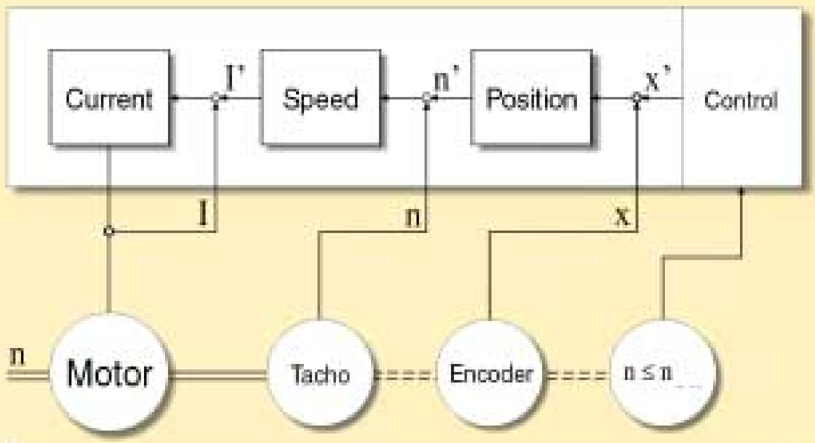


Figure 1: Principle of the cascade control: the control loops of motor current, speed and possibly position and speed monitoring are superposed.

Tachogenerators are used in measurement, control and automation engineering as sensors for converting the mechanical actual value “speed” into an electrical signal. Tachogenerators (Greek ταχοξ = speed, velocity) are **true** speed measuring devices, whose output signal $U_0(n)$ directly follows the speed n and the direction of rotation. This distinguishes them significantly from other speed sensors, such as resolvers, Digital-Tachos (incremental encoders) or sine-wave encoders, where the speed is derived by the signal rate per unit time, i.e. by differentiation.

The principle of the classic cascade control with tachogenerator is shown in ➔ Figure 1: The innermost and fastest control circuit detects the motor current I. The **speed control loop** is superimposed with the actual speed n delivered by the tachogenerator, which is compared with the set speed n’. Control of the position x takes place if necessary with a Digital-Tacho (incremental encoder).

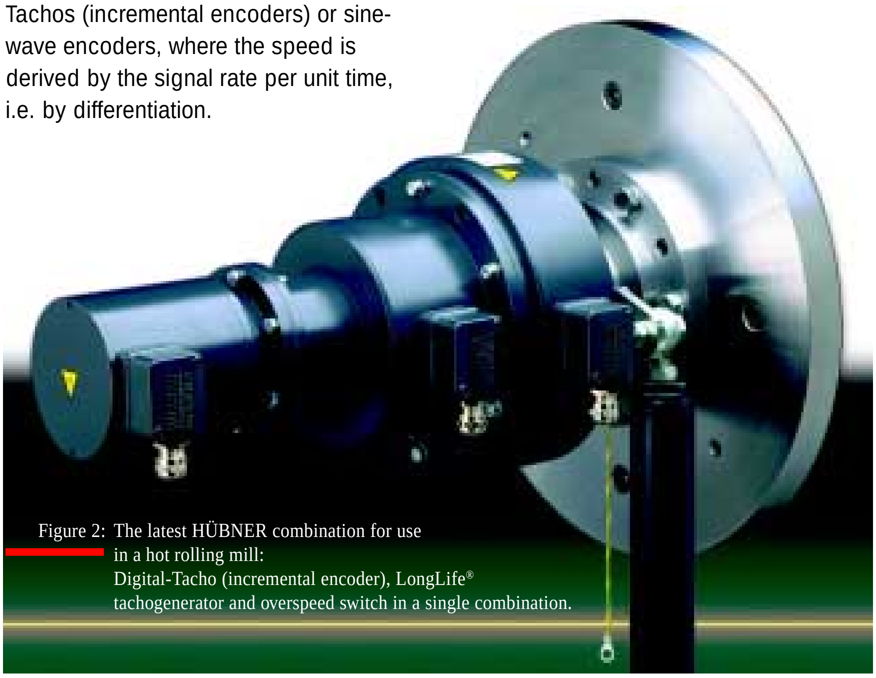


Figure 2: The latest HÜBNER combination for use in a hot rolling mill: Digital-Tacho (incremental encoder), LongLife® tachogenerator and overspeed switch in a single combination.

For monitoring a speed limit $n \leq n_{max}$, an overspeed switch can additionally be provided.
A HÜBNER combination for the variables “position”, “speed” and “speed monitoring” is shown in Figure 2 (➔ *Twin Tachogenerators and Combinations for special drive applications* on page 25).

Tachogenerator voltage

The tachogenerator armature (rotor) is connected as torsionally rigid as possible to the driving machine, whose speed is to be detected. As the armature rotates in the field of the permanent magnets, alternating voltages are induced in the armature winding. These voltages are tapped at the commutator with special brushes and in the process converted in correct phase relation (polarity dependent on direction of rotation) to a direct voltage. Available at the terminals is a no-load voltage U_0 (n), which is proportional to the speed (➔ Figure 3). For obtaining this signal, auxiliary power (voltage supply) is unnecessary, unlike other speed sensors.

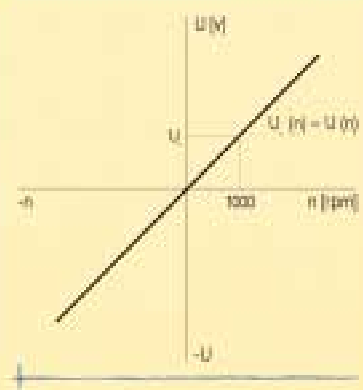


Figure 3: Tachogenerator speed-voltage characteristic.

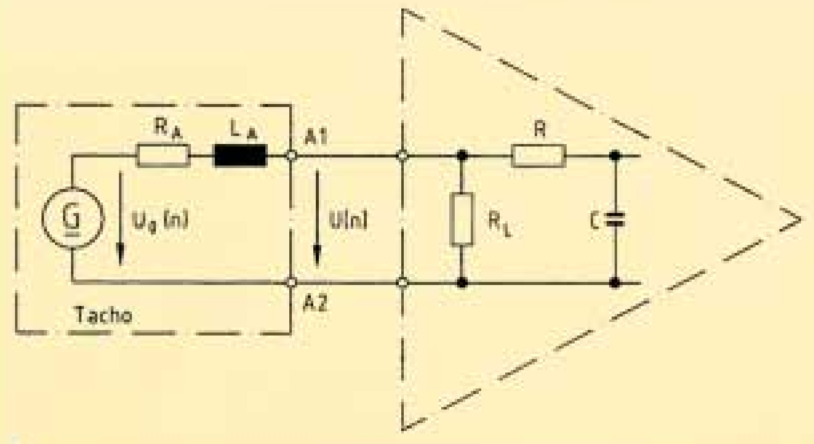


Figure 4: Equivalent circuit diagram of tachogenerator with subsequent control electronics.

From an electrical point of view, the tachogenerator represents a direct voltage source G with the no-load voltage U_0 (n), the armature (internal) resistance R_A and the armature inductivity L_A, which with the load resistance R_L is loaded, normally with the input resistance of the following control electronics (➔ Figure 4). For identification of the **speed-voltage characteristic** U_0 (n) (➔ Figure 3), the no-load voltage gradient [mV/rpm], i.e. the gradient of the straight line, or the no-load voltage U_0 normally delivered at rated speed n_n (typically n_n = 1,000 rpm), is specified. Both are standard reference values.

- Example:

The LongLife® tachogenerator TDP 0,2 LT-4 is characterized by the

–	no-load voltage gradient	60 mV/rpm or the
–	no-load voltage	60 V/1,000 rpm.

The **polarity** of the tachogenerator voltage (➔ Figure 3) depends on the direction of rotation and follows a reversal of direction without delay time. According to VDE specifications the polarity is defined with clockwise rotation of the drive, viewed from the drive end of the tacho-generator or drive (➔ Figure 5):

Terminal A1:+ Terminal A2:–

If the tachogenerator is loaded with the **load resistance** R_L or load current I_L (➔ Figure 4), applied to the terminals A1 and A2, the voltage is reduced by the voltage drop due to the armature resistance R_A

$$U(n) = U_0(n) - I_L \cdot R_A = U_0(n) \cdot \frac{R_L}{R_A + R_L}$$

As a rule, the load resistance R_L is very much higher than the armature resistance R_A, so that the following approximation applies

$$U(n) \approx U_0(n) \quad \text{for } R_L >> R_A$$

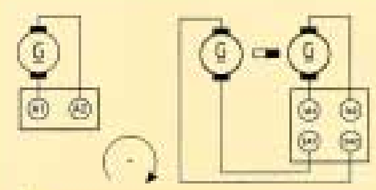


Figure 5: Terminals of the single and twin tachogenerator.

