A horseshoe magnet

A-1 Horseshoe magnet red silver iron

A horseshoe magnet (A-1) has a north and south pole. If a piece of carbon steel contacts both poles, a magnetic circuit is created. In an electromagnetic brake, the north and south pole is created by a coil shell and a wound coil. In a brake, the armature is being pulled against the brake field. (A-3) The frictional contact, which is being controlled by the strength of the magnetic field, is what causes the rotational motion to stop. All of the torque comes from the magnetic attraction and coefficient of friction between the steel of the armature and the steel of the brake field. For many industrial brakes, friction material is used between the poles. The material is mainly used to help decrease the wear rate. But different types of material can also be used to change the coefficient of friction (torque) for special applications. For example, if the brake was required to have an extended time to stop or slip time, a low coefficient material can be used. Conversely, if the brake was required to have a slightly higher torque (mostly for low RPM applications), a high coefficient friction material could be used.[1]

In a brake, the electromagnetic lines of flux have to attract and pull the armature in contact with it to complete brake engagement. Most industrial applications use what is called a single-flux two-pole brake. The coil shell is made with carbon steel that has a combination of good strength and good magnetic properties. Copper (sometimes aluminum) magnet wire, is used to create the coil, which is held in shell either by a bobbin or by some type of epoxy/adhesive.[2]

To help increase life in applications, friction material is used between the poles. This friction material is flush with the steel on the coil shell, since if the friction material was not flush, good magnetic traction could not occur between the faces. Some people look at electromagnetic brakes and mistakenly assume that, since the friction material is flush with the steel, that the brake has already worn down, but this is not the case.[3]

[edit] Basic Operation

There are three parts to an electrmagnetic brake: field, armature, and hub (which is the input on a brake) (B-2). Usually the magnetic field is bolted to the machine frame (or uses a torque arm that can handle the torque of the brake). So when the armature is attracted to the field the stopping torque is transferred into the field housing and into the machine frame decelerating the load. This can happen very fast (. 1-3sec).

Disengagement is very simple. Once the field starts to degrade flux falls rapidly and the armature separates. A spring(s) hold the armature away from its corresponding contact surface at a predetermined air gap.[4]

V-1 Right hand thumb rule

If a piece of copper wire was wound, around the nail and then connected to a battery, it would create an electro magnet. The magnetic field that is generated in the wire, from the current, is known as the " right hand thumb rule". (V-1) The strength of the magnetic field can be changed by changing both wire size and the amount of wire (turns). EM clutches are similar; they use a copper wire coil (sometimes aluminum) to create a magnetic field.

The fields of EM brakes can be made to operate at almost any DC voltage and the torque produced by the brake will be the same as long as the correct operating voltage and current is used with the correct brake. If a 90 volt brake had 48 volts applied to it, this would get about half of the correct torque output of that brake. This is because voltage/current is almost linear to torque in DC electromagnetic brakes.

A constant current power supply is ideal for accurate and maximum torque from a brake. If a non regulated power supply is used the magnetic flux will degrade as the resistance of the coil goes up. Basically, the hotter the coil gets the lower the torque will be produced by about an average of 8% for every 20°C. If the temperature is fairly constant, and there is a question of enough service factor in the design for minor temperature fluctuation, by slightly over sizing the brake can compensate for degradation. This will allow the use of a rectified power supply, which is far less expensive than a constant current supply.

Based on V = I – R, as resistance increases available current falls. An increase in resistance, often results from rising temperature as the coil heats up, according to: Rf = Ri – [1 + aCu – (Tf – Ti)] Where Rf = final resistance, Ri = initial resistance, aCu = copper wire's temperature coefficient of resistance, 0. 0039 °C-1, Tf = final temperature, and Ti = initial temperature.

