

明細書

ブラシレスDCモータ

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技術分野

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この発明はブラシレスDCモータに関し、さらに詳細に言えば、固定子と回転子とを有し、かつ、回転子の中心寄り所定位置に、回転子の回転軸と平行になるように所定厚みの板状の永久磁石が収容されてあるとともに、永久磁石収容空間の、上記回転軸と直交する方向の端部から回転子の外周に向かって延びる磁束短絡防止用空間が形成されてあるブラシレスDCモータに関する。

背景技術

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従来から、2次銅損がないことに起因して高効率化が可能であるという利点に着目してブラシレスDCモータを種々の分野に適用することの研究開発が進められている。ここで、ブラシレスDCモータは、回転子の表面に永久磁石を装着してなる構成のもの（以下、表面DCモータと称する）と、回転子の内部に永久磁石を埋め込んで保持してなる構成のもの（以下、埋込DCモータと称する）とに大別される。

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そして、埋込DCモータは、例えば、特開平5-236686号公報、
"Interior Permanent-Magnet Synchronous Motors for Adjustable-Speed Drives", IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. IA-22, NO. 4, JULY/AUGUST 1986に示すように、回転子を固定子の内部に回転可能に収容してあり、回転子の回転軸寄り所定位置

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に、回転子の回転軸と平行になるように所定厚みの板状の永久磁石が収容されてあるとともに、永久磁石収容空間の、上記回転軸と直交する方向の端部から回転子の外周に向かって延びる磁束短絡防止用空間が形成されてある。この埋込DCモータは、表面DCモータと比較して広範囲な運転が可能であり、高トルクを発生することができ、高トルクにより高効率な運転が可能であるという利点を有している。

また、埋込DCモータでは、永久磁石を回転子の回転軸寄り所定位置に埋め込み保持する関係上、永久磁石の体積が表面DCモータと比較して減少するので、エネルギー積が大きい希土類永久磁石を採用することになる。

上記埋込DCモータは、回転子の回転軸と平行な方向に延びる永久磁石収容空間の全範囲に板状の永久磁石が収容されているのであるから、モータの起動時、インバータの故障時、弱め磁束運転時等のように、回転子に埋め込み保持された永久磁石に逆磁界（固定子巻線により発生される磁界）がかかる場合に、永久磁石の端部（磁束短絡防止用空間に臨む端部）に逆磁界が集中することになるので、永久磁石の動作点が屈曲点を越えてしまい、永久磁石の減磁が発生してしまう（例えば、図12に示す希土類永久磁石の特性曲線中の点A、Bおよび矢印参照）。具体的には、永久磁石に逆磁界がかかった状態における磁力線は図13に示すとおりであり、永久磁石を 2×16 の小領域に仮想的に区分して各区分の磁束密度を計測したところ、図14に示すとおりであり、両端部における磁束密度が他の部分と比較して著しく小さくなっている。但し、実際には、両端部は屈曲点を越えているので、磁束密度は0になっている。また、図14中の数字は、各区分の中心での磁束密度を示している。そして、永久磁石の減磁が発生すると、初期の性能を維持することができなくなり、信頼性が低下してしまう。

このような不都合を防止するために、従来の埋込DCモータにおいて、永久磁石の端部に逆磁界が集中せず、永久磁石の減磁が発生しない程度に厚みが多い永久磁石を採用することが考えられるが、単価が高い希土類永久磁石の必要量が多くなるので、回転子がコストアップし、ひいては埋込DCモータがコストアップしてしまう。

また、希土類永久磁石の動作点が屈曲点を越えないように固定子巻線への通電電流を制限すること、温度を低くすることも考えられるが、このような制限を加えると、運転範囲が狭くなってしまい、十分に大きなトルクを発生させることができなくなってしまい、十分に高効率な運転を行なわせることができなくなってしまい、この結果、埋込DCモータの利点を十分には発揮させることができなくなってしまう。

この発明は上記の問題点に鑑みてなされたものであり、永久磁石の厚みを増加させることなく、永久磁石の端部における逆磁界の集中、減磁を未然に防止し、モータの性能を十分に発揮させることができるブラシレスDCモータを提供することを目的としている。

発明の開示

請求の範囲第1項のブラシレスDCモータは、永久磁石の幅方向端部に対応する永久磁石収容空間の回転子外周側境界面の部位から永久磁石収容空間、磁束短絡防止用空間の回転軸側境界面までの距離の最小値が、永久磁石の幅方向端部における永久磁石収容空間の上記厚み方向の距離よりも大きくなるように上記永久磁石収容空間または磁束短絡防止用空間が形成されてある。

請求項1のブラシレスDCモータであれば、固定子と回転子とを有し、かつ、回転子の中心寄り所定位置に、回転子の回転軸と平行に永久磁石収容空間が形成されており、この永久磁石収容空間に所定厚み、幅の板

5 状の永久磁石が收容されてあるとともに、上記永久磁石の幅方向に対する永久磁石收容空間の端部から回転子の外周に向かって延びる磁束短絡防止用空間が形成されてあるブラシレスDCモータにおいて、永久磁石の幅方向端部に対応する永久磁石收容空間の回転子外周側境界面の部位から上記両空間の回転軸側境界面までの距離の最小値が、永久磁石の幅方向端部における永久磁石收容空間の上記厚み方向の距離よりも大きくなるように上記永久磁石收容空間または磁束短絡防止用空間が形成されてあるので、永久磁石に逆磁界がかかる場合であっても、永久磁石の端部に逆磁界が集中することではなく、永久磁石の全範囲に逆磁界が均等にかかることになる。したがって、永久磁石の厚みを増加させることなく逆磁界の集中に起因する減磁を未然に防止することができ、埋込DCモータとしての性能を十分に発揮させることができるとともに、永久磁石の大形化に起因するコストアップをも未然に防止することができる。

10 請求の範囲第2項のブラシレスDCモータは、永久磁石の幅方向端部に対応する永久磁石收容空間の回転子外周側境界面の部位から永久磁石收容空間、磁束短絡防止用空間の回転軸側境界面までの距離の最小値が、永久磁石の幅方向端部における永久磁石收容空間の上記厚み方向の距離よりも大きくなるように永久磁石の幅、および收容位置が設定されている。

20 請求項2のブラシレスDCモータであれば、固定子と回転子とを有し、かつ、回転子の中心寄り所定位置に、回転子の回転軸と平行に永久磁石收容空間が形成されており、この永久磁石收容空間に所定厚み、幅の板状の永久磁石が收容されてあるとともに、上記永久磁石の幅方向に対する永久磁石收容空間の端部から回転子の外周に向かって延びる磁束短絡防止用空間が形成されてあるブラシレスDCモータにおいて、永久磁石の幅方向端部に対応する永久磁石收容空間の回転子外周側境界面の部位

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から上記両空間の回転軸側境界面までの距離の最小値が、永久磁石の幅方向端部における永久磁石收容空間の上記厚み方向の距離よりも大きくなるように永久磁石の幅、および收容位置が設定されているので、永久磁石に逆磁界がかかる場合であっても、永久磁石の端部に逆磁界が集中することはなく、永久磁石の全範囲に逆磁界が均等にかかることになる。

したがって、永久磁石の厚みを増加させることなく逆磁界の集中に起因する減磁を未然に防止することができ、埋込DCモータとしての性能を十分に発揮させることができるとともに、永久磁石の大形化に起因するコストアップをも未然に防止することができる。

請求の範囲第3項のブラシレスDCモータは、永久磁石收容空間および磁束短絡防止用空間の回転軸側境界面とおしのなす角を $\theta 2$ 、永久磁石收容空間の上記厚み方向の距離を $l m$ 、永久磁石收容空間および磁束短絡防止用空間の回転子外周側境界面とおしの接続部と、永久磁石收容空間および磁束短絡防止用空間の回転軸側境界面とおしの接続部との距離を $l w$ 、永久磁石收容空間の回転子外周側境界面と磁束短絡防止用空間の対応する境界面との接続部から永久磁石の幅方向端部までの距離を $l r$ 、永久磁石收容空間の回転軸側境界面と磁束短絡防止用空間の対応する境界面との接続部から永久磁石の対応する端部までの距離を $l r'$ とした場合に、 $l w < l m / \sin (\theta 2 / 2)$ かつ $l r \leq l r'$ であることに応答して $l r \geq l m (1 + \cos \theta 2) / \sin \theta 2 - (l w^2 - l m^2)^{1/2}$ に設定し、 $l w < l m / \sin (\theta 2 / 2)$ かつ $l r > l r'$ であることに応答して $l r \geq l m (1 + \cos \theta 2) / \sin \theta 2 + (l w^2 - l m^2)^{1/2}$ に設定したものである。

請求項3のブラシレスDCモータであれば、永久磁石收容空間および磁束短絡防止用空間の回転軸側境界面とおしのなす角を $\theta 2$ 、永久磁石收容空間の上記厚み方向の距離を $l m$ 、永久磁石收容空間および磁束短

絡防止用空間の回転子外周側境界面とおしの接続部と、永久磁石収容空間および磁束短絡防止用空間の回転軸側境界面とおしの接続部との距離を l_w 、永久磁石収容空間の回転子外周側境界面と磁束短絡防止用空間の対応する境界面との接続部から永久磁石の幅方向端部までの距離を l_r 、永久磁石収容空間の回転軸側境界面と磁束短絡防止用空間の対応する境界面との接続部から永久磁石の対応する端部までの距離を $l_{r'}$ とした場合に、 $l_w < l_m / \sin(\theta_2/2)$ かつ $l_r \leq l_{r'}$ であることに応答して $l_r \geq l_m(1 + \cos \theta_2) / \sin \theta_2 - (l_w^2 - l_m^2)^{1/2}$ に設定し、 $l_w < l_m / \sin(\theta_2/2)$ かつ $l_r > l_{r'}$ であることに応答して $l_r \geq l_m(1 + \cos \theta_2) / \sin \theta_2 + (l_w^2 - l_m^2)^{1/2}$ に設定しているので、請求項 2 と同様の作用を達成することができる。

請求の範囲第 4 項のブラシレス DC モータは、上記永久磁石の幅方向に対する移動を阻止する突部が永久磁石収容空間の境界面に形成されたものである。

請求項 4 のブラシレス DC モータであれば、上記永久磁石の幅方向に対する移動を阻止する突部が永久磁石収容空間の境界面に形成されてあるので、逆磁界が集中する可能性がある位置に永久磁石が移動してしまうという不都合の発生を未然に防止することができ、ひいては請求項 1 から請求項 3 の何れかと同様の作用を達成することができる。

請求の範囲第 5 項のブラシレス DC モータは、磁束短絡防止用空間が永久磁石収容空間の端部から直線的に回転子の外周に向かって形成されてあるとともに、永久磁石の幅が永久磁石収容空間の幅よりも小さく設定されてある。

請求の範囲第 5 項のブラシレス DC モータであれば、固定子と回転子とを有し、かつ、回転子の中心寄り所定位置に、回転子の回転軸と平行

に永久磁石收容空間が形成されており、この永久磁石收容空間に所定厚み、幅の板状の永久磁石が收容されてあるとともに、上記永久磁石の幅方向に対する永久磁石收容空間の端部から回転子の外周に向かって延びる磁束短絡防止用空間が形成されてあるブラシレスDCモータにおいて、
5 磁束短絡防止用空間が永久磁石收容空間の端部から直線的に回転子の外周に向かって形成されてあるとともに、永久磁石の幅が永久磁石收容空間の幅よりも小さく設定されてあるので、永久磁石に逆磁界がかかる場合であっても、永久磁石の端部に逆磁界が集中することはなく、永久磁石の全範囲に逆磁界が均等にかかることになる。したがって、永久磁石の厚みを増加させることなく逆磁界の集中に起因する減磁を未然に防止
10 することができ、埋込DCモータとしての性能を十分に発揮させることができるのと同時に、永久磁石の大形化に起因するコストアップをも未然に防止することができる。

請求の範囲第6項のブラシレスDCモータは、磁束短絡防止用空間の厚みが、永久磁石の幅方向端部における永久磁石收容空間の、永久磁石
15 の厚み方向における距離以下に設定されたものである。

請求の範囲第6項のブラシレスDCモータであれば、磁束短絡防止用空間の厚みが、永久磁石の幅方向端部における永久磁石收容空間の、永久磁石の厚み方向における距離以下に設定されているので、請求の範囲
20 第5項の作用に加えて、磁束短絡防止用空間を小さくすることに伴って永久磁石を回転子の回転軸寄りに位置させることができ、永久磁石表面の鉄部が増加し、より磁束が流れ易くなるので、リラクタンストルクをより有効に利用することができる。

請求の範囲第7項のブラシレスDCモータは、永久磁石の幅方向端部に対応する永久磁石收容空間の回転子外周側境界面の部位から上記両空間
25 の回転軸側境界面までの距離の最小値が、永久磁石の幅方向端部にお

ける永久磁石收容空間の上記厚み方向の距離よりも大きくなるように上記永久磁石收容空間または磁束短絡防止用空間が形成されてあるとともに、永久磁石收容空間の厚み方向の距離を 1 m 、磁束短絡防止用空間の、回転子の周方向の距離を 1 m とした場合に、 $1\text{ m} \geq 1\text{ m}$ に設定したものである。

請求の範囲第7項のブラシレスDCモータであれば、永久磁石の幅方向端部に対応する永久磁石收容空間の回転子外周側境界面の部位から上記両空間の回転軸側境界面までの距離の最小値が、永久磁石の幅方向端部における永久磁石收容空間の上記厚み方向の距離よりも大きくなるように上記永久磁石收容空間または磁束短絡防止用空間が形成されてあるとともに、永久磁石收容空間の厚み方向の距離を 1 m 、磁束短絡防止用空間の、回転子の周方向の距離を 1 b とした場合に、 $1\text{ m} \geq 1\text{ b}$ に設定しているので、永久磁石に逆磁界がかかる場合であっても、永久磁石の端部に逆磁界が集中することはなく、永久磁石の全範囲に逆磁界が均等にかかることになる。したがって、永久磁石の厚みを増加させることなく逆磁界の集中に起因する減磁を未然に防止することができ、埋込DCモータとしての性能を十分に発揮させることができるとともに、永久磁石の大形化に起因するコストアップをも未然に防止することができる。

また、永久磁石部と磁束短絡防止空間との磁気抵抗を比較すると、磁束短絡防止空間の方が磁気抵抗が小さくなるので、逆磁界中（減磁作用中）において固定子からの磁束が磁束短絡防止空間を通り易くなり、永久磁石に対する減磁作用を低減することができる。さらに、磁束短絡防止用空間を小さくすることに伴って永久磁石を回転子の回転軸寄りに位置させることができ、永久磁石表面の鉄部が増加し、より磁束が流れ易くなるので、リラクタンストルクをより有効に利用することができる。

図面の簡単な説明

図1はこの発明のブラシレスDCモータの一実施例を概略的に示す縦断面図である。

図2は同上要部拡大図である。

5 図3はこの発明のブラシレスDCモータの他の実施例の要部を拡大して示す概略図である。

図4は図3の実施例を適用した場合における回転子中の磁束線図を示す図である。

図5は従来の回転子中の磁束線図である。

10 図6はこの発明のブラシレスDCモータのさらに他の実施例の要部を拡大して示す概略図である。

図7はこの発明のブラシレスDCモータのさらに他の実施例の要部を拡大して示す概略図である。

15 図8はこの発明のブラシレスDCモータのさらに他の実施例の要部を拡大して示す概略図である。

図9は図8のIX-IX線断面図である。

図10は突部近傍を拡大して示す図である。

図11(A)～(D)はこの発明のブラシレスDCモータのさらに他の実施例の要部を拡大して示す概略図である。

20 図12は希土類永久磁石の特性曲線を示す図である。

図13は永久磁石に逆磁界がかかった状態における磁力線を示す図である。

図14は永久磁石を 2×16 の小領域に仮想的に区分して各区分の磁束密度を計測した結果を示す図である。

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発明を実施するための最良の形態

以下、実施態様を示す添付図面によってこの発明を詳細に説明する。

図1はこの発明のブラシレスDCモータの一実施態様を概略的に示す部分縦断面図、図2は同上要部拡大図である。このブラシレスDCモータは、固定子巻線2を有する固定子1と永久磁石4を有する回転子3とを有している。そして、回転子3は多数枚の電磁鋼板を積層してなるものであり、その中心を軸方向に貫通する回転軸3aを有している。また、回転子3は、この実施態様においては4極構成であるから、回転軸寄りの所定位置に、 90° ずつの回転対称位置における半径と直交し、かつ軸方向に延びるように、所定幅、所定厚み l_m の永久磁石收容空間3bをそれぞれ有しているとともに、各永久磁石收容空間3bの幅方向の端部から外周に向かって延びる磁束短絡防止用空間3cを有している。さらに、上記各永久磁石收容空間3bには、希土類磁石等からなる永久磁石4が收容されている。また、永久磁石收容空間3bの回転軸寄りの境界面3b1と磁束短絡防止用空間3cの対応する境界面3c1との第1交線をa、永久磁石收容空間3bの外周面寄りの境界面3b2と磁束短絡防止用空間3cの対応する境界面3c2との第2交線をb、永久磁石收容空間3bの回転軸寄りの境界面3b1と磁束短絡防止用空間3cの対応する境界面3c1とのなす角を θ_2 、永久磁石4の回転子外周側の面上における、回転子半径方向と直交する方向の端部をcでそれぞれ示している。そして、第2交線bと、永久磁石收容空間3bの回転軸寄りの境界面3b1に対応する磁束短絡防止用空間3cの境界面3c1との距離 l_m' が、永久磁石收容空間3bの上記両境界面3b1, 3b2間の距離 l_m よりも短く設定されている。また、永久磁石4の上記端部cと上記第2交線bとの距離 l_r が、永久磁石4の回転軸側の面上における、回転子半径方向と直交する方向の端部fと上記第1交線aとの距離 l_r' よりも大きく設定されている。即ち、第1交線aが第2交線bよ

