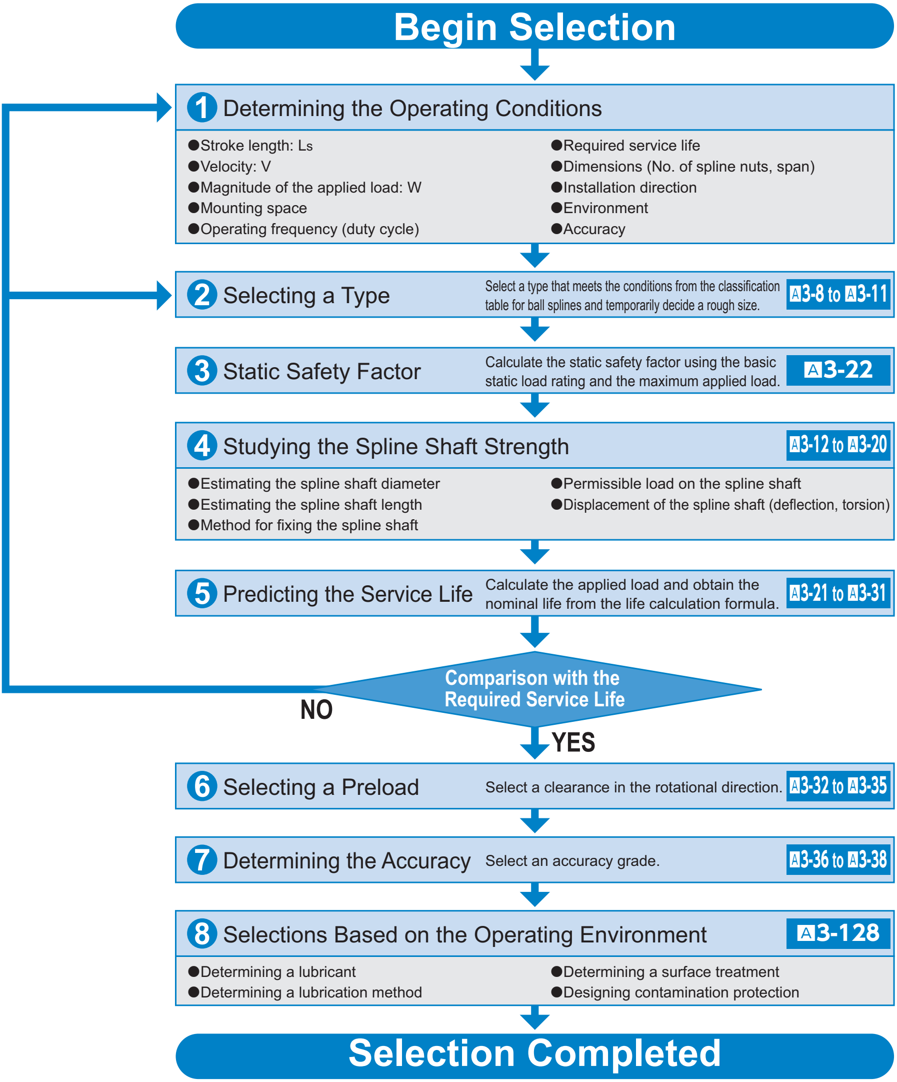
Flowchart for Selecting a Ball Spline

Ball Spline Selection Procedure

The following is a flowchart to reference when selecting a ball spline.



Begin Selection

① Determining the Operating Conditions

- Stroke length: Ls
- Velocity: V
- Magnitude of the applied load: W
- Mounting space
- Operating frequency (duty cycle)
- Required service life
- Dimensions (No. of spline nuts, span)
- Installation direction
- Environment
- Accuracy

② Selecting a Type

Select a type that meets the conditions from the classification table for ball splines and temporarily decide a rough size. A3-8 to A3-11

③ Static Safety Factor

Calculate the static safety factor using the basic static load rating and the maximum applied load. A3-22

④ Studying the Spline Shaft Strength A3-12 to A3-20

- Estimating the spline shaft diameter
- Estimating the spline shaft length
- Method for fixing the spline shaft
- Permissible load on the spline shaft
- Displacement of the spline shaft (deflection, torsion)

⑤ Predicting the Service Life

Calculate the applied load and obtain the nominal life from the life calculation formula. A3-21 to A3-31

Comparison with the Required Service Life

⑥ Selecting a Preload

Select a clearance in the rotational direction. A3-32 to A3-35

⑦ Determining the Accuracy

Select an accuracy grade. A3-36 to A3-38

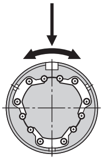
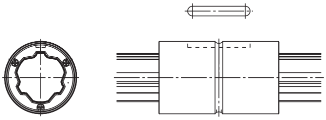
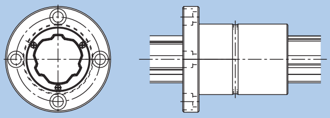
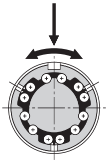
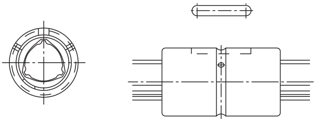
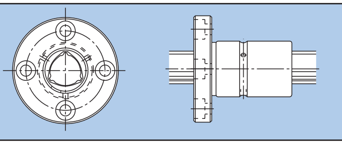
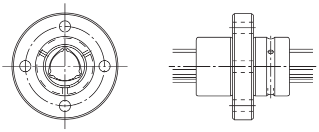
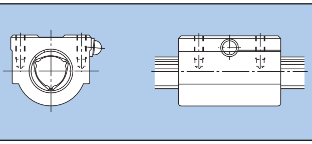
⑧ Selections Based on the Operating Environment A3-128

- Determining a lubricant
- Determining a lubrication method
- Determining a surface treatment
- Designging contamination protection

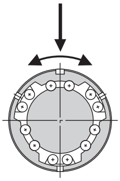
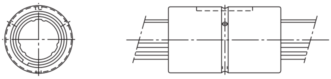
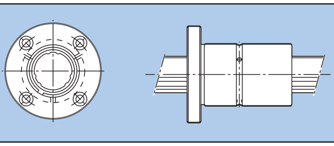
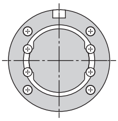
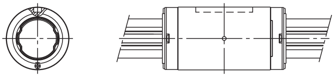
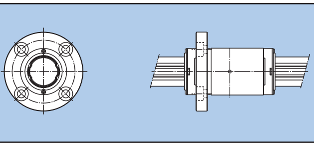
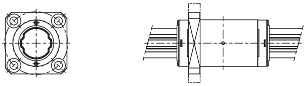
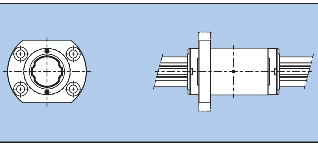
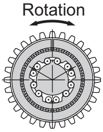
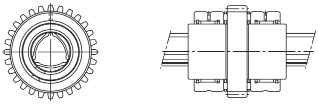
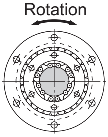
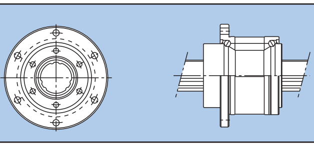
Selection Completed

Selecting a Type

There are three types of ball spline: high-torque, medium-torque, and rotary. You can choose a type according to the intended use. In addition, a wide array of spline nut shapes are available for each type, enabling the user to choose a desired shape according to the mounting or service requirements.