The voltage drop due to the armature resistance R_A in this case is so small that it does not appear in the speed-voltage characteristic (➔ Figure 3).

Minimum load resistance

The minimum load resistance is determined by the loading capacity of the tachogenerator. Shown in the HÜBNER data sheets is the **maximum power** P_{max}, with which the tachogenerator may be loaded. This depends on the size and is between 0.025 W (miniature hollow-shaft tachogenerator GT 3 for small servo-motors) and 40 W (tachogenerator with own bearings TDP 13 for rolling mills).

The minimum load resistance to be derived from the maximum power

$$R_{L\,min} = \frac{U_0^2(n)}{P_{max}}$$

increases with the square voltage U_0 or speed n. For the purpose of simplification, HÜBNER specifies in the data sheets three speed ranges

$$0 \ldots n_1 \quad \bullet \quad 0 \ldots n_2 \quad \bullet \quad 0 \ldots n_{max}$$

with the corresponding minimum load resistance R_{Lmin}.

- Example:

TDP 0,2 LT-4 (60 V/1,000 rpm, $R_A \approx 90\ \Omega$)		
0 ... n_1	0 ... n_2	0 ... n_{max}
0 – 3,000 rpm	0 – 6,000 rpm	0 – 10,000 rpm
R_{Lmin} = 2.7 kΩ	R_{Lmin} = 11 kΩ	R_{Lmin} = 30 kΩ

For practical application, this means that if the drive operates within a narrow speed range, the input resistance of the control amplifier can, if necessary, be much smaller than for a drive that uses the full speed range 0 ... n_{max}. The table also shows that the occasionally recommended rule of thumb R_{Lmin} = 100 x R_A results in a load resistance at higher speed which is too small.

In principle, a load resistance $R_L < R_{Lmin}$ is admissible, provided that at no speed on a time average the permissible temperature limit of +130 °C is exceeded defined in the regulation VDE 0530 according to the insulation class B.
The **thermal current limit** defines the maximum load: Above this limit, permanent damage to the tachogenerator can be expected due to internal heating.
A load resistance $R_L \leq R_{Lmin}$ limits the accuracy of the tachogenerator voltage, particularly at high speeds, due to the armature reaction (*Linearity tolerance* in next but one chapter).

A **short-circuit** of the tachogenerator is briefly admissible, however, there is a risk of the permanent magnets losing part of their field, thus affecting the calibration tolerance of the tachogenerator.

Calibration tolerance

The permanent magnets of the tachogenerators are "aged" in a special process, i.e. their magnetic properties balanced and stabilized. As a result, the no-load voltage gradient [mV/rpm] or no-load voltage U_0/1,000 rpm (Figure 3) is set ("adjusted") to a tolerance range of ±1 % (TDP 0,2), ±3 % (tachogenerators with own bearings) or ±5 % (hollow-shaft tachogenerators).
The calibration tolerance has no influence on the tachogenerator voltage linearity.

Linearity tolerance

The tachogenerator voltage $U_0(n)$ is proportional to the speed within a very narrow tolerance range, i.e. linear (Figure 3).

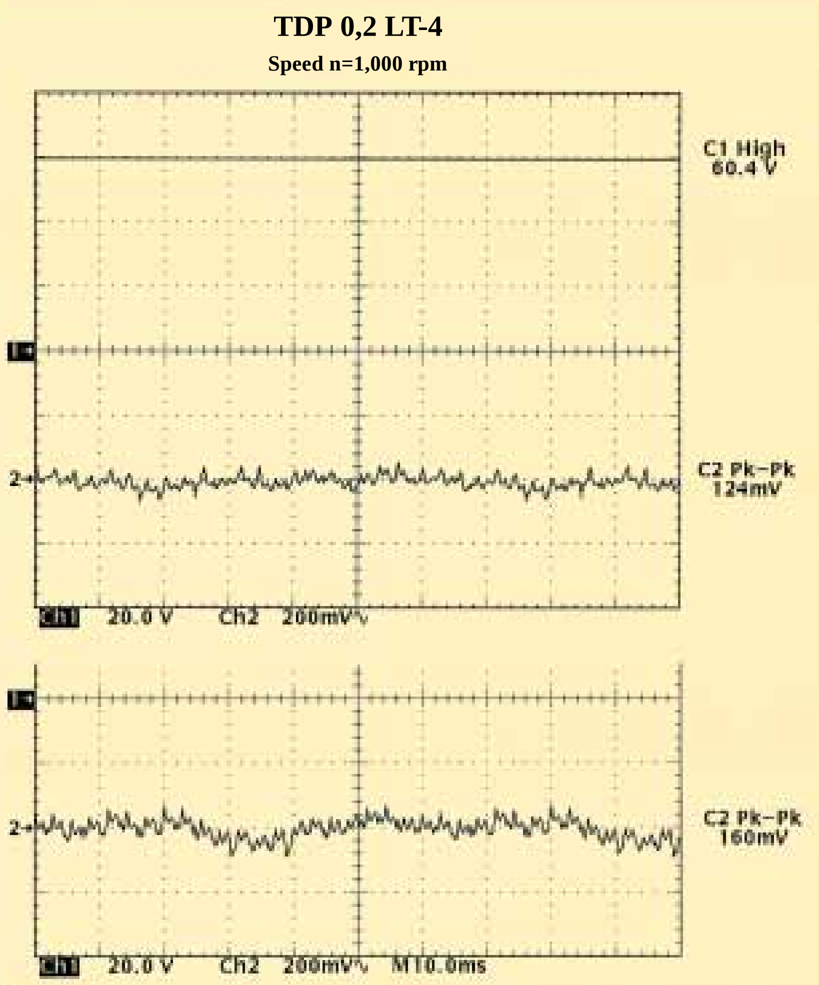


Figure 6: The tachogenerator voltages (above) are superposed by small ripple voltages (centre), incorrect mounting considerably increases the (low-frequency) ripple content (below).

The deviation

$$\frac{U_{\text{actual value}} - U_{\text{set value}}}{U_{\text{set value}}} \cdot 100\ \%$$

(normally ≤ 0.15%) occurs virtually only at high speeds. The causes are the armature reaction of the load current, the increase in the winding resistance due to the current displacement, the hysteresis loss in the core and the increased voltage drop due to the contact resistance between the commutator and brushes at the load current increasing with speed.

Reversing tolerance

With a reversal of direction, the position of the brushes on the commutator changes as a result of the brush clearance in the brush holders due to the design. This can result in a negligible difference in the tachogenerator voltage with clockwise and counter-clockwise rotation

$$\frac{U_{cw} - U_{ccw}}{U_{cw}} \cdot 100\ \%$$

The deviation is ≤ 0.1 %.

Ripple

The tachogenerator direct voltage is superposed with small ripple voltages u_{pp} (Figure 6), the frequency and amplitude of which depends on the speed, number of poles (number of magnetic poles), number of armature slots and number of commutator segments. Incorrect installation of the tachogenerator on the driving machine can increase ripple.
For this reason, special attention must be paid to correct installation (Page 15 and 18). Two methods are used for ripple characterization:

Peak-to-peak value: With an oscilloscope set to "AC", the harmonic voltage u_{pp} is measured, whereby the low pass character of the control electronics (Figure 4) is simulated by an RC filter with the time constant

$$\tau_{RC} \approx R \cdot C \quad \text{for } R > R_L >> R_A$$

Depending on the type of tachogenerator and particular application $\tau_{RC} = 0{,}2 \ldots 1$ ms.

The ripple voltage u_{pp} is referenced to the associated direct voltage U

$$\frac{u_{pp}}{U} \cdot 100\ \%$$

Some manufacturers base calculation on only half the peak-to-peak value, which *"optically"* improves the result by the factor 2.

For highly dynamic drives, however, the peak-to-peak value is of significance and should be as small as possible.

- **Root-mean-square value:** The root-mean-square value is measured with an evaluating measuring instrument. Because the higher frequency components of the ripple voltage make only a small contribution to the root-mean-square value, this value is lower than the peak-to-peak value. Definition of the root-mean-square value is therefore only of significance for large, less dynamic drives.

