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WHITE PAPER

The Difference Between Continuous Ratings and Holding Continuous Loads

This article explores additional servo motor sizing considerations and the often-resulting communication issues that may arise for an application requiring a dominantly maintained load with little movement through an in-depth explanation of the term: Stall, as typically utilized in the servo motor industry. This information is then utilized relative to the axis' effective RMS force/ torque calculation for proper motor sizing.

The expansion of closed-loop feedback systems into less traditional servo motor uses has brought about a higher level of specialized requirements. Some of these servo motor applications require a force or torque to maintain a load for an extended time relative to the axis' motion-profile. This presents a need for the clarification between several words and terms that are not equal or are only equivalent under specific operating conditions or events, but often interchangeably used by those incorporating other motor types. These potentially inconsistent communications can lead to incorrect interpretations between parties that affect the initial motor sizing, machine programming, machine startup, and/or trouble shooting of an event or some product - process issue.

For an example neither the words: stall nor stall-torque, appear in the specification of an induction motor, but they are often used to describe a condition that occurs during an event when a motor's load is greater than the Full-load or Breakdown, torque capacity. Non-servo motor's (i.e. induction motors for our example) operating, under some state other than a properly working condition, are at the very least referred sometimes as being, in a Locked-Rotor or stalled (zero RPM) state; where if the demanded power continues due to an applied load greater than the motor's continuous Full-load torque, the motor will overheat, and eventually burn up.

It is equally important to understand that if the motor is stalling (0_RPM < actual RPM < Full-Load RPM), the motor is drawing a current greater than its continuous capacity, and if this condition continues the motor's windings will overheat. These abnormal stall, stalled, or stalling, conditions of an open-loop style induction motor are not typically part of any normal application, and any induction motor under any one of these conditions is:

1. affected by the motor's ability to dissipate its heat losses relative to its load demand; and,
2. going to cause the motor's windings to overheat and burn up if an overload continues.

A stalling motor may continue to run for a while at a slower than rated speed, but when it stops running due to the tripping of an overload protection device or because it burned up, it is not stalled (For neither an unpowered motor nor burned-up motor can recognize a mechanical load).

Whereas the **servo-controlled** condition of purposefully holding position under a load, or maintaining a torque or force against a load, for a given application can be a normal operation, and one that is completely different than our induction motor example above, though often associated or communicated with the same words: **stall, stalled, stalling,** and/or **locked-rotor**. Hence when properly sized for any specific operating condition, the servo motor (being a closed loop system) is just doing what it is commanded to do and nothing else. When properly sized and operating normally as sized, the servo motor can handle its commanded load (e.g. holding position under a load or maintaining a torque/force against a load) within its defined event and/or motion profile for which it was sized, without concerns of overheating.

Hence, most of the confusion within the servo motor industry between these words/terms and their meaning stems from an issue in which a servo motor is NOT properly sized or otherwise NOT utilized per the specifications for which it was originally sized.

It is often through these types of application issues that our subject words/term start generating confusion due to the mixed interpretations and understandings of different styles of motor systems (e.g. open versus closed loop control).

Since the words in question are sometimes used interchangeably, it becomes important to understand how similar terms are utilized in the non-servo (e.g. induction) motor industry. For the powered open-loop induction motor the term: Locked-Rotor, is actually the condition or procedure for determining the maximum possible Starting Current (Locked-Rotor Current (LRC)) drawn by the motor while developing a maximum Starting Torque (Locked-Rotor Torque (LRT)). This maximum Starting Current and its resulting Maximum Starting Torque are typically measured in a lab environment with the motor's rotor locked in place, hence the term Locked-Rotor. The Locked Rotor Current (LRC) is typically found on an induction motor's nameplate identified as the Locked-Rotor Amps (LRA), which is the maximum possible Starting Current drawn by the motor at zero speed when the power is first applied (slip at maximum). In an actual induction-motor application this is the maximum possible current that may be seen for a short intermittent period of time when power is first applied to the motor, before the motor's rotor accelerates to reduce slip (the delta RPM between armature field and rotor), bringing the motor up to a balanced operating point of equilibrium against the applied load (desirably within its continuous rating). Induction motor open-loop intermittent currents greater than the motor's continuous capability are typically seen during acceleration when power is first applied and possibly during process load disturbances, but the overall RMS (Root Means Square) currents seen by the motor over time must remain within the motor's continuous capability.

