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DGUV
Fachbereich Holz und Metall
Berufsgenossenschaft
Holz und Metall

Fachbereich AKTUELL

FBHM-005

Gravity-loaded axes

Vertical axes – *Translation of the German version*

Sachgebiet Maschinen, Robotik und Fertigungsautomation (MRF)
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While it can be assumed that during horizontal movements in the automatic production no hazards to persons occur due to gravity in the de-energized state, for vertical movements, however, the risks of unintended gravity descent have to be considered in the risk assessment. These hazards particularly become obvious

- with linear robots (Figure 1) for the handling of heavy parts, e. g. engines or gears,
- with jointed-arm robots,
- inside machines, e. g. at vertical axes of machining or turning centers.

If the existing brakes do not provide sufficient protection against unintended gravity descent, control measures can contribute to reduce the risk of hazard.

Figure 1 – Vertical axes

1 Motor brakes

During the manufacturing process, vertical axes at a standstill are usually held solely by the brake which is installed in the drive motor. Mechanical wear or fouling by oil may cause the braking moment of the brakes to fall below its nominal value which may result in an unintended gravity descent or the fall down of the axis.

From the occupational safety point of view, the cases have to be considered in which persons have access to the danger zones and a full-time or a temporary stay under the axis, e. g. for feeding, setting, maintenance activities etc. is possible. If a failure of the holding brakes cannot be excluded in such situations, measures for a risk reduction shall be taken.

2 Risk assessment and control measures

According to the Machinery Directive [1] Annex I, every machine manufacturer is obliged to prepare a risk assessment. A particular standard for assessing risks at vertical axes does not exist. DIN EN ISO 12100 [2] provides general information for carrying out the risk assessment at machines including the identification of hazards.

Annex B of DIN EN ISO 12100 provides a useful table indicating possible hazards which have to be considered with machines, including those due to gravity. Depending on the practical case of application and the risk to be reduced, different technical safety devices are suitable to prevent the unintended gravity descent of vertical axes (see Table 3).

The examples indicated in Table 1 are intended to be a guidance for the risk assessment for such systems. By presenting typical hazardous situations, adequate technical and organizational measures are proposed in order to prevent unintended gravity descent. Besides the measures shown in Table 1, there are of course further requirements for occupational safety for the machinery in question, specified in the relevant EC directives and standards, the validity of which remains unaffected.

3 Self-acting (automatic) tests for upgrading existing (motor) brakes

According to the principles of the risk analysis, the summary in Table 1 considers the duration of stay, the severity of the possible injury and the probability of the occurrence of a hazardous situation. Therefore, redundant measures according to DIN EN ISO 13849-1 category 3 are proposed for highly exposed workplaces, which require a high duration of stay or frequent access [3]. Further explanations for implementing the measures according to category 3 are given in Table 2.

For other activities, in case of which e. g. a protective design prevents the access underneath the vertical axis or where the probability of the occurrence of a hazardous situation and the duration of stay is lower, a cyclic test of the single motor brake (brake test) can be a very effective measure. For this, a test moment is applied to the brake, e. g. a motor brake. This test should be carried out according to the requirements of DIN EN ISO 13849-1, category 2 (see Table 2). That means that the test shall take place automatically during normal production, e.g., during a process-related stop, in case of a change of the mode of operation or similar. If this is not possible, the test shall be carried out prior to releasing access by a guard with guard locking at the latest.

> According to DIN EN ISO 13849-1, the test rate for control systems of category 2 (checking) has to be estimated a 100 times more frequently than the demand upon the safety function. Due to the risks of vertical axes, i.e., particularly due to the accident history, such a high test rate is considered to be actually not required. Therefore, a calculation of the Performance Level according to the simplified procedures of DIN EN ISO 13849-1 is not possible

4 Brakes with emergency stop features

If the brakes should not only safely maintain the load in a raised position but should also be provided with emergency stop features (e. g. in case of protective stop actuation), it should be

pointed out that the self-acting static brake tests do not provide sufficient proof with regard to inadequate or decreasing emergency stop features. This means that despite a successfully performed static brake test, a slightly extended overrun in case of emergency stop is possible since the physical characteristics of the brake have different dynamic and static effects. The risk assessment of the machine manufacturer must indicate in such cases if a slightly different overrun in the course of the operating life represents an inacceptable risk.