- Example:

The tachogenerator voltage of the TDP 0,2 has a peak-to-peak value of ≤ 0.5 % and a root-mean-square value of ≤ 0.2 %.

Temperature coefficient

The energy content of the permanent magnets reduces with increasing temperature. This affects the tachogenerator voltage with a temperature coefficient of

$$T_C = -0{,}03\ \%/K$$

With special soft iron alloys, which have a positive temperature coefficient and short-circuit a portion of the permanent magnet field, the temperature coefficient can be reduced almost to the power of ten to

$$T_C = \pm 0{,}005\ \%/K$$

The temperature coefficient of the armature winding

$$R_A(t) = R_A(20\ °C)\,[1 + \alpha_{Cu}\,(t - 20\ °C)]$$

($\alpha_{Cu} = +0{,}0039$) can be disregarded, as usually $R_L >> R_A$.

Delay time (armature circuit time constant)

The equivalent circuit diagram of the tachogenerator (Figure 4) contains in addition to the armature resistance R_A also the armature inductivity L_A. When terminating the circuit with a load resistance R_L, the tachogenerator voltage U(n) follows a change in the generated tachogenerator voltage $U_0(n)$ with the armature circuit time constant

$$\tau_A = \frac{L_A}{R_A + R_L} \approx \frac{L_A}{R_L} \quad \text{for } R_L >> R_A$$

The armature inductivity

$$L_A = A_L \cdot N^2$$

depends on the square of the number of windings N. The factor A_L combines the electrical and mechanical properties of the tachogenerator. For the load resistance the power loss has to remain constant, independent of the tachogenerator voltage. This means that for the load resistance a square-law relation is also given,

$$R_L \sim N^2$$

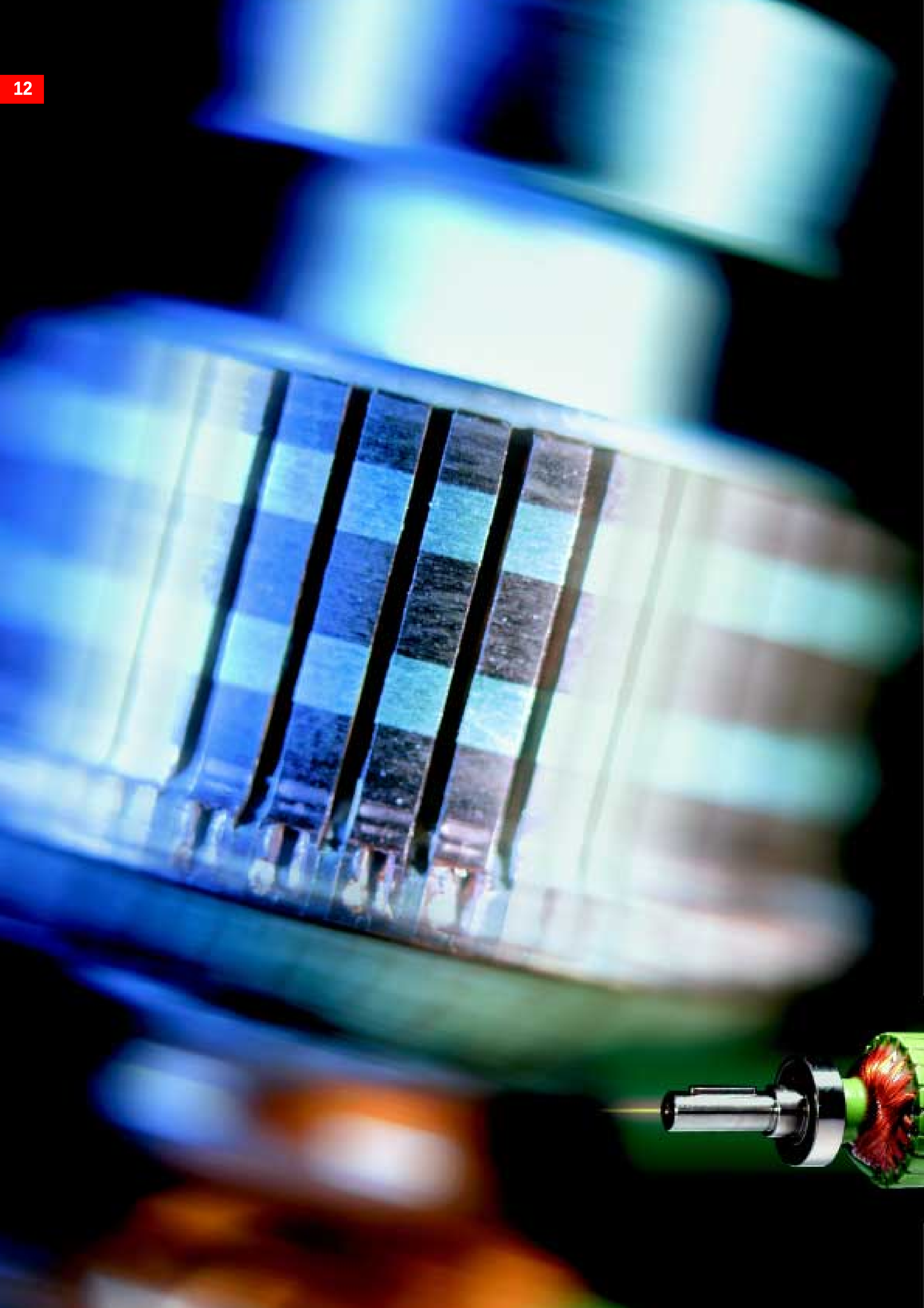
as explained on page 9, right column. The armature circuit delay time is thus

$$\tau_A \approx \text{const.}$$

This accordingly depends only on the tachogenerator type and not on the tachogenerator voltage.

The value specified in the HÜBNER data sheets for τ_A is based on the minimum load resistance R_{Lmin} and is in the µs range (tables on page 14 and 15).

For $R_L \to \infty$, i.e. no-load, $\tau_A \to 0$, i.e. with an unloaded tachogenerator, the tachogenerator voltage $U_0(n)$ follows the speed n virtually **without delay**.



LongLife® Technology

HÜBNER tachogenerators are characterized by high accuracy of the tachogenerator voltage $U_0(n)$ over the entire speed range n. An essential component is the standard-setting commutator – brush transfer system, which was further developed by HÜBNER:

Figure 7: Hollow-shaft armature (GTB 9) with embedded silver track.

Figure 8: Section through a LongLife® commutator (GT 5).

- **Copper commutator · Graphite brushes**

  This classic combination is technically overhauled. Low speeds cannot be detected precisely because the copper oxide layers on the commutator cause alternating contact resistances and in turn high tachogenerator voltage ripple. Advantageous by contrast is the long lifetime of the brushes, due to the good sliding properties of the graphite.

Figure 9: Armature of a two-pole tachogenerator with double silver track (TDP 0,2).

- **Copper commutator · Silver graphite brushes**

  The requirement for low speeds is met with noble-metal brushes which during operation apply a highly conductive layer to the commutator. However, the good transfer properties over the entire speed range can be lost in adverse atmospheres (oil, grease, sulphur and salt-laden air) if no layer develops. Because the metal-graphite brushes make direct contact with the copper, they are subject to wear.

- **LongLife® commutator · HÜBNER brushes**

  The LongLife® Technology, developed by HÜBNER and patented in 1987, combines the positive and eliminates the negative properties of both aforementioned techniques. In a special HÜBNER process, depending on the type of tachogenerator, one or two solid silver tracks are embedded in the commutator surface (➲ Figures 7 to 9). This ensures also in adverse ambient conditions a constant, small contact resistance. Because of the relatively small tachogenerator currents, the silver tracks can be narrow. The specially adapted HÜBNER brushes ensure together with the LongLife® commutator, freedom from maintenance that extends beyond the lifetime of ball-bearings (➲ *Ball bearings* on page 17).

The **LongLife® tachogenerators** are provided with **four** brushes for safe current transfer (redundancy), particularly under the influence of vibration and shock (➲ *Vibration and shock resistance* on page 19). (Exception: Miniature tachogenerator TDP 0,03 for use in measuring equipment):

- **Hollow-shaft tachogenerators**

  (Four-pole tachogenerators):
  The four brushes are accommodated in a brush holder each mechanically staggered by 90° (➲ Figure 10). Aposing brushes are electrically connected in parallel and all run on **one common** silver track (➲ Figure 7).

Figure 10: Four-pole tachogenerators are characterized by their four brushes staggered by 90° (GTB 9).

