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Research Article

EDDY CURRENT BRAKING EMBEDDED SYSTEM

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ABSTRACT
This paper presentation explores the working principle of eddy current brake mechanism, which can be analyzed by Maxwell 3D Transient solver. An eddy current brake, like a conventional friction brake, is responsible for slowing an object, such as a train or a roller coaster etc. Unlike the friction brakes, which apply pressure on two separate objects, eddy current brakes slow an object by creating eddy currents through electromagnetic induction which create resistance, and in turn either heat or electricity. In this paper, linear Halfback magnetized mover is applied to eddy current braking system for high speed. For such a breaker, we give analytical formulas considering end effects for its magnetic field, eddy current distribution, forces according to the secondary relative permeability, and conductivity. The results given here are purely analytic & applicable.

INTRODUCTION

The term "EDDY"

Focault Bae J. S.(2004) found that when magnetic flux linked with a metallic conductor changes, induced currents are set up in the conductor in the form of closed loops.
These currents look like eddies or whirl pools and likewise are known as eddy currents.
They are also known as Focault's Current.

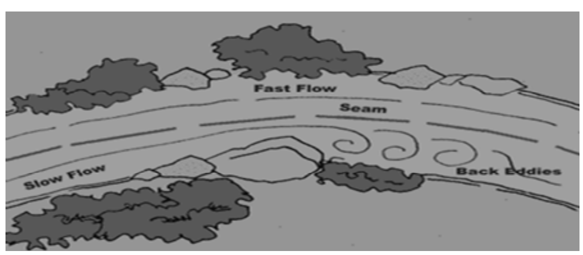

Figure 1: Formation of Eddy current

When a time-varying magnetic flux passes through a conductive material, eddy currents are generated in the conductor. These eddy currents circulate inside the conductor generating a magnetic field of opposite polarity as the applied magnetic field. Bae J. S.(2004) The interaction of the two magnetic fields causes a force that resists the change in magnetic flux. However, due to the internal resistance of the conductive material, the eddy currents will be dissipated into heat and the force will die out. As the eddy currents are dissipated, energy is removed from the system, thus producing a damping effect. There are several different methods of inducing a time-varying magnetic field, and from each method arises the potential for a different type of damping system. Therefore, the research into eddy current and magnetic damping mechanisms has led to a diverse range of dampers. The majority of the eddy current damping has taken place in the area of magnetic braking that has received significant interest is the use of eddy current dampers for the suppression of structural vibrations. However, much of this research is not concentrated in one area, but has been applied to a variety of different structural systems in a number of distinct ways.

In this various types of eddy current damping mechanisms and the future of eddy currents with some potential uses have been seen when a non-magnetic conductive material experiences a time-varying magnetic field, eddy current continuous change in flux that induces an electromotive force (e.m.f.), allowing the induced currents to regenerate and in turn produce a repulsive force that is proportional to the velocity of the conductive metal. Baz, A. (2000), Since the currents are dissipated, energy is being removing from the system, thus allowing the magnet and conductor to function like a viscous damper .One of the most useful properties of an eddy current damper is that it forms a means of removing energy from the system without ever contacting the structure. This means that unlike other methods of damping, such as constrained layer damping, the dynamic response and material properties are unaffected by its addition into the system. Furthermore, many applications require a damping system that will not degrade in performance over time. This is not the case for other viscous dampers; for instance, many dampers require a viscous liquid which may leak over time. These two points are just a few of the many advantages offered by eddy current damping systems. The most widely researched and well-developed area of eddy current damping systems falls in the category of magnetic braking. While the research in this area will be thoroughly discussed, the literature is very dense and every paper cannot be reviewed. The work in magnetic braking will be presented first, followed by studies into eddy current damping of rotating machinery, and finally a wide range of research using eddy currents for dynamic systems will be presented. The concept of using eddy currents for damping purposes has been known for a considerable time, with manuscripts dating to the late 1800s. Therefore, the history of the eddy current damper will not be presented and only work from the past few decades will be revilements are generated in the conductor. Cadwell, L. H., (1996)

