DESIGN PROCESS FOR AN ELECTROMAGNETIC POWER BRAKE WITH ABS FUNCTION: CORPORATE KNOWLEDGE MANAGEMENT

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Abstract

This paper will explain the methodology used to develop a new electromagnetic power brake, which, used together with the brake master cylinder, will reduce driver force required during the braking action. Until now, these mechanisms were assisted by engine vacuum, pneumatic pressure or hydraulic pressure. The idea was to create a new power brake design that would use the power from the vehicle battery to meet the pressure and volume requirements, functioning by using the principles of electromagnetism. The design team applied the company's highly valuable knowledge in the field of certain power brake models and made good use of its integrated corporate knowledge management framework. The result is a new product with a braking system that is connected separately to each wheel and which provides the pressure and volume requirements in accordance with the specific vehicle-road environment. The new design includes a considerably simplified ABS electronic control.

Keywords: methodology, design, knowledge management, environmental impact, brakes.

1. Introduction

The pressure applied by a driver to the brake pedal must be boosted to adequately adjust the pressure needed to stop or slow down the vehicle.

Normally to achieve this pressure, power brakes are designed that are regulated by the force on the pedal. Depending on the vehicle system, these systems generally use vacuum, air or oil pressure, the former being the most frequent system.

When the vehicle is also fitted with a brake ABS control unit, it needs a supplementary hydraulic circuit with hydraulic solenoids, which are electronically regulated in accordance with the wheel speed and slip to control the pressure sent to the brakes by the driver.

Depending on their requirements and usage, vehicles are fitted with a source of vacuum, air or oil pressure. All vehicles have a battery; this can be used as a power source to obtain the braking assistance that drivers need. In this project, the electronic control braking assistance would function via electrical inputs without the need for any mechanical parts. This would therefore potentially obtain a more direct regulation and dispense with the need for parts that can produce annoying mechanical vibrations in braking processes with ABS application requirements.
This paper will present the development process for a specific product. It will highlight the design and development process, and how this can be used to improve the company’s knowledge. When suitably classified and filed, this knowledge will help to manage and add to the company’s experiences and knowledge.

Moreover, this paper will underscore how this power brake has environmental advantages through reducing the waste generated at the end of its working life.

2. Design process

The product design process must be based on a method that identifies the stages of the product design and development throughout the project’s entire life cycle.

Work methods are a useful tool to help industrial designers achieve their goal – to design an efficient product that meets the needs of the customer and manufacturing company alike.

Pugh’s ‘Total Design’ philosophy was adopted to develop this power brake. The model used in this project includes four of the major stages in product design.

- Market analysis and product feasibility
- Design specifications
- Conceptual design
- Detail design
- Prototypes and tests
- Manufacturing
- Sale

In this case, the market analysis and product feasibility stages were avoided as this project was to initially develop a product using new technologies to then later study its technical feasibility. And the project logically had to end with the prototyping and testing stage, which is when conclusions could be drawn on the product’s technical and economic feasibility to see whether it could be commercialised.

The life cycle of this development project therefore ran from the design specifications stage to the prototype and testing stage.

The product-specific knowledge of the company and its assets was applied in these different stages as they were carried out.

3. Design specification (PDS)

In order to develop a useful product for immediate use, the aim was to create a prototype that could be mounted on a current vehicle. The PDS therefore had to be drawn up with a specific vehicle in mind.

Once the vehicle was chosen, a method was used to establish the product design specifications (PDS).
In this case we did not have to meet the needs of a particular customer. The design team itself was the customer. The RED method was used, with the following stages:

- Intuitive search
- Life cycle and environment
- Sequential analysis of functional elements
- Movements and forces
- Internal reference products
- External reference products (benchmarking)

The company's knowledge could be used in any stage of this process.

With the prior knowledge that the prototype had to be adapted to vehicle (A), the repository was consulted (figure 1, folder 1), as an example and to minimise the specifications, the following functional requirements or PDS were defined.

