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Understanding dimensional stability in gearing

How temperature and humidity can affect materials used in gearing.

In the retail community, the term shrinkage is defined as the difference between the value of the physical on-hand inventory minus the expected on-hand or book value of the inventory. After accounting for the stock added to inventory and subtracting the sold inventory, what is missing from the store is the shrink. In gearing, shrinkage can also be an issue as each material is victim of its unique coefficient of thermal expansion.

In order to understand this phenomenon, we need to take a trip back to elementary physics class. Every material constructed is a molecular homogenization of elements. Each of these molecules are made up of atoms. Each atom consists of a nucleus and a certain number of electrons. The electrons are in constant motion orbiting the nucleus. If we fix the temperature, the electrons will move at a constant speed. However, if we allow the temperature to rise, the electrons will absorb this heat as kinetic energy, and they will move at a higher speed. Conversely, if we lower the temperature, the kinetic energy flows from the electrons, thus slowing them down. This excited state causes the atom to expand slightly and the deenergized state causes the atom to decrease in size ever so slightly. This expansion or contraction is then perpetuated throughout the material at the molecular level.

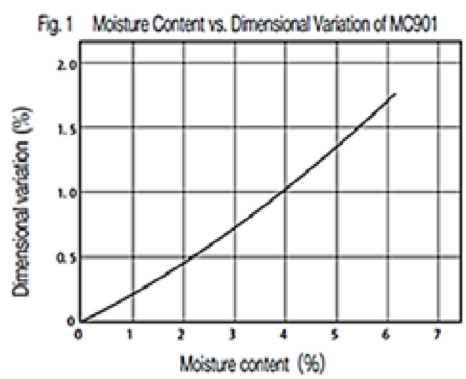

Figure 1: Moisture content vs. dimensional variation of MC901.

Although microscopic in scale, these size deviations add up to affect the dimensional stability of some products.

(The units for all values discussed in the balance of this article are 10^{-6} mm/mm $°K^{-1}$)

Some materials such as glass, mica, and molybdenum have very low coefficients and can be considered dimensionally stable. Glass has a value of 4. Mica has a value of 3. Molybdenum has a value of 5.

Metallic materials have values from 6 to 29. Some examples are cast iron with a value of 10.8, aluminum alloy, which varies from 21 to 24, nickel with a value of 13, gold at 14.2, and carbon steel at 10.8.

Plastic materials on the other hand have coefficients that range from 31 to 200. The materials that are most resistant to expansion are those with added fillers. For example, acrylonitrile butadiene styrene (ABS) with a glass fiber fill has a value of 31, but unfilled ABS ranges from 72 to 108. Another example is acetal with a glass fiber reinforcement, which has a value of 39, but its unreinforced variety ranges from 85 to 110.

Nylon resins vary from 50 to 90 depending on the structure. If you add reinforcing fibers, the values can be even lower. A simple cast nylon 6 has a value of 85, whereas a glass reinforced nylon has a value of 23.

Let us examine the following example situation. A gear company produces a cast nylon 6 gear rack that is one meter in length. The factory temperature is 20°C and the factory measures the rack to be exactly 1,000mm in length. At the place of installation, the temperature is 40°C.

Since the temperature difference is 20°, the deviation in the length of the rack is:

$$85\text{x}10^{-6}\text{mm/mm °K}^{-1} \text{ x } 1{,}000\text{mm x } 20\text{°K} = 1.7\text{mm}$$

Although small compared to the overall length, if being used in absolute positioning application, this difference in length due to temperature could cause the rack to be considered out of spec.

Another issue that can affect dimensional stability is expansion due to water absorption. The common cast nylon 6 designated as MC901 has a moisture absorption rate of 0.8 percent when submerged in water for 24 hours at room temperature. The glass fiber reinforced nylon designated as MC602st has a moisture absorption rate of 0.72 percent under the same conditions. The acetal sold under the brand name Duracon® has a moisture absorption rate of 0.22 percent.

Let us examine the following example situation. A gear company produces a cast nylon 6 gear rack that is one meter in length. The factory determines that the moisture content is 1 percent at the time of inspection, which results in a dimensional expansion of 0.2 percent as detailed in Figure 1. At the place of installation, the moisture content is measured to be 3 percent, thus resulting in a dimensional expansion of 0.75 percent.

Since the dimensional expansion increment is 0.55% (0.75%-0.2%), the deviation in the length of the rack is:

$$1{,}000\text{mm x } 0.55\% = 5.5\text{mm}$$

This is a significant deviation from the stock length and will affect both the installation and the operation of the rack and the mating pinion.

These two environmental factors are frequently not taken into consideration by most gear users and can result in frustrations between the manufacturer and the end-user. Fortunately, these expansions can be reversed by reducing the temperature and/or moisture content to the conditions measured at the time of manufacture of the products.

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