This time-varying magnetic field can be induced either by movement of the conductor in the field or by changing the strength or position of the source of the magnetic field. Once the eddy currents are generated, they circulate in such a way that they induce a magnetic field with opposite polarity as the applied field, causing a repulsive force. However, due to the electrical resistance of the conducting material, the induced currents will dissipate into heat at the rate of I2R and the force will disappear. In the case of a dynamic system, the conductive metal is continuously moving in the magnetic field and experiences a continuous change in flux that induces an electromotive force(e.m.f.), allowing the induced currents to regenerate and in turn produce a repulsive force that is proportional to the velocity of the conductive metal. Cadwell, L. H., (1996) Since the currents are dissipated, energy is being removing from the system, thus allowing the magnet and conductor to function like a viscous damper .One of the most useful properties of an eddy current damper is that it forms a means of removing energy from the system without ever contacting the structure. This means that unlike other methods of damping, such as constrained layer damping, the dynamic response and material properties are unaffected by its addition into the system. There are two basics types of Eddy current brake as follows:- Cunningham, R. E., (1986)

(a) Circular eddy current brake.

(b) Linear eddy current brake.

CIRCULAR EDDY CURRENT BRAKE

Electromagnetic brakes are similar to electrical motors; non-ferromagnetic metal discs (rotors) are connected to a rotating coil, and a magnetic field between the rotor and the coil creates a resistance used to generate electricity or heat. When electromagnets are used, control of the braking action is made possible by varying the strength of the magnetic field. A braking force is possible when electric current is passed through the electromagnets. The movement of the metal through the magnetic field of the electromagnets creates eddy currents in the discs. These eddy currents generate an opposing magnetic field, which then resists the rotation of the discs, providing braking force. The net result is to convert the motion of the rotors into heat in the rotors. Japanese Shinkansen trains had employed circular eddy current brake system on trailer cars since 100 Series Shinkansen. However, N700 Series Shinkansen abandoned eddy current brakes in favour of regenerative brakes since 14 of the 16 cars in the train set used electric motors. Davis, L. C. and Reitz, J. R., (1971)

LINEAR EDDY CURRENT BRAKE

The principle of the linear eddy current brake has been described by the French physicist Focault, hence in French the eddy current brake is called the "frein a courante de Foucault". The linear eddy current brake consists of a magnetic yoke with electrical coils positioned along the rail, which are being magnetized alternating as south and north magnetic poles. This magnet does not touch the rail, as with the magnetic brake, but is held at a constant small distance from the rail (approximately seven millimeters). It does not move along the rail, exerting only a vertical pull on the rail. When the magnet is moved along the rail, it generates a non-stationary magnetic field in the head of the rail, which then generates electrical tension (Faraday's induction law), and causes eddy currents. These disturb the magnetic field in such a way that the magnetic force is diverted to the opposite of the direction of the movement thus creating a horizontal force component, which works against the movement of the magnet. Gunter, E. J.,(1983)

II EDDY CURRENT BRAKING

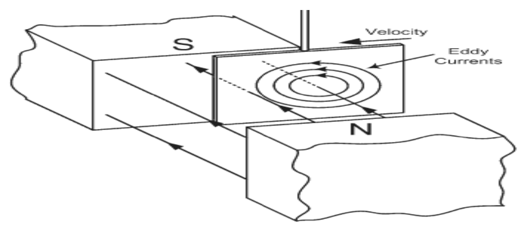

Figure 2: **Generation of Eddy current Bae J. S., (2004)**

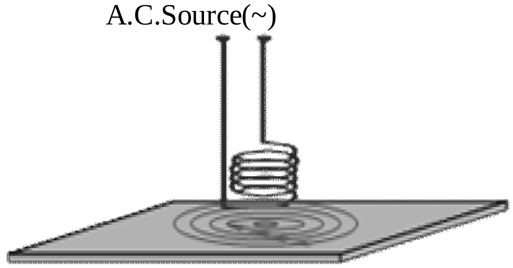

Figure 3: Phenomenon of Eddy Current Bae J. S., (2004)

Eddy currents are flow in a circular path. They get their name from “eddies” that are formed when a liquid or gas flows in a circular path around obstacles when conditions are right. In order to generate eddy currents for an inspection a “probe” is used. Inside the probe is a length of electrical conductor which is formed into a coil. Alternating current is allowed to flow in the coil at a frequency chosen by the technician for the type of test involved. A dynamic expanding and collapsing magnetic field forms in and around the coil as the alternating current flows through the coil. When an electrically conductive material is placed in the coil’s dynamic magnetic field electromagnetic, induction will occur and eddy currents will be induced in the material. Karnopp, M., (1989)Eddy currents flowing in the material will generate their own “secondary” magnetic field which will oppose the coil’s “primary” magnetic field acc. To the Lenz’s rule.

