

12

Charging Methods and Techniques: General Requirements and Selection of Chargers

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12.1 THE BATTERY'S REQUIREMENTS FOR THE CHARGER

Charging of batteries must be conducted with direct current. Alternative current or rotary current have to be transformed. Mostly semiconductor rectifiers are employed for this task. Methods for battery charging vary with demand and the charging time is of great importance. The charging devices can be divided into those that charge above gassing voltage and those that do not. Chargers that exceed gassing voltage during charging are employed for charging one battery at a time, while the ones that do not exceed gassing voltage can be used for parallel charging of several batteries. The chargers that exceed gassing voltage attain short times for recharge, whereas with chargers that do not charge above gassing voltage very long charging times must be expected.

12.2 TECHNICAL DATA AND TERMS

Technical data on the charging process for lead-acid and NiCd accumulators are summed up in [Table 12.1](#). The following illustrates the most common technical terms applied in connection with charging techniques (1).

Table 12.1 Technical data for charging of lead-acid accumulators.

Line	Traction batteries		Stationary batteries			Automotive batteries
	GiS	PzS	Gro	GroE	OPzS	
1 Rated capacity (C _n)	C ₅	C ₅	C ₁₀	C ₁₀	C ₁₀	C ₂₀
2 Charging coefficient	1.17	1.2	1.1	1.1	1.2	1.15
3 Energy efficiency after C _n has been drawn, standard values	0.70	0.68	0.75	0.75	0.68	0.75
4 Maximum permitted charging currents per 100 Ah nominal capacity (A)						
(a) current constant upon reaching gassing voltage (I characteristic)	5	8.5	5	5	10	
(b) decreasing current (W characteristic) allowed at 2.4 V/cell	8	12	12	7	12	
at 2.65 V/cell	4	6	6	3.5	6	
(c) nominal current of the charger for (b) at 2.0 V/cell (DIN 41774)	16	24	18	14	24	
5 Maximum for the final charging phase allowable for 2.5 days max., e.g. for IU characteristic (A)	2	3	3	2	2	
6 Float charge current (see line 10) (mA)	40–100					
7 Maximum initial current at 2.4 V/cell and 20°C (68°F) (U characteristic), tolerance ± 10% (A)	100	80	80	80	80	160

12.2.1 Battery Capacity, Discharge Current, and Charge Current

Electrical batteries are DC storage systems that can either store or produce electrical energy by chemical transformations. The process of storing energy is called 'charging', whereas the production of energy is called 'discharge'. The chemical transformations are proportional to the amount of current consumed, respectively produced, in Ah, corresponding to Faraday's laws. Therefore the size of a battery is given in Ah (amperes (A) $\times$ time (h)).

As the capacity is dependent on the discharge current and the duration of discharge, it is not a constant value. This can be derived by the designation given by the manufacturers. The nominal capacity is given for 5 hours discharge time (C_5) for vehicle batteries and NiCd batteries; whereas for stationary batteries (also common for gas-tight NiCd batteries) the 10-hour discharge capacity (C_{10}) is given; and for starter batteries, motorcycle batteries, and small lead-acid accumulators the capacity for a 20-hour discharge (C_{20}) is given. A C_5 of 100 Ah signifies that this battery produces 100 Ah during 5 hours of discharge and the 5-hour discharge current is $I_5 = 100/5 = 20$ A.

The corresponding discharge current (I_5 , I_{10}) is also a measure for the charging current. If a charging current of $2 \times I_5$ is mentioned, this means that charging is conducted with twice the 5-hour discharge current. For a capacity of 100 Ah this amounts to $2 \times 100/5 = 40$ A.

12.2.2 Charge Coefficient

The ratio of amount of current needed for full recharge to the drawn current is called the charge coefficient. It amounts to 1.1–1.2 for lead-acid batteries depending on their design and between 1.2 and 1.4 for NiCd accumulators (see also [Tables 12.2](#) and [12.3](#)).

During every charging process a part of the applied amount of energy is lost, especially above the gassing voltage, through the process of chemical decomposition of water and hydrogen in the electrolyte. Therefore a greater amount of energy must be applied for charging than has been drawn prior to recharge. For example, given a battery with a nominal capacity of 125 Ah; 80% discharged (100 Ah); with a charging coefficient of 1.2; in order to attain fully charged state, $100 \text{ Ah} \times 1.2 = 120 \text{ Ah}$ have to be provided.

12.2.3 Charging Time

The given charging times are idealized calculated values presuming that all battery- and rectifier-specific data are constant. Practically such conditions are not met as, for example, mains fluctuations influence uncontrolled chargers; aging of the battery and variant temperatures also have influence.

Variance of the electrolytes' temperature by 10°C (18°F) (reference temperature for traction batteries 30°C (86°F), for stationary batteries 20°C (68°F) and for starter batteries 27°C (80.6°F)) changes the charging time by 1 hour. If the temperature is lower than the corresponding reference temperature as above, then charging is prolonged, whereas higher temperature shorten charging time. As these disturbing variables cannot be controlled, they are not considered for calculations of

Table 12.2 Technical data for charging NiCd and NiFe accumulators.

