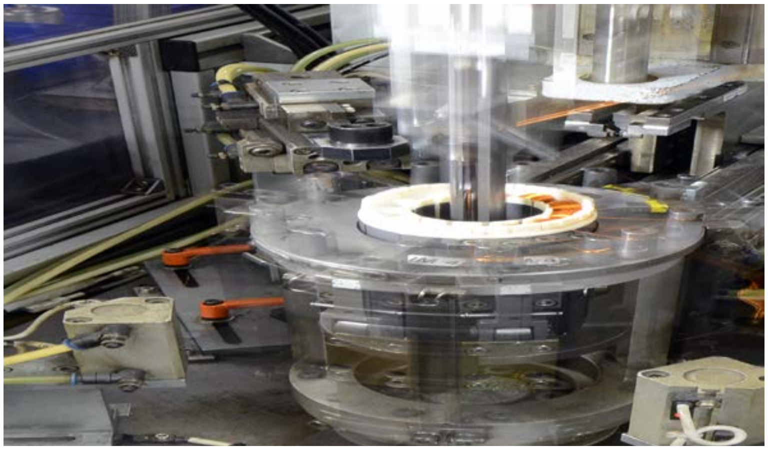

Servomotor Parameters and their Proper Conversions for Servo Drive Utilization and Comparison

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White Paper

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Utilization of servomotor parameters in their correct units of measure as defined by the drive manufacturer is imperative for achieving desired mechanism performance. But without proper understanding of motor and drive parameter details relative to their defined terms, units, nomenclature and the calculated conversions between them, incorrect units are likely to be applied which complicate both machine design development and the manufacturing process.

This white paper demonstrates exactly how machine designers can overcome challenges around servomotor parameters and apply them correctly for any motor or drive to meet specific requirements. A customary standard set of servo units is thoroughly explained together with their typical nomenclature and the applicable conversions between them.

While the motor parameter data entered into the servo drive must be in the units that the designer specifically intended, there are often differences between this data and their defined corresponding units of measure presented on a motor datasheet. But these variances could turn out to be very problematic if not recognized early on and adversely impact both machine design development and the manufacturing process. The reason why they exist is simple − there is no utilized standard method for publishing motor data consistently within the servo industry, or a standard set of units and nomenclature for the drive's motor parameter entry.

Correct understanding regarding the conversion of motor parameters is essential for drive parameter entry, motor comparisons, fine-tuning of an axis' operation and troubleshooting. Otherwise, the machine designer could easily encounter a flawed operation of their mechanism and not realize that the root cause stems from incorrect parameter units! Proper drive parameter unit entry is absolutely critical to achieve the desired operation of servo control loops. If there are inaccuracies, a servo drive's control algorithms cannot properly act and re-act to the ever changing mechanism**:** commands, loads and feedback signals.

Fortunately, there are only two main electronic control methods utilized for the commutation of a Brushless DC or AC PM (Permanent Magnet), 3-phase (Ø) Synchronous Servomotor: Sine-wave and 6-step *(i.e. trapezoidal commutation).* While most servomotor parameters are presented in one of three ways, they are often mixed between the two different electronic commutation methods. (*Refer to Motor Parameters Conversion Table on page 6.)*

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*Typical terminologies used to describe servomotors are**:** Brushless DC Motor (BDCM or BLDCM) Servo, Brushless DC/AC Synchronous Servomotor, AC Permanent Magnet (PM) Servo and other similar naming conventions. Most of these were established in the 1980's by several leading servo manufacturers. Their goal was to encourage market utilization and further the understanding that an AC Permanent Magnet (PM) Motor (PM AC Motor) with electronic commutation (creating an AC PM or PM AC, Servo) could replace the servo function of a Permanent Magnet DC Brush Motor.*

*Regardless of their different naming conventions, the motors are basically of the same design because they are all 3-phase (Ø) AC PM synchronous machines. There have been many explanations over the years as to why the different naming conventions exist within the industry, like those relating to the Bemf characteristics**:** Clean sine-wave for sinusoidal commutation or trapezoidal for six-step commutation. But what led to these differences had more to do with overcoming the false perceptions of a technology barrier in the marketplace than anything else.*

The most common commutation control methods are often identified as (1) Sine-wave or Sinusoidal commutation and (2) 6-step or Block commutation (i.e. Trapezoidal commutation) where each electrical cycle (*one electrical cycle/PM pole-pair)* is defined into six commutation steps.