Classification		Model	Shape	Shaft diameter
High-torque Caged Ball types		Model SLS Model SLS-L		Nominal shaft diameter 25 mm to 100 mm
		Model SLF		Nominal shaft diameter 25 mm to 100 mm
High-torque types		Model LBS Model LBST		Nominal shaft diameter 15 mm to 150 mm
		Model LBF		Nominal shaft diameter 15 mm to 100 mm
		Model LBR		Nominal shaft diameter 15 mm to 100 mm
		Model LBH		Nominal shaft diameter 15 mm to 50 mm

Dimensional table	Structure and features	Major applications
A3-46	● Making the shape more circular has significantly improved torsion and flexural rigidity compared to conventional high-torque spline shafts. ● Models SLS and SLF adopt Caged Ball technology to enable sustained circulating motion of evenly spaced balls and achieve high-speed response, improving the takt time of machines. ● Models SLS and SLF adopt Caged Ball technology to eliminate collision and mutual friction between balls and realize low noise, reduced running sound, and low particle generation. ● Models SLS and SLF adopt Caged Ball technology to substantially increase grease retention and achieve long-term maintenance-free operation. ● Models SLS and SLF adopt Caged Ball technology and a new circulation method, thus achieving stable and smooth motion with small rolling fluctuation.	● Columns and arms of industrial robots ● Automatic loaders ● Transfer machines ● Automatic conveyance systems ● Tire molding machines ● Spindles of spot-welding machines ● Guide shafts of high-speed automatic coating machines ● Riveting machines ● Wire winders ● Work heads of electric discharge machines ● Spindle drive shafts of grinding machines ● Speed gears ● Precision indexing machines
A3-48		
A3-60	● The spline shaft has three crests formed equidistantly every 120°. Six rows of balls (two for each crest) are arranged to hold the crests from both sides. The angular-contact design of the ball contact areas allows the even application of an appropriate preload. ● Since the balls circulate inside the spline nut, the outer dimensions of the spline nut are compactly designed. ● Even under a large preload, smooth straight motion is achieved. ● Since the contact angle is large (45°) and the displacement is minimal, high rigidity is achieved. ● No angular backlash occurs. ● These models are capable of transmitting a large torque.	
A3-64		
A3-66		
A3-68		

Classification		Model	Shape	Shaft diameter
Medium-torque types		Model LT		Nominal shaft diameter 4 mm to 100 mm
		Model LF		Nominal shaft diameter 6 mm to 60 mm
		Model LT-X		Nominal shaft diameter 4 mm to 30 mm
		Model LF-X		Nominal shaft diameter 4 mm to 30 mm
		Model LFK-X		Nominal shaft diameter 5 mm to 30 mm
		Model LFH-X		Nominal shaft diameter 5 mm to 30 mm
Rotary types		Model LBG Model LBGT		Nominal shaft diameter 20 mm to 85 mm
		Model LTR-A Model LTR		Nominal shaft diameter 8 mm to 60 mm

Dimensional table	Structure and features	Major applications	
A3-82	• The spline shaft has two to three crests. On both sides of each crest, two rows (four to six rows in total) of balls are arranged to hold the crest from both sides. This design allows an appropriate preload to be evenly applied. • The contact angle of 20° and an appropriate preload level eliminate angular backlash, providing high-torque moment rigidity.	• Die-set shafts and similar applications requiring straight motion under a heavy load • Loading systems and similar applications requiring rotation to a given angle at a fixed position • Automatic gas-welding machine spindles and similar applications requiring a whirl-stop on one shaft	• Columns and arms of industrial robots • Spot-welding machines • Riveting machines • Book-binding machines • Automatic fillers • XY recorderss • Automatic spinners • Optical measuring instruments
A3-84			
A3-86	• The length and external diameter of the LT-X ball spline's outer cylinder are the same as those of an LM-series linear bushing, meaning the nut can be replaced with a linear bushing.		
A3-88	• The length and external diameter of the LF-X ball spline's nut are the same as those of the Model LMF linear bushing, meaning the nut can be replaced with a linear bushing.		
A3-90	• The Model LFK-X is a lightweight and compact product designed with a lower core height than the Model LF-X.		
A3-92	• The Model LFH-X is a lightweight and compact product designed with a lower core height than the Model LFK-X.		
A3-104	• These models are unit types that have the same contact structure as Model LBS. The flange circumference on the spline nut is machined to have gear teeth, and radial and thrust needle bearings are compactly combined on the circumference of the spline nut.	• Speed gears for high torque transmission	
A3-116	• These are lightweight and compact types based on Model LT, but their spline nut circumference is machined to have angular-contact type ball raceways to accommodate support bearings.	• Z axes of SCARA robots • Wire winders	

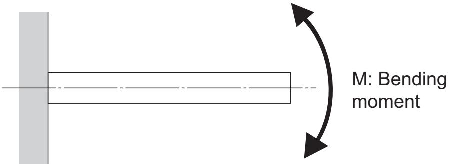
Studying the Spline Shaft Strength

The spline shaft of the ball spline is a compound shaft capable of receiving a radial load and torque. When the load and torque are large, the spline shaft strength must be taken into account.

Spline Shaft Receiving a Bending Load

When a bending load is applied to the spline shaft of a ball spline, obtain the spline shaft diameter using equation (1) below.

$$M = \sigma \cdot Z \quad \text{and} \quad Z = \frac{M}{\sigma} \quad \cdots\cdots\cdots\cdots(1)$$



M : Maximum bending moment acting on the spline shaft (N·mm)

σ : Permissible bending stress of the spline shaft (98 N/mm^2)

Z : Section modulus of the spline shaft (mm^3)

(see Table 3 on **A3-17**, Table 4 on **A3-18**, Table 5 on **A3-19**, and Table 6 on **A3-20**)

Reference: Section Modulus (Solid Circle)

$$Z = \frac{\pi \cdot d^3}{32}$$

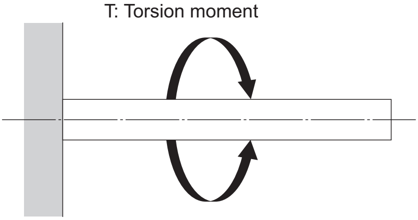
Z : Section modulus (mm^3)

d : Shaft outer diameter (mm)

Spline Shaft Receiving a Torsion Load

When a torsion load is applied on the spline shaft of a ball spline, obtain the spline shaft diameter using equation (2) below.

