## 19.3 Surface Contact Of Worm And Worm Gear

There is no specific Japanese standard concerning worm gearing, except for some specifications regarding surface contact in JIS B 1741.

Therefore, it is the general practice to test the tooth contact and backlash with a tester. Figure 19-5 shows the ideal contact for a worm gear mesh.

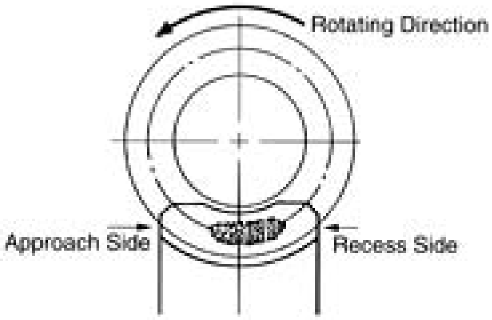



Fig. 19-5 Ideal Surface Contact of Worm Gear

From Figure 19-5, we realize that the ideal portion of contact inclines to the receding side. The approaching side has a smaller contact trace than the receding side.

Because the clearance in the approaching side is larger than in the receding side, the oil film is established much easier in the approaching side. However, an excellent worm gear in conjunction with a defective gear box will decrease the level of tooth contact and the performance.

There are three major factors, besides the gear itself, which may influence the surface contact:

1. Shaft Angle Error.
2. Center Distance Error.
3. Mounting Distance Error of Worm Gear.

Errors number 1 and number 2 can only be corrected by remaking the housing. Error number 3 may be decreased by adjusting the worm gear along the axial direction. These three errors introduce varying degrees of backlash.

### 19.3.1. Shaft Angle Error

If the gear box has a shaft angle error, then it will produce crossed contact as shown in Figure 19-6.

A helix angle error will also produce a similar crossed contact.

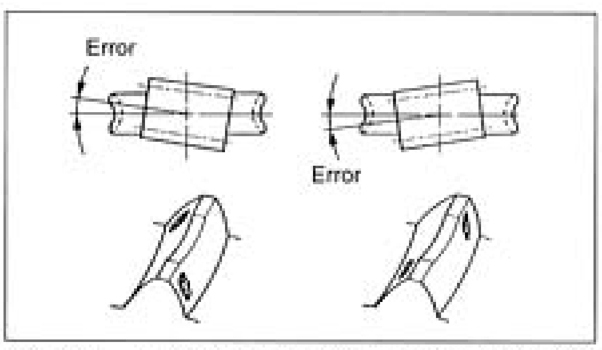



Fig. 19-6 Poor Contact Due to Shaft Angle Error

### 19.3.2 Center Distance Error

Even when exaggerated center distance errors exist, as shown in Figure 19-7, the results are crossed end contacts. Such errors not only cause bad contact but also greatly influence backlash.

A positive center distance error causes increased backlash. A negative error will decrease backlash and may result in a tight mesh, or even make it impossible to assemble.

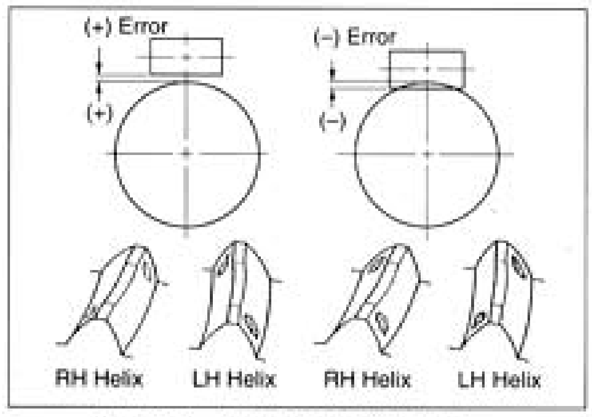



Fig. 19-7 Poor Contact Due to Center Distance Error

### 19.3.3 Mounting Distance Error

Figure 19-8 shows the resulting poor contact from mounting distance error of the worm gear. From the figure, we can see the contact shifts toward the worm gear tooth's edge. The direction of shift in the contact area matches the direction of worm gear mounting error. This error affects backlash, which tends to decrease as the error increases. The error can be diminished by micro-adjustment of the worm gear in the axial direction.