INSTALLATION LOCATION

The installation location of Electromagnetic brakes near to the moving part. Electromagnetic brakes work in a relatively cool condition and satisfy all the energy requirements of braking at high speeds, completely without the use of friction. Due to its specific installation location (transmission line of rigid vehicles), electromagnetic brakes have better heat dissipation capability to avoid problems that friction brakes face. Typically, electromagnetic brakes have been mounted in the transmission line of vehicles. Fredrick, J. R

(2002) The propeller shaft is divided and fitted with a sliding universal joint and is connected to the coupling flange on the brake. The brake is fitted into the chassis of the vehicle by means of anti-vibration mounting. The practical location of the retarder within the vehicle prevents the direct impingement of air on the retarder caused by the motion of the vehicle. Any air flow movement within the chassis of the vehicle is found to have a relatively insignificant effect on the air flow around tire areas and hence on the temperature of both front and rear discs. So the application of the retarder does not affect the temperature of the regular brakes. In that way, the retarders help to extend the life span of the regular brakes and keep the regular brakes cool for emergency situation. Electromagnetic brakes work in a relatively cool condition and satisfy all the energy requirements of braking at high speeds, completely without the use of friction. Due to its specific installation location (transmission line of rigid vehicles), electromagnetic brakes have better heat dissipation capability to avoid problems that friction brakes face. Typically, electromagnetic brakes have been mounted in the transmission line of vehicles. The propeller shaft is divided and fitted with a sliding universal joint and is connected to the coupling flange on the brake. The brake is fitted into the chassis of the vehicle by means of anti-vibration mounting. The practical location of the retarder within the vehicle prevents the direct impingement of air on the retarder caused by the motion of the vehicle. Any air flow movement within the chassis of the vehicle is found to have a relatively insignificant effect on the air flow around tire areas and hence on the temperature of both front and rear discs. So the application of the retarder does not affect the temperature of the regular brakes. In that way, the retarders help to extend the life span of the regular brakes and keep the regular brakes cool for emergency situation. Klingerman, Y. (1998)

III WORKING PRINCIPLE

The working principle of the electric retarder is based on the creation of eddy currents within a metal disc rotating between two electromagnets, which sets up a force opposing the rotation of the disc. If the electromagnet isn't energized, the rotation of the disc is free and accelerates uniformly under the action of the weight to which its shaft is connected. When the electromagnet is energized, the rotation of the disc is retarded and the energy absorbed appears as heating of the disc. If the current exciting the electromagnet is varied by a rheostat, the braking torque varies in direct proportion to the value of the current. It was the Frenchman Raoul Sarazinwho made the first vehicle application of eddy current brakes. The development of this invention began when the French company Telma associated with Raoul Sarazin, developed and marketed several generations of electric brakes based on the functioning principles described above (Reverdin,1974).

A typical retarder consists of stator and rotor. Klingerman, Y., (1998) The stator holds 16induction coils, energized separately in groups of four. The coils are made up of varnished aluminum wire mounded in epoxy resin. The stator assembly is 9supported resiliently through anti-vibration mountings on the chassis frame of the vehicle. The rotor is made up of two discs, which provide the braking force when subject to the electromagnetic influence when the coils are excited. Careful design of the fins, which are integral to the disc, permit independent cooling of the arrangement. Kobayashi, H. (1993)

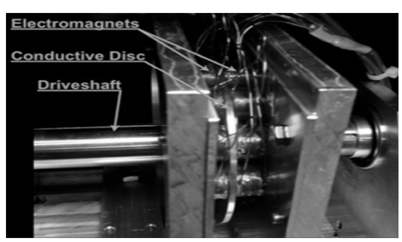

Figure 4: Electromagnetic break Klingerman, Y. (1998)

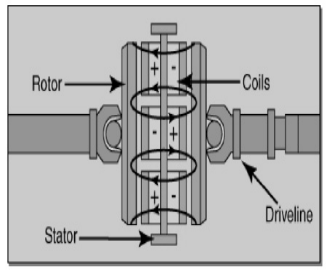

Figure 5: Breaking mechanism in vehicle

Diagram of Eddy current Brake

The simulation eddy current brakes is difficult because,

(1) A fine loop is required due to very small skin depths. A transient solution with time-stepping is necessary.