A servo motor like other motors is also affected by the motor's ability to dissipate its heat losses, though much less likely to overheat due to an overload state because of the control and feedback, closed-loop settings and limits, within its drive amplifier and potentially other controller programming. Unlike the overload condition of an open-loop induction motor, the typical servo motor can be and is, specifically controlled to operate intermittently above its continuous capacity. However, just like the open-loop induction motor, the RMS currents seen by the servo motor over time must remain within the motor's continuous capability or the motor's windings will overheat. The intermittent overload states of a servo motor are purposeful, and when so utilized to perform a function or process, must be properly accounted for during the motor-drive selection process to ensure its proper axis operation during normal machine operation, maintenance, potential process/machine failures, and safety events.

One of the more specialized utilizations of a servo motor for some Robotic, Industrial and/or Factory Automation process is to hold a specific torque or force against a load with little to no motor movement. The application may be as simple as a holding clamp or maintaining a vertical load against gravity (where the utilization of a holding brake would increase process time and/or lose precision), or maintaining a torque/force against a load for some test purpose, or dynamically holding a part in place for some process, or the slow expulsion of some high viscosity liquid, et cetera. Among other things, one of the key elements for sizing the servo motor and drive combination with this specific requirement is the required time this effectively continuous load with little to no actuator movement, will be utilized within its motion profile or for some specific event, relative to the motor's thermal time constants: motor & windings (and also drive capability). If the servo motor is properly sized and operating with proper drive system settings for a given application it will not overheat, trip a protection device, or burn up. Under such planned servo motor utilization, the worst-case condition or scenario for the servo motor may actually be the motor's continuous operation against its applied load (due to gravity or otherwise), during normal operation; or during a machine down or line-down situation, and/or maintenance operation, versus the calculated effective RMS torque/force requirement for the axis based on its motion-profile.

Unlike an open-loop asynchronous induction motor, capable of sacrificing itself while trying to satisfy the needs of its load; the closed-loop servo motor's torque, velocity, and/or position is controlled and limited, by the drive's current/velocity/position – loop gains & limits, in addition to the peak current limit by the drive's foldback circuitry and/or programming over time (I^2t foldback, typically set = Ic(motor) or Ic(drive)). Thus, even when the servo motor may appear to be in a physically stalled or locked-rotor state, when properly sized and programmed, it is being specifically controlled within its continuous capacity and thus within the motor's ability to dissipate its own heat losses. However, to describe this operation, especially when there is an axis issue, our subject words/terms are often communicated, with different meanings or interpretations in mind.

The servo motor industry's term: Stall, is often utilized as a torque/force subscript or other means, to define the servo motor's maximum obtainable continuous torque (Tc) and its resulting continuous current (Ic) requirement at a specified ambient temperature with an even steady-state heat loss distribution throughout the motor's windings to achieve, up to said torque capacity based on a specific temperature rise and heat sink (mounting plate) size, without overheating motor windings. Hence, this utilization generates a specifically different meaning than used to define the word: stall (to stop), and the condition in which an induction motor is no longer able to move at its designed RPM against its applied load (with an appearance of a locked rotor (stalled/stopped), stalling (on its way to be stopped), or stalling (running at a RPM slower than rated, but not at zero RPM)). The common misconception that the same meaning/utilization applies within the servo industry is simply not the case.

Due to the misconception of the word versus the term, some manufacturer's publications have even been found to state: Stall, means zero rpm or no rotor movement, when it should not!

Thus, the question arises how does one size an AC / Brushless PM servo motor, not to overheat the motor's windings for an application effectively requiring a continuous holding torque/force with little or no physical movement over such a time period that the axis' motion-profile effective RMS calculation becomes invalid (due to what would otherwise result in an uneven heat-loss distribution within the motor)?

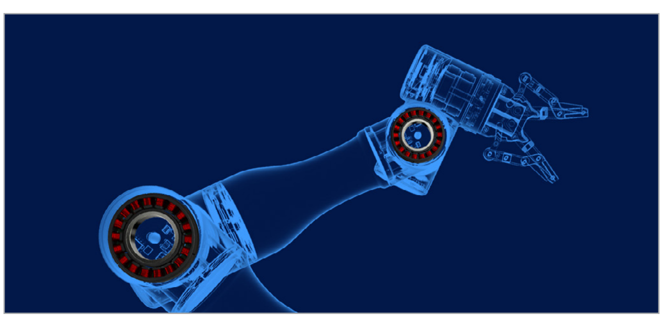
We will answer this using an application example; but first we need to understand the manufacturer's rating of continuous current: Ic(motor), and how it is determined. We will assume RMS current with sine-wave commutation; however, there are other variations of how Ic may be determined/specified between manufacturers.

