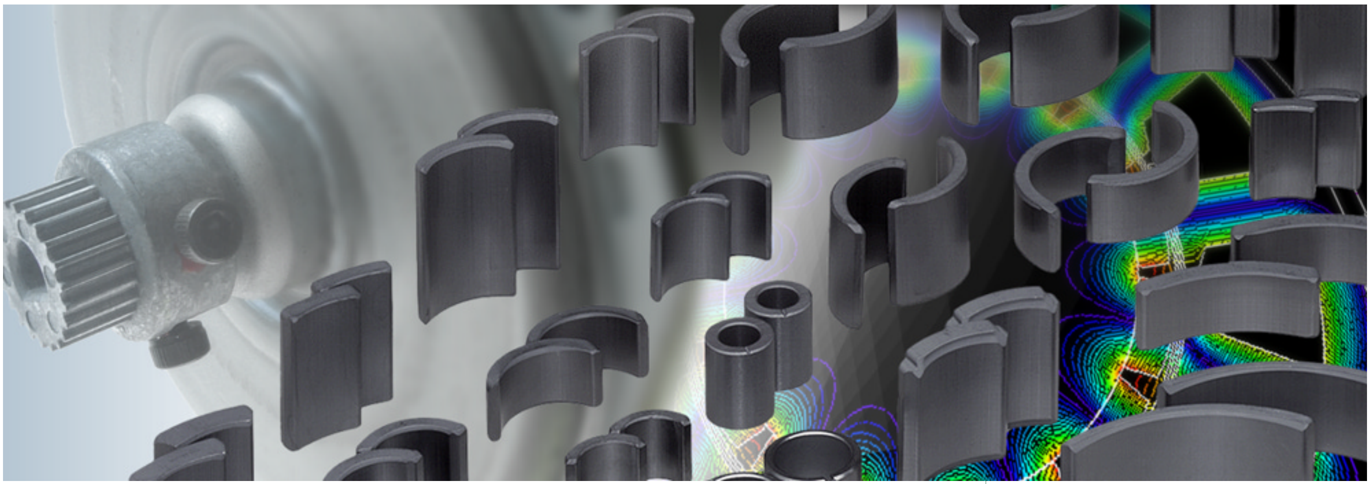


The World's Best Performing Lanthanum-Cobalt Ferrite Magnet
FB9N, FB9B, FB9H material

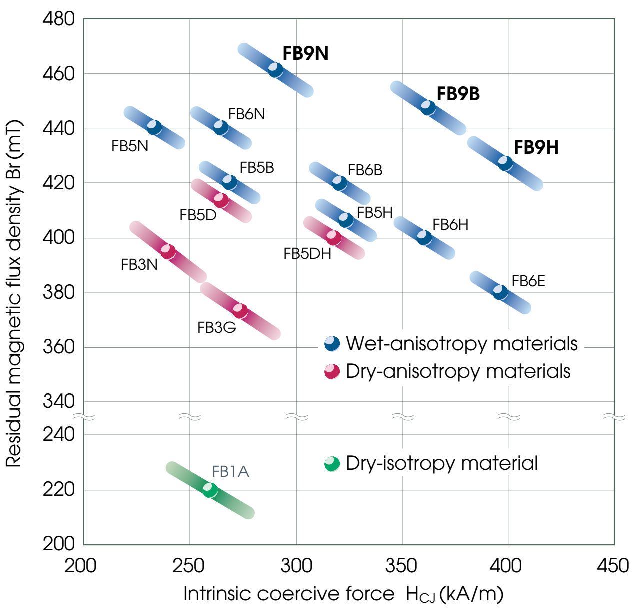
Conforming to RoHS Directive
Conformity to RoHS Directive: This means that, in conformity with EU Directive 2002/95/EC, lead, cadmium, mercury, hexavalent chromium, and specific bromine-based flame retardants, PBB and PBDE, have not been used, except for exempted applications.

The magnetic characteristics of the conventional ferrite magnet have been significantly improved. The world's best performances in residual magnetic flux density Br, intrinsic coercive force H_{CJ}, and maximum energy product (BH)max have been achieved.