りも外側に位置している。

図2を参照しながらさらに詳細に説明する。なお、図2において“／／”が付与された第1、第2破線d、eおよび実線3c1は互いに平行である。また、上記第2破線eは上記第2交線bを通る面を示す破線であり、上記第1破線dは、永久磁石収容空間3bの回転軸寄りの境界面3b1の延長上において上記第1交線aと正対する直線を通る面を示す破線である。

この実施態様においては、磁束短絡防止用空間3cの厚み l_m が永久磁石収容空間3bの厚み l_m よりも小さく設定されているとともに、第1交線aが第2交線bよりも外側に位置しているのであるから、永久磁石収容空間3bの回転軸寄りの境界面3b1の延長方向における両破線d、eの距離は $(l_w^2 + l_m^2)^{1/2}$ であり、磁束短絡防止用空間3cの境界面3c1と第1破線dとの距離は $-l_m \cos \theta_2$ であり、永久磁石4の上記端部cと第1破線dとの距離は $\{(l_w^2 + l_m^2)^{1/2} + l_r\} \sin \theta_2$ である。したがって、磁束短絡防止用空間3cの境界面3c1と永久磁石4の端部cとの距離は、 $-l_m \cos \theta_2 + \{(l_w^2 + l_m^2)^{1/2} + l_r\} \sin \theta_2$ となる。そして、この距離が l_m 以上であれば、永久磁石4の端部に逆磁界が集中することはないのであるから、この関係を整理すれば、 $l_r \geq l_m (1 + \cos \theta_2) / \sin \theta_2 - (l_w^2 + l_m^2)^{1/2}$ となる。

したがって、距離 l_r が上式を満足するように永久磁石4の端部cを上記第2交線bから離せば、逆磁界が永久磁石4の端部に集中することがなく、永久磁石4の全範囲に均等に作用することになるので、永久磁石4の厚みを増加させることなく逆磁界の集中に起因する永久磁石4の

減磁を未然に防止することができ、埋込DCモータとしての性能を十分に発揮させることができるとともに、永久磁石の大形化に起因するコストアップをも未然に防止することができる。

実施態様2

図3はこの発明のブラシレスDCモータの他の実施態様の要部を拡大して示す概略図であり、上記実施態様と異なる点は、第1交線aが第2交線bよりも内側に位置している点のみである。

この実施態様の場合には、永久磁石収容空間3bの回転軸寄りの境界面3b1の延長方向における両破線d、eの距離は $(lw^2 + lm^2)^{1/2}$ であり、磁束短絡防止用空間3cの境界面3c1と第1破線dとの距離は $-lm \cos \theta 2$ であり、永久磁石4の上記端部cと第1破線dとの距離は $\{lr - (lw^2 + lm^2)^{1/2}\} \sin \theta 2$ である。したがって、磁束短絡防止用空間3cの境界面3c1と永久磁石4の端部cとの距離は、

$-lm \cos \theta 2 + \{lr - (lw^2 + lm^2)^{1/2}\} \sin \theta 2$
となる。そして、この距離が lm 以上であれば、永久磁石4の端部に逆磁界が集中することはないのであるから、この関係を整理すれば、
 $lr \geq lm(1 + \cos \theta 2) / \sin \theta 2 + (lw^2 + lm^2)^{1/2}$

となる。

したがって、距離 lr が上式を満足するように永久磁石4の端部cを上記第2交線bから離せば、逆磁界が永久磁石4の端部に集中することがなく、永久磁石4の全範囲に均等に作用することになるので、永久磁石4の厚みを増加させることなく逆磁界の集中に起因する永久磁石4の減磁を未然に防止することができ、埋込DCモータとしての性能を十分

に発揮させることができるとともに、永久磁石の大形化に起因するコストアップをも未然に防止することができる。

図4はこの実施態様を適用した場合における回転子中の磁束線図を示す図であり、図5は従来の回転子中の磁束線図であり、図5の場合には、永久磁石の端部において逆磁界の影響で永久磁石の磁束が押え込まれているが、図4の場合には、永久磁石の全範囲において磁束が回転子鉄心まで出ている。したがって、逆磁界の局所的な集中を未然に排除できていることが分る。

また、図4の場合には、磁束短絡防止用空間3cの厚み1m^{*}が、永久磁石収容空間3bの厚み1m、即ち、永久磁石4の厚み以下に設定されているのであるから、永久磁石4を回転子3の回転軸3aに近い位置に配置することが可能になり、永久磁石4表面の鉄部（鉄心）を増加させることができる。この場合には、永久磁石4表面の鉄部の増加により磁束がより流れ易くなるので、リラクタンストルクをより有効に利用することができる。さらに、永久磁石4と磁束短絡防止用空間3cとの磁気抵抗は、後者の方が小さいので、逆磁界中（減磁作用中）には固定子1からの磁束が磁束短絡防止用空間3cを通り易くなり、永久磁石4に対する減磁作用を弱めることができる。

実施態様3

図6はこの発明のブラシレスDCモータのさらに他の実施態様の要部を拡大して示す概略図であり、図2の実施態様と異なる点は、第2交線bと、永久磁石収容空間3bの回転軸寄りの境界面に対応する磁束短絡防止用空間3cの境界面上の点との距離の最小値が、永久磁石収容空間3bの回転子半径方向の距離以上に設定されている点のみである。なお、図6中、実線は上記最小値が上記回転子半径方向の距離と等しい場合を

示しており、図6中、破線は上記最小値が上記回転子半径方向の距離よりも大きい場合を示している。

したがって、この実施態様の場合には、 $1r \geq 0$ となるように永久磁石4の端部cを上記第2交線bから離せば（ $1r = 0$ の場合には永久磁石4の端部cが第2交線bと一致する）、逆磁界が永久磁石4の端部に集中することがなく、永久磁石4の全範囲に均等に作用することになるので、永久磁石4の厚みを増加させることなく逆磁界の集中に起因する永久磁石4の減磁を未然に防止することができ、埋込DCモータとしての性能を十分に発揮させることができるとともに、永久磁石の大形化に起因するコストアップをも未然に防止することができる。

尚、以上の何れの実施態様においても、実際に第1交線aが存在する場合について説明したが、永久磁石收容空間3bの上記境界面と磁束短絡防止用の空間3cの上記境界面とが円弧状になだらかに連続されている場合であっても、上記両境界面の仮想的な交線を想定して何れかの実施態様を適用することにより、同様の作用を達成することができる。さらに、図7に示すように永久磁石收容空間3bの厚みよりも永久磁石收容空間の回転子外周側境界面の部位から磁束短絡防止用空間の回転軸側境界面までの距離の最小値を大きく設定し、しかも両空間の接統部に段部を形成することも可能である。

実施態様4

図8はこの発明のブラシレスDCモータのさらに他の実施態様の要部を拡大して示す概略図、図9は図8のIX-IX線断面図であり、上記実施態様と異なる点は、永久磁石收容空間3bの内部所定位置に位置して、永久磁石4の両端部における上記距離 $1r$ を確実に確保すべく、永久磁石4の幅方向における位置を規制する位置規制用の突部3dを回転

予3の所定位置に設けた点のみである。そして、この突部3dは、回転子3の全範囲に形成してもよいが、互いに異なる少なくとも2カ所において1枚以上の電磁鋼板と一体に設けてもよい。また、突部3dを形成すれば、この部分において永久磁石収容空間3bの厚み1mが局部的に小さくなるので、図10に示すように、局部的に小さくなった厚み1tが永久磁石4の厚み1d以上になるように永久磁石収容空間3bの厚みを大きく設定して、永久磁石4の端部に逆磁界が集中することを防止する。なお、永久磁石収容空間3bの厚みを大きく設定する範囲は、上記突部3dが局部的に設けられている場合に、突部3dが設けられている位置を基準として回転軸方向の所定範囲（逆磁界の集中を防止できる所定範囲）に設定しておく。

したがって、この実施態様の場合には、永久磁石4の両端部において上記距離1rを確実に確保することができるほか、上記実施態様と同様の作用を達成することができる。

実施態様5

図11(A)～(D)はこの発明のブラシレスDCモータのさらに他の実施態様の要部を拡大して示す概略図である。

これらの実施態様は、永久磁石収容空間3bと連続する部分において磁束短絡防止用空間3cの厚み1m'を永久磁石収容空間3bの厚み1mよりも大きくすべく段部を形成してある。なお、この段部は、回転子3の回転軸3aに向かうように形成されてある。

また、図11(A)(B)においては、磁束短絡防止用空間3cの厚み1m'が永久磁石収容空間3bの厚み1m（永久磁石4の厚み）よりも小さく設定されているとともに、永久磁石収容空間3bの回転子外周側の面と磁束短絡防止用空間3cの対応する面との接続部を基準として、

永久磁石4の端部が永久磁石収容空間3bの中央側に所定距離離されている（永久磁石4の幅が永久磁石収容空間3bよりも短く設定されている）。

図11(A)(B)の場合には、磁束短絡防止用空間3cの厚み1mが、永久磁石収容空間3bの厚み1m、即ち、永久磁石4の厚み以下に設定されているのであるから、永久磁石4を回転子3の回転軸3aに近い位置に配置することが可能になり、永久磁石4表面の鉄部（鉄心）を増加させることができる。この場合には、永久磁石4表面の鉄部の増加により磁束がより流れ易くなるので、リラクタンストルクをより有効に利用することができる。さらに、永久磁石4と磁束短絡防止用空間3cとの磁気抵抗は、後者の方が小さいので、逆磁界中（減磁作用中）には固定子1からの磁束が磁束短絡防止用空間3cを通り易くなり、永久磁石4に対する減磁作用を弱めることができる。

また、図11(C)(D)においては、磁束短絡防止用空間3cの厚み1mが永久磁石収容空間3bの厚み1m（永久磁石4の厚み）と等しく設定されているとともに、永久磁石収容空間3bの回転子外周側の面と磁束短絡防止用空間3cの対応する面との接続部と、永久磁石4の端部とが互いに一致するように永久磁石4が永久磁石収容空間3bに収容されている（永久磁石4の幅が永久磁石収容空間3bと等しく設定されている）。

図11(C)(D)の場合には、磁束短絡防止用空間3cの厚み1mが、永久磁石収容空間3bの厚み1m、即ち、永久磁石4の厚みと等しく設定されているのであるから、永久磁石4を回転子3の回転軸3aに近い位置（図11(A)(B)の場合よりもやや遠い位置）に配置することが可能になり、永久磁石4表面の鉄部（鉄心）を増加させることができる（ただし、鉄部の増加量は図11(A)(B)の場合よりもや

や少ない)。この場合には、永久磁石 4 表面の鉄部の増加により磁束が流れ易くなるので、リラクタンストルクを有効に利用することができる。さらに、永久磁石 4 と磁束短絡防止用空間 3 c との磁気抵抗は、互いに等しいので、永久磁石 4 を永久磁石収容空間 3 b の全範囲に収容することができる。

産業上の利用可能性

回転子の表面よりも内部に永久磁石を設けてなるブラシレス DC モータにおいて、永久磁石の減磁を抑制して安定した性能を発揮させることができるとともに、リラクタンストルクを有効に利用することができる。

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請求の範囲

1. 固定子(1)と回転子(3)とを有し、かつ、回転子(3)の中心寄り所定位置に、回転子(3)の回転軸(3a)と平行に永久磁石收容空間(3b)が形成されており、この永久磁石收容空間(3b)に所定厚み、幅の板状の永久磁石(4)が收容されてあるとともに、上記永久磁石(4)の幅方向に対する永久磁石收容空間(3b)の端部から回転子(3)の外周に向かって延びる磁束短絡防止用空間(3c)が形成されてあるブラシレスDCモータにおいて、永久磁石(4)の幅方向端部に対応する永久磁石收容空間(3b)の回転子外周側境界面の部位から上記両空間(3b)(3c)の回転軸側境界面までの距離の最小値が、永久磁石(4)の幅方向端部における永久磁石收容空間(3b)の上記厚み方向の距離よりも大きくなるように上記永久磁石收容空間(3b)または磁束短絡防止用空間(3c)が形成されてあることを特徴とするブラシレスDCモータ。

2. 固定子(1)と回転子(3)とを有し、かつ、回転子(3)の中心寄り所定位置に、回転子(3)の回転軸(3a)と平行に永久磁石收容空間(3b)が形成されており、この永久磁石收容空間(3b)に所定厚み、幅の板状の永久磁石(4)が收容されてあるとともに、上記永久磁石(4)の幅方向に対する永久磁石收容空間(3b)の端部から回転子(3)の外周に向かって延びる磁束短絡防止用空間(3c)が形成されてあるブラシレスDCモータにおいて、永久磁石(4)の幅方向端部に対応する永久磁石收容空間(3b)の回転子外周側境界面の部位から上記両空間(3b)(3c)の回転軸側境界面までの距離の最小値が、永久磁石(4)の幅方向端部における永久磁石收容空間(3b)の上記厚み方向の距離よりも大きくなるように永久磁石(4)の幅、およ



び収容位置が設定されていることを特徴とするブラシレスDCモータ。

3. 永久磁石収容空間(3b)および磁束短絡防止用空間(3c)の回転軸側境界面とおしのなす角を $\theta 2$ 、永久磁石収容空間(3b)の上記厚み方向の距離を $l m$ 、永久磁石収容空間(3b)および磁束短絡防止用空間(3c)の回転子外周側境界面とおしの接続部と、永久磁石収容空間(3b)および磁束短絡防止用空間(3c)の回転軸側境界面とおしの接続部との距離を $l w$ 、永久磁石収容空間(3b)の回転子外周側境界面と磁束短絡防止用空間(3c)の対応する境界面との接続部から永久磁石(4)の幅方向端部までの距離を $l r$ 、永久磁石収容空間(3b)の回転軸側境界面と磁束短絡防止用空間(3c)の対応する境界面との接続部から永久磁石(4)の対応する端部までの距離を $l r'$ とした場合に、 $l w < l m / \sin(\theta 2 / 2)$ かつ $l r \leq l r'$ であることに応答して $l r \geq l m (1 + \cos \theta 2) / \sin \theta 2 - (l w^2 - l m^2)^{1/2}$ に設定し、 $l w < l m / \sin(\theta 2 / 2)$ かつ $l r > l r'$ であることに応答して $l r \geq l m (1 + \cos \theta 2) / \sin \theta 2 + (l w^2 - l m^2)^{1/2}$ に設定する請求の範囲第2項に記載のブラシレスDCモータ。

4. 上記永久磁石(4)の幅方向に対する移動を阻止する突部(3d)が永久磁石収容空間(3b)の境界面に形成されてある請求の範囲第1項から第3項の何れかに記載のブラシレスDCモータ。

5. 固定子(1)と回転子(3)とを有し、かつ、回転子(3)の中心寄り所定位置に、回転子(3)の回転軸(3a)と平行に永久磁石収容空間(3b)が形成されており、この永久磁石収容空間(3b)に所定厚み、幅の板状の永久磁石(4)が収容されてあるとともに、上記永久磁石(4)の幅方向に対する永久磁石収容空間(3b)の端部から回転子(3)の外周に向かって延びる所定厚み、所定幅の磁束短絡防止



