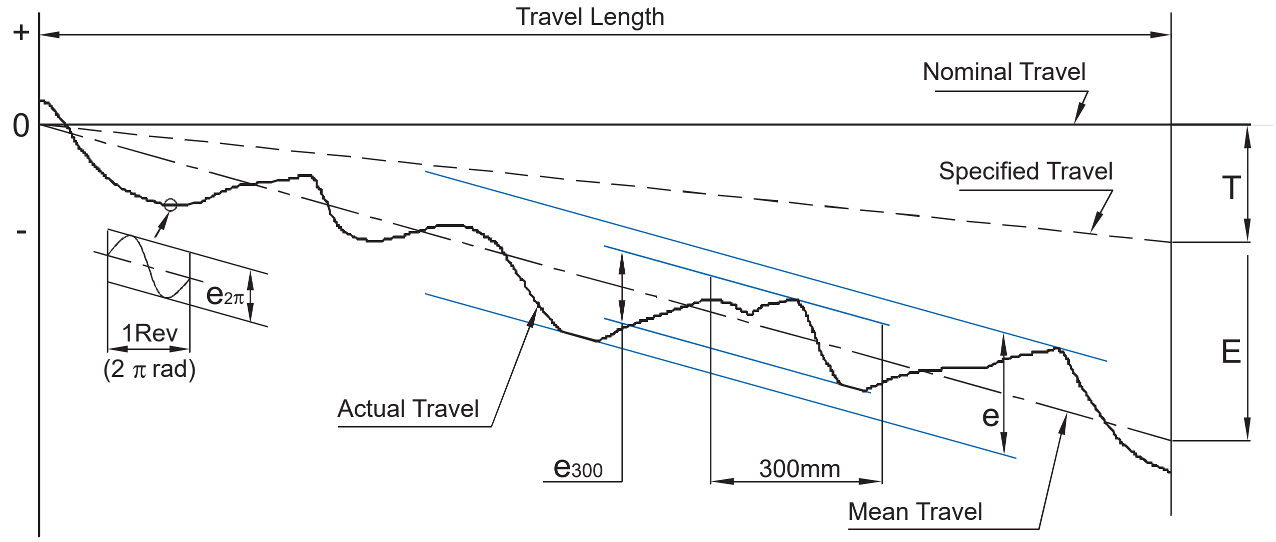
Lead and Travel Accuracy

Lead accuracy of ball screws are graded C0 to C10, lower figure means less lead error. Grade C0 to C5 are specified by 4 basic terms: E, e, e_{300} and $e_{2\pi}$. For grade C7 and C10, only the maximal travel variation for any 300 mm is specified (e_{300}).

Diagram of Lead Accuracy



Definition of Terms for Lead Accuracy

Terms	Reference	Definition
Travel compensation	T	Travel compensation is an intentional added or subtracted mean travel deviation. Used to compensate for the accuracy loss caused by operating the ball screw at lower or higher temperature than the reference temperature 20°C. Practically, travel compensation can only be specified and delivered for ground ball screws.
Actual travel		Position achieved in reality, sum of all deviations.
Mean travel deviation	E	The linearized average travel deviation over a specified travel length. This value (if known) could be used to make a simple accuracy improvement by using a one-term scale factor in the control system.
Travel variations	e	The maximal travel variation over specified travel length.
	e_{300}	The maximal travel variation over any measured 300 mm travel length. For C7 and C10, this value accumulates with longer travel.
	$e_{2\pi}$	Travel deviation measure over one revolution (travel length = lead of ball screw).