Realizing this revolution in performance defys established theories

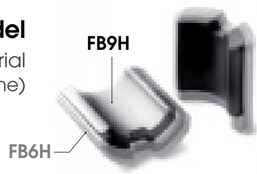
- Even in a comparison based on the superb intrinsic coercive force of the FB6 series, which had maintained the world's best performance, the residual magnetic flux density was improved by 10-15% and the maximum energy product by 30-40%.
- Also, the temperature coefficient of the intrinsic coercive force, a cause of low-temperature demagnetization, has been improved, making an important improvement in the conventional limit value of +0.5 - +0.3%/K, to as much as +0.18%/K, developing a technological field that goes beyond the existing theories of ferrite magnet physical property control.
- With a fully managed production and short-delivery-distribution service system, the early development of next-generation motors through the quick "Design-in System" is supported when designing and test producing optimal shapes.

Magnetic characteristics distribution charts of FB series



With downsizing, weight-reduction, and outstanding demagnetization resistance, the top specifications and shapes of next generation motors can be conquered.

Shape comparison model
FB6H material vs. **FB9H** material
(Demagnetization resistance at -40°C is set the same)

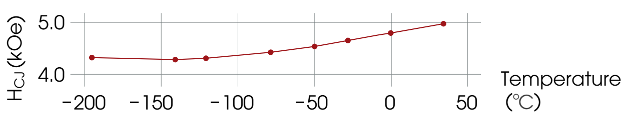


Magnet area: reduced by **7%**
Magnet thickness: reduced by **19%**
Magnet volume: reduced by **25%**

Using FB9H, next generation motors can be small and cold resistant

Top-notch next-generation motors can be easily realized with maximized features such as size, weight, enhanced performance, low-cost, and power-saving for small, light, and demagnetization resistance design of automobile motors which permit operation in −40 - +200°C environments; electrical power tools, elevators, industrial transportation device motors; and motors for refrigerators, washing machines, electric beds, wheelchairs, etc.