> In order to refrain from providing emergency stop features to the brakes, a category 1 stop (guided stopping) should be preferred in case of a protective stop.

5 Systems already placed on the market

The above-mentioned measures for the improvement of occupational safety at vertical axes are primarily suitable for application at systems which are intended to be put on to the market.

Machinery and systems (used systems) that have already been brought onto the market shall meet the requirements of the Betriebssicherheitsverordnung (German Ordinance on Industrial Safety and Health) [4] and the accident prevention regulations of the statutory accident insurance institutions (DGUV Regulations).

The technical safety measures which have to be specified correspondingly must not necessarily reach the same level as those specified for new machinery according to the Machinery Directive. The decisive factor is the state of the art at the time when the machine is put on the market for the first time and the follow-up of the state of the art by the DGUV regulations.

Particularly safety measures for risk reduction by control have mainly been only established owing to recent findings. Measures by control cannot be easily retrofitted with the existing hard- and software. The employer is required to take measures according to § 4 of the BetrSichV in order to keep the hazard as low as possible. If the risks cannot be adequately reduced by technical safety measures, organizational measures have to be taken which contribute to the risk reduction (avoidance of presence underneath the axis, support etc.). Furthermore, employees have to be enabled by relevant instructions to assess hazards adequately. An essential element in this connection should also be the provision of periodic tests for detecting hazardous wear conditions. The kind, the scope, the test periods and the skill level of the testing personnel have to be specified by the user. The person skilled in testing shall have sufficient knowledge and experience in the field of the work equipment to be tested and must be familiar with the relevant national occupational health and safety regulations, DGUV regulations and generally accepted rules of technique (e.g. regulations determined by the committee for rules for Operational Reliability, DIN standards, VDE regulations, technical regulations of other member countries of the European Union or other contracting states of the agreement about the European Economic Area) so that he or she is able to assess the safe state of the work equipment.

6 Brakes as safety component

Brakes for holding up vertical axes can be classified as safety component according to the Machinery Directive 2006/42/EC, article 2 no. c). The precondition is that the brakes are put on the market separately, i.e., independently from the machine or the drive motor. In this case, the conformity assessment procedures which apply to machines have to be used. That means, amongst others, that an EC Declaration of conformity shall be prepared, and the EC marking shall be applied.

These provisions do not apply to motor brakes since they are not separately put on the market

due to the fact that they are built into the drive motor.

In this connection it is pointed out that a brake proven in use can be tested and certified (category 1, Plc) according to Test Principle no. GS-MF-28 [5].

7 Summary and limits of application

This „Fachbereich AKTUELL“ is based on experience and knowledge gathered by the Expert Committee Woodworking and Metalworking (FB HM), Subcommittee Machinery, Robotics and Automation of DGUV (German Social Accident Insurance) in the field of gravity-loaded axes, especially vertical axes.

It was prepared in cooperation with manufacturers of industrial robots, including linear robots and handling systems, manufactures of drive and control systems and the users of these systems, especially in automotive construction. In addition, results of consultations of the Verein Deutscher Werkzeugmaschinen (VDW; German association of machine tool manufacturers) were considered.

The measures mentioned in this “Fachbereich AKTUELL” for occupational safety represent the results of detailed discussions in the Expert Committee Woodworking and Metalworking concerning an improved occupational safety for activities at or near vertical axes. They include practical technical control measures against unintended descent due to gravity.

This “Fachbereich AKTUELL” indicates typical hazardous situations in connection with vertical axes and provides suitable approaches for risk reduction by technical control measures. Other measures against unintended gravity descent which are not mentioned in this information sheet remain unaffected.

Subject of consideration are vertical axes driven by an electrical motor as well as inclined axes with motor-integrated brake or external brake which could descent in case of failure due to gravity. Relevant requirements stated in EC Directives and other codes of practice remain unaffected. The developments of new technologies as well as equivalent solutions are not impeded by this information sheet. The applicability of the findings to machinery and systems with similar hazards is not excluded.

The measures may preferably be applied for systems which are put onto the market for the first time. Particularities at systems which are already placed on the market will be dealt with separately. The contents of this information sheet are intended to be included in technical rules or have already been included.