A major contributor for the method of rating servo motors developed from a time-period when the majority of applications had no substansial loading during zero movement in relation to the application's overall motion profile. So, when one of these non-typical applications is under consideration its resulting requirements are separately evaluated for the special condition/event, which may or may not override the application's effective RMS torque calculation.

Typically, servo motors are rated to establish maximum continuous capacity with even heat distribution of its internal winding losses throughout the motor. This means that during the rating process the electrical cycles within the motor would be moving at a speed fast enough to provide even heat distribution of its internal losses but slow enough to ensure jXL and or core losses are essentially zero within the motor. This physical test speed is usually around 1-4_rps (revolutions per second) for motors, but may be slower or higher, as a function of the motor's pole-pairs. Most manufacturers define their continuous Torque (Tc) and resulting current (Ic) at this or similar speeds. The published continuous torque and current specifications are also often identified as Stall torque (Tc_stall) and Stall current (Ic) regardless of the type of commutation and resulting current units.

Note the difference between this term: Stall, here utilized under a controlled closed-loop dyno test for determining the maximum continuous capability of the servo motor versus our previous decisions of stall, stalled and stalling, relating to an overload condition greater than an Induction motor's maximum capability whether the rotor has stopped moving or not.

Furthermore, we need to understand what the servo drive's output is doing when a servo motor is essentially held under some load with little or no movement. Since we are using sinusoidal commutation for our example; the controlled 3-phase ac output is effectively at a standstill, presenting a continuously PWMed non-moving 3-phase output with an amplitude value (appropriate to servo motor's commutation position) equal to what would otherwise be considered an instantaneous snap shot at that position location (This may be envisioned in your



The main difference between the two major commutation methods is: 6-step/Block (i.e. unmodified trapezoidal) only allows current flow through two (2) of the three (3) motor phases at any given time (2-ON, 1-OFF, at all times); whereas, Sine-wave or sinusoidal commutation allows for current flow through three motor phases at the same time (when appropriate) and each electrical cycle of the motor is presented as a sine-wave to the servo motor.

mind's eye as an instantaneous snap shot of the moving sinewaves).

Today most rotary servo motor designs have a good thermal conductivity between motor windings, laminations, and frame, especially with epoxy encapsulation; however, each design has a different thermal conductivity between its windings and frame, which requires significant thermal modeling or actual measurement and test, to determine each motor's capability. Thus, for the purpose of this paper we will also assume each motor winding is a stand-alone mounted coil, where no coil sees a thermal advantage of transferring heat to the area of another winding/ coil within the motor.

Under the condition of a fully loaded servo motor, the two worst-case commutation positions can be defined:

1. All (100%) current (I_actual = Ic(rms) x √2) going through one winding and 50% through the remaining two windings **(Figure B)**
2. All applicable (86.6%) current going through only two windings (I_actual = Ic(rms) x cos(30°) x √2) **(Figure C)**.

These are the worst-case conditions the motor's windings would see, if the drive's Ipk elapsed time (controlled by a I^2t circuit/program) has folded back to the motor's published continuous current (Ic_stall, established with even heat-loss distribution: slow RPM).

Hence, for condition **(1; Figure B)**, if Ic(motor)_stall = 10_Arms and the commutation position and load, required 10_Arms through phase-U to hold said stationary position under a 10_Nm load requirement, then phase-U would have 14.14 DC-Amps [10_Arms x √2] continuously PWMed through it. Now that specific winding is trying to dissipate (14.14^2 x RmØ) watts-loss versus (10^2 x RmØ) watts-loss; twice its capacity, which of course it cannot continuously do!

Similarly, for condition **(2; Figure C)**, each of the two coils would be trying to dissipate (12.247^2 x RmØ) watts-loss versus the (10^2 x RmØ) watts-loss per each coil's capability (50% over capacity). From these calculations, it is seen that the effectively stand-still current required while holding some specific load effectively still, relative to the motor's ability to dissipate its winding's losses under these conditions is a critical factor requiring consideration when sizing a servo motor.

So, we need a motor that has a continuous torque rating (Tc) equal to the RMS value of T_hold x √2 required; not because we need any additional Torque from the motor, but because we need each of the motor's windings to be capable of handling what would otherwise be an instantaneous peak-crest of a moving sine-wave current for an effectively continuous period of time.

Under these conditions (assuming nominal values and no margin), using a servo motor rated Tc (stall) = 10_Nm in an application requiring 10_Nm to indefinitely hold a vertical load is not sufficient, but choosing a slightly larger motor capable of a Tc (stall) => 14.14_Nm would be sufficient. Additionally, if the drive is also rated in terms of Arms, it would only need to produce the continuous RMS current required to produce 10_Nm by the motor (e.g. Approximately 10_Arms, if the servo motor's Kt = 1_Nm/ Arms).