Line		Nickel cadmium				Ni/Fe	
		R	T	TS	F	RE	TNE
1	Rated capacity (C_n)	C_5	C_5	C_5	C_5	C_5	C_5
2	Charging coefficient	1.4	1.4	1.4	1.2	1.4	1.4
3	Energy efficiency after C_n has been drawn, standard values	0.50–0.55	0.55–0.60	0.60	0.75	0.45–0.50	0.50–0.55
4	Maximum permitted charging currents per 100 Ah nominal capacity above gassing voltage (A)						
	a) constant current (I characteristic)	About 20–30 A limited by heating up			10	About 20–30 A limited by heating up	
	b) current decreasing ^a	current decrease				current decrease	
	allowable at 1.5 V/cell	40–50%			8		
	allowable at 1.6 V/cell				6	30–40%	
	c) nominal current of the charger as in b) at 1.2 V/cell				20		
5	Lowest possible charging current (A)	—	—	—	—	7	—
6	Float charge current (see line 9) (mA)		20–60		100–300	—	—
	Charging voltages (V/cell)						
7	Initial voltage dependent of type, size, and current		1.3–1.4		1.3	1.4–1.6	
8	Charge end voltage dependent on type, size, and current		1.6–1.85		1.6	1.7–1.85	
9	Float charge voltage (see line 6)		1.38–1.40		1.36	—	—
10	Trickle charge voltage dependent on type		1.4–1.5		1.4	—	—
11	Buffer voltage at deactivation (vehicles and train lights)		1.6		1.5	—	—
12	Constant voltages for IU charging		1.6–1.7		1.5	1.7–1.75	
13	Secondary charging time (h)						
	for Wa characteristic, $I_N = I_5$	5.5	1.5	1.5	2.5		
	for WoWa characteristic	—	—	—	3.5		

^aFor R-, T-, and TS-type cells the W characteristic according to DIN 41775 with variable niveau. For F-type cells a W characteristic is employed, but adjusted by a ratio of 1.2:2.

Table 12.3 Allowed values for the charging current upon reaching gassing voltage for different types of cells.

Cell type (1)	Nominal capacity	Current (A) per 100 Ah nominal capacity for charging method			
		1 max.	2a max.	2b max.	3 max.
GiS, PzS	C ₅	5	8	4	2
Gro (vehicle) <i>K</i>	C ₅	10	14	7	3
Gro/GroE (stationary)	C ₁₀	8,5	12	6	3
OPzS	C ₁₀	5	7	3,5	2
Starter battery	C ₂₀	10	12	6	2

Charging method 1: charging with constant current and deactivation upon reaching fully charged state (Ia characteristic).

Charging method 2: charging with decreasing current and deactivation upon reaching fully charged state.
2a: allowed current at 2.4 V/cell.

2b: allowed end-of-charge current at 2.65 V/cell.

Charging method 3: allowed end-of-charge current without deactivation for up to 3 days charging time.

the charging time. A variance of ± 0.5 hour of the charging time should therefore be expected.

12.2.4 Gassing Voltage

The voltage above which a battery shows significant gassing action is termed ‘gassing voltage’. In reality the following values are encountered:

- 2.40 V/cell for lead-acid batteries.
- 1.65 V/cell for NiCd batteries, series T.
- 1.60 V/cell for NiCd batteries, series TS.
- 1.70 V/cell for NiCd batteries, series R.
- 1.50 V/cell for NiCd batteries, series F.

NiFe batteries show signs of gas emission immediately upon charge activation, but also in certain amounts during open circuit and discharge operation.

12.3 CHARACTERISTIC CURVES

The charging methods differ with respect to their current and voltage characteristics during charging and with the corresponding charging time. DIN 41 772 is the standardization for charging device characteristics.

A characteristic of a charging device is coordination of the DC voltage and the current valid for the given type of load.

The following progressions of characteristics have been determined by DIN 41 772 and fitted with the corresponding initial:

- Decreasing (taper) characteristic: W.
- Increasing characteristic: S.

- Limited characteristics: (I), (U).
- Constant characteristic: I, U.
- Assembled characteristics: e.g., IU, IUW, IO, Ia.

These abbreviations help describe the static behavior of the rectifier. Abbreviations for additional information are, e.g., 0, e, and a. Figures 12.1 and 12.2 show the most important modifications of charging characteristics.

Charging characteristics are generally influenced by external disturbances, such as variances of the mains voltage, its frequency, or the surrounding temperature. Special devices can largely diminish these influences. This is applied for constant and limited characteristics. The tolerances for constant characteristics must, if not stated otherwise, remain within the following marginal values:

- Mains voltage; $\pm 10\%$
- Mains frequency; $\pm 2\%$
- Ambient temperature; 0 to 40°C (32 to 104°F)
- Internal device temperature; 0 to 45°C (32 to 113°F)

The operating range for which the characteristics are valid can be found in the instruction manuals.

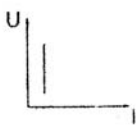
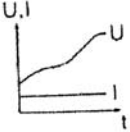
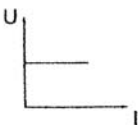
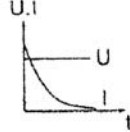
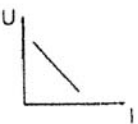
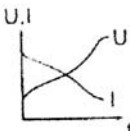
charging characteristic	abbreviation	temporal flow of the characteristic	application
	L		partial charging full charging overcharging deactivation by hand necessary
	U		Only permitted for limited periods of time temperature must be supervised
	W		only permitted for limited periods of time current has to be limited in such a way that the float-charge current can be harmless adsorbed by the battery

Figure 12.1 General charging characteristics.

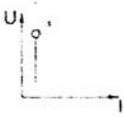
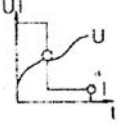
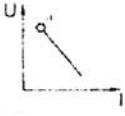
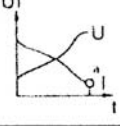
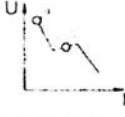
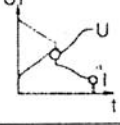
charging characteristic	abbreviation	temporal flow of the characteristic	application
	I_a		– for all large cells that would heat up beyond limits – for accelerated charging – for fast charging
	IOI_a		– partially charge up to a given deactivation-voltage, then – full charging conducted with reduced current
	W_a		– whenever the applications for an I_a-charger are to be fulfilled with low technical expenditure
	WOW_a		– whenever the applications for an IOI_a type charger are to be fulfilled with low technical expenditure

Figure 12.2 Modification of the I and W characteristics.