The provisions according to individual laws and regulations remain unaffected by this “Fachbereich AKTUELL”. The requirements of the statutory regulations apply without restriction.

In order to obtain detailed information, it is necessary to consult the applicable regulation contents.

This “Fachbereich AKTUELL” replaces the same-titled version, published as DGUV information sheet, FBHM 005, issued 09/2012. Updating was required as a result of editorial adjustments. This is the English translation of the German issue “FBHM 005 of 17 August 2021.

The Expert Committee Woodworking and Metalworking is composed among others of representatives of the German Social Accident Insurance Institutions, federal authorities, social partners, manufacturers and users.

Further Fachbereich AKTUELL or Information sheets of the Expert Committee Woodworking and Metalworking are available for download on the Internet [6].

Bibliography:

[1] Directive 2006/42/EC (Machinery directive) of the European Parliament, L157, 2006-06-09.

[2] DIN EN ISO 12100 Safety of machinery - General principles for design − risk assessment and risk reduction March 2011.

[3] DIN EN 13849-1 Safety of machinery −Safety-related parts of control systems − Part 1: General principles for design, July 2016.

[4] Verordnung über die Sicherheit und Gesund bei der Verwendung von Arbeitsmitteln (Betriebssicherheitsverordnung – BetrSichV).of February 03, 2015 (Bundesgesetzblatt I page 49 3777), latest amendment by Article 5 (7) of the Ordinance of October 18, 2017 (BGBl I page 3584),

[5] Prüfgrundsatz Nr. GS-MF-28 Notfallbremsen mit Haltebremsfunktion für lineare Bewegungen. Prüf- und Zertifizierungsstelle Maschinen und Fertigungsautomation im DGUV Test, Issac-Fulda-Allee 8 55124 Mainz. (Inhaltlich gleichlautend vorhanden bei IFA).

[6] Internet: www.dguv.de/fb-holzundmetall Publikationen

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Figure 1 – Vertical axes

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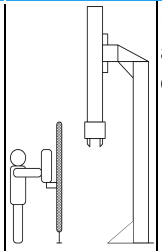
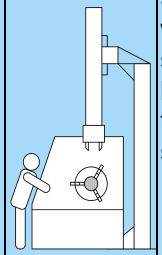
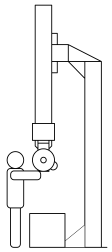
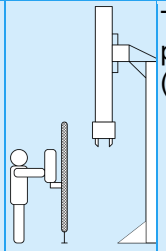
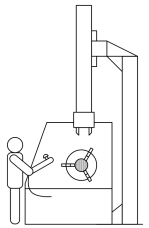
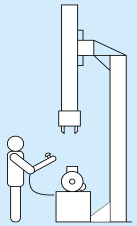
Table credits:

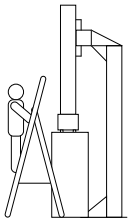
Tables 1, 2 and 3 − Fachbereich Holz und Metall, Sachgebiet Maschinen, Robotik und Fertigungsautomation.

Annex: Tables 1 to 3

Table 1: Typical hazardous situations and possible protective measures

Mode of operation	Hazardous situation/Intended use		Safety measures	
			Technical	Organizational
Automatic Manual intervention **A1**		During manual intervention, the vertical axis is located in a safe position for the operator (access-protected area).	• Guards have to be provided with guard lockings. • In case of access, unintended start of the vertical axis shall be safely prevented.	• Warning sign mounted at the machine/system: • „Do not stay underneath the vertical axis!“ • Point out to hazards due to vertical axis and suspended load in the operating instructions.
A2		The vertical axis is located within the hazardous area. Staying under the vertical axis with the whole body is prevented by the machine/ system design and not intended. A hazard exists for the upper limbs under the assumption of a short duration of stay	• Cyclic test of the braking device by the machine control according to DIN EN ISO 13849-1, category 2 (see table 2) • Unexpected start of the vertical axis shall be safely prevented[1)].	• Warning sign mounted at the machine/system: • „Do not stay underneath the vertical axis!“ • Point out to hazards due to vertical axis and suspended load in the operating instructions as well as to the need for skilled personnel. • Commissioning test to be carried out by the system manufacturer by means of a form with regard to the effectiveness of the brake test
A3		The vertical axis is located within the hazardous area. Staying under the vertical axis cannot be prevented (e.g. intended feeding or assembling activities).	• Redundant device for fall-down protection according to DIN EN ISO 13849-1, category 3, PLc (see table 2) • Unexpected start of the vertical axis shall be safely prevented[1)].	• Warning sign mounted at the machine / system: „ Do not stay underneath the vertical axis!“ • Point out to hazards due to vertical axis and suspended load in the operating instructions as well as to the need for skilled personnel. Limit stay under the vertical axis as far as possible.

