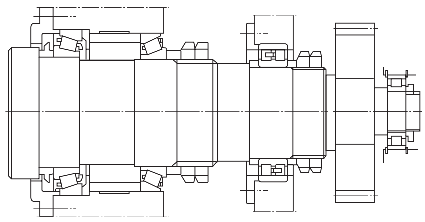
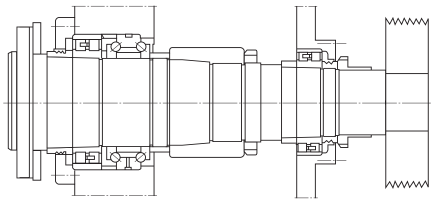
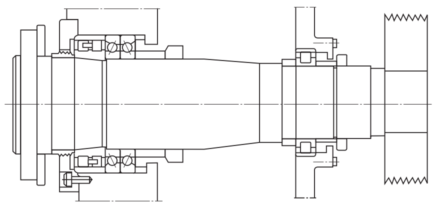
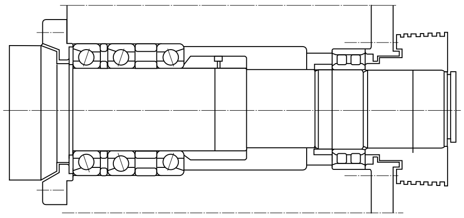
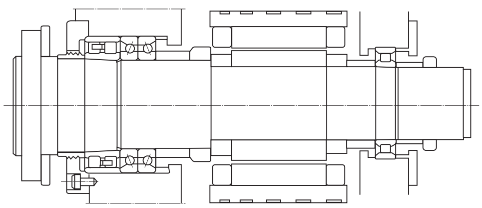
5. Bearing Arrangements and Structures of Bearings for Main Spindles

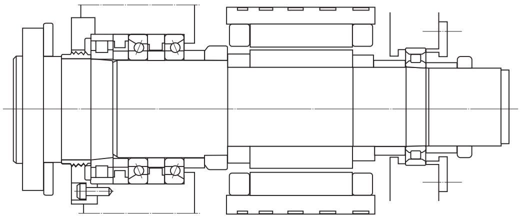
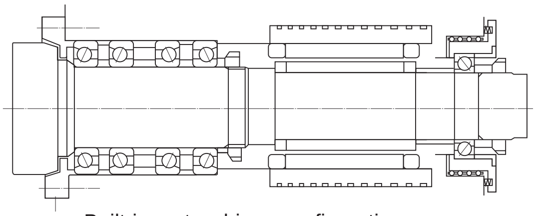
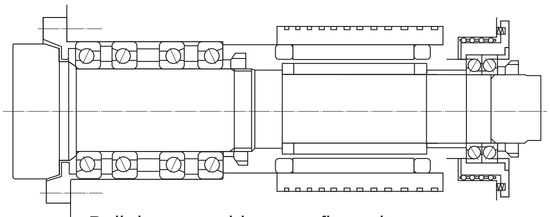
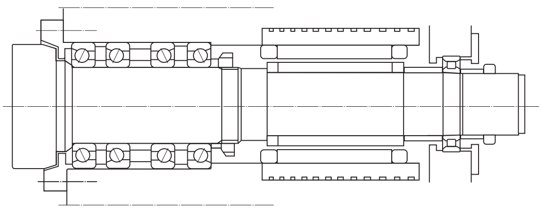
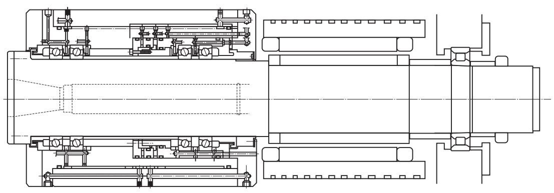
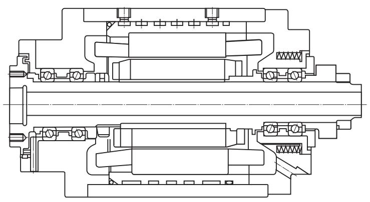
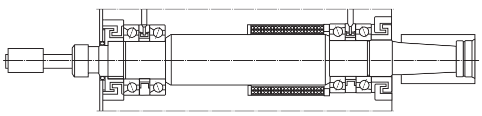
① Bearing Arrangement for Main Spindles

Typical examples of bearing arrangements for main spindles of machine tools are summarized in **Table 5.1**.

