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BRAKING MOMENT COMPARISON AND ANALYSIS FOR VARIOUS BRAKE DESIGNS USING RESULTS FROM SAMPLE AND FULL SCALE FRICTION MATERIAL TESTS

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Abstract

Brakes are one of the most important safety features in every mechanical vehicle starting from bikes and finishing on airplanes. Brakes have to be designed in order to meet safety, reliability, efficiency and economical requirements. One has to remember that not only design of brake is important but also friction material used in its construction. Without proper materials, brakes are not able to generate proper braking moment.

The braking moment is the most important parameter of brake from operation 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 moment is important in order to get optimized characteristics of the braking process itself. Most of the brake characteristics and efficiency calculations base on assumption that braking moment should be stable during braking process.

During years of tests made on full scale brakes and friction material sample tests, author observed that real braking moment curve is not stable during braking process. This phenomenon is likely to affect braking efficiency and in result slightly change braking distance.

In this paper author would like to address this issue by showing brake moment curves made for different brakes and friction materials. Tests, which were author's base for paper contents, were made using full scale brake testing and friction material sample testing. All of the tests described in the paper were performed 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, full scale tests, model tests, friction material*

1. Introduction

Brakes are the one of the most important safety system in every mechanical vehicle moving on the ground, especially with people or valuable cargo onboard. Need of use for such a device emerged with construction of first wheeled device used for transportation. History of brakes is as old as wheeled transport vehicles. Need to stop vehicle safely and precisely is equally important as its ability to move. During the centuries of use, brakes share common construction principle which is dissipation of the movement kinetic energy to thermal energy in order to stop. It is achieved mainly by using friction. Oldest brakes (Fig. 1.) were simply blocks of wood pressed against rim of the wooden wheel or leather stripes (belts) tightened on the axle of the vehicle. Such brakes were used by many centuries in animal driven carts or carriages as their rated power and speeds were limited. With XIX century development of modern transportation systems such as railroad, it was needed to make more efficient brakes in order to overcome higher speeds and power of the vehicles. In that time new concept of cast iron brakes was designed. These brakes (Fig. 2.) were used the same way as their wooden predecessors (block pressed against rim of the wheel). Actuation systems used were at first mechanical screw driven (very slow, every brake needed at least one person to operate) and later pneumatic – (fast, central actuation system ex. Westinghouse brake used till today).

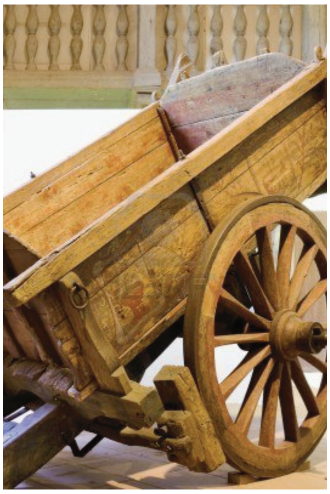

Fig. 1. The example of the wooden brake used in the horse driven cart. (source: Internet)

Fig. 2. The example of the railroad brake. Braking block (shoe) is seen next to wheel. (source: Internet)

By the end of XIX century and development of motorcars it was necessary to change brake systems in order of efficiency and portability. First was achieved by using special materials designed especially for highest possible friction and thermal conductivity. Second was to develop more effective friction distribution method by using drums and disks as part of the brake and in order to the need of use much higher forces to the brake for achieving higher braking moment. Mainly it was done by using hydraulic actuation systems.

After World War I aviation became more significant part of the both transportation and combat systems, it was needed to develop special brake system for safely stopping airplanes during the landing phase. Problem was (is in fact even now) in limited space in the landing gear, extreme weight restrictions, very big amounts of energy needed to be dissipated due to high speeds of the landing airplanes and limited runaway lengths requiring braking moment to be as high as possible. All of that connected together resulted in constructing modern aviation multi-disk and piston brake system (Fig. 3). The same principle is used in modern car brakes with one difference: car brake is single drum or disk with no more than three pistons.

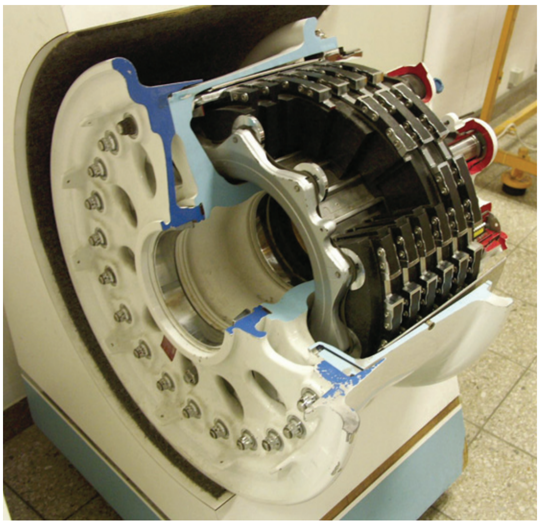

Fig. 3. Multi-disc aviation brake. (source: Internet)