Mode of operation	Hazardous situation/Intended use		Safety measures	
			Technical	Organizational
Set-up or programming **E1**		The vertical axis is located in a safe position for the operator during set-up (access-protected area).	• Guards have to be provided with guard lockings • In case of access, unintended start of the vertical axis shall be safely prevented).	• Warning sign mounted at the machine /system: „Do not stay underneath the vertical axis!“ • Point out to hazards due to vertical axis and suspended load in the operating instructions.
E2		The vertical axis is operated in the set-up mode and is located within the hazardous area. Staying under the vertical axis with the whole body is prevented by the machine/ ystem design and not intended. A hazard exists for the upper limbs under the assumption of a short duration of stay.	• Measures for set-up operation according to relevant standard, e.g. DIN EN ISO 10218-1, DIN EN 12417/DIN EN ISO 16090-1 (lockable mode selection switch, reduced speed + enabling device/ safely reduced speed …) • Cyclic test of braking device by the machine control system according to DIN EN ISO 13849-1, category 2 (see table 2).	• Warning sign mounted at the machine / system: „ Do not stay underneath the vertical axis!“ • Point out to hazards due to vertical axis and suspended load in the operating instructions as well as to the need for skilled personnel. • Commissioning test to be carried out by the system manufacturer by means of a form with regard to the effectiveness of the brake test.
E3		The vertical axis is operated in the set-up mode and is located within the hazardous area. Staying under the vertical axis with the whole body cannot be prevented, the duration of stay should, however, be short	• Measures for set-up operation according to relevant standard, e.g. DIN EN ISO 10218-1, DIN EN 12417/DIN EN ISO 16090-1 (lockable mode selection switch, reduced speed + enabling device/ safely reduced speed …) • Cyclic test of braking device by the machine control system according to DIN EN ISO 13849-1, category 2 (see table 2). • If, in exceptional cases a high duration of stay can be expected in the hazardous area, and if staying under the vertical axis cannot be avoided, measures according to DIN EN ISO 13849-1, category 3 have to be provided (see table 2).	• Warning sign mounted at the machine / system: „ Do not stay underneath the vertical axis!“ • Point out to hazards due to vertical axis and suspended load in the operating instructions as well as to the need for skilled personnel. • Commissioning test to be carried out by the system manufacturer by means of a form with regard to the effectiveness of the brake test.

Mode of operation	Hazardous situation/Intended use		Safety measures	
			Technical	Organizational
Maintenance, Repair, Cleaning **W1**		Maintenance, cleaning and repair works are carried out at or next to the vertical axis. Safe support of the vertical axis and / or suspension with reasonable effort is feasible.	• Observe the regulations in force for maintenance/ repair/ cleaning, e.g. lockable mains switch. • Support or, as far as still possible, move to lowest end position	• Warning sign mounted at the machine / system: „Do not stay underneath the vertical axis!“ • Point out to hazards due to vertical axis and suspended load in the operating instructions • Describe measures for safe support • Disconnect and lock mains switch
W2		Maintenance, cleaning and repair works are carried out at or next to the vertical axis. Safe support and / or suspension of the vertical axis is **not** feasible with reasonable effort.	• Observe the regulations in force for maintenance/ repair/cleaning, e.g. lockable mains switch. • Device to be operated automatically or electromechanically resp. manually for safe arresting of the axis in the defined positions, e.g. arresting device. • Clear marking of the positions „interlocked/unlocked“. • Interrogation of positions by the control „interlocked/ unlocked“ and interlocking with drive control.	• Warning sign mounted at the machine / system: „Do not stay underneath the vertical axis!“ • Point out to hazards due to vertical axis and suspended load in the operating instructions • Describe measures for the use of the devices for safe arresting (e.g. arresting device) • Disconnect and lock mains switch

[1)] Note: The control category and the Performance Level (PL) with regard to protection against unexpected start-up can usually be taken from the applicable product standards. In most cases, category 3, PLd applies

Table 2: Examples of measures against unintended descent of gravity-loaded axes (vertical axes) according to DIN EN ISO 13849-1 category 2 and 3.

