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NEW DISK BRAKE MOTOR (NB MOTOR)

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I. INTRODUCTION

Demands for motors equipped with built-in stop and hold brakes are increasing for such applications as gates, hoists and machine tools.

Fuji Electric has developed 3-phase ac brake motor equipped with ac exciting electromagnet. The performance of this brake motor is excellent and the faults found in the previous EB motors (dc excitation brake motors), SB motors (ac non-excitation brake motors with shaft movement) and MB motor (ac non-excitation brake motor with brake link mechanism) have been eliminated. The NB motors will be outlined in this article.

II. CONSTRUCTION AND OPERATION

Fig. 1 shows an external view of the NB motor and *Fig. 2* is a sectional view. The motor is our standard totally enclosed fan cooled type with class E insulation, except for braking side which is specifically designed for the installation of the brake.

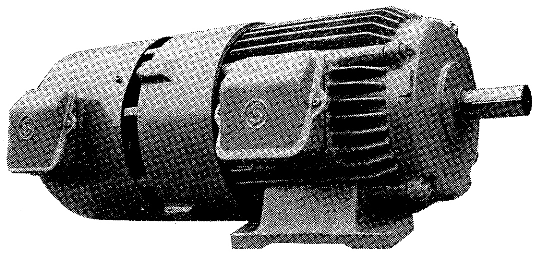
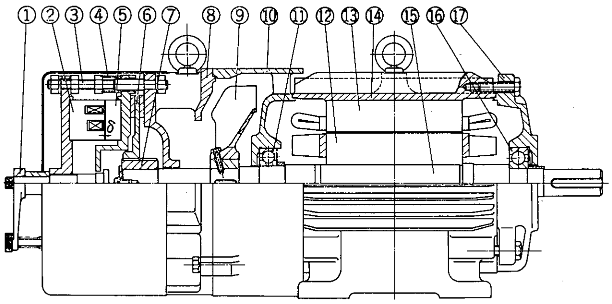


Fig. 1 External view of NB motor

1. Brake

Center ⑦ is fixed on the braking side of the motor, and the brake disk ⑥ is mounted on the center through splines in order to enable the brake disk to slide axially. Around the brake disk, studs ③ are fixed to the brake mounting flange at several points. The movable core is so mounted on the studs that it can slide only in the axial direction and is normally pressed against the brake disk by brake springs ④. The magnet core is fixed on the studs with appropriate gap δ between the magnet core and the movable core. When the magnet core is energized, the movable core is attracted by the magnetic force and the brake disk becomes free to rotate. When the magnet is switched off, the movable core is pushed back by the brake spring, and both sides of the brake disk are pressed by the movable core and the brake mounting flange respectively. The motor is then rapidly stopped. A handle for manual release of the brake (when the motor is stopped) is provided so that the brake can be released when the motor is stopped. If this handle is turned counterclockwise, the movable core is pulled to the side of the magnet core and the motor is released from the braking condition.



①	Manual releasc handle	⑩	Braking side bracket
②	Fixed (magnet) core	⑪	Sealed ball bearing
③	Stud	⑫	Rotor core
④	Brake spring	⑬	Stator core
⑤	Movable core	⑭	Frame
⑥	Brake disk	⑮	Shaft
⑦	Center	⑯	Sealed ball bearing
⑧	Brake mounting flange	⑰	Driving side bracket
⑨	External fan		

Fig. 2 Sectional view of NB motor

2. Operation Magnet

Previously, dc magnets which were inconvenient as operation power sources and had considerable residual magnetism were widely used for operation magnets because ac magnets gave rise to many problems concerning pulsating magnetic attraction, hum, large dimensions, processing, etc. These problems have been solved in the newly developed 3-phase ac magnet used for this brake. This magnet will be outlined below. The basic construction is shown in *Fig. 3*. The magnet core is E-shaped and the movable core is rectangular. Si-steel core plates punched out beforehand in these shapes are bent in an involute curve as shown in the diagram, laminated in a doughnut configuration, welded together in a sigle unit, and fixed to the base plate. All of the laminated

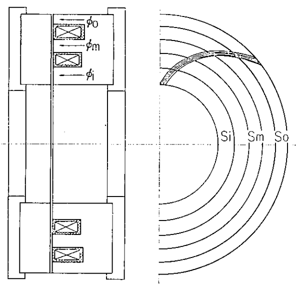


Fig. 3 Construction of magnet

plates are tightly stacked together so that no gaps will appear between them. The involute curves of the magnet core and the movable core are so bent that the curve direction of both cores will agree when the two cores face each other. Coils wound in a ring shape are inserted in the two E-shaped grooves after being molded with special resin. In this magnet, as in the dc magnet, hum and vibrations are very small since all the attractive force is distributed evenly over the circumference, and also for no space is wasted, a high degree of attraction can be obtained in spite of a small size when compared with usual ac magnets.