$$T = \tau_a \cdot Z_P \quad \text{and} \quad Z_P = \frac{T}{\tau_a} \quad \cdots\cdots\cdots\cdots(2)$$



T : Maximum torsion moment (N·mm)

τ_a : Permissible torsion stress of the spline shaft (49 N/mm^2)

Z_p : Polar section modulus of the spline nut (mm^3)

(see Table 3 on **A3-17**, Table 4 on **A3-18**, Table 5 on **A3-19**, and Table 6 on **A3-20**)

Reference: Section Modulus (Solid Circle)

$$Z_P = \frac{\pi \cdot d^3}{16}$$

Z_P : Section modulus (mm^3)

d : Shaft outer diameter (mm)

When the Spline Shaft Simultaneously Receives a Bending Load and a Torsion Load

When the spline shaft of a ball-spline receives a bending load and a torsion load simultaneously, calculate two separate spline shaft diameters: one for the equivalent bending moment (M_e) and the other for the equivalent torsion moment (T_e). Then, use the greater value as the spline shaft diameter.

Equivalent bending moment

$$M_e = \frac{M+\sqrt{M^2+T^2}}{2} = \frac{M}{2}\left\{1+\sqrt{1+\left(\frac{T}{M}\right)^2}\right\} \cdots\cdots\cdots\cdots(3)$$

$M_e = \sigma \cdot Z$

Equivalent torsion moment

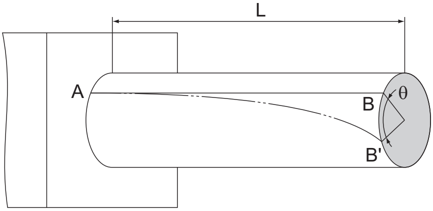
$$T_e = \sqrt{M^2+T^2} = M \cdot \sqrt{1+\left(\frac{T}{M}\right)^2} \cdots\cdots\cdots\cdots(4)$$

$T_e = \tau_a \cdot Z_p$

Torsional Rigidity of the Spline Shaft

The torsional rigidity of the spline shaft is expressed as a torsion angle per meter of shaft length. Its value should be limited within 1°/4.

$$\theta = 57.3 \times \frac{T \cdot L}{G \cdot I_P} \cdots\cdots\cdots\cdots(5)$$



$$\text{Rigidity of the shaft} = \frac{\text{Torsion angle}}{\text{Unit length}} = \frac{\theta \cdot \ell}{L} < \frac{1^\circ}{4}$$

θ : Torsion angle (°)

L : Spline shaft length (mm)

G : Transverse elastic modulus (7.9×10^4 N/mm^2)

ℓ : Unit length (1,000 mm)

I_p : Polar moment of inertia (mm^4)

(see Table 3 on **A3-17**, Table 4 on **A3-18**, Table 5 on **A3-19**, and Table 6 on **A3-20**)

Deflection and Deflection Angle of the Spline Shaft

The deflection and deflection angle of the ball spline shaft need to be calculated using equations that meet the relevant conditions. Table 1 and Table 2 represent these conditions and the corresponding equations.

Table 3 on **A3-17**, Table 4 on **A3-18**, Table 5 on **A3-19**, and Table 6 on **A3-20** show the section modulus of the spline shaft (Z) and the second moment of area (I). Using the Z and I values from the tables, the strength and displacement (deflection) of a typical ball spline within each model type can be obtained.

Table 1: Deflection and Deflection Angle Equations

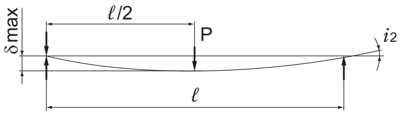
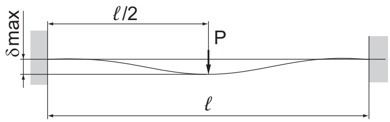
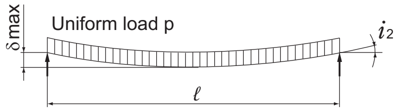
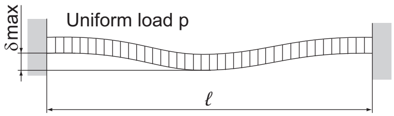
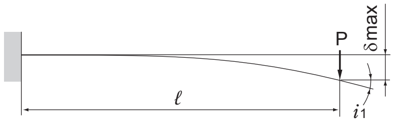
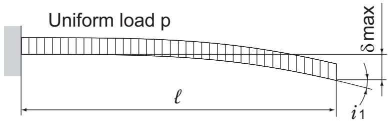
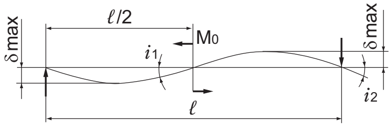
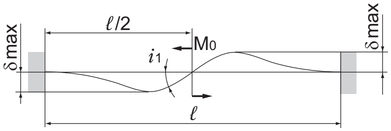
Support method	Operating conditions	Deflection equation	Deflection angle equation
Both ends free		$\delta_{max} = \frac{P\ell^3}{48EI}$	$i_1 = 0$ $i_2 = \frac{P\ell^2}{16EI}$
Both ends fastened		$\delta_{max} = \frac{P\ell^3}{192EI}$	$i_1 = 0$ $i_2 = 0$
Both ends free		$\delta_{max} = \frac{5p\ell^4}{384EI}$	$i_2 = \frac{p\ell^3}{24EI}$
Both ends fastened		$\delta_{max} = \frac{p\ell^4}{384EI}$	$i_2 = 0$

Table 2: Deflection and Deflection Angle Equations

Support method	Operating conditions	Deflection equation	Deflection angle equation
One end fastened		$\delta_{max} = \frac{P\ell^3}{3EI}$	$i_1 = \frac{P\ell^2}{2EI}$ $i_2 = 0$
One end fastened		$\delta_{max} = \frac{p\ell^4}{8EI}$	$i_1 = \frac{p\ell^3}{6EI}$ $i_2 = 0$
Both ends free		$\delta_{max} = \frac{\sqrt{3}M_0\ell^2}{216EI}$	$i_1 = \frac{M_0\ell}{12EI}$ $i_2 = \frac{M_0\ell}{24EI}$
Both ends fastened		$\delta_{max} = \frac{M_0\ell^2}{216EI}$	$i_1 = \frac{M_0\ell}{16EI}$ $i_2 = 0$

δ_{max}: Maximum deflection (mm)
M_0: Moment (N·mm)
ℓ: Span (mm)
I: Geometric moment of inertia (mm^4)
i_1: Deflection angle at loading point
i_2: Deflection angle at supporting point
P: Concentrated load (N)
p: Uniform load (N/mm)
E: Modulus of longitudinal elasticity 2.06×10^5 (N/mm^2)

Critical Speed of the Spline Shaft

When a ball spline shaft is used to transmit power while rotating, as the rotational speed of the shaft increases, the rotation cycle nears the natural frequency of the spline shaft. It may cause resonance and eventually result in loss of function. Therefore, the maximum rotational speed of the shaft must be limited to below the critical speed that does not cause resonance.
The critical speed of the spline shaft is obtained using equation (6).
(0.8 is multiplied as a safety factor.)

