



Roland Benzing | Ralf Wieland

Electromagnetic brakes and clutches

**PRECISION AND SAFETY
FOR THE WORLD OF TOMORROW**

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*"Did you know that
you can't spend a day
without coming across
thousands of our products?"*



***"You'll see -
we are essential
to your daily life!"***

FOREWORD

Do you know Wilhelm Eduard Weber, Heinrich Friedrich Lenz, Carl Friedrich Gauß or Michael Faraday?

Undoubtedly you remember at least one of those names from your physics lessons: a unit of magnetic flux is named after Mr Weber – Mr Lenz gave us Lenz's law – Mr Gauss is known to people with an affinity for statistics – and Mr Faraday made a name for himself by researching electromagnetic induction. All of them (plus a few more) were 19th century pioneers in the study of magnetism. Our company's activities are still based on their work today.

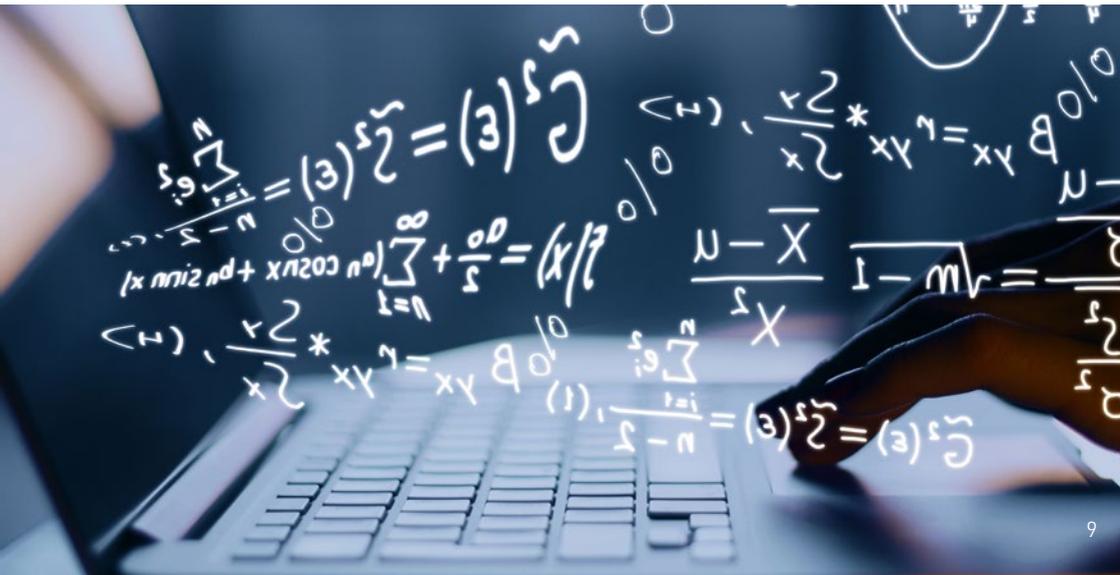
With this book, we would like to give you a brief overview of the fascinating world of electromagnetism, with a special emphasis on electromagnetic clutches and brakes. In the following chapters we will introduce you to the physical and technical basics of electromagnetism. The two essential operating principles of electromagnetically operated brakes are based on these concepts: spring-applied and permanent-magnet brakes. Both types do their work every day, e.g. in drive technology, medical technology or lift technology. Depending on the application, work task and requirement, one of the two brake technologies is used.

*It does not matter what your task is or which product you need.
Kendrion has the right solution for you.*

Thank you

But before we start, we would like to thank all those who made this book possible. In particular, Beate Hermannstädter, Maria Frank, Jürgen Berndt and Sören Storbeck as well as all other employees of our company, our partners and interested parties who also share our passion for electromagnetism. Without all of you, we would not have been able to create the following pages. Many thanks!

Villingen, May 2019



Chapter ①

KENDRION

KENDRION

The company

KENDRION stands for high-quality electromagnetic systems and components for the automotive and industrial sectors. With our versatile solutions, we provide safe and precise processes in dynamic industries of the future around the world. Our products are used in a variety of applications that you encounter on a daily basis, such as in cars, buses, lifts, ATMs, vending machines, wind turbines, medical equipment and countless

other products. For more than a century, Kendrion has been building on its magnetism expertise, offering complex components, customised systems, and market-specific solutions. This expertise leads to products with unique features. Collaborating with our customers results in an optimal package in terms of specific product and market requirements.



