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KTA 3504 (2022-11)

Electrical Drive Mechanisms of the Safety System in Nuclear Power Plants

(Elektrische Antriebe des Sicherheitssystems in Kernkraftwerken)

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If there is any doubt regarding the information contained in this translation, the German wording shall apply.

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Electrical Drive Mechanisms of the Safety System in Nuclear Power Plants

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All questions regarding this English translation should please be directed to the KTA office:

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Comments by the Editor:

Taking into account the meaning and usage of auxiliary verbs in the German language, in this translation the following agreements are effective:

shall	indicates a mandatory requirement,
shall basically	is used in the case of mandatory requirements to which specific exceptions (and only those!) are permitted. It is a requirement of the KTA that these exceptions - other than those in the case of shall normally - are specified in the text of the safety standard,
shall normally	indicates a requirement to which exceptions are allowed. However, exceptions used shall be substantiated during the licensing procedure,
should	indicates a recommendation or an example of good practice,
may	indicates an acceptable or permissible method within the scope of this safety standard.

Basic Principles

(1) The safety standards of the Nuclear Safety Standards Commission (KTA) have the task of specifying those safety-related requirements which shall be met with regard to precautions to be taken in accordance with the state of science and technology against damage arising from the construction and operation of the plant (Sec. 7, para. (2), subpara. (3) Atomic Energy Act - AtG) in order to attain the protective goals specified in the AtG, the Radiation Protection Act (StrlSchG) and the Radiation Protection Ordinance (StrlSchV) as well as further detailed in the Safety Requirements for Nuclear Power Plants (SiAnf) and the Interpretations of the SiAnf.

(2) Based on the Safety Requirements for Nuclear Power Plants and their Interpretations, the present safety standard specifies the requirements for the electrical drive mechanisms of the safety system and for their assignment to the process-engineering systems of the safety system.

(3) In the present safety standard, it is presumed that conventional requirements and technical standards (e.g., Accident Protection Requirements, DIN-Standards, VDE Regulations) are adhered to under consideration of the safety-related requirements specific to nuclear power plants.

(4) The present safety standard specifies those requirements for the electrical drive mechanisms of the safety system that cover the generally accepted design loads derived from the analyses of design basis accidents.

(5) This safety standard supplements the safety standards KTA 3701 through KTA 3705 dealing with the supply of power and operating media and KTA 3501, Reactor Protection System and Monitoring Equipment of the Safety System. Furthermore, regarding the valves and machines driven by the electrical drive mechanisms of the safety system, there is a connection in particular to safety standard KTA 3404, Isolation of Operating System Pipes Penetrating the Containment Vessel in the Case of a Release of Radioactive Substances into the Containment Vessel, and to safety standard KTA 3301, Residual Heat Removal Systems of Light Water Reactors.

(6) Safety standard KTA 1401 specifies the "General Requirements Regarding Quality Assurance".

1 Scope

(1) This safety standard applies to electrical drive mechanisms of the safety system in nuclear power plants. With respect to this safety standard, these include actuators, actuating magnets of valves, drive mechanisms of driven machines, and the control rod drive mechanisms.

(2) However, with respect to control rod drive mechanisms, only Section 8 of the present safety standard applies.

Note:

Further requirements for the control rod drive mechanisms are specified in safety standard KTA 3103, Shutdown Systems of Light Water Reactors.

(3) The present safety standard, furthermore, specifies requirements for the devices of the mechanical-equipment protection for those electrical drive mechanisms of the safety system whose signals do not have priority over reactor protection signals.

(4) The scope of this safety standard does not apply to:

- a) the mechanical-equipment protection whose signals do have priority over the signals of the reactor protection system,

Note:

Requirements for this kind of mechanical-equipment protection are specified in safety standard KTA 3501.

- b) the electric protective features,

Note:

The requirements for these devices are specified in safety standard KTA 3705, Switchgear, Transformers and Distribution Networks for the Electrical Power Supply of the Safety System in Nuclear Power Plants.

- c) the design, analysis, fabrication, assembly, tests and operation of actuator modules, control modules and priority-control modules.

Note:

The respective requirements are specified in safety standard KTA 3501 and in safety standard KTA 3503, Type Testing of Electrical Modules for the Safety Related Instrumentation and Control System.

