Gear Backlash

Introduction

Properly functioning mechanical systems need to have a certain “clearance” (“gap”, “play”) between the components transmitting motion under load.

Clearance is necessary to avoid interference, wear, and excessive heat generation, ensure proper lubrication, compensate for manufacturing tolerances etc. Clearance in the gear mesh means that the gap between the teeth of one gear is by a small amount larger than the tooth width of the mating gear.
We also find a certain clearance in the rolling bearings, namely a small clearance between the inner race, rolling body (ball, roller) and outer race of the bearing.
The key and keyway of a shaft or hub usually have also clearance.

Rotational backlash of a gearbox

The clearance of the above named main gearbox components causes that at a load reversal the output shaft will turn a slight angle even though the input is locked (not turning). “Input” and “output” of a gearbox is a matter of definition; in a speed reducer the output is the low speed end in a speed increaser the high-speed end. The value of the shaft “turn angle at zero load” is called the rotational backlash of the gearbox. Fig 1. shows the theoretical diagram of the angular turn of the gearbox shaft the over applied torque.

Theoretical stiffness curve and backlash of a gearbox

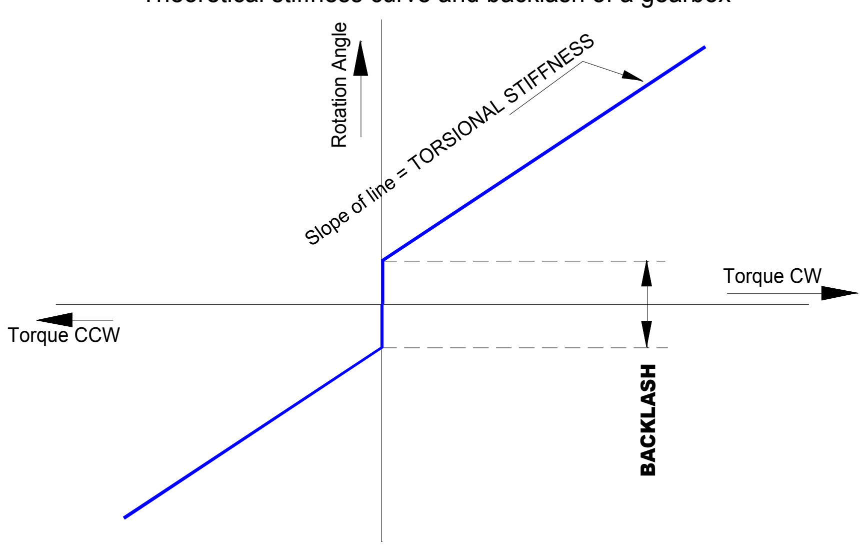

Fig 1.

Theoretically, there is no torque required to the backlash. i.e. this portion of the angular turn is load independent. However in real world systems a certain torque is needed to overcome internal friction to “settle the clearance” in the components. With increased torque the components deform elastically which appears at the output shaft as a load dependent angular turn and its magnitude is the measure for the stiffness of the gearbox.

Backlash is not an important issue for gearboxes used in applications where there is no load reversal or the position after a reversal is not critical.

In precision positioning applications with frequent load reversal (such as robotics, some automation tasks etc.) the backlash directly influences the positioning accuracy ***(See also lost motion definition Fig 2).***

Therefore, servo gear heads designed for these type of applications are made with a very low, strictly defined and controlled backlash and high stiffness.

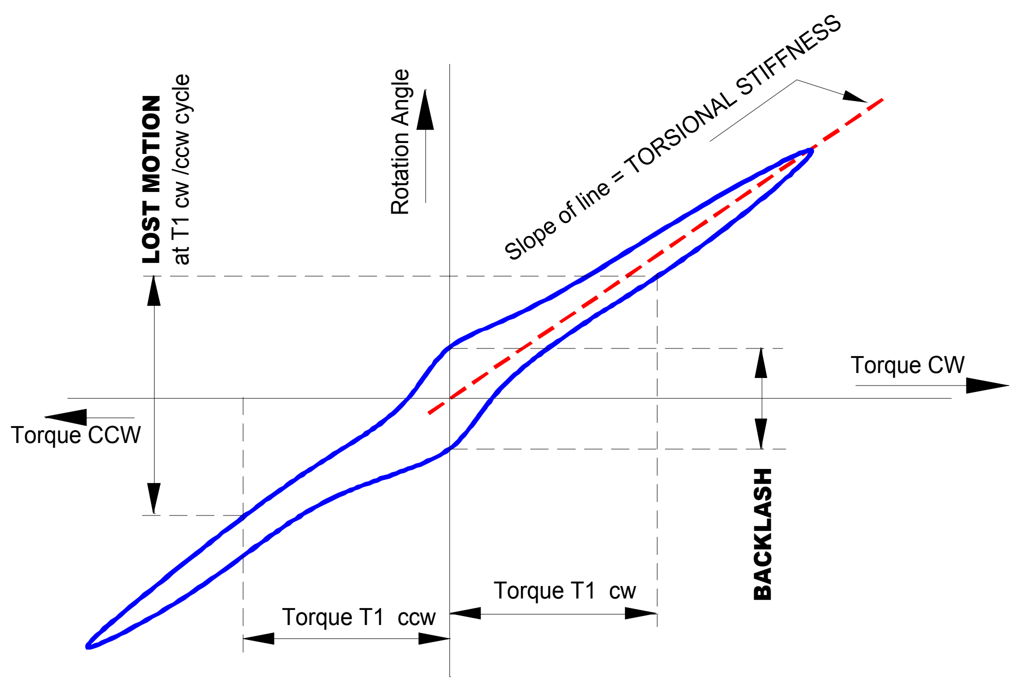

Fig 2.