- **Tachogenerators with own bearings** (Two-pole tachogenerators): The brushes are mechanically staggered in pairs by 180° and accommodated in double brush holders. The two brushes each arranged side by side are electrically connected in parallel and run along **two parallel** silver tracks (Figure 9).

Hollow-shaft tachogenerators
(Four-pole tachogenerators)

Distinctive characteristics are the **armature** with **hollow-shaft without own bearings**. The armature rotates in a magnet field, which in analogy to the arrangement of the brushes, contains four alternately magnetized magnetic poles, which are mechanically staggered by 90° in the stator.
These tachogenerators are therefore also known as "four-pole tachogenerators". Following HÜBNER hollow-shaft tachogenerators have this design:

Type	P_{max} [W]	U_0 [mV/rpm]	τ_A [µs]
GT 3	0.025	5	≤ 2
GT 5	0.075	7 ... 10	≤ 4.5
GT 7	0.3 ... 0.6	10 ... 60	≤ 4
GT 9	0.3	10 ... 20	≤ 9
GTB 9[1)]	0.3	10 ... 20	≤ 9
GTR 9	0.9	10 ... 60	≤ 5
GT 16	1.8	60, 100	≤ 7

[1)] Mounting tachogenerator with IP 68, otherwise as GT 9

and further special types, e.g. TDP 0,5 (predecessor of GTR 9) (*Technical Data).*

Hollow-shaft tachogenerators are designed for a lower load and lower tachogenerator voltage.
They are characterized by a very small delay time (armature circuit time constant) τ_A (Page 11), small armature moment of inertia and direct mounting on the driving machine without further intermediate components (Figures 11 and 12).

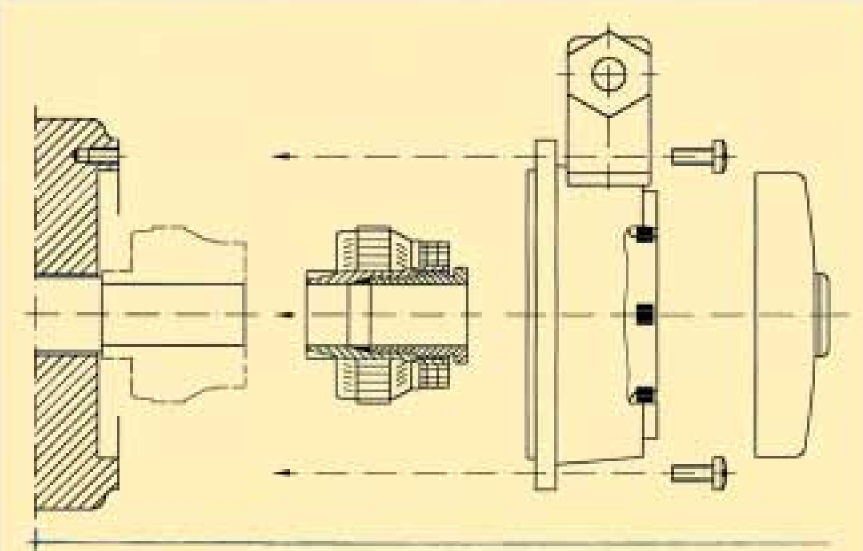


Figure 11: Hollow-shaft tachogenerators form together with the drive a torsionally stiff and particularly compact unit.

A body (stator) coupling is unnecessary, resulting in a **very high resonance frequency** of the closed control loop. Because of their extremely short design, hollow-shaft tachogenerators are also called "Pan cake tachogenerators" in American speaking countries.

HÜBNER hollow shaft tachogenerators contain a **two circuit winding** with a parallel armature current path, which for perfect functioning, would require only two brushes mechanically staggered by 90°. The two additional brushes increase safe current transfer without influencing the armature resistance R_A and in turn the tachogenerator voltage or ripple rate.

Figure 12: Hollow-shaft tachogenerator (GTB 9 in IP 68) on a precision CNC machine.

Some tachogenerator manufacturers use the less sophisticated lap winding with several parallel armature current paths, which are connected in parallel through the brushes. Brief lifting of the brushes due to mechanical influences increases the armature resistance R_A, which causes small reduction of the tachogenerator voltage and consequently a strong increase in the ripple rate.

Typical applications of hollow-shaft tachogenerators are drives with high demands on **speed dynamics**.

Hollow-shaft tachogenerators are delivered in two parts: as the armature (rotor) with the associated stator (with fitted brush holder). They are initially ready to use once assembled with the drive unit. This must therefore have a centering shoulder and a free shaft end (Figure 11). It is important that the dimensions and tolerances for the centering shoulder and shaft end specified in the data sheets are observed to maintain speed measurement accuracy.

- The **hollow-shaft armature** is fitted to the shaft without force and securely connected to the same by means of an integrated clamping element or a front screw fitting. The radial excentricity of the armature is limited to maximum ± 0.1 mm and the axial offset to maximum ± 0.5 mm. The radial excentricity should not exceed ± 0.05 mm.
- The **stator** of the hollow-shaft tachogenerator is slipped over the mounted armature onto the centering shoulder and screwed directly to the drive.
  To make the stator easier to slip over the armature without have to previously remove the brushes, HÜBNER has a mounting cone in its range of accessories.

Mounting of the armature and associated stator must be carried out with great care. Particularly the commutator and brushes have to be protected from damage and dirt. Care is required to avoid iron filings, which are attracted by the not yet mounted stator.

Assembly and **operating information** is available.

If necessary, hollow-shaft tachogenerators can be removed without a voltage loss occurring.

The protection class specified in the data sheets applies to correctly mounted hollow-shaft tachogenerators.

Tachogenerators with own bearings
(Two-pole tachogenerators)

Distinctive characteristics are the **armature** with **solid shaft** and **own bearings**. The armature rotates in a magnetic field, which, relative to the brush position, contains two alternatively magnetized poles, which are staggered by 180° in the stator. These tachogenerators are therefore also known as “two-pole tachogenerators”. Following HÜBNER tachogenerators have this design:

Type	P_{max} [W]	U_0 [mV/rpm]	τ_A [µs]
TDP 0,03	0.14 ... 0.32	7 ... 20	≤ 20
TDP 0,09	1.2	10 ... 60	≤ 25
TDP 0,2	12	10 ... 150	≤ 160
EEx GP 0,2 TG 74[1)]	12	20 ... 150	≤ 150
GMP 1,0	30	40 ... 175	≤ 550
TDP 13	40	20 ... 200	≤ 400

[1)] for use in hazardous areas

and several special types, e.g. rolling mill tachogenerator TDP 5,5.

Tachogenerators with own bearings are characterized in comparison to hollow-shaft tachogenerators by an enclosed, rugged housing, higher loading capacity, higher tachogenerator voltages and longer delay time (armature circuit time constant) τ_A (➔ Page 11).

A further characteristic is the tachogenerator drive via a coupling. Tachogenerators with flange, e.g. EURO® flange B10 (➔ *EURO® flange B10* on page 21), are mounted on the driving machine via a support housing (➔ Figures 13 and 14). Tachogenerators with foot (“B3 tachogenerators”) are fixed to their own bracket. With this mounting variant, particular attention should be paid to mounting errors (➔ *Coupling* on page 18). The tachogenerator shaft normally contains a key-way according to DIN 6885, page 1. The tachogenerator voltage can be transferred to the control electronics also over long distances, due to its amplitude and due to low tachogenerator internal resistance (➔ *Optimum signal transmission* on page 29).

Typical applications are machines and plants with high demands on **ruggedness** and **reliability**.

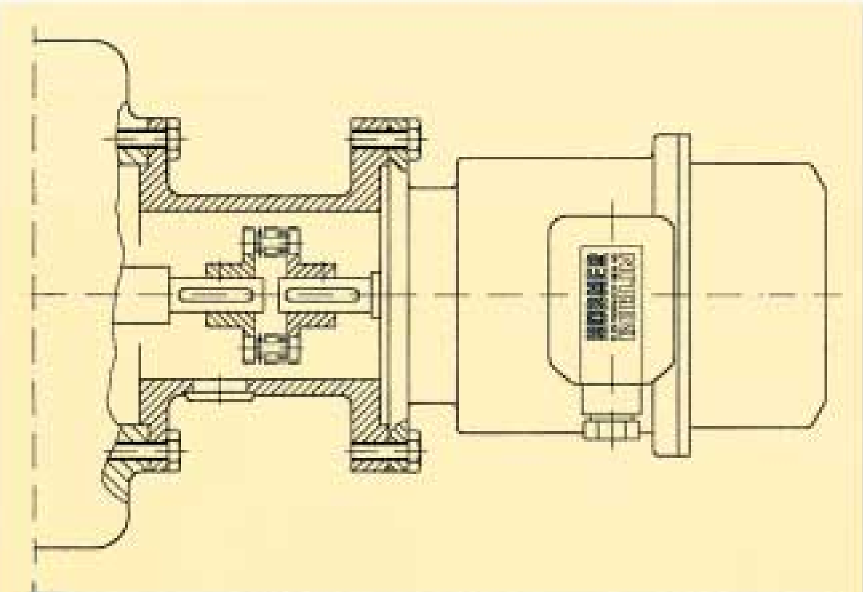


Figure 13: Tachogenerators with own bearings are connected to the drive via a support housing and coupling.