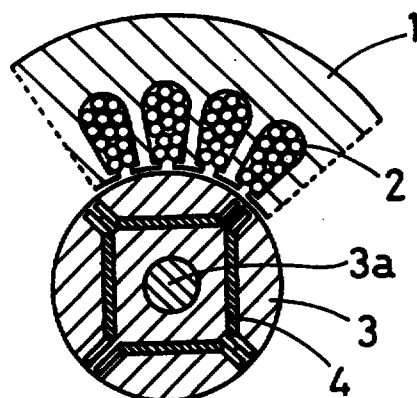
用空間（３ｃ）が形成されてあるブラシレスＤＣモータにおいて、磁束短絡防止用空間（３ｃ）が永久磁石収容空間（３ｂ）の端部から直線的に回転子（３）の外周に向かって形成されてあるとともに、永久磁石（４）の幅が永久磁石収容空間（３ｂ）の幅よりも小さく設定されてあることを特徴とするブラシレスＤＣモータ。

６．磁束短絡防止用空間（３ｃ）の厚みが、永久磁石（４）の幅方向端部における永久磁石収容空間（３ｂ）の、永久磁石（４）の厚み方向における距離以下に設定されてある請求の範囲第５項に記載のブラシレスＤＣモータ。

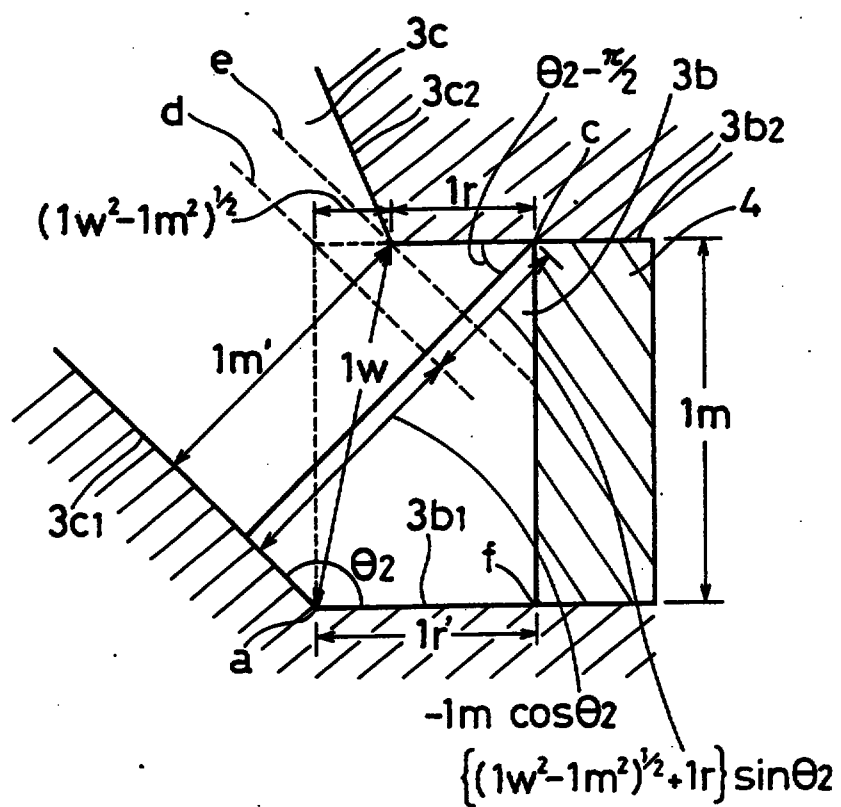
７．固定子（１）と回転子（３）とを有し、かつ、回転子（３）の中心寄り所定位置に、回転子（３）の回転軸（３ａ）と平行に永久磁石収容空間（３ｂ）が形成されており、この永久磁石収容空間（３ｂ）に所定厚み、幅の板状の永久磁石（４）が収容されてあるとともに、上記永久磁石（４）の幅方向に対する永久磁石収容空間（３ｂ）の端部から回転子（３）の外周に向かって延びる磁束短絡防止用空間（３ｃ）が形成されてあるブラシレスＤＣモータにおいて、永久磁石（４）の幅方向端部に対応する永久磁石収容空間（３ｂ）の回転子外周側境界面の部位から上記両空間（３ｂ）（３ｃ）の回転軸側境界面までの距離の最小値が、永久磁石（４）の幅方向端部における永久磁石収容空間（３ｂ）の上記厚み方向の距離よりも大きくなるように上記永久磁石収容空間（３ｂ）または磁束短絡防止用空間（３ｃ）が形成されてあるとともに、永久磁石収容空間（３ｂ）の上記厚み方向の距離を $l\text{ m}$ 、磁束短絡防止用空間（３ｃ）の、回転子（３）の周方向の距離を $l\text{ m}$ とした場合に、 $l\text{ m} \geq l\text{ m}$ に設定することを特徴とするのブラシレスＤＣモータ。