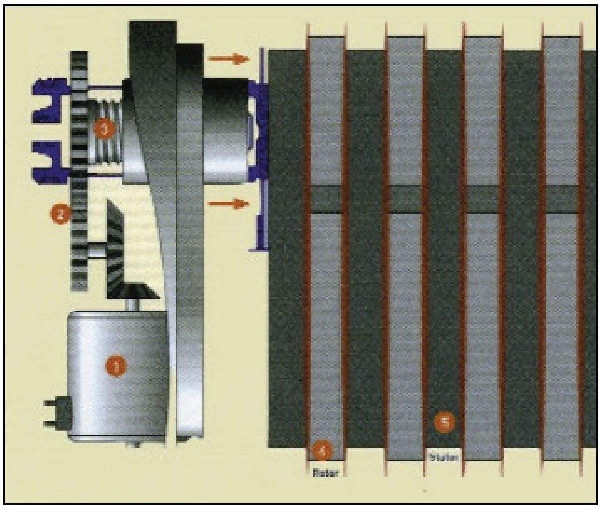

Fig. 4. Modern electric drive used in aviation brake for Boeing 787 Dreamliner. (source: Internet)

Evolution of modern braking systems is proceeding in two directions. One is to make friction material more temperature and stress resistant with better thermal conductivity which enables more frequent braking without declining of the braking parameters. Second is to develop more efficient, reliable and eco friendly way of controlling and actuating whole system.

Friction material change begun with developing composite materials based on ceramics mixed with resin. Composite materials are quite good thermal conductors (worse than steel or cast iron used before), receive quite little wear due to use ceramics and are elastic enough (thank to resin), not to break during thermal and mechanical shocks which occur during braking process. In older composites thermal conductivity was archived by using asbestos. It is now forbidden by EU law but it is used in some countries. Development of better friction materials are now based on use of carbon based materials such as carbon composites, SiC composites etc. These materials are used in high energy brakes (heavy aviation, racing cars).

For now, most common actuation brake system is hydraulic which is different in design in cars and aircrafts but share the same work principle and because of its history is still seen as the most reliable system existing. On the other hand, railway systems and tram systems base on air brakes which are easier to create complex multi unit systems.

First decades of XXI century see rapid development of electric actuation systems due to increasing use of computerised control systems for which electrical control is direct by its definition.

Still, even by using most advanced friction materials and actuation systems true measure of brake efficiency is braking moment achieved during the process. In order to stop the vehicle on the desired distance, braking moment has to be optimal, stable and repeatable in every working conditions of the brake. All of the mentioned properties are achieved by using right materials (friction, construction) and brake designs.

In this article author will address the phenomenon which occur in number of brake tests made through years in Landing Gear Laboratory of Institute of Aviation in Warsaw.

3. Braking moment measurement and test equipment used.

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

First test stand is designed to perform tests friction materials for brakes. It can perform tests which test only friction material without any interference from actual brake design. These tests give knowledge of general material behaviour in defined work conditions. It is also possible to have direct comparison between different tests due to optimal repeatability. Below it can be found technical data and pictures of IL68 test stand used for model friction material testing (Fig. 5, 6 and Tab. 1.)

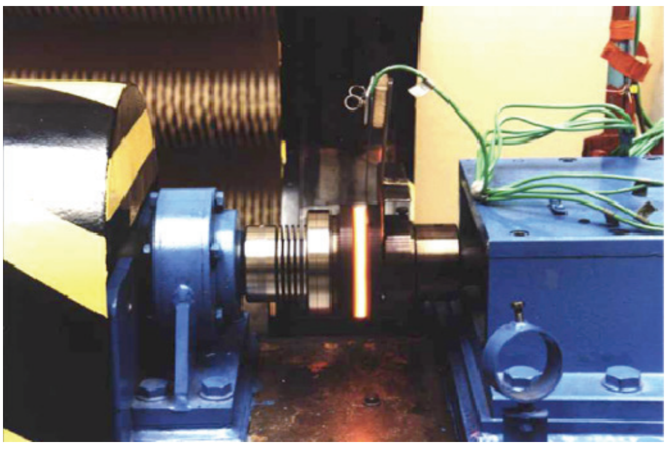

Fig. 5. Example of the test. Glowing part in the centre of the picture is friction material during testing. (source: IoA)

Fig. 6. Friction material mounted to test head of the IL68. (source: IoA)

Tab. 1. IL68 Technical Data

IL68 TECHNICAL DATA		
Nº	**Parameter name**	**Parameter value**
1.	Maximal drive shaft rotation velocity	9000 rpm
2.	Torque	0.154-1.54 kg x m^2
3.	Maximal loads on the sample surface	5.88 kN

Second 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 Młot 3T (Fig. 7, 8 and Tab. 2.) located in Landing Gear Laboratory in Institute of Aviation in Warsaw.