2 Definitions

- (1) Controlled shut-down of an electric actuator

The controlled shut-down of an electric actuator is the disconnection or shut-down of the drive motor by the associated controlling devices.

Note:

The controlled shut-down of an electric actuator may be effected as a function, e.g., of a specified position (path-dependent controlled shut-down) or of a specified torque (torque-dependent controlled shut-down).

- (2) Shut-down failure

A shut-down failure exists whenever the motor of an actuator is not disconnected or shut-down even though the specified end position has been reached.

- (3) Mechanical-equipment protection

The mechanical-equipment protection is a device that is assigned to a certain piece of equipment in order to protect this equipment against operating conditions for which the equipment is not designed or not planned.

Note:

The controlled shut-down of actuators is not a part of the mechanical-equipment protection.

- (4) Closed-loop actuator

The closed-loop actuator is the actuator of a control equipment.

- (5) Authorized expert

An authorized expert is a qualified person or organization consulted by the nuclear licensing or supervisory authority based on Sec. 20 AtG.

- (6) Safety system

The safety system comprises the entirety of those devices within a reactor plant that have the task of protecting the plant against impermissible loadings and, in case of the occurrence of a design basis accident, to prevent that the effects of this occurrence on the operating personnel, the plant and the environment exceed specified limits.

- (7) Spindle force

The spindle force is the longitudinally directed force as a result of the torque introduced to the spindle by the spindle nut.

- (8) Actuator

The actuator is a drive unit that positions a final control element.

Note:

Actuators may be open-loop or closed-loop actuators. The various types of actuators comprise, e.g., rotary actuators, linear actuators, pivoting actuators. Final control elements comprise, e.g., valves, butterfly valves, gate valves.

- (9) Open-loop actuator

The open-loop actuator is the actuator of a controlling device.

(10) Design basis accident

A design basis accident is a sequence of events upon the occurrence of which operation of the plant or the activity cannot be continued for reasons of safety, and which sequence was considered in the plant design or for which activities protective measures were provided.

Note:

With respect to the plants under Sec. 7 Atomic Energy Act, a "design basis accident" is defined as being a sequence of events upon the occurrence of which operation of the plant cannot be continued for reasons of safety, and which sequence of events was considered in the plant design.

3 Superordinate Requirements for the Interaction of Electrical Drive Mechanisms and Engineered Safety Features

3.1 Basic Requirements

It shall be verified that the electrical drive mechanisms, in their interaction with other active and passive engineered safety features, are designed, manufactured and operated such that intolerable effects from design basis accidents and internal and external hazardous events are prevented.

Note:

It is permissible to perform this verification mutually for the entirety of all components of the safety system.

3.2 Failure-Initiating Events

3.2.1 Failure-initiating events in the electrical drive mechanisms of the safety system

(1) The electrical drive mechanisms shall be planned and arranged in conjunction with the process-technological systems such that a failure-initiating event in the electrical drive mechanisms will not prevent the protective actions necessary in case of a design basis accident.

Note:

This can be achieved, e.g., by arranging the process-technological systems in separate trains.

(2) The failure-initiating events in the electrical drive mechanisms of the safety system that shall be taken into consideration are, among others:

- a) failures resulting from short circuits, power interruptions, shorts-to-ground, voltage or frequency changes, mechanical failures, fires,
- b) several of the failures specified under item a) occurring simultaneously or in short succession of each other because of their having a common cause (fabrication faults, design faults, drift), and
- c) human errors during operation or maintenance of the electrical drive mechanisms.

3.2.2 Failure-initiating events inside the reactor plant

Failure-initiating events inside the reactor plant shall be taken into consideration.

Note:

See also: Annex 4 of the "Safety Requirements for Nuclear Power Plants": Principles for applying the single failure criterion and the maintenance.

Examples of failure-initiating events inside the reactor plant include: electromagnetic interferences line-conducted and field-bound, fire, water ingress, pipe whip, debris from a failed component, mechanical impingement of fluid jets, e.g., from steam, water, gas and oil.

3.2.3 Failure-initiating events outside the reactor plant

The electrical drive mechanisms of the safety system shall be protected against the same external events as the process-engineering system to which they are assigned.