An optimal bearing arrangement must be determined through considerations about the properties required of a main spindle in question (maximum speed, radial and axial rigidities, main spindle size, required accuracies, lubrication system, etc.). Recently, an increasing number of new machine tool models incorporate built-in motor type main spindles. However, heat generation on a built-in motor can affect the accuracies of main spindle and performance of lubricant, a bearing for a main spindle should be selected very carefully.

Table 5.1 Typical examples of bearing arrangements for main spindles

Bearing arrangement for main spindle	Bearing type	Typical applications
 Gear-driven configuration	[Type Ⅰ] Tapered roller bearing + Tapered roller bearing + (Double-row cylindrical roller bearing)	Large turning machine (Oil country lathe) General-purpose turning machine Typical lubrication <Grease lubrication>
 Belt-driven configuration	[Type Ⅱ] Double-row cylindrical roller bearing + Double-direction angular contract hrust ball bearing + Double-row cylindrical roller bearing	CNC turning machine Machining center Boring machine Milling machine Typical lubrication <Grease lubrication>
 Belt-driven configuration	[Type Ⅲ] Double-row cylindrical roller bearing + High-speed duplex angular contact ball bearing for axial load + Single-row cylindrical roller bearing NOTE: high-speed variant of type Ⅱ	CNC turning machine Machining center Milling machine Typical lubrication <Grease lubrication>
 Belt-driven configuration	[Type Ⅳ] Duplex angular contact ball bearing (DBT arrangement) + Double-row cylindrical roller bearing NOTE: high-speed variant of type Ⅱ or Ⅲ	CNC turning machine Machining center Milling machine Typical lubrication <Grease lubrication>
 Built-in motor-driven configuration	[Type Ⅴ] Double-row cylindrical roller bearing + High-speed duplex angular contact ball bearing for axial load + Single-row cylindrical roller bearing NOTE: high-speed variant of type Ⅲ with built-in motor-driven configuration	CNC turning machine Machining center Milling machine Typical lubrication <Grease lubrication> <Air-oil lubrication>

Bearing arrangement for main spindle	Bearing type	Typical applications
 Built-in motor-driven configuration	[Type Ⅵ] Single-row cylindrical roller bearing + High-speed duplex angular contact ball bearing for axial load + Single-row cylindrical roller bearing NOTE: high-speed variant of type Ⅴ	CNC turning machine Machining center Typical lubrication <Grease lubrication> <Air-oil lubrication>
 Built-in motor-driven configuration	[Type Ⅶ] Duplex angular contact ball bearing (DTBT arrangement) + Single-row angular contact roller bearing (w/ ball slide) NOTE: super high-speed variant	Machining center <vertical> Typical lubrication <Grease lubrication> <Air-oil lubrication>
 Built-in motor-driven configuration	[Type Ⅷ] Duplex angular contact ball bearing (DTBT arrangement) + Duplex angular contact roller bearing (w/ ball slide) NOTE: super high-speed variant	Machining center <vertical> Typical lubrication <Grease lubrication> <Air-oil lubrication>
 Built-in motor-driven configuration	[Type Ⅸ] Duplex angular contact ball bearing (DTBT arrangement) + Single-row cylindrical roller bearing NOTE: super high-speed variant	Machining center Typical lubrication <Grease lubrication> <Air-oil lubrication>
 Built-in motor-driven configuration	[Type Ⅹ] Adjustable preload bearing unit + Duplex angular contact ball bearing (DBT arrangement) + Single-row cylindrical roller bearing NOTE: high-rigidity/super high-speed variant	Machining center Typical lubrication <Air-oil lubrication>
 Built-in motor-driven configuration	[Type Ⅺ] Duplex angular contact ball bearing (DT arrangement) + Duplex angular contact ball bearing (DT arrangement)	Machining center Small turning machine Grinding machine Typical lubrication <Grease lubrication> <Air-oil lubrication>
 Belt-driven configuration	[Type Ⅻ] Duplex angular contact ball bearing (DT arrangement) + Duplex angular contact ball bearing (DT arrangement)	Grinding machine Typical lubrication <Grease lubrication> <Air-oil lubrication> <Oil-mist lubrication>

② Bearing selection based on bearing arrangement for main spindle

An optimal bearing product that best suits your application is selected by referring to the bearing selection table in **Table 5.2** that contains the possible bearing arrangements for main spindles.

- The free side and fix side are designated.
- The bearing arrangement type (I to XII) on the free or fix side is selected.
- A set of bearing specifications applicable to the selected arrangement type is selected.
- A lubrication system suitable for the selected bearing specifications is chosen.

A product group that satisfies the above-mentioned considerations is selected.