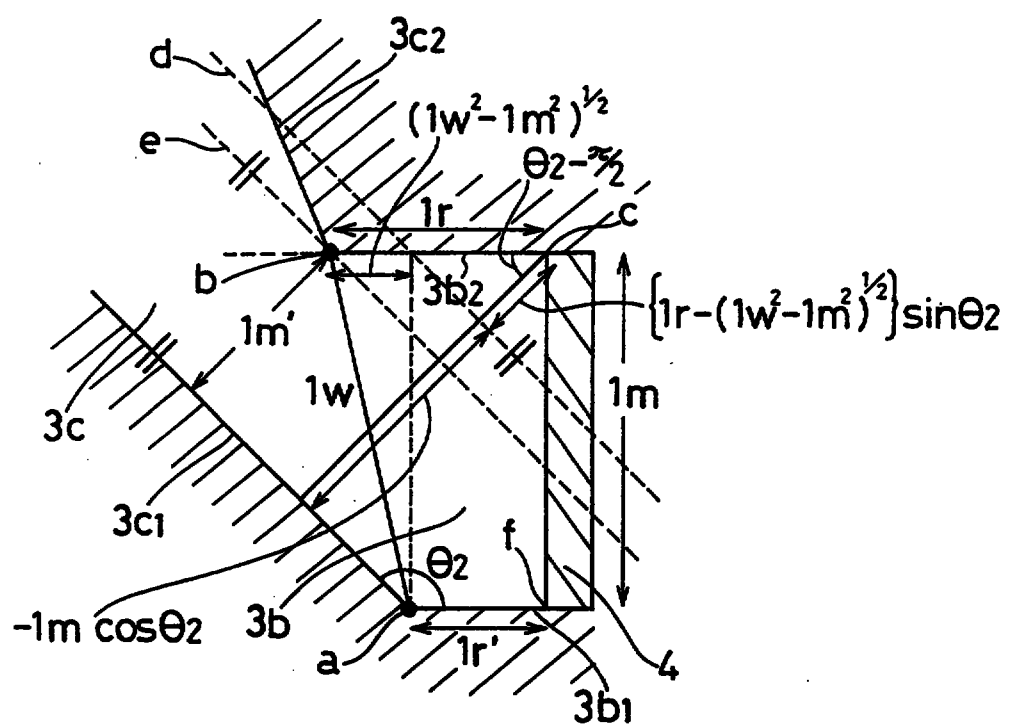
1/10
第 1 図



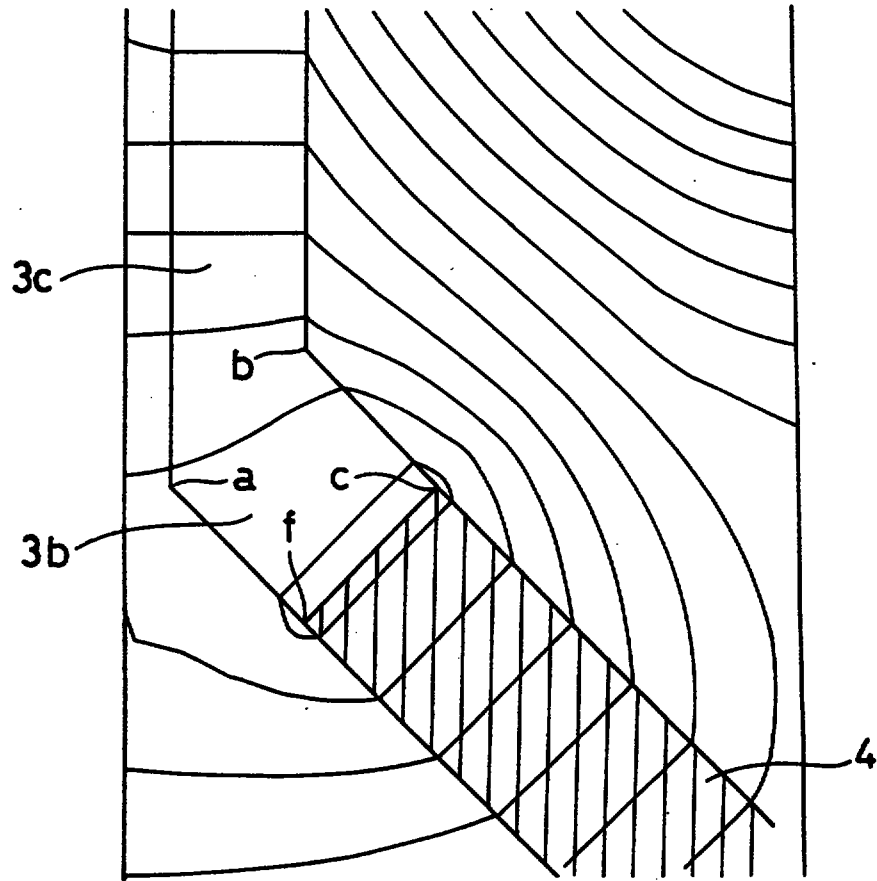
第 2 図



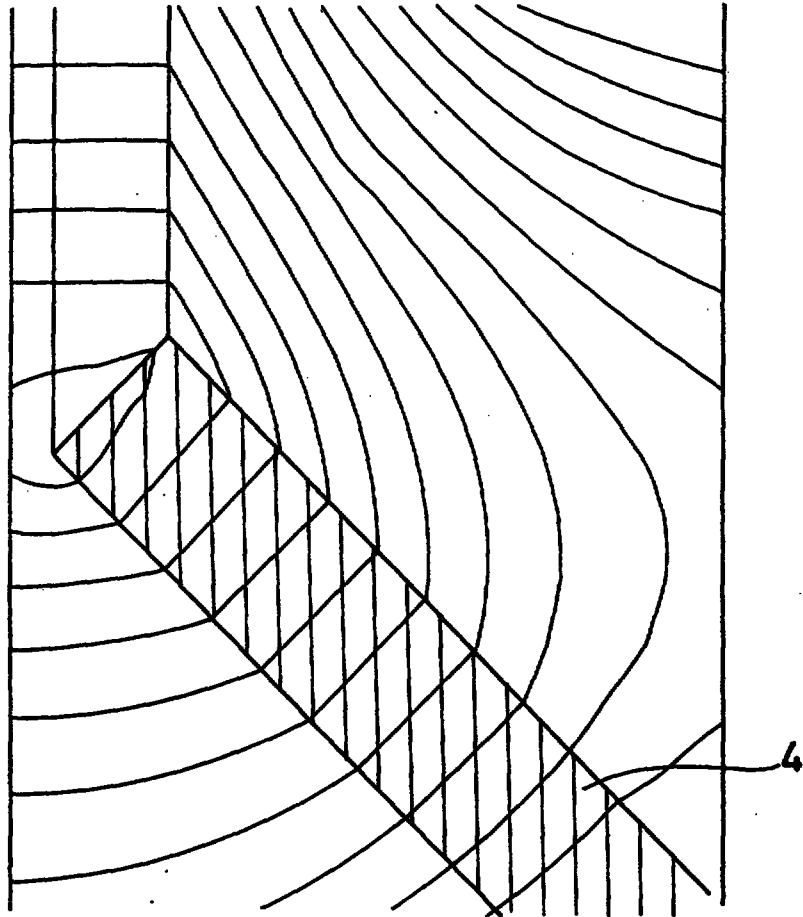
2/10
第 3 図



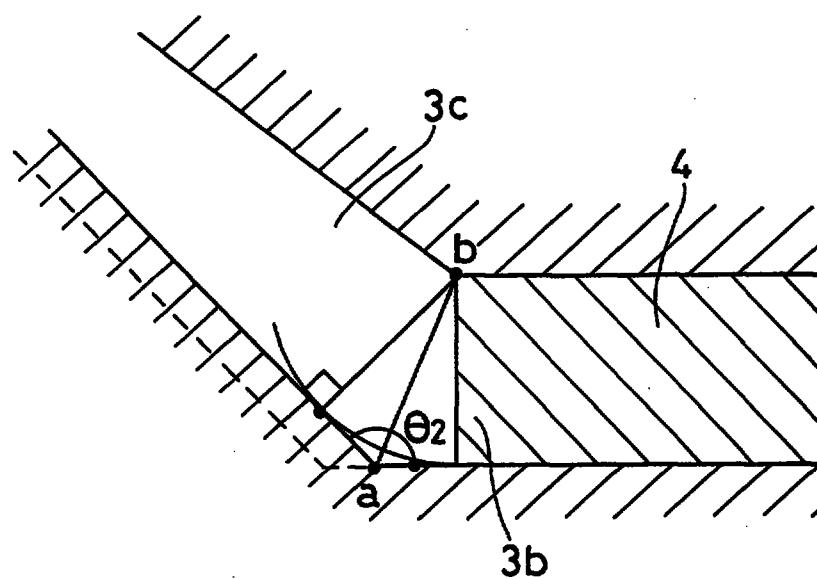
3/10
第 4 図



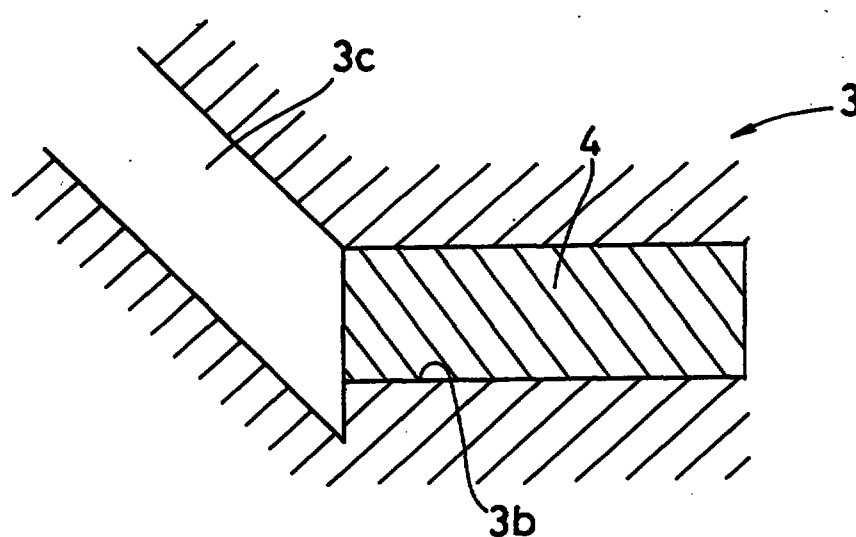
4/10
第 5 図



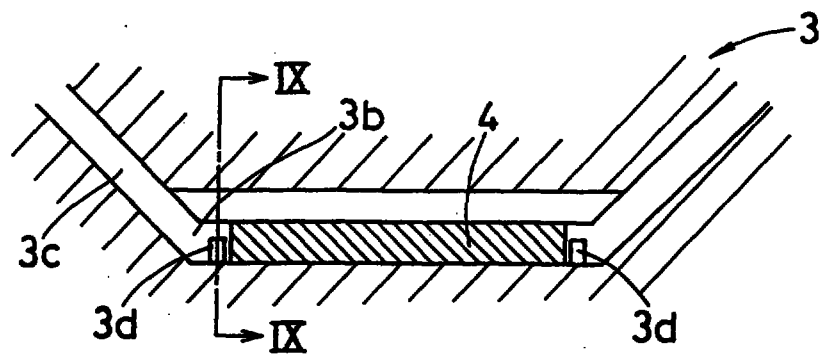
5/10
第 6 图



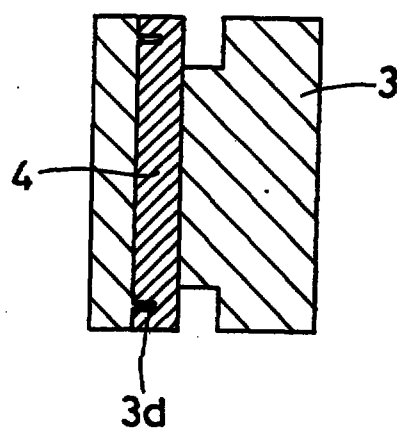
第 7 图



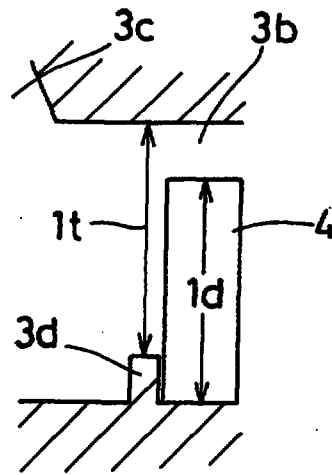
6/10
第 8 图



第 9 图

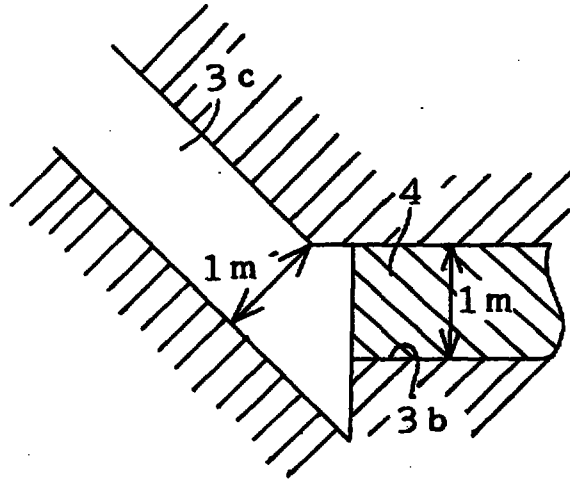


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第 10 図

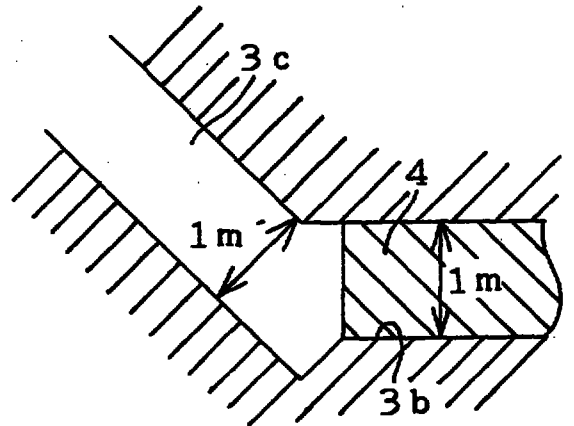


8/10
第 1 1 图

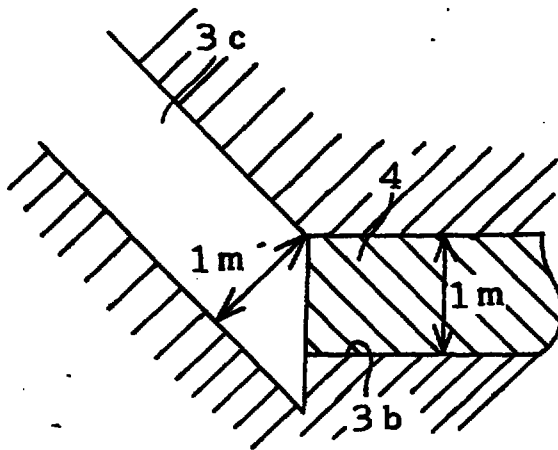
(A)



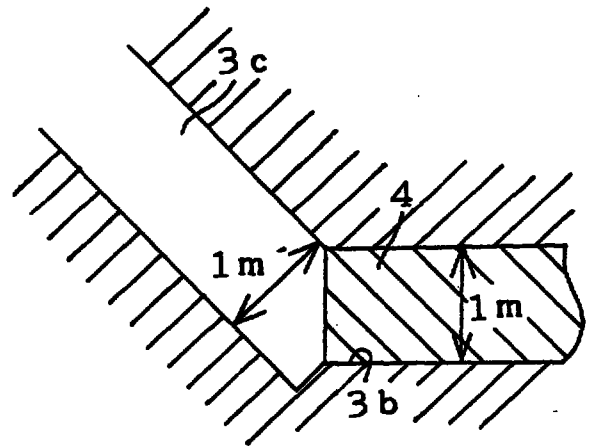
(B)

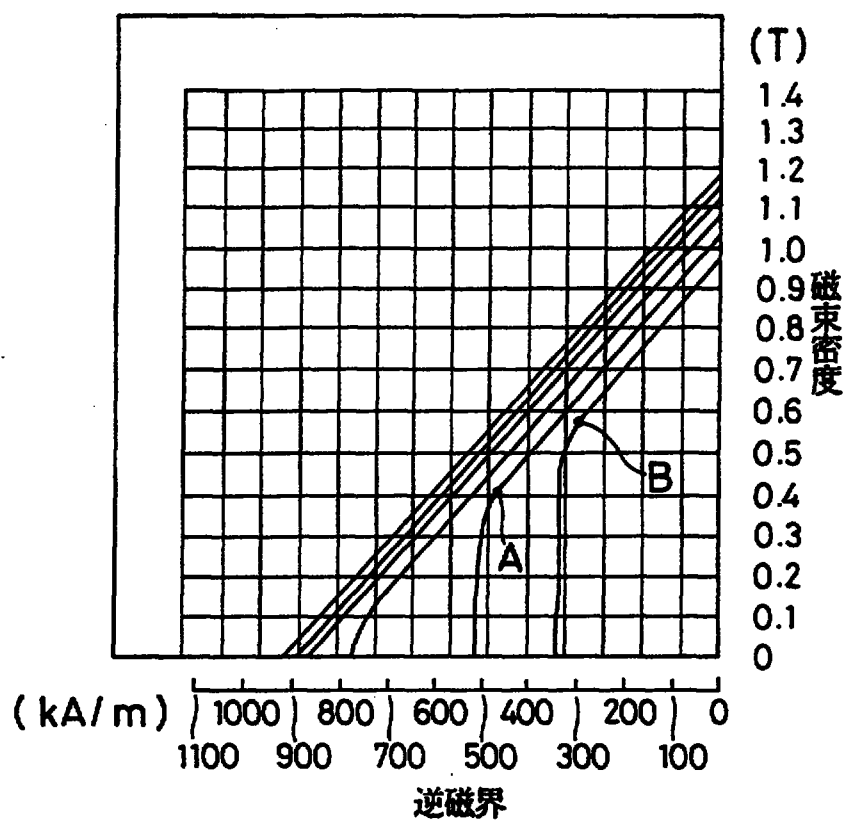


(C)

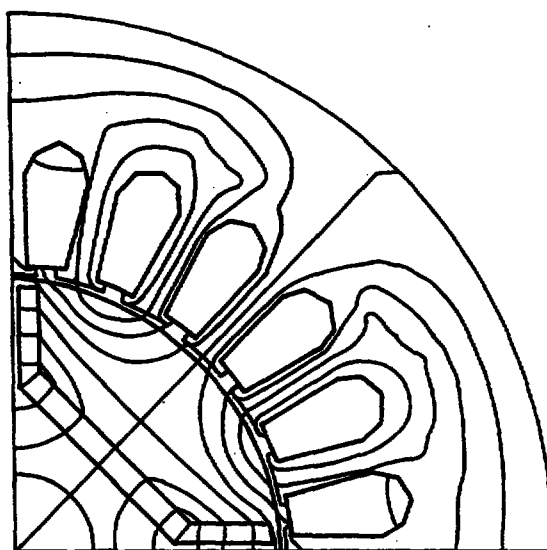


(D)

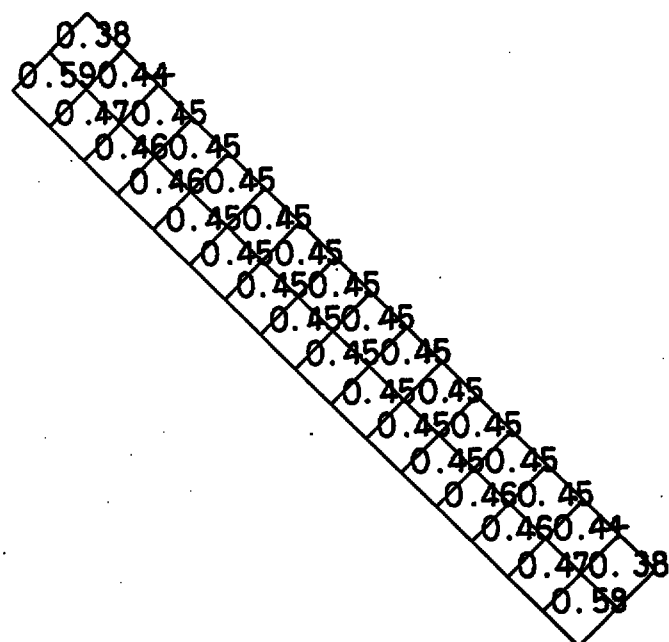


9/10
第 1 2 图

第 1 3 图



10/10
第 14 图



Specification

Brushless DC Motor

Technical Field

The present invention relates to a brushless DC motor. More particularly, the present invention relates to a brushless DC motor including a stator and a rotor, which rotor includes permanent magnets each having a plate shape and a predetermined thickness therein so that the permanent magnets are parallel to a rotation axis of the rotor, and which rotor includes spaces for flux barrier each of which space elongates from an edge section of a permanent magnet housing space in a direction which is vertical to the rotation axis to a rotor surface.

Background Art

From past, investigation and development are advanced for applying a brushless DC motor to various fields in view of advantage of possibility of improving of efficiency due to lack of secondary copper losses. A brushless DC motor is classified into two groups. One group has an arrangement that permanent magnets are mounted on a rotor surface

(hereinafter, referred to as a surface DC motor). The other group has an arrangement that permanent magnets are built in and maintained in an interior of the rotor (hereinafter, referred to as a built in DC motor).

The built in DC motor includes a rotor in an interior of a stator, which rotor includes permanent magnets each having a plate shape and a predetermined thickness therein so that the permanent magnets are parallel to a rotation axis of the rotor, and which rotor includes spaces for flux barrier each of which space elongates from an edge section of a permanent magnet housing space in a direction which is vertical to the rotation axis to an rotor surface, as is illustrated in Japanese Patent Laied-Open Gazette No. Hei 5-236686, and "Interior Permanent-Magnet Synchronous Motors for Adjustable-Speed Drives", IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. IA-22, NO. 4, JULY/AUGUST 1986, for example. A built in DC motor has advantages in comparison to a surface DC motor that driving in a wider range is possible, a higher torque is generated, and driving with higher efficiency is possible due to higher torque.

Further, a built in DC motor builds in and maintains permanent magnets within a rotor at predetermined positions which are near a rotation axis of the rotor so that a volume of each permanent magnet is smaller in comparison to a surface DC motor, therefore rare earth element permanent magnets

having larger energy products are employed as permanent magnets.

In a built in DC motor having the above arrangement, a plate shaped permanent magnet is housed in an entirety of each permanent magnet housing space which elongates in a direction which is parallel to a rotation axis. Therefore, a negative magnetic field converges at edge sections of the permanent magnet (each edge section faces a space for flux barrier) so that an operating point of the permanent magnet exceeds an inflection point and demagnetization of the permanent magnet occurs (refer to points A and B and an arrow of characteristic curves of a rare earth element permanent magnet illustrated in Fig. 12, for example), when a negative magnetic field is applied to the permanent magnet which is built in and maintained in an interior of a rotor such that when the built in DC motor is started, when an inverter is in trouble, when the built in DC motor is driven by magnetic flux weakening control and the like. Specifically, lines of magnetic force under a condition that a negative magnetic field is applied to a permanent magnet are lines of magnetic force illustrated in Fig. 13. When the permanent magnet is virtually divided into 2×16 number of small regions and a magnetic flux density of each region is measured, the measured magnetic flux densities are magnetic flux densities illustrated in Fig. 14 and magnetic flux densities at both

regions which are located at edges are extremely smaller than that of other regions. In actual, the both edge regions exceed the inflection point so that magnetic flux densities of the both edge regions are 0. Further, each numeral illustrated in Fig. 14 represents a magnetic flux density at a central point of each region.

When demagnetization of a permanent magnet occurs, an initial performance of a built in DC motor cannot be maintained so that reliability of a built in DC motor is lowered.

To prevent these disadvantages from occurrence, it can be thought that permanent magnets having greater thicknesses are employed for a conventional built in DC motor, the thickness being determined so that a negative magnetic field is not converged at edge sections of the permanent magnets and demagnetization does not occur. When this arrangement is realized, needed quantity of rare earth element permanent magnet having a higher cost is increased so that a cost of a rotor is raised and causes a cost of a built in DC motor to be raised.

Further, it can be thought that a flowing current is limited so that an operating point of a rare earth element permanent magnet does not exceed an inflection point, or that a temperature of a rare earth element permanent magnet is lowered. When such limitations are applied, an operating

range becomes narrower, a sufficiently great torque cannot be generated, driving with sufficiently high efficiency cannot be performed. Consequently, advantages of a built in DC motor cannot be sufficiently realized.

The present invention was made in view of the above problems.

It is an object of the present invention to offer a brushless DC motor which prevents convergence of a negative magnetic field at edge sections of each permanent magnet from occurrence and prevents demagnetization of each permanent magnet from occurrence without an increase in thickness of each permanent magnet so that sufficient performance of a brushless DC motor is realized.

Disclosure of The Invention

A brushless DC motor according to claim 1 determines a permanent magnet housing space and a space for flux barrier so that a minimum value of a distance from a portion of a boundary face of the permanent magnet housing space in a rotor surface side which boundary face corresponds to an edge section in an width direction of the permanent magnet to a boundary face of the permanent magnet housing space and the space for flux barrier in a rotation axis side of the rotor, is greater than a distance of the permanent magnet housing space

in its thickness direction at the edge section in the width direction of the permanent magnet.

When the brushless DC motor according to claim 1 is employed, the brushless DC motor includes a stator and a rotor, and the permanent magnet housing spaces are formed at predetermined positions which spaces are parallel to the rotation axis of the rotor, and each permanent magnet having a predetermined thickness and width is housed in corresponding permanent magnet housing space, and each space for flux barrier is formed in the rotor which space elongates from corresponding edge section of the permanent magnet housing space in the width direction of the permanent magnet towards a rotor surface. In the brushless DC motor, the permanent magnet housing space and the space for flux barrier are determined so that the minimum value of the distance from the portion of the boundary face of the permanent magnet housing space in the rotor surface side which boundary face corresponds to the edge section in the width direction of the permanent magnet to the boundary face of the permanent magnet housing space and the space for flux barrier in the rotation axis side of the rotor, is greater than the distance of the permanent magnet housing space in its thickness direction at the edge section in the width direction of the permanent magnet. Therefore, a negative magnetic field never converges at edge sections of each permanent magnet so that a negative

magnetic field is applied almost uniformly to an entirety of each permanent magnet, even when the negative magnetic field is applied to the permanent magnet. Consequently, demagnetization due to convergence of the negative magnetic field is prevented from occurrence without increase of thickness of the permanent magnet. Performance of a built in DC motor is sufficiently realized. An increase in cost of a built in DC motor due to enlarging the permanent magnets in their sizes is prevented from occurrence.

A brushless DC motor according to claim 2 determines a width and a housing position of each permanent magnet so that a minimum value of a distance from a portion of a boundary face of the permanent magnet housing space in a rotor surface side which boundary face corresponds to an edge section in a width direction of the permanent magnet to a boundary face of the permanent magnet housing space and the space for flux barrier in a rotation axis side of the rotor, is greater than a distance of the permanent magnet housing space in its thickness direction at the edge section in the width direction of the permanent magnet.

When the brushless DC motor according to claim 2 is employed, the brushless DC motor includes a stator and a rotor, and the permanent magnet housing spaces are formed at predetermined positions which spaces are parallel to the rotation axis of the rotor, and each permanent magnet having a

predetermined thickness and width is housed in corresponding permanent magnet housing space, and each space for flux barrier is formed in the rotor which space elongates from corresponding edge section of the permanent magnet housing space in the width direction of the permanent magnet towards an rotor surface. In the brushless DC motor, the width and the housing position of each permanent magnet are determined so that the minimum value of the distance from the portion of the boundary face of the permanent magnet housing space in a rotor surface side which boundary face corresponds to the edge section in an width direction of the permanent magnet to the boundary face of the permanent magnet housing space and the space for flux barrier in the rotation axis side of the rotor, is greater than the distance of the permanent magnet housing space in its thickness direction at the edge section in the width direction of the permanent magnet. Therefore, a negative magnetic field never converges at edge sections of each permanent magnet so that a negative magnetic field is applied almost uniformly to an entirety of each permanent magnet, even when the negative magnetic field is applied to the permanent magnet. Consequently, demagnetization due to convergence of the negative magnetic field is prevented from occurrence without increase of thickness of the permanent magnet. Performance of a built in DC motor is sufficiently realized. An increase in cost of a built in DC motor due to

enlarging the permanent magnets in their sizes is prevented from occurrence.