If the shaft's rotation cycle exceeds or nears the resonance point during operation, it is necessary to reconsider the spline shaft diameter.

● Critical Speed

$$N_c = \frac{60\lambda^2}{2\pi \cdot \ell_b^2} \cdot \sqrt{\frac{E \times 10^3 \cdot I}{\gamma \cdot A}} \times 0.8 \quad \cdots (6)$$

N_c : Critical speed (min^{-1})

ℓ_b : Distance between two mounting surfaces (mm)

E : Young's modulus (2.06×10^5 N/mm^2)

I : Minimum geometric moment of inertia of the shaft (mm^4)

$$I = \frac{\pi}{64} d^4 \qquad \text{d: Minor diameter} \quad \text{(mm)}$$

(see Table 10, Table 11, Table 12, and Table 13 on A3-26)

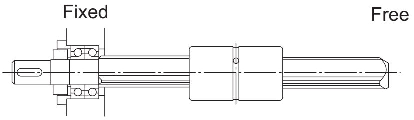
γ : Density (specific gravity) (7.85×10^{-6} kg/mm^3)

$$A = \frac{\pi}{4} d^2 \qquad \text{d: Minor diameter} \quad \text{(mm)}$$

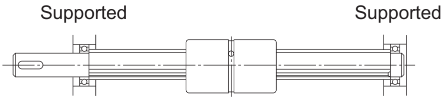
(see Table 10, Table 11, Table 12, and Table 13 on A3-26)

A : Spline shaft cross-sectional area (mm^2)

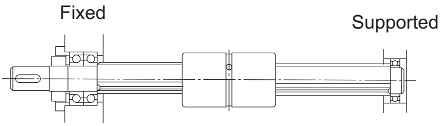
λ : Factor according to the mounting method
(1) Fixed - free $\lambda = 1.875$
(2) Supported - supported $\lambda = 3.142$
(3) Fixed - supported $\lambda = 3.927$
(4) Fixed - fixed $\lambda = 4.73$



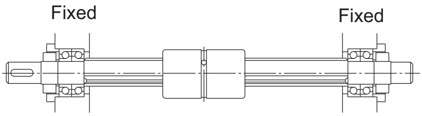
Fixed - free



Supported - supported



Fixed - supported



Fixed - fixed

Cross-Sectional Characteristics of the Spline Shaft

● Cross-Sectional Characteristics of the Spline Shaft for Ball Spline Models SLS, SLS-L, and SLF

Table 3: Cross-Sectional Characteristics of the Spline Shaft for Models SLS, SLS-L, and SLF

Nominal shaft diameter		I: Geometric moment of inertia mm⁴	Z: Section modulus mm³	I_P: Polar moment of inertia mm⁴	Z_P: Polar section modulus mm³
25	Solid shaft	1.61×10^4	1.29×10^3	3.22×10^4	2.57×10^3
	Hollow shaft Type K	1.51×10^4	1.20×10^3	3.01×10^4	2.41×10^3
30	Solid shaft	3.33×10^4	2.22×10^3	6.65×10^4	4.43×10^3
	Hollow shaft Type K	3.00×10^4	2.00×10^3	6.01×10^4	4.00×10^3
40	Solid shaft	1.09×10^5	5.47×10^3	2.19×10^5	1.09×10^4
	Hollow shaft Type K	9.79×10^4	4.90×10^3	1.96×10^5	9.79×10^3
50	Solid shaft	2.71×10^5	1.08×10^4	5.41×10^5	2.17×10^4
	Hollow shaft Type K	2.51×10^5	1.01×10^4	5.03×10^5	2.01×10^4
60	Solid shaft	5.83×10^5	1.94×10^4	1.17×10^6	3.89×10^4
	Hollow shaft Type K	5.32×10^5	1.77×10^4	1.06×10^6	3.54×10^4
70	Solid shaft	1.06×10^6	3.02×10^4	2.11×10^6	6.04×10^4
80	Solid shaft	1.82×10^6	4.55×10^4	3.64×10^6	9.10×10^4
	Hollow shaft Type K	1.45×10^6	3.62×10^4	2.90×10^6	7.24×10^4
100	Solid shaft	4.50×10^6	9.00×10^4	9.00×10^6	1.80×10^5
	Hollow shaft Type K	3.48×10^6	6.96×10^4	6.96×10^6	1.36×10^5

Note: For the hole shape of the hollow spline shaft, see **A3-50**.

● Cross-Sectional Characteristics of the Spline Shaft for Ball Spline Models LBS, LBST, LBF, LBR, LBH, LBG, and LBGT

Table 4: Cross-Sectional Characteristics of the Spline Shaft for Models LBS, LBST, LBF, LBR, LBH, LBG, and LBGT

Nominal shaft diameter		I: Geometric moment of inertia mm^4	Z: Section modulus mm^3	I_P: Polar moment of inertia mm^4	Z_P: Polar section modulus mm^3
15	Solid shaft	1.27×10^{3}	2.00×10^{2}	2.55×10^{3}	4.03×10^{2}
20	Solid shaft	3.82×10^{3}	4.58×10^{2}	7.72×10^{3}	9.26×10^{2}
	Hollow shaft Type K	3.79×10^{3}	4.56×10^{2}	7.59×10^{3}	9.11×10^{2}
25	Solid shaft	9.62×10^{3}	9.14×10^{2}	1.94×10^{4}	1.85×10^{3}
	Hollow shaft Type K	9.50×10^{3}	9.05×10^{2}	1.90×10^{4}	1.81×10^{3}
30	Solid shaft	1.87×10^{4}	1.50×10^{3}	3.77×10^{4}	3.04×10^{3}
	Hollow shaft Type K	1.78×10^{4}	1.44×10^{3}	3.57×10^{4}	2.88×10^{3}
40	Solid shaft	6.17×10^{4}	3.69×10^{3}	1.25×10^{5}	7.46×10^{3}
	Hollow shaft Type K	5.71×10^{4}	3.42×10^{3}	1.14×10^{5}	6.84×10^{3}
50	Solid shaft	1.49×10^{5}	7.15×10^{3}	3.01×10^{5}	1.45×10^{4}
	Hollow shaft Type K	1.34×10^{5}	6.46×10^{3}	2.69×10^{5}	1.29×10^{4}
60	Solid shaft	3.17×10^{5}	1.26×10^{4}	6.33×10^{5}	2.53×10^{4}
	Hollow shaft Type K	2.77×10^{5}	1.11×10^{4}	5.54×10^{5}	2.21×10^{4}
70	Solid shaft	5.77×10^{5}	1.97×10^{4}	1.16×10^{6}	3.99×10^{4}
	Hollow shaft Type K	5.07×10^{5}	1.74×10^{4}	1.01×10^{6}	3.49×10^{4}
85	Solid shaft	1.33×10^{6}	3.69×10^{4}	2.62×10^{6}	7.32×10^{4}
	Hollow shaft Type K	1.11×10^{6}	3.10×10^{4}	2.22×10^{6}	6.20×10^{4}
100	Solid shaft	2.69×10^{6}	6.25×10^{4}	5.33×10^{6}	1.25×10^{5}
	Hollow shaft Type K	2.18×10^{6}	5.10×10^{4}	4.37×10^{6}	1.02×10^{5}
120	Solid shaft	5.95×10^{6}	1.13×10^{5}	1.18×10^{7}	2.26×10^{5}
	Hollow shaft Type K	5.28×10^{6}	1.01×10^{5}	1.06×10^{7}	2.02×10^{5}
150	Solid shaft	1.61×10^{7}	2.40×10^{5}	3.20×10^{7}	4.76×10^{5}
	Hollow shaft Type K	1.40×10^{7}	2.08×10^{5}	2.79×10^{7}	4.16×10^{5}

