TBIMOTION

BALL SPLINE

BALL SPLINE CATALOG

TBI
TBIMOTION®

TBI MOTION TECHNOLOGY CO., LTD.
No.91, Zhong Shan Rd., Tucheng Dist, New Taipei City, 23680, Taiwan.
TEL : +886-2-2268-7211~4 FAX : +886-2-2268-7210
E-mail : tbi.tbi@msa.hinet.net http : //www.tbimotion.com.tw

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The past history of ...

TBI TBIMOTION®

1986

Taiwan Ball Screw Industrial Co.,Ltd. (*TBI*) was established in Tucheng Industrial District, Taipei, Taiwan. We were also the first manufacturer who produces ground type of precise ball screws in Taiwan.

1988

TBI established Research & Development Department and finished constructing the factory in Taichung that focuses on innovative products and producing precise grinding ball screws.

2002

COMTOP was established and exported ball screws to world wide based on a professional and successful marketing sales system.

2010

(*TBI MOTION*) has integrated the technology of *TBI* and the marketing strategy of **COMTOP** to develop *TBI MOTION* in a leading place of Linear Motion Industry. The main products are Ball Screws, Linear Guides, Ball Splines, Single Axis Robot, Linear Ball Bearing, Couplings, and Ball Screw Accessaries......etc.

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Ball Spline

1-1 *TBI MOTION* BALL SPLINE Structure and Benefits

1-1-1 Basic Structure of TBI Ball spline

The design of TBI Ball spline is to utilize the friction force through the contact of steel balls within in the Spline Nut and the grooves on the Spline Shaft. With TBI MOTION's unique 40° angular contact design which enables the Ball spline delivers high sensitivity and extreme high load carrying capacity. The concept is optimal for the application involve with high speed, vibrates, impacts of loading and precise positioning requirements. Also when the Ball spline is used to function as linear bushing, the Ball spline provides ten times loading capacity than the linear bushing in the like dimensioned but with a compact profile. Namely, Durability and reliablility is the reason for choosing TBI Ball spline in your application.

1-1-2 *TBI MOTION* Nut design and Shaft spec

TBI MOTION Spline Nut is available in two different designs: SLF (Flange design) and SLT (Non-flange design). Point of contacts on the Spline shaft is provided in two grooves (180°) (SLF/SLT6~20) and four grooves (70°) (SLF/SLT25~50) base on the diameter of the Spline shaft. Also TBI provides Hollow Spline shaft for alternative.

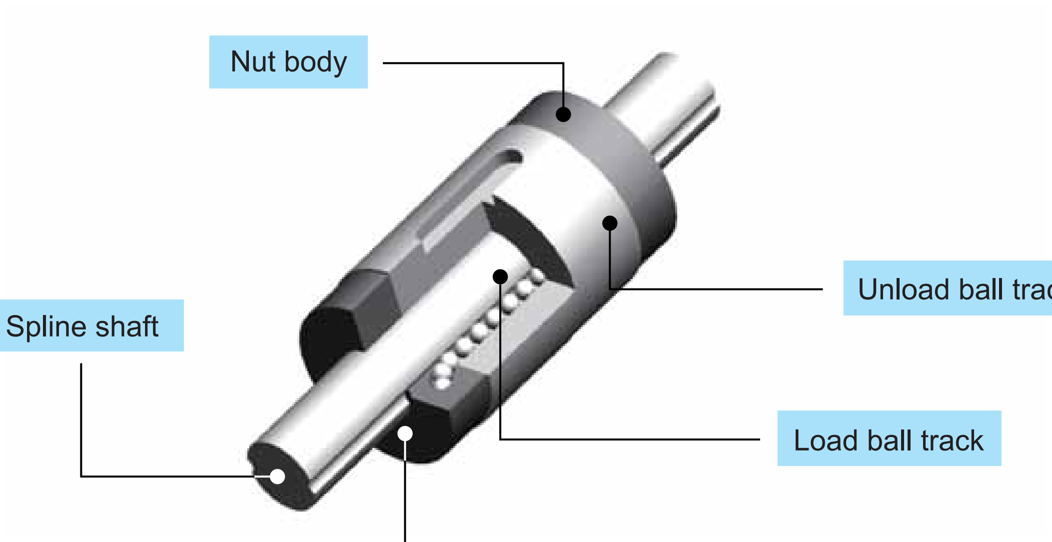


Fig 1.1

1-1-3 Feature

High Load-Carrying Capacity

Every groove on the TBI Spline shaft is precision ground to form a perfect 40° angular contact point. The concept of 40° contact design is to increases the load carrying capacity and rigidity so that it is able to handle a greater moment load.

Zero Angular clerance/backlash

Every groove on the TBI Spline shaft is precision ground to form a perfect 40° angular contact point which is called the Gothic arch. The Gothic design eliminates clearance that could generate deflections and therefore best suited for the applications that requiring maximum precision.

High Sensitivity

The unique TBI 40° angular contact is design to drive with the minimum of friction force while the design performs not only the highest sensitivity but also the rigidity.

High Rigidity

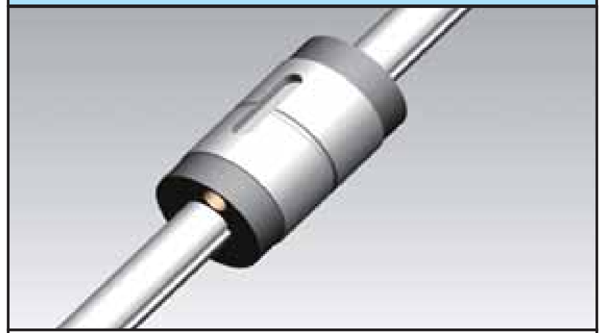
A wide contact angle and an appropriate level off preload are combined to provide high torque and moment rigidity.

EZY Mount on design

TBI Ball spline is low and simple maintenance designed, therefore even if disassembly is required. When the Spline Nut is necessary to remove for the spline shaft due to the ball retaining design the steel balls will not fall apart like the traditional Nut design.

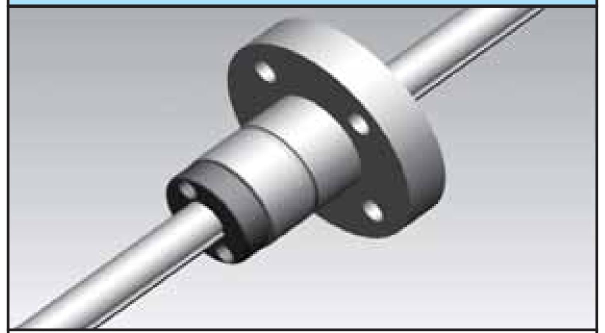
1-1-4 TBI Ball Spline Type and Feature

SLT, Non-flanged Spline nut



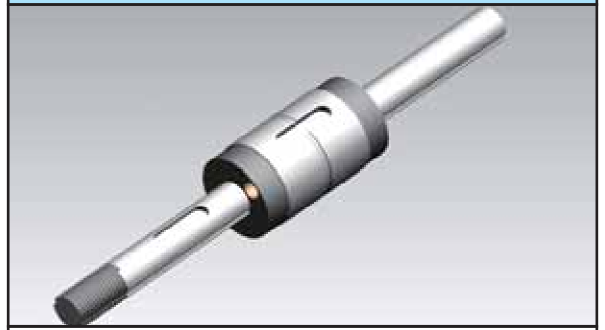
SLT Spline nut is with a straight cylindrical shape without flange; the standard mode ofmounting a cylindrical nut is by using a key. The cylindrical nut will have a keyway and separate key. A matching keyway must bebored into the housing or block that will be mounted on the cylinder nut. The type SLT is the most compact profile Spline nut in TBI Ball spline product line.

SLF, Flanged Spline nut



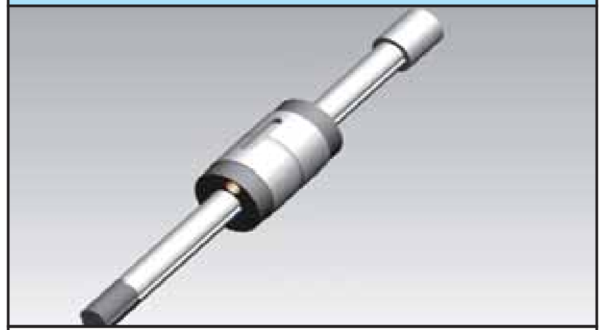
flange nut is simpler to install because it only requires a rough bore and mounting holes drilled and tapped to secure the flange to the housing.

Standard precision Spline shaft



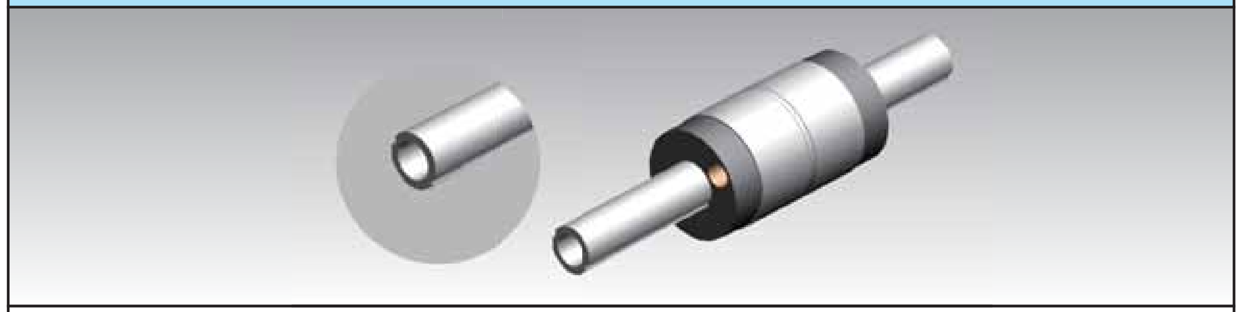
The Standard precision Spline shaft is precisely ground to reach high accuracy and smoothness.

Custom machining Spline shaft



TBI has the capability to manufacturing custom made Spline shaft by machining it to meet the requirements of special Spline shaft shape. For example a shaft with a bigger diameter on both ends or on the center of spline shaft can be manufactured upon request.

Hollow Spline Shaft (H-Type)



Hollow Spline shaft is optional for the customer to choose for its application. Hollow Spline shaft is design to reduce weight, accommodate pipes, ventilation.

1-1-5 Selecting your TBI Ball spline

Steps	Description
1.Set the Operational conditions	● Stroke Length：Ls ● Velocity：V ● The Applied Load：W ● Size ● Installation ● Use of the environment ● Service life expectancy ● Accuracy ● Frequency of use (load cycle) ● Rigidity
2.Select a Style	● Refer to Type, Shaft Spec to determine the your Ball spline.
3.Calculating the strength of Spline shaft	● Spline Shaft Diameter ● Spline-Shaft Length ● End Fixity ● The permissible load of Ball spline ● The displacement under torque and delecting
4.Service expectancy	IF → Calculating TBI Ball spline service life expectancy by using expectancy formula. NO → NO Required service life.
5.Determined the preload	● Determined the permissible axial clearance/backlash
6.Determine the Accuracy Grade	● Accuracy Grades
7.Operational condition	● Lubrication ● Lubrication methods ● Surface treatment ● Dust prevention methods
	Selected

2-1 The strength of Spline shaft

The Spline shaft is designed to absorb radial load and torque during operation. Therefore, the strength of Spline shaft must be taken into consideration when the Ball spline operates under extreme loading ortorque.