(2) Physical effects such as nonlinear saturation, skin effects and motion induced eddy currents must be considered simultaneously.

(3) A multiple domain eddy current regions are needed including master/slave boundaries.

The results from three unique simulations will be shown while pointing out the challenges of each design and the methodology needed to allow the simulation to be successful Collaborative.

They can be analyzed by Maxwell 3D Transient solver .Which is well suited for magnetic problems with motion. Solves transient magnetic fields caused by time-varying or moving electrical sources and permanent magnets. It uses both linear and nonlinear materials. The excitation can be DC, sinusoidal and transient voltages or currents. An external schematic circuit is available and considers skin and proximity effects. It also considers motion-induced eddy currents and time-diffusion of magnetic field.

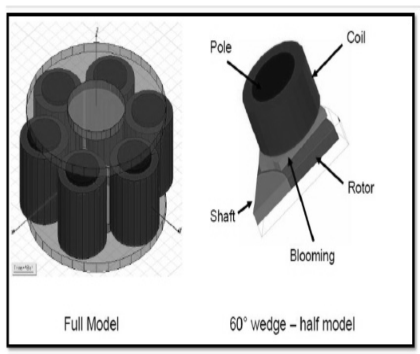

Figure 6: Parts of Breaking Mechanism system

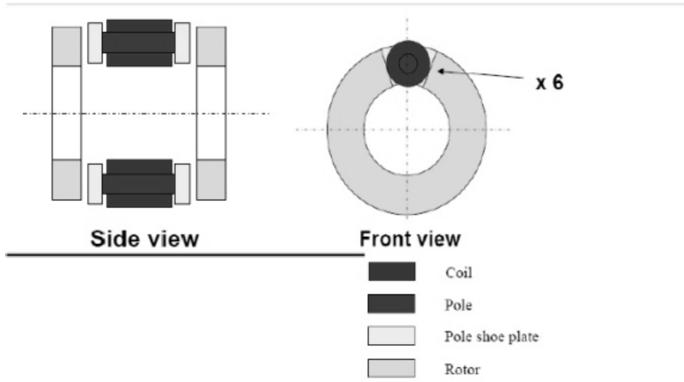

Figure 7: Model set up for eddy current brake simulation

Red coils are fed by a continuous DC current that creates a permanent magnetic field. Poles, blooming, and rotor use the same non linear iron. The rotation of the light blue rotor, produces Foucault's currents that brake the device. Kobayashi, H.(1993)

While the single most prominent application of eddy currents for suppressing dynamic motion has come in the form of magnetic braking, numerous studies have been performed that utilize eddy current damping for the suppression of vibrations in a range of applications. In this section we do not concentrate on a single application, but detail some of the many research applications that have been performed in the area of magnetic damping was increased by 30 and 28 dB, respectively, while the higher-frequency untargeted modes in the range of 0.4–0.8 Hz were damped between 11 and 16 dB. These results indicate the high damping forces that can be achieved using magnetic damping techniques. In a later study, Kienholtz et al. (1996) once again investigated a magnetic damping system for use in space. They focused on the development of a vibration isolation system to protect a large optical instrument intended for the Hubble telescope from the harsh vibrations experienced during shuttle launch that may damage the sensitive equipment. The isolation system uses eight telescoping struts consisting of a titanium coil spring and a passive damper. The passive damping system used in this application consisted of four permanent magnet rings and a conductive tube. Two magnetic rings fitted inside and two outside the conductive tube, allowing eddy currents to be generated as the strut was extended and compressed. This particular type of damping system was chosen because it did not require any liquid that could leak during operation, had low friction (because of its non-contact nature, no friction is present from the damper), and provided small variation in damping over a fairly wide temperatures range. Kwak, M. K.,(2003)