[edit] Engagement Time

There are actually two engagement times to consider in an electromagnetic brake. The first one is the time it takes for a coil to develop a magnetic field, strong enough to pull in an armature. Within this, there are two factors to consider. The first one is the amount of ampere turns in a coil, which will determine the strength of a magnetic field. The second one is air gap, which is the space between the armature and the coil shell. Magnetic lines of flux diminish quickly in the air. The further away the attractive piece is from the coil, the longer it will take for that piece to actually develop enough magnetic force to be attracted and pull in to overcome the air gap. For very high cycle applications, floating armatures can be used that rest lightly against the coil shell. In this case, the air gap is zero; but, more importantly the response time is very consistent since there is no air gap to overcome. Air gap is an important consideration especially with a fixed armature design because as the unit wears over many cycles of engagement the armature and the coil shell will create a larger air gap which will change the engagement time of the brakes. In high cycle applications, where registration is important, even the difference of 10 to 15 milliseconds can make a difference, in registration of a machine. Even in a normal cycle application, this is important because a new machine that has accurate timing can eventually see a " drift" in its accuracy as the machine gets older.

The second factor in figuring out response time of a brake is actually much more important than the magnet wire or the air gap. It involves calculating the amount of inertia that the brake needs to decelerate. This is referred to as " time to stop". In reality, this is what the end-user is most concerned with. Once it is known how much inertia is present for the brake to stop then the torque can be calculated and the appropriate size of brake can be chosen.

Most CAD systems can automatically calculate component inertia, but the key to sizing a brake is calculating how much inertial is reflected back to the brake. To do this, engineers use the formula: T = (WK2 – ? N) / (308 – t) Where T = required torque in lb-ft, WK2 = total inertia in lb-ft2, ? N = change in the rotational speed in rpm, and t = time during which the acceleration or deceleration must take place.

Inertia Calculator There are also online sites that can help confirm how much torque is required to decelerate a given amount of inertia over a specific time. Remember to make sure that the torque chosen, for the brake, should be after the brake has been burnished.

[edit] Burnishing – What Is It and Why Is It Important?

Burnishing is the wearing or mating of opposing surfaces. When the armature and brake faces are produced, the faces are machined as flat as possible. (Some manufacturers also lightly grind the faces to get them smoother.) But even with that the machining process leaves peaks and valleys on the surface of the steel. When a new " out of the box" brake is initially engaged most peaks on both mating surfaces touch which means that the potential contact area can be significantly reduced. In some cases, an out of box brake may have only 50% of its torque rating.

Burnishing is the process of cycling the brake to wear down those initial peaks, so that there is more surface contact between the mating faces

Even though burnishing is required to get full torque out of the brake it may not be required in all applications. Simply put, if the application torque is lower than the initial out of box torque of the brake, burnishing would not be required; however, if the torque required is higher, then burnishing needs to be done. In general this tends to be required more on higher torque brakes than on smaller lower torque brakes.

The process involves cycling the brake a number of times at a lower inertia, lower speed or a combination of both. Burnishing can require from 20 to over 100 cycles depending upon the size of a brake and the amount of initial torque required. For bearing mounted brakes where the rotor and armature is connected and held in place via a bearing, burnishing does not have to take place on the machine. It can be done individually on a bench or as a group at a burnishing station. Two piece brakes that have separate armatures should try to have the burnishing done on the machine verses a bench. The reason for this is if burnishing on a two piece brake is done on a bench and there is a shift in the mounting tolerance when that brake is mounted to the machine the alignment could be shifted so the burnishing lines on the armature, rotor or brake face may be off slightly preventing that brake from achieving full torque. Again, the difference is only slight so this would only be required in a very torque sensitive application.

[edit] Torque

Burnishing can affect initial torque of a brake but there are also factors that affect the torque performance of a brake in an application. The main one is voltage/current. In the voltage/current section we showed why a constant current supply is important to get full torque out of the brake.

When considering torque, the question of using dynamic or static torque for the application is key? For example, if running a machine at relatively low rpm (5 – 50 depending upon size) there is minimal concern with dynamic torque since the static torque rating of the brake will come closest to where it is running. However, when running a machine at 3, 000rpm and applying the brake at its catalog torque, at that rpm, is misleading. Almost all manufacturers put the static rated torque for their brakes in their catalog. So, when trying to determine a specific response rate for a particular brake, the dynamic torque rating is needed. In many cases this can be significantly lower. It can be less than half of the static torque rating. Most manufacturers publish torque curves showing the relationship between dynamic and static torque for a given series of brake.