12.3.1 Decreasing (Taper) Characteristics (W Type)

A characteristic is termed decreasing when the voltage decreases with increasing current (type W).

12.3.2 Increasing Characteristics (S Type)

A characteristic is termed increasing when the voltage increases with increasing current (type S).

12.3.3 Limited Characteristics

Characteristics which independent of external disturbances do not vary by more than ± 10 from their nominal values are termed 'limited characteristics'.

1. If the desired limited value is a voltage, then a limited voltage characteristic is at hand.
2. When the desired limited value is a current, then a limited current characteristic is at hand.

12.3.4 Constant Characteristics

Characteristics which independent of external disturbances do not vary by more than $\pm 2\%$ from their nominal values are termed 'constant characteristics'.

1. When the desired value is a voltage, then a constant voltage characteristic is at hand (type U).
2. When the desired value is a current, then a constant current characteristic is at hand (type I).

12.3.5 Assembled Characteristics

An assembled characteristic is at hand if different characteristics pass over into one another continuously or by a step (types WOWa, IU, SU).

12.4 EMPLOYMENT OF CHARGING METHODS

12.4.1 Installation and Operation of Batteries and Chargers

DIN 57 510/VDE 0510 (3) deals with operation and installation of batteries and chargers.

12.4.2 Demands of Vented Lead-Acid Accumulators

The most important feature of chargers for lead-acid accumulators is the current being limited when the gassing voltage (2.4 V/cell) is reached. When reaching this value, the charging current is partially employed for decomposition of the electrolytes' water, and heat is excessively produced. Therefore the charge current when the gassing voltage is reached has to be reduced to the values permitted by the battery manufacturer.

12.4.3 Demands of the Maintenance-Free Lead-Acid Battery

In order to prevent the formation of gas inside the battery, charging may not be conducted above the gassing voltage. The charging voltage is limited to 2.35 V/cell for cyclic operation.

12.4.4 Demands of Vented Nickel/Cadmium Batteries

Here the current must not be reduced above gassing voltage (exception: cells with sintered electrodes), but the allowed temperatures of 45°C (113°F) must be respected (for cells with pocket electrodes 35°C (95°F)).

12.4.5 Charging Lead-Acid Batteries According to the W Characteristic

12.4.5.1 Application

1. Mainly for charging traction batteries. If 10 hours charging time is available, then charging is conducted according to the Wa characteristic; if only 7–9 hours are available, then the WOWa characteristic must be applied.
2. For charging small lead batteries with W characteristic with manual deactivation.
3. For charging centralized batteries of safety-lighting equipment in alternative charging operation to WOW characteristic.

12.4.5.2 Basic Demands

1. For protection of the battery the W characteristic must not allow the current limit values determined by the manufacturer to be exceeded at gassing voltage and at the end-of-charge voltage. The limit current values upon reaching gassing voltage are listed in DIN 57 510/VDE 0510, paragraph 12.2.3 (3), and in [Table 12.3](#)
2. The battery has to be disconnected manually (W) or automatically (Wa) upon reaching the fully charged state.

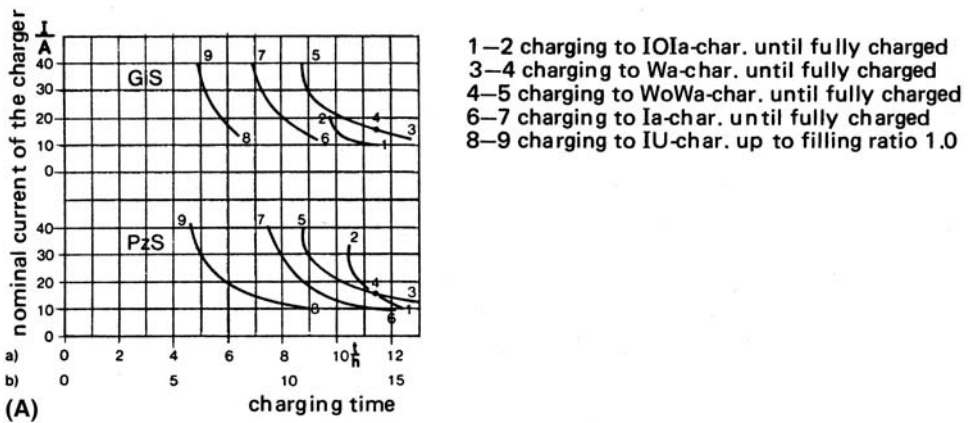


Figure 12.3 Charging time for lead-acid and NiCd batteries. (A) Rectifier nominal current for charging traction lead-acid cells GiS and PzS at 20°C (68°F) after discharge of (a) 80% and (b) 100% of C_5 . (B) Rectifier nominal current for charging of stationary lead-acid cells OPzS, Gro, GroE at 20°C per 100 Ah K_5 after discharge of (a) 80% and (b) 100% of C_5 (operation conforming to DIN 40729). (C) Rectifier nominal current for charging R-, TN/TS-, and F-type cells at 20°C per 100 Ah C_5 after discharge of (a) 80% and (b) 100% of C_5 (operation conforming to DIN 40729).

12.4.5.3 Characteristic

1. *Progression* (see [Figures 12.1](#) and [12.2](#)). Flow of the W characteristic is determined by three pairs of values:

Nominal current of the device at 2.0 V/cell.