Table 5.2 Bearing selection table

<table>
<tr><th rowspan="2">Fix side</th><th rowspan="2">Free side</th><th rowspan="2">Bearing specifications</th><th rowspan="2">Lubrication system</th><th colspan="2">Applicable product groups/ULTAGE</th><th rowspan="2">Considerations for selection procedure</th></tr>
<tr><th colspan="2">Steel balls/ceramic balls</th></tr>
<tr><td rowspan="5">Duplex angular contact ball bearing or adjustable preload bearing mechanism
+
Duplex angular contact ball bearing

Bearing arrangement [Type Ⅳ,Ⅵ,Ⅶ, Ⅸ, ⅩⅠ, or ⅩⅡ]</td><td rowspan="5">Single-row angular contact ball bearing or duplex angular contact ball bearing (w/ ball bush)

Bearing arrangement [Type Ⅶ, Ⅷ, ⅩⅠ, or ⅩⅡ]</td><td rowspan="5">Angular contact ball bearing for radial load

Contact angle 30˚ or smaller</td><td>Grease lubrication</td><td>Sealed</td><td>【15˚】70CD/5S-70CD
79CD/5S-79CD
【25˚】70AD/5S-70AD
79AD/5S-79AD
【15˚, 20˚, 25˚,】
2LA-BNS9/5S-2LA/BNS9
2LA-BNS0/5S-2LA/BNS0</td><td rowspan="11">Bearing selection
① High-speed performance (general)
High ⇔ Low
Contact angle 15˚, 20˚, 25˚, 30˚

② Rigidity
・Radial rigidity
High ⇔ Low
Contact angle 15˚, 20˚, 25˚, 30˚
・Axial rigidity
Low ⇔ High
Contact angle 15˚, 20˚, 25˚, 30˚, 40˚, 60˚

・Complex rigidity (radial and axial)

High (4-row)
Medium (3-row)
Low (2-row)

③ Recommended arrangement
4-row (DTBT) or 2-row (DB)

④ Recommended lubrication specifications
Standard main spindle : Grease
High-speed main spindle : Air-oil
Low-noise : Grease or eco-friendly air-oil

⑤ Presence of cooling jacket around the bearing.
In particular, grease lubrication is recommended.</td></tr>
<tr><td>Air-oil lubrication / Grease lubrication</td><td></td><td>【15˚】78C/5S-78C
【15˚, 25˚, 30˚,】
79U/5S-79U
70U/5S-70U
72/5S-72
【15˚, 20˚, 25˚,】
2LA-HSE9/5S-2LA-HSE9
2LA-HSE0/5S-2LA-HSE0</td></tr>
<tr><td>Air-oil lubrication / Grease lubrication</td><td></td><td>Grinding machine main spindle/ motor shaft series
【15˚】BNT9/5S-BNT9
BNT0/5S-BNT0
BNT2/5S-BNT2</td></tr>
<tr><td>Air-oil lubrication</td><td></td><td>Super high-speed/dedicated air-oil lubrication series
【25˚】5S-2LA-HSF0</td></tr>
<tr><td>Air-oil lubrication</td><td></td><td>Eco-friendly type
【15˚, 20˚, 25˚,】
2LA-HSL9/5S-2LA-HSL9
2LA-HSL0/5S-2LA-HSL0
5S-2LA-HSFL0</td></tr>
<tr><td rowspan="5">Cylindrical roller bearing
+
Duplex angular contact ball bearing

Bearing arrangement [Type Ⅱ, Ⅲ, Ⅴ or Ⅵ]</td><td rowspan="3">Double-row cylindrical roller bearing or single-row cylindrical roller bearing

Bearing arrangement [Type Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ, Ⅵ, Ⅸ, or Ⅹ]</td><td rowspan="3">Cylindrical roller bearing</td><td>Air-oil lubrication / Grease lubrication</td><td>Double-row</td><td>NN30/NN30K
NN30HS/NN30HSK
NN49/NN49K
NNU49/NNU49K</td></tr>
<tr><td>Air-oil lubrication / Grease lubrication</td><td rowspan="2">Single-row</td><td>N10HS/N10HSK
N10HSR/N10HSRK</td></tr>
<tr><td>Air-oil lubrication</td><td>Eco-friendly type
N10HSL/N10HSLK</td></tr>
<tr><td rowspan="3"></td><td>Angular contact ball bearing for axial load