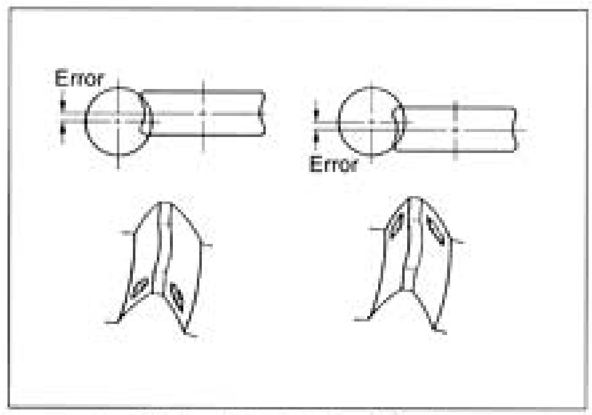



Fig. 19-8 Poor Contact Due to Mounting Distance Error

# SECTION 20 LUBRICATION OF GEARS

The purpose of lubricating gears is as follows:

1. Promote sliding between teeth to reduce the coefficient of friction ($\mu$).
2. Limit the temperature rise caused by rolling and sliding friction.

To avoid difficulties such as tooth wear and premature failure, the correct lubricant must be chosen.

## 20.1 Methods Of Lubrication

There are three gear lubrication methods in general use:

1. Grease lubrication.
2. Splash lubrication (oil bath method).
3. Forced oil circulation lubrication.

There is no single best lubricant and method. Choice depends upon tangential speed (m/s) and rotating speed (rpm). At low speed, grease lubrication is a good choice. For medium and high speeds, splash lubrication and forced circulation lubrication are more appropriate, but there are exceptions. Sometimes, for maintenance reasons, a grease lubricant is used even with high speed. Table 20-1 presents lubricants, methods and their applicable ranges of speed.

The following is a brief discussion of the three lubrication methods.

#### 20.1.1 Grease Lubrication

Grease lubrication is suitable for any gear system that is open or enclosed, so long as it runs at low speed. There are three major points regarding grease:

1. Choosing a lubricant with suitable viscosity.
   A lubricant with good fluidity is especially effective in an enclosed system.
2. Not suitable for use under high load and Continuous operation. The cooling effect of grease is not as good as lubricating oil. So it may become a problem with temperature rise under high load and continuous operating conditions.
3. Proper quantity of grease.
   There must be sufficient grease to do the job. However, too much grease can be harmful, particularly in an enclosed system. Excess grease will cause agitation, viscous drag and result in power loss.

#### 20.1.2 Splash Lubrication

Splash lubrication is used with an enclosed system. The rotating gears splash lubricant onto the gear system and bearings. It needs at least 3 m/s tangential speed to be effective. However, splash lubrication has several problems, two of them being oil level and temperature limitation.

1. Oil level.

There will be excessive agitation loss if the oil level is too high. On the other hand, there will not be effective lubrication or ability to cool the gears if the level is too low. Table 20-2 shows guide lines for proper oil level. Also, the oil level during operation must be monitored, as contrasted with the static level, in that the oil level will drop when the gears are in motion. This problem may be countered by raising the static level of lubricant or installing an oil pan.

2. Temperature limitation.

The temperature of a gear system may rise because of friction loss due to gears, bearings and lubricant agitation. Rising temperature may cause one or more of the following problems:

- Lower viscosity of lubricant.
- Accelerated degradation of lubricant.
- Deformation of housing, gears and shafts.
- Decreased backlash.