We can prove this by first determining the watts-loss capability at continuous rating (Figure A.) and then comparing wattage dissipation capability against the two worst-case commutation points of the 3-phase motor coils where the current is 100%, 50%, 50% **(Figure B)** and 86.6%, 86.6%, 0% **(Figure C)**.

Given the motor information:

Tc(stall) = 10_Nm

Ic(stall) = 10_Arms

Kt=1.0_Nm/Arms

Rm(L-L)_25°C = 1.006_ohms, where Rm(L-L)_150°C = (1.006_ohms x 1.491); and

Rm Ø_150°C = 1.5/2 = 0.75_ohms

Temp (ultimate winding temperature for continuous operation) = 150°C

Temp-Rise (max. from a 25°C ambient) = 150°C-25°C = 125°C

Figure A: Maximum total watts loss obtainable with published data.

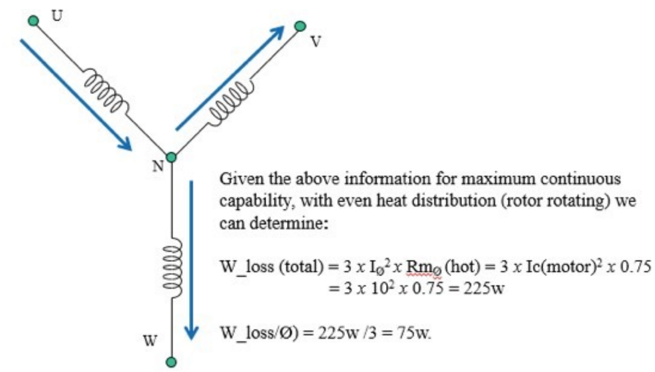


Figure B: 100% RMS current (Ic) entering phase-U with 1/2 split between phase-V and phase-W

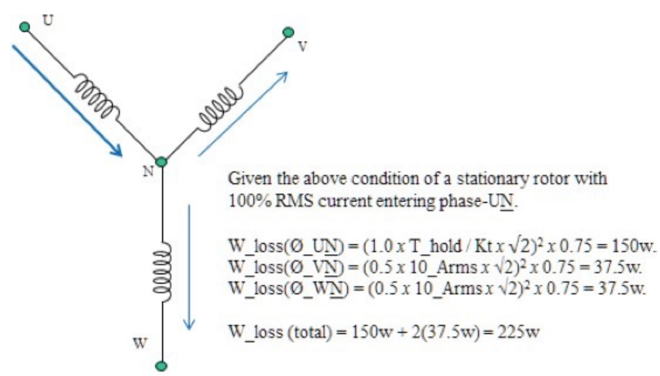
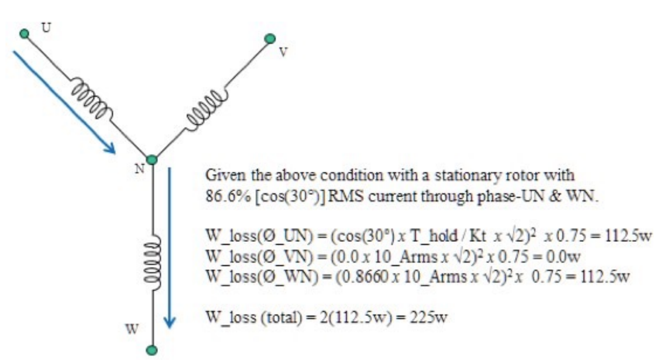


Figure C: Entering phase-U and leaving phase-W, is Ic x cos(30º); phase-V winding current = 0.0.



Hence, with our given information, conditions, and assumption, where each motor winding is a standalone phase(Ø) branch or coil, with no advantage of heat transfer to another winding's thermal area; each winding can dissipate up to 75_watts.

If we consider the first of the two worst-case commutation positions with all (100%) current (I_actual = Ic x √2), we can conclude the watts-loss (total) will still equal 225w **(Figure B)**; but the specific wattage needing to be dissipated through one winding (Ø_UN) is 100% over the previously calculated thermal capability of 75_watts **(Figure A)** and the other two windings are each at 50% capacity.

In the case of **Figure B**, to keep any of this motor's windings from overheating due to this specific commutation position we would need to limit the Ic(drive) to 70.7% of the Ic(motor). For our example, if the given 10_Nm holding load requirement is maintained, this motor selection will NOT accomplish the job without overheating. Hence, a possible solution would be to select a motor with a capability: Tc => √2 x T_hold, desirably with about the same motor torque constant (Kt) so the maximum required application RPM may be maintained without changing the drive.