- Braking pressure: 75 bar
- Driver force on the pedal: 300N
- Volume to fill in the brakes: 5.34 cm³
- Brake master cylinder: Ø 23.8 mm or 4.45 cm²
- Cylinder pressure: 10 bar
- Braking starts: 100 N
- Oil: Dot 4
- Operating Temperature: 20 ºC – 110 ºC.
- ABS: Pressure regulation on each wheel
- Pedal ratio: 5 to 1

Once the design specifications were defined and the knowledge was stored by the company, information was provided on the way in which product performance level had to be reached along with the details of the product operation:

Presión = Pressure; Volumen = Volume
Figure 2 Volume-pressure curve (Repository Folder 2).

Fuerza pedal = Brake Pedal Force; Presión freno = Braking Pressure

Figure 3 Pressure-Force Curve.
(Repository Folder 2)
4. Conceptual design

Once the PDS were defined, the next step was the conceptual design. Here, we had to bear the following features in mind:

- A single pressure generator behind the brake pedal
- A power brake per wheel that increased the pressure on each wheel differently so as to separately regulate the pressure on each wheel.
- Sensors on each of the wheels
- Power supply for each of the power brakes from the battery.
- Power supply regulated by an electronic control that reacts to pedal force signals and wheel signs of speed and deceleration.

Taking these features into account we arrived at the conceptual design shown in figure 4.

The brake master cylinder is unique, a first section of pressure is generated inside it to fill the brake calipers or brake wheel cylinders. As can be seen in the volumes area of figure 2, the pressure the cylinder has to achieve must be adjusted to the needs of that section and to the force $F_p$, which is set according to regulations and specified in the PDS at 300N. The volume (4.45 cm³), also contained in the PDS document, determines the stroke.

The brake master cylinder feeds 4 power brakes, one for each wheel, where an increase in pressure takes place until the braking pressure is reached – established in the PDS document at 75 bar.

The power brake starts to operate when the pressure reaches the end of the volumes area and therefore only has to fill 40% of the wheel volume. As each wheel has its own power brake, only ¼ of that volume needs to be filled.

To increase the pressure reaching the wheels, an energy source is needed to create a controlled force to add to the pressure that is transmitted from the cylinder.

That energy source is the vehicle battery. An electronic circuit was used to create this controlled force: its inputs being the force exerted on the pedal and the wheel slip and its outputs being the different currents transmitted to each power brake to regulate the brake assist force.

Figure 4: Conceptual design.

- $F_p$ = Brake Pedal Force
- $Bateria$ = Battery
- $Controlador$ = Control Unit
- $Servofreno$ = Power Brake
- $Pinza$ = Clip
- $Sensor$ = Sensor
- $Bomba$ = Master Cylinder
- $P_Bomba$ = Master Cylinder Pressure
- $Pf$ = Brake Pressure
- $W$ = Angular Velocity
- $I$ = Current

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The design team had prior experience in designing brake master cylinders and vacuum power brakes. This experience is stored in the folder 5 of the Knowledge Repository. This experience was also to be used for hydraulic part of the power brake and an alternative solution had to be devised to vacuum, air and oil power brakes.

5. Conceptual design and sizing of the hydraulic components

5.1 Brake master cylinder.
Prior experience and knowledge was used to size the brake master cylinder. The brake volume was a conditioning factor in the cylinder diameter. After making a calculations, we established a Ø 23.8 mm brake master cylinder, which, based on the PDS, gives a pressure output of 29 bar at the operating point. The remaining pressure to reach 75 bar had to be generated through the power brake.

5.2. Power brake
Our experience led us to use a tried and tested solution. The conceptual design of this solution is shown below in figure 5.