Electromagnetic-Power-Off-Brake

Over excitation is used to achieve a faster response time. It’s when a coil momentarily receives a higher voltage then its nominal rating. To be effective the over excitation voltage must be significantly, but not to the point of diminishing returns, higher than the normal coil voltage. Three times the voltage typically gives around 1/3 faster response. Fifteen times the normal coil voltage will produce a 3 times faster response time.

With over excitation the in rush voltage is momentary. Although it would depend upon the size of the coil the actual time is usually only a few milliseconds. The theory is, for the coil to generate as much of a magnetic field as quickly as possible to attract the armature and start the process of deceleration. Once the over excitation is no longer required the power supply to the brake would return to its normal operating voltage. This process can be repeated a number of times as long as the high voltage does not stay in the coil long enough to cause the coil wire to overheat.

[edit] Wear

It is very rare that a coil would just stop working in an electromagnetic brake. Typically if a coil fails it is usually due to heat which has caused the insulation of the coil wire to break down. That heat can be caused by high ambient temperature, high cycle rates, slipping or applying too high of a voltage. Most brakes are flanged mounted and have bearings but some brakes are bearing mounted and like the coils, unless bearings are stressed beyond their physical limitations or become contaminated, they tend to have a long life and they are usually the second item to wear out.

The main wear in electromagnetic brakes occurs on the faces of the mating surfaces. Every time a brake is engaged during rotation a certain amount of energy is transferred as heat. The transfer, which occurs during rotation, wears both the armature and the opposing contact surface. Based upon the size of the brake, the speed and the inertia, wear rates will differ. With a fixed armature design a brake will eventually simply cease to engage. This is because the air gap will eventually become too large for the magnetic field to overcome. Zero gap or auto wear armatures can wear to the point of less than one half of its original thickness, which will eventually cause missed engagements.

[edit] Backlash

Some applications require very tight precision between all components. In these applications even a degree of movement between the input and the output when a brake is engaged can be a problem. This is true in many robotic applications. Sometimes the design engineers will order brakes with zero backlash but then key them to the shafts so although the brake will have zero backlash there's still minimal movement occurring between the hub or rotor in the shaft.

Most applications, however, do not need true zero backlash and can use a spline type connection. Some of these connections between the armature and the hub are standard splines others are hex or square hub designs. The spline will have the best initial backlash tolerance. Typically less than 2 degrees but the spline and the other connection types can wear over time and the tolerances will increase.

[edit] Environment / Contamination

As brakes wear they create wear particles. In some applications such as clean rooms or food handling this dust could be a contamination problem so in these applications the brake should be enclosed to prevent the particles from contaminating other surfaces around it. But a more likely scenario is that the brake has a better chance of getting contaminated from its environment. Obviously oil or grease should be kept away from the contact surface because they would significantly reduce the coefficient of friction which could drastically decrease the torque potentially causing failure. Oil midst or lubricated particles can also cause surface contamination. Sometimes paper dust or other contamination can fall in between the contact surfaces. This can also result in a lost of torque. If a known source of contamination is going to be present many clutch manufactures offer contamination shields that prevent material from falling in between the contact surfaces.

In brakes that have not been used in a while rust can develop on the surfaces. But in general this is normally not a major concern since the rust is worn off within a few cycles and there is no lasting impact on the torque.

[edit] Other Types of Electromagnetic Brakes

Electormagnetic Power Off Brake Spring Set

Introduction – Power off brakes stop or hold a load when electrical power is either accidentally lost or intentionally disconnected. In the past, some companies have referred to these as “ fail safe” brakes. These brakes are typically used on or near an electric motor. Typical applications include robotics, holding brakes for Z axis ball screws and servo motor brakes. Brakes are available in multiple voltages and can have either standard backlash or zero backlash hubs. Multiple disks can also be used to increase brake torque, without increasing brake diameter. There are 2 main types of holding brakes. The first is spring applied brakes. The second is permanent magnet brakes.