Note: For the hole shape of the hollow spline shaft, see **A3-71** and **A3-108**.

● Cross-Sectional Characteristics of the Spline Shaft for Ball Spline Models LT, LF, LTR, and LTR-A

Table 5: Cross-Sectional Characteristics of the Spline Shaft for Models LT, LF, LTR, and LTR-A

Nominal shaft diameter			I: Geometric moment of inertia mm^4	Z: Section modulus mm^3	I_P: Polar moment of inertia mm^4	Z_P: Polar section modulus mm^3
4	Solid shaft		11.39	5.84	22.78	11.68
5	Solid shaft		27.88	11.43	55.76	22.85
6	Solid shaft		57.80	19.7	1.19×10^{2}	40.50
	Hollow shaft	Type K	55.87	18.9	1.16×10^{2}	39.20
8	Solid shaft		1.86×10^{2}	47.4	3.81×10^{2}	96.60
	Hollow shaft	Type K	1.81×10^{2}	46.0	3.74×10^{2}	94.60
10	Solid shaft		4.54×10^{2}	92.6	9.32×10^{2}	1.89×10^{2}
	Hollow shaft	Type K	4.41×10^{2}	89.5	9.09×10^{2}	1.84×10^{2}
13	Solid shaft		1.32×10^{3}	2.09×10^{2}	2.70×10^{3}	4.19×10^{2}
	Hollow shaft	Type K	1.29×10^{3}	2.00×10^{2}	2.63×10^{3}	4.09×10^{2}
16	Solid shaft		3.09×10^{3}	3.90×10^{2}	6.18×10^{3}	7.80×10^{2}
	Hollow shaft	Type K	2.97×10^{3}	3.75×10^{2}	5.95×10^{3}	7.51×10^{2}
		Type N	2.37×10^{3}	2.99×10^{2}	4.74×10^{3}	5.99×10^{2}
20	Solid shaft		7.61×10^{3}	7.67×10^{2}	1.52×10^{4}	1.53×10^{3}
	Hollow shaft	Type K	7.12×10^{3}	7.18×10^{2}	1.42×10^{4}	1.43×10^{3}
		Type N	5.72×10^{3}	5.77×10^{2}	1.14×10^{4}	1.15×10^{3}
25	Solid shaft		1.86×10^{4}	1.50×10^{3}	3.71×10^{4}	2.99×10^{3}
	Hollow shaft	Type K	1.75×10^{4}	1.41×10^{3}	3.51×10^{4}	2.83×10^{3}
		Type N	1.34×10^{4}	1.08×10^{3}	2.68×10^{4}	2.16×10^{3}
30	Solid shaft		3.86×10^{4}	2.59×10^{3}	7.71×10^{4}	5.18×10^{3}
	Hollow shaft	Type K	3.53×10^{4}	2.37×10^{3}	7.07×10^{4}	4.74×10^{3}
		Type N	2.90×10^{4}	1.95×10^{3}	5.80×10^{4}	3.89×10^{3}
32	Solid shaft		5.01×10^{4}	3.15×10^{3}	9.90×10^{4}	6.27×10^{3}
	Hollow shaft	Type K	4.50×10^{4}	2.83×10^{3}	8.87×10^{4}	5.61×10^{3}
		Type N	3.64×10^{4}	2.29×10^{3}	7.15×10^{4}	4.53×10^{3}
40	Solid shaft		1.22×10^{5}	6.14×10^{3}	2.40×10^{5}	1.21×10^{4}
	Hollow shaft	Type K	1.10×10^{5}	5.55×10^{3}	2.17×10^{5}	1.10×10^{4}
		Type N	8.70×10^{4}	4.39×10^{3}	1.71×10^{5}	8.64×10^{3}
50	Solid shaft		2.97×10^{5}	1.20×10^{4}	5.94×10^{5}	2.40×10^{4}
	Hollow shaft	Type K	2.78×10^{5}	1.12×10^{4}	5.56×10^{5}	2.24×10^{4}
		Type N	2.14×10^{5}	8.63×10^{3}	4.29×10^{5}	1.73×10^{4}
60	Solid shaft		6.16×10^{5}	2.07×10^{4}	1.23×10^{6}	4.14×10^{4}
	Hollow shaft	Type K	5.56×10^{5}	1.90×10^{4}	1.13×10^{6}	3.79×10^{4}
80	Solid shaft		1.95×10^{6}	4.91×10^{4}	3.90×10^{6}	9.82×10^{4}
	Hollow shaft	Type K	1.58×10^{6}	3.97×10^{4}	3.15×10^{6}	7.95×10^{4}
100	Solid shaft		4.78×10^{6}	9.62×10^{4}	9.56×10^{6}	1.92×10^{5}
	Hollow shaft	Type K	3.76×10^{6}	7.57×10^{4}	7.52×10^{6}	1.51×10^{5}

Notes: For the hole shape of the hollow spline shaft, see **A3-96** and **A3-120**.