2-1-1 The bending load applied on the operating Ball spline

The maximum of bending moment(M) can be attributed to multi factors such as the end fixity methods, length of Spline shaft, load capacity, etc. Equation(1) is equipped to help the user to obtain the ideal length of the Spline shaft in order to be the reference of obtaining the ideal strength of Ball spline.

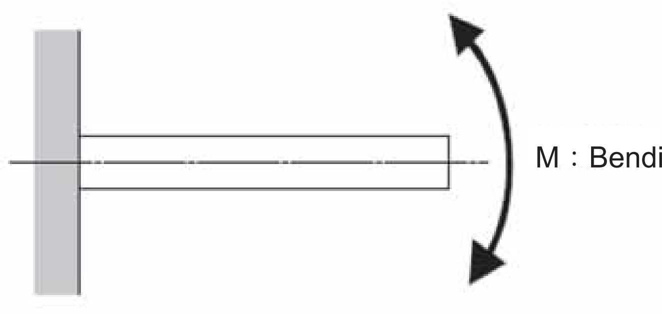


Fig 2.1

$M = \sigma \cdot Z$ and $Z = \frac{M}{\sigma}$ .....(1)

M : Bending moment(N-mm)

σ : Shaft permissible bending stress(98N/mm^2)

Z : Shaft section modulus (mm^3)

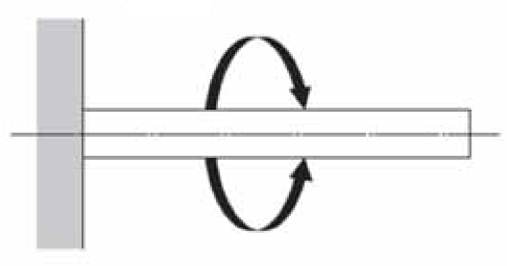


Fig 2.2

2-1-2 The torque applied on the operating Ball spline

The maximum torque applied on the Spline shaft can be calculated through maximum twisting moment (T).
Equation (2) is equipped to help the user to obtain the ideal length of the Spline shaft in order to be the reference of obtaining the ideal strength of Ball spline.

$T = \tau_a \cdot Z_P$ and $Z_P = \frac{T}{\tau_a}$ .....(2)

T : Maximum twisting moment (N · mm)

τ_a : Shaft permissible twisting Stress (49N/mm^2)

Z_p : Shaft polar section modulus (mm^3) See Table 2.3

2-1-3 Both Bending Moment and Twisting Moment applied simultaneously on the Spline shaft.

To calculate the figure for both bending (M)and twisting moments (T) applied on the Spline shaft via equation (3) and (4) in order to get the equivalent bending moment (Me) and equivalent twisting moment (Te). Adopt the greater value from equation (3) and (4) to determine the ideal Spline-shaft length.

Equivalent Bending Moment

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

$$M_e = \sigma \cdot Z$$

Equivalent Twisting Moment

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

$$T_e = \tau_a \cdot Z_P$$

2-1-4 Rigidity of the Spline Shaft

The rigidity of the Spline Shaft is expressed in torsion angle caused by twisting moment. The twisting angle should be limited to no further than 0.25° per 1000 mm.

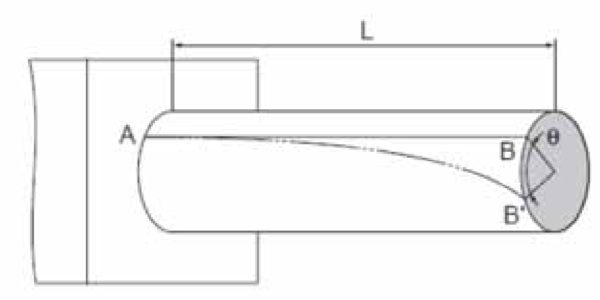


Fig 2.3

$$\theta = 57.3 \cdot \frac{T \cdot L}{G \cdot I_p} \quad .....(5)$$

Shaft Rigidity = Torsion Angle/Unit Length = $\frac{\theta}{\ell} < \frac{1°}{4}$

θ : Torsion Angle(°)

L : Shaft Length(mm)

G : Transeverse Elastic Modulus(7.9 · 10^{4}N/mm^2)

ℓ : Unit Length(1000mm)

I_p : Polar Moment of Inertia I_p(mm^4) See Table 2.3

2-1-5 Deflection and Deflection Angle of the Spline shaft

These should be calculated using equations satisfying the relevant operating conditions.

Tables 2.1 and 2.2 present the operating conditions and the corresponding equations.

Tables 2.3 presents the cross-section factors (Z) and cross-section secondary moments (I).

Through the use of the Z and I values given in these tables, the strength and degree of displacement (deflection) of Ball spline model can be obtained.

Table 2.1 Deflection and Deflection-Angle Equation

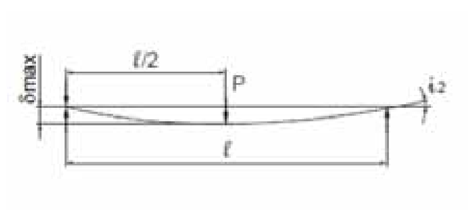
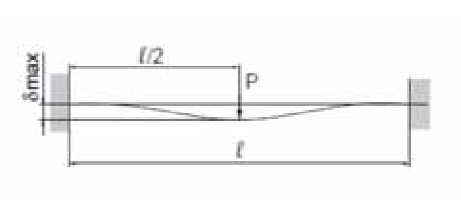
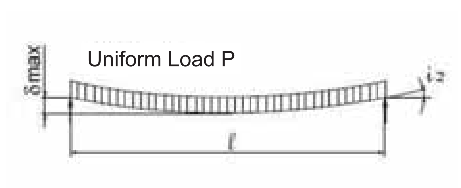
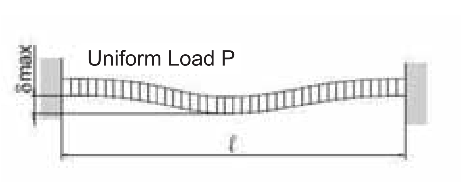
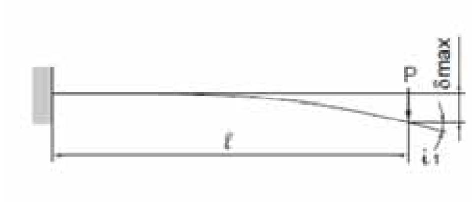
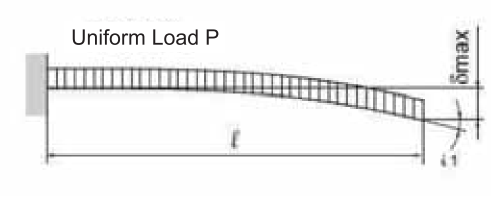
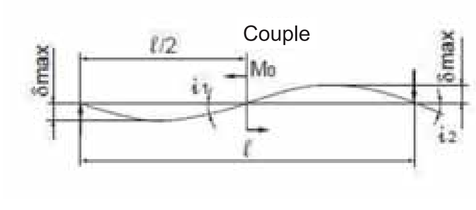
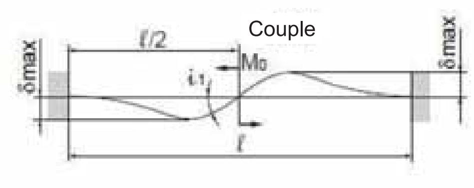
End Fixity	Specification Conditions	Deflection Equation	Deflection-Angle Equation
Both Ends Free		$\delta_{max} = \frac{P\ell^3}{48EI}$	$i_1 = 0$ $i_2 = \frac{P\ell^2}{16EI}$
Both Ends Fixed		$\delta_{max} = \frac{P\ell^3}{192EI}$	$i_1 = 0$ $i_2 = 0$
Both Ends Free		$\delta_{max} = \frac{5P\ell^4}{384EI}$	$i_2 = \frac{P\ell^3}{24EI}$
Both Ends Fixed		$\delta_{max} = \frac{P\ell^4}{384EI}$	$i_2 = 0$

Table 2.2 Deflection and Deflection-Angle Equation

End Fixity	Specification Conditions	Deflection Equation	Deflection-Angle Equation
One Ends Free		$\delta_{max} = \frac{P\ell^3}{3EI}$	$i_1 = \frac{P\ell^2}{2EI}$ $i_2 = 0$
One Ends Fixed		$\delta_{max} = \frac{P\ell^4}{8EI}$	$i_1 = \frac{P\ell^3}{6EI}$ $i_2 = 0$
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 Fixed		$\delta_{max} = \frac{M_0\ell^2}{216EI}$	$i_1 = \frac{M_0\ell}{16EI}$ $i_2 = 0$

δ_{max} : Maximum Deflection (mm)
i_1 : Deflection Angle at a Loading Point (deg)
i_2 : Deflection Angle at a Supporting Point (deg)
M_0 : Moment (N-mm)
P : Concentrated Load (N)
p : Uniform Load (N/mm)
ℓ : Span (mm)
I : Geometrical Moment of Inertia (mm^4)
E : Longitudinal Elastic Modulus (2.06×10^5 N/mm^2)

2-1-6 Critical Speed of Spline Shaft

When an operating Ball spline reaches critical speed, the mechanical resonance occurs and no further operation can be performed under mechanical resonance. Namely, to keep Ball spline under ideal operational, the speed limit must be kept under monitor. Therefore, to set an ideal operational speed for safety factor must be settled as 80% of critical speed as shown on equation (6)

Critical Speed

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

N_c : Critical Shaft Speed (min^{-1})

ℓ_b : Center Distance (mm)

E : Young's Modulus ($2.06 \cdot 10^5 N/mm^2$)

I : Moment of Inertia of the Shaft (mm^4)

$I = \frac{\pi}{64} d_1^4$ d_1 : Diameter (mm)

γ : Density(Specific Gravity) ($7.85 \cdot 10^{-6} kg/mm^3$)

$A = \frac{\pi}{4} d_1^2$ d_1 : Diameter (mm)

A : Spline-Shaft Cross-Sectional Area (mm^2)