How It Works

Spring Type – When no electricity is applied to the brake, a spring pushes against a pressure plate, squeezing the friction disk between the inner pressure plate and the outer cover plate. This frictional clamping force is transferred to the hub, which is mounted to a shaft.

Permanent Magnet Type – A permanent magnet holding brake looks very similar to a standard power applied electromagnetic brake. Instead of squeezing a friction disk, via springs, it uses permanent magnets to attract a single face armature. When the brake is engaged, the permanent magnets create magnetic lines of flux, which can turn attract the armature to the brake housing. To disengage the brake, power is applied to the coil which sets up an alternate magnetic field that cancels out the magnetic flux of the permanent magnets.

Both power off brakes are considered to be engaged when no power is applied to them. They are typically required to hold or to stop alone in the event of a loss of power or when power is not available in a machine circuit. Permanent magnet brakes have a very high torque for their size, but also require a constant current control to offset the permanent magnetic field. Spring applied brakes do not require a constant current control, they can use a simple rectifier, but are larger in diameter or would need stacked friction disks to increase the torque.

[edit] Electromagnetic Particle Brake

Magnetic Particle Brake

Introduction – Magnetic particle brakes are unique in their design from other electro-mechanical brakes because of the wide operating torque range available. Like an electro-mechanical brake, torque to voltage is almost linear; however, in a magnetic particle brake, torque can be controlled very accurately (within the operating RPM range of the unit). This makes these units ideally suited for tension control applications, such as wire winding, foil, film, and tape tension control. Because of their fast response, they can also be used in high cycle applications, such as magnetic card readers, sorting machines and labeling equipment.

How It Works – Magnetic particles (very similar to iron filings) are located in the powder cavity. When electricity is applied to the coil, the resulting magnetic flux tries to bind the particles together, almost like a magnetic particle slush. As the electric current is increased, the binding of the particles becomes stronger. The brake rotor passes through these bound particles. The output of the housing is rigidly attached to some portion of the machine.

As the particles start to bind together, a resistant force is created on the rotor, slowing, and eventually stopping the output shaft.

When electricity is removed from the brake, the input is free to turn with the shaft. Since magnetic particle powder is in the cavity, all magnetic particle units have some type of minimum drag associated with them.

[edit] Electromagnetic Hysteresis Power Brake

Electomagnetic Hysteresis Power Brake

Introduction – Electrical hysteresis units have an extremely wide torque range. Since these units can be controlled remotely, they are ideal for test stand applications where varying torque is required. Since drag torque is minimal, these units offer the widest available torque range of any of the hysteresis products. Most applications involving powered hysteresis units are in test stand requirements.

How It Works – When electricity is applied to the field, it creates an internal magnetic flux. That flux is then transferred into a hysteresis disk passing through the field. The hysteresis disk is attached to the brake shaft. A magnetic drag on the hysteresis disk allows for a constant drag, or eventual stoppage of the output shaft.

When electricity is removed from the brake, the hysteresis disk is free to turn, and no relative force is transmitted between either member. Therefore, the only torque seen between the input and the output is bearing drag.

[edit] Multiple Disk Brakes

Electromagnetic Multiple Disk Brake

Introduction – Multiple disk brakes are used to deliver extremely high torque within a small space. These brakes can be used either wet or dry, which makes them ideal to run in multi speed gear box applications, machine tool applications, or in off road equipment.

How It Works – Electro-mechanical disk brakes operate via electrical actuation, but transmit torque mechanically. When electricity is applied to the coil of an electromagnet, the magnetic flux attracts the armature to the face of the brake. As it does so, it squeezes the inner and outer friction disks together. The hub is normally mounted on the shaft that is rotating. The brake housing is mounted solidly to the machine frame. As the disks are squeezed, torque is transmitted from the hub into the machine frame, stopping and holding the shaft.

When electricity is removed from the brake, the armature is free to turn with the shaft. Springs keep the friction disk and armature away from each other. There is no contact between breaking surfaces and minimal drag.