Note:

Failure-initiating events are, e.g., earthquake, plane crash, blast wave from an explosion, flooding.

3.3 Failure Assumptions

(1) It shall be verified that the electrical drive mechanisms in their interaction with active and passive engineered safety features will, in addition to a design basis accident, be able to deal with

- a) one random failure (single failure),
- b) one maintenance case, and
- c) consequential failures,

provided, this is also required for the associated process-engineering systems.

(2) The random failure and maintenance case shall only be assumed once for the entirety of those components of the safety system that are required in dealing with a specific design basis accident.

(3) Common mode failures do not need to be assumed, provided, the probability of common mode failures is sufficiently reduced by taking the following measures:

- a) selecting suitable types of electrical drive mechanisms,
- b) design of the electrical drive mechanisms taking all possible ambient conditions, including those caused by design basis accidents, and also any possible impairments of the power and media supply into account,
- c) physical separation or other precautions against consequential damage, and
- d) quality assurance (type approval tests, suitability tests, factory tests, commissioning tests, inservice inspections).

3.4 Process-Engineering Design

(1) The electrical drive mechanisms of valves and driven machines for a process-engineering system shall normally be physically arranged according to the train of the associated process-engineering system.

(2) If a secure closing and opening of a media supply system is required, the circuitry of the valves shall be such that a high level of reliability is achieved for each of these actions.

Note:

This can be achieved, e.g., by connecting two sets of series-connected valves parallel to each other.

(3) Process-engineering systems shall normally be designed such that valves and driven machines of the safety system, including the associated electrical drive mechanisms, can be operated for the purpose of testing during specified normal operation of the reactor plant without any impermissible reduction of the safety of the plant, and under load, e.g., in the case of pumps at their minimum delivery rates.

(4) With regard to monitoring the process-engineering-related function of a subsystem of the safety system (safety subsystem), feedback signals shall normally be derived from process-engineering parameters. If position checkback signals from electrical drive mechanisms are used to monitor the process-engineering-related function of a safety subsystem, a reliable coupling between position-signal generator and final control element shall be ensured.

3.5 Testability and Monitoring of Electrical Drive Mechanisms of the Safety System

(1) It shall normally be possible to test the electrical drive mechanisms of the safety system such that, even during the test, all protective features are functional when triggered by operational signals.

(2) If the electrical drive mechanisms of the safety system are connected by means of plug-in connections (i.e., power cables and cables for the instrumentation and controls), any disconnection of such plug-in connections shall normally be detectable from the main control room either directly, e.g., by wire-break monitoring, or indirectly, e.g., by a functional check of the drive mechanism.

(3) It shall be possible to test the actuators of the safety system such that, even during the test, the controlled shut-down of the electric actuators is possible [when triggered by operational signals].

3.6 Loadings from Leak Rate Tests of the Containment Vessel

Electrical drive mechanisms inside the containment vessel shall be designed such that their functional capability will not be impaired by the overpressure during inservice inspections of the containment vessel.

3.7 Redundancy and Independence

(1) The redundancy and independence existing as a result of the construction of the process-engineering equipment shall be maintained in the design and physical arrangement of the electrical drive mechanisms of the safety system.

(2) As protection against the failure-initiating events specified in Section 3.2, the electrical drive mechanisms of redundant process-engineering trains of the safety system shall normally be physically separated from each other or arranged such that they are protected from each other. A physical separation is not required if the failure-initiating events cannot prevent the protective actions.

4 Suitability Certification

(1) The suitability of the electrical drive mechanisms that will be used in the safety system shall be verified.

Note:

The suitability test includes the suitability certification as specified in Section 4 and the suitability review as specified in Section 13.

(2) It is permissible to submit the suitability certification for an entire production series of electrical drive mechanisms of the safety system. In this context, those individual drive mechanisms of the production series which would be subjected to the most severe assumed loads shall normally be subjected to the type approval test.

Note:

Electrical drive mechanisms of the safety system are considered as belonging to an individual production series if they are designed and fabricated according to the same mechanical and electro-technical design principles.