New high-performance lubricants can withstand up to 80 to 90°C. This temperature can be regarded as the limit. If the lubricants temperature is expected to exceed this limit, cooling fins should be added to the gear box, or a cooling fan incorporated into the system.

#### 20.1.3 Forced-Circulation Lubrication

Forced-circulation lubrication applies lubricant to the contact portion of the teeth by means of an oil pump. There are drop, spray and oil mist methods of application.

1. Drop method:

An oil pump is used to suck-up the lubricant and then directly drop it on the contact portion of the gears via a delivery pipe.

2. Spray method:

An oil pump is used to spray the lubricant directly on the contact area of the gears.

3. Oil mist method:

Lubricant is mixed with compressed air to form an oil mist that is sprayed against the contact region of the gears. It is especially suitable for high-speed gearing.

Oil tank, pump, filter, piping and other devices are needed in the forced-lubrication system. Therefore, it is used only for special high-speed or large gear box applications. By filtering and cooling the circulating lubricant, the right viscosity and cleanliness can be maintained. This is considered to be the best way to lubricate gears.

### 20.2 Gear Lubricants

An oil film must be formed at the contact surface of the teeth to minimize friction and to prevent dry metal-to-metal contact. The lubricant should have the properties listed in Table 20-3.

#### 20.2.1 Viscosity of Lubricant

The correct viscosity is the most important consideration in choosing a proper lubricant. The viscosity grade of industrial lubricant is regulated in JIS K 2001. Table 20-4 expresses ISO viscosity grade of industrial lubricants.

JIS K 2219 regulates the gear oil for industrial and automobile use. Table 20-5 shows the classes and viscosities for industrial gear oils.

JIS K 2220 regulates the specification of grease which is based on NLGI viscosity ranges. These are shown in Table 20-6.

Besides JIS viscosity classifications, Table 20-7 contains AGMA viscosity grades and their equivalent ISO viscosity grades.

#### 20.2.2 Selection of Lubricant

It is practical to select a lubricant by following the catalog or technical manual of the manufacturer. Table 20-8 is the application guide from AGMA 250.03 "Lubrication of Industrial Enclosed Gear Drives".

Table 20-9 is the application guide chart for worm gears from AGMA 250.03.

Table 20-10 expresses the reference value of viscosity of lubricant used in the equations for the strength of worm gears in JGMA 405-01.

**Table 20-1(A) Ranges of Tangential Speed (m/s) for Spur and Bevel Gears**

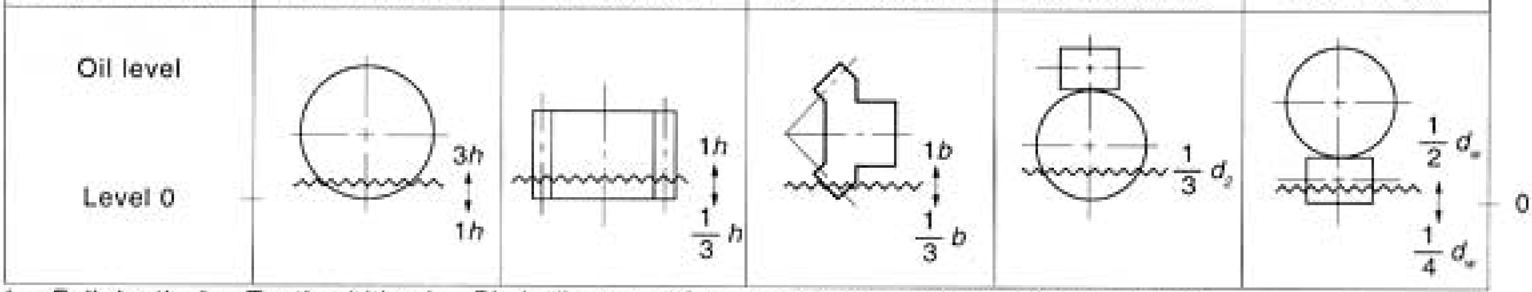
| No. | Lubrication | Range of Tangential Speed (m/s) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 5 | 10 | 15 | 20 | 25 |
| 1 | Grease Lubrication | ← | → | | | | |
| 2 | Splash Lubrication | | ← | | → | | |
| 3 | Forced Circulation Lubrication | | | | ← | | |