Architecture of an Electromechanical Braking System

General architecture of an electromechanical braking (EMB) system in a drive-by-wire car is shown in Fig. 1. The system mainly comprises five types of elements:

- Processors including an Electronic Control Unit (ECU) and other local processors
- Memory (mainly integrated into the ECU)

- Sensors
- Actuators
- Communication network(s).

Once the driver inputs a brake command to the system via a human-machine interface – HMI (e. g. the brake pedal), four independent brake commands are generated by the ECU based on high level brake functions such as anti-lock braking system (ABS) or vehicle stability control (VSC). These command signals are sent to the four electric calipers (e-calipers) via a communication network. As this network might not be able to properly communicate with the e-calipers due to network faults, HMI sensory data are also directly transmitted to each e-caliper via a separate data bus.

In each e-caliper a controller uses the brake command (received from ECU) as a reference input. The controller provides drive control commands for a power control module. This module controls three phase drive currents for the brake actuator which is a permanent magnet DC motor, energised by 42V sources. In addition to tracking its reference brake command, the caliper controller also controls the position and speed of the brake actuator. Thus, two sensors are vitally required to measure the position and speed of the actuator in each e-caliper. Because of the safety critical nature of the application, even missing a limited number of samples of these sensory data should be compensated for.

[edit] Voting

A brake-by-wire system, by nature, is a safety critical system and therefore fault tolerance is a vitally important characteristic of this system. As a result, a brake-by-wire system is designed in such way that many of its essential information would be derived from a variety of sources (sensors) and be handled by more than the bare necessity hardware. Three main types of redundancy usually exist in a brake-by-wire system:

1. Redundant sensors in safety critical components such as the brake pedal.
2. Redundant copies of some signals that are of particular safety importance such as displacement and force measurements of the brake pedal copied by multiple processors in the pedal interface unit.
3. Redundant hardware to perform important processing tasks such as multiple processors for the electronic control unit (ECU) in Fig. 1.

In order to utilize the existing redundancy, voting algorithms need to be evaluated, modified and adopted to meet the stringent requirements of a brake-by-wire system. Reliability, fault tolerance and accuracy are the main targeted outcomes of the voting techniques that should be developed especially for redundancy resolution inside a brake-by-wire system.

Example of a solution for this problem: A fuzzy voter developed to fuse the information provided by three sensors devised in a brake pedal design.

[edit] Missing data compensation

In a by-wire car, some sensors are safety-critical components, and their failure will disrupt the vehicle function and endanger human lives. Two examples are the brake pedal sensors and the wheel speed sensors. The electronic control unit must always be informed of the driver’s intentions to brake or to stop the vehicle. Therefore, missing the pedal sensor data is a serious problem for functionality of the vehicle control system. Wheel speed data are also vital in a brake-by-wire system to avoid skidding. The design of a by-wire car should provide safeguards against missing some of the data samples provided by the safety-critical sensors. Popular solutions are to provide redundant sensors and to apply a fail-safe mechanism. In addition to a complete sensor loss, the electronic control unit may also suffer an intermittent (temporary) data loss. For example, sensor data can sometimes fail to reach the electronic control unit. This may happen due to a temporary problem with the sensor itself or with the data transmission path. It may also result from an instantaneous short circuit or disconnection, a communication network fault, or a sudden increase in noise. In such cases, for a safe operation, the system has to be compensated for missing data samples.

Example of a solution for this problem: Missing data compensation by a predictive filter.

[edit] Accurate estimation of position and speed of brake actuators in the e-calipers

The caliper controller controls the position and speed of the brake actuator (besides its main task which is tracking of its reference brake command). Thus, position and speed sensors are vitally required in each e-caliper and an efficient design of a measurement mechanism to sense the position and speed of the actuator is required. Recent designs for brake-by-wire systems use resolvers to provide accurate and continuous measurements for both absolute position and speed of the rotor of the actuators. Incremental encoders are relative position sensors and their additive error needs to be calibrated or compensated for by different methods. Unlike the encoders, resolvers provide two output signals that always allow the detection of absolute angular position. In addition, they suppress common mode noise and are especially useful in a noisy environment. Because of these reasons, resolvers are usually applied for the purpose of position and speed measurement in brake-by-wire systems. However, nonlinear and robust observers are required to extract accurate position and speed estimates from the sinusoidal signals provided by resolvers.