● Cross-Sectional Characteristics of the Spline Shaft for Ball Spline Models LT-X, LF-X, LFK-X, and LFH-X

Table 6: Cross-Sectional Characteristics of the Spline Shaft for Models LT-X, LF-X, LFK-X, and LFH-X

Nominal shaft diameter			I: Geometric moment of inertia mm^4	Z: Section modulus mm^3	I$_P$: Polar moment of inertia mm^4	Z$_P$: Polar section modulus mm^3
4	Solid shaft		11.2	5.7	23.2	11.8
5	Solid shaft		27.7	11.3	57.2	23.3
6	Solid shaft		57.7	19.6	119.1	40.4
	Hollow shaft	Type K	55.8	18.9	115.3	39.1
8	Solid shaft		175.6	45	366.2	93.9
	Hollow shaft	Type K	171.6	44	358.2	91.8
10	Solid shaft		422.3	86.5	896.9	183.8
	Hollow shaft	Type K	409.7	84	871.7	178.6
13	Solid shaft		1,215.3	191.3	2,574.6	405.3
	Hollow shaft	Type K	1,184.6	186.5	2,513.2	395.6
16	Solid shaft		2,734.3	350.8	5,844.5	749.7
	Hollow shaft	Type K	2,616.4	335.6	5,608.8	719.5
		Type N	2,015.6	258.6	4,407.2	565.4
20	Solid shaft		7,043.9	716.5	14,731.7	1,498.5
	Hollow shaft	Type K	6,553	666.6	13,749.9	1,398.7
		Type N	5,158.1	524.7	10,960.2	1,114.9
25	Solid shaft		17,268.2	1,404.2	36,067.4	2,932.9
	Hollow shaft	Type K	16,250.3	1,321.4	34,031.6	2,767.4
		Type N	12,115.2	985.2	25,761.4	2,094.8
30	Solid shaft		36,115.8	2,444.1	75,160	5,086.3
	Hollow shaft	Type K	32,898.8	2,226.4	68,726.1	4,650.9
		Type N	26,569.7	1,798	56,067.4	3,794.2

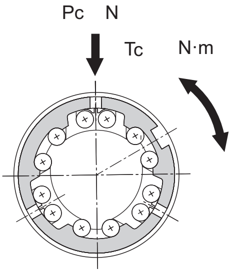
Applied Load

The load applied to the spline nut varies with the location of the center of gravity of the load, the position of the thrust, inertia generated by acceleration and deceleration during starts and stops, external forces, and torque. When selecting a ball spline, it is necessary to obtain the value of the applied load while taking these conditions into account.

● When a Torque Load and a Radial Load are Applied Simultaneously

When a torque load and a radial load are applied simultaneously, calculate the nominal life by obtaining the equivalent radial load using formula (7) below.

$$P_E = P_C + \frac{4 \cdot T_C \times 10^3}{i \cdot dp \cdot \cos\alpha} \quad \cdots\cdots\cdots(7)$$



P_E : Equivalent radial load (N)
P_C : Calculated radial load (N)
T_C : Calculated load torque (N·m)
$\cos\alpha$: Contact angle i = Number of rows of balls under a load

(Type LBS α = 45° i = 3
Type LT α = 70° i = 2 (LT13 or smaller)
i = 3 (LT16 or greater)
Type SLS α = 40° i = 3
Type LT-X α = 65° i = 2)

dp : Ball center-to-center diameter (mm)
(see **A3-26** Table 10, Table 11, Table 12, Table 13)

● When a Moment Load is Applied to a Single Nut or Two Nuts in Close Contact with Each Other

Calculate the nominal life by obtaining the equivalent radial load using formula (8) below.

$$P_u = K \cdot M \quad \cdots\cdots\cdots(8)$$

P_u : Equivalent radial load (N)
(with a moment applied)
K : Equivalent Factors
(see **A3-29** on Table 14, **A3-30** on Table 15, **A3-31** and Table 16 on Table 17)
M : Applied moment (N·mm)

However, M should be within the range of the static permissible moment.

● When a Moment Load and a Radial Load are Simultaneously Applied

Calculate the static safety factor and nominal life from the sum of the radial load and the equivalent radial load.

Static Safety Factor

When using a ball spline, a static safety factor derived from the basic static load rating and the calculated load in each direction must be considered. In particular, if the system starts and stops frequently, or if impact loads are applied, large moment loads or torque caused by overhanging loads may be applied to the system. When selecting a model, make sure that a sufficient static safety factor has been ensured for its maximum load (whether stationary or in motion). In addition, the static safety factor must be confirmed for each load direction using Formulas 9 and 10. For radial loads, you can obtain the static safety factor for the basic static load rating, and for moment loads, you can obtain the static safety factor for the basic static torque rating. Table 7 shows guideline values for the static safety factor.

- Static Safety Factor per Basic Static Torque Rating

$$f_S = \frac{f_T \cdot f_C \cdot C_{0T}}{T_{max}} \quad \cdots\cdots\cdots(9)$$

- Static Safety Factor per Basic Static Load Rating

$$f_S = \frac{f_T \cdot f_C \cdot C_0}{P_{max}} \quad \cdots\cdots\cdots(10)$$

f_s : Static safety factor

C_{0T} : Basic static torque rating[1] (N·m)

C_0 : Basic static load rating[2] (N)

T_{max} : Maximum load torque[3] (N·m)

P_{max} : Maximum applied load[3] (N)

f_T : Temperature factor (see **A3-25** on Fig. 1)

f_C : Contact factor (see **A3-25** on Table 8)

[1] The basic static torque rating is a static torque of a defined direction and size where the sum of the permanent deformation of the ball and that of the raceway at the contact area under maximum stress is 0.0001 times the ball diameter.

[2] The basic static load rating is a static load of a defined direction and size where the sum of the permanent deformation of the ball and that of the raceway at the contact area under maximum stress is 0.0001 times the ball diameter.

[3] The maximum values for T_C and P_C during a travel cycle, as given on **A3-21**, are applied to the maximum torque load T_{max} and the maximum load P_{max}.

Table 7: Guideline for the Static Safety Factor (f_S)

Load conditions[1]	Lower Limit of f_S
Without vibrations or impacts	3
With vibrations or impacts	5

[1] Vibrations and impacts are typically caused by factors such as acceleration and deceleration, sudden starting and stopping, vibrations and impacts from an external machine, and changes in processing power over time.

Nominal Life

A ball spline in motion under an external load receives repeated stress on its raceways and rolling elements. When the stress reaches the limit, the surface of the raceways and rolling elements flake in places due to rolling fatigue. This phenomenon is called flaking. The service life of the ball spline is the total travel distance until the first flaking occurs on any of the raceways or the rolling elements as a result of rolling fatigue of the material. The nominal life defined below is used as an estimate for the service life of a ball spline. Nominal life is the total travel distance that 90% of a group of identical ball splines independently operating under the same conditions can achieve without flaking.

Calculating the Nominal Life

The nominal life of a ball spline varies with types of loads applied during operation: torque load, radial load, and moment load. The corresponding nominal life values are obtained using the equations (11) to (15) below. (The basic load ratings in these loading directions are indicated in the specification table for the corresponding model number.)

● Calculating the Nominal Life

The nominal life of the THK ball spline is defined as 50 km. The nominal life (L_{10}) is calculated from the basic dynamic load rating (C) and the load acting on the ball spline (P_C) using the following formulas.

- When a torque load is applied

$$L_{10} = \left(\frac{C_T}{T_C}\right)^3 \times 50 \quad \cdots\cdots\cdots(11)$$

- When a radial load is applied

$$L_{10} = \left(\frac{C}{P_C}\right)^3 \times 50 \quad \cdots\cdots\cdots(12)$$

L_{10} : Nominal life (km)
C_T : Basic dynamic torque rating (N·m)
C : Basic dynamic load rating (N)
T_C : Calculated torque applied (N·m)
P_C : Calculated radial load (N)

Note: These nominal life formulas may not apply if the length of the stroke is less than or equal to twice the length of the ball spline nut.