Contact angle less than 60˚</td><td>Air-oil lubrication / Grease lubrication</td><td rowspan="2"></td><td rowspan="2">【30˚】HTA9A/5S-HTA9A
HTA0A/5S-HTA0A
【40˚】HTA9/5S-HTA9
HTA0/5S-HTA0
【60˚】5629/5S-5629M
5620/5S-5620M</td></tr>
<tr><td>Thrust contract ball bearing</td><td>Grease lubrication</td></tr>
<tr><td>Tapered roller bearing
+
Cylindrical roller bearing

Bearing arrangement [Type Ⅰ]</td><td>Cylindrical roller bearing</td><td>Oil lubrication / Grease lubrication</td><td></td><td>329XU
4T-320X/320XU
Inch series tapered roller bearing</td></tr>
</table>

③ Adjustable preload bearing unit

Higher speed has been increasingly needed for main spindles of machine tools, typically, machining centers, and, the maximum $d_m n$ value (pitch circle diameter across rolling elements d_m [mm] multiplied by speed n [min^{-1}]) of main spindles that are air-oil lubricated reach 250 to 380 × 10^4. At the same time, main spindles of machine tools are required of higher rigidity from a lower speed to a higher speed. Therefore, the bearings for main spindles must be capable of high-speed operation and high rigidity by optimal preloading.

As a bearing preloading system for satisfying both high speed and high rigidity, a fixed preload (spring preload) system is usually employed. To be able to increase the rigidity of main spindle, a spindle unit that can adjust a fixed position preload at an arbitrary speed appears to be advantageous.

The NTN Adjustable preload bearing unit is a high-speed high-rigidity unit that is capable to adjust from a particular fixed position preload to another fixed position preload.

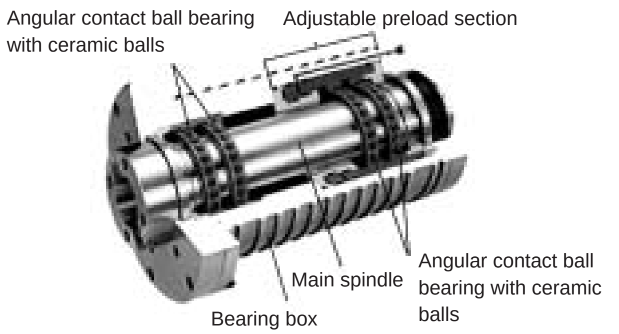


Fig. 5.1 Adjustable preload bearing unit

A typical main spindle incorporating the NTN Adjustable preload bearing unit is illustrated in **Fig. 5.1**. By hydraulically shifting the position of the preload adjustable sleeve situated in the rear bearing section (rear position in this diagram) in steps to alter the preload in the bearing.

A spindle incorporating a 3-step adjustable preload bearing unit is illustrated in **Fig. 5.2**. The sleeve in the adjustable preload section comprises the hydraulic pressure chambers A and B, and the spiral groove for sliding motion. By exerting and removing oil pressure to and from the hydraulic pressure chambers A and B on the adjustable preload sleeve, the preload on the bearing can be adjusted to one of the three settings Ñthe high preload, medium preload and low preload. To achieve an instantaneous and reliable adjustable preload operation, high pressure oil (whose pressure is same as that for the hydraulic pressure chambers) is fed into the spiral groove that is formed on the outer circumference of the sleeve so as to move the sleeve smoothly.

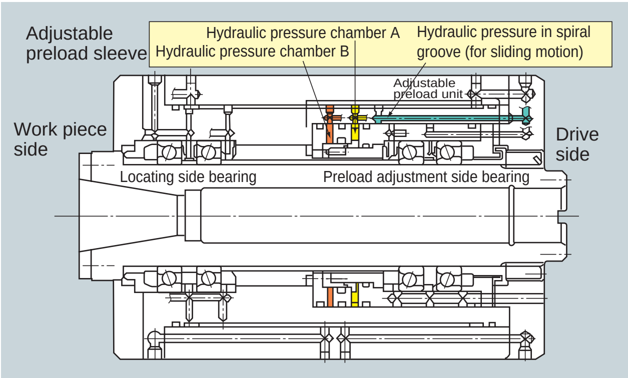


Fig. 5.2 Typical spindle configuration incorporating 3-step Adjustable preload type bearing unit

■ Operating mechanism

Hydraulic pressure ON/OFF status for the hydraulic pressure chambers in the three preloading conditions as well as the associated motions of adjustable preload sleeve are illustrated in **Fig. 5.3**.

