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INFLUENCE OF ABS SYSTEM USE ON AVIATION BRAKE TEMPERATURE

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Abstract

The main functions of an aviation brake system are to slow the speed of the vehicle, to perform stable deceleration, and to hold the vehicle stationary after it stopped. They must perform safely under a variety of operating conditions such as slippery, wet and dry runways, full or light load of the vehicle, new or worn brake linings, novice or experienced pilot, etc.

The experimental tests show that about 95% of friction energy is converted into thermal energy by plastic deformation of brake linings surface layers and other deformations. The friction materials temperature growth is caused by this energy transformation. The influence of braking temperature is very important to the tribology characteristics, durability and reliability of friction brakes.

Landing Gear Department Laboratory performed many experimental tests on full-scale brakes and also on friction material samples. It was performed on the special laboratory test rigs.

During the Anti Lock Braking system test, the Landing Gear Department Laboratory workers performed the brake linings temperature measurements. Author observed a positive influence of ABS system use on temperature curve. The aim of this article is to compare the test results of braking with ABS system applied to braking without ABS.

Keywords: *Anti Lock braking system, ABS, landing gear, brakes, test, temperature measurements*

1. Introduction

Landing Gear design requires knowledge of more engineering disciplines than any other aspect of aircraft design. It includes heavy forgings, machined parts, mechanisms, sheet metal parts, electrical systems, hydraulic systems and a wide variety of materials such as aluminum alloy, steel, titanium, carbon and composites. Landing Gear designer must also have knowledge of strength calculations.

Brakes, in connection with an Anti Lock Braking system (ABS) (if provided), are used to stop, or help to stop, an aircraft. Brake use also involves steering the aircraft by differential action, holding the aircraft stationary when parked and controlling speed while taxiing. Most aircraft use multi-disk brakes [2].

Anti Lock Braking, system is used to minimize stopping distance (if possible) and to reduce the possibility of excessive tire wear and blowout caused by excessive braking. ABS system does this by constant measurement of the wheel speed to provide constant brake force near skidding point.

Scrubbing tire in an undetected skid can, in seconds, burn and explode. In an even shorter time, the tire can wipe out and be doomed to be removed and replaced. These problems are eliminated by using an Anti Lock Braking system that combines mechanical, electrical and hydraulic technology [1].

ABS calculations are performed in the following manner. The momentary speed of each wheel is periodically updated and compared to a calculated aircraft velocity. The difference between wheel speed and aircraft velocity expresses the wheel slip. When the slip exceeds its maximum, braking efficiency begins to decrease. The electronic control unit detects this excessive wheel slip and produces signal reducing the brake pressure. The electronic control unit reduces the brake pressure until the wheel slip returns to the optimum level. When the calculated slip is below the maximum required value no signal is generated. The pilot's brake pedal controls the braking level [3].

Fig. 1. Landing Gear damaged by burned tire after excessive braking [6]

Instytut Lotnictwa (Institute of Aviation) Landing Gear Department engineers designed and tested the ABS system for an existing aircraft of MTOW 2500 kg. Author performed many experimental tests on the full-scale brake with ABS applied. The brake linings temperature measurements were carried out during the ABS system optimization.

2. Temperature measurement

For an aircraft decelerating from a higher velocity V_1 to a lower velocity V_2 the braking energy E_b is:

$$E_b = \frac{m}{2}(V_1^2 - V_2^2) + \frac{I}{2}(\omega_1^2 - \omega_2^2)\,, \tag{1}$$

where:
I – mass moment of inertia of rotating parts,
m – aircraft mass,
V_1 – velocity at begin of braking,
V_2 – velocity at the end of braking,
ω_1 – angular velocity of rotating parts at begin of braking,
ω_2 – angular velocity of rotating parts at end of braking.