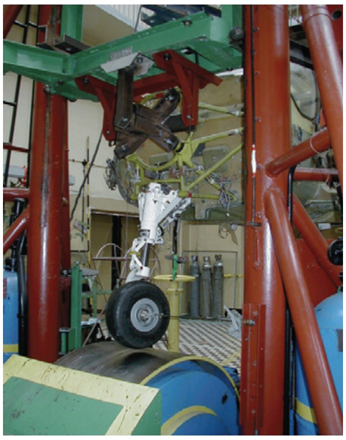

Fig. 7. Młot 3T test rig for full scale brake testing with mounted airplane landing gear

Fig. 8. Młot 3T test rig with automotive brake and wheel mounted during tests

Tab. 2. Młot 3T Technical Data

MŁOT 3T TECHNICAL DATA		
Nº	**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

Presented test stands can record number of parameters such as: braking moment, braking force, speed, temperature, hydraulic pressure.

4. Braking moment curves

Results of brake tests are the several curves showing recorded parameters mentioned in the previous chapter. As it can be seen on the graphs shown below (Fig. 9-12) there is strong dependence of the braking moment to the force of braking or hydraulic pressure (which is directly connected with the braking force) during the braking process. One of the most important assumptions is that braking moment is constant during whole process if the braking force is stable. If braking force is not constant during process, braking moment should resemble it. As it can be seen on the graphs below (Fig. 9-12) there is clear deviation from this rule. Braking moment is not exactly correlated with braking force. Such a phenomenon can be explained by various processes occurring in the brake during work. These processes can be: change of temperature of material and disk(s), temporary deformation of brake or friction material only, influence of grated friction materials (material can get between brake pad and brake disk). All of this cause irregularity of moment curve and in result can affect efficiency of the whole brake.