By definition, a unit of measure is a definite magnitude of some physical quantity, defined and adopted by a convention and/or by a law, that is used as a standard for the measurement of the same physical quantity.[1] Therefore it stands to reason that different servomotor commutation methods, as previously described, would develop into different customary standard sets of parameter units.

KBM™ servomotor series from Kollmorgen is designed to be directly embedded into the machine, using the machine's own bearings to support the rotor.

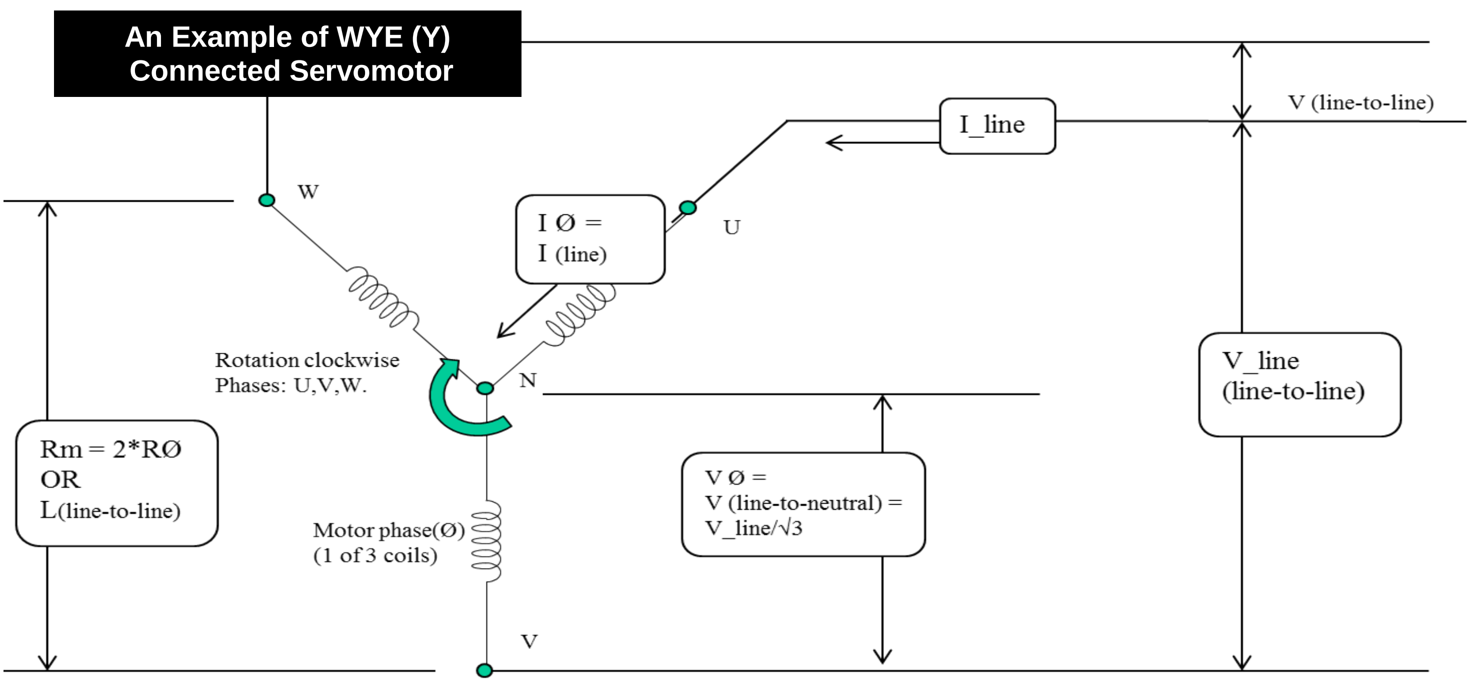
At this point, we have established an important requirement to achieve optimal servomotor performance in every application. The best operation depends on the specific physical parameters, the specific quantities and units of the motor being correctly converted and then entered precisely into the controlling drive's database, per the specific definitions defined by the servo drive manufacturer. This specific parameter and unit understanding is just as important for fine-tuning an axis operation, troubleshooting, and comparing one servomotor to another.