H_{CJ} temperature coefficient : **+0.2%/K** or below

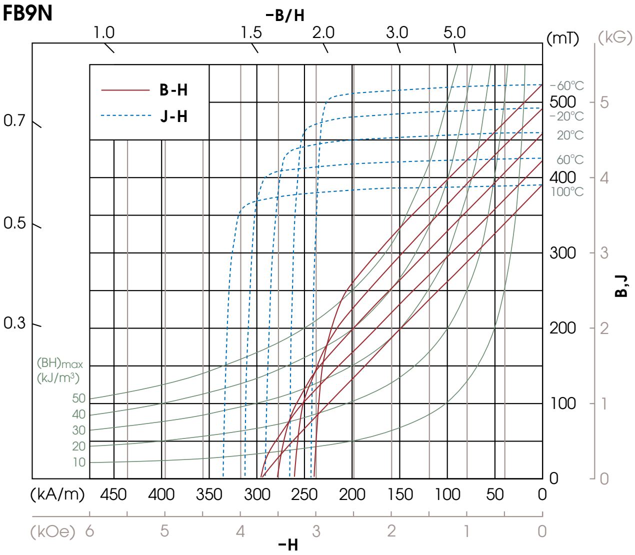


Material characteristics

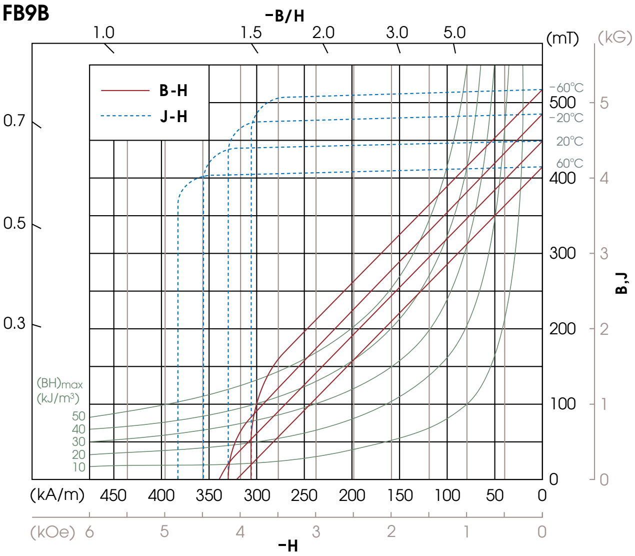
FB9N, FB9B, FB9H material

B-H/J-H characteristics

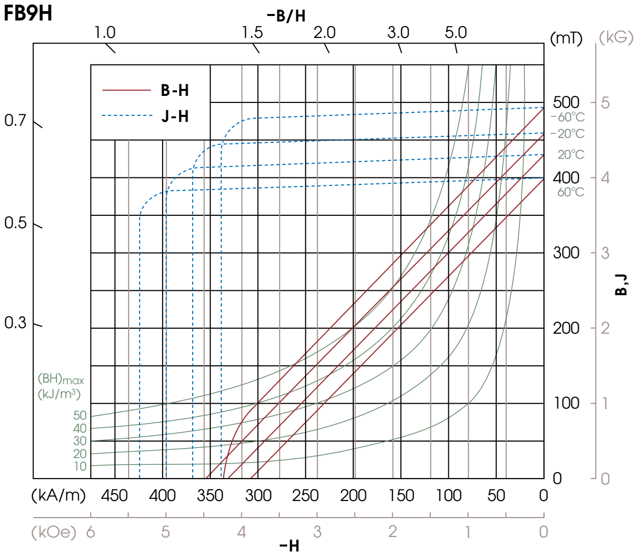
FB9N



FB9B



FB9H



Magnetic characteristics / Physical, mechanical characteristics

Material name			FB9N	FB9B	FB9H
Residual magnetic flux density Br	(mT)		460±10	450±10	430±10
Coercive force H_{CB}	(kA/m)		278.5±11.9	342.2±11.9	330.2±11.9
Intrinsic coercive force H_{CJ}	(kA/m)		386.5±11.9	358.1±11.9	397.1±11.9
Maximum energy product (BH)max	(kJ/m³)		40.4±16	38.6±1.6	35.0±1.6
Temperature coefficient of Br ⊿Br/Br/⊿T	(%/K)		-0.18	-0.18	-0.18
Curie temperature Tc	(K)		733	733	733
Thermal expansion coefficient	(1/K)	C//*	15×10^{-6}	15×10^{-6}	15×10^{-6}
		C⊥**	10×10^{-6}	10×10^{-6}	10×10^{-6}
Specific heat	(J/kgK)		837	837	837
Density	(kg/m³)		5.0 to 5.1 x 10^3	4.95 to 5.05 x 10^3	4.9 to 5.0 x 10^3
Flexural strength	(N/m²)		0.5 to 0.9 x 10^8	0.5 to 0.9 x 10^8	0.5 to 0.9 x 10^8
Compressive strength	(N/m²)		>6.9 x 10^8	>6.9 x 10^8	>6.9 x 10^8
Tensile strength	(N/m²)		0.2 to 0.5 x 10^8	0.2 to 0.5 x 10^8	0.2 to 0.5 x 10^8

* C// : Measurement value in the direction of easy magnetization
** C⊥ : Measurement value in the direction perpendicular to the direction of easy magnetization

Advantages of the world's first lanthanum-cobalt ferrite magnet FB9 material

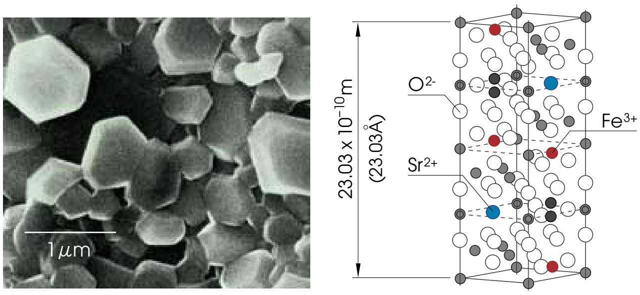
Development process

FB9N, FB9B, FB9H material

Concepts toward enhanced performance

The degree of a ferrite magnet's residual magnetic flux density Br and intrinsic coercive force H_{CJ} are determined by the angstrom order crystal structure and micron order fine structure as shown in Fig.1.

Fig.1



Residual magnetic flux density Br	=	Saturation magnetization $4\pi Is$	×	Density	×	Orientation degree
Intrinsic coercive force H_{CJ}	=	Anisotropic magnetic field $H_A(=2K_1/Is)$	×	Single-magnetic domain crystal grain ratio		
		Crystal structure ~10^{-10}m		Fine structure ~10^{-6}m		

Density, orientation degree, and single-magnetic domain crystal grain ratio are fine structure factors, and the saturation magnetization and crystal magnetization anisotropic coefficient K_1 depend on the crystal structure (magnetic structure of the magnetic ion). Also, for the most part the temperature characteristics of Br and H_{CJ} depend on the crystal structure, but that of H_{CJ} is also affected by the fine structure. To realize a high-performance ferrite magnet, all of these factors must be improved.

