



DESIGN OF A BRAKE AND BRAKE ASSIST SYSTEM FOR AN ELECTRIC RACE CAR

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Abstract

The project investigates the conversion of a Toyota MR2 W10 passenger car. The aim was to replace the car's original braking system with a more modern one, so that the car's braking system could cope with more demanding conditions than planned in competition. The design took into account the stresses on the braking system and the adhesion and friction coefficients.

Keywords: *prototype electric race car, brake system, brake assist system, design.*

1. Introduction

DEAC Motorsport has been competing in the Slalom Championship organised by the MNASZ for more than 4 years. During this time we have won several races in several categories.

In the future we would like to compete in other categories with vehicles of our own design. As part of this, we have started the modification of a Toyota MR2 at the University of Debrecen, Faculty of Engineering.

The project consists of several parts, the current study is on the braking system. The vehicle is represented in [Figure 1](#).

First, we looked at the original brake system. The front disc is 252 mm in diameter and has a floating caliper. According to the factory data, the braking distance from 100km/h to a stop is 44 metres. This is 32-35 metres for today's cars with ABS.

2. Modification of the vehicle braking system

The force on the disc of the original brake system is calculated as follows, depending on the factory values:

- Hydraulic pressure (P): 80 bar
 - Piston diameter (d): 51 mm
 - Coefficient of friction (μ): 0,3
 - Number of pimps (n): 1
 - Effective radius of brake disc (r): 0,12 m [\[2\]](#).
- Pumping surface calculation [\[3\]](#):

$$A = \pi d^2 / 4 \quad (1)$$

The force exerted by the brake lining:

$$F_r = P \cdot A \cdot n \quad (2)$$

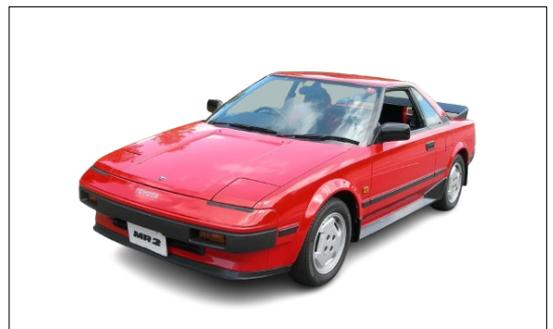


Fig. 1. [Toyota MR2 \[1\]](#)

The force on the brake disc is given by the force exerted by the brake pad multiplied by the coefficient of friction:

$$F_f = \mu \cdot F_r \quad (3)$$

Torque applied by the braking force on the brake disc:

$$M = F_f \cdot r \quad (4)$$

The same principle is used to determine the braking force of the new braking system to be installed.

We had several options for the design of the Toyota MR2 braking system. One is to design a new one from scratch, the other is to transfer it from an existing vehicle. As the University owns several vehicles, the braking system will be transferred from an Opel Vectra C car. However, it should be noted that this modification will also change the behaviour of the vehicle.

The EBC Orangestuff brake pad will probably be the biggest change, as it has a coefficient of friction of 0.5, which can rise to over 0.6 under load. The other changes are the brake disc diameter, which increases to 285 mm, and the brake piston size, which increases to 57 mm.

The force on the disc of a modified brake system can be calculated using the formulae described above [2].

Basic values of the modified braking system:

- Hydraulic pressure (P): 80 bar
- Piston diameter (d): 57 mm
- Coefficient of friction (μ): 0.5
- Number of pimps (n): 1
- Effective radius of brake disc (r): 0.135m.

The next step was to modify the caliper to accommodate the new caliper stirrup. The wheel

bearing's splitter circle is 4×100 , which means that there are 4 holes on a 100 mm diameter circle. The brake disc to be installed has a 5×110 pitch circle, therefore a pitch circle modifier (Figure 2) must be placed between the brake disc and the wheel bearing.

To facilitate scaling, we created a pattern splitter modifier in Solid Edge [5], and printed it from STL format using a 3D printer.

For 3D printing, we used a machine with FDM (Fused Deposition Modelling) technology [6]. Since it is a vehicle part, ABS+ industrial plastic was chosen as the pattern splitter modifier. It is important to point out that 3D print (Figure 3) is only a "sample" and not a final component to be incorporated.

In order to mount the brake caliper unit on the stub, an adapter has to be made. With the factory caliper clamp, only the smaller brake pads could be used, which would not grip the full extent of the brake disc, and the caliper would also have less force to exert.