IV ELECTRIC CONTROL SYSTEM

The energization of the retarder is operated by a hand control mounted on the steering column of the vehicle. This control has five positions the first is 'off', and the four remaining positions increase the braking power in sequence. This hand-control system can be replaced by an automatic type that can operate mechanically through the brake pedal. In this case, the contacts are switched on successively over the slack movement of the brake pedal. The use of an automatic control must be coupled with a cut-off system operating at very low vehicle speed in order to prevent energization of the retarder while the vehicle is stationary with the driver maintaining pressure on the brake pedal. Both the manual control and the automatic control activate four solenoid contractors in the relay box, which in turn close the four groups of coil. circuits within the electric brake at either 24 volts or 12 volts, as appropriate(Revering 1974 and Omega Technologies).

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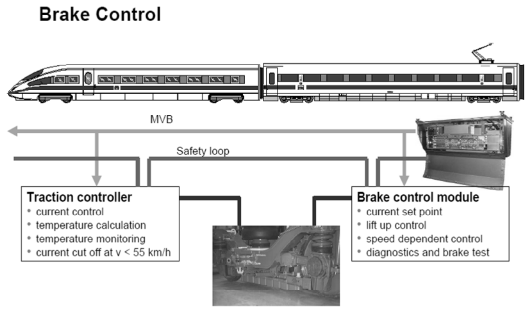

Figure 8: Breaking mechanism of Train

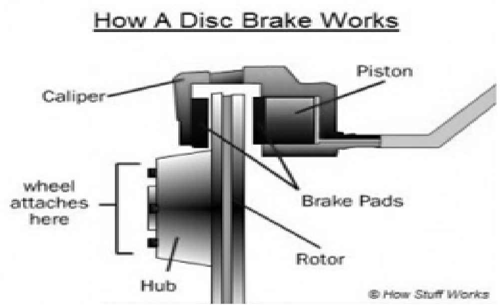

Figure 9: Breaking mechanism of moterbyke

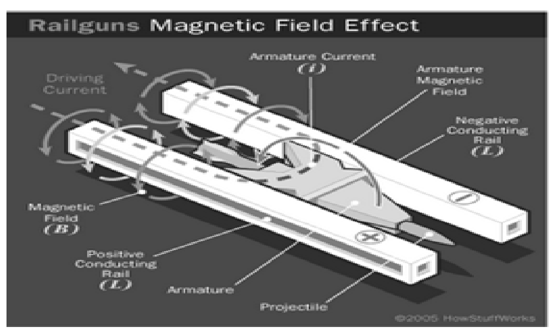

Figure 10: Artificial aircraft launching through Eddy Current

V GENERAL CHARACTERSTICS

It was found that electromagnetic brakes can develop a negative power which represents nearly twice the maximum power output of a typical engine, and at least three times the braking power of an exhaust brake (Reverdin 1974). These performances of electromagnetic brakes make them much more competitive candidate for alternative retardation equipments compared with other retarders. By using the electromagnetic brake as supplementary 10 retardation equipment, the friction brakes can be used less frequently and therefore practically never reach high temperatures. The brake linings would last considerably longer before requiring maintenance, and the potentially “brake fade” problem could be avoided. In res each conducted by a truck manufacturer, it was proved that the electromagnetic brake assumed 80percent of the duty which would otherwise have been demanded of the regular service brake (Reverdin 1974). Furthermore, the electromagnetic brake prevents the dangers that can arise from the

prolonged use of brakes beyond their capability to dissipate heat. This is most likely to occur while a vehicle descending a long gradient at high speed. The installation of an electromagnetic brake is not very difficult if there is enough space between the gearbox and the rear axle. It does not need a subsidiary cooling system. It does not rely on the efficiency of engine components for its use, as do exhaust and hydrokinetic brakes. The electromagnetic brake also has better controllability.
The exhaust brake is anon/off device and hydrokinetic brakes have very complex control system. The electromagnetic brake control system is an electric switching system which gives it superior controllability. From the foregoing, it is apparent that the electromagnetic brake is an attractive complement to the safe braking of heavy vehicles.