***OBSERVATION**: Issues often emerge from lack of clarity between the presented units and identifying nomenclature for the two commutation methods, combined with inconsistently used parameters and units presented by motor and drive manufacturers.*

To effectively overcome such issues and meet your objectives, a higher understanding of motor units and nomenclature is necessary for proper servomotor comparisons and their correct conversion and entry into the servo drive amplifier that utilizes them.

As knowledge and technology of the motion control field has matured, most 3-phase **(Ø) AC PM** servomotors have come to utilize a **wye (Y)** wound armature, especially for sinusoidal commutation. For the purpose of this article, a **wye (Y)** wound armature is used to describe the different customary standard sets of units and conversions between them.

Assumptions for the Figure Below: A 3-Phase wye (Y) connected motor has been selected for its typical capability of presenting 3-phase sinusoidal emf waveforms when back driven as a generator, with electrically balanced windings versus a delta (Δ) wound armature. *Note: Considerations of torque angle advance, field weakening and harmonic issues are beyond the article's scope.*



1. "measurement unit", in International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM) (3rd ed.), Joint Committee for Guides in Metrology, 2008, pp. 6–7."

Important Notes: Just because a drive's nomenclature is presented exactly as those within this article, it does not mean the required units are consistent with those presented by a given manufacturer. Furthermore, just because the drive's required units are presented exactly as those herein, it does not mean their definitions are the same. In the power industry for example, some of the subject units are typically standardized in RMS values, but lack the specific notation defining root-mean-square (RMS) through subscripts. However, the lack of subscript specificity for a required unit in this specific discipline of motion control can easily convey the wrong meaning of the unit.

In order to maintain the most consistent industry symbols and definitions, the utilized nomenclature of the designated constants are defined below**:**

1. **Voltage (emf) constant:** Ke (a.k.a. K_{emf}, K_E and K_b) defined as the maximum line-to-line voltage developed per some velocity unit.

   Note: When the Voltage constant velocity unit is rad/second and Kt is in Nm/A, the specific motor constants are equal**:**
   Ke(V/rad/sec) = Kt(Nm/A).
   This is also true for **PM DC Brush Servomotors**, where K_E(V_{DC} /rad/sec) =Kt(Nm/$AMPS_{DC}$), with no consideration for the difference between hot and/or cold units.

Two popular Ke Units are: V/rad/sec and V/kRPM, where V/kRPM =1000{Ke(V/rad/sec)}**/**{(60_sec/min)**/** (2π_rad/revolution)} = 1000{Ke(V/rad/sec)}**/**9.55*.*

Specific Notes:

(a) **V = VDC-bus** is equal to the maximum (crest) voltage available *(VDC-bus for most drive systems)* and specifically NOT in RMS units.

(b) **Voltage (emf) constant**. Ke in the units: V/rad/sec or V/kRPM (or other equivalent), are typically associated with 6-step commutation versus sine-wave commutation.

(c) **For a wye (Y) wound armature**, if a motor datasheet defines the Voltage (emf) constant as the phase (Ø) (line-to-neutral) voltage developed per some velocity unit, *it must be multiplied by √3 to achieve the line-to-line Ke units defined by number 1 (above).*

2. **Voltage (Bemf) constant**: Kb (a.k.a. K_{Bemf}, K_B and K_e) defined as the line-to-line RMS voltage developed per some velocity unit.