When comparing the nominal life (L_{10}), you must take into account whether the basic dynamic load rating was defined based on 50 km or 100 km. Convert the basic dynamic load rating based on ISO 14728-1 as necessary.

ISO-regulated basic dynamic load rating conversion formula:

$$C_{100} = \frac{C_{50}}{1.26}$$

C_{50} : Basic dynamic load rating based on a nominal life of 50 km
C_{100} : Basic dynamic load rating based on a nominal life of 100 km

● Calculating the Modified Nominal Life

During use, a ball spline may be subjected to vibrations and shocks as well as fluctuating loads, which are difficult to detect. In addition, the operating temperature and having nuts arranged in close contact will significantly impact the service life. Taking these factors into account, the modified nominal life (L_{10m}) can be calculated according to the following formulas (13) and (14).

- Modified factor α

$$\alpha = \frac{f_T \cdot f_C}{f_W}$$

α	: Modified factor	
f_T	: Temperature factor	(see Fig. 1 on **A3-25**)
f_C	: Contact factor	(see Table 8 on **A3-25**)
f_W	: Load factor	(see Table 9 on **A3-25**)

- Modified nominal life L_{10m}
  - When a Torque Load is Applied

$$L_{10m} = \left(\alpha \times \frac{C_T}{T_C}\right)^3 \times 50 \quad \cdots\cdots\cdots(13)$$

  - When a Radial Load is Applied

$$L_{10m} = \left(\alpha \times \frac{C}{P_C}\right)^3 \times 50 \quad \cdots\cdots\cdots(14)$$

L_{10m}	: Modified nominal life	(km)
C_T	: Basic dynamic torque rating	(N·m)
C	: Basic dynamic load rating	(N)
T_C	: Calculated torque applied	(N·m)
P_C	: Calculated radial load	(N)

● Calculating the Service Life Time

When the nominal life (L_{10}) has been obtained in the equation above, if the stroke length and the number of reciprocations per minute are constant, the service life time is obtained using the equation (15) below.

$$L_h = \frac{L_{10} \times 10^3}{2 \times \ell_S \times n_1 \times 60} \quad \cdots\cdots\cdots(15)$$

L_h	: Service life time	(h)
ℓ_S	: Stroke length	(m)
n_1	: Number of reciprocations per minute	(min^{-1})

■f_T: Temperature Factor

If the temperature of the environment surrounding the operating ball spline exceeds 100℃, take into account the adverse effect of the high temperature and multiply the basic load ratings by the temperature factor indicated in Fig. 1.
In addition, the ball spline must be of a high-temperature type.

Note: If the environmental temperature exceeds 80°C, high-temperature types of seal and retainer are required. Contact THK for details.

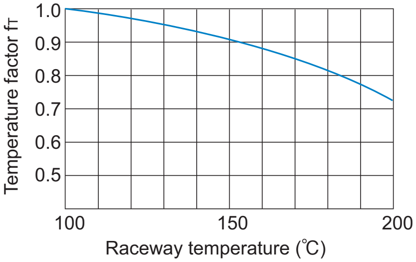


Fig. 1: Temperature Factor (f_T)

■f_C: Contact Factor

When multiple spline nuts are used in close contact with each other, their linear motion is affected by moments and mounting accuracy, making it difficult to achieve uniform load distribution. In such applications, multiply the basic load rating (C) and (C_0) by the corresponding contact factor in Table 8.

Note: If uneven load distribution is expected in a large machine, take into account the respective contact factor indicated in Table 8.

Table 8: Contact Factor (f_c)

Number of spline nuts in close contact with each other	Contact factor f_c
2	0.81
3	0.72
4	0.66
5	0.61
Normal use	1

■f_W: Load Factor

In general, reciprocating machines tend to experience vibrations or impacts during operation, and it is difficult to accurately determine the vibrations generated during high-speed operation and impacts during frequent starts and stops. When the actual load applied to a ball spline cannot be obtained, or when speed and vibrations have a significant influence, divide the basic dynamic load rating (C) by the corresponding load factor in Table 9, which has been empirically obtained.

Table 9: Load Factor (f_w)

Vibrations/ impacts	Speed (V)	f_w
Faint	Very low $V \leqq 0.25$ m/s	1 to 1.2
Weak	Slow $0.25 < V \leqq 1$ m/s	1.2 to 1.5
Medium	Medium $1 < V \leqq 2$ m/s	1.5 to 2
Strong	High $V > 2$ m/s	2 to 3.5

Cross-Sectional Shape of the Spline Shaft

● Spline Shaft for Models SLS, SLS-L, and SLF

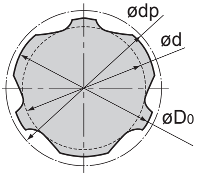


Table 10: Cross-Sectional Shape

Unit: mm

Nominal shaft diameter	25	30	40	50	60	70	80	100
Minor diameter ød	21.6	25.8	35.2	44.4	54.0	62.8	71.3	90
Major diameter $øD_0$ h7	25	30	40	50	60	70	80	100
Ball center-to-center diameter ødp	25.2	30.2	40.6	50.6	61	71	80.8	101.2

Note: The minor diameter ød must be a value at which no groove is left after machining.

● Spline Shaft for Models LBS, LBST, LBF, LBR, LBH, LBG, and LBGT

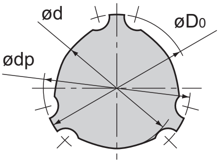


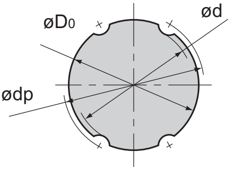
Table 11: Cross-Sectional Shape

Unit: mm

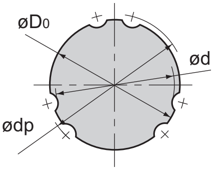
Nominal shaft diameter	15	20	25	30	40	50	60	70	85	100	120	150
Minor diameter ød	11.7	15.3	19.5	22.5	31	39	46.5	54.5	67	81	101	130
Outer diameter $øD_0$	14.5	19.7	24.5	29.6	39.8	49.5	60	70	84	99	117	147
Ball center-to-center diameter ødp	15	20	25	30	40	50	60	70	85	100	120	150

Note: The minor diameter ød must be a value at which no groove is left after machining.

