Parameters for Correctly Selecting and Applying Precision Planetary Gearboxes and Gear Reducers

Precision Planetary Gearboxes are common mechanical transmission devices widely used in various applications, such as machinery, manufacturing, automation equipment, food machinery, and conveyor systems. Understanding the parameters of planetary gearboxes and gear reducers is crucial for correct selection and application of this equipment. This article will introduce the main parameters of planetary gearboxes and the important specifications to consider when connecting them to motors.

Planetary gearboxes are favored for their unique characteristics: high precision, compact size, high transmission efficiency, and a wide range of reduction ratios. They are extensively used in stepper motors, servo motors, and precision transmission systems. Their primary function is to ensure precise transmission in mechanical devices while reducing the load/motor's moment of inertia and decreasing speed to increase torque.

When connecting a servo planetary gearbox to a corresponding servo motor, it is essential to confirm the parameters and corresponding models. Generally, the following points should be verified:

Rated Output Torque: The rated output torque of the gearbox is calculated by multiplying the rated output torque of the compatible motor by the gearbox's reduction ratio. This torque should be equal to or less than the rated output torque of the gearbox. Additionally, there is an acceleration torque, which refers to the maximum torque allowed at the output during short-term loading when the working cycle is less than 1000 times per hour. When the working cycle exceeds 1000 times per hour, impact factors must be considered. The acceleration torque serves as a maximum value during periodic operation; actual usage must keep acceleration torque below this limit.

Rated Input Speed: This is the driving speed of the planetary gearbox. If directly connected to a motor, the speed value will match that of the motor. The rated input speed mentioned here is measured at an ambient temperature of 20 degrees Celsius; if temperatures are higher, please reduce the speed accordingly.

Allowed Input Shaft Diameter: The input shaft hole of the gearbox and the motor output shaft are generally connected via a sleeve with variable thickness. Without this sleeve, the input shaft hole of the gearbox will be at its maximum diameter.

Once these primary data points are confirmed, one can select a model for the planetary gearbox. Gearboxes with smaller outer diameters can be paired with motors that have larger outer diameters and vice versa. It is also important to choose an appropriate connection flange to ensure correct alignment between the motor and gearbox.

The four critical dimensions for selecting a precision planetary gearbox include determining:

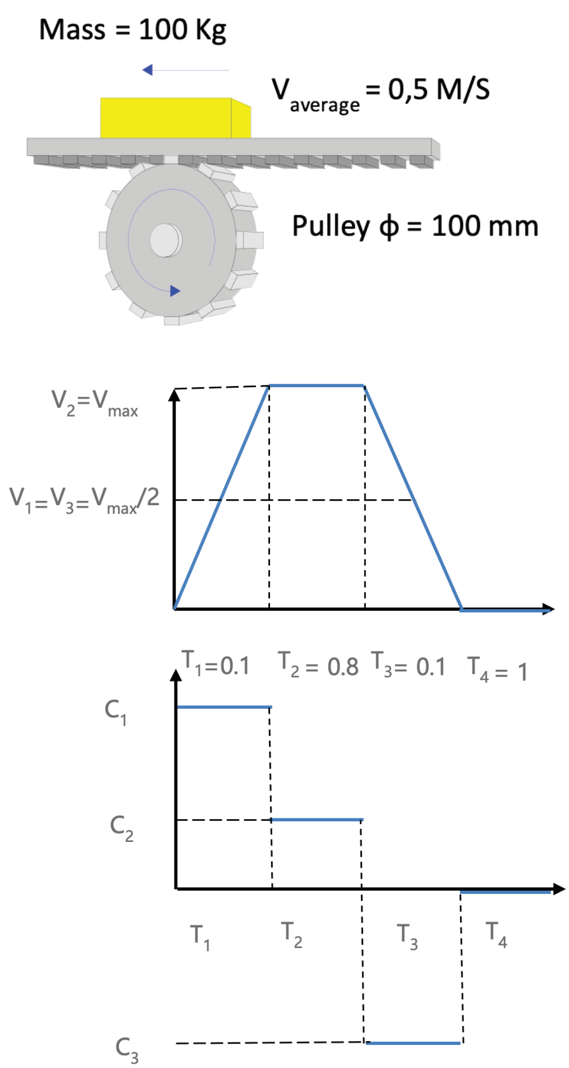
1. The ratio between motor speed and final output speed.
2. The ratio between final output torque and motor torque.
3. The ratio between mechanical moment of inertia and motor moment of inertia.
4. Ensure that the motor's final output torque multiplied by the gearbox ratio is less than that of the gearbox's maximum torque. Choose an appropriate precision level based on requirements and verify compatibility between the motor and gearbox according to design drawings. By following these steps for selecting a gearbox, one can effectively choose a suitable servo motor, maximizing its operational efficiency.