3. Braking Torque Adjustment

The standard static braking torque is 150% (at 50 Hz) of the rated motor torque. However, when lower braking torque is required, the torque can be adjusted simply by adjusting screws, thereby changing the length of the brake springs. At this time, each spring must be made the same length in order to equalize the pressure applied on the exterior of the movable core.

4. Adjustment Against Brake Lining Wear

Since wear occurs when the brake lining is used for a long time, the magnet gap will become large making it difficult to perform magnetic attraction. Therefore, adjustments must be made to provide a suitable gap. These adjustments are carried out by adjusting the hexagonal nut of the studs which support the magnet core and providing a gap of 0.5 to 0.7 mm with the aid of a gap gauge inserted in the magnet. The interval between adjustments depends upon operating conditions, but under normal operation, the equipment can be used for approximately 500,000 times for motors with 0.4~3.7 kw ; 300,000 times for 5.5 to 7.5 kw and 100,000 for 11 to 15 kw without adjustment. However, it is advisable to adjust at shorter intervals for excellent electrical and mechanical operation.

III. SPECIFICATIONS AND FEATURES

1. specifications

Motor: Totally enclosed, fan cooled, three phase induction motor
Foot mounting ORK or flange mounting SORK
Class E insulation, continuous rating
200 · 200 · 220 v, 50 · 60 · 60 Hz
Output 4-poles 400 w~15 kw
6-poles 200 w~11 kw
8-poles 200 w~7.5 kw
Specified standard JIS C4210

Brake: NB 3-phase ac electromagnetic brake
Spring braking system (Non excitation braking system)
Braking torque 150/180% at 50/60 Hz
200 · 200 · 220 v, 50 · 60 · 60 Hz
Continuous rating

2. Features

1) Since it is of totally enclosed construction, the brake is fully protected from dust, oil particles, water droplets and other foreign particles.

2) A new magnet system has no lever or link mechanisms for brake operation. Since the mechanism is simple and few parts subjected to wear, operation is reliable, and because brake lining materials have been very carefully selected, long service life is passured.

3) Since the brake is compactly built on the rear part of the external fan, this motor is completely interchangeable with the standard E-type motor in terms of dimensions and capacity. Mounting is simple and there are no limitations concerning connections to load machines.

4) Standard braking torque is 150/180% (at 50/60 Hz) of rated motor torque, but lower values (stepless) can be obtained by simple screw adjustment.

5) Since an ac magnet is used, braking operation is fast, and braking time short. Attraction balance is good, and hum and vibrations almost eliminated.

6) The magnet coil is molded to the iron core in a single unit by means of a special resin; and electrical insulation, thermal resistance capacity and resistance to mechanical vibrations and impact are all highly reliable. These features, along with the simplicity of the brake mechanism, allow heavy duty operation.

7) Since brake lining wear is slight, adjustment intervals are long, and maintenance is simple.

8) Due to rationalization of the magnet construction, the entire unit is compact and lightweight.

IV. DRIVE CHARACTERISTICS

1. Magnet Force

In general, the magnet force F is indicated by the following formula.

$$F=\frac{1}{2\mu}\cdot B_g^2\cdot S\times\frac{1}{9.8}\ \text{[kg]}\ \cdots\cdots\cdots\cdots\cdots\cdots(1)$$

where

μ : Permeability [Wb/AT-m] $\fallingdotseq \mu_0=4\pi\times10^{-7}$
B_g : Flux density in air gap [Wb/m^2]
S: Area of air gap [m^2]

The e.m.f. induced in the magnetic coil is

$$E=4.44fN\Phi_m \text{ [v]} \qquad (2)$$

f: Source frequency [Hz]
N: Number of turns in magnet coil
Φ_m: Magnet flux (max.) [Wb]

By V-connecting the outer and inner coil, a 3-phase circuit is obtained. The magnet flux passing through the outer, middle and inner cores is determined, and by adding these various components, the total magnet force can be calculated.

