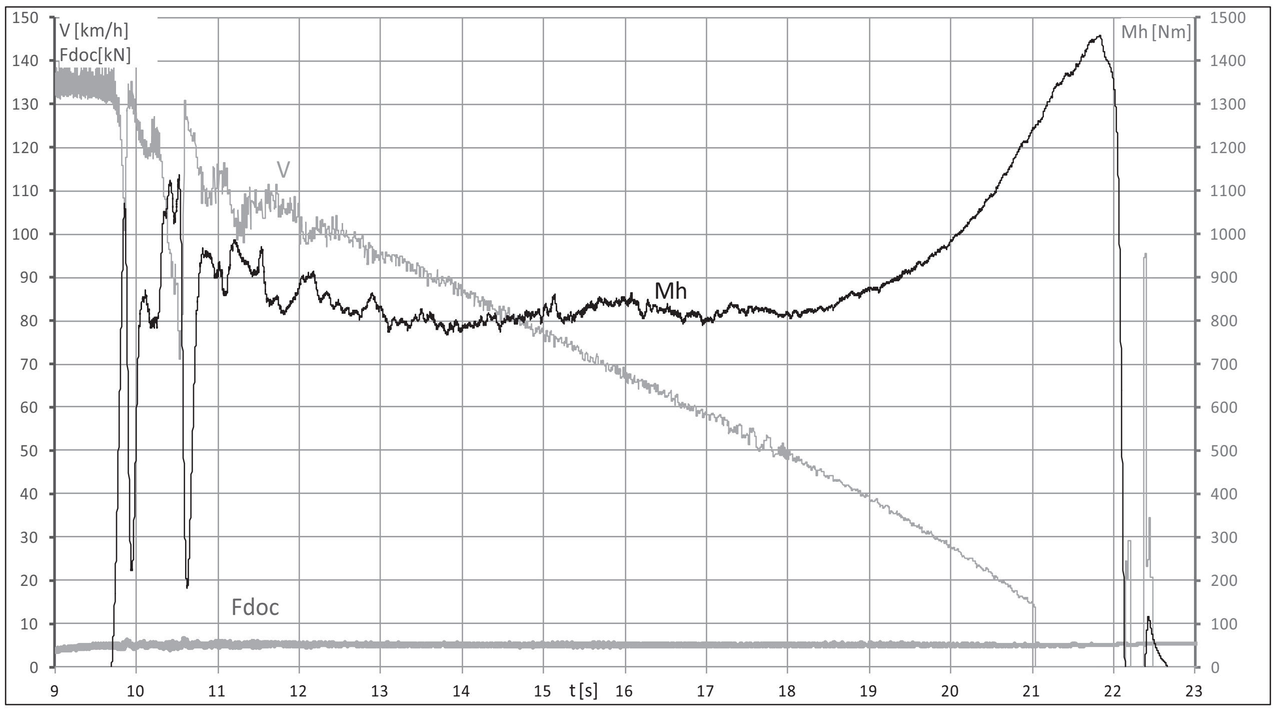

Fig. 8. Test 222, ABS-on, non-slippery surface, pushing force 5 kN

Ratio between maximal and average braking torque in non-slippery case ratio is similar every time between 0.5 and 0.65. Braking time in all of the non-slippery surface cases was similar and ABS enabling and disabling had little effect on it.

In slippery surface tests, there was visible change in brake behaviour depending on ABS state. First of all characteristic of braking torque is different. For non-ABS tests graph shows standard braking curve similar to non-slippery with difference in time of maximal braking torque achievement. In ABS enabled tests, average braking torque is much more stable than in non-ABS tests and it is visible that system logic tries to avoid wheel lock during process.