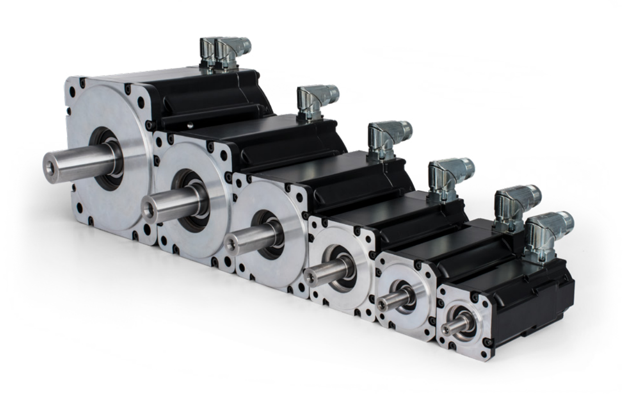
If we consider the second worst-case commutation position with all available (86.6%) current going through only two windings (I_actual = cos(30°) x Tc(motor) x √2), we can conclude the watts-loss (total) will again equal 225w **(Figure C)**; but the specific wattage needing to be dissipated through windings (Ø_UN) and (Ø_WN) is 50% over the previously calculated thermal capability of 75_watts **(Figure A)** for each winding.

In this case **(Figure C)**, we would only need to limit the RMS drive current (Ic(drive)) to 81.6% [100 x $(75w/112.5w)^{1/2}$] of the Ic(motor) to keep the motor's windings from overheating due to this specific commutation position, yielding a W_loss(Ø_UN) = W_loss(Ø_ WN) = $((10\_Arms / \sqrt{1.5} \times \cos(30)) \times \sqrt{2})^2 \times 0.75$ = 75w.

Still, if the 10_Nm holding load requirement is not re-specified to a lower value, this motor selection would also NOT accomplish the job (as with the case: Figure B). For this specific condition, we could select a motor with the capability: Tc => √1.5 x T_hold; however, this still allows a 33.3% wattage overload of the first commutation condition **(Figure B)**. Hence the better solution, ignoring statistical failure probability, is to select a motor with a capability: Tc => √2 x T_hold, as presented in the information of **Figure B**.

Conclusion

The appropriate understanding of the specific servo motor term: Stall, allows the engineer to correctly consider the specifics of an axis' Motion Profile and its load demands over relative load demand times versus total cycle times, such that dominant factors can be determined and analyzed for sizing calculations, machine-axis programming, and/or trouble-shooting, whether during normal operation or otherwise. These dominant factors allow reasonable consideration between the results: RMS calculations and any effectively constant or constant, loads held for a relatively long time as compared to the axis' total Motion Profile time, the motor's thermal time constants: TCT_motor & TCT_winding, and the servo drive's I^2t foldback algorithm. A good understanding of the motor's worst-case commutation positions when holding a continuous load with effectively no movement and its resulting standstill PWM drive commutation is essential for proper consideration of an axis' motor & drive sizing. Holding a torque for a relatively long time, against a load (external or otherwise), as compared to the Motion Profile time(s) and/or thermal time constants, can create erroneous RMS conclusions. Similar considerations [another subject] are required for high intermittent torque requirements relative to a Motion Profile's times & demands, and any proposed motor's thermal time constants.



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In real-world applications, the √2 torque multiplier may be conservative considering the good thermal conductivity between today's motor windings, laminations, & frame. Nevertheless, this author's experience from limited feedback over many years, motor designs & applications, is that the √2 multiplier for iron core rotary servo motors generally presents a margin of safety in the range of 9-11%. Though this information has not been specifically verified, the worst-case scenario with the √2 multiplier appears to offer enough margin to overcome the typical manufacturing tolerances of +/-10%. Thus, selecting a motor with a continuous capability equal to the calculated continuous requirement or slightly above, utilizing the √2 torque multiplier seems reasonable. However, for ironless core motors no margin is assumed. For Ironless core servo motors, it is advisable, as in all cases, to specifically consider each manufacturer's Stall rating definition. The AC servo motor industry's Stall, is a limited term with a specific definition; but not so fixed that it could not be re-defined in part or in whole, for some special purpose or particular-style servo motor (e.g. AC PM ironless core servo motor). The importance of good communication should not be underestimated, whether potential misconceptions arise between the word: stall and its derivatives, and the term: Stall, defined within the servo motor industry as part of normal parameterization, operation, or otherwise.

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