(3) The suitability of an electrical drive mechanism of the safety system or of an individual production series of electrical drive mechanisms shall be considered as certified, if

- a) the type of drive mechanism has been successfully subjected to a type approval test as specified in Section 9 and furthermore, depending on the individual type of drive, as specified in Section 10, 11 or 12, or
- b) the selected drive mechanisms of an individual production series have been subjected to type approval tests as specified in Section 9 and furthermore, depending on the individual type of drive, as specified in Section 10, 11 or 12

and if a satisfactory service experience under comparable operating conditions has been certified on ten drive mechanisms of the production series for at least five years of service in the case of actuators and actuating magnets of valves, or for at least three years of service in the case of drive mechanisms of driven machines. In the case of indications of overloaded components, of a wrong selection of materials or of other common mode failures, a proof that the cause of failure has been removed shall be presented.

(4) If an electrical drive used in the safety system has individual components which differ from those of the type-tested production series, a separate suitability test on those components is permissible.

(5) If modifications are made to a type-tested series with a certified satisfactory service life of electrical drives of the safety system which have functionally important characteristics, the suitability of the modified series for use in the safety system shall be demonstrated by supplementary or renewed type tests in accordance with paragraph 3 (see KTA 1401 Section 3 (9) and Section 6.2 (2)).

(6) If a new production series of electrical drive mechanisms is to be used for which a satisfactory service experience has not yet been certified, however, the important functional properties are comparable to those of a prior production series for which proof of successful operating experience is available, then it is permissible to perform supplementary tests only with respect to the new properties.

(7) If the deployment in nuclear power plants requires additional safety-related properties not covered by the certified satisfactory service experience and by the type approval tests as specified in Section 9 and furthermore, depending on the individual type of drive, as specified in Section 10, 11 or 12, then additional suitability tests shall be performed.

(8) Kind and scope of the suitability tests specified in paras. 4, 5, 6 and 7 shall be specified in agreement with the authorized expert.

5 Design of the Actuators

5.1 General

With respect to linear actuators, the term "torque" used in the following requirements shall be replaced by the term "thrust force".

5.2 Basic Requirements

The actuator (open-loop actuator or closed-loop actuator) shall be designed such that it will meet the requirements of the actuated valve and process-engineering system under the ambient conditions of specified normal operation and of the design basis accidents to be considered.

Note:

Requirements for the valve design are specified only insofar as they concern the mutual interdependency of valve and actuator.

5.3 Required Valve Torque

(1) The actuators shall be designed for the largest torque required for the valve which shall be determined under consideration of both task-related and design-related influences (e.g., ageing, wear).

(2) In the case of open-loop actuators, the torque characteristic shall be specified and tuned to the mode of operation of the drive motor and, for the case that the regular torque characteristic is exceeded, to the strength of the actuator.

Note:

Regarding the regular torque characteristic for open-loop actuators, it shall be assumed that the highest torque will not be sustained longer than 2 seconds, that the torque during actuation (operating

torque) will not exceed 50 % of the highest torque and the travel time will not exceed 60 seconds.

(3) In the case of closed-loop actuators, the torque characteristic shall be specified and tuned to the mode of operation of the drive motor.

5.4 Torque Delivered by the Actuator

(1) The torque to be delivered by the actuator shall be determined based on the required valve torque as specified in Section 5.3, and under consideration of the transmission ratio and efficiency of any intermediate transmissions and remote-control components.

(2) The actuator shall be designed for a higher torque than the torque required for the valve. In the case of actuators with a torque trip device, the maximum permissible adjustable cut-out torque shall be larger than the highest required torque by an amount equal to the adjustment tolerance specified in Section 5.8 para. 6.

5.5 Torque Magnification Factors

(1) Regarding the actuator and valve design, all possible torque magnification factors shall be determined which occur during operational travel at the end positions against a mechanical stop (in case of a valve, e.g., the valve seat or a mechanical path limiter). In this context, the tripping delay of Section 5.12 and the stiffness of the valve shall be specified. The torque magnification factors shall not cause the permissible torques for the valve and the actuator to be exceeded.

(2) Regarding the actuator and valve design, those torques and torque magnification factors shall be determined which may be applied to the actuator upon a shut-down failure or in the course of manual operation (by means of a hand wheel).