Mean Travel Deviation (±E) and Travel Variation (e) (JIS B 1192)

	Grade		C0		C1		C2		C3		C5		C7	C10
Travel Length (mm)	Over	Incl.	±E	e	±E	e	±E	e	±E	e	±E	e		
		100	3	3	3.5	5	5	7	8	8	18	18		
	100	200	3.5	3	4.5	5	7	7	10	8	20	18		
	200	315	4	3.5	6	5	8	7	12	8	23	18		
	315	400	5	3.5	7	5	9	7	13	10	25	20		
	400	500	6	4	8	5	10	7	15	10	27	20		
	500	630	6	4	9	6	11	8	16	12	30	23		
	630	800	7	5	10	7	13	9	18	13	35	25		
	800	1000	8	6	11	8	15	10	21	15	40	27		
	1000	1250	9	6	13	9	18	11	24	16	46	30	±50/	±210/
	1250	1600	11	7	15	10	21	13	29	18	54	35	300mm	300mm
	1600	2000			18	11	25	15	35	21	65	40		
	2000	2500			22	13	30	18	41	24	77	46		
	2500	3150			26	15	36	21	50	29	93	54		
	3150	4000			30	18	44	25	60	35	115	65		
	4000	5000					52	30	72	41	140	77		
	5000	6300					65	36	90	50	170	93		
	6300	8000							110	60	210	115		
	8000	10000									260	140		
	10000	12500									320	170		

Unit: µ m

Pre-load and Clearance

Single nuts always perform best and produce the smoothest running having some axial clearance. Rollco offers reduced clearance (P1) as an option for all sizes. Light preload (P2) is possible for most sizes of single nuts but will always introduce some roughness of running under no-load conditions. If requirements on both pre-load and smoothness at zero load are high, a double nut FDCR is the solution. Pre-loaded nuts require at least C5 rolled ball screw to work well. On request, Rollco can offer ground ball screw in C5 and C3 quality. This improve the running behavior and decrease the noise level substantially.

Standard clearance (P0)

Screw shaft ød	Rolled ball screw clearance in the axial direction (max)	
4 ~ 14	0,05	small size of ball screw
15 ~ 49	0,08	middle size of ball screw
50 ~ 80	0,12	big size of ball screw

Unit: mm

Reduced clearance (P1)

Max 0,02 mm clearance for all sizes

Light preload (P2)

Light preload P2 means that there is an internal load on the balls because of oversized balls. In applications with very high life-time requirements, this internal load will affect the life time.

Recirculation type:
I: internal by radial inserts
E: internal by end inserts

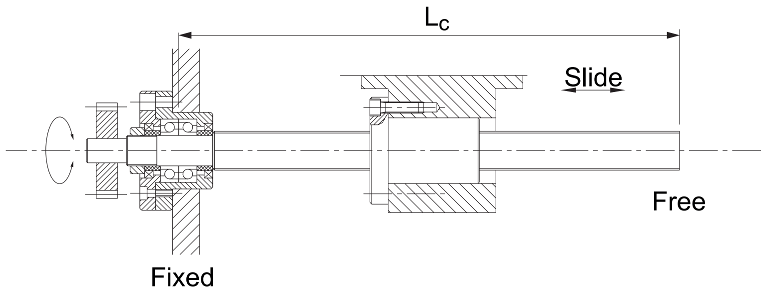
Type	Recirculation type	Preload (% of Ca)	Reference torque T_P (Nm)
FSCR1605	I	3%	0,029
FSCRN1610	E	2%	0,026
FSCR2005	I	3%	0,046
FSCR2505	I	3%	0,059
FSCR2510	I	3%	0,109
FSCR3205	I	3%	0,074
FSCR3210	I	3%	0,257
FSCR3220	E	2%	0,142
FSCR4005	I	3%	0,093
FSCR4010	I	3%	0,325
FSCR4020	E	2%	0,308
FSCR5010	I	3%	0,413
FSCR6310	I	3%	0,532
FSCR6320	I	3%	1,283
RSKR1204	I	3%	0,022
RSKR1605	I	3%	0,027
FSER1616	E	2%	0,043
FSER2020	E	2%	0,044
FSER2525	E	2%	0,086
FSER3232	E	2%	0,158
FSER4040	E	2%	0,324
FSER5050	E	2%	0,721

Reference torque T_P is defined for an oil lubricated nut without wipers, measured at 100 rpm. Allowed fluctuation is typical +/- 30% but may be more on long screw shafts. (Length/diameter > 40.)