   Kb(Vrms/kRPM) = Ke(V/kRPM)**/**√2 **OR**
   Kb(Vrms/rad/sec) =Ke(V/rad/sec)**/**√2, where Kb (Vrms/kRPM) =1000{Ke(V/rad/sec)**/**9.55}**/**√2.

Specific Notes:

(a) **Voltage (Bemf) constant**: Kb in the units: Vrms/rad/sec and Vrms/kRPM (or other equivalent) are associated with sine-wave communication versus 6-step commutation.

(b) If a motor datasheet defines the **Voltage (Bemf) constant as the Ø (line-to-neutral) RMS voltage** developed per some velocity unit, *it must be multiplied by the √3 to achieve the line-to-line Kb units defined by number 2 above.*

3. **Torque constant**: Kt (a.k.a. K_T) defined as the ratio of some torque (T) unit per Amp where Amp is **(a.),** the maximum (crest) motor phase (Ø) current (line-to-neutral) or **(b.)**, the RMS Ø current (line-to-neutral).

Specific Notes:

There are **two different specifications for the Kt term** due to the conventional differences between the 6-step and sine-wave, commutation control methods. As a result, the relationship between the two Kt current units (A and A-rms, as used herein) should not be assumed. Furthermore, specific knowledge that the torque constant is torque developed per some unit of current through one phase (Ø) of the wye (Y) wound armature is generally assumed and therefore not always published in-motor datasheets by the motor manufacturer. The line-to-line current is equal to the line-to-neutral current for a wye (Y) wound armature.

(a.) **Torque constant**: K_T (a.k.a. Kt) defined as the ratio of some torque (T) unit per the maximum (crest) phase (Ø) current (line-to-neutral), where K_T in the units Torque/**A** is associated with 6-step/Block controlled commutation versus sine-wave. **Note:** By this defined commutation method for a 3-phase wye (Y) connected servomotor, current only flows through two of the three (3) motor coils (2-ON, 1-OFF, at all times).

(b.) **Torque constant**: Kt (a.k.a. K_T) defined as the ratio of some torque (T) unit per the RMS phase (Ø) current (line-to-neutral), where Kt in the units T/A-rms is associated with sine-wave commutation versus 6-step commutation. **Note:** For this commutation method using a 3-phase wye (Y) connected servomotor, current may flow through all three coils at the same time.

NOTE: In the event a manufacturer has published the torque constant for sine-wave commutation in units: T/**Amp** (crest of sine-wave), then T/**A-rms** = √2xT/**Amp** (crest of sine-wave).

<u>Conversion between the two commutation methods for the torque constant can be calculated</u>:

(a) Kt(T/A) = Kt(T/A-rms)**/**√1.5 **AND**
(b) Kt(T/A-rms) = Kt(T/A)x√1.5.

So for the same motor, the continuous current Ic (RMS) required to achieve full motor capacity will have a lower value than if presented as an Ic (crest of sine-wave or DC style) current. Just as one would expect!

Note that the formal derivation of the √1.5 conversion factor for the torque constant (Kt) and current between a 6-step commutated system and sine-wave commutated system, or vice versa, is not covered within this article. Nonetheless, it is proven correct by the equivalency of the 6-step and sine-wave power (loss) calculations ***(See Motor Parameters Conversion Table on page 6).*** Furthermore, it should be noted that the most common conversion mistake is the improper utilization of the RMS *(root-mean-square)* conversion factor of the√2, between the crest value of a sinusoidal wave-form and its effective steady state value, in place of the conversion factor of the √1.5. However, the √2 RMS conversion is NOT the same unit conversion as seen between the motor's Kt (Torque/**A**) and (Torque/**A-rms**) due to the two different commutation control methods and resulting current required to produce a specific torque, from a 6-step commutated system to a sinusoidal commutated system, or vice versa.