5.6 Design of the Drive Motor

(1) The drive motor shall be designed such that the actuator can deliver a torque that is at least equal to the maximum torque specified in Section 5.4 even when the motor is started with the operationally lowest possible voltage at the motor connecting terminals. In this context, the following conditional requirements shall be taken into account:

- The limit values of the motor torque deviations (i.e., of the startup, saddle and pull-out torques) relative to the design-basis values shall be taken into account. In this context, limit values may be specified that will restrict the deviations otherwise permissible in accordance with Table 20 of DIN EN 60034-1.
- The reduction of motor torques due to the voltage drop during motor startup shall be taken into account. The lowest voltage at the motor connecting terminals during startup shall normally be assumed at 80 % of the design-basis motor voltage. In the case of a connection to a voltage-controlled busbar with a high voltage stability, e.g., to a converter unit with limit values in accordance with Table 4-1 of safety standard KTA 3704, it is permissible to assume that the lowest voltage will not be lower than 90 % of the design-basis motor voltage.
- If a functional capability is required under design basis accident conditions, e.g., a loss-of-coolant accident in the case of light water reactors, the reduction of the motor torque due to the increased ambient temperature on account of the design basis accident conditions shall be taken into account.

(2) Both the heat rating and the type of insulation material of the motor coil shall be selected with regard to the most unfavorable ambient conditions and the largest loading.

5.7 Electric Power Supply

(1) The actuator shall be connected to an electric power supply such that, taking the voltage drop during motor startup into account, the connecting terminal voltage is never lower than the lowest design-basis connecting terminal voltage taken into account in the design under Section 5.6 para. 1 item b).

(2) The voltage drop shall be determined based on the lowest specified static busbar voltage as follows:

- In the case of a connection to an emergency diesel switchgear, the basis shall be that limit value of the design-basis busbar voltage specified as startup criterion in accordance with Sec. 3.12.2 of safety standard KTA 3702.

Note:

In order to be able to maintain a minimum connecting terminal voltage of 80 % of the design-basis motor voltage as specified in Section 5.6 para. 1, it may be necessary to install a voltage stabilizer.

- In the case of a connection to a voltage-controlled busbar with a high voltage stability, e.g., to a converter unit with the limit values in accordance with Table 4-1 of safety standard KTA 3704, the basis shall be the lower limit value of the static voltage deviation.

(3) If a functional capability is required under design basis accident conditions, e.g., a loss-of-coolant accident in the case of light water reactors, the increase in ohmic resistance of the supply cables due to the increased ambient temperature on account of the design basis accident conditions shall be taken into account.

5.8 Controlled Shut-down, Torque Limitation and Position Checkback Signals

(1) The devices involved in the controlled shut-down and the torque limitation, including the existing bypass circuits, shall be designed to such a degree of reliability that they are not the determining factor of the non-availability of the actuator with its associated valve.

Note:

Devices that are involved in the controlled shut-down may depend on, e.g., path, time, flow or torque.

(2) During startup and change-over procedures, the torque limitation may not cause any disconnection or shut-down of the actuator on account of the accelerated mass.

(3) In the case of actuators with a torque-dependent controlled shut-down, if, in a certain control range, the breakaway torque can be greater than the preset cut-out torque, then the torque-dependent controlled shut-down shall be bypassed in this control range. In this context, after the bypass is removed, it shall be ensured that the differential of the by-passed torque switch does not lead to any unintentional disconnection or shut-down of the actuator.

(4) During bridged-mode operation, the stress calculation specified in Section 5.9 shall normally be based on the maximum torque achievable by the actuator. The calculation may be based on a torque smaller than the maximum achievable torque, provided, preventive measure ensure that this smaller torque is not exceeded during the by-pass mode of operation.

Note:

This may be achieved, e.g., by activating an overriding second torque switch that is adjusted to a higher torque limit value or by a slip clutch, provided, either one of these methods remains active whenever the torque-dependent disconnection or shut-down is bypassed.

(5) The position checkback signal of the actuator may be used as position checkback for the valve, provided, a reliable relationship exists between the position checkback signal transmitter and the position of the valve.

(6) Any torque limiting device shall be designed such that the cut-out torque cannot deviate from the required value by more than 10 % of the maximum permissible adjustable cut-out torque.

5.9 Stress Calculation

The component parts subjected to mechanical loads shall be designed such that they can absorb any of the loads to be considered without the permissible stresses being exceeded and their functional capability being reduced.