If the aircraft comes to a complete stop, then equation becomes

$$E_b = \frac{mV_1^2}{2} + \frac{I\omega_1^2}{2}\,. \tag{2}$$

Braking energy corresponding to the aircraft of mass m moving with longitudinal velocity V_1 can be imitated in the laboratory by the drum of mass moment of inertia I_b rotating with angular velocity ω_b. For the laboratory brake test needs the equation (2) becomes:

$$E_b = \frac{I_b\omega_b^2}{2} + \frac{I\omega_1^2}{2}\,. \tag{3}$$

During braking, the energy of a moving aircraft is converted into thermal energy via the mechanism of deforming the friction partners. There are two different locations where frictional forces are produced and where heat is generated. Heat generation occurs when a motion exists between the friction materials. A decelerated aircraft with its tires operating near their maximum braking capability, without complete wheel lockup occurring, has the tires operating, at approximately 8 to 12% slip. A tire slip of 10%, for example, means that the circumferential velocity of the tire is only 90% of the longitudinal velocity of the vehicle. This indicates that only 90% of the kinetic energy of the vehicle is absorbed by the brakes. The remaining 10% is absorbed by the tires and the road surface [5].

Estimation of the brake disc temperature is relatively complicated. The solution depends on many issues, e.g. heat transfer coefficient, heat flux direction, thermal properties of friction partners, ambient temperature. One of the easies methods is estimation of the *"μpv"* product and comparison to the acceptable empirical values, but is little accurate. Although other methods especially numerical, FEA methods are more reliable, laboratory test results are the most representative [4].

For the ABS system test purpose, it was decided to perform non-contact temperature measurements, which advantages are:

– temperature measurement of moving objects,
– very fast response time,
– no influence on the measuring object,
– non-destructive measurement.

Each body with a temperature above the absolute zero emits an electromagnetic radiation, which is proportional to its internal temperature. A part of it is infrared radiation, which can be used to measure the body`s temperature. The beams are focused on a detector element, which generates an electrical signal proportional to the radiation. The object temperature is

$$T_{obj} = \sqrt[n]{\frac{U - C \cdot T_{amb}^{n} + C \cdot \varepsilon T_{amb}^{n} + C \cdot T_{Pyr}^{n}}{C \cdot \varepsilon}}\,, \tag{4}$$

where:

T_{obj} – measured object temperature,
U – detector signal,
T_{amb} – temperature of background radiation,
T_{Pyr} – temperature of the device,
C – device specific constant,
ε – emissivity.

Infrared thermometers do not cover the whole wavelength range, thus the exponent n depends on the wavelength λ. At wavelengths ranging from 1 to 14 μm n is between 17 and 2.

The equation shows that the emissivity ε is significant when determining the temperature with radiation measurement. The emissivity stands for the relation of thermal radiations, which are generated by a grey and black body at the same time. The maximum emissivity for the black body is 1. A black body is a radiator, which absorbs all incoming radiation. It shows neither reflection nor transmissivity. A black body radiates the maximum energy possible at each wavelength. A grey body is an object, which has the same emissivity at all wavelengths and emits less infrared radiation than a black radiator (ε<1). The emissivity depends on the material, its surface, temperature, wavelength and sometimes on the measurement arrangement. The emissivity data for various materials can be found in the technical literature. However, the best measurement results require the object emissivity determination. It can be managed by additional temperature measurement with a thermocouple. The emissivity should be adapted so that the temperature measured by pyrometer corresponds to the value shown with the thermocouple measurement [7].

Tab. 1. Technical data of the non-contact temperature measurement

Temperature range	-35° to +900°C (-30°F to 1650°F)
Spectral response	8 – 14 μm
Accuracy	±0.75°C or ±0.75% of reading
Temperature coefficient	0.05K/K or ±0.05%/K
Temperature resolution	0.1°C
Repeatability	±0.5°C or ±0.5% of reading
Ambient temperature	0°C-50°C

3. Test rig setup

Testing the full brake with ABS system applied was performed on the Młot 3T test stand, rotating drum and the pushing ramp.