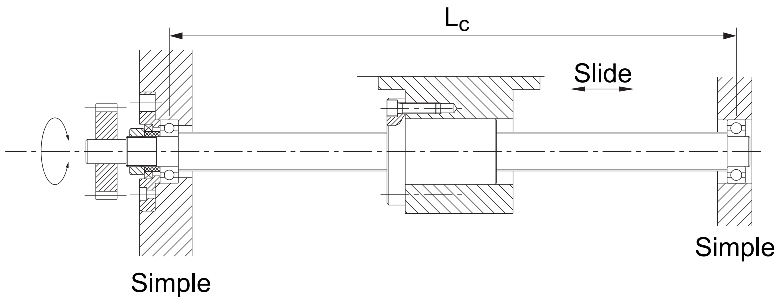
It is normal that the starting torque measured without seals is 2-3 times higher than T_P. The influence of seal friction, lubrication, temperature etc. may result in even higher starting torques. Consult Rollco if start torque is critical for your application.

Mounting Methods

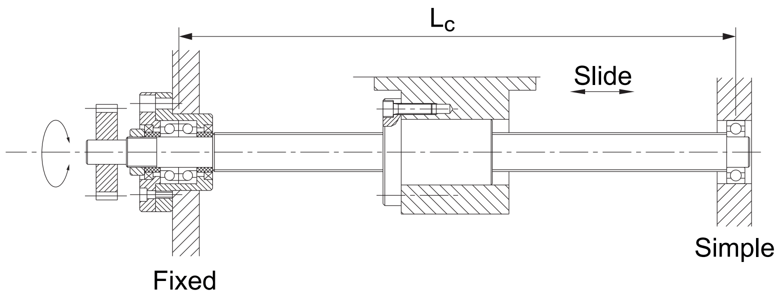
The way the screw shaft is supported and fixed in the ends determine both the Critical shaft speed and the buckling load. By using combinations of Rollco support units, type 1, 3 and 4 can be arranged:



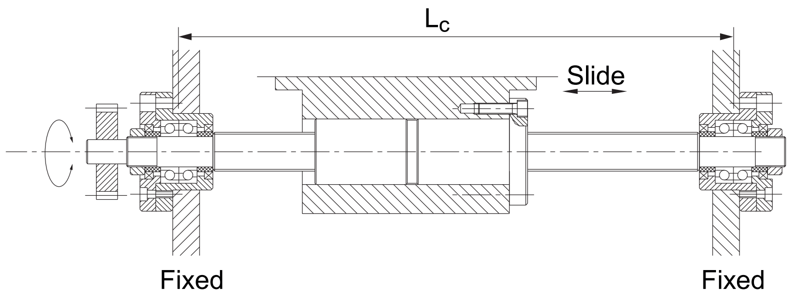
Type 1



Type 2



Type 3



Type 4

The most common and strongly recommended combination is the Type 3 “Fixed-Simple” and for short strokes, Type 1 “Fixed-Free”. Type 4 “Fixed-Fixed” requires very careful mounting and should only be used in specific cases, consult Rollco. Type 2 “Simple-Simple” is sometimes an economic solution but is limited in load capacity and will always have a quite large axial play. The axially free end can be utilized using Rollco units type BFN and FFN but we do not offer any unit with axially fixed single bearing.

Buckling Load

If a ball screw is loaded in compression, it will at a certain load level go into elastic buckling and collapse! The type of Mounting Method have large influence on this limit, along with the diameter and the free length of the ball screw shaft. The best way to avoid risk of buckling is always to identify the main load direction and to place the Fixed bearing unit in the end where it make the screw shaft receive the largest force in tension.

The critical buckling load, including a safety factor 3 is calculated using:

$$F_c = \frac{34000 \cdot f_3 \cdot {d_2}^4}{{L_c}^2}$$

F_C = Buckling strength (N)

d_2 = Root diameter* of screw shaft (mm)
*d2 = d - Da (nominal shaft diameter minus ball diameter Da)

L_C = Critical length (mm), the distance between center of bearing units or the free end

f_3 = Mounting method factor for buckling

Mounting method	Factor f_3
Type 1, fixed-free	0,25
Type 2, simple-simple	1
Type 3, fixed-simple	2
Type 4, fixed-fixed	4

Critical Speed of the Screw Shaft

Any rotating shaft have an eigenfrequency that needs to be avoided. If the nut is linearly guided, hitting the eigenfrequency (resonance) will create vibrations, noise and excessive wear. In a system with an un-guided nut, the resonance will make the system to collapse by bending of the shaft.