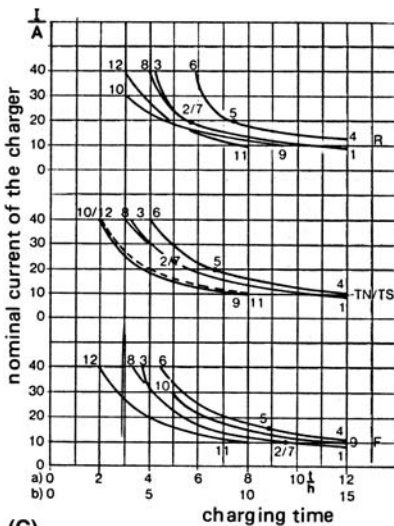
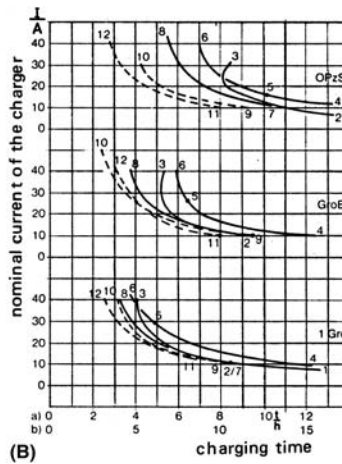
50% nominal current of the device at 2.4 V/cell.

25% nominal current of the device at 2.65 V/cell.

A tolerance of ± 0.05 V/cell is permitted.

2. *Nominal current of the device, charging current, and charging time* (Figure 12.3). Flow of the W characteristic allows a nominal current of

1–2 charging to Ia-char. until fully charged
2–3 charging to IOIa-char. until fully charged
4–5 charging to Wa*-char. until fully charged
5–6 charging to WoWa*-char. until fully charged
7–8 charging to IOIa-char. until fully charged
9–10 charging to Wa*-char. up to filling ratio 1.0
11–12 charging to IU-char. up to filling ratio 1.0
* characteristic according to DIN 41774



1–2 charging to Ia-char. until fully charged
2–3 charging to IOIa-char. until fully charged
4–5 charging to Wa*-char. until fully charged
5–6 charging to WoWa*-char. until fully charged
7–8 charging to IOIa-char. until fully charged
no advantages to IOIa
9–10 charging to Wa*-char. up to filling ratio 90%
11–12 charging to I, Ia-char. up to filling ratio 100%
* characteristic for R-, TN/TS-type cells acc. to DIN 41775 with adjustable niveau;
characteristic for F-types acc. to DIN 41774 but adjusted by a ratio of 1.2:2 to 1.2 V nominal current at I_N

Figure 12.3 Continued.

the device (= charging current at 2.0 V/cell), which is twice as high as the allowed charging current at gassing voltage.

The initial charging current lies a bit lower than the device's nominal current as the battery voltage increases rapidly to 2.1 V/cell.

The nominal device current (I_L) related to 100 Ah is to be respected for the presently standardized lead-acid batteries (4). The device's nominal current I_{dn} leads to the following equation:

$$I_{dn} \text{ (A)} = I_L \text{ (A)} \times \frac{\text{nominal capacity(Ah)}}{100(\text{Ah})}$$

If shorter charging times are demanded than the W characteristic allows for, then a higher device current can be adjusted, but must be limited to the battery-specific limit value for the charging current (see [Table 12.3](#)) above gassing voltage of 2.4 V/cell. This method corresponds to the WOWa characteristic (see [Figure 12.2](#)). Best efficiency (ratio of costs for the charger/charging time) is attained for a nominal device current of 32 Ah. The shortest charging time is attained with a nominal device current of 40 A per 100 Ah.

3. Influence of the mains voltage. Charging currents from chargers with a W characteristic are generally dependent on the mains voltage, which means the device's current yield is influenced by fluctuations of the mains voltage. A mains voltage increased by 5% increases the current by 25% at 2.0 V/cell, by 35% at 2.4 V/cell, and by 50% at 2.65 V/cell. Therefore the mains voltage must be closely observed upon reaching the gassing voltage of 2.4 V/cell. In order to prevent damage to the battery, the charging device must be adjusted to the augmented mains voltage (e.g. at night) by means of a step-down transformer.

12.4.5.4 Guidelines for Operation

1. The resistance of the cables between the charger and the battery may influence the gradient of the characteristic curve and therefore the charging current. The length of these cables must therefore be considered (generally the charging devices are adjusted to a certain cable length).
2. Charging of two or more batteries in parallel operation with a W-type charger is not allowable since the current limit is not guaranteed for each battery.
3. Charging in series operation is only allowable if the current value does not exceed the smallest battery's charge acceptance capability and the fully charged batteries are switched off in time.
4. Chargers with a W characteristic have only to be dimensioned thermally for 80% of the nominal device current (because of the course of the charging process). Therefore it is advisable to determine the nominal current by the following equation (see also Section 12.4.5.3):

$$I_{dn} = I_L \times \frac{\text{nominal capacity(Ah)}}{100(\text{Ah})}$$

If a smaller nominal device current is chosen (for instance when there is enough time), this has to be respected for dimensioning the device.

12.4.6 Charging Lead-Acid Batteries Corresponding to the I Characteristic

12.4.6.1 Application

1. Mainly for charging starter batteries and batteries of the GroE type according to the la characteristic.
2. Especially suitable for initial charging (activation charging) following the la characteristic.
3. For charging batteries of the GiS and PzS type according to the IOIa characteristic.

12.4.6.2 Basic Demands

1. For protection of the battery, the I characteristic has to prevent the charging currents from rising above the manufacturer's specifications above gassing voltage. The limits for the charging currents are listed in [Table 12.3](#).
2. The battery has to be manually (I) or automatically (la) disconnected from the charger upon reaching fully charged state.

12.4.6.3 Characteristic

1. *Progression* (see [Figures 12.1](#) and [12.2](#)). Charging is conducted with constant current throughout the charging period followed by the deactivation of the charger.
2. *Charging device nominal current, charging current, and charging time* (see [Figure 12.3](#)). Course of the I characteristic allows a charging device current (= charging current at 2.0 V/cell) of the same magnitude as the permitted charging current at gassing voltage (see [Table 12.3](#)). For the batteries of the GiS and the PzS type charging with a constant current (I, la) value results in excessively long charging times because the current values are very low, as [Table 12.3](#) shows.