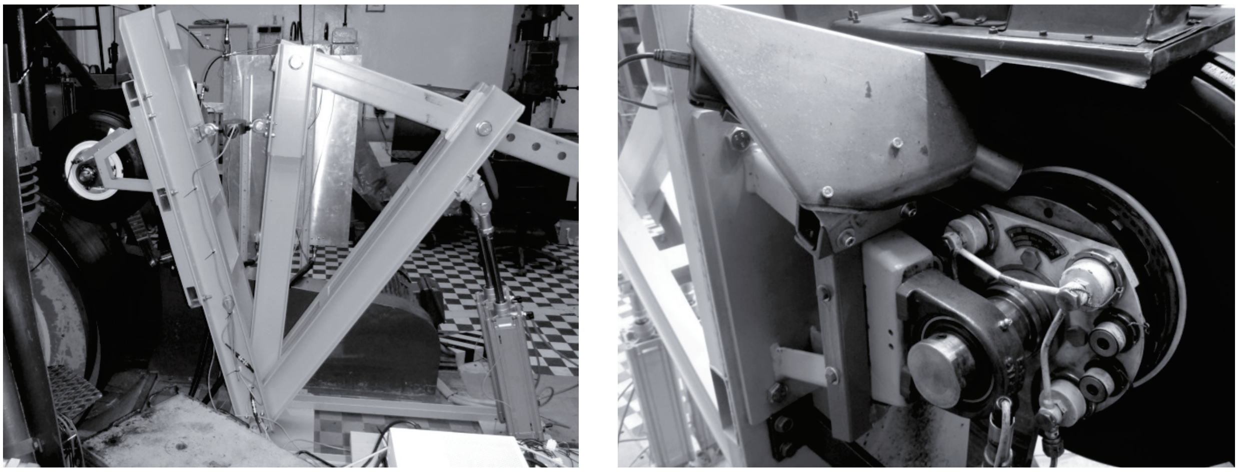

Fig. 2. ABS system test rig: pushing ramp, shielded pyrometer for temperature measurements

Młot 3T test stand with rotating drum allows performing similar to real conditions brake tests. The main purpose of the test is as good as possible imitation of the braking conditions including wheel load, velocity, tire pressure, braking torque and braking distance. The pushing ramp allows imitating conditions similar to landing, e.g. growing tire load due to reducing lift force and changing slip coefficient due to surface condition.

Complete brake set is mounted on the test rig and checked for its functionality, which involves hydraulic tightness, proper disk movement and general assembly. Afterwards, the series of test are performed on the test rig, during which the following parameters are measured:

- braking torque,
- hydraulic pressure,
- velocity of the wheel and rotating drum,
- pushing force,
- brake linings temperature,
- braking distance.

4. Measurements

Tests of the existing brake were made using calculations made in Instytut Lotnictwa Landing Gear Department in order to set up correct test parameters. Brake temperature was measured on the rotating disk lining outer surface. During the tests different parameters were used: pushing force 5 kN and 11.36 kN, ABS enabled and disabled. The aim of the tests was to imitate real brake exploitation conditions, such as wet and dry runway, different aircraft masses or tire load reduced by lift force.

Results of the brake tests are shown below.

Tab. 2. Braking test results

N°	Test N°	V_s [km/h]	T_{MAX} [°C]	T_{AVGB} [°C]	T_{AVG90} [°C]	t_h [s]	F_P [kN]	ABS	Surface
1	221	140	371	303	336	15.74	5.15	OFF	Slippery
2	225	138	502	410	328	11.43	11.33	OFF	Slippery
3	227	140	422	303	394	11.58	5.11	ON	Slippery
4	228	140	576	448	343	10.90	11.24	ON	Slippery