λ : Installation-Method-Dependent Factor

(Fig2.4)Fixed/ Free $\lambda = 1.875$

(Fig2.5)Supported/ Supported $\lambda = 3.142$

(Fig2.6)Fixed/ Supported $\lambda = 3.927$

(Fig2.7)Fixed/ Fixed $\lambda = 4.73$

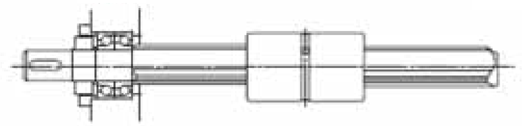


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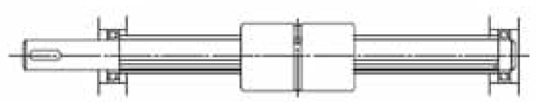
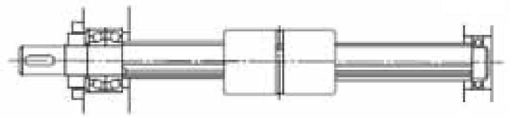
Fig 2.4



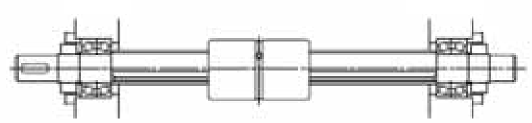
Supported — Supported

Fig 2.5



Fastened — Supported

Fig 2.6



Fastened — Fastened

Fig 2.7

2-1-7 Spline-Shaft Cross-Section

Table 2.3

Nominal Diameter		$I(mm^4)$	$I_p(mm^4)$	$Z(mm^3)$	$Z_p(mm^3)$
SLF6	Standard	63.49	119.23	55.74	39.74
	Hollow	62.70	117.66	54.96	39.22
SLF8	Standard	200.93	387.53	186.59	96.88
	Hollow	196.96	379.57	182.62	94.89
SLF10	Standard	490.25	933.29	443.05	186.66
	Hollow	477.68	908.16	430.48	181.63
SLF13	Standard	1400.81	2691.54	1290.72	414.08
	Hollow	1282.96	2455.82	1172.86	377.82
SLF16	Standard	3215.60	6242.70	3027.10	780.34
	Hollow	3014.53	5840.57	2826.04	730.07
SLF20	Standard	7851.80	15336.59	7484.79	1533.66
	Hollow	7360.93	14354.84	6993.91	1435.48
SLF25	Standard	18466.30	36932.60	18466.30	2954.61
	Hollow	15981.25	31962.50	15981.25	2557.00
SLF30	Standard	33122.31	66244.62	33122.31	4416.31
	Hollow	29905.32	59810.64	29905.32	3987.38
SLF40	Standard	120667.43	241334.87	120667.43	12066.74
	Hollow	112813.45	225626.90	112813.45	11281.35
SLF50	Standard	297123.73	594247.47	297123.73	23769.90
	Hollow	274691.98	549383.95	274691.98	21975.36

I : Geometrical moment of inertia (mm^4) I_p : Polar moment of inertia (mm^4)

Z : Section modulus (mm^3) Z_p : Polar section modulus (mm^3)

2-2 Service Life Expectancy

2-2-1 Nominal Life

TBI define the nominal life of Ball Spline as 90% of the average running distance before flaking within in the Ball Spline on the same manufacture cycle. Please note that therefore the nominal life expectancy is only for reference use.

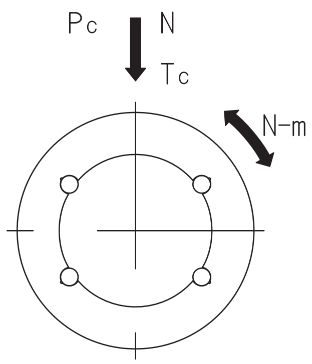


Fig 2.8

2-2-2 Calculating Nominal Life

The factors which influence the service life for Ball Splines can be attributed to three main aspects, the torque, radial load and moment. The influence of each aspect can be calculated through equations (7) to (10).

Under a Torque

$$L = \left(\frac{f_T \cdot f_C}{f_W} \cdot \frac{C_T}{T_C} \right)^3 \cdot 50 \text{.....} (7)$$

Under a Radial Load

$$L = \left(\frac{f_T \cdot f_C}{f_W} \cdot \frac{C}{P_C} \right)^3 \cdot 50 \text{.....} (8)$$

L : Nominal Life (km)
C_T : Basic Dynamic-Torque (N-m)
T_C : Calculated Torque Applied (N-m)
C : Basic Dynamic-Load Rating (N)
P_C : Radial Load (N)
f_T : Temperature (See Fig 2.9)
f_C : Contact (See Table 2.4)
f_W : Load Factor (See Table 2.5)

Under both a torque and radial load applied simultaneously

In this case, calculate the equivalent radial load to determine service life by equation.(9)

$$P_E = P_C + \frac{4 \cdot T_C \cdot 10^3}{i \cdot dp \cdot \cos\alpha} \text{.....} (9)$$

P_E : Equivalent radial Load(N)
$\cos\alpha$: Contact Angle
i : Number of Loaded Rows of Balls
dp : Ball Center-to-Center Shaft Diameter(mm) (Table 2.6)

Under a moment on one spline nut or two closely linked to one another

Obtain the equivalent radial load using the equation, and determine the service life by equation.(10)

$$P_U = K \cdot M \text{.....} (10)$$

P_U : Equivalent Radial Load(N)(Moment Applied)
K : Equivalent Factor(Table 2.6)
M : Applied Moment(N-mm)
Hower, M should be within the range of the stacic permissible moment.

Under both a moment and radial load applied simultaneously

Calculate the service life from the sum of the radial load and the equivalent radial load.

Calculating Nominal Life

Once the nominal life (L) is obtained, if the stroke length and the number of reciprocal operations are consistent, the service life in hours can be obtained by using the following equation.

$$L_h = \frac{L \cdot 10^3}{2 \cdot \ell_S \cdot n_1 \cdot 60} \text{.....} (11)$$

L_h : Service Life in Hours (h)
ℓ_S : Stroke Length (m)
n_1 : Number of Reciprocal Operations per Minute (min^{-1})

Temperature Factor (f_T)

When the Ball Spline operates in an environment which the temperature reaches 100°C or higher, considering that the heat may adversely affect the operation of the Ball Spline. To avoid malfunction under extreme temperature, Fig 2.9 should be taken into account. In addition that the material of Ball Spline should be heat resistant and custom made when use under extreme environment.

Note: Please inform TBI sales for upgrading the material for the operation environment exceeds 80°C for the reason that the materials of seal and retainers should be upgraded to sustain the high-temperature.

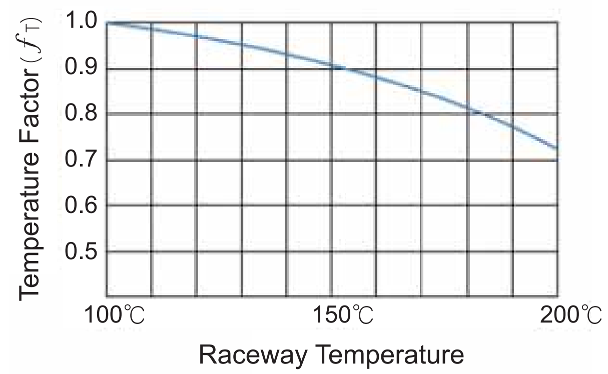


Fig 2.9 Temperature Factor (f_T)

Contact Factor (f_C)

When one o multiple Spline nuts mounts on the Spline shaft closeley , their linear motion is affected by moments and mounting accuracy, resulting in nonuniform load distribution. When closely linked spline nuts are used, multiply the basic load rating (C or Co) by one of the contact factors specified below.

Note: if a non-uniform load distribution is expected, as in large equipment, take the contact factor explained in Table 4 into account.

Table 2.4 Contact Factor (f_C)

No. of Spline nuts Linked	f_C
2	0.81
3	0.72
4	0.66
5	0.61
In Normal Use	1.0

Load Factor (f_W)

The operation of reciprocal machines is likely to cause vibration and impact. It is difficult to determine the rating of vibration and impact in the event of vibration and repeated impact during high speed operation and triggering and ceasing of operation. Therefore, when loads exerted on a linear-motion or operation velocity and vibration is extreme. Take the basic load rating (C or Co) and multiply the figure shown in table 2.5.

Table 2.5 Load Factor (f_W)

Vibration Impact	Velocity (V)	f_W
Minor	Minor velocity $V \leqq 0.25$ m/s	1-1.2
Little	Low velocity $0.25 < V \leqq 1.0$ m/s	1.2-1.5
Medium	Medium Velocity $1.0 < V \leqq 2.0$ m/s	1.5-2.0
Heavy	High velocity $V > 2.0$ m/s	2.0-3.5

2-2-3 Calculating the average applied load

The Applied load fluctuates during the operation of Ball Spline, For example, the applied load during the activities of an industrial robotic arm is different before holding a workpiece and reurn without it In a machine tool, the spline nut of the Ball Spline receives varying loads. Therefore, variables of the applied which influence the to calculate the service life of Ball Spline under on the hose-system operating conditions. The service life of the Ball Spline should therefore be calculated in consideration of such fluctuations in load. The mean load (Pm) is the load under which the service life of the Ball Spline becomes equivalent to that under varying loads exerted on the spline nut while in operation.

The Equation is as below

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

P_m : Mean Load (N)
P_n : Fluctuating Load (N)
L : Total Running Distance (mm)
L_n : Running Distance Under Load Pn (mm)

For Loads That Change Stepwise

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

P_m : Mean Load (N)
P_n : Fluctuating Load (N)
L : Total Running Distance (mm)
L_n : Running Distance Under Load Pn (mm)