In order to attain acceptable values in this regard, the initial current is increased until gassing voltage is reached, so an IOI characteristic is formed. For batteries of the GroE type and starter batteries, acceptable charging times are attained with the la characteristic.

3. *Mains voltage influence*. For simple controlled charging devices the constant current changes proportionally with the fluctuations of the mains voltage. This must be considered.

12.4.6.4 Guidelines for Operation

1. Parallel charging of batteries is not recommended as after gassing voltage has been exceeded, limitation of the current value must be guaranteed for every battery (see [Table 12.3](#)).

2. Series charging of starter batteries is common. Several batteries are series-connected dependent on the charging devices' voltage. Fully charged batteries are disconnected and reconnected when discharged.

12.4.7 Charging of Lead-Acid Accumulators According to the IUIa Characteristic

12.4.7.1 Application

1. Mainly for charging traction batteries when shortest possible charging time (below 8 h) is demanded.
2. For “heedful” charging.

12.4.7.2 Basic Demand

1. For protection of the battery the charging current has to be reduced in the second I period so it does not exceed the manufacturer's limits above gassing voltage.
The limit values for the charging currents above gassing voltage are listed in [Table 12.3](#). During the constant-voltage charging period (2.4 V/cell) an allowed tolerance of $\pm 1\%$ may not be exceeded (5).
2. The battery must be disconnected manually (IUI) or automatically (IUIa) after the fully charged state has been attained.

12.4.7.3 Characteristic

1. *Progression.* Charging is initially conducted with constant current until gassing voltage is reached (first I part). Then the voltage is kept constant (U part), and the current decreases permanently as the battery's state of charge increases. As soon as the current has dropped to the allowed end-of-charge current (see Table 12.3), the final charging phase (second I part) is activated. Upon reaching the fully charged state, the battery has to be disconnected.
2. *Nominal device current, charging current, and charging time.* The charging current for the first I period does not have to be limited by the charging device. This is done, however, to protect the charging device and the equipment (charging cables, etc.). Charging with the IUIa characteristic permits charging times below 8 hours. Charging currents of twice or three times I_5 are not of interest as the gassing voltage is attained too fast and forces lowering of the charging current, and apart from that makes the chargers more expensive. The most economic solution is a nominal device current of 25 A per 100 Ah. The shortest charging time is attained with 40 A charging current per 100 Ah.
3. *Mains voltage influences.* The given tolerances of the characteristic curves (constant voltage $\pm 1\%$, constant current $\pm 2\%$) have to be guaranteed for mains fluctuations of $\pm 10\%$ and frequency fluctuations of $\pm 2\%$. For devices that are not dimensioned to cope with these fluctuations, the manufacturer must specify the allowed ranges. If greater mains fluctua-

tions of private networks are to be expected, this must be mentioned when ordering the charging device.

12.4.7.4 Guidelines for Operation

Parallel charging of batteries is not recommended in the second I period for the charging-current limit must be guaranteed for all of the batteries charged (see [Table 12.3](#)). Devices with a possibility to switch over from IU to IUIa can be employed for parallel charging in the IU position.

12.4.8 Charging According to the IU characteristic

12.4.8.1 Application

1. Mainly for charging traction batteries, whereas IU-type charging is conducted in large battery stations for parallel charging of several batteries at a time.
2. For fast charging of batteries (in pauses, for increase of the operational time), whereas fully charged state is not attained.
3. For heedful charging of sulfated batteries. (The voltage does not exceed 2.4 V/cell; the initial current is low and only increases when the sulfation has been reduced. Hereby the voltage even decreases for a transitory period of time. With an uncontrolled charging device the voltage would immediately rise above 2.4 V/cell, the initial current would be higher, the battery would start to gas strongly, and the temperature could rise to unallowed values.)

12.4.8.2 Basic Demand

For protection of the battery, the voltage of 2.4 V/cell must be kept constant within $\pm 1\%$ during the U phase (5).

12.4.8.3 Characteristic

1. *Progression.* Initial charging is conducted with constant current (I section) until gassing voltage is reached. Upon reaching the gassing voltage the charging device's voltage is kept constant (U section) and the charging current decreases. Fully charged state is only attained after a longer period of charging.
2. *Device's nominal current, charging current, and charging time.* The charging current during the I period would not have to be limited because of the battery, but only for protection of the charger and the equipment (charging cables, etc.). The battery is also indifferent to the tolerance of current limitation, but the smaller the tolerance, the better, as the charger's electric power is optimally employed and thus the charging time shortened (especially for simultaneous charging of several batteries). State of charge of 100%, respectively 80%, is attained by partial charge in very short periods of time. (Fully charged state corresponds to 120%, respectively 100%, with a charging coefficient of 1.2.)

3. *Mains voltage influences.* The given tolerances of the characteristic curves (constant voltage $\pm 1\%$, constant current $\pm 2\%$) have to be guaranteed for mains fluctuations of $\pm 10\%$ and frequency fluctuations of $\pm 2\%$. For devices that are not dimensioned to cope with these fluctuations, the manufacturer must specify the allowed ranges. If greater mains fluctuations of private networks are to be expected, this must be mentioned when ordering the charging device.