Example of a solution for this problem: A hybrid resolver-to-digital conversion scheme with guaranteed robust stability and automatic calibration of the resolvers used in an EMB system.

[edit] Measurement and/or estimation of clamp force in the electromechanical calipers

A clamp force sensor is a relatively expensive component in an EMB caliper. The cost is derived from its high unit value from a supplier, as well as marked production expenses because of its inclusion. The later emanates from the complex assembly procedures dealing with small tolerances, as well as on-line calibration for performance variability from one clamp force sensor to another. The successful use of a clamp force sensor in an EMB system poses a challenging engineering task. If a clamp force sensor is placed close to a brake pad, then it will be subjected to severe temperature conditions reaching up to 800 degrees Celsius that will challenge its mechanical integrity. Also temperature drifts must be compensated for. This situation can be avoided by embedding a clamp force sensor deep within the caliper. However, embedding this sensor leads to hysteresis that is influenced by friction between the clamp force sensor and the point of contact of an inner pad with the rotor. This hysteresis prevents a true clamp force to be measured. Due to the cost issues and engineering challenges involved with including the clamp force sensor, it might be desirable to eliminate this component from the EMB system. A potential opportunity to achieve this presents itself in accurate estimation of the clamp force based on alternative EMB system sensory measurements leading to the omission of a clamp force sensor.

Example of a solution for this problem: Clamp force estimation from actuator position and current measurements using sensor data fusion.

A magnetometer is a scientific instrument used to measure the strength and/or direction of the magnetic field in the vicinity of the instrument. Magnetism varies from place to place and differences in Earth's magnetic field (the magnetosphere) can be caused by the differing nature of rocks and the interaction between charged particles from the Sun and the magnetosphere of a planet. Magnetometers are often a frequent component instrument on spacecraft that explore planets.

[edit] Uses

Magnetometers are used in ground-based electromagnetic geophysical surveys (such as magnetotellurics) to assist with detecting mineralization and corresponding geological structures. Airborne geophysical surveys use magnetometers that can detect magnetic field variations caused by mineralization, using airplanes like the Shrike Commander.[1] Magnetometers are also used to detect archaeological sites, shipwrecks and other buried or submerged objects, and in metal detectors to detect metal objects, such as guns in security screening. Magnetic anomaly detectors detect submarines for military purposes.

They are used in directional drilling for oil or gas to detect the azimuth of the drilling tools near the drill bit. They are most often paired up with accelerometers in drilling tools so that both the inclination and azimuth of the drill bit can be found.

Magnetometers are very sensitive, and can give an indication of possible auroral activity before one can see the light from the aurora. A grid of magnetometers around the world constantly measures the effect of the solar wind on the Earth’s magnetic field, which is published on the K-index.[2]

A three-axis fluxgate magnetometer was part of the Mariner 2 and Mariner 10 missions.[3] A dual technique Magnetometer is part of the Cassini-Huygens mission to explore Saturn.[4] This system is composed of a vector helium and fluxgate magnetometers.[5] Magnetometers are also a component instrument on the Mercury MESSENGER mission. A magnetometer can also be used by satellites like GOES to measure both the magnitude and direction of a planet’s or moon’s magnetic field.

Further information: Spacecraft magnetometer

[edit] Mobile phones

Magnetometers are appearing in mobile phones. The Apple iPhone 3GS has a magnetometer and comes with a compass app for showing direction. It can also reorient maps to show the direction you’re facing.[6]

[edit] Types

Magnetometers can be divided into two basic types:

- Scalar magnetometers measure the total strength of the magnetic field to which they are subjected, and
- Vector magnetometers have the capability to measure the component of the magnetic field in a particular direction, relative to the spatial orientation of the device.

The use of three orthogonal vector magnetometers allows the magnetic field strength, inclination and declination to be uniquely defined. Examples of vector magnetometers are fluxgates, superconducting quantum interference devices (SQUIDs), and the atomic SERF magnetometer. Some scalar magnetometers are discuss