(continued on next page)

Selecting a gear box will request then to do some calculation to verify the selected gearbox with associated motor will meet the motion application requirement.

Below is a full calculation process example to select a gear reducer for an application step by step.

The **first step** is to know the hardest duty cycle of the machine. Generally, it's a distance to move in a given time plus a resting time to perform other operation and the cycle start again



Take the example of a toothed belt conveyor with a main driving pulley diameter of 100 mm. The application request to move 0.5 m in 1 second with 0.1 second acceleration and deceleration time and 0.8 second at the maximum speed. The resting time will be 1 second.

The **second step** is to calculate the gear reducer ratio

The displacement average speed will be 0.5 m / 1 s = 0.5 m/s but you need to reach a higher maximum speed V2 = Vmax because during acceleration and deceleration phase the average speed V1 and V3 = Vmax/2

The maximum and average speed are linked with the following equation:

$(0.5 \times V_{max} \times T_1 + V_{max} \times T_2 + 0.5 \times V_{max} \times T_3)/(T_1 + T_2 + T_3) = V_{average}$

or $V_{max} \times$ $(0.5\times0.1+0.8+0.5\times0.1)/(0.1+0.8+0.1)=V_{average}$

$V_{max} = V_{average} / 0.9 = 0.55$ M/s

With V_{max} speed, you calculate the rotational speed of the pulley:

0.55 / 0.05 = 11.11 rad/s or 106.15 rpm

If you select a motor speed of 4000 rpm

The maximum gear ratio = 4000/106.15 = 37.68

The closest lower available ratio being **35** you select this one.
The maximum motor speed will be:

106.15 x 35 = 3715,25 rpm

Note: chosen acceleration and deceleration time have to be coherent with the motor size. Don't select a too short acceleration time with a large motor and gear reducer, as well the opposite. 0,1 second is coherent with a small size servo application

The **second step** is to calculate the requested torques on the pulley, therefore on gear reducer output for each segment of time $T_1 - T_2$ and T_3

For this, you need to know the total mass to move, the friction coefficient of the belt conveyor as well the efficiency. Let's take the following data: Total mass = 100 Kg – Efficiency μ= 0.85 and friction coefficient = 0.15

(continued on next page)

You need to calculate all torque component to achieve the motion

For acceleration component the acceleration torque C_{acc} is equal to J/μ x dω/dt

The moment of inertia J of a mass m with a pulley of radius R = m x R^2 = 100 x 0.05^2 = 0.25 Kgm2

The acceleration torque equal = 0.25/0.85 × 11.11/0.1 = 32,68 Nm

The friction torque C_{frict} is equal to mass m x 9,81 x Friction coefficient x R divided by efficiency
= 100 x 9.81 x 0.15 x 0.05 / 0.85 = 8,66 Nm

While efficiency help during braking = 100 x 9.81 x 0.15 x 0.05 x 0.85 = 6.25 Nm

The deceleration torque uses the same formula than acceleration but the efficiency help:

= 0.25 x 0.85 x 11.11/0.1 = 23.61 Nm

Now we have all information to calculate C_1 – C_2 and C_3 torque

C_1 = acceleration torque + friction torque = 32.68 + 8.66 = **41.34 Nm**

C_2 = friction torque only = **8.66 Nm**

C_3 = deceleration torque minus friction torque (friction help) = 23.61 – 6.25 = **17,36 Nm**