How is backlash defined and measured

As mentioned above the backlash of a gearbox can be defined (measured) at the output (at locked input) or at the input (at locked output)

There is no strict standard (such as AGMA, ISO, DIN, etc.) mandating the measurement and listing of the gearbox backlash at the input or at the output. (This is correct since the definition of the input and output side of a gearbox depends on how the gearbox it is used in an application either as a speed increaser or a speed reducer.

The relationship between the backlash at the input and output depends basically on the reduction ratio.

$$S_{input} = i \times S_{output}$$

S – Backlash, i – Reduction Ratio

Note!
The above equation is theoretical. Deviations can be experienced when measuring, particularly with multiple stage gearboxes, since the effects of the individual clearances depend upon where the clearance is in the "gear train" furthermore the clearances are not exactly the same in each mesh.

Servo gearheads have a well-defined input side namely the side where it is connected to the motor. It is an unwritten "industry standard" to list the backlash referenced to the output side (which is almost in all cases the slow speed side).

Industry standard for the servo gear-heads is to list the backlash at the output side

Rotational backlash is measured in units of angular degrees and its fractional (minutes and seconds) or it can be measured as an arc value to the angle in radians. Since the backlash is generally a fairly small angle it is mainly measured in angular minutes. Unfortunately, it became common to call it "arc minutes" which is a mathematical and physical nonsense, because the arc of an angle is not measured in minutes but in radians.

The correct unit for the rotational backlash of a gearbox is the "angular minute"

A true precision low backlash servo gear head has a backlash of 2 to 8 angular minutes (measured at he output)

Backlash measurement

Even though it appears trivial, to measure correctly the backlash of a gearbox requires a proper test rig and instrumentation. The fixture holding the gearbox and its output shaft should be as be as rigid as possible. The generally very small rotational angle of the output shaft can be measured direct by a precision encoder or by indirect methods. The indirect method utilizes mainly a long rigid arm at the shaft allowing measuring the displacement at a defined distance with a dial indicator and calculating the corresponding rotational angle.

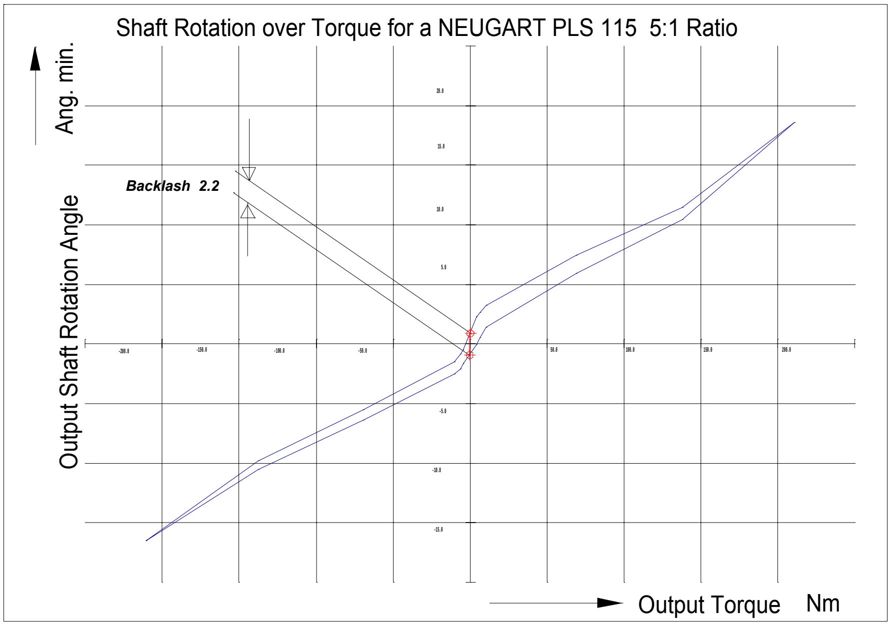

Fig 3.

Since a certain amount of torque is required to overcome all clearances in the system the most exact method is to measure a complete load reversal cycle of the gearbox (from zero to clockwise rated torque load torque value, followed by unloading and torque reversal to the counter clockwise rated torque value) see Fig 2 and 3 . By this means a whole "hysteresis plot" of the gearbox is obtained which will allow determine not only the true backlash, bat also the "***torsional stiffness"*** (see section "rotational stiffness) of the gearbox and the "***lost motion"*** at any given load .

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