Drive Selection: For illustration purposes, it is assumed the customer's drive selection is a *sinusoidal commutation controller* requiring motor parameters in the following units:

1. **Continuous motor current units**: A-rms [Ic(motor) as RMS value of motor's continuous capability per Ø (line-neutral)]

2. **Peak motor current limit**: A-rms [Ip(motor) as RMS value of the motor's peak limit per Ø (line-neutral)]

3. **Kt constant units**: T/A-rms [Torque**/**A-rms, sine-wave controller, line-to-neutral RMS (Ø) current]

4. **Kb constant units**: Vrms/kRPM [RMS voltage line-to-line per 1000_RPM]

5. **Rm (typical 20 or 25 ºC: room temperature) resistance units**: Ohms (Ω) line-to-line [two phases in series: Rm_Ø =Rm (L-L)/2]

6. **L or Lm, inductance units**: milli-Henry (mH) line-to-line [two phases in series: L_Ø =Lm(L-L)/2]

7. **Jm - motor rotor inertia units**: Kg.cm^2

The **Motor Parameters Conversion Table** on the next page (page 6) is for converting the motor parameters to the drive's required sinusoidal input units for any given wye (Y) wound armature.

Instructions are provided and important information such as **Table Subscripts Notes and Terms** continue on page 7.

We highly recommend you review Pages 6 and 7 side by side to effectively understand the Motors Parameters Conversion Table.

MOTOR PARAMETERS CONVERSION TABLE

The table below is for converting the motor parameters to the drive's required sinusoidal input units for any given wye (Y) wound armature using any one of the three parameter forms. **Instructions** for desired drive units of Column G:

- **For any motor parameter presented in the units of Column B**: use the conversion factors of Column C to achieve the units in Column D, then use conversion factors of Column E to achieve the units in Column F, **and** match the specific units for the Drive in Column G.
- **For any motor parameter presented in the units of Column D**: use the conversion factors of Column E to achieve the units in Column F, and match the specific units for the Drive in Column G.

Column A	**Column B**	**Column C**	**Column D**	**Column E**	**Column F**	**Column G**
Motor: X, (Wye-Wound Armature):	**Units: X, Commutation 6-step:**	**Column B to Column D Conversions:**	**Alternate Units: Commutation 6-step:**	**Column D to Column F Conversions:**	**Units: Y, Commutation Sine-Wave:**	**Drive Units Required for Sine Commutation Wye-Wound:**
Tc	12.7_Nm	=	12.7_Nm	=	12.7_Nm	Tc(Nm)
Tp	41.2_Nm	=	41.2_Nm	=	41.2_Nm	Tp(Nm)
Ic(current/$Ø_1$)	13_A/$Ø_1$	=	13_A_1	÷√1.5 =	10.614_A-rms_1	Ic(A-rms)/phase(Ø)$_{1\&7}$
Ip(current/$Ø_1$)	53.3_A/$Ø_1$	=	53.3_A_1	÷√1.5 =	43.52_A-rms	Ip(A-rms)/phase(Ø)$_{1\&7}$
Kt	1.00 Nm/A	=	1.00 Nm/A	**x**√1.5 =	1.224745 Nm/A-rms	Kt(Nm/A-rms)
Ke or Kb	0.57735 V(Ø)/rad/sec	**x**√3 =	1.00 V(L-L)/rad/sec	**x(**1000**/**9.55)÷√2 =	74.05 Vrms(L-L)/kRPM	Kb(Vrms/kRPM)
OR	0.57735 V(Ø)/rad/sec	√3**x**1000÷9.55 =	104.72 V(L-L)/kRPM	÷√2 =	74.05 Vrms(L-L)/kRPM	
Rm(Ohms)$_3$ (line-to-line);25°C	0.540_Ω/$Ø_3$	**x**2 =	1.08_Ω (line-to-line)	=	1.08_Ω (line-to-line)	Rm(Ω: line-to-line) at 25°C
Lm_2 (mH)	4.25_mH/$Ø_2$	**x**2 =	8.5_mH(L-L)	=	8.5_mH(L-L)	L or Lm (mH: line-to-line)
Jm(inertia)	0.00152 Kg.m^2	**x**100^2 =	15.2 Kg.cm^2	=	15.2 Kg.cm^2	Jm (Kg.cm^2)
Motor Poles	10_Poles	=	10_Poles	÷2 =	5_Pole-Pair	Pole-Pair (PP)
Thermal resistance	0.460°C/Watt	=	0.460°C/Watt	=	0.460°C/Watt	
Equality: Watts(loss) Power Calculations Utilizing Table Data Above						
Watts(loss) 25°C ambient; Calculated Using Thermal Resistance	NA	NA	{(155**-**25) ÷0.467} =278W	=	{(130°C_rise) ÷0.467} = 278W	Based on table and conversion data above
Power(6-step)$_{5\&6}$ = VIcos $θ_5$ = 2**x**IØ^2**x**RmØ(hot)$_4$ = I_line^2**x**Rm(L-L; hot)$_4$	2**x**13^2**x** (0.54**x**1.51) = 276W	=	13^2**x**(1.08**x** 1.51) = 276W	NA	NA	Checks out, based on the given or converted data above
Power(sine-wave)$_{5\&6}$ (Note: V=Vrms and I= Irms) = 3**x**VØ**x**IØ**x**cos$θ_5$ = 3**x**IØ^2**x**RmØ(hot)$_4$ = 3**x**IØ^2**x**Rm(L-L; hot)$_4$÷2	NA	NA	NA	NA	3**x**10.614^2**x** (1.08**x**1.51)÷2= 276W	Checks out, based on the given or converted data above