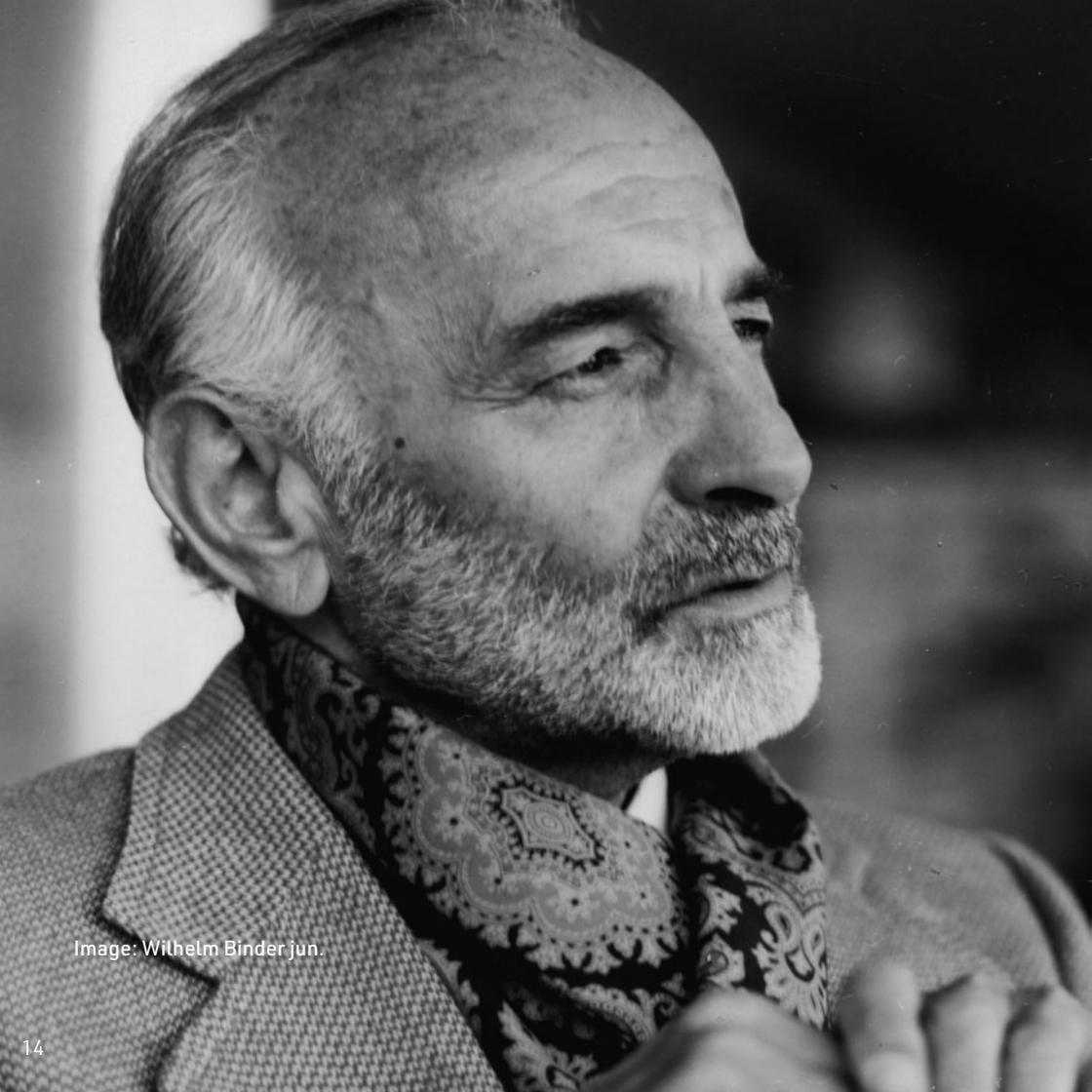


Image: Wilhelm Binder jun.

Tradition meets innovation: over 100 years of Kendrion

In 1911, Wilhelm Binder, together with his business partner Rudolf Moog and a starting capital of 8,500 Marks, founded the company W. Binder in Villingen.

In the early 1920s, Wilhelm Binder began to develop and produce electromagnetic components such as clamping devices, protective magnets, magnetic drums and solenoids. Binder put every penny he had into the company and successfully overcame such obstacles as world wars and economic crises. Within 25 years, the workforce grew to 400 employees.

In 1938, Binder's son joined the company. Wilhelm Binder had created a world-renowned company with great passion and innovation in just a quarter of a century.