**Table 20-1(B) Ranges of Sliding Speed (m/s) for Worm Gears**

| No. | Lubrication | Range of Sliding Speed (m/s) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 5 | 10 | 15 | 20 | 25 |
| 1 | Grease Lubrication | ← | → | | | | |
| 2 | Splash Lubrication | | ← | → | | | |
| 3 | Forced Circulation Lubrication | | | ← | | | |

**Table 20-2 Adequate Oil Level**

| Types of Gears | Spur Gears and Helical Gears | | Bevel Gears | Worm Gears | |
|---|---|---|---|---|---|
| Gear Orientation | Horizontal Shaft | Vertical Shaft | Horizontal Shaft | Worm Above | Worm Below |




$h$ = Full depth, $b$ = Tooth width, $d_2$ = Pitch diameter of worm gear, $d_w$ = Pitch diameter of worm

Table 20-3 The Properties that Lubricant Should Possess

| No. | Properties | Description |
|---|---|---|
| 1 | Correct and Proper Viscosity | Lubricant should maintain a proper viscosity to form a stable oil film at the specified temperature and speed of operation. |
| 2 | Antiscoring Property | Lubricant should have the property to prevent the scoring failure of tooth surface while under high-pressure of load. |
| 3 | Oxidization and Heat Stability | A Good lubricant should nor oxidized easily and must perform in moist and high-temperature environment for long duration. |
| 4 | Water Antiaffinity Property | Moisture tends to condense due to temperature change, when the gears are stopped. The lubricant should have the property of isolating moisture and water from lubricant. |
| 5 | Antifoam Property | If the lubricant foams under agitation, it will not provide a good oil film. Antifoam property is a vital requirement. |
| 6 | Anticorrosion Property | Lubrication should be neutral and stable to prevent corrosion from rust that may mix into the oil. |

Table 20-4 ISO Viscosity Grade of Industrial Lubricant (JIS K 2001)

| ISO Viscosity Grade | | Kinematic Viscosity Center Value $10^{-6}m^2/s$ (cSt) (40°C) | Kinematic Viscosity Range $10^{-6}m^2/s$ (cSt) (40°C) | | | |
|---|---|---|---|---|---|---|
| ISO VG | 2 | 2.2 | More Than | 1.98 | and less than | 2.42 |
| ISO VG | 3 | 3.2 | More Than | 2.88 | and less than | 3.52 |
| ISO VG | 5 | 4.6 | More Than | 4.14 | and less than | 5.06 |
| ISO VG | 7 | 6.8 | More Than | 6.12 | and less than | 7.48 |
| ISO VG | 10 | 10 | More Than | 9.00 | and less than | 11.0 |
| ISO VG | 15 | 15 | More Than | 13.5 | and less than | 16.5 |
| ISO VG | 22 | 22 | More Than | 19.8 | and less than | 24.2 |
| ISO VG | 32 | 32 | More Than | 28.8 | and less than | 35.2 |
| ISO VG | 46 | 46 | More Than | 41.4 | and less than | 50.6 |
| ISO VG | 68 | 68 | More Than | 61.2 | and less than | 74.8 |
| ISO VG | 100 | 100 | More Than | 90.0 | and less than | 110 |
| ISO VG | 150 | 150 | More Than | 135 | and less than | 165 |
| ISO VG | 220 | 220 | More Than | 198 | and less than | 242 |
| ISO VG | 320 | 320 | More Than | 288 | and less than | 352 |
| ISO VG | 460 | 460 | More Than | 414 | and less than | 506 |
| ISO VG | 680 | 680 | More Than | 612 | and less than | 748 |
| ISO VG | 1000 | 1000 | More Than | 900 | and less than | 1100 |
| ISO VG | 1500 | 1500 | More Than | 1350 | and less than | 1650 |