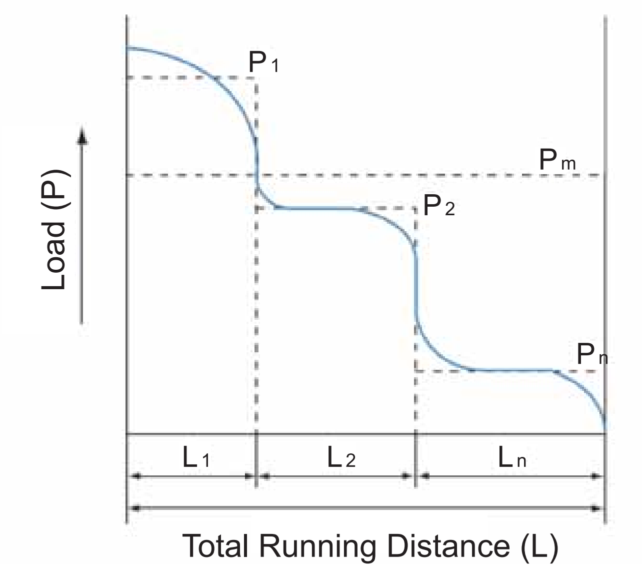


Fig 2.10

For Loads That Change Monotonically

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

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

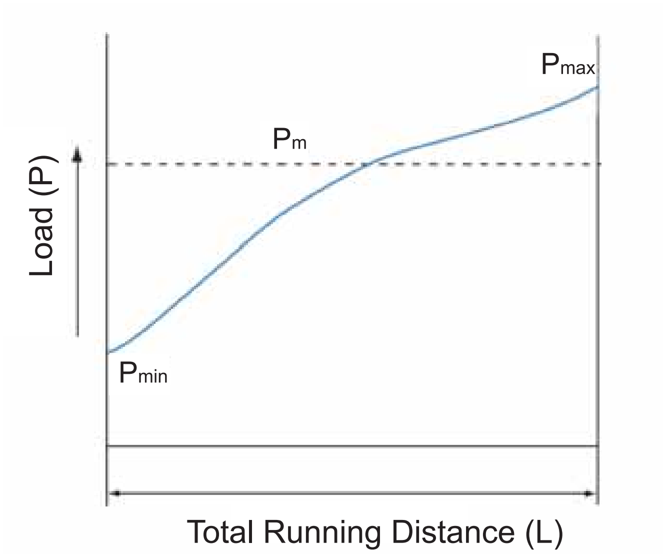


Fig 2.11

For Loads That Change Sinusoidal

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

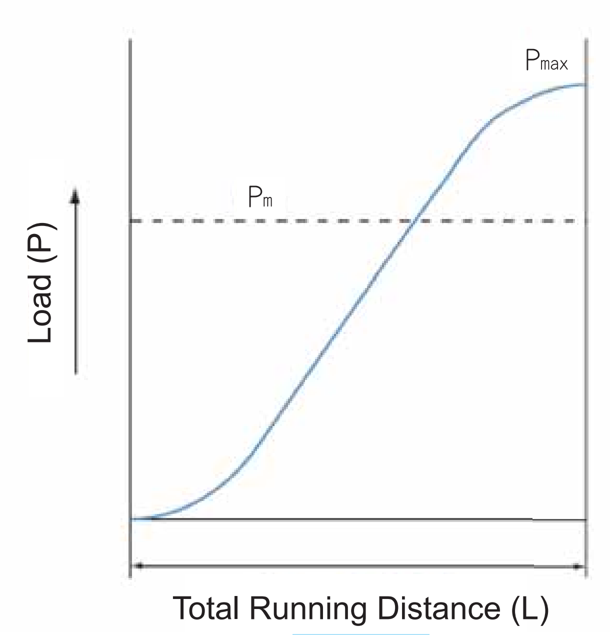


Fig 2.12

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

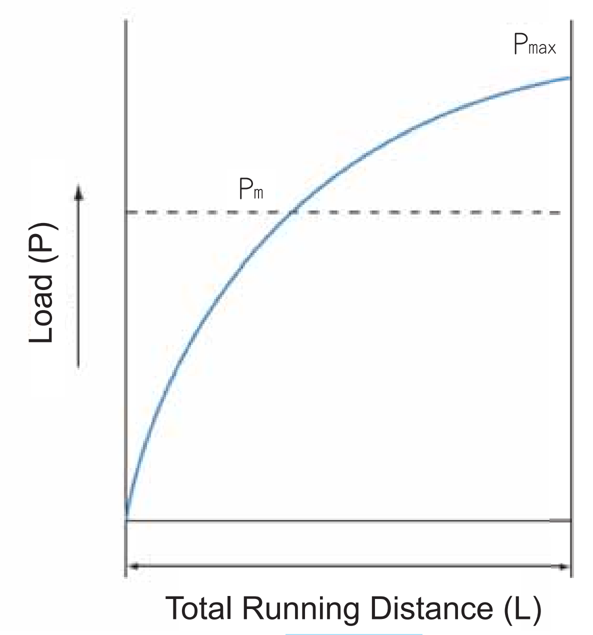


Fig 2.13

2-2-4 Equivalent Factor

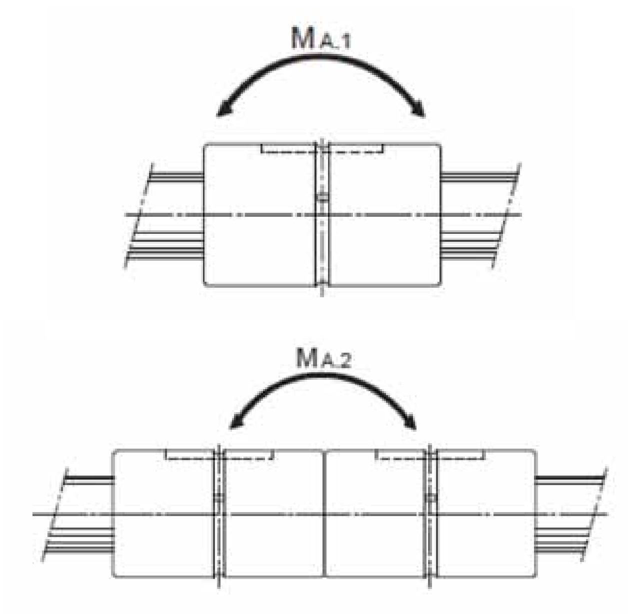


Fig 2.14

Table 2.6

Model number	Equivalent Factor : K	
	One Spline Nut	Two spline nuts
SLF06	0.434	0.055
SLF08	0.434	0.055
SLF10	0.375	0.047
SLF12	0.326	0.043
SLF13	0.211	0.032
SLF20	0.181	0.028
SLF25	0.142	0.023
SLF30	0.118	0.020
SLF40	0.104	0.016
SLF50	0.079	0.013

2-3 Calculating the Service life

HORIZONTAL APPLICATION

A 300 mm long Ball Spline supported by two fixed nuts on each end setup for an horizontal application, the load of the Spline falls vertically downward on the fixed side with 30 mm away from the center of ball spline with the gravity force of W = 30kg. The figure is shown as :

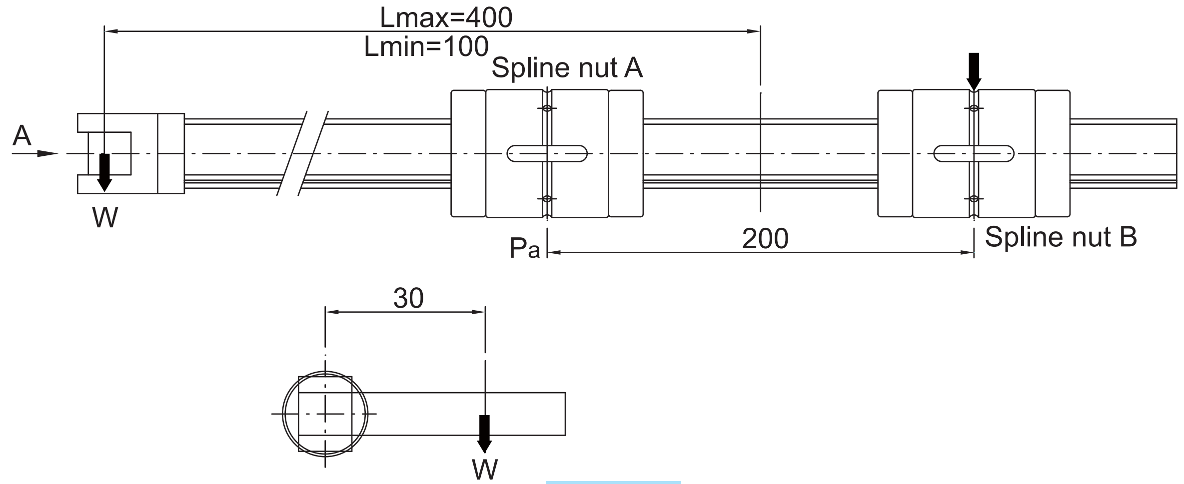


Fig One

A.Calculates the Spline shaft strength

The present structure of ball spline is an extended bridge, it is designed to absorb torque, therefore the maxima bending load occurs on Spline nut A :

Maxima Bending Moment   M = 30 • 9.81 • 400 = 117720 N-mm

Maxima Torsion Moment   T = 30 • 9.81 • 30 = 8829 N-mm

For Ball Spline shafts subjected to the simultaneous application of torsion and bending loads, thus the calculation should include Equivalent Bending Moment, Me and Equivalent Torsion Moment Te :

$M_e = \frac{M + \sqrt{M^2 + T^2}}{2} = 117885$ N-mm $T_e = \sqrt{M^2 + T^2} = 118051$ N-mm

Te > Me

$T_e = \tau a \cdot Z_p$

$\therefore Z_p = T_e / \tau a = 118051/49 = 2409.2\ mm^3$

According to figure of cross section showed on the spline, the minimum of 25mm in diameter is required to in order to gain enough of strength for Ball Spline, therefore SLF25 matches the requirement above thus choose SLF25.

B.Calculating the Mean Load

When the bridge extension reached Lmax=400mm, it reaches it' maxima load(Pmax)
When it retrieved back to Lmin=100mm, it absorbed the minimum of load(Pmin)
According to mechanics it allows us to find out the maxima and minimum Radial Load of Nut A and nut B :

$P_{Amax} = 30 \cdot 9.81 \cdot (400+200)/200 = 882.9$ N $P_{Bmax} = 30 \cdot 9.81 \cdot 400/200 = 588.6$ N

$P_{Amin} = 30 \cdot 9.81 \cdot (100+200)/200 = 441.5$ N $P_{Bmin} = 30 \cdot 9.81 \cdot 100/200 = 147.2$ N

When the movement of Ball Spline occurs, the load on the spline is gradual and repeated, according to Fig 2.11 the equation of the load on ball spline is shown as :

$P_{Am} = 1/3(P_{Amin} + 2P_{Amax}) = 735.8$ N $P_{Bm} = 1/3(P_{Bmin} + 2P_{Bmax}) = 441.5$ N

The nuts receive both torsion and bending load simultaneously, therefore assuming that the torsion lies equally on the nuts. The equation for torsion is shown as T :

$T' = T / 2 = 30 \cdot 9.81 \cdot 30 / 2 = 4414.5$ N-mm

The equivalent factor Pe(P11, type 9) :

$$P_e = P_m + \frac{4 \cdot T'}{i \cdot dp \cdot \cos\alpha}$$

$P_{AE} = 735.8 + \frac{4 \cdot 4414.5}{4 \cdot 27 \cdot \cos 50°} = 990.2$ N $P_{BE} = 441.5 + \frac{4 \cdot 4414.5}{4 \cdot 27 \cdot \cos 50°} = 695.9$ N

C. Service life Ball Spline

Nut A life $L_A = \left(\frac{f_T \cdot f_C}{f_W} \cdot \frac{C}{P_{AE}}\right)^3 \cdot 50 = 14518$ km

Nut B life $L_B = \left(\frac{f_T \cdot f_C}{f_W} \cdot \frac{C}{P_{BE}}\right)^3 \cdot 50 = 41829$ km

Factors
f_T : Temperature = 1
f_C : Friction = 1
f_W : Load = 1.5
C : Coa = 9835 N

The service life of Ball Spline is correlated with Nut A and the of service life is estimated as 14518 km.

VERTICAL APPLICATION

A 1200mm long ball spline with stroke of 1000 mm is mounted on a working platform supported by two fixed nuts on both end. The geometry is shown as Fig Two.