After World War II, the company had to be rebuilt. After a new factory building in 1951, the company's first appearance at the Han-



nover Messe (Hanover Fair) in 1953 helped gain it international recognition. Magnetism became a fascination for Wilhelm Binder; he developed into an inventor and was able to register over 100 patents and utility models over the years, such as the invention of the proportional magnet, still in use today.

The right brake for every situation

Automation solutions are an integral part of industry and everyday life today. The spread of automation solutions is promoted by mechatronics. This also increases the variety of applications. Electromagnetic brakes frequently meet the necessary safety requirements for holding loads and for safe braking in an emergency.

Optimal coordination with the industry-specific requirements

The variety of applications also entails a strong differentiation of specifications – for example, regarding torque, sliding speed and braking energy. Meeting these different requirements while maintaining product standardisation is a challenge Kendrion faces. Thus, customer-specific solutions based on an existing product portfolio can be developed and produced. The prerequisite for this is the analysis and understanding of the industry-specific requirements of the customers. With the right product portfolio and a high level of expertise in automation technology, robotics, machinery and lift technology, Kendrion Industrial Drive Systems, as a reliable partner, can offer the optimum individual brake solution for every application.

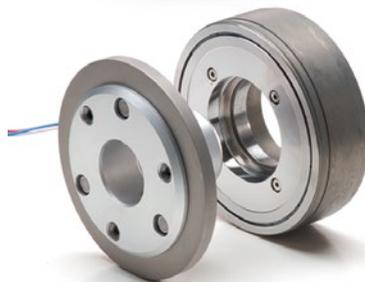


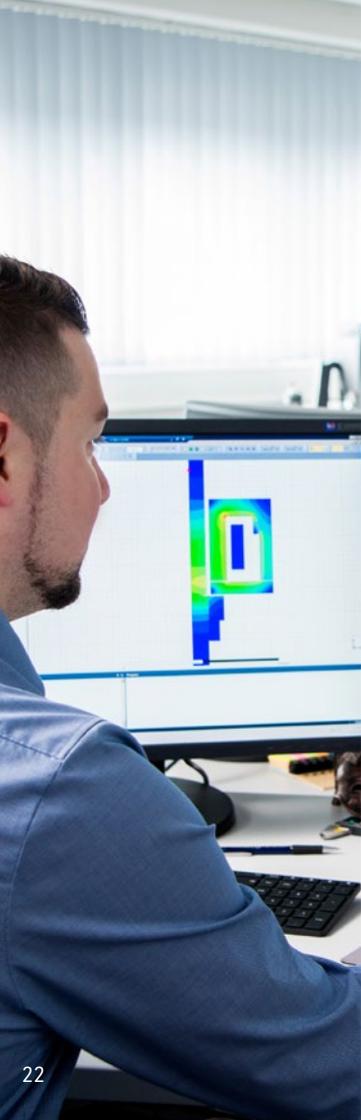
Market-oriented implementation of products

The basis for individually optimised brake solutions from Kendrion is its broad product portfolio. This includes permanent-magnet brakes, spring-applied brakes and electronic components.

In the field of permanent-magnet brakes, both standard solutions and brakes using "High Torque" technology are offered for a temperature range of -40°C to $+120^{\circ}\text{C}$. In addition, Kendrion manufactures spring-applied brakes for asynchronous motors, lifts or explosion-proof areas.

New developments such as the spring-applied brake for servo motors or the very flat spring-applied brake for robotics round out the product portfolio and demonstrate the innovative power of the company. Thus, the optimal solution can be offered for every application.





Customer-specific solutions and service

Kendrion develops individual solutions that are optimally tailored to the respective customers and their specific application. The brake expert has the necessary project and process expertise for this purpose. The core expertise acquired from decades in the field of electromagnetism enables the market-driven implementation of products. The implementation of innovative designs and state-of-the-art technologies in development combined with the latest manufacturing and logistics processes are the company's strengths. By using standard product platforms, customers can always receive individual solutions, both for high order volumes and small quantities. The ongoing optimisation of business processes continuously expands the company's expertise.

Kendrion also offers a wide range of specialty products, standard modifications and a comprehensive repair service.

Large spare parts warehouses allow an experienced and highly skilled service team to provide fast and efficient service.



WHAT YOU SEE IS WHAT YOU GET.