Figure 14: Tachogenerators with own bearings form a rugged unit with the driving machine (here a TDP 0,2 on one of the 500 kW drives of the Zugspitz cable-car).

If tachogenerators with own bearings should be dismantled for replacement of the ball bearings, the applicable **Assembly and Operating Information** must be observed, so that no voltage loss occurs after assembly. Only the TDP 0,2 can be dismantled without the otherwise required magnetic short-circuiting ring.

An exception to the classic division of "hollow-shaft tachogenerators"/"tachogenerators with own bearings" are **modified hollow-shaft tachogenerators**, which HÜBNER has in its range for special applications, e.g. the hollow shaft tachogenerator GTL 5 with own bearings and the solid shaft tachogenerator GTF 7 with EURO flange® B10, which were derived from the hollow-shaft tachogenerators GT 5 and GT 7. The designations indicate own bearings ("**L**ager") or **f**lange.

Minimum – Maximum speed

- The minimum speed depends on the tachogenerator type, tachogenerator voltage level, transmission interference (➲ *Optimum signal transmission* on page 29) and sensitivity of the evaluating electronics. HÜBNER Long-Life® Technology is capable of resolving tachogenerator voltages below 5 mV. This value is on the level of sinewave encoders, whose analog sine/cosine voltages of $1V_{pp}$ with appropriate quality of the signals (➲ Data sheets of HÜBNER LowHarmonics® sinewave encoders and special publication *"The rest are just noise"*), are similarly interpolated in steps in the order of some millivolts. With this guide value, the following are minimum speeds for several typical HÜBNER tachogenerators:

GT 5	(10 mV/rpm)	➔ ≤ 0.5 rpm
TDP 0,2	(60 mV/rpm)	➔ ≤ 0.08 rpm
HTA 16	(1,000 mV/rpm)	➔ ≤ 0.005 rpm

The GT 5 is capable, as demonstrated at the Hannover Fair, to measure the "speed" of a seconds hand. The HTA 16 is a special tachogenerator for very slow (direct) drives.

- The **maximum** speed can have a mechanical or electrical limit:

– The **mechanical speed limit** is determined by the maximum permissible armature circumferential speed, or in the case of tachogenerators with own bearings, by the maximum ball bearing speed and is normally about n_{max} = 10,000 rpm (➲ *Ball bearings* on page 17).

– The **electrical speed limit** is determined by the maximum permissible voltage between adjacent commutator segments (segment voltage) and is about 30 V. From this it follows that tachogenerators with a lower voltage gradient have a higher maximum speed:

GT 5	(10 mV/rpm)	➔ 10,000 rpm (mechanical limit)
TDP 0,2	(60 mV/rpm)	➔ 10,000 rpm (mechanical = electrical limit)
HTA 16	(1,000 mV/rpm)	➔ 360 rpm (electrical limit)

The mechanical or electrical maximum speed is shown in the data sheets.

Thus, for the tachogenerators mentioned as an example result the following **speed range**:

GT 5	(10 mV/rpm)	➔ ≥ 1 : 20,000
TDP 0,2	(60 mV/rpm)	➔ ≥ 1 : 125,000
HTA 16	(1,000 mV/rpm)	➔ ≥ 1 : 72,000

Comparison: Modern 14-bit A/D converters have a dynamic range of 1:16,384.

Housings

For ruggedness, HÜBNER housings consist of a nickel-plated steel ring (preferably hollow-shaft tachogenerators) or die-cast, powder coated light-alloy in the colour anthracite RAL 7021 (tachogenerators with own bearings).

Some hollow-shaft tachogenerators are provided with a transparent cover (➲ Figure 10 and 12), to enable the direction of rotation of the drive to be easily checked.

The **tachogenerator size** and in turn the **housing size** should be adapted to suit to the application:

– Large driving machines require a tachogenerator of **adequate size** (➲ *Typical applications* on page 30).

– For use in maritime or particularly damp or humid climates, the tachogenerators can be provided with optional **protection against maritime climates and tropicalization**.

We will be pleased to give you **advice** on all design and planning matters.

Types

The types conform to the standard IEC 34-7. Modified types are distinguished by additional letters. The devices shown **horizontally** in the dimension drawings of the data sheets are also suitable for **vertical** operation. The dimensions in the dimensioned drawings are guide values and can change in line with technological advance or at the request of the customer. Technical drawings provided on request are binding.

Ball bearings

The permanently greased ball bearings are amply dimensioned for high vibration and shock resistance. The lifetime is decisively influenced by vibration, shock, temperature, angular acceleration and reversing. The **maximum speed** n_{max} specified in the data sheets must not be exceeded. The specified value is determined either by the bearings, the maximum circumferential speed of the armature, or the maximum permissible voltage between the commutator segments (segment voltage). (➲ *Minimum – Maximum speed* on page 16).

The ball bearing manufacturers specify as a nominal **life expectancy** (number of revolutions) the following relation, which is reached or exceeded by 90 % of the bearings:

$$L = \left(\frac{C}{P}\right)^3$$

- L: Number of revolutions
- C: Dynamic load rating [N]
- P: Bearing load [N]

- Example:

For a HÜBNER tachogenerator with own bearing, e.g. TDP 0,2, the two ball bearings of which each equally support the armature with a weight of about 700 g, the following can be taken as basis

- C (typ. value) = 5,600 N
- P (typ. value) = 3.5 N

➔ L = $4.1 \cdot 10^9$ revolutions

This value coincides with normal practice: At 2,000 rpm, the ball bearings have a lifetime of over 40,000 hours, which corresponds to $4.8 \cdot 10^9$ revolutions.

The guide value of **10^9 revolutions** specified in the HÜBNER data sheets or 20,000 operating hours is greatly exceeded under normal conditions.

No-load drive torque

The brushes sliding on the commutator and, in the case of tachogenerators with own bearings, the ball bearings and shaft seals cause a no-load drive torque in the case of the unloaded tachogenerator, which is specified in the data sheets. With electrical load, this value increases according to the output power.

Bearings at both ends

Two-pole tachogenerators with bearings at both ends are characterized by a high radial and axial loading capacity of the shaft due to the armature being supported at both ends. This is of significance when the tachogenerator, for example, is driven with a toothed belt or friction wheel. The bearings at both ends also offer for the majority of tachogenerators the following **mounting variants** (➲ *Twin Tachos and Combinations for special drive applications* on page 25):

- *Rear shaft end:*
  - Tachogenerators with rear shaft option can have *hollow-shaft* devices mounted and directly connected without coupling.
  - The rear shaft end of tachogenerator drives via a coupling devices with *own bearings*.
- *Twin tachogenerators and Combinations with common shaft:*
  - Tacho + Tacho (Twin tachogenerator) with two separate tachogenerator voltages
  - Tacho/Twin Tacho + Incremental encoder
  - Tacho/Twin Tacho + Overspeed switch.

Figure 15: HÜBNER spring disk couplings with insulated hub protect against shaft currents.

Coupling

The coupling between the drive and tachogenerator with own bearings is decisive for the accuracy of the tachogenerator voltage (➔ *Ripple* on page 11):

- The coupling is designed to connect the drive and tachogenerator as **backlash-free** and **torsionally rigid** as possible. HÜBNER has suitable spring disk couplings K 35, K 50 and K 60 in its product range (➔ Figure 15), offering high torsional stiffness and axial offset up to ± 0.7 mm to compensate thermal expansion of the drive.
  In the version with insulated output hub of high-strength plastic, they protect against **shaft currents** (➔ next chapter).
- The coupling must be mounted on the tachogenerator shaft **without exerting force** to avoid subjecting the precision ball bearings to uncontrolled axial pressure. The use of a hammer must be avoided in any event. The careful use of a rubber hammer is recommended for tight fits.
- **Parallel, angular and axial offset** (Shaft misalignment, mounting errors and coupling errors) must be kept to a minimum in the interest of high transmission accuracy. This applies in particular to tachogenerators with foot ("B3-tachogenerators") (➔ Figure 16).