1.	**General requirements**
1.1	The mechanical parts of power transmission and the safety devices shall be at least designed to withstand the occurring static and dynamic stresses at double weight load.
1.2	If a brake fault is detected by control means according to DIN EN ISO 13849-1, category 2 or 3, the vertical axis shall immediately approach a safe position in case of protective devices or unlocked protective doors, as far as this is still possible. The indications given by the machine control shall request for brake repair. In case of guards with locked protective doors, a safe position shall not be approached until an unlock demand signal has been given.
1.3	One or several warning signs shall be visibly fixed at the machine pointing out to hazards due to vertical axes and suspended loads.
1.4	The operating instructions shall describe measures for fall-down protection. They shall point out to hazards due to vertical axes and suspended loads.
1.5	Measures against unauthorised access to safety relevant programme parts of the control system shall be provided, e.g. by one of the following measures: • write protection for relevant parts of the programme • password protection • modification protection by means of a key switch
1.6	In order to prevent unnecessary wear of the brakes, preference should be given to stop category 1 (controlled stopping) − if permitted by the risk assessment − according to EN 60204-1, for operational stop and for emergency stop, instead of stopping with mechanical brakes.
2.	**Measures according to DIN EN ISO 13849-1, category 2 (cyclic brake test)**
2.1	The brake test shall be carried out in a safe position for the operator, e.g. safe parking position, closed guard.
2.2	The brake test shall become effective automatically during normal operation of the vertical axis, however, after 8 hours or a shift at the latest. For systems to which access is safely prevented, (e.g. by means of protective doors with guard locking), the test may be effected immediately prior to access after unlock demand signal. Note: According to DIN EN ISO 13849-1, the test rate for control systems of category 2 (checking) has to be estimated a 100 times more frequent than the demand upon the safety function. Due to the risks of vertical axes, i.e. particularly due to the accident history, such a high test rate is considered to be actually not required. Therefore, a calculation of the Performance Level according to the simplified procedures of DIN EN ISO 13849-1 is not possible and can be omitted in this particular case according to DIN EN ISO 13849-1, clause 6.2.2.
2.3	By the brake test it shall be established, that at least the maximum static weight of the load of the axis occurring in the case of application is held safely. The level of the test moment has to be selected accordingly, i.e. 1,3-times the load torque. If several brakes are applied in a parallel manner, (e.g. two brakes) this is considered to be fulfilled if the braking devices are tested separately one after the other on the simple weight load.
2.4	In order to ensure its total effectiveness, the test moment shall be applied over a sufficient time period.
2.5	After repair of a defective brake, a brake test shall be forced by the control system and completed successfully prior to further operation.

Table 2 continued

2.6	As to the effectiveness of the brake test, an acceptance test at the commissioning of the machine shall be carried out and recorded. During this acceptance test, a failure condition of the brake device shall be simulated and the corresponding fault reaction shall be checked. For this acceptance test, the machinery manufacturer shall provide a form and prescribe the need for skilled personnel. The acceptance test shall be carried out with a reasonable effort.
3.	**Measures according to DIN EN ISO 13849-1, category 3 (redundant measures for fall-down protection):**
3.1	Devices for holding the vertical axis shall be of redundant design (see also Table 3: Assignment of common braking devices to the individual modes of operation). If devices are applied which are not considered in table 3, they have to be classified logically according to table 1.
3.2	Measures for partial fault detection according to DIN EN ISO 13849-1 category 3 PLc shall be provided. Those measures include:
3.2.1	For electronic signal processing units: compilation of measures for detecting and controlling systematic and random faults.
3.2.2	Evaluation of signal states of sensors and actuators and signal processing units. Fault conditions shall result in a fail safe reaction.
3.2.3	If a continuous state monitoring of parts of the control system is not feasible, forced dynamizations shall be provided. E.g.: since motor brakes in general do not dispose of reliable signal outputs with regard to the brake state „open/closed“, a forced dynamization according to 2 (cyclic brake test) may be provided as a measure for fault detection for the motor brake, for the case that one channel of the dual channel holding system with motor brake is implemented.