12.4.8.4 Guidelines for Operation

1. Batteries may remain connected to chargers of the IU type for up to 3 days if the final value of the charging current does not exceed 10% of I_5 . If the final charging-current value is higher, then charging must be interrupted upon reaching the maximum permissible electrolyte temperature of 35°C (131°F).
2. If the available daily charging time is not sufficient during the week, an equalizing charge has to be conducted once a week. If the batteries are fully charged during the day, then one equalizing charge every 4 weeks is sufficient. This equalizing charge can be conducted by a prolonged charging according to the IU characteristic during a weekend (guideline 1 must be respected!) or through charging with an increased voltage above gassing voltage (2.4 V/cell) if the charging devices are equipped with the corresponding device (such as an IU-IUW-IUI switch). The necessity for single charging during the W phase (for IUW) or the second I phase (for IUI) must be respected when parallel charging is conducted and the limit charging-current values listed in [Table 12.3](#) are not exceeded.
3. When dimensioning the cables connecting the battery to the charger, a voltage drop of less than 2% should be realized for nominal current.
4. When charging according to the IU characteristic, the electrolyte gravity and temperature of every cell have to be checked once a week in order to notice shorts between plates in time.
5. If a battery of low capacity is charged with a charging device of strong nominal current, then the electrolytes' temperature has to be surveyed above 2.4 V/cell or the charging current has to be reduced.

12.4.9 Charging of Nickel/Cadmium Batteries

NiCd batteries are generally charged according to one of the following three charging methods: I (Ia)-, W (Wa)-, or IU-type charging.

Charging according to the IOIa, WOWa, and IUIa characteristics is of course possible but not common as these characteristics are not necessary for charging NiCd accumulators (except IOIa-type charging for cells with sintered electrodes).

12.4.9.1 Basic Demands

1. NiCd batteries (except sintered cells) do not demand limitation of the charging current. For protection of the battery, however, it must be guaranteed that the limits for the electrolyte temperature (45°C (113°F); for pocket-plate cells 35°C (95°F)) are not exceeded.

2. Batteries have to be disconnected upon reaching fully charged state.
3. Equalizing charging with a current value of 15 should be conducted for 15 hours every 2 to 3 months for NiCd batteries.

12.4.10 Charging of Nickel/Cadmium Batteries to the I Characteristics

12.4.10.1 Application

Suitable for all designs.

12.4.10.2 Characteristic

1. *Progression.* The charging-current value is kept constant throughout the charge and the battery must be disconnected manually (I) or automatically (Ia) upon reaching fully charged state.
2. *Device's nominal current, charging current, and charging time.* Currents of 0.5 to 1.5 times I_5 are applied. For NiCd cells with sintered electrodes, the charging current must be limited above gassing voltage (see [Table 12.1](#)). This causes long charging periods for cells with sintered electrodes. In order to attain shorter charging times, the initial charging current (up to the gassing voltage) is augmented, forming an IOI (IOIa) characteristic.
For NiCd batteries of the R, T, and TS types, acceptable charging times are attained when applying a current of $1.5 \times I_5$.
3. *Mains voltage influences.* For regulated charging devices of simple design, the constant current changes proportionally to the mains fluctuations.

12.4.10.3 Guidelines for Operation

The charging current must be reduced for high electrolyte or ambient temperatures (greater than 45°C (113°F)).

12.4.11 Charging Nickel/Cadmium Batteries According to the W Characteristic

12.4.11.1 Application

For all types of constructions and designs this is the most common and heedful charging method (temperature and water consumption are kept especially low).

12.4.11.2 Characteristic

1. *Progression for series R, T, and TS NiCd cells.* As these series exhibit different initial voltage (1.25 to 1.5 V/cell), a range for the characteristic was fixed for which the characteristic of the charger must be adjustable (6). The adjustment in this range can be accomplished either by adjustment of the characteristics' niveau or gradient. As the gradient adjustment is of greater technical expenditure, the niveau adjustment method is more commonly applied. This kind of adjustability, however, is not demanded for the charging device when the charger is only applied for one type of

battery, which is generally practiced. Development has lead to the initial voltage generally being 1.4 V/cell as the voltage of lower-situated battery voltage levels rises quickly to this value when charged.

Two pairs of values therefore determine progression of the characteristic: (a) device's nominal current at 1.4 V/cell and (b) 40 to 50% of the devices' nominal current at 1.75 V/cell.

2. *Progression for series F NiCd cells.* For charging NiCd batteries with sintered electrodes a characteristic according to DIN 41 774 (W-type charging for lead-acid batteries) is employed with the following values:

Device's nominal current (DNC) at 1.2 V/cell.

About 40% of DNC at 1.5 V/cell.

About 25% of DNC at 1.6 V/cell.

3. *Progression for Ni/Fe batteries.* Series RE and TNE also have different initial voltages (1.5 and 1.75 V/cell); therefore a range was determined in which the characteristic must be adjustable (6). Adjustability is also not demanded when the charger is only applied for one type of battery. The progression for an adjustable characteristic is determined by the following values: (a) DNC for 1.5 to 1.75 V/cell and (b) 40 to 50% of DNC for 1.65 to 1.9 V/cell.

Ni/Fe batteries only attain fully charged state if the charging current does not drop below one-third of I_5 in the course of charge.

4. *Device nominal current, charging current, and charging time.* Adjustment of the DNC (= initial charging current) for type and size of the battery is determined by the time available for recharge. Standard value for the charging current is 0.5 to I_5 times I_5 . The electrolytes' temperature is kept within acceptable limits for these charging currents.
5. *Mains voltage influences.* For charging devices with W characteristic the current value is generally influenced by mains fluctuation. Variance of 10% of the mains voltage results in 30 to 50% variance of the charging current. The battery is indifferent to these changes of current, but the charging device is not. Therefore in the case of mains fluctuations over longer periods of time, step-down transformers must stabilize the charger.

12.4.11.3 Guidelines for Operation

Parallel charging of batteries cannot be advised for W-type chargers as varying battery voltage levels result in unequal charging of the batteries and therefore in an uneven state of charge. For Ni/Fe batteries the lower current limit is not guaranteed during recharge.