Table 20-5 Industrial Gear Oil

| Types of Industrial Gear Oil | | Usage |
|---|---|---|
| Class One | ISO VG 32<br>ISO VG 46<br>ISO VG 68<br>ISO VG 100<br>ISO VG 150<br>ISO VG 220<br>ISO VG 320<br>ISO VG 460 | Mainly used in a general and lightly loaded enclosed gear system |
| Class Two | ISO VG 68<br>ISO VG 100<br>ISO VG 150<br>ISO VG 220<br>ISO VG 320<br>ISO VG 460<br>ISO VG 680 | Mainly used in a general medium to heavily loaded enclosed gear system |

Table 20-6 NLGl Viscosity Grades

| NLGl No. | Viscosity Range | State | Application |
|---|---|---|---|
| No. 000<br>No. 00<br>No. 0<br>No. 1<br>No. 2<br>No. 3<br>No. 4<br>No. 5<br>No. 6 | 445 … 475<br>400 … 430<br>335 … 385<br>310 … 340<br>265 … 395<br>220 … 250<br>175 … 205<br>130 … 165<br>85 … 115 | Semi-liquid<br>Semi-liquid<br>Very soft paste<br>Soft paste<br>Medium firm paste<br>Semi-hard paste<br>Hard paste<br>Very hard paste<br>Very hard paste | For Central Lubrication System<br>For Automobile Chassis<br>For Ball & Roller Bearing, General Use<br>For Automobile Wheel Bearing<br>For Sleeve Bearing (Pillow Block) |

Table 20-7 AMGA Viscosity Grades

| AGMA No. of Gear Oil | | ISO Viscosity Grades |
|---|---|---|
| R & O Type | EP Type | |
| 1 | | VG 46 |
| 2 | 2 EP | VG 68 |
| 3 | 3 EP | VG 100 |
| 4 | 4 EP | VG 150 |
| 5 | 5 EP | VG 220 |
| 6 | 6 EP | VG 320 |
| 7 7 comp | 7 EP | VG 460 |
| 8 8 comp | 8 EP | VG 680 |
| 8A comp | | VG 1000 |
| 9 | 9EP | VG 1500 |

Table 20-8 Recommended Lubricants by AGMA

| Gear Type | | Size of Gear Equipment (mm) | | Ambient temperature °C | |
|---|---|---|---|---|---|
| | | | | -10 … 16 | 10 … 52 |
| | | | | AGMA No. | |
| Parallel Shaft System | Single Stage Reduction | Center Distance (Output Side) | Less than 200 | 2 to 3 | 3 to 4 |
| | | | 200 … 500 | 2 to 3 | 4 to 5 |
| | | | more than 500 | 3 to 4 | 4 to 5 |
| | Double Stage Reduction | | Less than 200 | 2 to 3 | 3 to 4 |
| | | | 200 … 500 | 3 to 4 | 4 to 5 |
| | | | More than 500 | 3 to 4 | 4 to 5 |
| | Triple Stage Reduction | | Less than 200 | 2 to 3 | 3 to 4 |
| | | | 200 … 500 | 3 to 4 | 4 to 5 |
| | | | More than 500 | 4 to 5 | 5 to 6 |
| Planetary Gear System | | Outside Diameter of Gear Casing | Less than 400 | 2 to 3 | 3 to 4 |
| | | | More than 400 | 3 to 4 | 4 to 5 |
| Straight and Spiral Bevel Gearing | | Cone Distance | Less than 300 | 2 to 3 | 4 to 5 |
| | | | More than 300 | 3 to 4 | 5 to 6 |
| Gearmotor | | | | 2 to 3 | 4 to 5 |
| High Speed Gear Equipment | | | | 1 | 2 |