The point of drive force F is X_1 = 50mm from the center of Ball Spline, The weight platform W_1 is 27kg, The center of the weight is X_2 = 300mm away from the center of ball spline, The working cycle of platform is a carriage of W_2 = 5kg with a downward movement for 5sec hold for 10sec and elevation for 5sec hold for 10sec to unload the carriage repeatedly. The center of gravity of carriage is X_3 = 500mm from the center of ball spline, The travelling of velocity is shown as Fig Two.

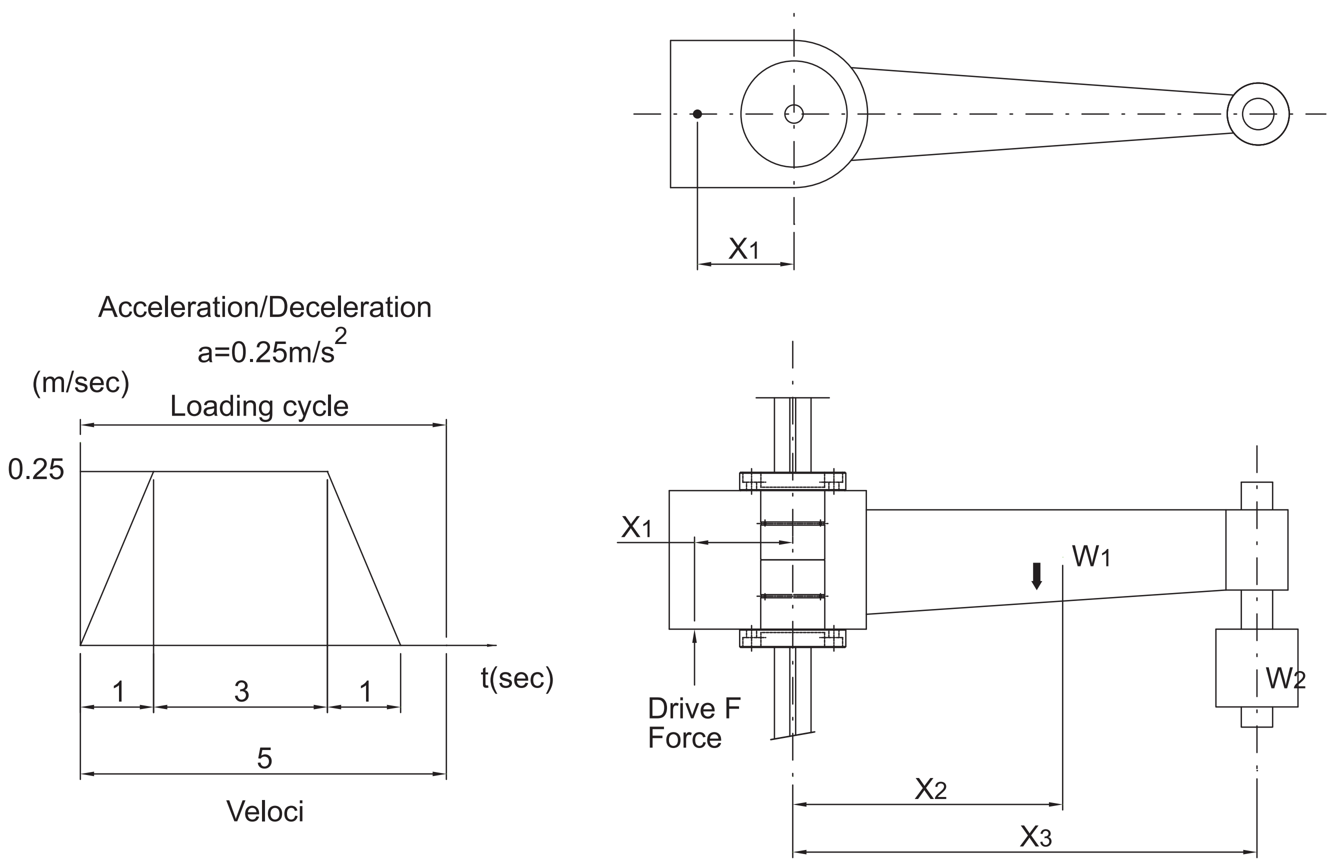


Fig Two

A.Analysis on Different Stage of Exertion

Inertial force occurs when a platform is in working modes, drive force is the source of the inertial force.

Inertial force of a m/s^2 in acceleration ascent and deceleration decent : F = W · (9.81+a)

Inertial force of Constant velocity in acceleration and deceleration : F = W · (9.81a)

Inertial force of a m/s^2 in acceleration decent and deceleration ascent : F = W · (9.81-a)

Below are the equations of the bending force absorb by the nuts during acceleration, constant velocity, deceleration while ball ascent and decent.

A.(Without carriage)Acceleration while decent

$M_{da} = W_1 \cdot (9.81-a) \cdot 300 + W_1 \cdot (9.81-a) \cdot 50 = 90342$ N-mm

B.(Without carriage)constant velocity while decent

$M_{dc} = W_1 \cdot (9.81) \cdot 300 + W_1 \cdot (9.81) \cdot 50 = 92704.5$ N-mm

C.(Without carriage)deceleration while decent

$M_{dd} = W_1 \cdot (9.81+a) \cdot 300 + W_1 \cdot (9.81+a) \cdot 50 = 95067$ N-mm

D.(With carriage)acceleration while ascent

$M_{aa} = W_1 \cdot (9.81+a) \cdot 300 + W_1 \cdot (9.81+a) \cdot 50 + W_2 \cdot (9.81+a) \cdot 500 + W_2 \cdot (9.81+a) \cdot 50 = 122732$ N-mm

E.(With carriage)constant velocity while ascent

$M_{ac} = W_1 \cdot (9.81) \cdot 300 + W_1 \cdot (9.81) \cdot 50 + W_2 \cdot (9.81) \cdot 500 + W_2 \cdot (9.81) \cdot 50 = 119682$ N-mm

F.(With carriage)deceleration while ascent

$M_{ad} = W_1 \cdot (9.81-a) \cdot 300 + W_1 \cdot (9.81-a) \cdot 50 + W_2 \cdot (9.81-a) \cdot 500 + W_2 \cdot (9.81-a) \cdot 50 = 116632$ N-mm

B.The calculation of spline strength

The present structure of ball spline is supported by two fixed nuts on both ends with an bridge of absorbing bending in the middle. it designed to absorb torque. According to mechanics the maxima bending load occurs on the supporting end. The Maxima Bending Moment should occur on at the end of acceleration.

Maxima Bending Moment M=122732 N-mm

$\therefore Z = M / \sigma a = 122732/98 = 1252.4\ mm^3$

According to figure of cross section showed on the spline, the minimum of 25mm in diameter is required to in order to gain enough of strength for Ball Spline, therefore SLF25 matches the requirement above thus choose SLF25.

C.Calculating the Mean Load

The nuts and spline mainly affect by the force of bending, therefore represent(P11, type 10) by converting the force of bending into radial load.

$P_n = K \cdot M$

According to Table 2.6, when joint two SLF25 nuts, The equivalent factor K = 0.023

$P_{da} = 0.023 \cdot 90342 = 2078$ N

$P_{dc} = 0.023 \cdot 92704.5 = 2132.2$ N

$P_{dd} = 0.023 \cdot 95067 = 2186.5$ N

$P_{aa} = 0.023 \cdot 122732 = 2822.8$ N

$P_{ac} = 0.023 \cdot 119682 = 2752.7$ N

$P_{ad} = 0.023 \cdot 116632 = 2682.5$ N

The average load in every time peroid can be calculate as P_m :

$P_m = \sqrt[3]{\frac{1}{L} \cdot \sum_{n=1}^{n} (P_n^3 \cdot L_n)}$	P_m : Average Load	(N)
	P_n : Load in variable	(N)
	L : Total service distances	(mm)
	L_n : P_nService distances under loading	(mm)

$$P_m = \sqrt[3]{\frac{1}{1000}\{125 \cdot 2078^3 + 750 \cdot (2132.2)^3 + 125 \cdot (2822.8)^3 + 750 \cdot (2752.7)^3 + 125 \cdot (2682.5)^3} = 2481.6\ N$$

D.Analysis of Ball Spline Service

$$\text{Servicee Life } L = \left(\frac{f_T \cdot f_C}{f_W} \cdot \frac{C}{P_m}\right)^3 \cdot 50 = 922\ km$$

f_T : Temperature = 1

f_C : Friction = 1

f_W : Load = 1.5

C : Coa = 9835 N

2-4 Determining the Preload

The preload a significant factor toward the accuracy, load resistance and rigidity of Ball Spline during operation. Therefore, it is very important to determine the most appropriate size of the clearance for your purpose of use. The size of the clearance is standardized for each type, enabling the one best-suited for operating conditions to be selected.

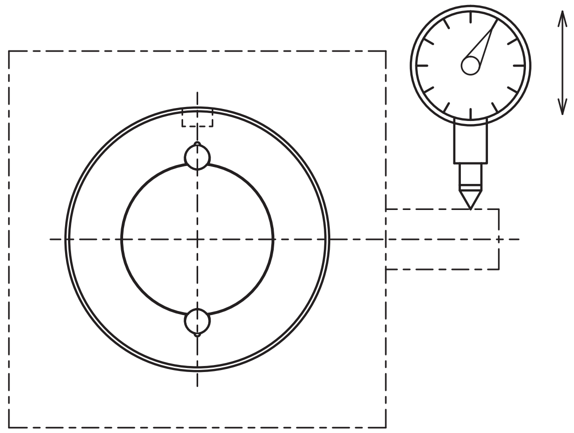


Fig 2.15

2-4-1 Clearance in the Rotational Direction

With the Ball Spline, the sum of clearances in the circumferential direction is standardized as the clearance in the rotational direction. Clearance in the Rotational Direction (BCD)

2-4-2 Preload and Rigidity

The preload is the load applied to balls prior to use for the purposes of eliminating angular backlash (clearance in the rotational direction) and improving rigidity. The application of a preload can eliminate angular backlash in the Ball Spline in accordance with the level of applied preload, and can improve rigidity. Fig 2.16 shows the amount of displacement in the rotational direction when a rotational torque is applied. As shown, the effect of preloading continues until the torque becomes Fig 2.16 times greater than the preload applied. Compared with a setting without a preload, displacement at the same rotational torque is half that under a preload or less, and the rigidity is twice as great.