The Vectra C caliper, on the other hand, has a larger piston diameter and the brake pads have almost double the area of the Toyota MR2 brake. However, with the increase in disc diameter and the change in pitch, the factory rims will not be compatible with the car, so 5×110 or possibly 5×112 rims can be fitted, and 5×112 rims require the use of conical wheels. The holes for the 2 mounting bolts on the caliper bracket almost match the holes on the wheel studs, but there is a slight difference. The distance between the holes on the wheel hub is 130 mm, while the distance between the holes on the stirrup is 125 mm.



Fig. 2. The pitch circle modifier. [4]



Fig. 3. 3D printed pattern splitter.

The holes are the same size, with 12 mm diameter holes in both the stub and the stirrup, but threads are only in the stirrup, with a thread pitch of 1.25 mm (Figure 4).

The first brake pad chosen was the EBC DP41414R „Yellowstuff” [7] racing brake pad. This brake pad is designed for track use, mainly for slalom and mountain racing (Figure 5).

Generally, the brake pad of choice has a friction coefficient of 0.6, is above 800 degrees Celsius and is fail-safe. EBC brake pads are typically free of health-damaging material [7].

The handbrake in this case is a bowden cable, so it can be operated with a custom-made bowden cable that can be folded in the car. It is important that the cables are the same length, so that the two calipers apply the same amount of brake on both sides of the handbrake at the same time. The car's handbrake lever has a sensor in it, which was designed so that if the handbrake was applied with the ignition on and the engine running, it activated an indicator light on the instrument panel to show that the handbrake was applied.

This will also be provided with a circuit breaker after the electric motor has been installed, which breaks the connection between the "throttle" and the motor controller. This means that when the handbrake is applied, the accelerator pedal will not transmit a signal to the motor controller, thus protecting the motor and the rest of the drive

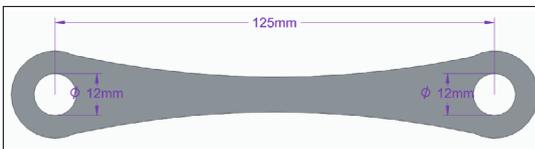


Fig. 4. Distance between holes on the console.

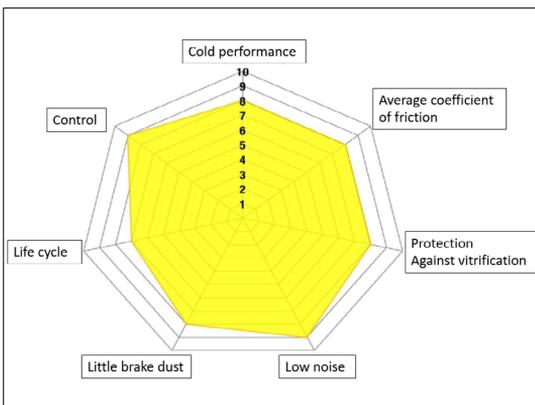


Fig. 5. EBC DP91414 performance chart [7]

train. There will also be an indicator light in the dashboard that will illuminate when the handbrake is applied, as the car is currently just an empty body with no dashboard.

3. Brake „Line-lock”system

The brake line lock system, or "line-lock system", is used to lock the front or rear brake circuit so that the circuit does not receive the hydraulic pressure and only the open circuit will apply the braking force when the brake pedal is depressed (Figure 6).

The universal kits can be installed one brake hose at a time and operate on a 12V system [8].

When locked, the indicator light illuminates to indicate to the driver that the brake circuit is not in use. The car will be fitted with 2 sets of rear brakes. The end will be connected to a cap-switch, so that the entire rear brake system can be locked at the push of a button.

This is necessary because the car will run on racing tyres, whose operating range is temperature dependent. The sudden rise in surface temperature is achieved by a process known as rubber burnout. During a burnout, the driven wheels, in this case the rear and rear wheels, spin while the car is held stationary with the brakes on. In the absence of a brake hose locking system, the rear brake would also be applied, providing both propulsion and deceleration, which would put a heavy load on both the drivetrain and the brake. If the car is fitted with this system, the rear brake can be locked before the tyre is burnt and only the front brake will engage during the warm-up, allowing the car to remain stationary and reducing the load on the driveline as there will be no braking force on the rear axle.



Fig. 6. Brake „Line-lock” system kit [8]

4. Electric vacuum pump brake assist

The car is equipped with brake assist, so that comfortable and powerful braking can be achieved with the factory system, but due to the lack of an internal combustion engine (as the brake assist in this version is supplied from the intake manifold) it is inoperable in its current state.