The critical speed is calculated using:

$$n_{cr} = 49 \cdot 10^6 \frac{f_1 \cdot d_2}{{L_c}^2}$$

n_{Cr} = Critical speed (rpm)

d_2 = Root diameter* of screw shaft (mm)
*d2 = d - Da (nominal shaft diameter minus ball diameter Da)

L_C = Critical length (mm), the distance between center of bearing units or the free end

f_1 = Mounting method factor for critical speed

Mounting method	Factor f_1
Type 1, fixed-free	0,9
Type 2, simple-simple	2,5
Type 3, fixed-simple	3,8
Type 4, fixed-fixed	5,6

Limiting Speed of the Ball Nut

All ball nuts have some type of ball recirculation mechanism. The deflection of the balls creates increasing forces, wear and noise as the speed increases. The limiting speed of the nut is called the speed product and is designated “dm · n”. Effectively, dm is equal to the nominal diameter “d” of the ball screw and “n” is the speed in rpm.

Limiting speed of Rollco ball nuts are:

Type	dm · n limit
SFKR	70 000
RSKR	70 000
RSCR	70 000
FSCR, lead 5 & 10	70 000
FSCR, lead 20	100 000
FSCRN 1610	100 000
FDCR	70 000
FSER	100 000
SFYR	100 000

The rule is:

$dm \cdot n \text{ limit} \geq d \cdot n_{(max)}$

d = ball screw diameter

$n_{(max)}$ = highest speed used in the application

If the product exceed the “dm · n limit”, a lower rotational speed must be used, most common is to select a ball screw with higher lead to be able to keep the desired linear speed.

It is recommended to only utilize 80 % of the “dm · n limit” for long life applications. Exceeding the “dm · n limit” may cause destruction of the recirculation mechanism and will at least shorten the life and reliability of the ball nut.

Life Calculation

Nominal Life Calculation of Ball Screws

As a general advise, there is normally no need to make any detailed life calculation if real load vs the Ca-value is 5 or greater. A long life will be achieved for most applications and conditions using this simple rule. But if size and cost restrict you, an optimization may be required.

As with all ball and roller based bearings there is a theory of how to calculate the fatigue life, applicable also for ball screws. The basic life theory L10 is well proven and the result represent a 90% probability to reach or exceed the calculated life. Definition of fatigue life is when the material of the rolling elements or raceways start to fail (flake). In reality, there are a number of other factors influences the service life, mainly the lubrication conditions, assembly precision and cleanliness during operation.

A nominal life for ball screws can be calculated using:

$$L_{10nom} = \left(\frac{C_a}{P_a \cdot fw}\right)^3$$

L_{10nom} = Nominal fatigue life in millions of revolutions
C_a = Basic dynamic load rating (N)
P_a = Equivalent axial load (N)
fw = Load factor for ball screw

Level of vibration and impact	Relative speed (% of dm·n)	fw
Low	5 - 50 %	1,0 – 1,2
Medium	50 - 80 %	1,2 – 1,5
High	< 1 % or > 80 %	1,5 – 3,0

The selection of fw have very strong impact on the calculation. If in doubt how to select suitable load factor for your application, please contact Rollco for support.

The equivalent load Pa is the cubic mean load over distance. In most cases, it is enough to use the highest load that occurs in the application. Contact Rollco if optimization is required.

Nominal Life Calculation of Fixed Bearing Units

The fatigue life of fixed bearing units follows the same basic theory as the ball screws. However, due to the construction of the units and type of bearings, there are a "Permissible loads" to take into account. The load factor for bearing units also have lower values as the speed used have very low derating influence.

A nominal life for fixed bearing units can be calculated using:

$$L_{10nom} = \left(\frac{C_a}{P_a \cdot f_{wKU}}\right)^3$$

L_{10nom} = Nominal fatigue life in millions of revolutions
C_a = Basic dynamic load rating (N)
P_a = Equivalent axial load (N)
f_{wKU} = Load factor for fixed bearing unit

Valid only if the actual load during motion is kept below the Dynamic Permissible axial Load!