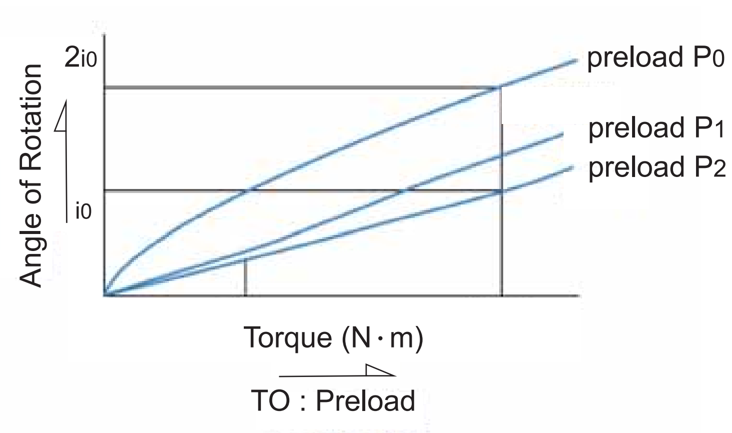


Fig 2.16

2-4-3 Operating Conditions and Determination of the Preload Level

Table 2.7 presents guidelines for determining the appropriate clearance in the rotational direction for the given operating conditions. The rotational clearance of the Ball Spline significantly affects the accuracy and rigidity of the Spline nut. Therefore, it is critical to select the clearance best suited for the intended uses of the Ball Spline. Normally, the Ball Spline in use is preloaded. When it is subjected to repeated swiveling and reciprocal linear motion, a system receives heavy vibration and impact. In such an environment, preloading prolongs the service life and improves accuracy.

Table 2.7 Guidelines for Determining an Appropriate Ball Spline Clearance according the Rotational Direction.

	Preloading	Operating conditions	Conditions
Clearance in the Rotational Direction	Medium Preload P2	• High rigidity is required. Vibration and impact are severe. • The moment load must be borne by a single spline nut.	• Construction-work-vehicle steering shaft. • Spot-welding-machine shaft. • Automatic-lathe-tool rest indexing shaft.
	Slight Preload P1	• Hanging loads and moments are applied. • Highly reproducible accuracy is required. • Alternate loads are applied.	• Industrial robot arm Various automatic. • loaders. • Automatic-painting-machine guide shaft. • Electric-discharge-machine spindle. • Press die-set guide shaft. • Drilling-machine spindle.
	Normal P0	• Smooth movement should be achieved with only a low magnitude of force. • Torque is continually applied in a given direction.	• Various measuring instruments. • Automatic drafting machine. • Shape-measuring instrument. • Dynamometer. • Wire winder. • Automatic arc cutter. • Honing-machine spindle. • Automatic packing machine.

Table 2.8 SLT and SLF Clearance in the Rotational Direction

Unit : μm

Nominal Diameter \ Preload		No preload	Slight preload	Medium Preload
		P0	P1	P2
6, 8	10, 13	-2～+1	-6～-2	-
16	20	-2～+1	-6～-2	-9～-5
25	30	-3～+2	-10～-4	-14～-8
40	50	-4～+2	-16～-8	-22～-14

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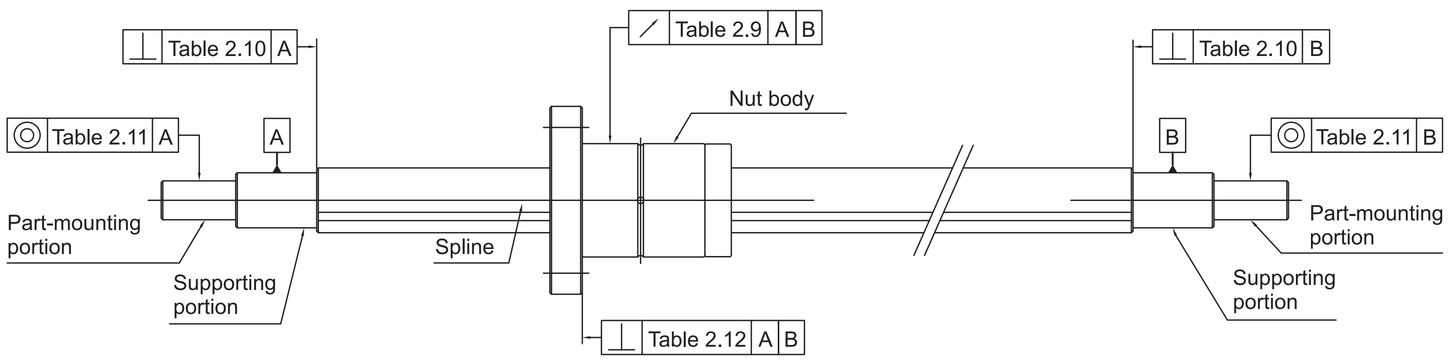
2-5 Accuracy

2-5-1 Accuracy Grade

The accuracy of the Ball Spline is determined by the callout of the spline-nut and thus divided into three accuracy grades of Normal(N), High(H), and Precision(P).



2-5-2 Accuracy Spec

Tables 2.9 ~ 13 indicates the the measurement items of the Ball Spline.

Table 2.9 The Maximum call out of Spline Nut on the support unit

Unit : μm

Length \ Nominal Diameter		6, 8			10			13, 16, 20			25, 30			40, 50		
Above	Below	N	H	P	N	H	P	N	H	P	N	H	P	N	H	P
-	200	72	46	26	59	36	20	56	34	18	53	32	18	53	32	16
200	315	133	89	57	83	54	32	71	45	25	58	39	21	58	36	19
315	400	185	126	82	103	68	41	83	53	31	70	44	25	63	39	21
400	500	236	163	108	123	82	51	95	62	38	78	50	29	68	43	24
500	630	-	-	-	151	102	65	112	-	-	88	57	34	74	47	27
630	800	-	-	-	190	130	85	-	-	-	103	68	42	84	54	32

Table 2.10 The Maximum perpendicularity of Spline-shaft end on the journal ends

Unit : μm

Nominal Diameter \ Accuracy	Normal (N)	High (H)	Precision (P)
6, 8, 10	22	9	6
13, 16, 20	27	11	8
25, 30	33	13	9
40, 50	39	16	11

Table 2.11 The maximum radial call out on the attach surface

Unit : μm

Nominal Diameter \ Accuracy	Normal (N)	High (H)	Precision (P)
6, 8	33	14	8
10	41	17	10
13, 16, 20	46	19	12
25, 30	53	22	13
40, 50	62	25	15

Table 2.12 The perpendicularity of flange on the attach surface

Unit : μm

Nominal Diameter \ Accuracy	Normal (N)	High (H)	Precision (P)
6, 8	17	11	8
10, 13	33	13	9
16, 20, 25, 30	30	16	11
40, 50	46	19	13

Table. 2.13 The accuracy level on the effective length accuracy

Unit : μm

Accuracy	Normal(N)	High(H)	Precision(P)
Permissible	33	13	6

Note：Measurement according to any 100mm on the Spline shaft.

2-6 Lubrication

The spline nut is prelubricated prior to shipment for immediate use and the maintenance period is varied according to the operating conditions. TBI suggested that under normal operation condition re-lubricate your TBI Ball Spline after 100 kilometer or 6-12 months of operation. Apply lubricant within the nut body or on the groove of Spline shaft.

2-7 Material and Surface treatment

TBI provides customize material and surface treatment in order to meet extreme operation condition. Please contact TBI service window for customized surface treatment and material.

2-8 Caution

2-8-1 General maintenance

(1) Disassemble ball spline without supervise of TBI certified engineer will casue malfunction on the ball spline.

(2) Gravity causes the spline nut slides when lining the ball spline, handle with care.

(3) DO NOT hammering, freefall the ball spline such action will damaging the ball spline and might hinder the performance of ball spline.

(4) Prevent debris, scraps from intervene the ball spline cause it will decrease the performance to ball spline or lead to malfunction.

(5) Prevent the ball spline operates under extreme condition. Contact TBI service window when the TBI ball spline is intend to use under extreme condition.

(6) Coolant might casue malfunction on the ball spline, please contact TBI certified engineer for consulting the use of coolant.

(7) Clean attached debris and scraps before relubrication.

(8) Please contact TBI certified engineer for consulting when the ball spline is designed to operates under frequently vibrates, vacuum, extreme high and low temperature condition.

(9) Please contact TBI certified engineer for consulting when mounting a through hole on the flanged ball spline.

2-8-2 Lubrication

(1) Remove anti-dust oil before seal the ball spline with grease.

(2) Prevent mix different kind of grease, it will cause unexpected chemical deform.

(3) Please contact TBI certified engineer for consulting the use of grease when the ball spline is designed to operates under frequently vibrates, vacuum, extreme high and low temperature condition.

(4) Please contact TBI certified engineer for consulting the use NON TBI certified grease.

(5) When using of motor oil to serve the purpose of lubrication, it might cause performance declining due to the un-proper installation. Please contact TBI certified engineer for consulting.

2-8-3 Storage

Prevent extreme temperature and humidity when store ball spline, also use TBI certified seal and storage and it in a horizontal position.

2-9 Mounting

2-9-1 Tolerance on support unit

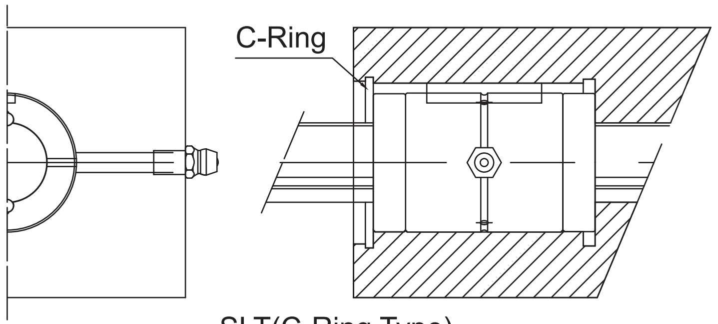
Ball spline nut and its support unit is bore to minimize the clearance. If high accuracy is not required, then a clearance fit can be used.

Table 2.14

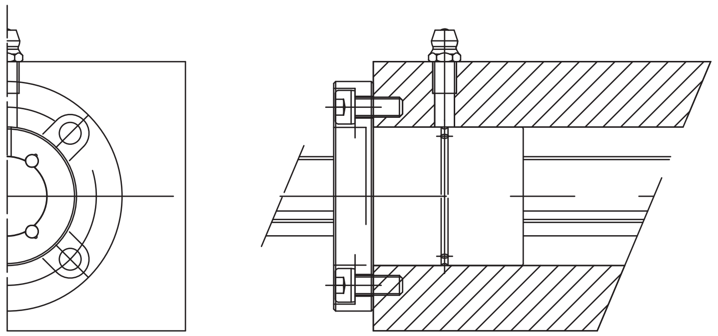
Condition	Tolerance within support Unit
General operation condition	H7
Operation under minimize of axial clearance	J6

2-9-2 Installation of ball spline

The installation of the ball spline is shown as Fig 2.18. Though the strength of mounting is not strictly standard, but it has to be certain that the the spline shaft has to be firmly fixed on the support unit.



SLT(C-Ring Type)



SLF(Flange One-Stage Type)

Fig 2.18 Sample of Spline-Nut Assembly

2-9-3 Installation of Spline Nut

When intalling a spline nut into the spline shaft, use a jig like Fig 2.19 to insert the spline but with care.