The **third step** is to select a gear reducer ratio 35 able to stand output average duty cycle torque and peak torque

Nominal output torque of a gear reducer qualifies the continuous nominal output torque or the equivalent average torque of the duty cycle

But the vast majority of servo application are not continuous duty except some winder – unwinder control or accurate dosing pump. It's therefore necessary to calculate the equivalent average nominal torque of the duty cycle. Because the wear of a mechanical device is function of power 3 of the torque the average duty cycle is given by the formula:

$$\sqrt[3]{\frac{C1^3 \times T1 \times V1 + C2^3 \times T2 \times V2 + C3^3 \times V3 \times T3}{T1 \times V1 + T2 \times V2 + T3 \times V3}} =$$

$$\sqrt[3]{\frac{41.34^3 \times 0.1 \times 1858 + 8.66^3 \times 0.8 \times 3715 + 17.36^3 \times 0.1 \times 1858}{0.1 \times 1858 + 0.8 \times 3715 + 0.1 \times 1858}} = \mathbf{16.91\ Nm}$$

The gear reducer must be able to stand duty cycle peak torque = 41.34 Nm. But the total duty cycle last 2 second which means up to 1800 cycles an hour. The peak output torque is defined for 1000 cycles an hour. Therefore, the gear reducer peak output torque has to stand application peak torque multiply by the load factor according below array:

Load factor	No of cycles / hour
1	0 - 1000
1.1	1000 - 1500
1.3	1500 - 2000
1.6	2000 - 3000
1.8	3000 - 5000

The derating factor for 1800 cycle an hour will: 1.3. The output peak torque of the selected gear reducer will need to be above 41.34 Nm x 1.3 = 53.3 Nm

For this application we select TB 60 – Ratio 35 – Efficiency = 0.94

Nominal output torque = 50 Nm > 16.91 Nm

Peak output torque = 90 Nm > 53.3 Nm

(continued on next page)

The **fourth step** is to select the motor

The motor will have to supply input torque to produce output torque we have calculated, including gear reducer efficiency plus a torque to accelerate or decelerate himself plus reducer own inertia

Let's calculate the gear reducer input torque for C_1, C_2 and C_3

C_{1input} = 41.34 Nm / (35 x 0.94) = 1.25 Nm

C_{2input} = 8.66 Nm / (35 x 0,94) = 0.26 Nm

C_{3input} = 17.36 Nm x 0.94 / 35 = 0.46 Nm (Gear reducer efficiency help during braking phase)

Let select a motor with 2 Nm nominal torque and 5 Nm peak torque with an inertia
= 6.8 10^{-5} Kgm^2 + 1.3 10^{-5} (Reducer own inertia) = 8.1 10^{-5} Kgm^2

The acceleration and deceleration torque of the motor itself with inertia of the gear reducer will be:

C_{accmot} = J x dω/dt = 8.1 10^{-5} x 11.11/0.1 x 35= 0.31 Nm

The total motor torque will be:

C_{1input} = 1.25 + 0.31 = 1.56 Nm

C_{2input} = 0.26 Nm

C_{3input} = 0.46 + 0.31 = 0.77 Nm

The ratio Load inertia – motor inertia will be:

Load inertia at gear reducer input: 0.25 / 35^2 +1.3 10^{-5} (Reducer own inertia) = 21.71 10^{-5} Kgm^2

Ratio = 21.71 / 6.8 = 3.19 which is good ratio for servo motor full control

Note: With such application the chosen motor is a little be oversized but ratio inertia load / motor inertia is good – A smaller motor will have a lower inertia and a ratio with inertia load not so favorable