Level of vibration and impact	f_{wKU}
Low	1,0 – 1,1
Medium	1,1 – 1,3
High	1,3 – 2,0

Static Loads

For applications not requiring a very long life, the static load rating may be the limiting factor. Every application should however be checked for the static safety factor to avoid damage and shortened life.

For ball screws:

$F_{max} \leq s_0 \cdot C_{a0}$ ...or... $C_{a0} \geq s_0 \cdot F_{max}$

F_{max} = the highest occurring force in the application (N)

C_{a0} = static load rating of the ball nut

s_0 = static safety factor

Recommended static safety factors:

Category	Application characteristics	Typical machinery	s_0
1	High accuracy of assembly, 100% control of occurring forces, low dynamics, no shock loads.	Material test benches, precision machines.	1,5
2	Normal assembly precision, moderate speeds and accelerations, small chock loads.	Automation, material handling equipment, light machine tools.	2,5
3	High speeds and accelerations and/or heavy vibrations and shock loads	High speed automation, normal machine tools	3 to 5
4	Heavy shock and vibrations	Press tool, riveting, metal forming and cutting tools	5 to 10

For Rollco fixed bearing units, the “Static Permissible axial Load” can be used in general.
For category 4 an additional safety margin may be needed. Always consult Rollco for demanding applications.

Angular Acceleration

At quick rotational speed changes, the balls in the ball nut may slide instead of roll. This will cause more or less damage to the balls or the raceways. A lot of factors of both the ball nut and the application conditions influence if slipping will occur or not.

Our recommendation is to avoid long term use of angular accelerations above 3000 rad/s^2

Lead mm	Linear acceleration m/s^2
1	1,0
2	1,9
2,5	2,4
4	3,8
5	4,8
10	10
16	15
20	19
25	24
32	31
40	38
50	48

Linear acceleration for different leads at 3000 rad/s^2.

Torque and Force

The torque needed to produce a linear force is calculated using this formula:

$$T = \frac{F \cdot l}{2000 \cdot \pi \cdot \eta_P}$$

T = Drive torque (Nm)
F = Axial load on the ball nut (N)
l = Lead (mm)
η = Practical efficiency (typical 0,8)

The theoretical efficiency of a ball screw is between 90 to 96 % depending on design and load conditions. For all common applications, we recommend to calculate with a practical efficiency of 80%.

If the brake or holding torque needs to be calculated:

$$T_B = \frac{F \cdot l \cdot \eta'}{2000 \cdot \pi}$$

T_B = brake torque (Nm)
η′ = Theoretical indirect efficiency (typical 0,95)

When calculating holding torque, the theoretical indirect efficiency is used of safety reasons.

Lubrication

For a ball screw or any ball and roller based bearing, clean and sufficient lubrication is essential to achieve the predicted life and performance. Rollco ball screws do not offer any “life time lubricated” solutions, periodic re-lubrication is mandatory.

Rollco bearing units are closed and sealed and can normally be operated w/o re-lubrication 10 000 to 30 000 h. If a reliable service life exceeding 5 years are required, re-lubrication or exchange of the bearing units are recommended. On request, the fixed bearing units can be supplied with grease nipple.

Grease Lubrication

For ball screws of lead 5 mm or above, the basic recommendation is to use a lithium complex based grease of NLGI grade 2 with a base oil viscosity of 46 to 100 cSt. Smaller lead ball screws benefit and work better with a less stiff grease, for example NLGI 1 or NLGI 1,5.

Additivies

It has shown that grease containing additives such as graphite of MoS_2 does not work well with ball screws as the particles tends to build up and cause blocking of the recirculation mechanism.

Oil Lubrication

Continues oil lubrication is many times a good way to ensure a long life of any bearing type. The cost of an automatic lubrication system has to be compared to the cost of more frequent failures and part replacements. The main advantages of oil lubrication is that it keep the ball nut clean, offer the lowest friction and act like a coolant.