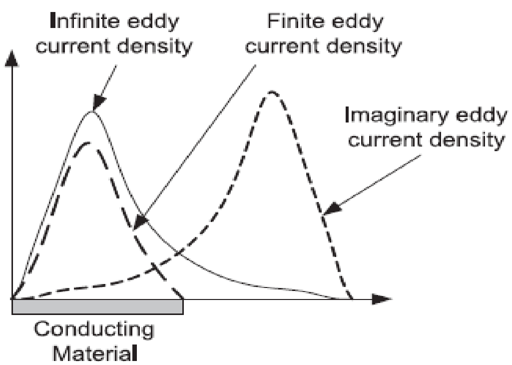

Figure 11: Schematic diagram demonstrating the effect of the imaginary eddy currents. Bae J. S.,(2004)

VI FUTURE OF EDDY CURRENT BRAKING

The assortment of papers that have been reviewed in this paper shows that use of eddy current dampers has seen a number of diverse applications. However, many of the applications are not directed towards the commercial market and are developed to suit a niche field. The eddy current damper does have numerous advantages over other damping systems. For instance, due to the non-contact nature of the damper it does not change the dynamics of the structure or cause mass loading and added stiffness, as many other damping mechanisms do. Additionally, because the damper does not contact the structure, there is no need for a viscous fluid, seals, or the periodic maintenance needed by many other damping and braking systems. Furthermore, eddy current damping systems are easy to install, and the damping force can easily be controlled through adjustment of the position or strength of the magnets. The question left unanswered is, where will eddy current damping mechanisms be in the future? There are several locations that are particularly well suited for eddy current dampers, but perhaps the most promising is in space. The advantages listed above provide a combination of attributes
that are not available in other damping mechanisms. When a device is placed into orbit, the system must function for its entire lifespan without requiring any type of maintenance. This can place limitations on the type of damper used, leaving
few systems left. Perhaps the two damping systems that require the least amount of maintenance after their placement are eddy current dampers and constrained layer damping. The drawback of constrained layer damping is that it modifies the system's structural properties, while the drawback of the eddy current damper is that it typically requires a second structure to support the magnets. However, the extremely cold temperatures that are present in space actually improve the damping performance of the eddy current damper, due to the decrease in resistivity of the conductor.
The opposite is the case for constrained layer damping treatments, because the extreme cold can cause stiffening of the viscoelastic material and the vacuum pressure could cause outgassing if not properly

sealed, thus making their use in space problematic. The use of these dampers in space may be the key to developing better eddy current technology that may open a commercial market. One commercial market that may be a key location for eddy current damping is the vibration absorbers used in vehicles. The dampers currently used tend to require replacement throughout the life of the automobile and lose effectiveness over time. The eddy current damper could potentially replace these devices if sufficient research were carried out. A second area of the automobile that may benefit from the use of eddy currents is the braking system. The use of eddy currents for braking purposes could potentially lead to regenerative braking that would reduce the amount of electrical energy required to power the electromagnets. The automobile market is a key commercial market that can typically open doors for the technology used.

Finally, the use of eddy currents for active damping mechanisms may allow a more effective damper to be developed. The use of eddy current dampers as active control mechanisms is limited in the current literature. One application that may be effective is to displace the magnet relative to the moving conductor, in an attempt to increase the net velocity between the two devices and instigate a higher damping force. Other active control methods may use electromagnets to damp vibrations out. If the amount of research into eddy current damping continues to grow, this type of damper will surely find its way out of niche applications and into the commercial market.

Advantages

These are non mechanical, no moving parts hence no friction., Fully resettable, no parts need to be replaced., Can be activated at will via electrical signal., Low maintenance cost., Operates at any rotational speed.

Disadvantages

Braking force diminishes as speed diminishes with no ability to hold the load in position at standstill., That could be considered to be a safety issue, but it really means that friction braking may need to be used as well., Eddy-current brakes can only be used where the infrastructure has been modified to accept them.

Conclusion

With all the advantages of electromagnetic brakes over friction brakes, they have been widely used on heavy vehicles where the ‘brake fading’ problem is serious. The same concept is being developed for application on lighter vehicles.

A Halbach magnetized mover was applied to a high-speed eddy current braking system. Based on analytical 2-D field solutions considering dynamic end effect, the magnetic field, eddy current distribution, and forces according to the secondary relative permeability and conductivity were presented. It was observed that the air-gap flux density has a non uniform distribution for the high speed. Comparisons between numerical simulations and experimental data were also presented.

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