12.4.12 Charging of NiCd Batteries According to the IU Characteristic

12.4.12.1 Application

This charging method is only employed in a very few cases for single-battery charging, but is mostly employed for parallel recharge of several batteries.

12.4.12.2 Characteristic

- 1. *Progression.* Charging is conducted with constant current (I section up to gassing voltage). After the gassing voltage has been reached, the device's voltage is kept constant (U part) and the current values decrease to lower values.
Upon reaching the fully charged state the battery has to be disconnected. This constant voltage having a tolerance of $\pm 2\%$ (DIN 41 772) lies between 1.6 and 1.7 V/cell depending on the type of cell (2).
- 2. *Device's nominal current, charging current, and charging time.* The charging current (DNC for the first I section) is only limited by the electrolyte temperature. Charging currents of 1.5 to 2 times I_5 show good results for the charging time.
- 3. *Mains voltage influences.* The given tolerances of the characteristic curves (constant voltage $\pm 2\%$, constant current $\pm 2\%$) have to be guaranteed for mains fluctuations of $\pm 10\%$ and frequency fluctuations of $\pm 2\%$.

12.4.12.3 Guidelines for Operation

- 1. When parallel charging is performed, only batteries with the same number of cells and of the same type are connected.
- 2. For high ambient and electrolyte temperatures (greater than 45°C (113°F)) the charging current must be reduced.

12.4.13 Charging Valve-Regulated Lead-Acid Batteries

12.4.13.1 Charging Methods

Two methods are commonly practiced: (a) charging according to the W characteristic and (b) charging according to the IU characteristic. The W method is not advisable as the charge current is dependent on mains fluctuations.

12.4.13.2 Charge Currents and Charging Time

Charging data are given in Table 12.4

Table 12.4 Comparison of charging data for W- and IU-type charging characteristics.

Characteristic	Charging current	Charging voltage ^a	Charging time	Filling ratio	Operation mode
W	Max. $2 \times I_{20}$	2.3 V/cell	ca. 14 h	90%	Cyclic operation
IU	$2\text{--}10 \times I_{20}$	2.25–2.3 V/cell	14–4 h	90%	Float-charge operation (parallel operation)

^aambient temperature 20°C (68°F)

12.4.14 Charging Gas-Tight Nickel/Cadmium Batteries

12.4.14.1 Charging Methods

The two following methods are generally applied:

1. *Charging according to I (Ia, IOIa) characteristic.*
IOIa characteristic;
3 to 10 times I_{10} (series dependent) to end-of-charge voltage.
Half of I_{10} to I_{10} to end of charge (full charging).
2. *Charging according to W (Wa, WOWa) characteristic.*
W characteristic;
 $1.2 \times I_{10}$ initial charge current.
 $0.8 I_{10}$ end-of-charge current.

Charging according to I and W characteristics without deactivation is only allowed for currents 0.1 to 0.3 times I_{10} (series dependent).

When charging with higher current values, deactivation of the charge process must be controlled as it is time-, voltage-, and temperature dependent.

Charging according to an IU characteristic is prohibited.

12.4.14.2 Application

The option for applying charging methods according to the I or W characteristics, respectively their modifications, can be derived from [Figure 12.2](#).

12.4.14.3 Charging Currents and Charging Time

Charging data are given Table 12.5.

12.5 COMPARING CHARGING METHODS FOR LEAD BATTERIES

[Table 12.6](#) compares some charging methods for lead batteries

Table 12.5 Charging data for gas-tight NiCd batteries.

Type of charge	Charging current	Charging period	Characteristic	Filling ratio
Standard charge	I_{10}	14 hrs	Ia	100%
Accelerated standard charge	$2 - 3 \times I_{10}$ (series-dependent)	7 – 4.5 hrs	Ia	100%
Fast charge	$3 - 10 \times I_{10}$ (series-dependent)	2.5 – 1 hrs	Ia	70–90%
Float charge	$0.1 - 0.3 I_{10}$ (series dependent)	unlimited	I	

12.6 INSTALLATION COSTS OF CHARGING DEVICES

The costs for IU-type charging devices contain costs for one secondary charger for every three parallel charged batteries and for two secondary chargers for every three to eight batteries. The following comparison is on batteries 250 Ah, 80 V (= 40 cells). The battery-dependent charging currents of the charging devices are listed in Table 12.7.

Figure 12.4 shows a comparison between the initial costs for chargers of different characteristics.

12.7 GUIDELINES FOR THE SELECTION OF CHARGERS

This comparison of the charging method (Figure 12.3) and the initial costs (Section 12.6) allow for judgment of which devices are to be applied.

Device characteristics are to be chosen, when:

- Wa: (a) The mains voltage fluctuations are less than $\pm 5\%$.
(b) A charging time of 10–12 hours is available.
- WOWa: (a) The charging time is limited to 7–9 hours.
(b) The mains voltage fluctuations are less than $\pm 5\%$
- IUIa: (a) Charging time is limited to 6–7 hours.
(b) The mains voltage fluctuations are significant.
(c) Heedful charging is desired.
(d) The high initial costs are acceptable.
- IU: (a) Parallel charging of batteries is to be conducted.
(b) Short partial charging (e.g. at noon) is desired.
(c) The mains voltage fluctuations are significant.
(d) Additional secondary, respectively equalizing, charging is acceptable.

12.8 SPECIAL DEMANDS AND RECOMMENDATIONS FOR THE CHOICE OF CHARGER

12.8.1 Demands of Valve-Regulated Lead-Acid Batteries

To avoid gassing charge current, charge voltage and charging time are limited.

12.8.1.1 Charging Characteristic of Traction Batteries with VRLA Cells

The charge characteristic is specified by the battery manufacturer. Mostly this characteristic is a modification of the above-described IUI characteristics. The initial charge current is between 0.7 to 1 times I_5 , the final charge current between 0.07 to 0.08 times I_5 (a following additional charge sometimes is performed in current pulses). The total charging time is between 11 and 14 hours. Standardized characteristics do not yet exist.