When the motor is not torque oversized it's necessary to calculate the equivalent average torque. Because this is a thermal equivalent torque it's function of the square of each torque phase including torque at zero speed. In our case it will be:

$$\sqrt{\frac{1.56^2 \times 0.1 + 0.26^2 \times 0.8 + 0.77^2 \times 0.1}{0.1+0.8+0.1+1}} = 0.42 \text{ Nm}$$

The **fifth step** is to calculate the emergency stop torque to check if acceptable for the chosen gear reducer

Very often the emergency stop torque is supplied by a holding brake fit on motor shaft. It could be also be supplied by the motor peak torque capability for a quick and controlled stop. In both case we need to calculate the emergency stop time when emergency braking torque is applied. The base equation is the same. The braking torque is equal

$C_{braking} = d\omega/dt \times J_{load} \times (\mu_{reducer} \times \mu)/(R^2_{reducer}) - C_{Friction} + (J_{motor}+J_{reducer}) \text{ x } d\omega/dt$

(continued on next page)

The friction torque being a constant:

$C_{braking}+C_{friction}$ = dω/dt x (J_{load} x ($\mu_{reducer} \times \mu$)/($R^2_{reducer}$)+(J_{motor}+$J_{reducer}$)) and

dt= dω/($C_{braking}$+$C_{friction}$) x (J_{load} x ($\mu_{reducer} \times \mu$)/($R^2_{reducer}$)+(J_{motor} + $J_{reducer}$))

In our application let's assume the motor is fit with a 3 Nm holding brake

The $C_{friction}$ (Gear reducer efficiency help) = 6.25 x 0.94 / 35 = 0.168

dω= 11.11 x 35 = 388.85 rd/s

dt = (388.85/ (3+0.168)) x (0.25 x 0.94 x 0.85 / 35^2 + 8.1 10^{-5}) = 0.03 second

Let calculate the braking torque to stop the motor + reducer own inertia

C = 8.1 10^{-5} X 388.85/0.03 = 1.05 Nm

The remaining torque to break the load will be 3 Nm – 1.05 Nm = 1.95 Nm

The corresponding output torque at reducer will be: 1.95 x 35 / 0.94 = 72,6 Nm (Gear reducer efficiency help – Corresponding torque at reducer output higher)

In our case 72,6 Nm < 150 Nm (TB 60 ratio 35 emergency stop torque)

The sixth and final step is to verify the gear reducer output will stand axial and radial forces on its output shaft

Axial and radial forces applied on gear reducer output shaft are fully dependent of mechanical design and coupling of gear reducer to the load. If there is an intermediate gearing between the reducer and the load this gearing will stand the axial and radial forces

In case of a teethed pulley directly mounted on reducer output shaft, it will have to stand a radial force depending of teethed belt tension and reducer output torque. Because this output torque is not constant during the duty cycle, an equivalent radial force has to be calculated. Because the wear of a mechanical device is function of power 3 of the applied radial force the average equivalent force is given by the formula:

$$F_{radial} = \sqrt[3]{\frac{F1^3 \times T1 \times V1 + F2^3 \times T2 \times V2 + F3^3 \times V3 \times T3}{T1 \times V1 + T2 \times V2 + T3 \times V3}}$$

With F1 = Belt tension + C1 /Pulley Radius

With F2 = Belt tension + C2 /Pulley Radius

With F3 = Belt tension + C3 /Pulley Radius

If there are axial forces same formula applies for average axial force

Checking these axial and radial forces are compatible with the selected gear is the final verification

(continued on next page)

Conclusion

Calculating a servo gear reducer is not a so easy task with different possible solutions, requesting to repeat above calculation to find the optimum choice of the motor with associated gear reducer

Additionally, if there are space constraints or any other specific requirements, it's essential to inform the design personnel in advance. Only then can the design team evaluate and recommend specifications that meet the exact needs of the application. Through comprehensive evaluations and considerations, you can determine the reducer specification that best fits your needs.

GearKo focuses on the research and development of high-quality planetary gear boxes and reducers, committed to providing customers with the best products and solutions. If you wish to learn more about how our precision planetary gearboxes or reducers can enhance the performance of your equipment, please feel free to **contact us**.