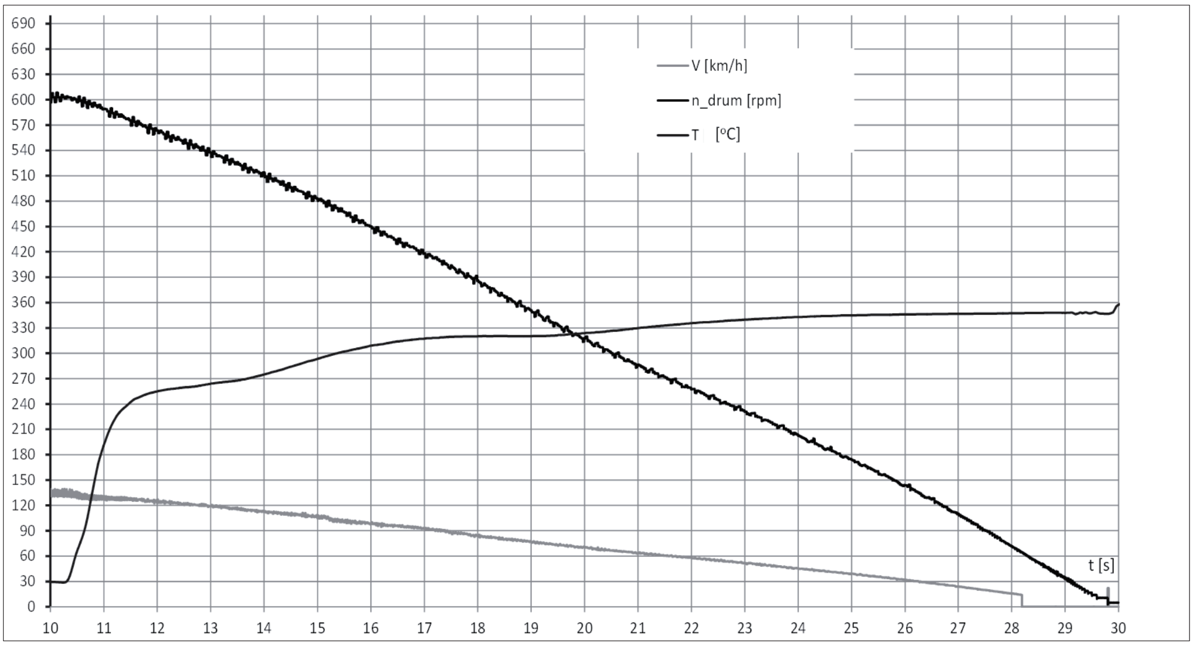

Fig. 3. Test 221. ABS – OFF, slippery surface, pushing force 5.15kN

Braking time t_h was calculated from braking beginning to V=30 km/h, which is the range of ABS operation. T_{MAX} is maximum brake temperature during the trial. T_{AVGB} is average brake temperature during braking time t_h. Average brake temperature T_{AVG90} is calculated from the braking beginning to 90 seconds after. F_p is average pushing force in braking time t_h.