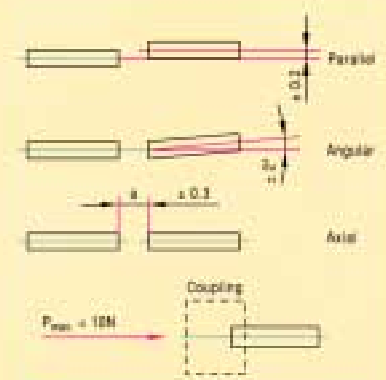


Figure 16: Parallel, angular and axial offset should be as small as possible.

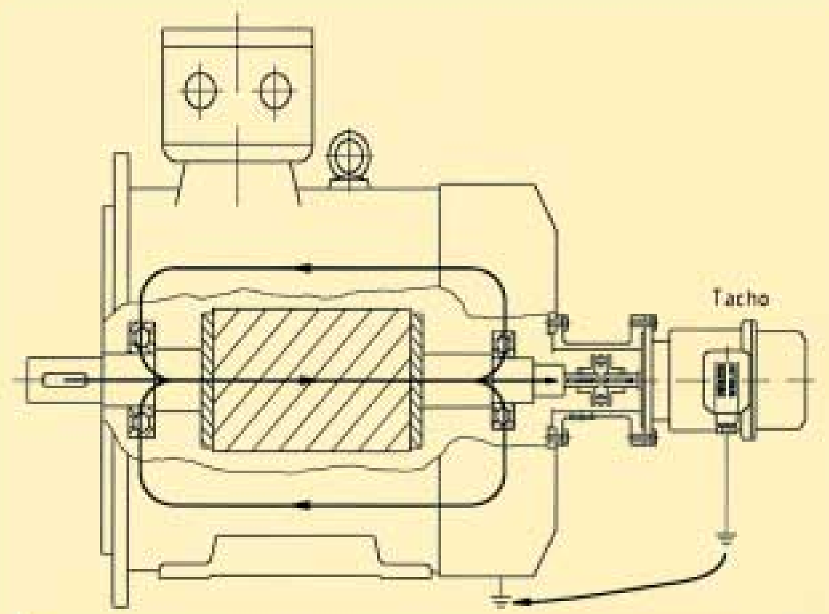


Figure 17: Voltage differences between each end of the rotor create shaft currents which can damage connected components if the rear bearing is insulated.

The **spring-mass system** of coupling and tachogenerator armature should have in the closed loop a **resonance frequency** f_R that should be as high as possible:

$$f_R = \frac{1}{2\pi}\sqrt{\frac{C_{T\,dyn}}{J}}$$

- f_R : Resonance frequency [Hz]
- $C_{T\,dyn}$: Torsional rigidity of coupling [Nm/rad]
- J : Moment of inertia of tachogenerator armature [kgm^2]

The values are given in the data sheets.

- Example:

- Coupling K 35:
  $C_{T\,dyn}$ = 900 Nm/rad
- Analog-Tacho TDP 0,09:
  J = 0.25 Kgcm^2

➔ f_R = 955 Hz

Protection against shaft currents

For motors above 100 kW or motors that are operated by high-speed frequency converters, voltage differences can be expected in the rotor, which may result in shaft currents (➔ Figure 17). From a current density of about 1 A/mm^2, the running surface of ball bearings can be damaged (➔ Figure 18).

The following causes are possible:

- Asymmetry in the magnetic circuit
- Capacitive coupling by high-speed frequency converter
- Interference voltages from driven machines
- Electrostatic charge through vee-belts or lubricants
- Unipolar voltages of sliding bearings.

For protection against **inductively** generated shaft currents, modern motors are provided with an insulated bearing at the rear end. In this way, the problem is shifted to the mounted devices (➔ Figure 17):

Figure 18: Ball bearings damaged by shaft currents are marked by a corrugated ball race surface.

- In the case of **tachogenerators with own bearings**, the tachogenerator housing is connected to the motor via the rear support housing and thus earthed. For safety reasons, the tachogenerators should additionally be earthed via their own **earth connection**. The shaft currents of the motor would accordingly find a way via the tachogenerator bearings to "earth". HÜBNER spring disk couplings K 35, K 50 or K 60 with insulated hub (Figure 15) separate the path from the motor to the tachogenerator shaft and so suppress the shaft currents via the tachogenerator bearings.
- In the case of **hollow-shaft tachogenerators**, the tachogenerator armature is permanently connected both mechanically and thus electrically to the motor shaft. Protection against shaft currents is provided by the insulation between the armature core and tachogenerator winding.
The **isolation voltage** according to VDE specifications is

2 × max. tacho voltage + 1,000 V ≥ 1,500 V

This isolating voltage generally applies to all HÜBNER tachogenerators, including the tachogenerators with own bearings.

For protection against **capacitive** coupled shaft currents, insulation of the ball bearings, coupling and winding is insufficient, as shaft currents flow from beyond these insulating clearances according to the capacitive voltage divider principle. HÜBNER has therefore developed **earthing devices** with slipring contacts, for which a patent has been applied for, featuring HÜBNER LongLife® Technology. The shaft currents are accordingly able to by-pass the motor and tachogenerator bearings to "earth".

Further information on the subject of *shaft currents* is provided in the special publication **"Protecting Rotary Sensors by fitting Insulated Ball Bearings".**

Temperature range

The temperature range specified in the data sheets relates to the housing surface temperature and is the same for all analog tachogenerators

– 30 °C to +130 °C

The **characteristic temperature** of the tachogenerator (heating of the armature winding under load and of the ball bearings and their seals at high speeds) must be observed.

Vibration and shock resistance

The vibration and shock resistance depends on the design of the tachogenerator or the tachogenerator combination and is specified in the leaflets according to:

- **IEC 68-2-6** *"Vibrations, sinewave"*
- **IEC 68-2-27** *"Shocks"*
- **IEC 68-2-29** *"Repeated Shocks".*

Vibration tests, particularly relating to possible resonance frequencies of components, are carried out by HÜBNER on a special test bench (Figure 19). The certificate of an accredited testing institute for successfully passed vibration and shock tests can be provided for the tachogenerator TDP 0,2.

Figure 19: Vibration test, particularly with regard to resonance frequencies; the electronics board of a HeavyDuty® Digital-Tacho (encoder) for the analog-digital combination TDP 0,2 + OG 9 in the frequency range 2 Hz to 4 kHz being tested on a test bench with air suspension.

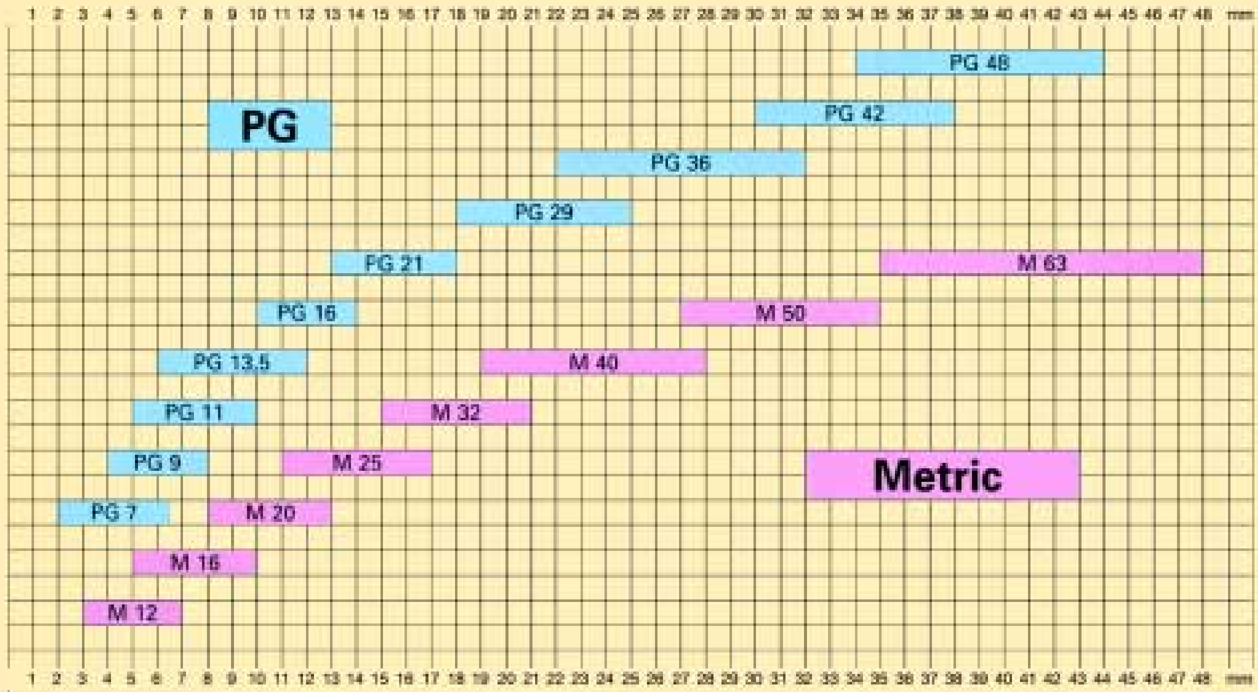


Figure 20: Clamping ranges of cable glands “metric”/“PG” (Jacob GmbH).