Controlling fine structures

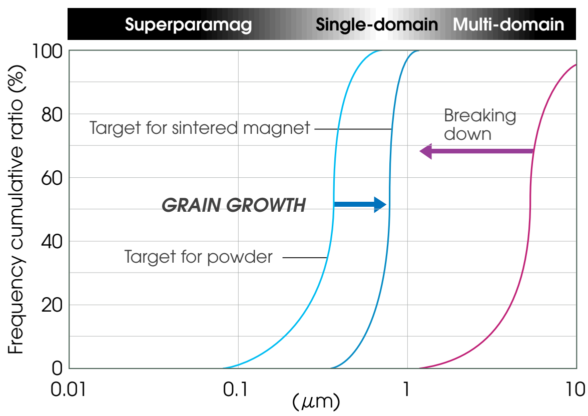
The intrinsic coercive force expression mechanism of a ferrite magnet is the single-magnetic domain crystal grain type and the critical diameter where the Sr ferrite grain entering the single-magnetic condition is about 1 μm if it's an isolated single grain. This means that the best characteristic can be obtained when the crystal grain is 1um or less and they are all aligned in the same direction as the axis of easy magnetization, and 100% density has been achieved. The following are the three key technologies required to achieve this ideal condition.

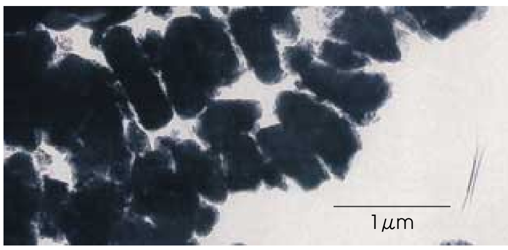
1) Control technology of fine particles with the ideal grain size distribution (calcination technology/milling technology)
2) High-orientation technology upon molding of magnetic field (milling technology/additive control)
3) Additive control/sintering technology to reduce crystal grain growth and obtain high density

1. Submicron grain control technology

To realize a crystal grain size of 1 μm or less using a sintered body, the size of the crystal grain has to be around 0.3 μm in the molding stage before sintering, if the growth of crystal grains during the sintering stage is considered. However, in the conventional method, where large grains are broken down by milling, this type of submicron fine particle is difficult to obtain. TDK solved this issue by lowering the calcination temperature with equally mixed refined materials, establishing a technology to make crystal grains at a submicron size during the calcination stage before milling (Fig.2).

Fig.2





The world's first picture image of
the single-magnetic domain crystal grain of
a lanthanum-cobalt ferrite magnet

2. Submicron grain high-orientation technology

Two technologies which make submicron-sized ferrite crystal grains with high-orientation will be discussed next.

The first is lowering the magnetic cohesion force. Because each submicron grain of a ferrite magnet is strongly magnetic, the issue is of magnetic coherence and easily degraded orientation. However, by introducing crystal distortion while milling to lower a grain's intrinsic coercive force temporarily, the magnetic cohesion can be eased (Fig.3).

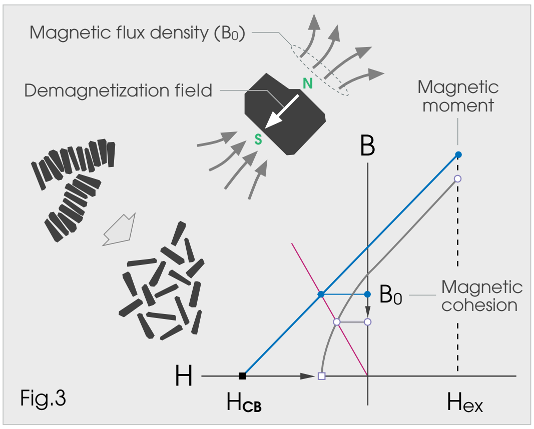
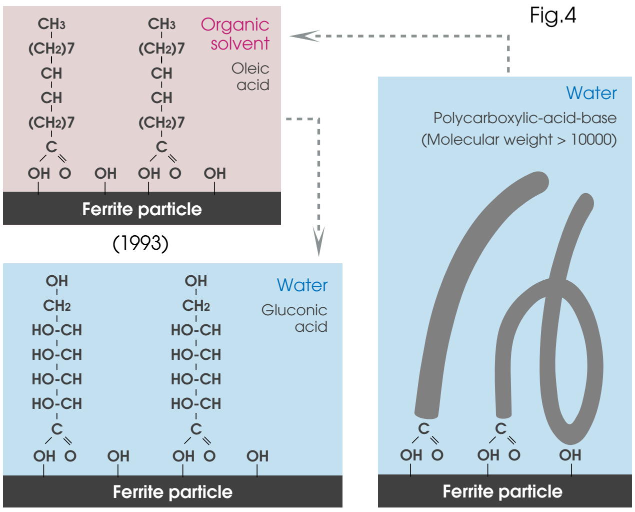