General Advice for Ball Screw Grease Re-lubrication:

For all ball nuts having a seal or wiper:
Every 50 million revolutions or after 500 hours operation time, whatever occurs first.

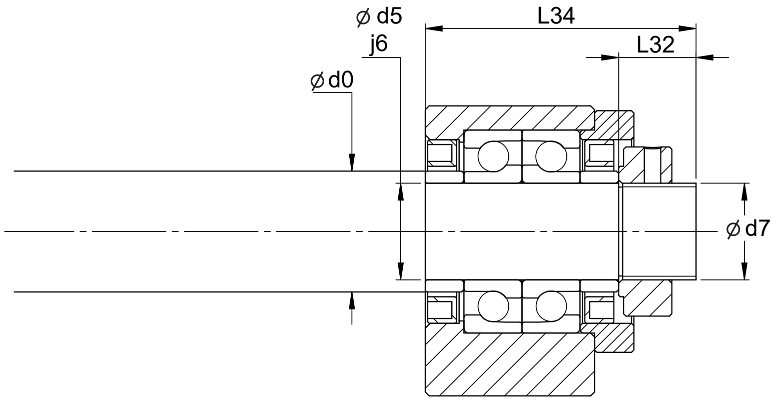
Screw lead	Distance @ 50 Mrev
2,5	125 km
3	150 km
4	200 km
5	250 km
10	500 km
16	800 km
20	1000 km
25	1250 km
32	1600 km
40	2000 km
50	2500 km

Recommendation above valid for typical operation conditions:

- Temperature +10 to +30°C
- Load ≤ 0,2*Ca
- Speed ≤ 80% of max recommended dm·n

Standard End Journals

E1

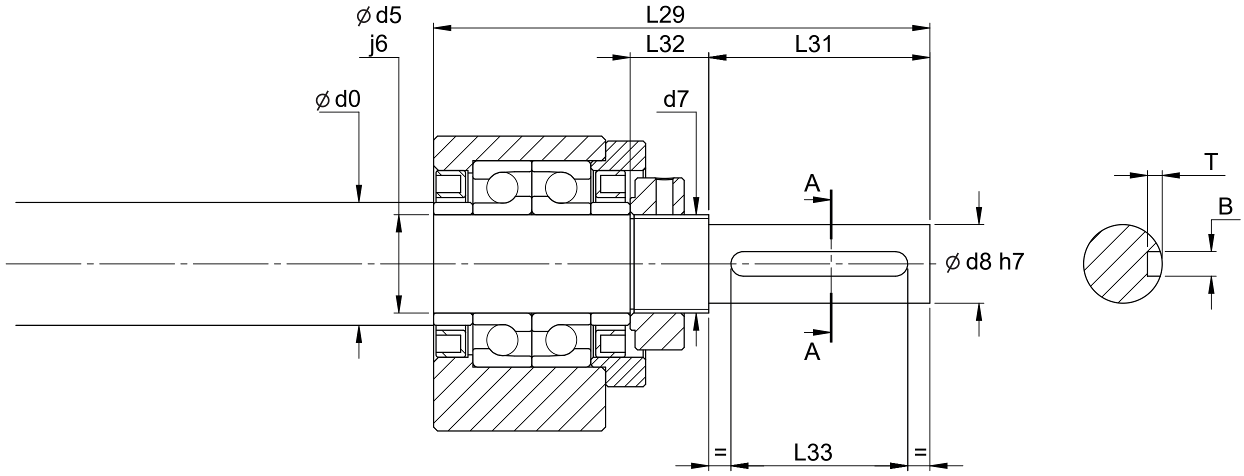


Code	Unit	d0*	d5	d7	L32	L34
E1B	BKN08	12	8	M8x1	12	36
E1B	BKN10	14	10	M10x1	10	36
E1B	BKN12	16	12	M12x1	13	40
E1B	BKN 15	20	15	M15x1	13	43
E1B	BKN17	25	17	M17x1	17	55
E1B	BKN20	25	20	M20x1	16	56
E1B	BKN25	32	25	M25x1.5	17	65
E1B	BKN30	40	30	M30x1.5	21	71
E1B	BKN 40	50	40	M40x1.5	26	92
E1F	FKN06	8	6	M6x0.75	8	28
E1F	FKN06	10	6	M6x0.75	8	28
E1F	FKN08	12	8	M8x1	12	36
E1F	FKN10	14	10	M10x1	10	36
E1F	FKN12	16	12	M12x1	13	40
E1F	FKN 15	20	15	M15x1	13	47
E1F	FKN17	25	17	M17x1	17	59
E1F	FKN20	25	20	M20x1	16	64
E1F	FKN25	32	25	M25x1.5	20	73
E1F	FKN30	40	30	M30x1.5	21	71
E1WF	WBK25DF	32	25	M25x1.5	26	89
E1WF	WBK30DF	40	30	M30x1.5	26	89
E1WF	WBK40DF	50	40	M40x1.5	30	92
E1WFF	WBK30DFF	40	30	M30x1.5	26	119
E1WFF	WBK40DFF	50	40	M40x1.5	30	122

* Nominal ball screw diameter.

E2 and E2 -N

(-N = with keyway)

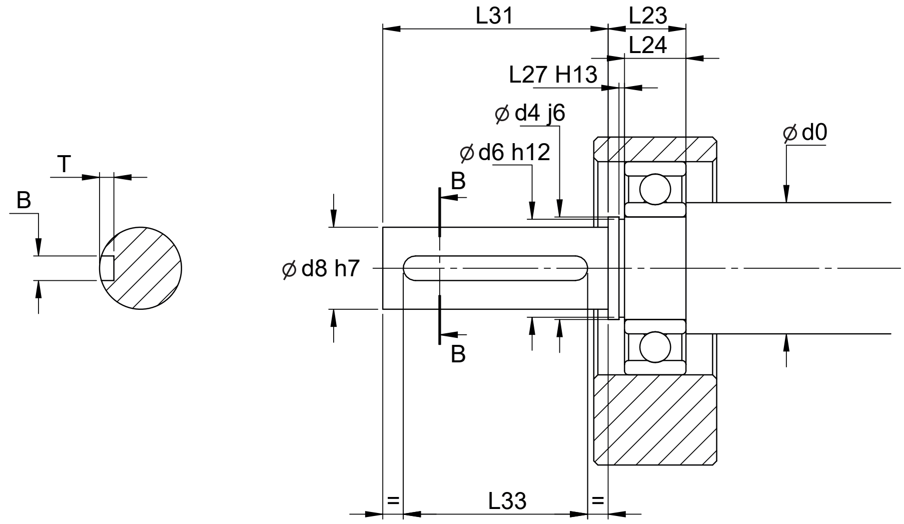


Code	Unit	d0*	d5	d7	d8	L29	L31	L32	- N B_{P9} x L_{33} x T
E2B	BKN08	12	8	M8x1	6	51	15	12	2x10x1,2
E2B	BKN10	14	10	M10x1	8	51	15	10	2x10x1,2
E2B	BKN12	16	12	M12x1	10	65	25	13	3x18x1,8
E2B	BKN 15	20	15	M15x1	12	78	35	13	4x27x2,5
E2B	BKN17	25	17	M17x1	15	78	23	17	5x18x3
E2B	BKN20	25	20	M20x1	16	101	45	16	5x36x3
E2B	BKN25	32	25	M25x1.5	20	120	55	17	6x45x3,5
E2B	BKN30	40	30	M30x1.5	25	133	62	21	8x50x4
E2B	BKN40	50	40	M40x1.5	36	168	76	26	10x63x5
E2F	FKN06	8	6	M6x0.75	4	36	8	8	-
E2F	FKN06	10	6	M6x0.75	4	36	8	8	-
E2F	FKN08	12	8	M8x1	6	51	15	12	2x10x1,2
E2F	FKN10	14	10	M10x1	8	51	15	10	2x10x1,2
E2F	FKN12	16	12	M12x1	10	65	25	13	3x18x1,8
E2F	FKN 15	20	15	M15x1	12	82	35	13	4x27x2,5
E2F	FKN17	25	17	M17x1	15	82	23	17	5x18x3
E2F	FKN20	25	20	M20x1	16	109	45	16	5x36x3
E2F	FKN25	32	25	M25x1.5	20	128	55	20	6x45x3,5
E2F	FKN30	40	30	M30x1.5	25	133	62	21	8x50x4
E2WF	WBK25DF	32	25	M25x1.5	20	144	55	26	6x45x3,5
E2WF	WBK30DF	40	30	M30x1.5	25	153	64	26	8x50x4
E2WF	WBK40DF	50	40	M40x1.5	36	170	78	30	10x63x5
E2WFF	WBK30DFF	40	30	M30x1.5	25	183	64	26	8x50x4
E2WFF	WBK40DFF	50	40	M40x1.5	36	200	78	30	10x63x5