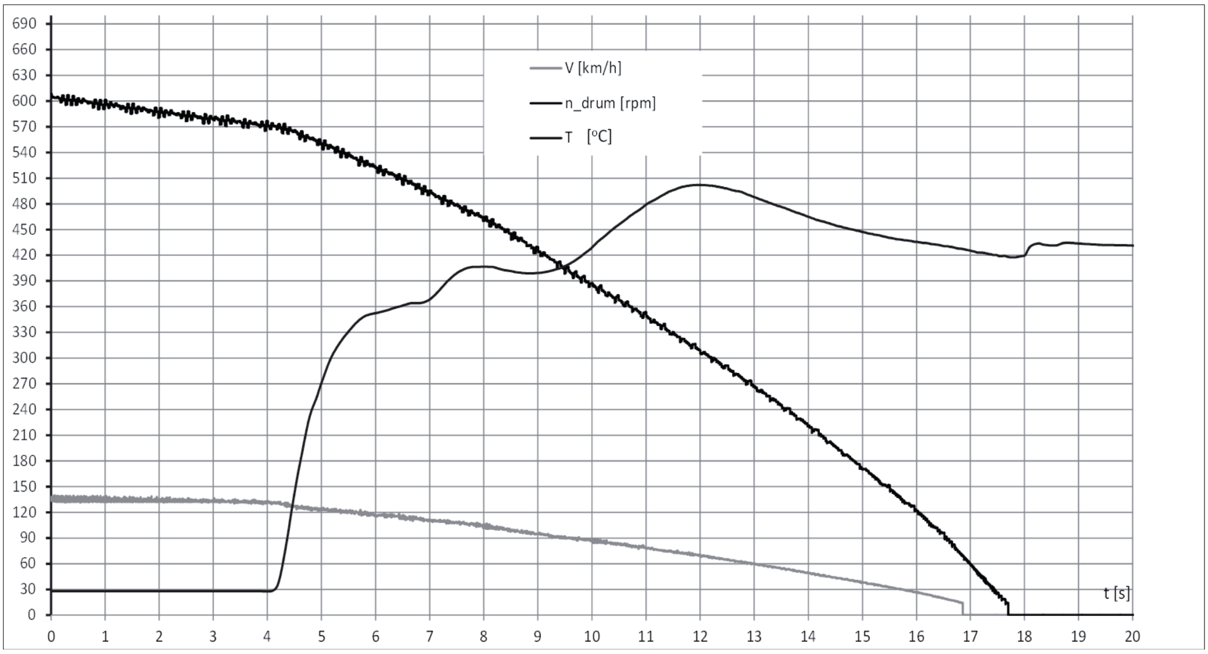

Fig. 4. Test 225. ABS – OFF, slippery surface, pushing force 11.33 kN

ABS disabled test shown similar temperature curves shape. It is noticeable that temperature rose very fast at the beginning of the braking process, reached its maximum value and slowly dropped to stable value to the end of the braking. Average and maximum temperature values calculated after the test depend on the pushing force F_p; causing differences in braking time t_h.