We first looked into the brake assist solutions used in today's electric cars. There are several solutions used by car manufacturers, in lower-end cars a conventional vacuum brake booster is used and an electric vacuum pump supplies the brake booster with the necessary vacuum of around 0.8-1 bar [9] (Figure 7).

This solution is also applicable here, as the car has a 12V electrical system. These pumps can be operated in 2 ways, with regulation and with control (Figure 8).

5. Vehicle validation by simulation measurement

Since vehicle redesign is a multi-step process and several developments take place in parallel, a virtual model had to be created for the preliminary vehicle test (Figure 9).

For this purpose Automation [11] developed by Camshaft Software and BeamNG.Drive [12] were used. Both programs are widely used for testing engines and vehicles.

First, in Automation, the original and modified brakes were adjusted to give the calculated brake force. All tests were simulated at 8:52 a.m. in sunny weather with no wind. The ambient air temperature is set to 25°C. Gravity acceleration: 9.81m/s². The asphalt of the track used for the tests and simulation has a coefficient of friction of 0.98 and a coefficient of sliding friction of 0.7.

Factory brake simulation:

First, we took the factory brake data. The red solid line indicates the front brake force, while the blue line indicates the rear brake force. On the left is the brake force in N and below is the vehicle's speed.

The weight of the car in this case is 1090kg with 252mm diameter discs at the front and 240mm diameter discs at the rear. The dashed lines show the grip limit for the tyres. All factors are included in these values, including downforce and even centre of gravity drift (Figure 10).

The following figure shows the braking time. The left side shows the speed of the vehicle, while



Fig. 7. Electric vacuum pump. [9]

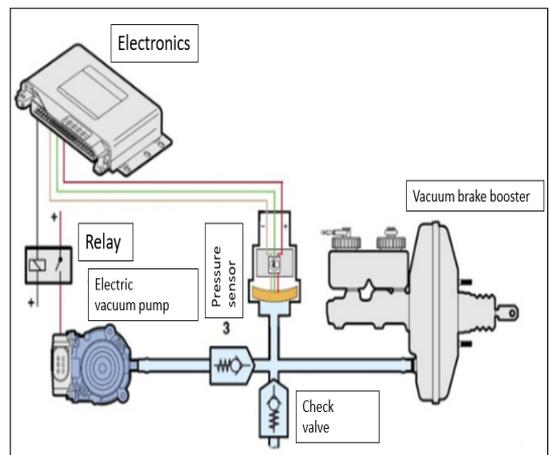


Fig. 8. Electric vacuum pump circuit. [10]



Fig. 9. Toyota MR2 BeamNG.Drive.

the bottom side shows the time elapsed since the brake pedal was depressed (Figure 11).

The car will stop from its top speed in almost 7 seconds, and its stop from 100-0 km/h will be 44 metres. The tyre is 185/55R15 street rubber.

Electric Toyota MR2 with modified brakes:

The next step was to enter the data of the car being developed. As it will be fitted with fibreglass batteries and the internal combustion engine will be replaced by an electric motor and a battery, there will be a change in both centre of gravity and weight.

This reduces the weight of the car to 958 kg. A modified brake caliper is also fitted, so the diameter of the brake discs is now 285 mm at the front and 278 mm at the rear.

The red solid line (Figure 12) indicates front brake force, while the blue line indicates rear brake force. On the left is the braking force in N and below is the vehicle speed.

The dashed lines also indicate the grip limit of the rubber, which has also increased since the tyres have been replaced with 305/30ZR15 semi-slick tyres, the size we like to use in races.

From the Automation program, you can directly transfer the finished models to BeamNG.Drive, where you can use the designed cars on the road. So we continued in this program and tested the credibility of the data provided by Automation on the asphalt road.

The test consisted of 4 races and the best time counted. One race consisted of accelerating to 100 km/h and then braking completely. This was followed by the same from 150 km/h. In addition, the temperature of the brake discs was monitored continuously.

First the measurement was done with the factory data.

The brake disc temperature was imported into an Excel spreadsheet with a sample of 1 second (Table 1. and 2.).