Protection class

The protection class IP (International Protection) according to **EN 60034-5** and **IEC 34-5** *(Classification of Protection Classes by Housings)* is of importance for the tachogenerator application and is specified in the data sheets as follows:

First digit: Protection against harmful contact and ingress of solid objects

- **5** = Protection against damaging dust deposit (dust protection)
- **6** = Protection against the ingress of dust (dust tight)

Second digit: Protection against the ingress of water

- **4** = Protection against splash-water
- **5** = Protection against jet-water
- **6** = Protection against flooding
- **7** = Protection against immersion
- **8** = Protection against submersion.

HÜBNER attaches particular importance to the degree of protection: Special sealing measures ensure that the hollow-shaft tachogenerator GTB 9, for example, has the protection class IP 68 after mounting on the driving machine.

Cable connection

The way in which the cable is connected depends on the device and application:

- Terminal box with Combicon® terminals and terminal cover reversable by 180° for cable outlet on the right or left of the tachogenerator
- Internal terminal strip
- Metal-bodied mating connector
- Flying connecting cable.

The connecting cable must have the diameter specified in the dimension drawings of the data sheets, so that the **cable entry** (cable gland) can ensure the protection class.

The new European standard

EN 50 262 – *Metric cable glands for electrical installations*

replaces the previous steel conduit thread PG by the **metric ISO fine-thread**. Instead of the PG 7 to PG 48 thread divided into ten categories, the M 12 to M 63 metric thread is divided into eight categories (➲ Figure 20).

The **cable shield** must be connected electrically with the cable gland, with special attention being given to the **earthing** of the tachogenerator. (➲ *Protection against shaft currents* on page 18 and *Optimum signal transmission* on page 29).

EURO flange® B10

With the internationally standardized EURO flange® B10 (➔ Figure 21 left), HÜBNER offers the widest range for diverse drive applications:

- **Analog-Tachos/Twin-Tachos**
- **Digital-Tachos (incremental encoders)**
- **Mechanical/electronic overspeed switches**
- **Combinations** of these devices **with common shaft** (➔ *Twin-Tachos and combinations for special drive applications* on page 25).

In the Section *"Technical Data"* on pages 36 to 45, reference is made to the EURO flange® B10 in the case of the respective devices. The standard tachogenerator TDP 0,2 is also available with **NEMA flange** (➔ Figure 21 right as TDP 0,2 US). Further devices with NEMA flange are available on request.

A complete summary of devices with EURO flange® and typical application examples can be found in the publication

"EURO flange® B10",

available on our website
www.huebner-berlin.de
or which we will be pleased to send to you.

Explosion proof

The German Federal Institute of Standards (PTB) has confirmed with the Declarations of Conformity that the tachogenerators **EEx GP 0,2** and **TG 74 d** according to

- **EN 50 014** *General Definition*
- **EN 50 018** *Explosion proof enclosure "d"*
- **EN 50 019** *Increased safety "e"*

are approved for operation with standard industrial cabling in hazardous areas, code **"EEx de IIC T6"** (➔ Figure 22).

ISO 9001

We will be pleased to make available to you the **ISO 9001 certificate** of the TÜV CERT as a recognized reprint for your quality management system.

EU Declaration of Conformity · CE

We will be pleased to send you the Manufacturer's Declaration that our products conform to the European Directive **89/336/EEC** *(Directive on Electromagnetic Compatibility).*

Figure 22: PTB certificate and tachogenerator on a motor both protected for use in hazardous locations.

AC tachogenerators

AC tachogenerators are brushless devices with a permanent magnet rotor which rotates in a three-phase stator winding system with neutral point (Y):

- They generate three linked **no-load alternating voltages $u_0(n)$**, each offset by 120°, the amplitude and frequency of which are proportional to the speed n (Version "D", ➔ Figure 23 above).
- The type with integrad three-phase bridge rectifier delivers from a minimum speed n_{min} (diode threshold voltage) a **no-load direct voltage $U_0(n)$**, the polarity of which is independent on the direction of rotation (Version "DG", ➔ Figure 23 below). The ripple rate content is 4.5 % rms.

AC tachogenerators with incorporated rectification are used for indicating speed measuring devices and simple controlled drives, where neither reversing nor speeds occur close to zero and where the relatively high ripple rate in comparison to dc tachogenerators does not play any noteworthy role (e.g. fan drives).

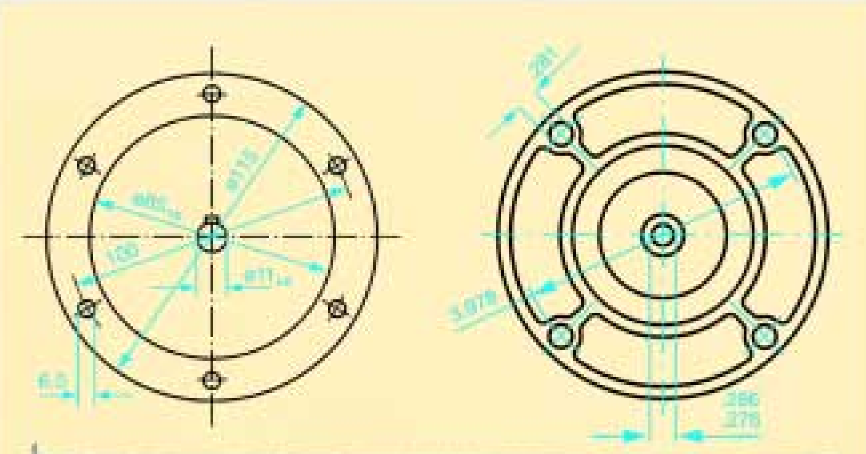


Figure 21: Left: The EURO flange® B10 is widely used as a standard flange for rugged devices, such as for diverse drive applications, see also Figure 14.
Right: The HÜBNER range also includes numerous devices with NEMA flange.

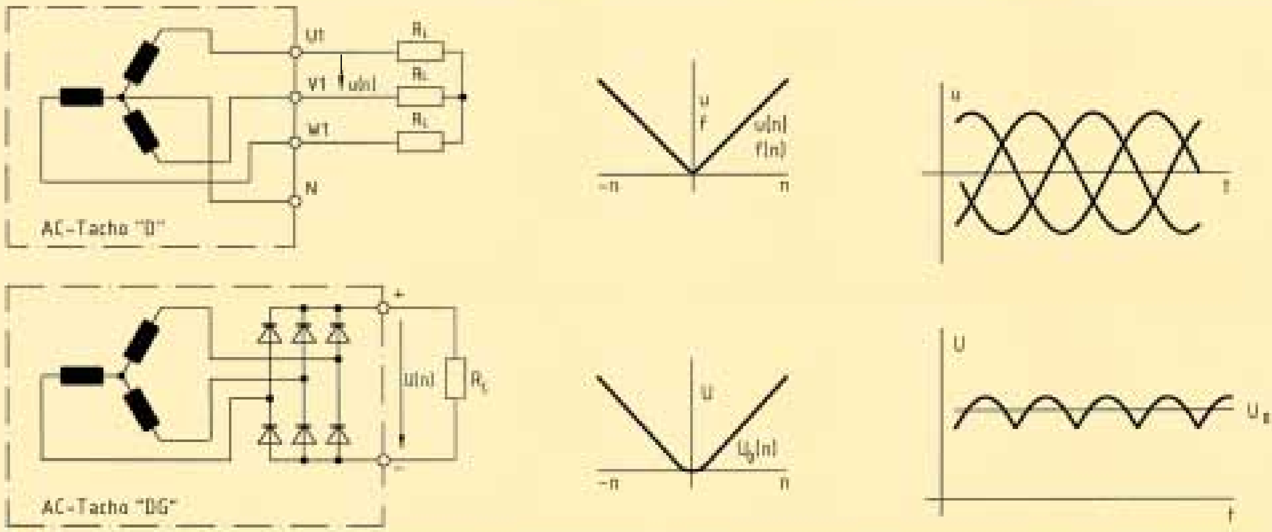


Figure 23: AC tachogenerators generate three-phase alternating voltages (above) proportional to the speed. The rectified alternating voltages are independent of the direction of rotation and have a rather high ripple rate (below).