September 2014. Note: It is the responsibility of the user to determine the parameters and units for their specific application when using the table.

IMPORTANT REMINDER: Table Subscript Notes and Terms continue on page 7.
We recommend you follow Pages 6 and 7 side by side when reviewing the Motor Parameters Conversion Table.

Table Subscript Notes

1. **The motor current defined as the phase (Ø) current (line-to-neutral**) is typically buried somewhere in the manufacturer's set of publications, but this detail is often *presumed to be understood when using a specific motor datasheet.*
2. **For a wye (Y) wound winding**, **if presented with Lm=LØ (line-to-neutral),** multiply LØ by 2 for the total motor inductance: Lm (line-to-line). For a delta wound motor, inductance is Lm/Ø=Lm (line-to-line). However, in the event the drive requires motor inductance parameter to be entered for a **wye(Y)** wound motor per phase (LØ: line-to-neutral) and the motor inductance (Lm) is presented as Lm/Ø (delta winding), then equivalent LØ (line-to-neutral, wye-wound) = (Lm/Ø_delta-wound**/**3).
3. **For a wye (Y) wound winding**, **if presented with Rm=RØ (line-to-neutral),** multiply RØ by 2 for the total resistance**:** Rm (line-to-line). For a delta wound motor, resistance is Rm/Ø=Rm (line-to-line). However, in the event the drive requires motor resistance parameter to be entered for a **wye(Y)** wound motor per phase (RØ: line-to-neutral) and the motor resistance (Rm) is presented as Rm/Ø (delta winding), then equivalent RØ (line-to-neutral, wye-wound)=(Rm/Ø_delta-wound**/**3).
4. **Resistance of the copper will rise from a 25°C ambient** to 155°C, by a factor of approx. 1.525.
5. **When the Power (6-step commutation) is set equal to the Power (sine-wave calculation)** at 2**x**VØ**x**IØ**x**cosθ=3**x**VrmsØ**x**IrmsØ**x**cosθ, the cos θ factors out of the equation for same motor.
6. **A conventional 3-phase Trapezoidal (6-step) commutation drive controls only 2 motor windings** at a time (2-ON,1-OFF, at all times), compared to a Sinusoidal commutation drive which has the ability to control and apply power to all three (3) windings at the same time.
7. **For sine-wave commutation, if the specific drive unit in Column F for the parameters: Ic** (continuous) and/or Ip (Ipeak) are to be entered in the units as Ic (crest of the sine-wave)/phase(Ø) and/or Ip (crest of the sine-wave)/phase (Ø), then the corresponding value in Column F must be **multiplied by** $\sqrt{}$**2**, and if the specific parameters are to be entered in the units as Ic (crest-to-crest of the sine-wave)/phase(Ø) and/or Ip (crest-to-crest of the sine-wave)/phase (Ø), then the corresponding value in Column F must be **multiplied by 2** x $\sqrt{}$**2**.