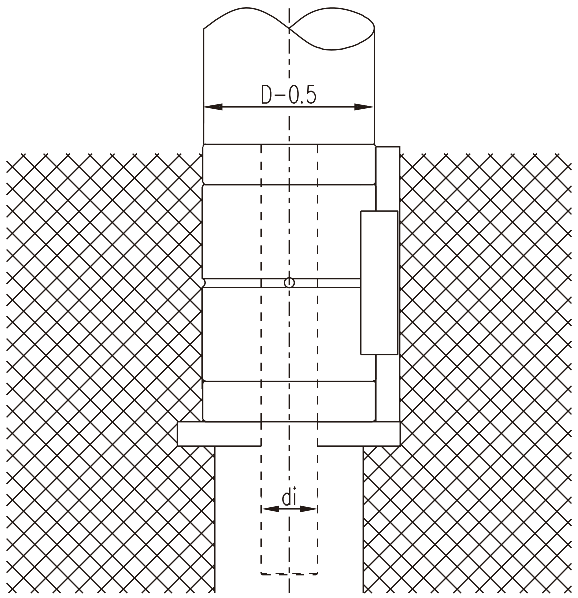


Fig 2.19

Table 2.15 Specification of the jig

Unit：mm

Nominal Dia	6	8	10	13	16	20	25	30	40	50
di	5.0	7.0	8.5	11.5	14.5	18.5	23	28	37.5	46.5

3-1 Nominal code of SL

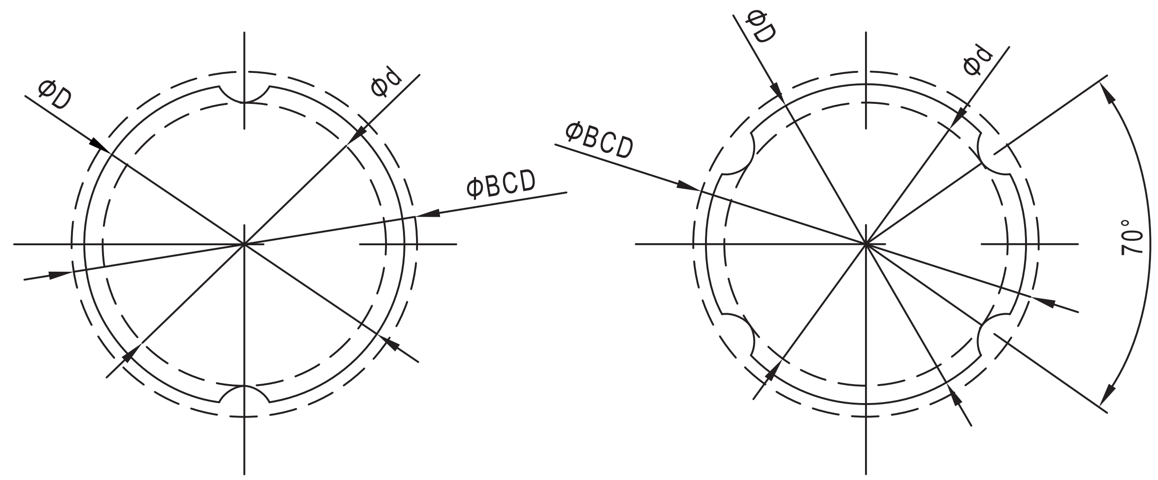
SLF 006 T2 N N S - 500 - P0 - B2

- **SLF** — Spline Nut
  SLF : Flanged SLT : Cylindrical
- **006** — Nominal Diameter
  Unit : mm
- **T2** — Groove
  T2 : 2 Rows T4 : 4 Rows
- **N** — Type of Flange
  N : Round (No Symbol When It is Without the Flange)
- **N** — Accuracy grade
  N : Normal H : High P : Precision
- **S** — Spline shaft type
  S : Solid shaft H : Hollow Shaft
- **500** — Length of Ball Spline
  Unit : mm
- **P0** — Preload Level
  P0 : No preload P1 : light preload P2 : Medium preload
- **B2** — Number of Spline nut
  (Leave blank if only one nut is required) Ex : Two install two spline nuts in a shaft : B2

3-2 Spline Shaft

3-2-1 Solid Spline Shaft Cross-Sectional Shape

Table 3.1, 3.2 indicates the cross-section of spline shaft. When the shaft is round pillar type the minor diameter must be no smaller than groove ridge.



D≦20 D≧25

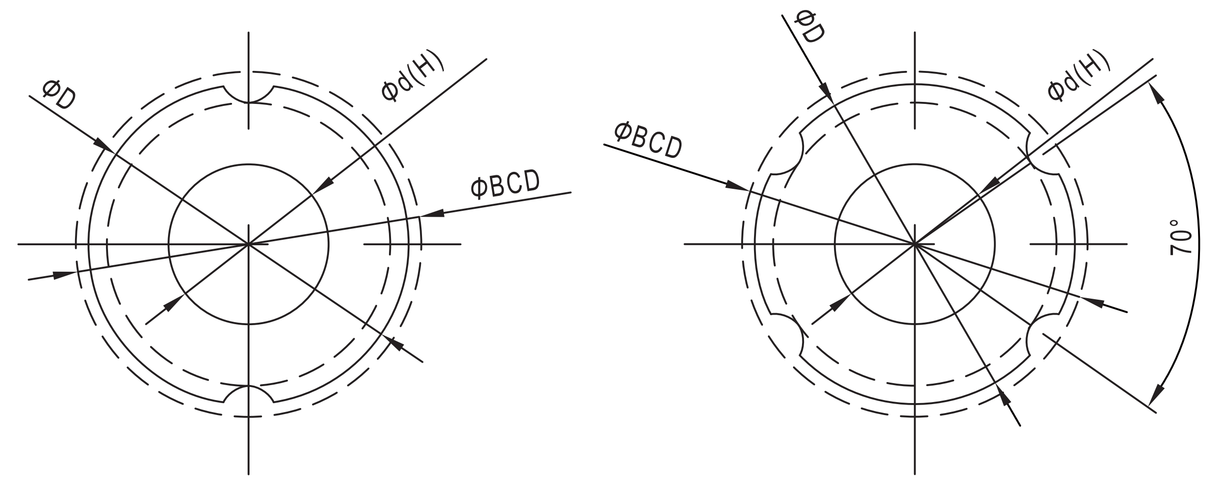
Solid Spline Shaft

Table 3.1 Solid Spline Shaft Cross-Sectional Shape

Unit : mm

Nominal Dia / Stats	6	8	10	13	16	20	25	30	40	50
Inner Diameter Φd	5.25	7.27	8.97	11.82	14.72	18.63	23.43	28.53	37.3	47.05
Outer Diameter ΦD h7	6	8	10	13	16	20	25	30	40	50
Mass(kg/m)	0.22	0.39	0.6	1.03	1.56	2.44	3.8	5.49	9.69	15.19
Ball Center ΦBCD	6.75	8.77	11.35	14.6	17.5	21.8	27	32.1	43.65	54.2
Tolerance μm	0 -15	0 -15	0 -18	0 -18	0 -18	0 -21	0 -21	0 -25	0 -25	0 -30

3-2-2 Hollow Spline Shaft Cross-Sectional Shape



D≦20 D≧25

Hollow Spline Shaft

Table 3.2 Hollow Spline Shaft Cross-Sectional Shape

Unit : mm

Nominal Dia / Stats	6	8	10	13	16	20	25	30	40	50
Inner Diameter Φd	2	3	4	7	8	10	15	16	20	26
Outer Diameter ΦD h7	6	8	10	13	16	20	25	30	40	50
Mass(kg/m)	0.177	0.33	0.506	0.872	1.25	1.82	2.92	3.93	6.75	11.4
Ball Center ΦBCD	6.75	8.77	11.35	14.6	17.5	21.8	27	32.1	43.65	54.2
Tolerance μm	0 -15	0 -15	0 -18	0 -18	0 -18	0 -21	0 -21	0 -25	0 -25	0 -30

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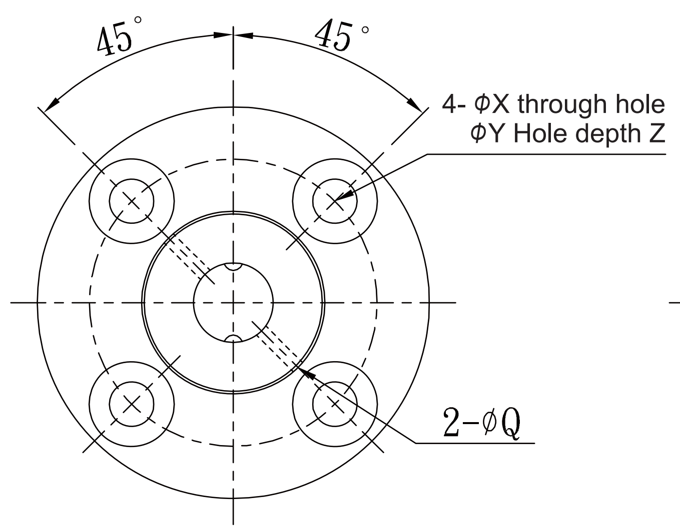
3-2-3 SLF Specifications



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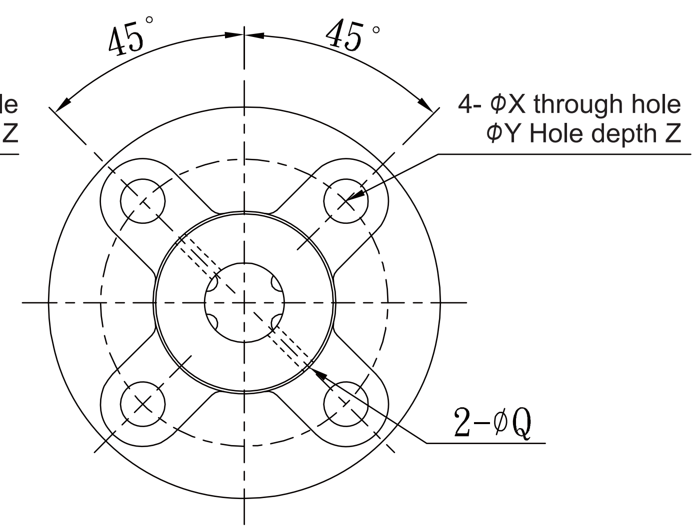
Shaft diameter d≦20