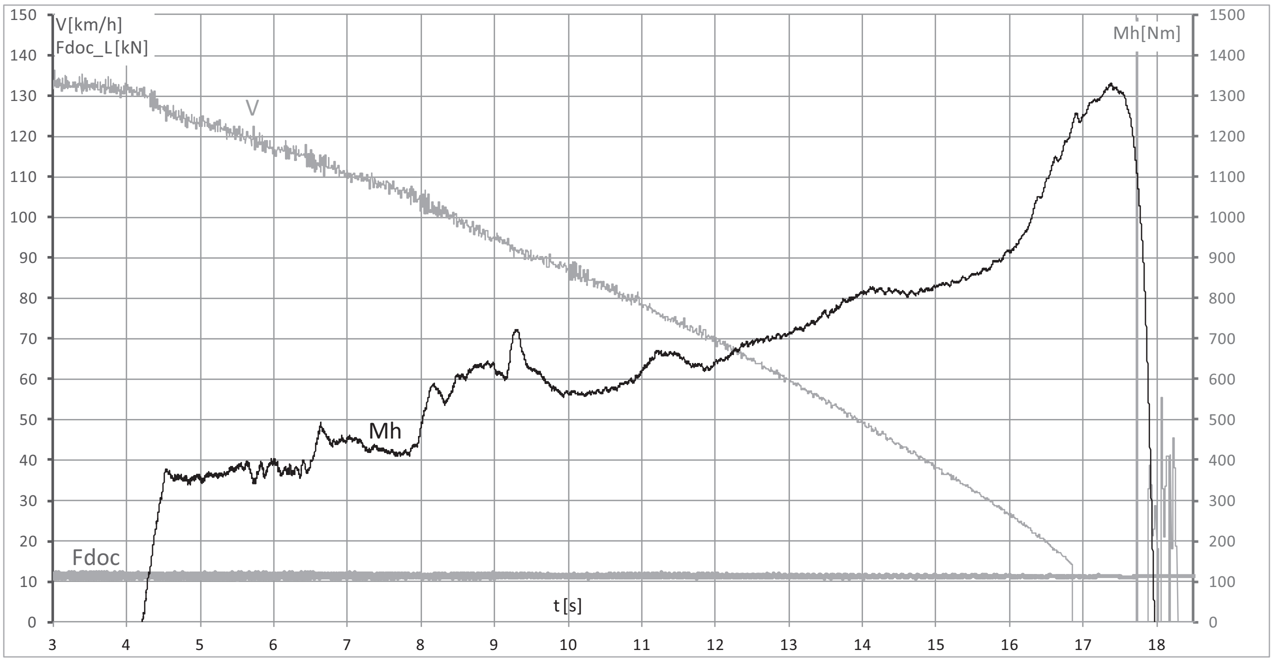

Fig. 9. Test 225, ABS-off, slippery surface, pushing force 11 kN

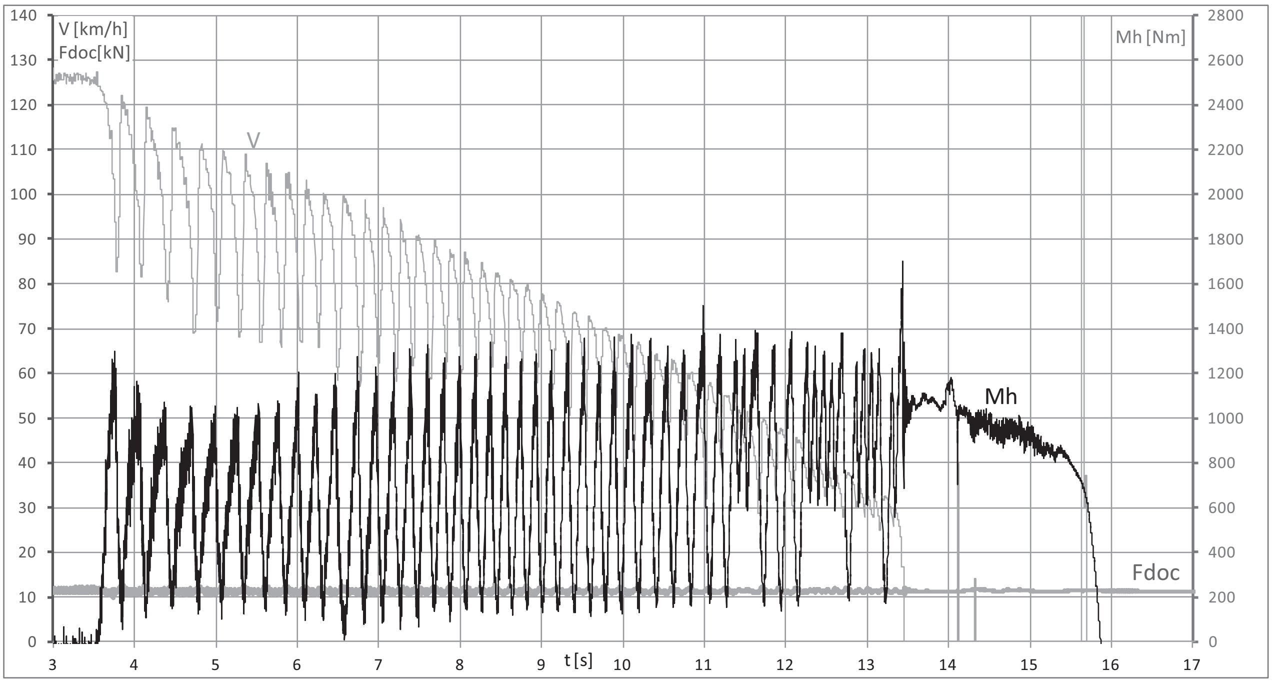

Fig. 10. Test 224, ABS-on, slippery surface, pushing force 11 kN

Maximal and average braking torque ratio is almost the same for ABS enabled and disabled tests, it varies between 0.38 and 0.42. It is visible that ABS enabled system-improved braking time. This phenomenon occurred in most of the tests performed.

5. Summary

During the laboratory tests, ABS system proved not making visible difference in braking torque behaviour on non-slippery surface, what is explainable due to unnecessary of the system in such conditions. On the other hand, ABS system is designed to aid braking process on slippery surface and tests had proven this behaviour. Braking torque improved when ABS is enabled (as well as the time of braking) what can be translated to lower braking distance. It is also worth to mention that Anti-Lock systems could lower braking torque and braking distance but their main purpose is not letting to lose traction during braking process [4].

References

[1] Paprzycki, I., Skorupka, Z., *Analiza Systemów ABS w Pojazdach Mechanicznych,* TTS, Technika Transportu Szynowego, 2013.

[2] Smith, M., *Dunlop Maxaret Anti-skid unit for new high-performance aircraft*, Flight International, No. 2356, 1954.

[3] Smith, M., *Non-skid Braking*, Flight International, No. 2336, 1953.

[4] Paprzycki, I., Skorupka, Z., *Założenia projektowe układu ABS do małego samolotu o masie startowej nieprzekraczającej 2500 kg*, Logistyka, 2, 2014.

[5] Ścieszka, S. F., *Hamulce cierne*, Gliwice – Radom 1998.