A brushless DC motor according to claim 3 determines a formula of $l_r \geq l_m (1 + \cos \theta/2) / \sin \theta/2 - (l_w^2 - l_m^2)^{1/2}$ in correspondence to formulae of $l_w < l_m / \sin(\theta/2)$ and $l_r \leq l_r'$, and determines a formula of $l_r \geq l_m (1 + \cos \theta/2) / \sin \theta/2 + (l_w^2 - l_m^2)^{1/2}$ in correspondence to formulae of $l_w < l_m / \sin(\theta/2)$ and $l_r > l_r'$, when an angle between boundary faces in rotation axis side of a permanent magnet housing space and a space for preventing short circuit of magnetic flux from occurrence is determined to be θ , a length of the permanent magnet housing space in its thickness direction is determined to be l_m , a distance between a connection section of boundary faces of the permanent magnet housing space and the space for flux barrier in a rotor surface side and a connection section of boundary faces of the permanent magnet housing space and the space for flux barrier in an rotation axis side is determined to be l_w , a distance from a connection section of the boundary face of the permanent magnet housing space in a rotor surface side and corresponding boundary face of the space for flux barrier to an edge section of the permanent magnet in its width direction is determined to be l_r , and a distance from a connection section of the boundary face of the permanent magnet housing space in an rotation axis side and corresponding boundary face of the space for flux barrier

to an corresponding edge section of the permanent magnet in its width direction is determined to be l_r' .

When the brushless DC motor according to claim 3 is employed, functions which are similar to those of claim 2 are performed because the formula of $l_r \geq l_m (1 + \cos\theta_2) / \sin\theta_2 - (l_w^2 - l_m^2)^{1/2}$ in correspondence to formulae of $l_w < l_m / \sin(\theta_2/2)$ and $l_r \leq l_r'$, and determines the formula of $l_r \geq l_m (1 + \cos\theta_2) / \sin\theta_2 + (l_w^2 - l_m^2)^{1/2}$ in correspondence to formulae of $l_w < l_m / \sin(\theta_2/2)$ and $l_r > l_r'$, when the angle between boundary faces in rotation axis side of the permanent magnet housing space and the space for preventing short circuit of magnetic flux from occurrence is determined to be θ_2 , the length of the permanent magnet housing space in its thickness direction is determined to be l_m , the distance between the connection section of boundary faces of the permanent magnet housing space and the space for flux barrier in a rotor surface side and the connection section of boundary faces of the permanent magnet housing space and the space for flux barrier in an rotation axis side is determined to be l_w , the distance from the connection section of the boundary face of the permanent magnet housing space in a rotor surface side and corresponding boundary face of the space for flux barrier to the edge section of the permanent magnet in its width direction is determined to be l_r , and the distance from the connection section of the boundary face of the permanent

magnet housing space in an rotation axis side and corresponding boundary face of the space for flux barrier to the corresponding edge section of the permanent magnet in its width direction is determined to be lr' .

A brushless DC motor according to claim 4 further includes projection sections for preventing movement of a permanent magnet in its width direction which projection sections are formed at a boundary face of a permanent magnet housing space.

The brushless DC motor according to claim 4 prevents a disadvantage from occurrence that the permanent magnet moves to a position at which a negative magnetic field may converge so that functions which are similar to those of one of claims 1 through 3 are performed, because the brushless DC motor further includes projection sections for preventing movement of the permanent magnet in its width direction which projection sections are formed at the boundary face of the permanent magnet housing space.

A brushless DC motor according to claim 5 determines a space for flux barrier to be formed from an edge section of a permanent magnet housing section towards a rotor surface in an linear manner, and determines a width of a permanent magnet to be smaller than a width of a permanent magnet housing space.

When the brushless DC motor according to claim 5 is

employed, the brushless DC motor includes a stator and a rotor, and the permanent magnet housing spaces are formed at predetermined positions which spaces are parallel to the rotation axis of the rotor, and each permanent magnet having a predetermined thickness and width is housed in corresponding permanent magnet housing space, and each space for flux barrier is formed in the rotor which space elongates from corresponding edge section of the permanent magnet housing space in the width direction of the permanent magnet towards a rotor surface. In the brushless DC motor, the space for flux barrier to be formed from the edge section of the permanent magnet housing section towards the rotor surface in an linear manner, and determines the width of the permanent magnet to be smaller than the width of the permanent magnet housing space. Therefore, a negative magnetic field never converges at edge sections of each permanent magnet so that a negative magnetic field is applied almost uniformly to an entirety of each permanent magnet, even when the negative magnetic field is applied to the permanent magnet. Consequently, demagnetization due to convergence of the negative magnetic field is prevented from occurrence without increase of thickness of the permanent magnet. Performance of a built in DC motor is sufficiently realized. An increase in cost of a built in DC motor due to enlarging the permanent magnets in their sizes is prevented from occurrence.

A brushless DC motor according to claim 6 determines a thickness of a space for flux barrier to be equal or smaller than a distance of a permanent magnet housing space in a thickness direction of a permanent magnet which distance is a distance at an edge section of the permanent magnet housing space in a width direction of the permanent magnet.

When the brushless DC motor according to claim 6 is employed, the permanent magnet is positioned at a position of a rotor following a decrease in size of the space for flux barrier which position is more close position to a rotation axis of the rotor so that an iron section in an outer surface side of the permanent magnet and a magnetic flux flows more easily, therefore a reluctance torque is effectively utilized, in addition to the function of claim 5, because the brushless DC motor determines the thickness of the space for flux barrier to be equal or smaller than the distance of the permanent magnet housing space in a thickness direction of the permanent magnet which distance is a distance at the edge section of the permanent magnet housing space in a width direction of the permanent magnet.

A brushless DC motor according to claim 7 forms a permanent magnet housing space and a space for flux barrier so that a minimum value of a distance from a portion of a boundary face of the permanent magnet housing space in a rotor surface side which portion corresponds to an edge section of a

permanent magnet in its width direction to boundary faces of the both spaces in a rotation axis side of the rotor, is greater than a distance of the permanent magnet housing space in its thickness direction at the edge section of the permanent magnet in its width direction, and determines a formula of $l_m \geq l_m'$ when the distance of the permanent magnet housing space in its thickness direction is determined to be l_m , and a distance of the space for flux barrier in a circumferential direction is determined to be l_m' .

When the brushless DC motor according to claim 7 is employed, a negative magnetic field never converge at edge sections of each permanent magnet so that the negative magnetic field almost uniformly applied to the permanent magnet in its entirety even when the negative magnetic field is applied to the permanent magnet, because the brushless DC motor forms the permanent magnet housing space and the space for flux barrier flux so that the minimum value of the distance from the portion of the boundary face of the permanent magnet housing space in the rotor surface side which portion corresponds to the edge section of the permanent magnet in its width direction to boundary faces of the both spaces in a rotation axis side of the rotor, is greater than the distance of the permanent magnet housing space in its thickness direction at the edge section of the permanent magnet in its width direction, and determines the formula of $l_m \geq l_b$ when the

distance of the permanent magnet housing space in its thickness direction is determined to be l_m , and the distance of the space for flux barrier in a circumferential direction is determined to be l_b . Consequently, demagnetization due to convergence of the negative magnetic field is prevented from occurrence without increase of thickness of the permanent magnet. Performance of a built in DC motor is sufficiently realized. An increase in cost of a built in DC motor due to enlarging the permanent magnets in their sizes is prevented from occurrence. Further, a magnetic resistance of the space for flux barrier is smaller when magnetic resistances of the permanent magnet section and the space for flux barrier are compared to one another, therefore a magnetic flux from a stator easily passes through the space for flux barrier within a negative magnetic field (during demagnetizing operation) so that demagnetizing operation to the permanent magnet is reduced. Furthermore, the permanent magnet is positioned in a position which is more close position to the rotation axis of the rotor following a decrease in size of the space for flux barrier so that an iron section in an outer surface side of the permanent magnet and a magnetic flux flows more easily, therefore a reluctance torque is effectively utilized.

Brief Description of The Drawings

Figure 1 is a cross sectional view schematically illustrating a brushless DC motor of an embodiment according to the present invention,

Figure 2 is an enlarged diagram of a main portion in Fig. 1,

Figure 3 is a schematic diagram illustrating a main portion of a brushless DC motor of another embodiment according to the present invention,

Figure 4 is a diagram illustrating lines of magnetic flux within a rotor when the embodiment illustrated in Fig. 3 is employed,

Figure 5 is a diagram illustrating lines of magnetic flux within a conventional rotor,

Figure 6 is a schematic diagram illustrating a main portion in an enlarged condition of a brushless DC motor of a further embodiment according to the present invention,

Figure 7 is a schematic diagram illustrating a main portion in an enlarged condition of a brushless DC motor of a further embodiment according to the present invention,

Figure 8 is a schematic diagram illustrating a main portion in an enlarged condition of a brushless DC motor of a further embodiment according to the present invention,

Figure 9 is a cross sectional view taken along a line IX-IX in Fig. 8,

Figure 10 is a diagram illustrating a projection portion in

an enlarged condition,

Figures 11(A) through 11(D) are schematic diagrams illustrating a main portion of brushless DC motors of further embodiments according to the present invention,

Figure 12 is a diagram illustrating characteristic curves of a rare earth element permanent magnet,

Figure 13 is a diagram illustrating lines of magnetic force under a condition that a negative magnetic field is applied to a permanent magnet, and

Figure 14 is a diagram illustrating a measurement result of a magnetic flux density of each region when a permanent magnet is virtually divided into 2 X 16 small regions.

Best Modes For Utilizing The Present Invention

Hereinafter, referring to the attached drawings, we explain the present invention in detail.

Fig. 1 is a cross sectional view schematically illustrating a brushless DC motor of an embodiment according to the present invention, while Fig. 2 is an enlarged diagram of a main portion in Fig. 1.

The brushless DC motor includes a stator 1 having stator windings 2 and a rotor 3 having permanent magnets 4. The rotor 3 is made by laminating a plurality of electromagnetic steel plates and the rotor has a rotation shaft (rotation axis) 3a

which passes through their center in the shaft direction. Further, the rotor 3 includes permanent magnet housing spaces 3b each having a predetermined width and a predetermined thickness of l_m and spaces 3c for flux barrier. Each permanent magnet housing space 3b crosses at right angle to a radius at rotation symmetry position by 90 degrees, and elongates in the direction of the rotation shaft, and is positioned at a predetermined position which is a close position to the rotation shaft, because the brushless DC motor of this embodiment has a four pole arrangement. Each space 3c for flux barrier elongates from an edge section of corresponding permanent magnet housing space 3b towards a rotor surface 3. A permanent magnet 4 made of rare earth element magnet and the like is housed in each permanent magnet housing space 3b. Further, a first cross line of a boundary face 3b1 of the permanent magnet housing space 3b in the rotation shaft side and a corresponding boundary face 3c1 of the space 3c for flux barrier is represented with a, a second cross line of a boundary face 3b2 of the permanent magnet housing space 3b in a rotor surface side and a corresponding boundary face 3c2 of the space 3c for flux barrier is represented with b, an angle between the boundary face 3b1 of the permanent magnet housing space 3b in the rotation shaft side and the corresponding boundary face 3c1 of the space 3c for flux barrier is represented with θ , and an

edge section of the permanent magnet 4 on a face which is in the rotor surface side and in a direction which crosses at right angle to a radial direction of the rotor 3 is represented with c. Furthermore, a distance lm' between the second cross line b and the boundary face 3c1 of the space 3c for flux barrier which boundary face 3c1 corresponds to the boundary face 3b1 of the permanent magnet housing space 3b in the rotation shaft side, is determined to be shorter than a distance lm between the boundary faces 3b1 and 3b2 of the permanent magnet housing space 3b. A distance lr between the edge section c of the permanent magnet 4 and the second cross line b is determined to be longer than a distance lr' between an edge section f on a face of the permanent magnet 4 which face is rotation shaft side and in a direction which crosses at right angle to the radial direction of the rotor 3 and the first cross line a. That is, the first cross line a is positioned outer side with respect to the second cross line b.

Referring to Fig. 2, description is made in more detail. Further, a first and second dashed lines d and e and the solid line 3c1 which are applied "///" in Fig. 2 are parallel to one another. Furthermore, the second dashed line e is a dashed line which represents a plane which passes through the second cross line b, the first dashed line d is a dashed line which represents a plane which passes through a straight line opposite to the first cross line a on an elongated portion of the

rotation shaft-ward boundary face 3b1 of the permanent magnet housing space 3b.

In this embodiment, the thickness l_m' of the space 3c for flux barrier is determined to be smaller than the thickness l_m of the permanent magnet housing space 3b and the first cross line a is positioned outward with respect to the second cross line b, therefore a distance between the both dashed lines d and e in an elongate direction of the boundary face 3b1 of the permanent magnet housing space 3b in an rotation shaft side of the rotor 3 is $(lw^2 + lm^2)^{1/2}$, a distance between the first dashed line d and the boundary face 3c1 of the space 3c for flux barrier is $-lm\cos\theta_2$, and a distance between the first dashed line d and the edge section c of the permanent magnet 4 is $\{(lw^2 + lm^2)^{1/2} + lr\}\sin\theta_2$. Consequently, a distance between the boundary face 3c1 of the space 3c for flux barrier and the edge section c of the permanent magnet 4 is $-lm\cos\theta_2 + \{(lw^2 + lm^2)^{1/2} + lr\}\sin\theta_2$. When the distance is greater than l_m , a reverse magnetic field never converge at edge sections of the permanent magnet 4, therefore a formula of $lr \geq l_m(1 + \cos \theta_2) / \sin\theta_2 - (lw^2 + lm^2)^{1/2}$ is obtained by putting the relationship in order.

Consequently, when the edge section c of the permanent magnet 4 is apart from the second cross line b so that the distance lr satisfies the above formula, a negative magnetic field never converge the edge sections of the permanent



magnet 4 and the negative magnetic field is applied uniformly to the permanent magnet 4 in its entirety. As a result, demagnetization due to convergence of the negative magnetic field is prevented from occurrence without increase of thickness of the permanent magnet 4. Performance of a built in DC motor is sufficiently realized. An increase in cost of a built in DC motor due to enlarging the permanent magnets in their sizes is prevented from occurrence.

Second Embodiment

Fig. 3 is a schematic diagram illustrating a main portion of a brushless DC motor of another embodiment according to the present invention.

This embodiment differs from the above embodiment in that the first cross line a is positioned at an inner position with respect to the second cross line b.

When this embodiment is employed, a distance between the both dashed lines d and e in an elongate direction of the boundary face 3b1 of the permanent magnet housing space 3b in an rotation shaft side of the rotor 3 is $(lw^2 + lm^2)^{1/2}$, a distance between the first dashed line d and the boundary face 3c1 of the space 3c for flux barrier is $-lm\cos 2$, and a distance between the first dashed line d and the edge section c of the permanent magnet 4 is $\{lr - (lw^2 + lm^2)^{1/2}\} \sin \theta 2$.



Consequently, a distance between the boundary face 3c1 of the space 3c for flux barrier and the edge section c of the permanent magnet 4 is $-lm \cos \theta^2 + \{lr - (lw^2 + lm^2)^{1/2}\} \sin \theta^2$.

When the distance is greater than lm , a negative magnetic field never converge at edge sections of the permanent magnet 4, therefore a formula of $lr \geq lm(1 + \cos \theta^2) / \sin \theta^2 + (lw^2 + lm^2)^{1/2}$ is obtained by putting the relationship in order.

Consequently, when the edge section c of the permanent magnet 4 is apart from the second cross line b so that the distance lr satisfies the above formula, a negative magnetic field never converge the edge sections of the permanent magnet 4 and the negative magnetic field is applied uniformly to the permanent magnet 4 in its entirety. As a result, demagnetization due to convergence of the negative magnetic field is prevented from occurrence without increase of thickness of the permanent magnet 4. Performance of a built in DC motor is sufficiently realized. An increase in cost of a built in DC motor due to enlarging the permanent magnets in their sizes is prevented from occurrence.

Fig. 4 is a diagram illustrating lines of magnetic flux within a rotor when the embodiment illustrated in Fig. 3 is employed, while Fig. 5 is a diagram illustrating lines of magnetic flux within a conventional rotor.

In Fig. 5, a magnetic flux of a permanent magnet is suppressed in edge sections of the permanent magnet due to



influence of a negative magnetic field, but in Fig. 4, a magnetic flux goes out from a permanent magnet to a core of a rotor for entire extent of the permanent magnet. Therefore, it is understood that local convergence of a negative magnetic field is prevented from occurrence.