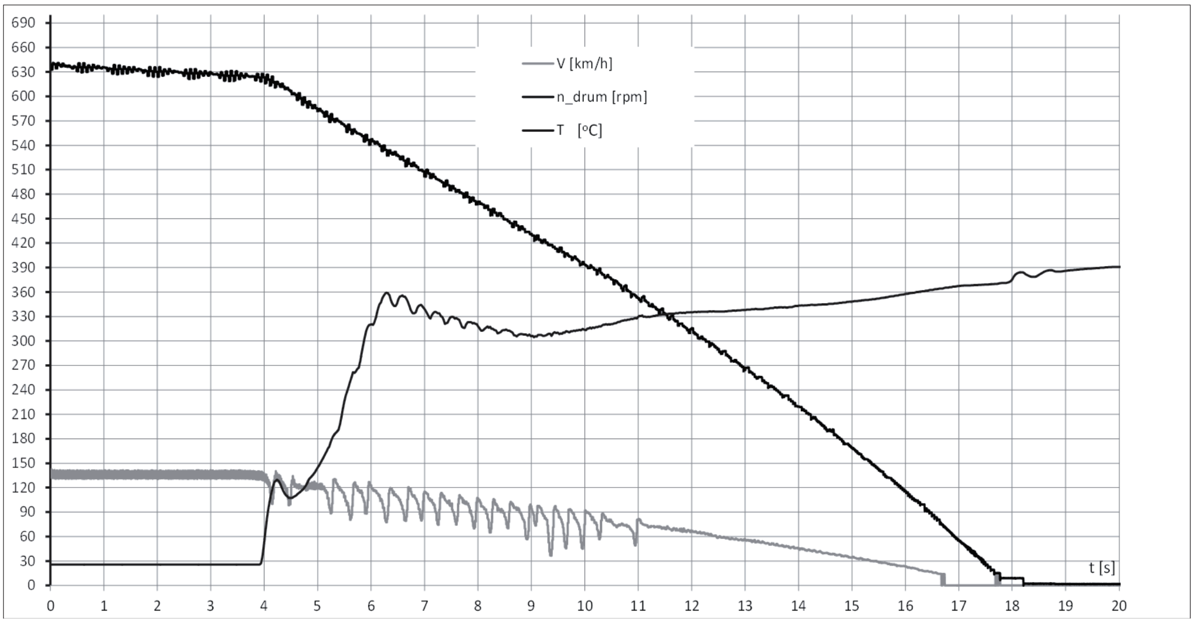

Fig. 5. Test 227. ABS – ON, slippery surface, pushing force 5.11 kN

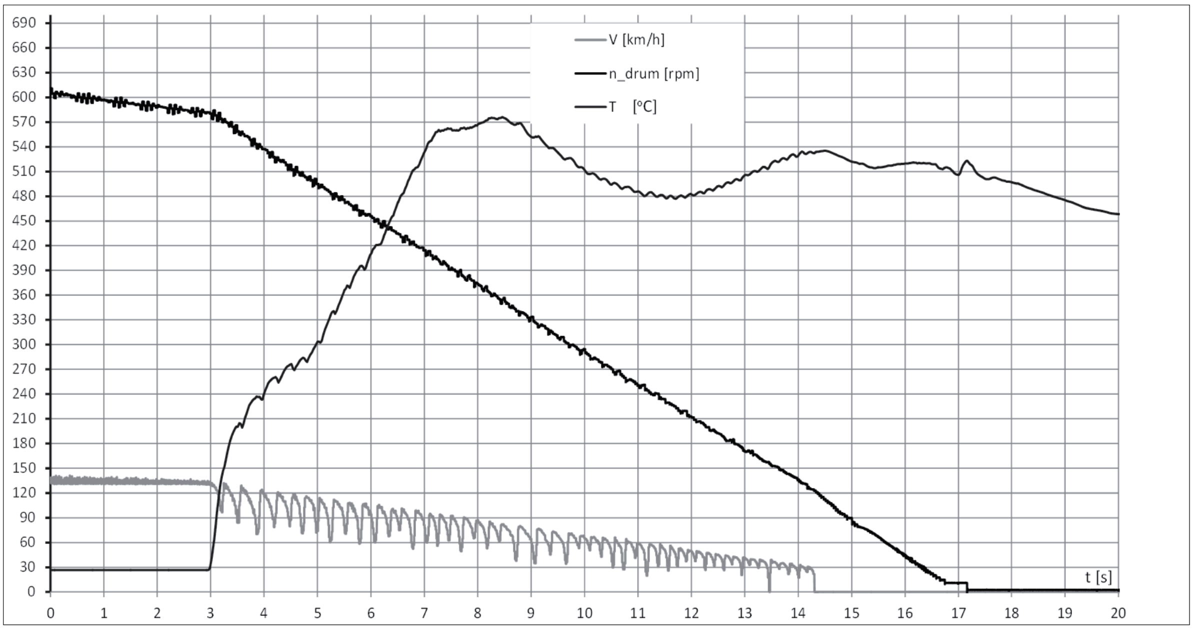

Fig. 6. Test 228. ABS – ON, slippery surface, pushing force 11.24 kN

ABS enabled test shown differences in temperature curve shape from the ABS disabled test. It was noticeable that every brake pressure reduction caused momentary temperature drop. The temperature rise at the braking beginning was slower but reached higher maximum value. Differences in maximum values were about 12-13% and in average values did not exceed 14%. Higher temperature values were caused by shorter braking time and distance. Braking energy was distributed in shorter time.

As it can be seen on the Fig. 7 and 8 temperature curve shapes after the end of the braking are very similar. The values may vary depending on the braking time t_h, when shorter braking distance cause faster energy absorption, or be almost equal when braking time is comparable with ABS disabled and enabled test for the same trial parameters.