The brake torque T_B is indicated by the following formula. From this the required brake spring force can be determined.

$$T_B=\mu \cdot P \cdot R \cdot n \text{ [kg-m]} \qquad (3)$$

μ: Coefficient of friction
P: Brake spring force [kg]
R: Mean radius of lining [m]
n: Number of braking surfaces

The required magnet force must be sufficient to attract the movable core by overcoming this spring force. However, it is also necessary in practice to consider (1) source voltage variations, (2) gap length due to lining wear, i.e., change in magnet stroke, and (3) spring force dispersion.

The e.m.f. induced in the magnet E and the terminal voltage E_t are related as follows:

$$E=\sqrt{E_t^2-(I_0R)^2} \qquad (4)$$

where

I_0: Exciting current [amp]
R: Coil resistance per phase [Ω]

Therefore, with constant terminal voltage, if the stroke (gap length) becomes large, I_0 increases, and the drop in E cannot be disregarded.

2. Exciting Current

The required exciting ampere turns can be expressed as follows:

$$NI=\frac{B_g\cdot\delta}{\mu}+\Sigma H_i l_i \qquad (5)$$

where

δ: Gap length
H_i: Magnetic intensity of magnet iron core
l_i: Length of H_i section

However, with this involute magnet iron core:

1) The length of the magnetic path differs in the inner and outer coil sections.
2) The leakage coefficient is not equal
3) When the number of coil turns is the same, the resistance values differ at the inner and outer ends.

For these reasons, the exciting current becomes unbalanced in each phase. When the air gap is extended to its maximum length, this unbalance factor sometimes becomes about 30%. Since the magnitude of this exciting current at most is about 10% of the motor main unit current, it presents no problem in practice.

3. Temperature Rise

For this motor, the following operating conditions can be considered.

1) Applications with continuous or short-time excitation condition and cases which require braking and hold torque when stopping
2) Intermittent duty

In the case of 1), the temperature rise in each part of the main motor unit and the temperature rise in each part of the brake system can be considered independently, and the influence of the temperature rise in the brake parts during braking on the temperature rise in the magnet coils can be disregarded. However, in the case of 2), the temperature rise in each part of the main motor unit can be considered the same as the usual intermittent rating; but in the brake parts, there is a close relation between the temperature rise in the magnet section and that in the lining section, and heat loss can be mutually intrepolated.

In the case of 2), the magnet coil temperature rise θ_p under normal condition is indicated by the following approximate formula

$$\theta_p=\frac{\varepsilon W_m+ZW_c+K\cdot Z\cdot\dfrac{GD^2\cdot n^2}{730}}{\varepsilon\lambda_a S_a+(1-\varepsilon)\lambda_b S_b} \qquad (6)$$

where

ε: %ED
Z: Starting or braking frequency [SW/sec]
W_m: Magnet excitation loss [W]
W_c: Magnet excitation loss during attraction [W]
GD^2: Moment of inertia of complete rotation system [kg-m^2]
n: Rotational speed [rpm]
λ_a: Heat dissipation coefficient when magnet is excited [W/m^2·deg]
λ_b: Heat dissipation coefficient when magnet is not excited (braking time) [W/m^2·deg]
S_a, S_b: Heat dissipation area during magnet excitation and braking respectively [m^2]

V. CONTROL CHARACTERISTICS

1. Stopping Time

The stopping time, or the time needed from switching off until complete halt, can be divided into two parts: the operating time needed until the movable core makes contact with the brake disk (dead time) and the time needed from when this contact begins until complete stopping is achieved. The dead time t_d and braking time t_b are given by the following formulae and the complete stopping time is the total of these two times.

