**Introduction to GD&T (Geometric Dimensioning & Tolerancing), Limits, Fits & Tolerances**

**Geometric Dimensioning and Tolerancing (GD&T)** is a standardized system used in engineering drawings to define the allowable variation in part geometry. It improves **manufacturing accuracy, interchangeability, and cost-effectiveness** while ensuring functional fit between components.

**1. Limits, Fits & Tolerances**

**A. Limits and Tolerances**

* **Limits**: The maximum and minimum permissible sizes of a feature.
* **Tolerance**: The allowable variation in a dimension to ensure proper function and assembly.
  + **Unilateral Tolerance** → Tolerance in one direction (e.g., 25.00 +0.05 / -0.00 mm).
  + **Bilateral Tolerance** → Tolerance in both directions (e.g., 25.00 ± 0.05 mm).
  + **Limit Dimensions** → Directly specifying upper and lower limits (e.g., 24.95 – 25.05 mm).

**B. Types of Fits (ISO 286-1:2010 / ANSI B4.1-1967)**

Fits define how two mating parts will interact based on tolerances.

| **Type** | **Description** | **Example** |
| --- | --- | --- |
| **Clearance Fit** | Always leaves space between mating parts. | Shaft (Ø19.95) in Hole (Ø20.05). |
| **Interference Fit** | Always requires force to assemble. | Shaft (Ø20.05) in Hole (Ø20.00). |
| **Transition Fit** | May be clearance or interference, depending on tolerance. | Shaft (Ø20.00 ± 0.02) in Hole (Ø20.00 ± 0.02). |

Common Fit Types (Holes & Shafts):

* **H7/g6 (Loose Fit)** – Rotating parts with free movement.
* **H7/m6 (Transition Fit)** – Gear assemblies.
* **H7/p6 (Interference Fit)** – Press-fit gears and bushings.

**2. Geometric Tolerances (GD&T)**

GD&T uses **symbols and feature control frames** to define allowable variations in form, orientation, and location.

**A. Key GD&T Symbols & Meanings**

| **GD&T Category** | **Symbol** | **Description** | **Example** |
| --- | --- | --- | --- |
| **Form Tolerances** | ○ (Straightness) | Flat or straight feature. | Shaft alignment. |
|  | ⭕ (Roundness) | Cylindrical feature accuracy. | Bearings, shafts. |
|  | ⬭ (Flatness) | Surface evenness. | Precision plates. |
| **Orientation Tolerances** | ∠ (Perpendicularity) | 90° feature accuracy. | Bolt holes, machined faces. |
|  | ∠ (Parallelism) | Feature parallelism. | Guiding rails. |
| **Location Tolerances** | ⊕ (Position) | Precise hole/shaft placement. | Bolt patterns, hole alignment. |
|  | ⊥ (Concentricity) | Axis alignment. | Rotating components. |
| **Runout Tolerances** | ⌖ (Circular Runout) | Surface variation while rotating. | Bearings, shafts. |
|  | ⌖ (Total Runout) | Full 3D surface variation. | High-speed components. |

**3. Feature Tolerances**

Feature tolerances ensure that specific part features (holes, slots, surfaces) meet design intent.

* **Surface Finish** → Controls roughness (e.g., Ra 0.8 µm).
* **Hole Tolerances** → Ensures bolt-hole alignment.
* **Thread Tolerances** → Defines pitch accuracy.

**4. Cost Aspects of GD&T & Tolerancing**

Applying **tight tolerances and unnecessary GD&T controls increases production cost**.

**A. Cost Factors**

1. **Tight Tolerances** → Require precision machining, increasing production cost.
2. **Complex GD&T Specifications** → Higher inspection and quality control expenses.
3. **Material Selection** → Harder materials increase machining difficulty and cost.
4. **Manufacturing Process** → CNC, casting, forging, and additive manufacturing have different cost implications.

**B. Cost Reduction Strategies**

* **Apply GD&T Only Where Necessary** → Avoid excessive precision where not functionally required.
* **Choose Economical Fits & Tolerances** → Standard H7/g6 fits are cost-effective.
* **Optimize Manufacturing Process** → Use casting for rough shapes, machining only for critical areas.

**5. Conclusion**

* **Limits & Fits** ensure proper assembly and function.
* **GD&T** enhances design accuracy but must be applied judiciously to **avoid excessive costs**.
* **Feature Tolerances** help control surface quality and assembly precision.
* **Cost Optimization** is key to balancing **quality, performance, and manufacturing expenses**.