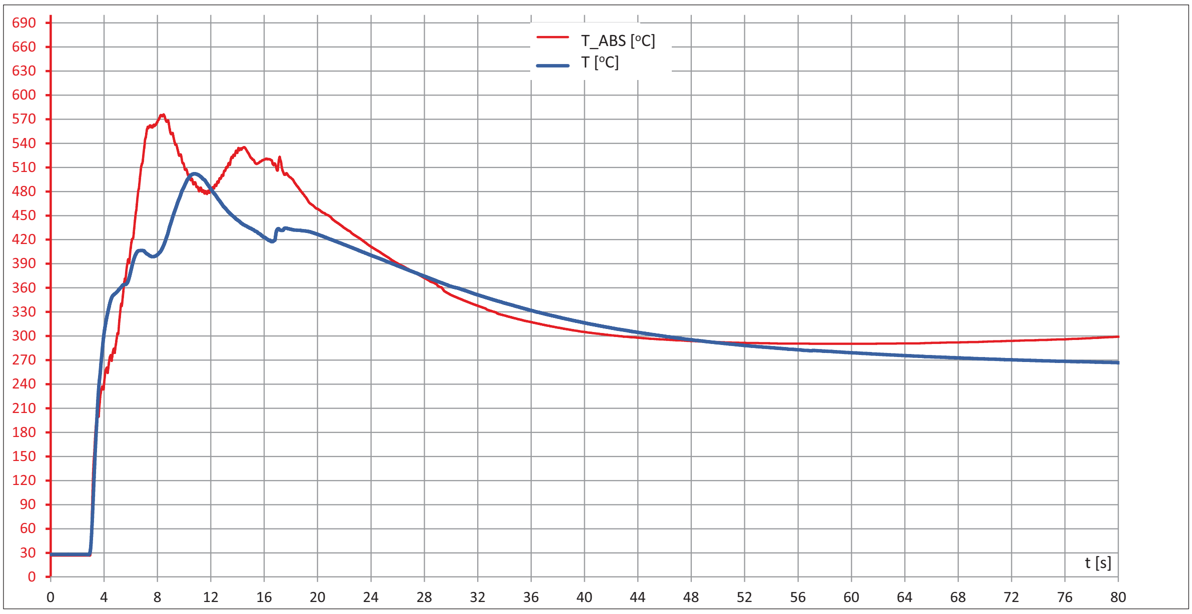

Fig. 7. Temperature comparison from 228 and 225 test

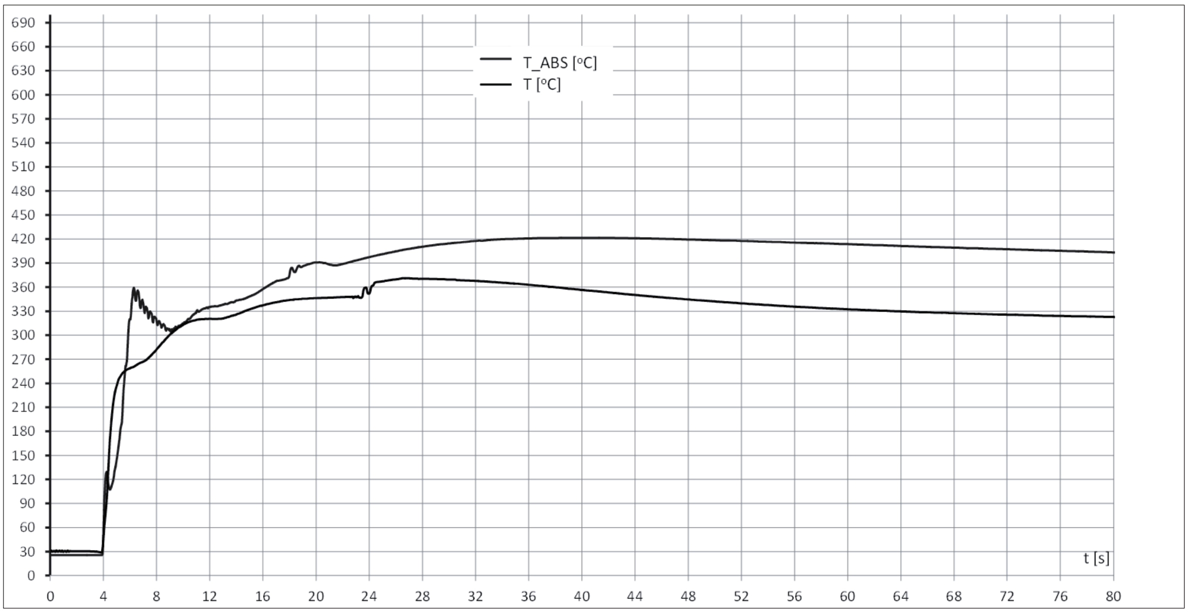

Fig. 8. Temperature comparison from 227 and 221 test

5. Summary

Although, the ABS system laboratory tests shown temperature rise when the system controls the tire slip coefficient on the slippery surface, it was proved that the differences did not exceed 14%. What is more important, in most of the ABS system laboratory test it was shown that braking time (and distance) was shortened. The main assumptions of the ABS system were proved [3].

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