Fig.3

The second is wet molding a slurry with dispersant (surface active agent). Wet molding is a basic technology used to obtain high orientation and TDK achieved orientations as high as 98% through wet processing using organic solvents such as xylene and oleic acid as a dispersant. However, organic solvents are harmful to the human body and to nature in general, so a large-scale collection device is required for mass production. Through studies using water as a solvent, it was discovered that with low-molecular weight solvents, which are completely different from high-molecular weight solvents which had been believed to be most effective, very high orientation could be obtained (Fig.4).

Fig.4



Controlling crystal structures

Fig.5 shows a hexa-aluminate magnetoplumbite (M type) structured Sr ferrite unit cell (the smallest unit

FB9N, FB9B, FB9H material

of a crystal) model. It is easy here to imagine that a magnetic characteristic changes if the ions (Sr^{2+}, Fe^{3+}, O^{2-}), which comprise the M-type, are replaced by other ions. In the past several decades, diverse studies have been conducted based on this theory. But there has been no report that saturation magnetization or the crystal magnetic anisotropy constant have been improved; the performance features of ferrite magnets had not been increased.

1. Developing an La, Zn substitution new composition that goes beyond existing limitations

Through diverse substitution processes, TDK, in 1996, developed a new composition ($Sr_{1-x}La_xFe_{12-x}Zn_xO_{19}$) where lanthanum La and zinc Zn are mixed to an M-type Sr ferrite at the same time. Saturation magnetization was improved about 4%, and a saturation magnetic flux density of 4.6kG, which had been unobtainable with the conventional Sr ferrite, and a maximum energy product exceeding 5MGOe were achieved. However, the crystal magnetic anisotropy constant K_1 of this La-Zn composition is about 10% lower than that of the existing Sr ferrite, leaving issues regarding the improvement of H_{CJ} (Fig.5).

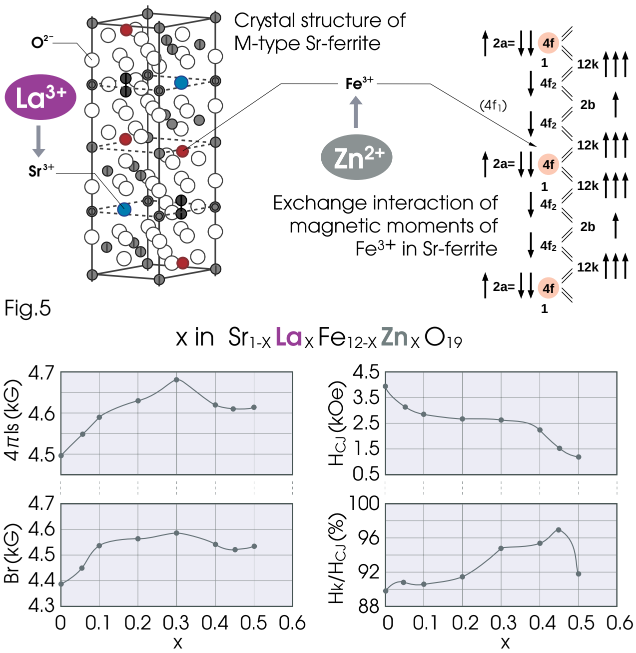
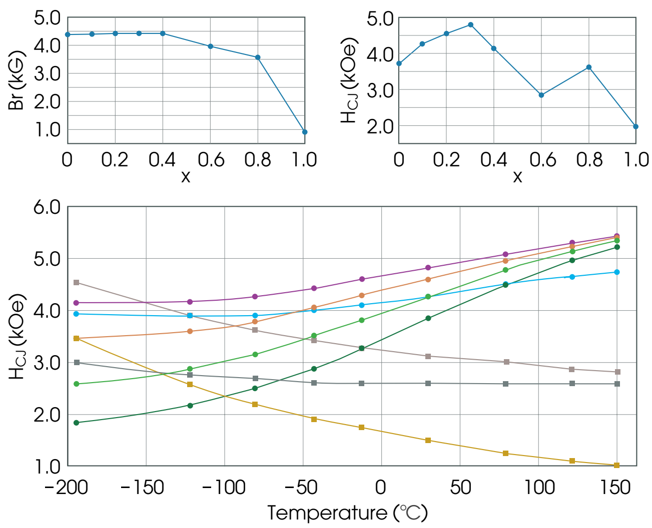


