Rating and sizing of precision low backlash planetary gearboxes for Automation Motion Control and Robotics applications

By Dr. Gerhard G. Antony

If in a tough application your gearbox from "A", "B", "M", "S" … is not holding up to the promised performance and is failing, turn to the Servo-Gearboxes from NEUGART. This insider advice is spreading between the OEMS, and users.

What is the secret behind the NEUGART performance?

There is no secret! It is the honest rating and associated sizing.

Before we compare the rating and sizing practices of Manufacturers such as "A", "B", "M" and "S" to the NEUGART rating and sizing method we will make a short excursion into the material phenomena determining the life durability of a Servo-Gearbox (which is basically applicable for all mechanical devices made of ferrous materials).

Fatigue behavior of parts made of ferrous metals

All major components of a gearbox are subjected to cyclic stresses (bending, shear, compression, tension) even if the external loads are constant. Consider for instance the gear teeth. With every rotation of the wheel each tooth becomes fully loaded (during the engagement) and unloaded i.e. goes through a dynamic load cycle. In the case of a sun-gear of a planetary gearbox with 3 planets this occurs actually 3 times per revolution due to the multiple contact. Assuming the gearbox is driven by a servo motor at speed moderate input speed of 2000 rpm, within an 8 hour period the teeth of the sun-gear have had to endure: 2000 x 3 x 8 x 60 = 2880000 (2.88 x 10^6) load cycles.

The fatigue phenomena of metallic components are well known. Parts subjected to cyclic loads will fail after a certain finite number of load cycles even though the magnitude of the stress load is considerably lower than the static strength, which the part can endure without any damage. If the magnitude of the cyclic stress load is decreased, one can observe that at a certain stress level the part can endure unlimited load cycles. This stress level is called the ***"endurance limit"***. This behavior is well represented graphically by the so-called ***"S-N Curve"*** (***S***tress over the ***N***umber of Cycles). We can conclude, components loaded at or below the endurance limit will endure unlimited load cycles.

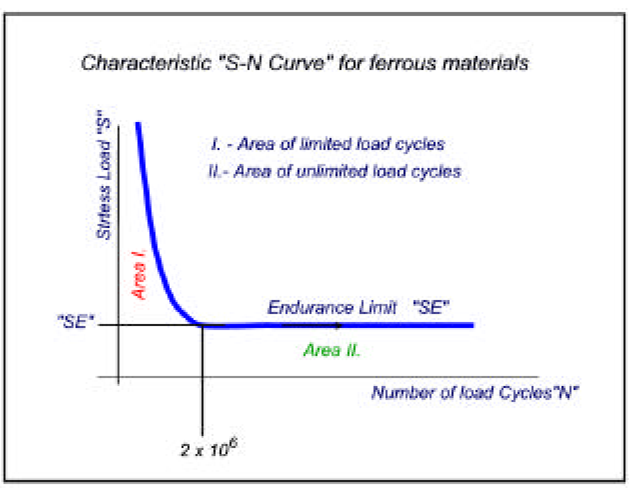

Figure 1.

Countless tests have confirmed that for ferrous materials the progressive exponential relationship between the stress S and the Number of endured load cycles without damage "levels" into the "***endurance limit***" (the constant horizontal part of the S-N curve) at about 2 x 10^6 to 10^7 cycles. This is valid if the part is subjected to bending, shear, tension or compression. Based on this we can distinguish 2 characteristic areas of the S-N relationship namely:

I. The "***area of limited load cycles***" (limited life) - exponential relationship between S and N (this area is mathematically described as "$S = 1 / N^{1/E} = N^{-1/E}$" or "$N = 1/S^E$" (Because the large numbers, the S-N relationship, it is mainly handled and plotted in its logarithmic form, "$\log S = -1/E \times \log N$" or "$\log N = -E \times \log S$"

II. The "***area of unlimited load cycles***" - the horizontal portion of the S-N curve.

The exponent "E" determines how steep the slope of the S-N relationship is, it depends on the alloy, heat treatment conditions and type of loading. The value of E covers in a quite wide range of about 6 to 80 (see comparison in logarithmic scale which allows the slope to appear as a constant linear slope). The Exponent E depends mainly upon material (alloy), its heat treatment and on the type of loading. (See Figure 2. with some examples) The above relationships allow us to calculate life expectancy at a certain stress load level. For a range or set of different stress levels and its frequency of stress level occurrence "damage accumulation calculation methods" are used such as the well know "Palmgren/Miner rule".