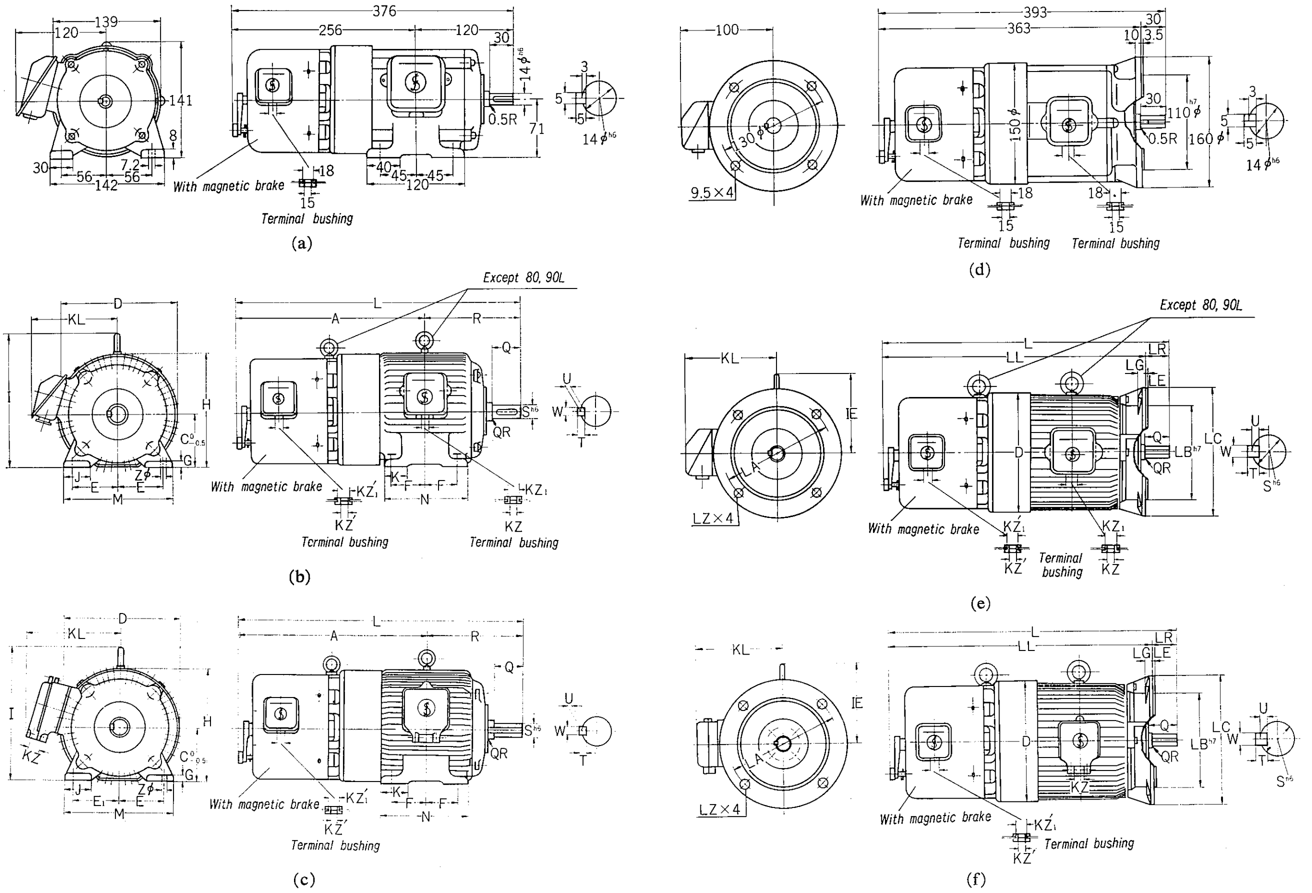
$$t_d=\sqrt{\frac{2W\delta}{gP}} \qquad (7)$$

$$t_b=\frac{nGD^2}{375(T_B+T_L)} \qquad (8)$$

where

W: Weight of movable core [kg]
δ: Magnet gap [m]
g: Acceleration due to gravity 9.8 m/sec^2

***Table 1* Dimensions of NB motor (Unit : mm)**



(b)

Output (kw)		Motor Model	Brake Model	Dimensions																										Bearing (Sealed)	
4-poles	6-poles			A	C	D	E	F	G	H	I	J	K	KL	KZ	KZ$_1$	KZ′	KZ$_1'$	L	M	N	Q	QR	R	S	T	U	W	Z	Driv. Side	Anti D.S.
0.75	0.4	ORK 80	NB08	292	80	164	62.5	50	12	162	—	45	40	135	20	27	15	18	432	155	135	40	—	140	19	5	3	5	9.5	6204	6204
1.5	0.75	ORK 90L	NB15	314	90	174	70	62.5	13	177	—	50	40	155	20	27	15	18	482.5	180	155	50	—	168.5	24	7	4	7	9.5	6205	6205
2.2	1.5	ORK100L	NB22	342	100	194	80	70	14	—	230	50	45	167	20	27	15	18	525	200	170	50	—	183	24	7	4	7	11	6305	6206
3,7	2.2	ORK112M	NB40	355	112	236	95	70	15	—	271	60	50	185	20	27	15	18	555	230	175	60	0.5	200	28	7	4	7	11	6306	6207
5.5	3.7	ORK132S	NB55	409	132	260	108	70	17	—	302	64	54	210	26	34	15	18	648	256	180	80	1.5	239	32	8	4.5	10	11	6308	6308
7.5	5.5	ORK132M	NB80	429	132	260	108	89	17	—	302	64	54	210	26	34	15	18	687	256	218	80	1.5	258	32	8	4.5	10	11	6308	6308