Further, the thickness $l_{m'}$ of the space 3c for flux barrier is determined to be equal to or smaller than the thickness l_m of the permanent magnet housing space 3b, that is the thickness of the permanent magnet 4, in the case illustrated in Fig. 4, therefore permanent magnets 4 are possibly positioned at close positions to the rotation shaft 3a of the rotor 3, and iron sections (steel core) located in an outer side with respect to outer faces of the permanent magnets 4 are increased their volumes. In this case, a magnetic flux flows more easily due to the increase of the iron sections located in an outer side with respect to outer faces of the permanent magnets 4, therefore a reluctance torque is utilized more effectively. Further, a magnetic resistance of the space 3c for flux barrier is smaller than a magnetic resistance of the permanent magnet 4, therefore a magnetic flux from the stator 1 passes through the space 3c for flux barrier more easily within a negative magnetic field (during demagnetizing operation is performed) so that demagnetizing operation to the permanent magnet 4 is weakened.

Third Embodiment

Fig. 6 is a schematic diagram illustrating a main portion in an enlarged condition of a brushless DC motor of a further embodiment according to the present invention.

This embodiment differs from the embodiment illustrated in Fig. 2 in that a minimum value of a distance between the second cross line b and a point on a boundary face of the space 3c for flux barrier which boundary face corresponds to a boundary face of the permanent magnet housing space 3b in a rotation shaft side of the rotor, is determined to be equal to or greater than a distance of the permanent magnet housing space 3b in a radial direction of the rotor. Further, in Fig. 6, a solid line represents a case in which the minimum value is equal to the distance of the permanent magnet housing space 3b in a radial direction of the rotor, while a dashed line represents a case in which the minimum value is greater than the distance of the permanent magnet housing space 3b in a radial direction of the rotor.

In this embodiment, when the edge section c is apart from the second cross line b so that a formula of $l_r \geq 0$ is satisfied (when $l_r = 0$, the edge section c is coincident to the second cross line b), a negative magnetic field never converge the edge sections of the permanent magnet 4 and the negative magnetic field is applied uniformly to the permanent magnet 4

in its entirety. As a result, demagnetization due to convergence of the negative magnetic field is prevented from occurrence without increase of thickness of the permanent magnet 4. Performance of a built in DC motor is sufficiently realized. An increase in cost of a built in DC motor due to enlarging the permanent magnets in their sizes is prevented from occurrence.

Further, in any one of the above embodiments, description was made for a case in which the first cross line actually exists. When the above boundary face of the permanent magnet housing space 3b and the above boundary face of the space 3c for flux barrier are smoothly connected in an arc shape, an operation which is similar to the operation of any one of the above embodiments is performed by supposing a virtual cross line of the both boundary faces and by applying any one of the above embodiments. Furthermore, it is possible that a minimum value of a distance from a portion on a boundary face of the permanent magnet housing space in a rotor surface to a boundary face of the space for flux barrier in a rotation shaft side of the rotor, is determined to be greater than a thickness of the permanent magnet housing space 3b, and a step section is formed at a connection section of the both spaces, as is illustrated in Fig. 7.

Fourth Embodiment

Fig. 8 is a schematic diagram illustrating a main portion in an enlarged condition of a brushless DC motor of a further embodiment according to the present invention, while Fig. 9 is a cross sectional view taken along a line IX-IX in Fig. 8.

This embodiment differs from the above embodiment in that projection sections 3d for regulating a position of the permanent magnet 4 in its width direction are provided at predetermined positions of the rotor 3 so that the distances l_r at both edge sections of the permanent magnet 4 are securely maintained, which projection sections 3d are positioned at predetermined positions in an interior of the permanent magnet housing space 3b. Each projection section 3d may be formed in an entire extent of the rotor 3 in a direction which is parallel to the rotation axis. Each projection section 3d also may be provided at least two positions which are different from one another and each projection section 3d may be formed in one body with one or more electromagnetic steel plates. Further, the thickness l_m of the permanent magnet housing space 3b is locally decreased at a portion corresponding to the projection section 3d. Therefore, the thickness of the permanent magnet is determined to be greater so that a thickness l_t which is a locally decreased thickness is equal or greater than the thickness l_d of the permanent magnet 4, as is illustrated in Fig. 10, and convergence of a negative magnetic field to the edge

sections of the permanent magnet 4 is prevented from occurrence. Further, an extent for determining the thickness of the permanent magnet housing space 3b to be greater, is determined to be a predetermined extent (a predetermined extent for preventing convergence of a negative magnetic field from occurrence) in a direction which is parallel to the rotation shaft with respect to the position at which the projection section 3d is provided, when the projection sections 3d are locally provided.

Therefore, the distances l_r are securely maintained at both edge sections of the permanent magnet 4, and an operations which is similar to the operation of the above embodiment is performed, when this embodiment is employed.

Fifth Embodiment

Figs. 11(A) through 11(D) are schematic diagrams illustrating a main portion of brushless DC motors of further embodiments according to the present invention.

In these embodiments, a step section is provided at a connection section of the space 3c for flux barrier to the permanent magnet housing section 3b so that the thickness l_m' of the space 3c for flux barrier is greater than the thickness l_m of the permanent magnet housing space 3b. Further, the step section is formed toward the rotation shaft 3a of the rotor 3.

Further, in Figs. 11(A) and 11(B), the thickness lm' of the space 3c for flux barrier is determined to be smaller than the thickness lm of the permanent magnet housing space (the thickness of the permanent magnet 4), and the edge section of the permanent magnet 4 is apart to a center side of the permanent magnet housing space 3b by a predetermined distance with respect to a connection section of a face of the permanent magnet housing space 3b in a rotor surface side to a corresponding face of the space 3c for flux barrier (the width of the permanent magnet is determined to be smaller than the width of the permanent magnet housing space 3b).

When the embodiments illustrated in Figs. 11(A) and 11(B) are employed, the permanent magnets 4 are possibly disposed at close positions to the rotation shaft 3a of the rotor 3 so that iron sections (steel cores) which are positioned outer side with respect to permanent magnets 4 are increased, because the thickness lm' of the space 3c for flux barrier is determined to be greater than the thickness lm of the permanent magnet housing space 3b, that is the thickness of the permanent magnet 4. In this case, a magnetic flux flows more easily due to the increase of the iron sections located in an outer side with respect to outer faces of the permanent magnets 4, therefore a reluctance torque is utilized more effectively. Further, a magnetic resistance of the space 3c for flux barrier is smaller than a magnetic resistance of the

permanent magnet 4, therefore a magnetic flux from the stator 1 passes through the space 3c for flux barrier more easily within a negative magnetic field (during demagnetizing operation is performed) so that demagnetizing operation to the permanent magnet 4 is weakened.

Further, in Figs. 11(C) and 11(D), the thickness lm' of the space 3c for flux barrier is determined to be equal to the thickness lm of the permanent magnet housing space (the thickness of the permanent magnet 4), and the permanent magnet 4 is housed within the permanent magnet housing space 3b so that the edge section of the permanent magnet 4 is coincident to a connection section of a face of the permanent magnet housing space 3b in a rotor surface side to a corresponding face of the space 3c for flux barrier (the width of the permanent magnet is determined to be equal to the width of the permanent magnet housing space 3b).

When the embodiments illustrated in Figs. 11(C) and 11(D) are employed, the permanent magnets 4 are possibly disposed at close positions to the rotation shaft 3a of the rotor 3 {slightly apart positions with respect to the positions of Figs. 11(A) and 11(B)} so that iron sections (steel cores) which are positioned outer side with respect to permanent magnets 4 are increased {quantities of increase of iron sections are slightly smaller than quantities of increase of iron sections of Figs. 11(A) and 11(B)}, because the thickness lm' of the space 3c

for flux barrier is determined to be equal to the thickness l_m of the permanent magnet housing space 3b, that is the thickness of the permanent magnet 4. In this case, a magnetic flux flows more easily due to the increase of the iron sections located in an outer side with respect to outer faces of the permanent magnets 4, therefore a reluctance torque is utilized more effectively. Further, magnetic resistances of the permanent magnet 4 and the space 3c for flux barrier are same to one another, therefore the permanent magnet 4 can be housed within the permanent magnet housing space 3b in its entirety.

Possibility of Industrial Utilization

Stable performance is achieved by suppressing demagnetization of permanent magnets and reluctance torque is effectively utilized when a brushless DC motor in which permanent magnets are provided at inner positions with respect to a surface of a rotor.

What Is Claimed Is:

1. A brushless DC motor comprising a stator (1) and a rotor (3), and permanent magnet housing spaces (3b) are formed at predetermined positions which spaces are parallel to a rotation shaft (3a) of the rotor (3), and permanent magnets (4) having a predetermined thickness and width are housed in corresponding permanent magnet housing space (3b), and spaces (3c) for flux barrier is formed in the rotor (3) each of which space (3c) elongates from corresponding edge section of the permanent magnet housing space (3b) in the width direction of the permanent magnet (4) towards a rotor surface, and wherein the permanent magnet housing space (3b) and the space (3c) for flux barrier are determined so that the minimum value of the distance from the portion of the boundary face of the permanent magnet housing space (3b) in the rotor surface side which boundary face corresponds to the edge section in the width direction of the permanent magnet (4) to the boundary face of the permanent magnet housing space (3b) and the space (3c) for flux barrier in the rotation axis side of the rotor (3), is greater than the distance of the permanent magnet housing space (3b) in its thickness direction at the edge section in the width direction of the permanent magnet (4).

2. A brushless DC motor comprising a stator (1) and a



rotor (3), and permanent magnet housing spaces (3b) are formed at predetermined positions which spaces are parallel to a rotation shaft (3a) of the rotor (3), and permanent magnets (4) having a predetermined thickness and width are housed in corresponding permanent magnet housing space (3b), and spaces (3c) for flux barrier is formed in the rotor (3) each of which space (3c) elongates from corresponding edge section of the permanent magnet housing space (3b) in the width direction of the permanent magnet (4) towards a rotor surface, and wherein a width and a housing position of each permanent magnet (4) is determined so that a minimum value of a distance from a portion of a boundary face of the permanent magnet housing space (3b) in a rotor surface side which boundary face corresponds to an edge section in an width direction of the permanent magnet (4) to a boundary face of the permanent magnet housing space (3b) and the space (3c) for flux barrier in a rotation axis side of the rotor (3), is greater than a distance of the permanent magnet housing space (3b) in its thickness direction at the edge section in the width direction of the permanent magnet (4).

3. A brushless DC motor as set forth in claim 2, wherein a formula of $l_r \geq l_m (1 + \cos\theta_2) / \sin\theta_2 - (lw^2 - lm^2)^{1/2}$ is determined in correspondence to formulae of $lw < lm / \sin(\theta_2/2)$ and $l_r \leq l_r'$, and a formula of $l_r \geq lm (1 + \cos\theta_2) / \sin\theta_2 + (lw^2 - lm^2)^{1/2}$ is determined in correspondence to



formulae of $lw < lm / \sin(\theta/2)$ and $lr > lr'$, when an angle between boundary faces in rotation axis side of the permanent magnet housing space (3b) and the space (3c) for flux barrier is determined to be θ , a length of the permanent magnet housing space (3b) in its thickness direction is determined to be lm , a distance between a connection section of boundary faces of the permanent magnet housing space (3b) and the space (3c) for flux barrier in a rotor surface side and a connection section of boundary faces of the permanent magnet housing space (3b) and the space (3c) for flux barrier in a rotation axis side is determined to be lw , a distance from a connection section of the boundary face of the permanent magnet housing space (3b) in a rotor surface side and corresponding boundary face of the space (3c) for flux barrier to an edge section of the permanent magnet (4) in its width direction is determined to be lr , and a distance from a connection section of the boundary face of the permanent magnet housing space (3b) in a rotation axis side and corresponding boundary face of the space (3c) for flux barrier to an corresponding edge section of the permanent magnet (4) in its width direction is determined to be lr' .

4. A brushless DC motor as set forth in one of claims 1 through 3, further comprising projection sections (3d) for preventing movement of a permanent magnet (4) in its width direction which projection sections (3d) are formed at a



boundary face of a permanent magnet housing space (3b).

5. A brushless DC motor comprising a stator (1) and a rotor (3), and permanent magnet housing spaces (3b) are formed at predetermined positions which spaces are parallel to a rotation shaft (3a) of the rotor (3), and permanent magnets (4) each having a predetermined thickness and width are housed in corresponding permanent magnet housing space (3b), and spaces (3c) for flux barrier are formed in the rotor (3) each of which space (3c) elongates from corresponding edge section of the permanent magnet housing space (3b) in the width direction of the permanent magnet (4) towards a rotor surface, and wherein the space (3c) for flux barrier is formed from the edge section of the permanent magnet housing section (3b) towards a rotor surface in an linear manner, and a width of the permanent magnet (4) is determined to be smaller than a width of the permanent magnet housing space (3b).

6. A brushless DC motor as set forth in claim 5, wherein a thickness of the space (3c) for flux barrier is determined to be equal to or smaller than a distance of the permanent magnet housing space (3b) in a thickness direction of the permanent magnet (4) which distance is a distance at an edge section of the permanent magnet housing space (3b) in a width direction of the permanent magnet (4).

7. A brushless DC motor comprising a stator (1) and a



rotor (3), and permanent magnet housing spaces (3b) are formed at predetermined positions which spaces are parallel to a rotation shaft (3a) of the rotor (3), and permanent magnets (4) each having a predetermined thickness and width are housed in corresponding permanent magnet housing space (3b), and spaces (3c) for flux barrier are formed in the rotor (3) each of which space (3c) elongates from corresponding edge section of the permanent magnet housing space (3b) in the width direction of the permanent magnet (4) towards a rotor surface, and wherein the permanent magnet housing space (3b) and the space (3c) for flux barrier are formed so that a minimum value of a distance from a portion of a boundary face of the permanent magnet housing space (3b) in a rotor surface side which portion corresponds to an edge section of the permanent magnet (4) in its width direction to boundary faces of the both spaces (3b)(3c) in a rotation axis side of the rotor (3), is greater than a distance of the permanent magnet housing space (3b) in its thickness direction at the edge section of the permanent magnet (4) in its width direction, and a formula of $l_m \geq l_m'$ is determined when the distance of the permanent magnet housing space (3b) in its thickness direction is determined to be l_m , and a distance of the space (3c) for flux barrier in a circumferential direction is determined to be l_m' .



Abstract

Permanent magnet housing spaces 3b and spaces 3c for flux barrier are formed within a rotor 3, and a minimum value of a distance from a portion on a boundary face of the permanent magnet housing space in a rotor surface side which portion corresponds to an edge section of a permanent magnet 4 in its width direction to boundary faces of the both spaces in a rotation shaft side of the rotor 3 is determined to be greater than a distance of the permanent magnet housing space 3b in the thickness direction at an edge section of the permanent magnet 4 in its width direction, so that initial performance is maintained by preventing demagnetization of permanent magnet due to a negative magnetic field from occurrence, and decrease in cost of a brushless DC motor is realized by decreasing a volume of the permanent magnet.