5.10 Design for Design Basis Accident Conditions

Any actuator required to perform its function under design basis accident conditions, e.g., a loss-of-coolant accident in the case of light water reactors, shall, including its cable connecting terminals, be designed taking the design-basis-accident-related influences into account, e.g., temperature, pressure, humidity, radiation, corrosive media. The influence of any prior operational loadings shall be taken into account.

5.11 Manual Operation, Monitoring and Mechanical Safety Features

- (1) Motorized operation shall always have priority over manual operation (by means of a hand wheel).
- (2) Electro-technical plug-in devices and plug connectors shall be secured such that no self-unplugging is possible. The unplugged condition shall be detectable as specified in Section 3.5 para. 2.

5.12 Controlled Shut-Down Time

- (1) The actuator controls and the utilization of the limit switches shall be coordinated with each other.
- (2) The maximum time required for a controlled shut-down, i.e., the time period between the triggering of the controlled shut-down devices of the actuator and the separation from the power grid (shut-down delay), shall be specified. This shut-down delay shall be taken into account when determining the torque magnification factor as specified in Section 5.5.

5.13 Technical Documents

- (1) The technical documents specified in paras. 2 and 3 shall indicate how the actuators are designed, fabricated, assembled and tested in accordance with the safety requirements.
- (2) The following superordinate technical documents shall be prepared:
 - a) list of the actuators of the safety system, including a specification of the type of required resistance to design basis accident conditions and including their assignment to the respective valves and final locations,
 - b) list of the technical requirements.
- (3) The following technical documents shall be prepared for the actuators to be used:
 - a) specification of the technical data of the actuators (without the drive motor):
 - aa) manufacturer,
 - ab) designation of the type,
 - ac) design-basis output speed,
 - ad) maximum adjustable cut-out torque, or design-basis torque,
 - ae) maximum permissible torque during operation and in the case of a cut-out failure,

- af) torque magnification factors as a function of the valve stiffness during operation and in the case of a cut-out failure,
- ag) transmission ratio and efficiency of the transmission, and
- ah) total mass, and the location of the center of gravity.
- b) specification of the technical data of the drive motor:
 - ba) manufacturer,
 - bb) designation of the type,
 - bc) design-basis power,
 - bd) mode of operation,
 - be) design-basis voltage, design-basis frequency and permissible deviations,
 - bf) design-basis current and startup current,
 - bg) design-basis speed,
 - bh) maximum torque,
 - bi) minimum startup torque at the lowest specified connecting terminal voltage and at the maximum ambient temperature and, if required, at the design basis accident temperature,
 - bk) heat rating,
 - bl) type of protective enclosure, and
 - bm) type of construction.
- c) indications and certifications that the design requirements specified in Section 5 are fulfilled,
- d) certification regarding the suitability of the actuator for its deployment in nuclear power plants and that the requirements specified in Section 4 are fulfilled,
- e) schedule of the planned commissioning tests,
- f) schedule of the planned inservice inspections.

6 Design of the Valve-Actuating Magnets

6.1 Basic Requirements

The actuating magnet of a valve (individual valve, pilot valve or supplementary magnetic load) shall be designed such that it meets the requirements of the actuated valve and of the associated process-engineering system under the ambient conditions prevailing during specified normal operation and during the design basis accidents to be considered.

Note:

Requirements regarding valve design will be specified only as far as they relate to the mutual dependencies of actuating magnet and valve, or if tests can only be performed on the entire solenoid-operated valve. Actuating magnets may actuate, e.g., independent solenoid-operated valves or the pilot valves of hydraulic or pneumatic valves.

6.2 Determining the Magnetic Counterforce and the Biasing Force

The stroke-length dependent forces shall be determined that are required for actuating and repositioning the valve and which, considering the given actuation times and operational influences (e.g., ageing, wear), result from overcoming the system-related differential pressure across the valve; the actuating magnet and the biasing-force elements shall be designed accordingly (magnetic-counterforce versus stroke-length characteristic). The largest and the smallest magnetic forces shall be specified with regard to the strength calculation of the valve and other components, e.g., biasing spring.

6.3 Electro-technical Design

- (1) The actuating magnet shall be designed to deliver a magnetic force over the entire travel distance and within the