(c)

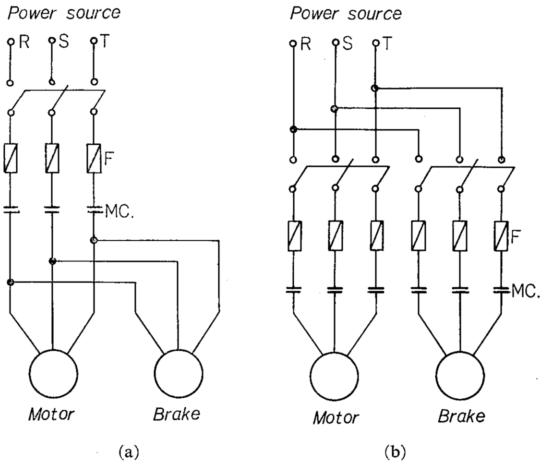
Output (kw)		Motor Model	Brake Model	Dimensions																										Bearing (Sealed)	
4-poles	6-poles			A	C	D	E	F	G	H	I	J	K	KL	KZ	KZ$_1$	KZ′	KZ$_1'$	L	M	N	Q	QR	R	S	T	U	W	Z	Driv. Side	Anti D.S.
11	7.5	ORK160M	NB110	493	160	307	127	105	20	—	359	70	65	250	40	—	15	18	816	306	256	110	1	323	42	8	4.5	12	15	6309	6309
15	10	ORK160L	NB160	515	160	307	127	127	20	—	359	70	65	250	40	—	15	18	860	306	300	110	1	345	42	8	4.5	12	15	6309	6309

(e)

Output (kw)		Motor Model	Brake Model	Dimensions																				Bearing (Sealed)	
4-poles	6-poles			D	IE	L	KL	KZ	KZ$_1$	KZ′	KZ$_1$	LA	LB	LC	LE	LG	LL	LR	LZ	Q	QR	S	T	U	W	Driv. Side	Anti D.S.
0.75	0.4	SORK 80	NB08	170	—	453	127	20	27	15	18	165	130	200	3.5	12	413	40	11	40	—	19	5	3	5	6204	6204
1.5	0.75	SORK 90L	NB15	175	—	518	135	20	27	15	18	165	130	200	3.5	12	468	50	11	50	—	24	7	4	7	6205	6205
2.2	1.5	SGRK100L	NB22	195	135	545	155	20	27	15	18	215	180	250	4	16	495	50	15	50	—	24	7	4	7	6305	6206
3.7	2.2	SORK112M	NB40	236	160	575	175	20	27	15	18	215	180	250	4	16	515	60	15	60	0.5	28	7	4	7	6306	6207
5.5	3.7	SORK132S	NB55	260	170	662	200	26	34	15	18	265	230	300	4	20	582	80	15	80	1.5	32	8	4.5	10	6308	6308
7.5	5.5	SORK132M	NB80	260	170	701	200	26	34	15	18	265	230	300	4	20	621	80	15	80	1.5	32	8	4.5	10	6308	6308

(f)

Output (kw)		Motor Model	Brake Model	Dimensions																				Bearing (Sealed)	
4-poles	6-poles			D	IE	L	KL	KZ	KZ$_1$	KZ′	KZ$_1'$	LA	LB	LC	LE	LG	LL	LR	LZ	Q	QR	S	T	U	W	Driv. Side	Anti D.S.
11	7.5	SORK160M	NB110	320	200	826	230	40	—	15	18	300	250	350	5	20	716	110	19	110	1	42	8	4.5	12	6309	6309
15	11	SORK160L	NB160	320	200	870	230	40	—	15	18	300	250	350	5	20	760	110	19	110	1	42	8	4.5	12	6309	6309



(a) (b)