Fig.1

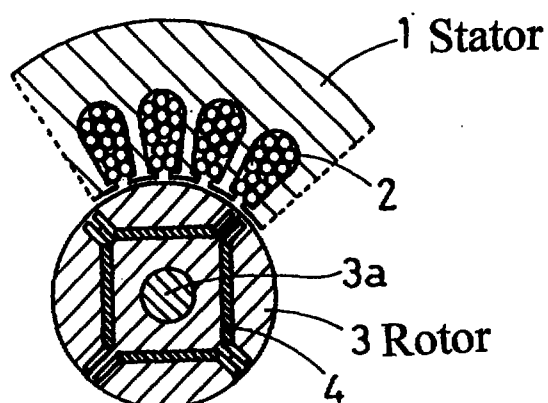
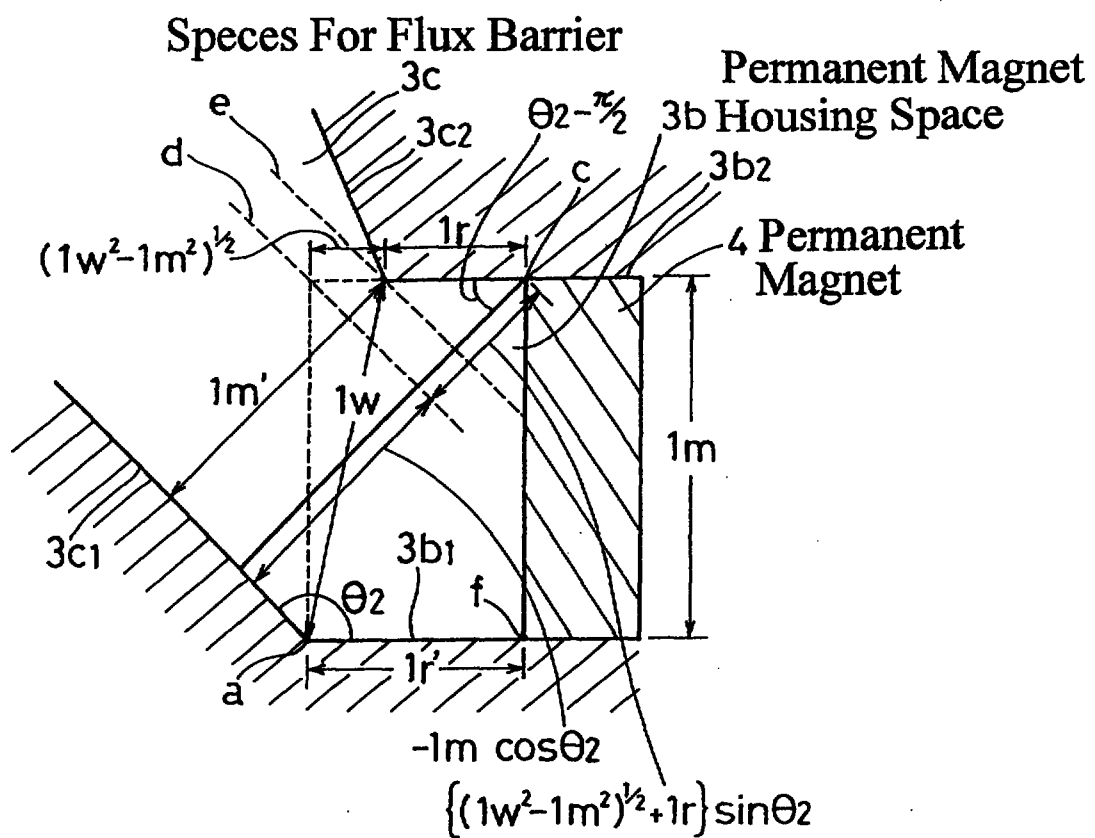
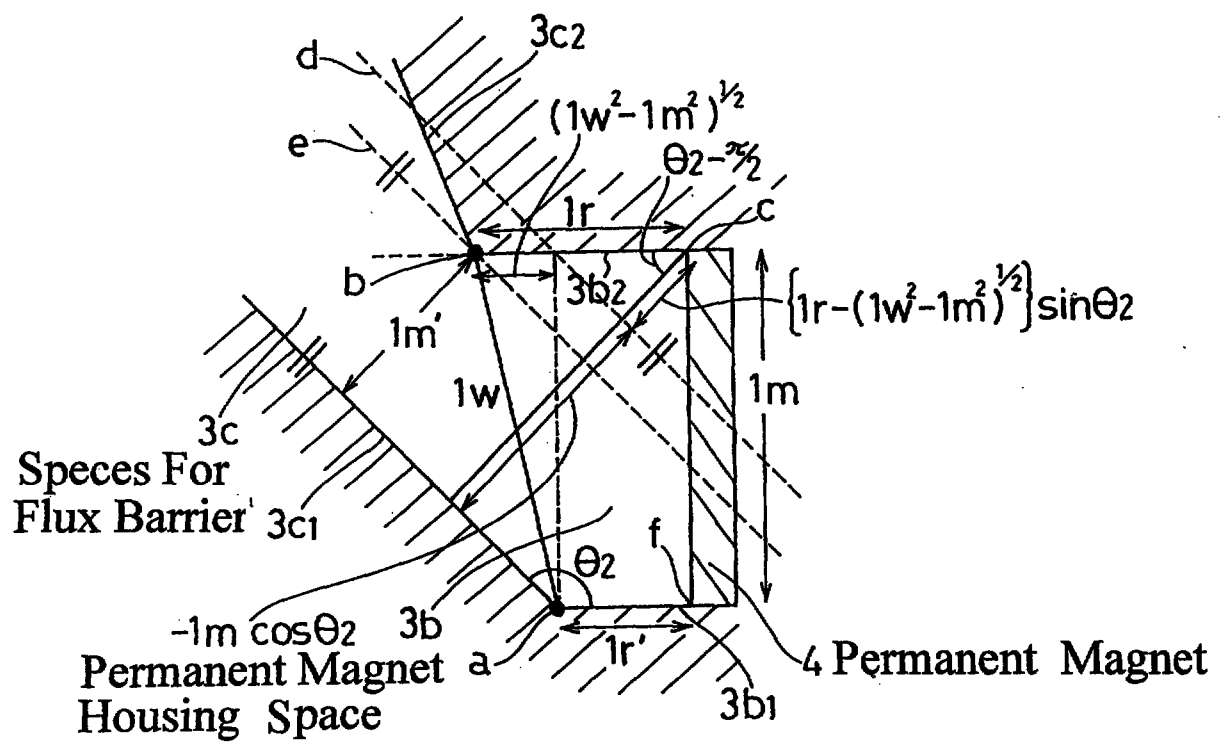


Fig.2



2/10
Fig.3



3/10
Fig.4

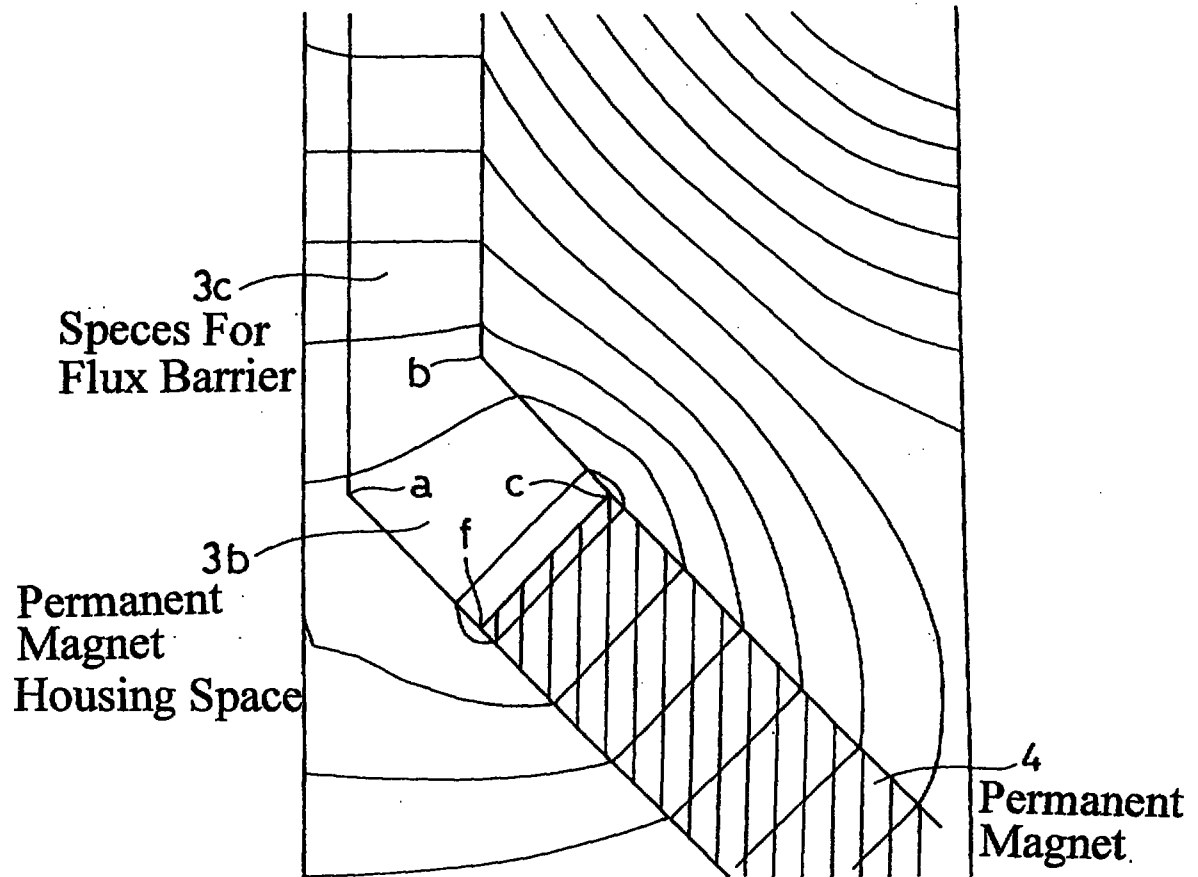


Fig.5

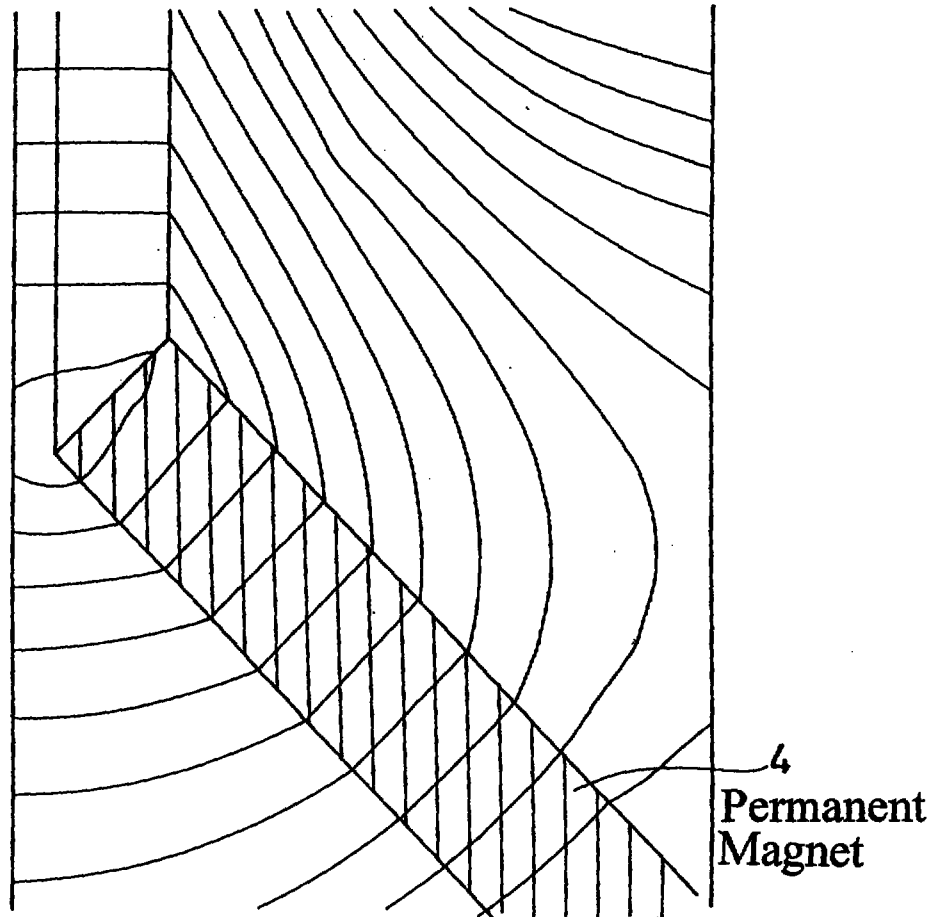


Fig.6

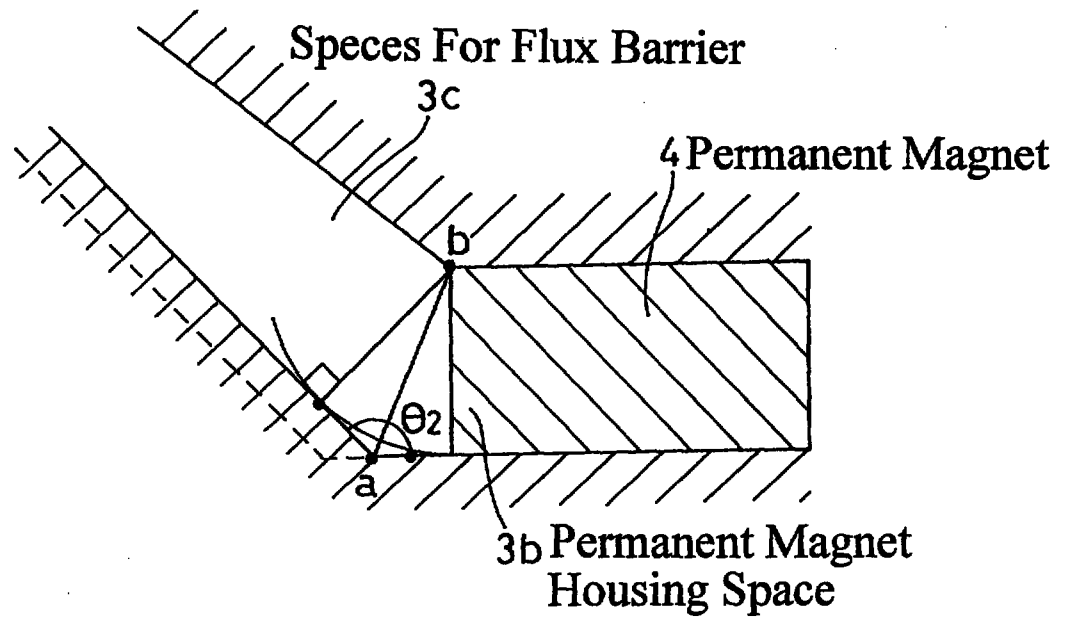
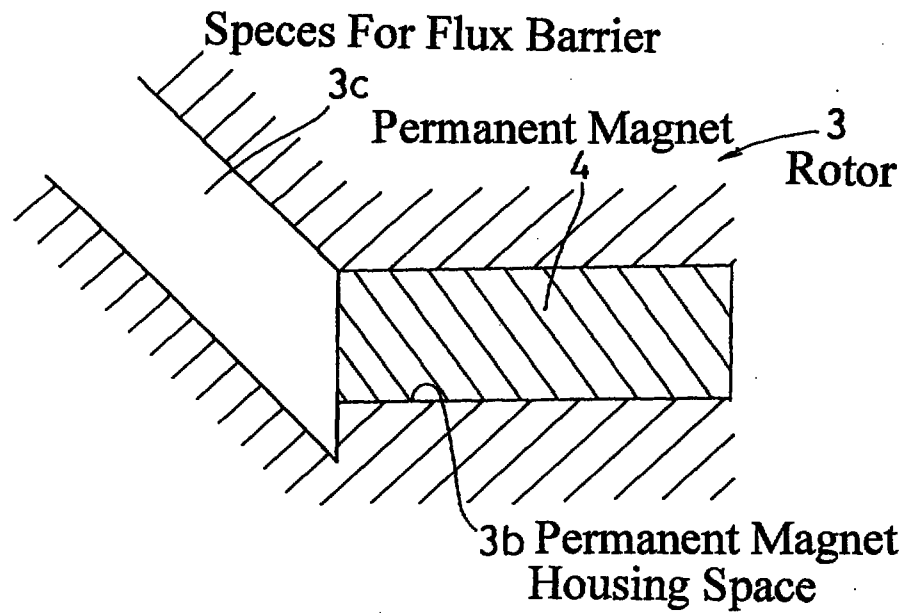