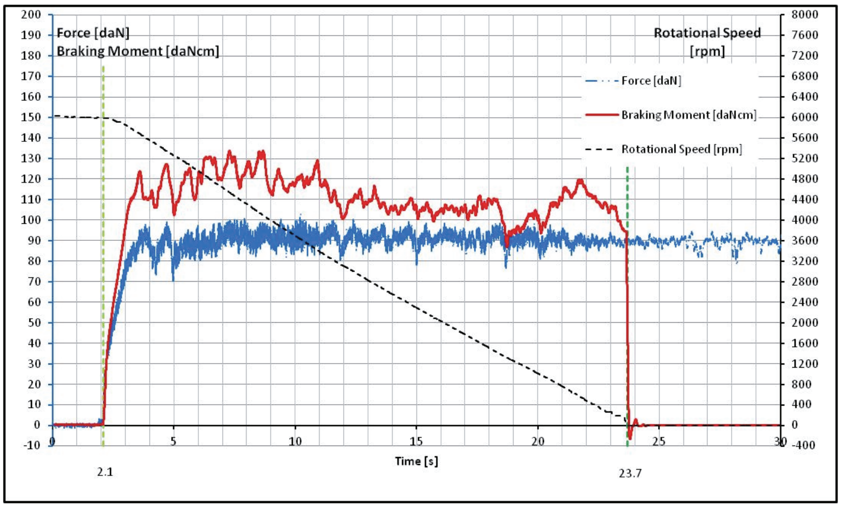

Fig. 9. Model (friction material) test of the aviation brake – IL68 Test Stand

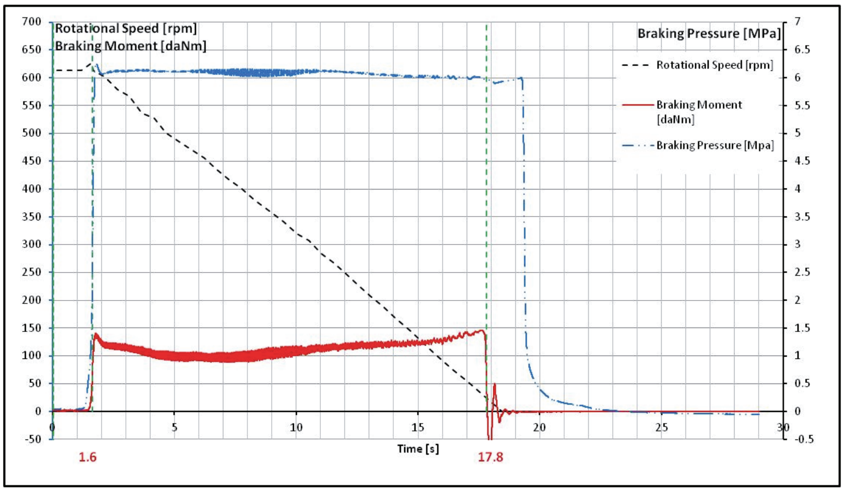

Fig. 10. Full scale test of the aviation brake – Młot 3TTest Stand

It is also significant that braking moment trend is the same in model and full scale tests of the same material. This can give us conclusion that most important is the friction pair material not the brake design. Brake design can help in achieving better braking moment values (in most of the cases it doesn't occur due to test procedure which requires to replicate real braking parameters in the model testing) but general behaviour of the friction pair is rather unchangeable. This conclusion is proven by curves 11 and 12 which are the graphs of tests made on the same material using model and full scale approach in automotive brake.

5. Summary

As it can be seen on the presented graphs, all of the braking moment curves are more or less similar for different designs of the brakes themselves. It is expected because all of the tested brakes base on the same principle (friction brakes) and use ceramic composite friction material. Differences between curves in values are the result of the different energies needed to be dissipated.

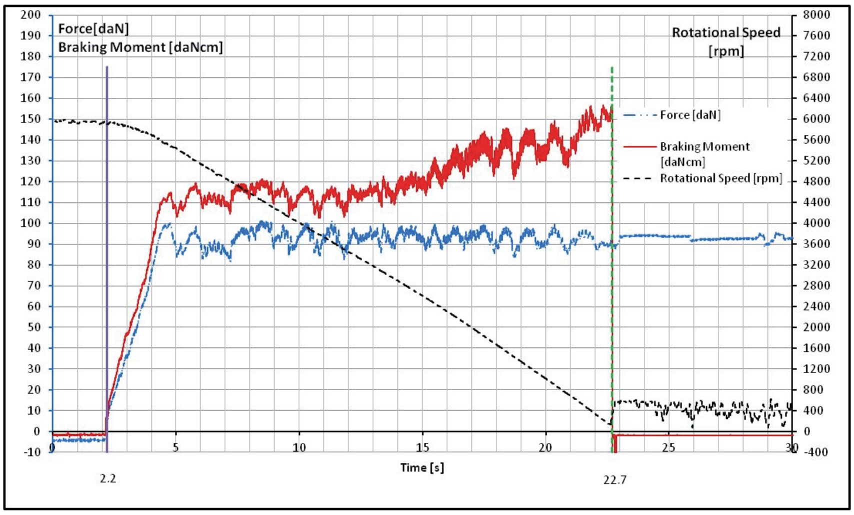

Fig. 11. Model (friction material) test of the automotive brake – IL68 Test Stand

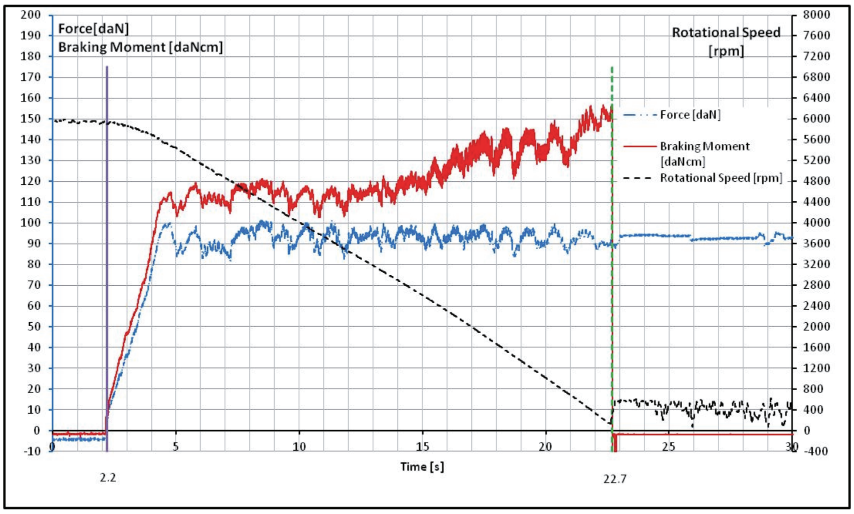

Fig. 12. Full scale test of the automotive brake (the same friction material as in the fig. 11.) – Młot 3TTest Stand

Rest of the differences are mostly material based and show irregularity of the braking moment which is the result of different temperatures in the brake as well as different type of attrition resulting in amount of abraded material present.

This article can introduction to more detailed work on braking moment instability shown on the presented graphs and for many more tests performed in the past.

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