When validating and verifying the values, the user can rely on the expert laboratory team of the brake specialist. Over the years, Kendrion has developed a high level of expertise in the testing and qualification of its products. The laboratory is equipped with testing devices for the measuring range of 0.1 Nm up to 10,000 Nm. The test set-ups reflect the application conditions exactly and can thus represent real conditions. All measured data is recorded under different operating conditions such as temperature, friction work, speed and direction of rotation and are used in the technical data. These options provide the end user with substantiated technical information.

Chapter ②

BASICS OF MAGNETISM

BASICS OF MAGNETISM

The following chapters provide an introduction to the world of magnetism and will enable you to understand, step by step, the operating principle of an electromagnetic actuator.

After a summary of the technical basics, the individual specific solutions and the corresponding application examples will be brought into focus.

Finally, we will look at topics and trends at the cutting edge, as well as insights into current and future technological developments that will shape our future.

The electromagnet

Electromagnets are used as drive or positioning elements in technology as a result of the mechanical work involved during the movement of the armature or the holding force emerging from the tightened armature. The mechanical work is created by conversion of electrical energy, which is supplied via electrical conductors to the electromagnetic transducer element (coil). The electromagnet is thus essentially an en-

ergy converter. In various applications there are electromagnets for DC and AC operation, polarised electromagnets with permanent magnets and electromagnets as part of complex assembly units, e.g. in clutches, brakes for opening and closing the clutch or brake, as valve solenoids in pneumatic and hydraulic systems and as actuating, rotary and holding magnets, etc.

Exemplary versions of electromagnets



Permanent-magnet brake



Locking magnet



Holding magnet



Spring-applied single-disc brake

As a result of the magnetic field in the switched-on state of the electromagnet, there is an electromagnetically generated force on the axially or rotatably limited movable "*armature*" of the electromagnet. As a result, alternating movements can be implemented with two usually stable end positions of the armature, which adjust themselves depending on whether the electromagnet is switched on or off. The resetting of the movable armature takes place either by external forces, for example using springs, or by switching on a second coil or a second electromagnet, such as in a rotary magnet with two coils that can be independently switched on and off.

Design of electromagnets depending on the electrical control

- Electromagnet for DC connection with and without adaptation of the magnetic force characteristic curve depending on the load case with solid magnetic circuit.
- Electromagnets for single-phase and three-phase alternating current connection with finned, multi-plate design of the magnetic circuit and short circuit ring, if necessary.

Electromagnets are "*electro-magneto-mechanical*"¹ energy converters that convert the electrical energy supplied first into magnetic energy and subsequently into mechanical kinetic energy.



Electromagnetic clutches and brakes

Electromagnetic brakes or clutches are power transmission elements that are developed, built and tested in accordance with the guidelines and regulations of DIN VDE 0580 (Electromagnetic devices and components). DIN VDE 0580 differentiates between an electromagnetic device and electromagnetic components. The electromagnetic de-

vice is intended to be operated as an independent functional unit. As laid down in DIN VDE 0580, clutches and brakes are electromagnetic components, which are components of a device. DIN VDE 0580 describes the key parameters and terms needed for the design, construction, testing and operation of brake and clutch systems.

Definition of a brake and clutch according to DIN VDE 0580

The standard DIN VDE 0580 published in DIN (Deutsches Institut für Normung e.V. – German Institute for Standardisation) and VDE (Verband der Elektrotechnik, Elektronik, Informationstechnik e.V. – Association for Electrical, Electronic and Information Technologies) applies to electromagnetic components and devices with a limited working stroke for clutch activation or braking and

a rated voltage of up to 1000 V. In this case, the electromagnetic component uses the force of an electrically generated magnetic field on a ferromagnetic body to achieve a clutch-activating or braking effect. To be able to realise high clutch or braking torques, most electromagnetically operated clutches and brakes use tribological friction systems with one or more friction pairings.

What is an electromagnetic clutch as laid down in DIN VDE 0580?

The electromagnetic clutch is a component for connecting and disconnecting an energy flow in the form of a torque transmission.

In accordance with DIN VDE 0580, electromagnetically operated clutches and brakes are divided according to their physical operational principles **into closing clutch or brake** energised to engage and **opening residual current-operated clutch or brake**.

What is an electromagnetic brake as laid down in DIN VDE 0580?

The electromagnetic brake is a special kind of the electromagnetic clutch in which the output side is stationary.

Closing clutch or brake energised to engage

Clutch or brake in which the torque transmission is produced by electromagnetic force.

Clutches and brakes with this operating principle use the force of an electromagnetic field to build up the clutch or braking torque. As a result of a magnetic field, an axial force is produced at the pole system of

the clutch or brake, which acts on the axially movable component (armature) in the magnetic system. The clutch or braking torque is generated through a frictional connection.