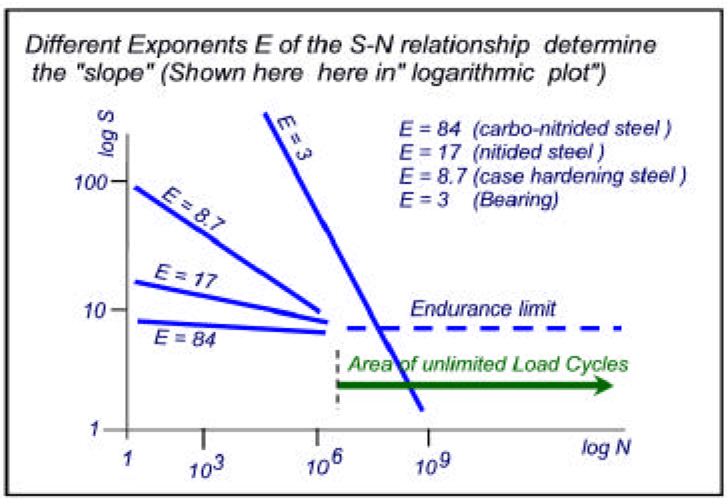

Figure 2

However, keep in mind if the number of the load cycles is above the 2 x 10^6, the stress load has to be at or below the endurance limit, otherwise the component will fail. As we can see from the above example for the number of load cycles a sun-gear has to endure during an 8-hour period (2.88 x 10^6), it becomes obvious that the components must be sized and designed to endure unlimited load cycles at the rated load.

Based on the above, the rated torque of a gearbox must be the torque level at which all components, are loaded at or below their endurance limits.

There is unfortunately another phenomenon which makes the so far straightforward design / sizing approach less transparent, the bearing. Rolling element bearings have a somewhat different behavior from the above, namely bearings do not have a clearly definable endurance limit. The very high pressure loading between the rolling elements and the races do not follow the above described endurance behavior. It is well known bearings are sized / designed / rated for a certain lifetime, say 10 000 hours, generally with 10% statistical failure probability i.e. "L10" life.

The relationship between the load and number of load cycles is exponential as discussed above, with an exponent of 3 to 10/3 however, as said with no defined endurance limit. The familiar exponent 3 is applied for bearing calculations and also to determine a Root Mean Cube RMC value of a complex load cycle consisting of different loads of different durations.

$$T_{RMC} = [N_1 t_1 T_1^3 + N_2 t_2 T_2^3 + \ldots + N_i t_i T_i^3) / (N_1 t_1 + N_2 t_2 + \ldots N_i t_i)]^{1/3}$$

This formula is valid for bearings but not really applicable for the other components of a gearbox such as the gears or shafts etc. A real calculation is needs to apply different exponents, valid for the components made of different materials, with different heat treatment and loading conditions, (as it is shown in Figure 2)

The recommended torque rating of gearboxes – the NEUGART rating

Majority of real world applications subject the gear components too much more than 2 x 10^6 load cycles. Therefore, the recommendation of practically all gear rating standards (AGMA, ISO, DIN etc.) is to determine and list the torque rating of a gearbox based on the endurance limit and on a certain minimum bearing life (AGMA recommends for industrial gearboxes 5000 hrs).

Rating of the NEUDART Gearboxes:

The rated torque of the PLS line is for continuous running without any life limitation on the gears and shafts, the bearings are rated for 20 000 hrs L10 life.
The torque rating of PLE-series gearboxes is based on the same endurance criteria listed above, the bearings are rated for 10 000 hours L10 life

The fact remains, only in applications where the number of load cycles is below 2x10^6 is a higher load than the rated load permissible. However the majority of real world automation applications reach this number of load cycles in a few days, weeks or in a best case some months of operation. A good rule is:

" if the peak load cycle is part of the designed standard working duty cycle of the machinery, the peak load should not be higher than the rated torque unless the machinery is only working a very limited time "say an hour a day" or if the user and OEM does not expect an extended long maintenance free life from the machinery. In such cases submit data to the manufacturer since as we said a simple RMC calculation is not applicable to the other main internal components of the gearbox."

The rating Game? - Comparison of the ratings of A, B, and S

Some servo-gearbox manufacturer are listing additional fictive adjusted torque ratings or listing rated torques, which are obviously very "progressively" determined. Whatever the reason is, whether they just want to have optically higher values listed or make a comparison more difficult or just make the sizing process less transparent, it certainly does not serve the user.

If you examine for instance the listing of the torque ratings of "A", you will find an "acceleration torque" listed which is limited to "1000 cycles / hour" (in the small print.) " A" is listing also a rated torque considerably lower than the "acceleration torque". (The torque ratings of comparable size Neugart units are below the acceleration torque but substantially higher then the "rated torque" of the "A" units.)

The ratings of the units from "B" are truly amazing. First of all it seems "B" found a secret way to design planetary gears, since all ratios in a given frame size have the same torque ratings. Assuming the rated torques are true rated torques based on the endurance limit of the components, as it should be, you have to wonder why the catalog is recommending to apply as a minimum a 1.2 service factor, even for the lightest duty application? According their sizing recommendation this service factor should be applied to the calculated RMC (Root Mean Cube) torque load value. (As we discussed above the RMC approach is only really applicable to bearings.)

The rating practice of Manufacturer “S” is to a certain extent a copy of the “A” method. This is somewhat surprising because the company “S” has a reputable industrial gearbox line which follows the standard rating praxis based on the accepted standards. Listing true rated torque values.

Conclusion - Recommandation

Next time you need a servo-gearbox for your demanding application do not get burned by the “Rating Game”. By selecting a NEUGART unit you know what you have, you know what to expect.

Use our online selection utility from our website www.neugartusa.com which calculates the real required torque rating for a given motor peak torque / inertia ratio / and load torque.

Just in case you wonder who is who in our examples.
“A” – Alpha, “B” – Bayside, “S’ - Stober

.