● Spline Shaft for Models LT, LF, LTR, and LTR-A



Nominal shaft diameter: 13 mm or less



Nominal shaft diameter: 16 mm or more

Table 12: Cross-Sectional Shape

Unit: mm

Nominal shaft diameter	4	5	6	8	10	13	16	20	25	30	32	40	50	60	80	100
Minor diameter ød	3.5	4.5	5	7	8.5	11.5	14.5	18.5	23	28	30	37.5	46.5	56.5	75.5	95
Outer diameter $øD_0$ h7	4	5	6	8	10	13	16	20	25	30	32	40	50	60	80	100
Outer diameter tolerance	0 −0.012			0 −0.015		0 −0.018		0 −0.021				0 −0.025		0 −0.03		0 −0.035
Ball center-to-center diameter ødp	4.6	5.7	7	9.3	11.5	14.8	17.8	22.1	27.6	33.2	35.2	44.2	55.2	66.3	87.9	109.5

Note: The minor diameter ød must be a value at which no groove is left after machining.

● Spline Shaft for Models LT-X, LF-X, LFK-X, and LFH-X

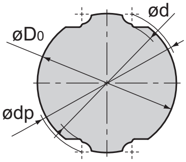


Table 13: Cross-Sectional Shape

Unit: mm

Nominal shaft diameter	4X	5X	6X	8X	10X	13X	16X	20X	25X	30X
Minor diameter ød	3.6	4.5	5.4	7	8.6	11.3	13.9	17.9	22.4	27
Major diameter $øD_0$	4	5	6	8	10	13	16	20	25	30
Ball center-to-center diameter ødp	4.4	5.5	6.6	8.6	10.7	13.8	17.1	21.1	26.4	31.6

Calculating the Average Load

In cases where the load applied to each spline nut fluctuates under different conditions, such as an industrial robot advancing while holding a workpiece with its arm then retreating with its arm empty, or a machine tool handling various workpieces, it is necessary to calculate the service life of the spline nut while taking into account such fluctuating load conditions.

The average load (P_m) is a constant load under which the service life is equal to that of a ball spline operating with its spline nut receiving a fluctuating load due to varying conditions.

The following is the basic equation.

$$P_m = \sqrt[3]{\frac{1}{L} \cdot \sum_{n=1}^{n} (P_n{}^3 \cdot L_n)}$$

P_m : Average load (N)
P_n : Varying load (N)
L : Total travel distance (mm)
L_n : Distance traveled under P_n (mm)

● With Stepwise Load Fluctuation

$$P_m = \sqrt[3]{\frac{1}{L} (P_1{}^3 \cdot L_1 + P_2{}^3 \cdot L_2 \cdots\cdots + P_n{}^3 \cdot L_n)} \quad \cdots\cdots\cdots\cdots(16)$$

P_m : Average load (N)
P_n : Varying load (N)
L : Total travel distance (m)
L_n : Distance traveled under load P_n (m)

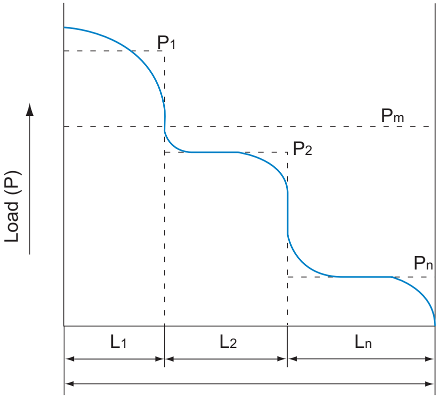


Fig. 2

● With Monotone Load Fluctuation

$$P_m \fallingdotseq \frac{1}{3}(P_{min} + 2 \cdot P_{max}) \cdots\cdots\cdots\cdots (17)$$

P_{min}	: Minimum load	(N)
P_{max}	: Maximum load	(N)

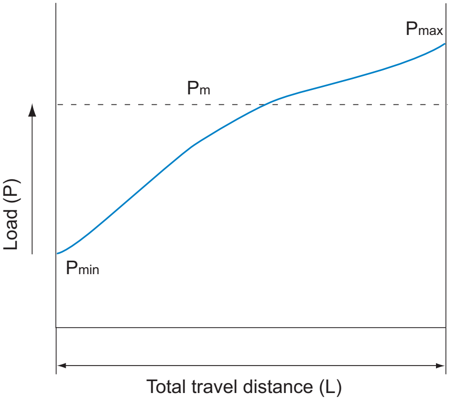


Fig. 3

● With Sinusoidal Load Fluctuation

(a) $P_m \fallingdotseq 0.65P_{max} \cdots\cdots\cdots\cdots (18)$

(b) $P_m \fallingdotseq 0.75P_{max} \cdots\cdots\cdots\cdots (19)$

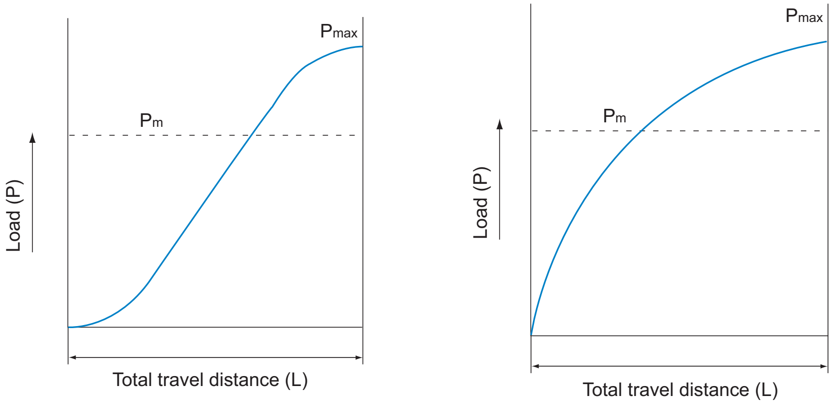
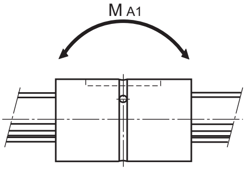


Fig. 4

Equivalent Factor

Table 14 on **A3-29**, Table 15 on **A3-30**, Table 16 and Table 17 on **A3-31** show equivalent radial load factors calculated under a moment load.

● Table of Equivalent Factors for Ball Spline Models SLS/SLF



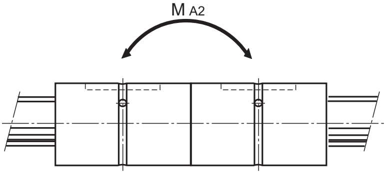


Table 14

Model No.	Equivalent factor: K	
	Single spline nut	Two spline nuts in close contact with each other
SLS/SLF 25	0.187	0.030
SLS 25L	0.148	0.027
SLS/SLF 30	0.153	0.027
SLS 30L	0.129	0.024
SLS/SLF 40	0.114	0.021
SLS 40L	0.102	0.019
SLS/SLF 50	0.109	0.018
SLS 50L	0.091	0.017
SLS/SLF 60	0.080	0.015
SLS 60L	0.072	0.014
SLS/SLF 70	0.101	0.016
SLS 70L	0.076	0.014
SLS/SLF 80	0.083	0.013
SLS 80L	0.072	0.012
SLS/SLF 100	0.068	0.011
SLS 100L	0.056	0.010