* Nominal ball screw diameter.

D1 and D1 -N

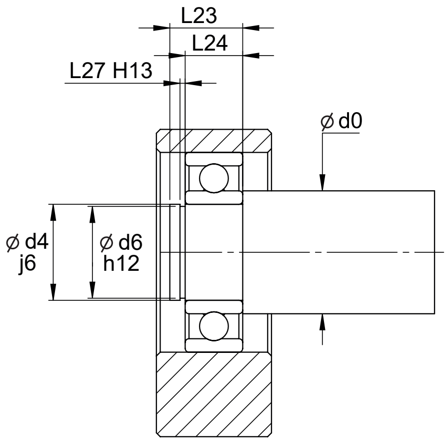
(-N = with keyway)



Code	Unit	d0*	d4	d6	d8	L23	L24	L27	L31	- N $B_{P9} \times L_{33} \times T$
D1B	BFN 08	12	6	5,7	6	8	6	0,9	15	2x10x1,2
D1B	BFN10	14	8	7,6	8	10	7	0,9	15	2x10x1,2
D1B	BFN12	16	10	9,6	10	10,5	8	1,15	25	3x18x1,8
D1B	BFN15	20	15	14,3	12	13	9	1,15	35	4x27x2,5
D1B	BFN 17	25	17	16,2	15	16	12	1,15	23	5x18x3
D1B	BFN 20	25	20	19	16	16	12	1,35	45	5x36x3
D1B	BFN25	32	25	23,9	20	19	15	1,35	55	6x45x3,5
D1B	BFN30	40	30	28,6	25	21	16	1,65	62	8x50x4
D1B	BFN 40	50	40	37,5	36	25	18	1,85	76	10x63x5
D1F	FFN10	14	8	7,6	8	10	7	0,9	15	2x10x1,2
D1F	FFN12	16	10	9,6	10	10,5	8	1,15	25	3x18x1,8
D1F	FFN15	20	15	14,3	12	13	9	1,15	35	4x27x2,5
D1F	FFN 20	25	20	19	16	18	14	1,35	45	5x36x3
D1F	FFN25	32	25	23,9	20	19	15	1,35	55	6x45x3,5
D1F	FFN30	40	30	28,6	25	21	16	1,65	62	8x50x4

* Nominal ball screw diameter.

D2



Code	Unit	d0*	d4	d6	L23	L24	L27
D2B	BFN 08	12	6	5,7	8	6	0,9
D2B	BFN10	14	8	7,6	10	7	0,9
D2B	BFN12	16	10	9,6	10,5	8	1,15
D2B	BFN15	20	15	14,3	13	9	1,15
D2B	BFN 17	25	17	16,2	16	12	1,15
D2B	BFN 20	25	20	19	16	12	1,35
D2B	BFN25	32	25	23,9	19	15	1,35
D2B	BFN30	40	30	28,6	21	16	1,65
D2B	BFN 40	50	40	37,5	25	18	1,85
D2F	FFN10	14	8	7,6	10	7	0,9
D2F	FFN12	16	10	9,6	10,5	8	1,15
D2F	FFN15	20	15	14,3	13	9	1,15
D2F	FFN 20	25	20	19	18	14	1,35
D2F	FFN25	32	25	23,9	19	15	1,35
D2F	FFN30	40	30	28,6	21	16	1,65

* Nominal ball screw diameter.