Opening residual current-operated clutch or brake

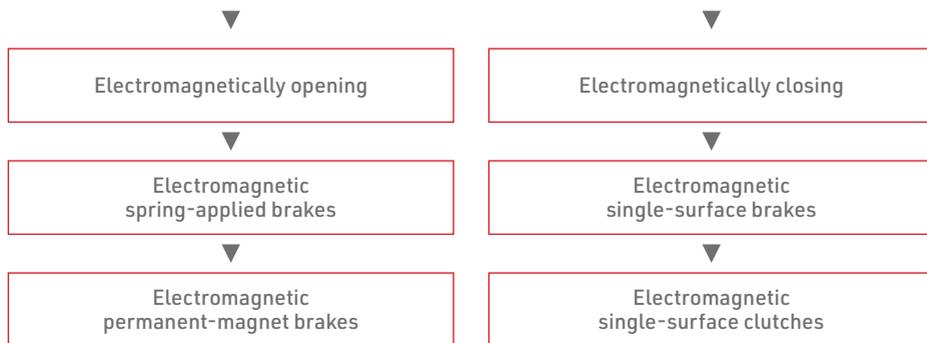
Clutch or brake in which the torque transmission is nullified by electromagnetic force.

Clutches and brakes with this operating principle use the force of an electromagnetic field to nullify the clutch or braking torque. Due to the structure of the magnetic field, an axial force is produced at the pole system of the clutch or brake that acts on the

axially movable component (armature) in the magnetic system and nullifies either the permanent magnetic field (in permanent-magnet systems) or the spring force (spring-applied systems).

Electromagnetically operated brakes and clutches

Electromagnetically operated brakes and clutches according to DIN VDE 0580



Chapter ③

TECHNICAL BASICS

TECHNICAL BASICS

Electromagnetically actuated clutches and brakes are designed to either connect (engage) loads under the force of a torque, or to bring a load to a halt or hold it in place (brake). When engaging (synchronising) drive and output and braking loads, kinetic energy (switching work according to DIN VDE 0580) is transformed into heat by fric-

tion in the tribological friction system of the clutch or brakes. The design and operation of the components requires knowledge of the technical and physical laws of electromagnetic circuits and specific knowledge of the tribological system of clutch and brake to be used.

Terms and definitions

The following terms and definitions according to DIN VDE 0580 are important in the operation and design of the components. The use of uniformly defined terms allows the developer, and the user, of electromagnetic

clutches and brakes, to interpret the technical features of the products safely and also to compare technical features of different product versions.

Basic elements of an electromagnetic brake

- 1.1 Magnet housing**
Part that contains the coil or the excitation winding (1.2)
- 1.2 Coil or excitation winding**
Part for the generation of the magnetic field
- 2 Armature**
Part that is stopped or moved by the magnetic field
- 3 Friction disc**
Part for generating the braking torque
- 4 Springs**
Part for generating the axial spring force

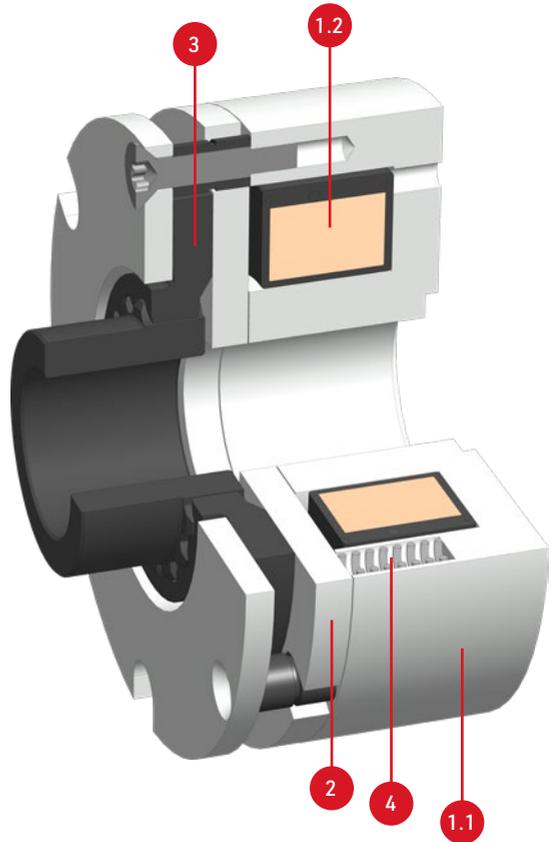


Fig. 01: Spring-applied brake, Servo Line series

Torque terms according to DIN VDE 0580 (excerpt)