Trapezoidal tachogenerators

Some applications require contactless signal acquisition, the quality of which is far higher than that of AC tachogenerators. In view of the work to electronically rectify each phase voltage, the number of windings, the voltages of which are to be rectified, must be minimized. The induced alternating voltages must therefore have a long linear characteristic to produce a continuous smooth direct voltage.

Figures 24 and 25 show the solution:

A six-pole, specially developed permanent magnet rotor induces in the appropriately dimensioned three winding systems, three time offset, overlapping **trapezoidal voltages**. The rotor also activates Hall-sensors in order to generate position-dependent commutation signals.

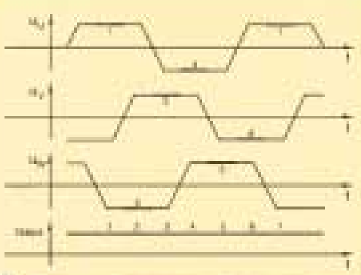


Figure 24: The six horizontal portions of the trapezoidal voltages are combined to a direct voltage.

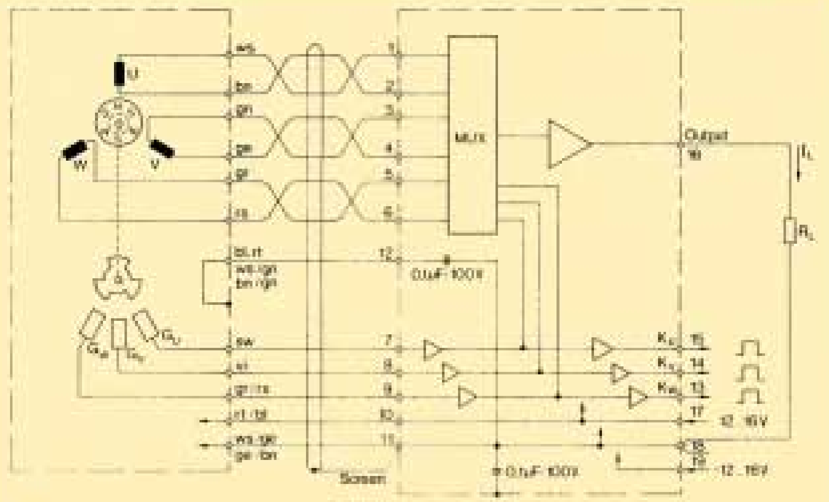


Figure 25: The trapezoidal tachogenerator also delivers the signals for the electronic rectification and block commutation of the brushless direct-current motor.

These signals switch the electronic rectifier (multiplexer MUX with operation amplifier), so that from the positive and negative trapezoidal voltages u_U, u_V and u_W, the segments 1 ... 6 are cut out and connected to the output signal. During a revolution of the rotor, $3 \times 6 = 18$ partial voltages are connected to the rectified voltage.

The commutation signals of the position sensor are also available at the driver outputs for control of the three-phase voltages of a six-pole, **block commutated brushless dc motor**. For this purpose, the winding systems in the trapezoidal tachogenerator and motor must be aligned. The trapezoidal tachogenerator housing is therefore provided with a servo-flange for adjustment purposes.

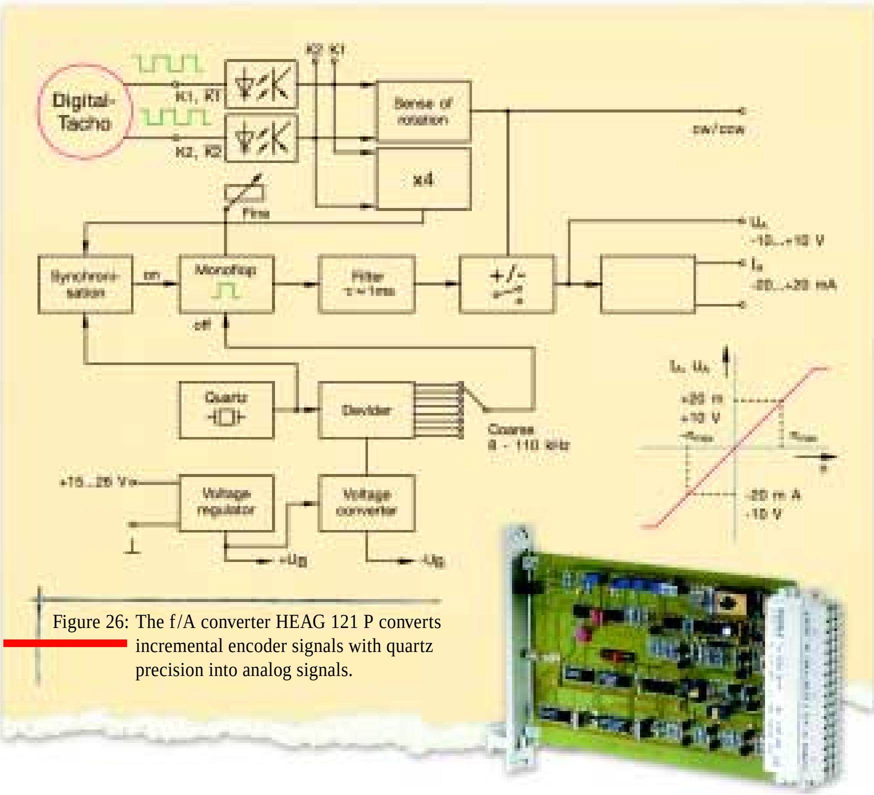


Figure 26: The f/A converter HEAG 121 P converts incremental encoder signals with quartz precision into analog signals.

f/A converter HEAG 121 P

Some drive engineering applications need to derive from a Digital-Tacho (incremental encoder) an additional analog or tachogenerator signal. The f/A converter HEAG 121 P developed and produced by HÜBNER converts the pulse frequency f delivered by the Digital-Tacho with quartz precision into speed and direction dependent **bipolar analog signals**: voltage U_A (f) or load-independent current I_A (f) (➔ Figure 26).

The "P" in the type designation HEAG 121 P indicates the **electrical isolation** of the outputs with opto-couplers.

The analog signal **ripple** is negligibly small above a pulse frequency $f_{Encoder} \geq 1$ kHz. Below this limiting frequency, the residual ripple increases, as only a limited number of incremental signals are available for evaluation. The limiting frequency can be shifted to lower values by providing the lowpass filter with an external capacitor.

However, the time constant τ increases as a result.

The maximum frequency f [Hz] of the Digital-Tacho depends on the resolution (counts z per turn) and the speed n [rpm]:

$$f = z \cdot \frac{n}{60}$$

The HEAG 121 P has eight adjustable input frequency ranges f = 8 ... 110 kHz and a fine adjustment to enable the customer to adapt the maximum frequency of the Digital-Tacho at the highest speed to the input frequency of the f/A converter.

- Example:

Digital-Tacho with
z = 2,048 counts per turn

max. speed n_{max} = 3,000 rpm

➔ f_{max} = 102.4 kHz < 110 kHz.

Min. speed (negligible analog voltage ripple) n = 29 rpm.

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The height of precision in speed and position: HÜBNER Technology.

LongLife® DC Tachogenerators with the patented silver track embedded into the commutator. We support this with a two year guarantee.

Digital-Tachos (incremental encoders) in **HeavyDuty®** technology: rugged electrical and mechanical construction.

LowHarmonics® Sinus-Tachos: Sinewave signals with significantly low harmonics - a new level of precision.

Overspeed switches: mechanically by centrifugal actuator or electronically with own or external voltage supply.

ExtendedSpeed® angular and linear acceleration sensors with no speed limit.

Combinations: Digital-Tachos, dc tachogenerators or overspeed switches in one single housing with continuous shaft.

A.1