![Power brake conceptual design](image)

- Servofreno = power brake
- Circuito hidráulico en reposo = quiescent hydraulic circuit
- Circuito hidráulico trabajando = operational hydraulic circuit
- \( P_f \) = brake pressure
- \( P_b \) = Master cylinder pressure

The operating conditions are determined by the curve in figure 3. The power brake had to provide the force necessary to raise the 29 bar pressure generated by the cylinder to 75 bar,
which in turn, had to determine the size of the whole system. The hydraulic part is shown in Figure 6:

![Diagram of hydraulic system]

**Figure 6**: Balance of power in the hydraulic area.

Pbomba = master cylinder pressure; Pf = brake pressure; Fs = Power brake force

We made the relevant calculations and sized a Ø 12 mm piston and a Ø 5 mm pushrod, which required a force of 675 N to be received from the power brake.

Figure 6 shows the conceptual design of the electromagnetic power brake and the force-generating magnetic element – an electrical coil that is powered from the battery and a magnetic circuit with a fixed cover and mobile pushrod that generates the force to transmit to the hydraulic circuit.

Once the required force and displacements were calculated, the coil and circuit were sized. A coil was designed with an operating current of 25 A.

Figure 7 shows the curves calculated for different currents and positions.

![Graph of forces]

**Figure 7**: Curve of forces depending on the position and current.

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6. Detail design

The total design (figure 8) was reached by using the conceptual design and the sizes. The structural solutions of this design take into account similar designs included in the Knowledge Repository, folder number 6.

![Figure 8: Electromagnetic power brake.](image)

Moreover, as this was a prototype that needed to be tested, this first design had to allow the positions of the different parts to be easily and quickly changed.

7. Control: detail design

The conceptual design of the control unit had the following stages:

- Input signal conditioning
- Analog-to-digital conversion
- Calculator
- Power stage
- Error check

![Figure 9: Control unit Block design.](image)

Fp = Brake Pedal Force; Unidad De Control= Control Unit; Bateria = Battery
8. Control unit design details

This was the last stage. The design is shown below in figure 10

- P alta = high pressure
- P baja = low pressure
- P alta = high pressure
- Intensidad = current
- Fuerza = force
- Curva fricción = friction curve
- Peso = weight
- Par Frenado = Brake torque
- Velocidad vehículo = vehicle speed
- Deslizamiento = slip
- Par rozamiento = friction torque
- Velocidad rueda = vehicle speed
- Velocidad vehículo (angular) = Vehicle Speed (angular)
9. Prototype and tests

To validate the product it had to be tested to check it met the requirements set out in the PDS document.

The prototype was built and placed on the test bench as shown in figure 11. A computer was used to simulate the characteristics of a vehicle in transit.

- Distancia de frenado = Braking distance

- Bench = cylinder
- Pbomba = cylinder pressure
- Batería = Battery
- Etapa de potencia = Power stage
- Apagado / Encendido = Off / On
- Servo freno = power brake
- Pinza = clip
- Esquema = Layout
- Tarjeta de adquisición = Acquisition card
- Ordenador = Computer
- Controlador = control unit
- Modelo rueda = Wheel model
- Pf = Brake pressure
- Fp = Brake pedal force
- I = Current
• $X = $ Magnetic body displacement

10. Results
A pressure-force curve was generated using the test results (figure 12). This demonstrates that the product fulfils its function to increase pressure, which depends on the force.

And a slip curve was also generated, which shows the ABS function is successfully performed.

![Pressure-Force Curve and Slip Curve](image)

**Figure 12: pressure-force curve and slip curve.**

11. Environmental impact
In the electromagnetic power brake, the coil replaces the vacuum power brake and the brake pressure modulation system has less parts and a set of valves, which operate with a high level of vibrations and consume oil, is completely dispensed with.

12. Conclusions
• The electromagnetic power brake design met the specifications set out in the PDS document.
• Both when drawing up the PDS document and seeking conceptual design and detail design solutions, the company’s information and past experiences gathered together in the Knowledge Repository were useful.
• The design replaces other designs currently in use and has clear advantages in terms of recycling and the use of less polluting materials

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