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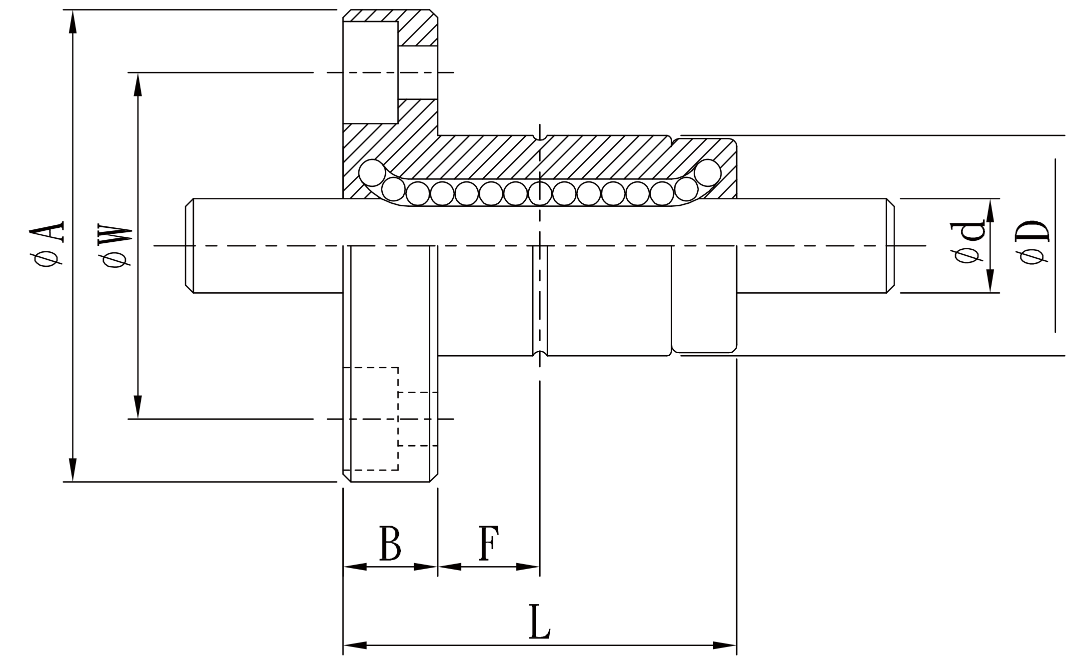
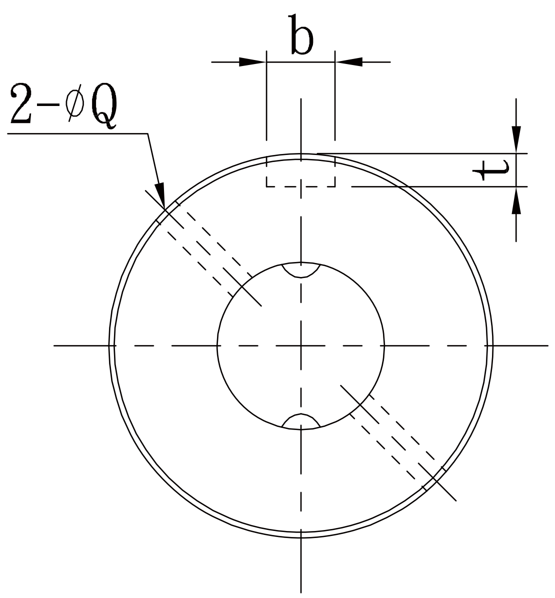
Shaft diameter d≧25



Nominal Diameter	Spline Nuts								Groove deepth	Row
	D	L	A	B	F	Oil Q	W	Mouning hole X · Y · Z	d h7	
SLF6	14	25	30	6	7.5	1	22	3.4 · 6.5 · 4.5	6	2
SLF8	16	27	32	8	7.5	1.5	24	3.4 · 6.5 · 4.5	8	2
SLF10	21	33	42	9	10.5	1.5	32	4.5 · 8 · 4	10	2
SLF13	24	36	44	9	11	1.5	33	4.5 · 8 · 4.5	13	2
SLF16	31	50	51	10	18	2	40	4.5 · 8 · 6	16	2
SLF20	35	56	58	10	18	2	45	5.5 · 9.5 · 5.4	20	2
SLF25	42	71	65	13	26.5	3	52	5.5 · 9.5 · 8	25	4
SLF30	47	80	75	13	30	3	60	6.6 · 11 · 8	30	4
SLF40	64	100	100	18	36	4	82	9 · 14 · 12	40	4
SLF50	80	125	124	20	46.5	4	102	11 · 17.5 · 12	50	4

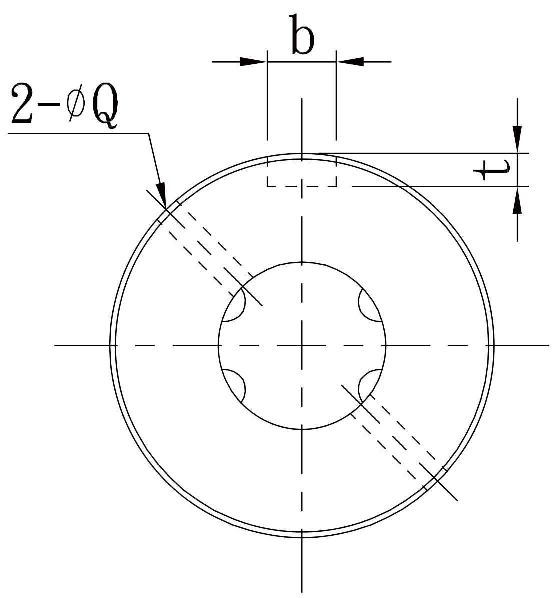
Nominal Diameter	Basic Rating Load		Basic torsional		Diameter		Mass	
	C	Co	CT	CoT	MA1	MA2	Spline Nut	Spline Shaft
	kgf	kgf	kgf · m	kgf · m	kgf · m	kgf · m	g	kg/m
SLF6	137	225	0.46	0.76	0.39	3.48	36.7	0.22
SLF8	137	225	0.60	0.99	0.39	3.82	47	0.39
SLF10	285	397	1.62	2.25	0.95	8.53	100	0.60
SLF13	396	540	2.89	3.94	1.50	12.46	117	1.03
SLF16	545	849	4.77	7.43	3.71	26.09	226	1.56
SLF20	724	1109	7.90	12.09	5.53	38.00	303	2.44
SLF25	1003	1593	21.99	43.01	10.35	68.59	458	3.80
SLF30	1160	1980	30.26	62.93	15.68	93.27	633	5.49
SLF40	2972	4033	105.37	176.05	36.59	246.34	1430	9.69
SLF50	4086	5615	179.89	304.35	51.58	428.72	2756	15.19

3-2-4 SLT Specifications



< Two row >

Shaft diameter d≦20



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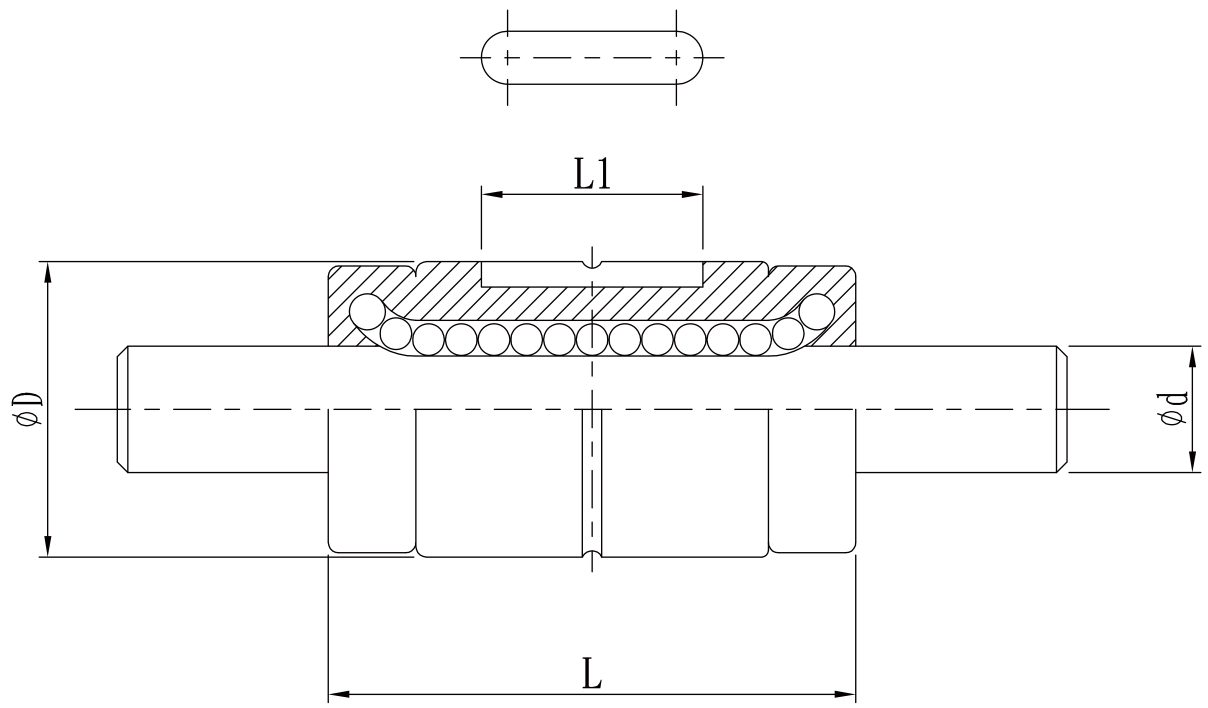
Shaft diameter d≧25



Nominal Diameter	Spline Nuts				Keyway Dimensions		Groove deepth	
	D	L	L1	Oil	b	t	d	Row
				Q	H8	+0.05 ~0	h7	
SLT6	14	25	10.5	1	2.5	1.2	6	2
SLT8	16	27	10.5	1.5	2.5	1.2	8	2
SLT10	21	33	13	1.5	3	1.5	10	2
SLT13	24	36	15	1.5	3	1.5	13	2
SLT16	31	50	17.5	2	3.5	2	16	2
SLT20	35	56	29	2	4	2.5	20	2
SLT25	42	71	36	3	4	2.5	25	4
SLT30	47	80	42	3	4	2.5	30	4
SLT40	64	100	52	4	6	3.5	40	4
SLT50	80	125	58	4	8	4	50	4

Nominal Diameter	Basic Rating Load		Basic torsional		Diameter		Mass	
	C	C0	CT	C0T	MA1	MA2	Spline Nut	Spline Shaft
	kgf	kgf	kgf·m	kgf·m	kgf·m	kgf·m	g	kg/m
SLT6	137	225	0.46	0.76	0.39	3.48	14	0.22
SLT8	137	225	0.60	0.99	0.39	3.82	16	0.39
SLT10	285	397	1.62	2.25	0.95	8.53	37	0.60
SLT13	396	540	2.89	3.94	1.50	12.46	52	1.03
SLT16	545	849	4.77	7.43	3.71	26.09	130	1.56
SLT20	724	1109	7.90	12.09	5.53	38.00	188	2.44
SLT25	1003	1593	21.99	43.01	10.35	68.59	285	3.80
SLT30	1160	1960	30.26	62.93	15.68	93.27	395	5.49
SLT40	2972	4033	105.37	176.05	36.59	264.34	843	9.69
SLT50	4086	5615	179.89	304.35	51.58	428.72	1758	15.19

E-mail:tbi.tbi@msa.hinet.net
http://www.tbimotion.com.tw