Table 1. Braking from 100km/h for the first time

| Temperature | Rear brake | Front brake |
|-------------|------------|-------------|
| Surface | 118 °C | 137 °C |
| Internal | 108 °C | 130 °C |

Table 2. Braking from 100 km/h for the fourth time

| Temperature | Rear brake | Front brake |
|-------------|------------|-------------|
| Surface | 208 °C | 243 °C |
| Internal | 186 °C | 226 °C |

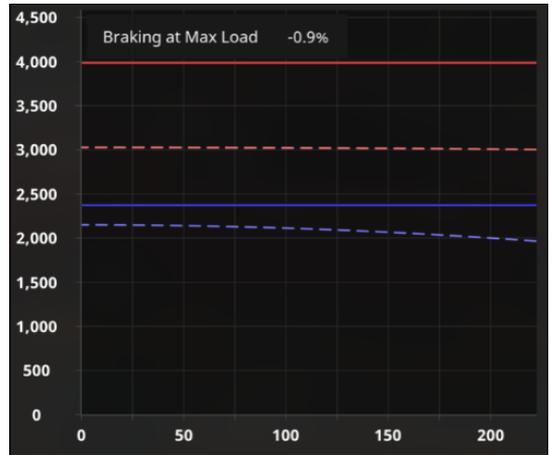


Fig. 10. Simulated factory brake performance.

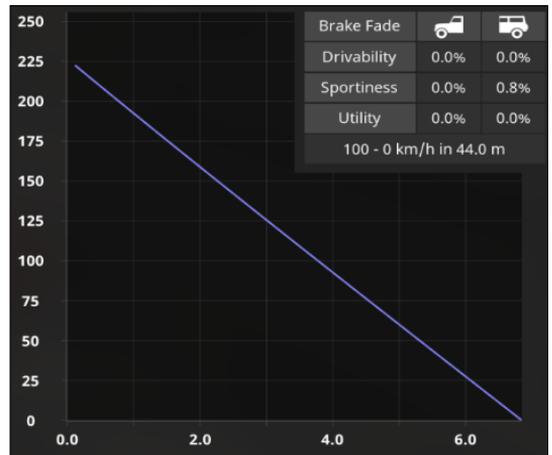


Fig. 11. Factory braking distance.



Fig. 12. Simulated performance of modified brake.

Afterwards, the braking data with the modified brakes were examined (Table 3. and 4.).

Table 3. *Braking from 100km/h for the first time*

| Temperature | Rear brake | Front brake |
|-------------|------------|-------------|
| Surface | 143 °C | 218 °C |
| Internal | 144 °C | 208 °C |

Table 4. *Braking from 100 km/h for the fourth time*

| Temperature | Rear brake | Front brake |
|-------------|------------|-------------|
| Surface | 119 °C | 292 °C |
| Internal | 119 °C | 278 °C |

As you can see, the rear brake doesn't heat up much, the centre of gravity is too far forward, and the braking of the electric motor makes it easier for the rear brake to do its job, plus it also recovers energy. This can be controlled very well with the iBooster.

6. Digital infrastructure & developments

The University of Debrecen, Faculty of Technology has made significant developments in recent years, and thanks to the new infrastructure, developments have been launched in a number of directions. In the Vehicle Manufacturing Laboratory, the renovation of old machine units with AI functions has started [13]. Furthermore, just as we have applied digital models to the vehicle crank in our project, Digital-Twin models have been used in education to facilitate teaching [14, 15]. And machine learning techniques [16] have been used to sort and sort other parts [17], which is also important for vehicle manufacturing and development. For composite materials, there are also advances that can contribute to better body manufacturing [18]. In the context of vehicle modelling, the collection and processing of telemetric data [19] is of particular importance, and with this in mind we have started to build our own Linux distribution-based server [20]. In the future, this will allow us to design further vehicle simulation models [21]. Furthermore with our 3D printing [22] capability, we also have the ability to launch aircraft-related projects [23].

7. Conclusion

The braking system should be considered a top priority when it comes to track days, especially if the car will be used exclusively on a race track. It's no use having a high endurance if you can't stop the car and drive it steadily. After all, it is rapid deceleration that you want to experience be-

fore every corner, not sudden stops. Thanks to the increased braking force and the semi-slick tyres, the braking distance has been reduced from 44 metres to 29 metres from 100km/h to a stop, according to simulation data. The higher the speed from which the braking is performed, the greater the improvement. Once the parts designed in Solid Edge have been produced and the parts mentioned in the project have been sourced, the construction and modification of the car will begin, together with the other students and DEAC Motorsport team members.

Our aim is to have a finished car for the first race and to test our work so far. The simulation-based validation showed how important it is to have a simulation environment in advance where we can test a braking system developed directly for racing on the basis of recorded data. It is estimated that at higher temperatures, the stopping distance did not deteriorate and the low temperature difference between the internal and friction surfaces shows how good the heat transfer and heat conduction properties of the disc are.

Of course, there is still room for improvement on the vehicle, the ones just outlined are just one of the many.

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