Switching torque M_1

Dynamic torque acting in the shaft train in the event of slipping clutch or during the braking process

Transmittable torque M_4

Maximum static torque with which the closed clutch or brake may be loaded without the occurrence of slippage

Nominal torque M_2

The switching torque M_1 assigned by the manufacturer to the device or component for designation or identification

Load torque M_6 (not illustrated)

Torque acting at the output of the closed clutch or brake

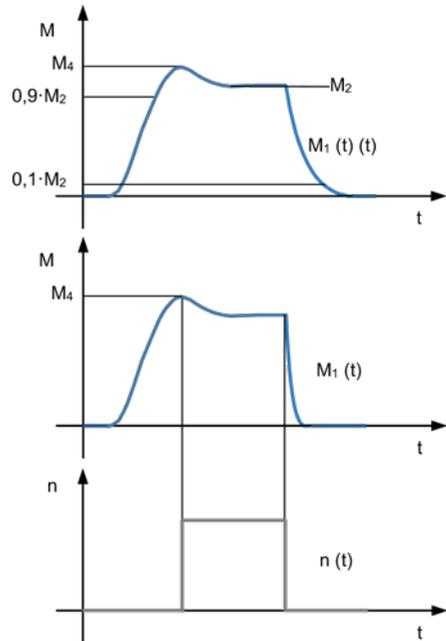


Fig. 02/1: Torques for clutches and brakes

Time concepts according to DIN VDE 0580 (excerpt)

Engagement delay during clutch

engagement t_{11}

Time from switching on the current (closing systems) or from switching off the current (opening systems) until the beginning of the torque increase

Rise time t_{12}

Time from the beginning of the torque increase until reaching 90% of the nominal torque M_2

Engagement time t_1

Sum of engagement delay t_{11} and rise time t_{12}

Engagement delay when disconnecting t_{21}

Time from switching off the current (closing systems) or from switching on the current (opening systems) to the beginning of the torque decrease

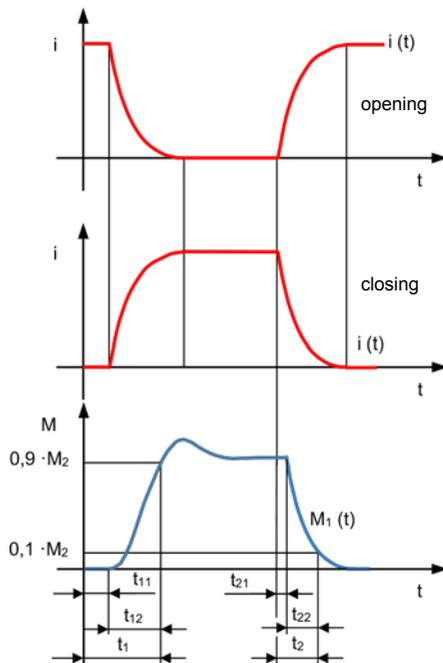


Fig. 02/2: Coupling and disconnecting process

Fall time t_{22}

Time from the beginning of the torque decrease until reaching 10% of the nominal torque M_2

Disengagement time t_2

Sum of engagement delay t_{21} and fall time t_{22}

Further terms and definitions according to DIN VDE 0580 (excerpt)

Switching work of a clutch**or brake W**

Heat generated by friction due to a switching operation in the clutch

Maximum switching work W_{\max}

Switching work, with which the clutch or brake may be maximally loaded

Switching capacity of a clutch**or brake P**

Permissible switching work converted into heat per time unit

Maximum switching capacity P_{\max}

Maximum permissible switching work converted into heat per time unit



Magnetic parameters

The laws of electromagnetic systems are based on physico-magnetic parameters that interact to influence the function of the electromagnetic clutch and brake.

- Magnetic voltage (flux) Θ
- Magnetic flux Φ
- Magnetic field strength H
- Magnetic flux density (induction) B
- Magnetic conductivity (permeability) μ
- Magnetic resistance R_m

Electromagnetic energy conversion

The conversion of electrical energy into mechanical energy does not take place directly in the electromagnet, but rather via the energy of the magnetic field. Therefore, in the case of the electromagnet, one speaks of an "*electro-magneto-mechanical*" energy conversion¹. As with all energy converters, the law of conservation of energy also applies to the electromagnet.