Charger manufacturers offer chargers allowing the charge of batteries designed by different manufacturers (the chargers are controlled by a microprocessor that recognizes the characteristics specified by the battery manufacturer).

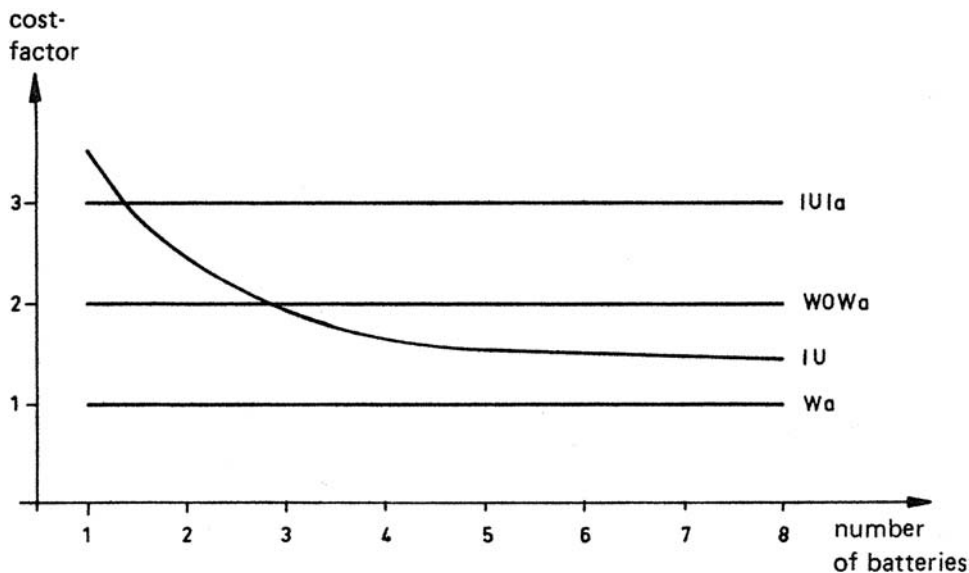


Figure 12.4 Initial costs for charging devices with different characteristics compared to the initial costs for a Wa-type charger (cost for Wa-type charger = 1).

12.8.2 Demands of Modified Traction Batteries

Note: *Traction batteries of the modified type are equipped with a device for electrolyte circulation).*

To increase the service life and to reduce maintenance to a minimum a heedful charge of the batteries is recommended. This can be performed by electrolyte circulation (reduced charging factor to 1.04 to 1.08, and reduced battery temperature means a double effect) or cooling with water or a cooling device (to reduce the battery temperature).

12.8.2.1 Charging of Modified Traction Batteries

The above-described charge characteristics Wa, WoWa, IU, and IU Ia may be performed (depending on the battery manufacturer's advice for the modified form). The initial charge current is chosen depending on the charging time wanted.

The complete charging process needs in addition to the battery;

1. *Electrolyte circulation.* Charger with the specified characteristic and a correct charging factor (1.04 to 1.08), and a pumping device for the electrolyte circulation with a control set.
2. *Cooling with water.* Charger with the specified characteristic and a cooling device with connection to a fresh water supply.
3. *Cooling device.* Charger with the specified characteristic and cooling device.

Depending on the battery manufacturer these variants are offered as a complete system.

Table 12.6 Comparison of charging methods for lead batteries.

	Wa	WOWa	IUIa	IU
Progress of charge	Device nominal current $0.8 \times I_5$, current decreases with rising voltage	Device nominal current $1.6 \times I_5$, after gassing voltage of 2.4 V/cell is reached automatic changeover (0) to Wa characteristic	Device nominal current (1.5 to $2 \times I_5$) constant up to gassing voltage of 2.4 V/cell. Then automatic changeover to constant voltage until current has decreased to $0.2 \times I_5$, then automatic changeover to the Ia phase. Charging conducted with constant current until deactivated.	Device nominal current (1.5 to $2 \times I_5$) constant up to gassing voltage of 2.4 V/cell, then automatic changeover to constant current
Charging	10–12 h	7–9 h	6–7 h	2.5–3.5 h for 80% full charge with secondary charger 10–12 h
Advantages	Upon reaching fully charged state automatic deactivation (a); simple technology	Short charging periods; upon reaching fully charged state automatic deactivation (a); simple technology	Shortest charging period; especially heedful charging of the battery; mains voltage fluctuations ($\pm 10\%$) are without effect on the charging current	Partial charges up to 80% in very short periods of time; parallel charging of several batteries possible; less water loss through gassing; mains voltage fluctuations ($\pm 10\%$) are without effect on the charging current; no time-dependent deactivation

Table 12.6 Continued.

	Wa	WOWa	IUIa	IU
Disadvantages	Only single charging possible; charging current generally varies substantially with mains fluctuations	Only single charging possible; charging current varies substantially with mains fluctuations	Only single charging possible, but parallel charging also possible with additional devices	Very low gassing action during daily charge, therefore unfavorable mixture of the electrolyte. Equalizing charging necessary during the weekend; in some cases secondary charger is necessary; If one IU charger is employed for simultaneously charging several batteries a breakdown has more severe consequences than if several chargers were employed.

Table 12.7 Comparison of charging devices with different charging characteristics for a charging current for 40 cells with 250 Ah.

Wa characteristic	$0.8 I_5 = 40 \text{ A}$
WOWa characteristic	$1.6 \times I_5 = 80 \text{ A}$
IU characteristic	$1.8 \times I_5 = 90 \text{ A}$
IUIa characteristic	$1.8 \times I_5 = 90 \text{ A}$

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