Fig.5

2. Development of the world's first La-Co composition realizing K1's drastic improvement

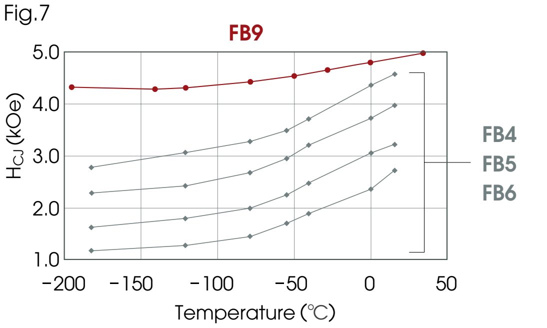
By further exploring the concentration of lanthanum, we discovered that both saturation magnetization and crystal magnetic anisotropy could be improved in a new composition ($Sr_{1-x}La_xFe_{12-x}Co_xO_{19}$) where lanthanum La and cobalt Co were mixed to M-type Sr ferrite at the same time. In short, efforts succeeded in improving the saturating magnetization ($4\pi IS$) by about 2% and crystal magnetic anisotropy K_1 by at least 15% at the same time, for the first time in the history of these materials. It was also discovered that with this composition the temperature characteristic of H_{CJ} changes markedly, and by controlling the composition, the H_{CJ}'s temperature constant can be zero, or positive or negative (Fig.6).

Fig.6



FB9 material which exceeds the best conventional material with a similar H_{CJ} by 10-15% in Br, and by 30-40% in (BH)max - an unprecedented specification level. In practice the abovementioned study processes and achievements are used. Of course, as mentioned above, ideal values of H_{CJ}'s temperature constant ($\Delta H_{CJ}/H_{CJ}/\Delta T$) are sought by controlling the composition. While the conventional material is near +0.3% - +0.5%/K, FB9 material is +0.2%/K or lower, achieving remarkably high stability (Fig. 7).

Fig.7



FB9N, FB9B, FB9H material

Typical applications and recommended materials

As overall comparison of the characteristics of other materials of ferrite magnet and each material of rare-earth magnet and bonded magnet, representative use examples where the FB9 series is recommended are presented.

Of course, the advanced performance can be utilized for other uses. Please contact us for details.

Automotive Sector

Fuel pump motor ***9N,9B***

Power window lift motor ***9B***

Anti-lock brake system pump motor ***9H***

Blower motor, wiper motor ***9B***

Power steering motor ***9N,9B***

Power brake motor ***9B,9H***

Motor for electronic throttle control ***9B***

Motor for continuously variable Transmission (CVT) ***9B,9H***

Starter motor ***9B,9H***

Alternator ***9B***

Home Appliance Sector

Air conditioner (outdoor unit) : compressor motor ***9N,9B,9H*** / fan motor ***9B***

Air conditioner (indoor unit) : fan motor ***9B***

Washing machine : driving (DD axis) motor, water pump ***9N,9B***

Refrigerator : compressor motor ***9N,9B,9H***

Power tools : driving motor ***9N,9B***

Telecommunications Devices Sector

Mobile phone, PHS system : isolator ***9B,9H***

Industrial & Medical Equipment Sector

Machine tools : table drive motor ***9N,9B*** / belt drive motor ***9B,9H***

Elevator : servo motor for motor elevation ***9B,9H***

Electric bed ***9N,9B,9H***

Other Applications

Motor for radio controlled models ***9N,9B,9H***