   Note: *The specific use of the word "crest" has been utilized herein to minimize confusion with the motor and drive subscripted nomenclature for peak capability of one unit or another, versus the sine-wave peak (crest of the sine-wave) and sine-wave peak-to-peak (crest-to-crest of the sine-wave).*

Terms:

1.	**emf**	= electro-motive-force (see Bemf in regard to motor operation).
2.	**Bemf**	= Back (opposing or counter) electro-motive-force, the induced voltage in opposition to and resulting from the flowing current required by the motor to drive the load at any given point in time
3.	**colon (:) symbol**	may be replaced with the words "of the" when read
4.	**rad**	= radians
5.	**sec**	= second(s)
6.	**θ (theta)**	= angle between the current and voltage.
7.	**Ø (phi)**	= phase line-to-neutral current through or voltage across one branch of a **wye (Y)** wound coil and specifically NOT line-to-line voltage for this article
8.	**Y**	= wye wound armature
9.	**Δ**	= delta wound armature
10.	**crest**	= maximum possible voltage or current available of a sinewave; and the word "peak" is specifically not utilized in order to minimize confusion between a sinewave's crest and rms units, and motor-drive parameters like I_peak, whether in terms of a crest current units or rms units.
11.	**RMS and rms**	= root-mean-square

Conclusion

The ***Motor Parameters Conversion Table on page 6*** *can be utilized as a reference for the correct understanding and conversion of parameter units and nomenclature. One quick check that can be used to verify that Kt & Kb (or Ke) are both in RMS units for typical sinusoidal commutation is to divide what is thought to be Kb (Vrms/kRPM) by Kt (Nm/A-rms). If the corresponding RMS units are correct, the resulting quotient will range between 60 and 65 (ideal being 60.46), and few are the round-off exceptions resulting in a quotient just under 60 or over 65. This is true, regardless of the PM servo type or whether presented as hot and/or cold units of Kt and Kb/Ke. In contrast one can verify that Ke(V/kRPM) and Kt(Nm/A) are indeed both in typical 6-step/Block commutation units when the resulting quotient ranges between: ~103 and 113 (ideal being 104.72).*

The importance of acquiring proper understanding about servomotor parameters and their conversion relative to the manufacturer's drive cannot be underestimated. They influence a number of critical factors that impact both machine design development and the manufacturing process. It's especially critical for drive parameter entry, motor comparisons, fine-tuning of an axis' operation and troubleshooting.

Variances exist between manufacturers because there is no utilized industry standard for publishing motor data consistently with reference to their units of measure and/or nomenclature. This white paper presents a unique opportunity to overcome these challenges and master the complex discipline around servomotor parameters. It supplies detailed information and actual conversion tools that may not be available to perform correct interpretation, data entry and measurement. Exact calculations and their concepts are thoroughly explained.

Machine designers, engineers and technicians armed with complete knowledge from this article can be confident in their ability to engage in the following actions and achieve specific goals:

- Cost-effective, yet thorough and timely decision making approach throughout the machine design process
- Fine-tuning of motion control components for enhanced machine performance, higher product quality and increased throughput

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ABOUT KOLLMORGEN

Kollmorgen is a leading provider of motion systems and components for machine builders around the globe, with over 70 years of motion control design and application expertise.

Through world-class knowledge in motion, industry-leading quality and deep expertise in linking and integrating standard and custom products, Kollmorgen delivers breakthrough solutions unmatched in performance, reliability and ease-of-use, giving machine builders an irrefutable marketplace advantage.

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