Fig. 4 Motor and brake connection diagram

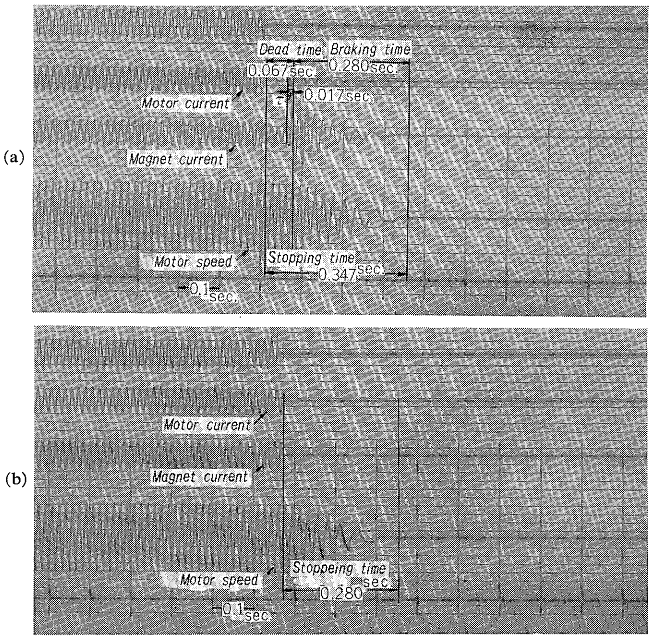


Fig. 5 Oscillogram of braking characteristics

P: Spring force [kg]
n: Rotational speed [rpm]
GD^2: Moment of inertia of complete rotation system [kg-m^2]
T_B: Braking torque [kg-m]
T_L: Load counter torque [kg-m]

Fig. 5(a) is an oscillogram showing the case when the motor and brake parallel circuits are switched with one switch as shown in *Fig. 4 (a)*. *Fig. 5 (b)* shows the case when the same motor and brake circuits are switched independently by 2 switches as shown in *Fig. 4(b)*. The dead time of about 0.004 sec. calculated from the above formula presents no problem, but the dead time in *Fig. 5(a)* (illegible in *Fig. 5(b)*) is very long. The magnet exciting current attenuation is slow and its amplitude once more becomes large from about the time brake dead time finishes. The reason for this is a transfer of magnetic energy between the magnet coil inductance and the motor circuit inductance. The starting component (τ) is due to the inductance variation caused by the gap change when the movable coil separates. Because of this, τ is longer than the dead time calculated by the above-described method. The connections shown in *Fig. 4 (b)* are recommended for shortening the stopping time.

2. Brake Service Life

Fig. 6 shows the results of a service life test of a 7.5 kw, 4-pole, 60 Hz motor with load GD^2 about 3 times that of this motor.

In this test the amount of brake lining wear differed on the magnet side and the motor side since the materials subjected to friction on the magnet side are of steel, while those on the motor side are of cast iron. Brake lining wear shows up less in the cast iron. According to this test result, wear develops rapidly up to 200,000 operations (initial wear), but after this it becomes stable. From the viewpoint of magnet-side wear, service life is about 1,700,000 operations.

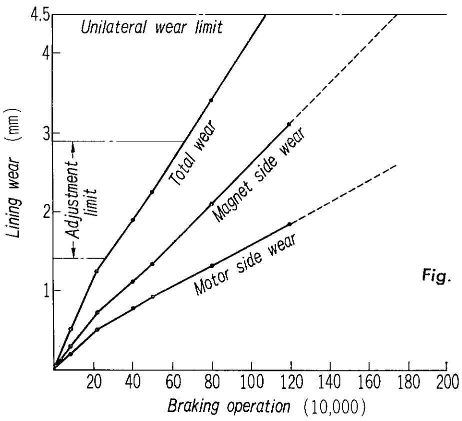


Fig. 6 Brake lining wear

The initial magnet gap is set at 0.6 mm. Considering a maximum gap of 2 mm, the first gap adjustment must be made after 260,000 operations because of rapid initial wear. After this, adjustment must be made every 400,000 operations. This service life is applicable in practice to all models.

VI. EXTERNAL DIMENSIONS

The external dimensions are shown in *Table 1.*

VII. CONCLUSION

The superiority of the NB motors is evident from the construction, features, characteristics, etc. given above. Outdoor types and open types are also being manufactured. We are quite sure that our epockmaking NB motors will be of great service to the rationalization of your equipment and the improvement of your production efficiency.

References:

(1) K. Hamerak: Energie und Technik, Okt. (1962).
(2) J. Döll: Siemens-Z **41.** H. 4 (1967).
(3) H.C. Roters: Electromagnetic Devices, 130 (1861).
(4) R. Richter: Elektrische Maschinen, Bd. I. 360 (1951).