- **Low speed range (high preload): hydraulic pressure is fed into the hydraulic pressure chamber A.**
  The component ① moves to the right by the preset clearance L_1 to come into contact with the component ③, thereby the axial clearance on the bearing becomes δ_1.
- **Medium speed range (medium preload): hydraulic pressure is fed into the hydraulic pressure chamber B.**
  The components ① and ② move to the right by the preset clearance L_2 to cause the component ② to come into contact with the component ④ , thereby the axial clearance on the bearing becomes δ_2.
- **High speed range (low preload): no hydraulic pressure is fed into the hydraulic pressure chambers A and B.**
  The components ① and ② return to the left by the reaction force of bearing to cause the component ② to come into contact with the component ⑤, thereby the axial clearance on the bearing returns to the initial setting of δ_3.

NOTE: The return motion of the components ① and ② is achieved by the reaction force of bearing or a separately provided spring.

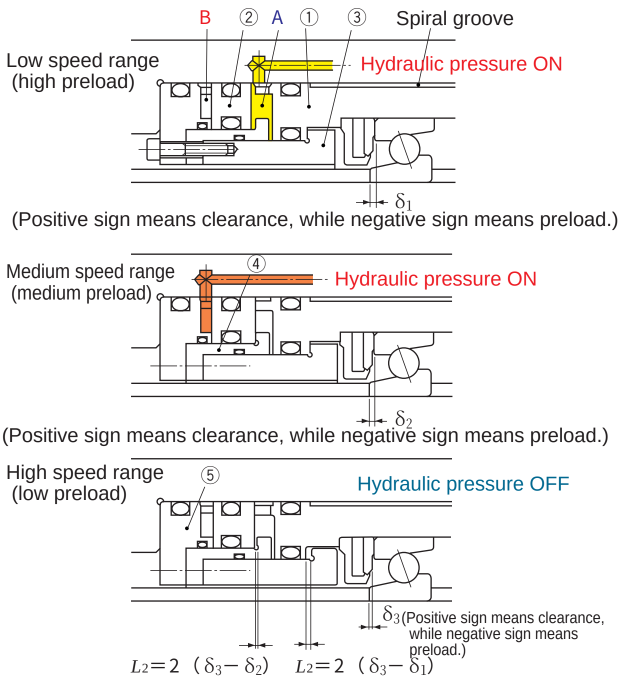


Fig. 5.3 Operating mechanism of Adjustable preload

④ Bearing jacket cooling system

With a built-in motor drive system, a main spindle is directly driven by a motor and is therefore suitable for rapid acceleration or deceleration. However, this system can be adversely affected by temperature rise and is oil-cooled with a spiral groove for cooling that is provided around the housing outside the motor and the outer surface of motor.

If heat generated on the motor affects the bearing, overheating of the bearing as well as degradation of grease can occur -- a problem which must be strictly avoided. When designing a cooling system with a spiral groove situated around the housing (called "jacket cooling"), the following considerations must be exercised.

■Considerations about cooling of jacket

With the bearing arrangement shown in **Figs. 5.4** and **5.5**, comprising a double-row cylindrical roller bearing and an angular contact ball bearing for bearing an axial load, the cooling groove on the jacket in **Fig. 5.4** starts at around an area above the angular contact ball bearing for bearing an axial load, and appears not to cool the double-row cylindrical roller bearing effectively.

(The fit of outside surface of outer ring of angular contact ball bearing for bearing an axial load into the bore of housing is clearance-fit -- the bearing is not directly in contact with the housing.) In the configuration in **Fig. 5.5**, the cooling groove extends to above the double-row cylindrical roller bearing, and appears to cool not only the angular contact ball bearing for bearing an axial load but also the double-row cylindrical roller bearing effectively.

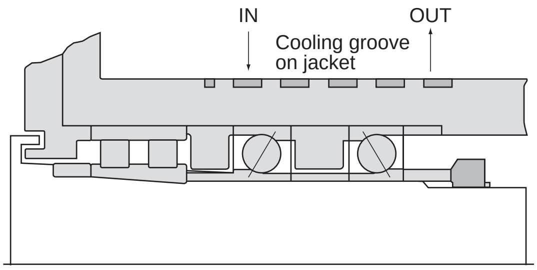


Fig. 5.4 Inadequate cooling groove on jacket

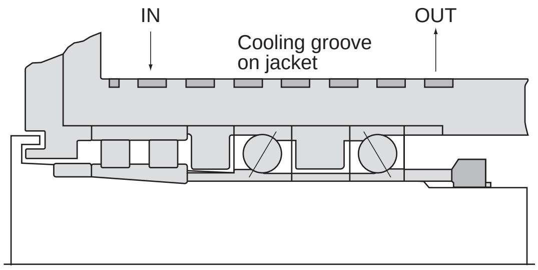


Fig. 5.5 Adequate cooling groove on jacket