Table 3: Assignment of common braking devices to the individual modes of operation

Design of braking device(s)		Suitable for mode of operation A1	Suitable for mode of operation A2	Suitable for mode of operation A3	Suitable for mode of operation E1	Suitable for mode of operation E2	Suitable for mode of operation E3	Suitable for mode of operation W1	Suitable for mode of operation W2
		During manual intervention, the vertical axis is located in a safe position for the operator within the hazardous area (in waiting position) or in an access-protected area.	The vertical axis is located within the hazardous area. Staying under the vertical axis is prevented by the machine / system design. A hazard exists for the upper limbs.	The vertical axis is located within the hazardous area. Staying under the vertical axis cannot be avoided.	The vertical axis is not operated in the set-up mode and is located during manual intervention in a safe position for the operator within the hazardous area or in an access-protected area. Staying under the vertical axis is not required for technical reasons.	The vertical axis is operated in the set-up mode and is located within the hazardous area. Staying under the vertical axis is prevented by the machine / system design. A hazard exists for the upper limbs.	The vertical axis is operated in the set-up mode and is located within the hazardous area. Staying under the vertical axis cannot be prevented.	Maintenance, cleaning and repair works are carried out at the vertical axis. Safe support of the vertical axis is feasible.	Maintenance, cleaning and repair works are carried out at the vertical axis. Safe support of the vertical axis is not feasible.
V0	Holding brake	✓	-	-	✓	-	-	-	-
V1	Holding brake with cyclic test	✓	✓	-	✓	✓	✓	-	-
V2	Holding brake with safety-related control and drives	✓	✓	✓*	✓	✓	✓	-	-
V3	Holding brake + second brake	✓	✓	✓	✓	✓	✓	-	-
V4	Safe brake	✓	✓	✓	✓	✓	✓	✓	✓
V5	Holding brake + mechanical counterweight	✓	✓	✓	✓	✓	✓	-	-
V6	Support or mechanical lock	-	-	-	-	-	-	✓	✓
V7	Holding brake + hydraulic/pneumatic counterweight	✓	✓	-	✓	✓	-	-	-

Design of braking device(s)		Suitable for mode of operation A1	Suitable for mode of operation A2	Suitable for mode of operation A3	Suitable for mode of operation E1	Suitable for mode of operation E2	Suitable for mode of operation E3	Suitable for mode of operation W1	Suitable for mode of operation W2
		During manual intervention, the vertical axis is located in a safe position for the operator within the hazardous area (in waiting position) or in an access-protected area.	The vertical axis is located within the hazardous area. Staying under the vertical axis is prevented by the machine / system design. A hazard exists for the upper limbs.	The vertical axis is located within the hazardous area. Staying under the vertical axis cannot be avoided.	The vertical axis is not operated in the set-up mode and is located during manual intervention in a safe position for the operator within the hazardous area or in an access-protected area. Staying under the vertical axis is not required for technical reasons.	The vertical axis is operated in the set-up mode and is located within the hazardous area. Staying under the vertical axis is prevented by the machine / system design. A hazard exists for the upper limbs.	The vertical axis is operated in the set-up mode and is located within the hazardous area. Staying under the vertical axis cannot be prevented.	Maintenance, cleaning and repair works are carried out at the vertical axis. Safe support of the vertical axis is feasible.	Maintenance, cleaning and repair works are carried out at the vertical axis. Safe support of the vertical axis is not feasible.
V8	Holding brake + hydraulic counterweight with brake valve	✓	✓	✓	✓	✓	✓	✓	✓
V9	Holding brake + safe clamping device	✓	✓	✓	✓	✓	✓	✓	✓
V10	Hydraulic/pneumatic axis + mechanical counterweight	✓	✓	✓	✓	✓	✓	-	-
V11	Hydraulic/pneumatic axis + hydraulic/pneumatic counter-weight	✓	✓	-	✓	✓	-	-	-

„* V2 only permitted in mode of operation A3 with additional protection in case of power failure.“

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