Fig.7



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Fig.8

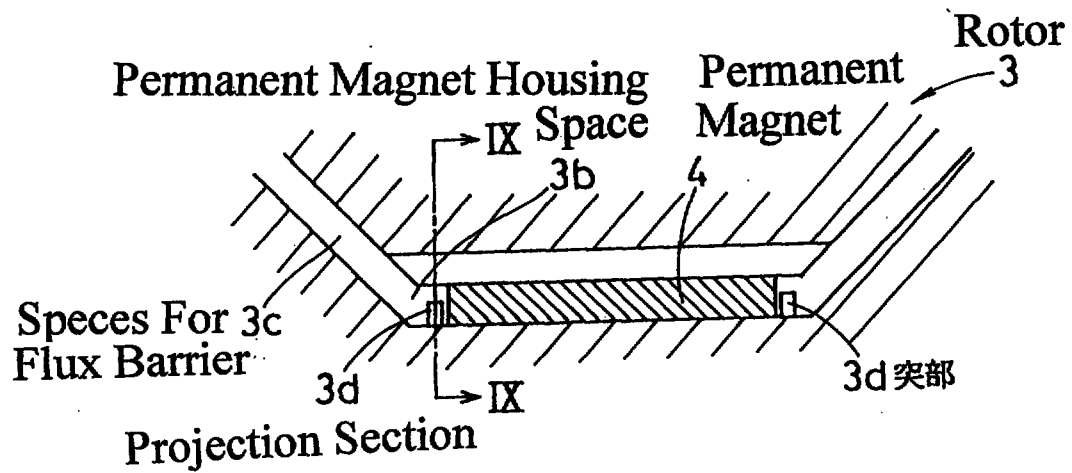


Fig.9

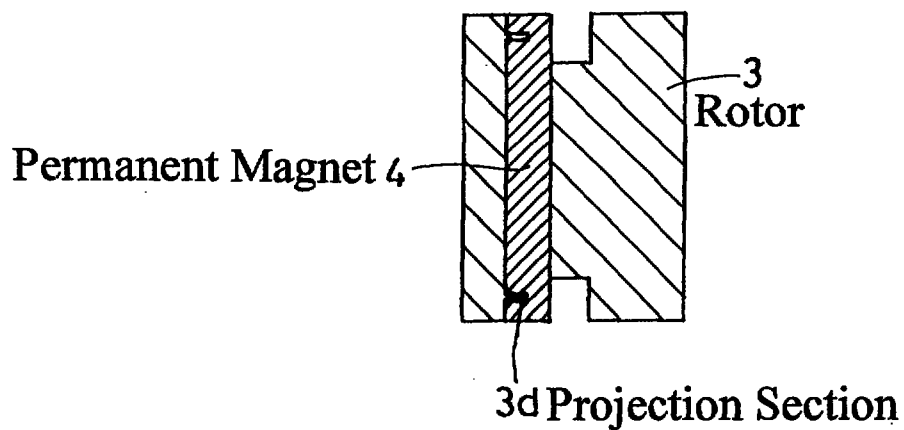
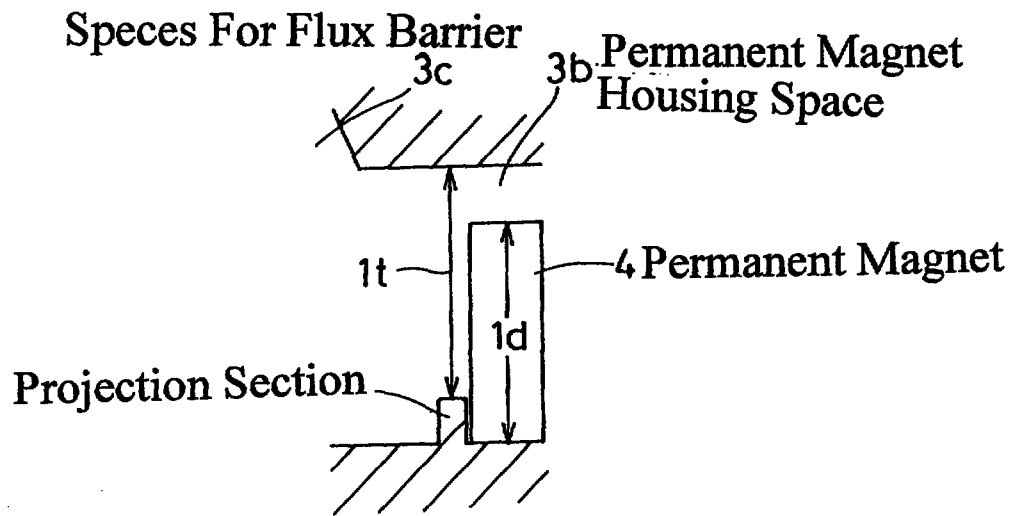
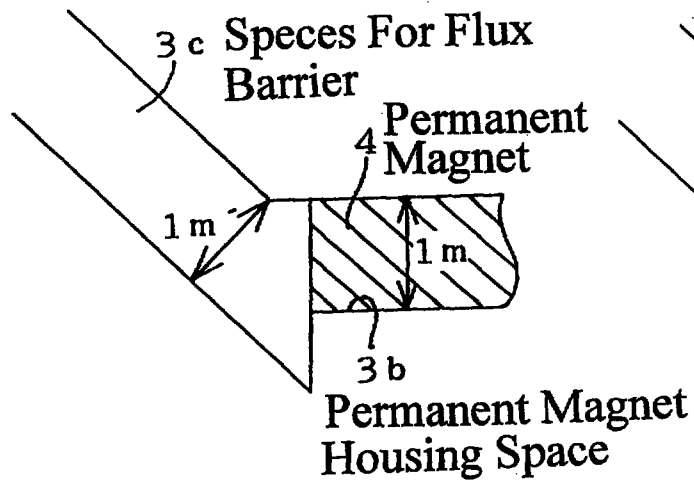


Fig.10

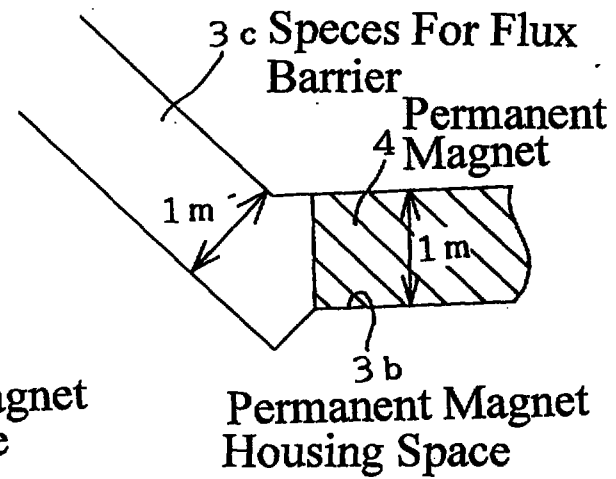


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Fig.11

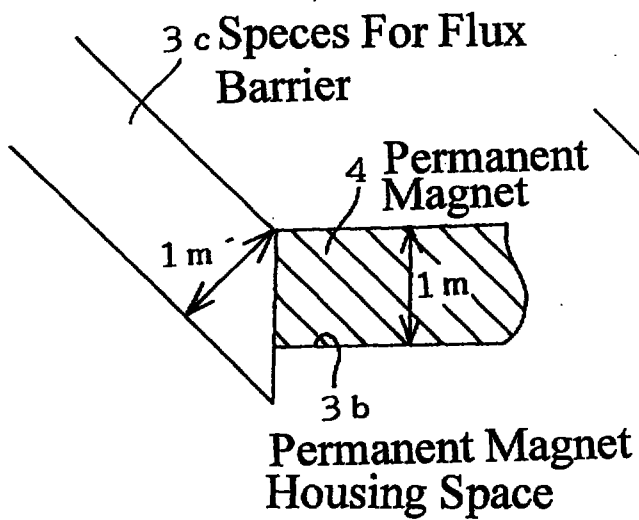
(A)



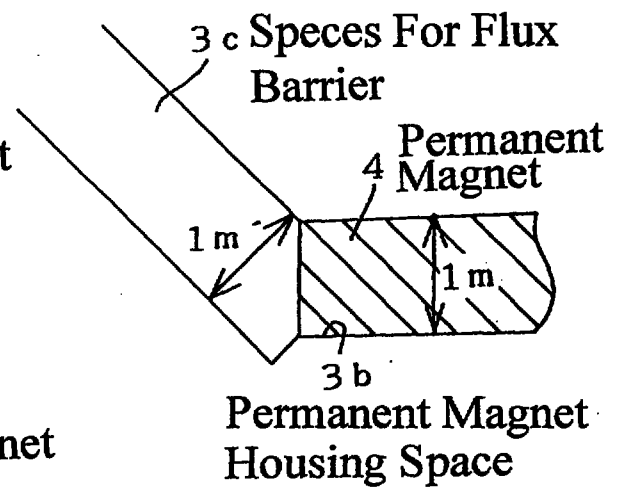
(B)



(C)



(D)



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Fig.12

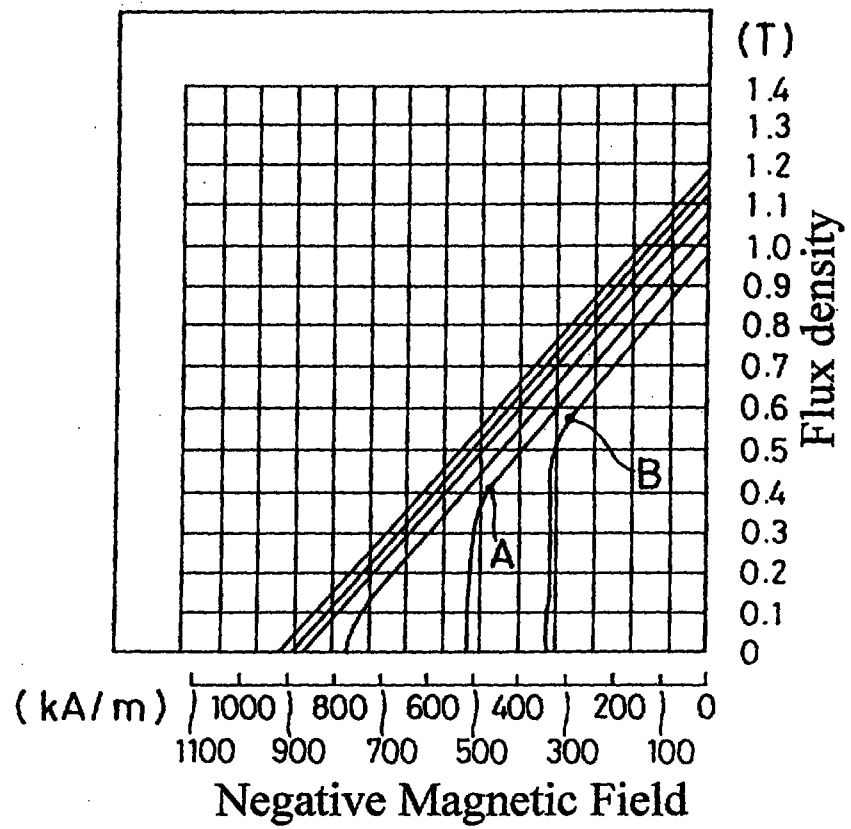


Fig.13

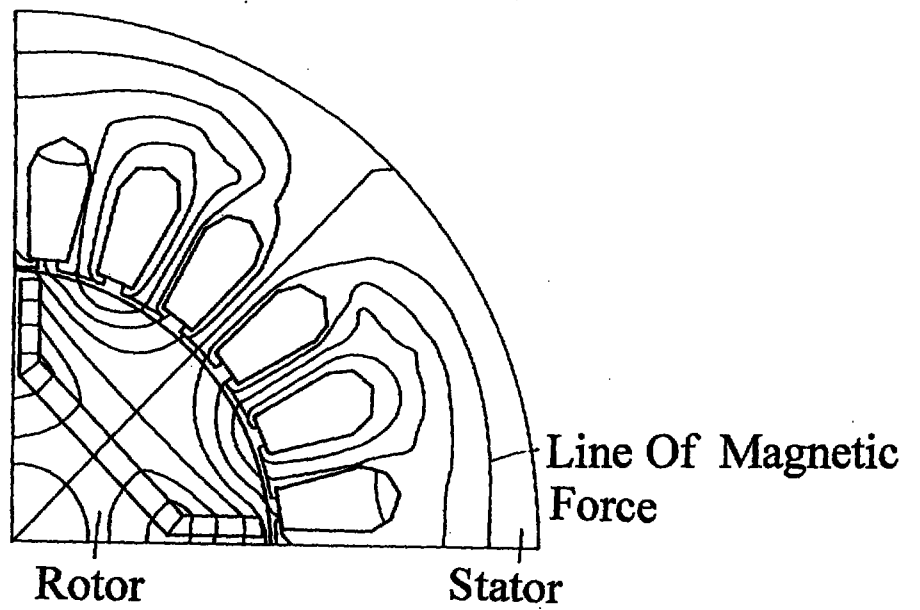
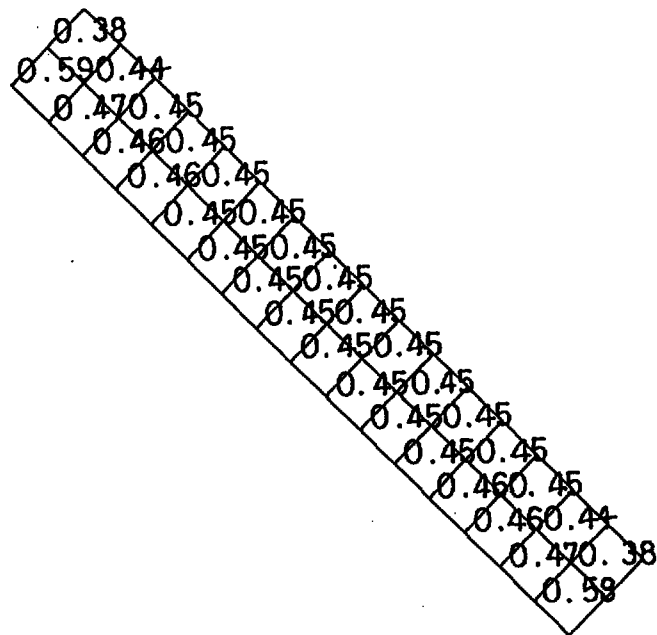


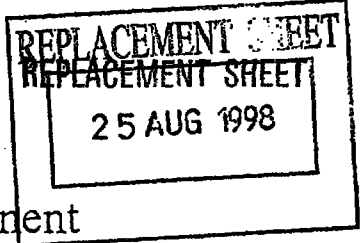
Fig.14



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4. (After Amendment) A brushless DC motor as set forth in claim 3, further comprising projection sections (3d) for preventing movement of a permanent magnet (4) in its width direction which projection sections (3d) are formed at a boundary face of a permanent magnet housing space (3b).

5. (After Amendment) A brushless DC motor comprising a stator (1) and a rotor (3), and permanent magnet housing spaces (3b) are formed at predetermined positions



rotation shaft-ward boundary face 3b1 of the permanent magnet housing space 3b.

In this embodiment, the thickness l_m' of the space 3c for flux barrier is determined to be smaller than the thickness l_m of the permanent magnet housing space 3b and the first cross line a is positioned outward with respect to the second cross line b, therefore a distance between the both dashed lines d and e in an elongate direction of the boundary face 3b1 of the permanent magnet housing space 3b in an rotation shaft side of the rotor 3 is $(lw^2 - lm^2)^{1/2}$, a distance between the first dashed line d and the boundary face 3c1 of the space 3c for flux barrier is $-lm\cos\theta_2$, and a distance between the first dashed line d and the edge section c of the permanent magnet 4 is $\{(lw^2 - lm^2)^{1/2} + lr\}\sin\theta_2$. Consequently, a distance between the boundary face 3c1 of the space 3c for flux barrier and the edge section c of the permanent magnet 4 is $-lm\cos\theta_2 + \{(lw^2 - lm^2)^{1/2} + lr\}\sin\theta_2$. When the distance is greater than l_m , a reverse magnetic field never converge at edge sections of the permanent magnet 4, therefore a formula of $lr \geq l_m(1 + \cos \theta_2) / \sin\theta_2 - (lw^2 - lm^2)^{1/2}$ is obtained by putting the relationship in order.

Consequently, when the edge section c of the permanent magnet 4 is apart from the second cross line b so that the distance lr satisfies the above formula, a negative magnetic field never converge the edge sections of the permanent

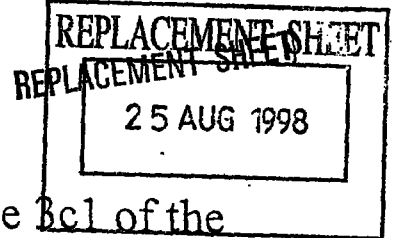
magnet 4 and the negative magnetic field is applied uniformly to the permanent magnet 4 in its entirety. As a result, demagnetization due to convergence of the negative magnetic field is prevented from occurrence without increase of thickness of the permanent magnet 4. Performance of a built in DC motor is sufficiently realized. An increase in cost of a built in DC motor due to enlarging the permanent magnets in their sizes is prevented from occurrence.

Second Embodiment

Fig. 3 is a schematic diagram illustrating a main portion of a brushless DC motor of another embodiment according to the present invention.

This embodiment differs from the above embodiment in that the first cross line a is positioned at an inner position with respect to the second cross line b.

When this embodiment is employed, a distance between the both dashed lines d and e in an elongate direction of the boundary face 3b1 of the permanent magnet housing space 3b in an rotation shaft side of the rotor 3 is $(lw^2 - lm^2)^{1/2}$, a distance between the first dashed line d and the boundary face 3c1 of the space 3c for flux barrier is $-lm\cos 2$, and a distance between the first dashed line d and the edge section c of the permanent magnet 4 is $\{lr - (lw^2 - lm^2)^{1/2}\}\sin \theta/2$.



Consequently, a distance between the boundary face $Bc1$ of the space $3c$ for flux barrier and the edge section c of the permanent magnet 4 is $-lm\cos\theta_2 + \{lr - (lw^2 - lm^2)^{1/2}\}\sin\theta_2$. When the distance is greater than lm , a negative magnetic field never converge at edge sections of the permanent magnet 4, therefore a formula of $lr \geq lm(1 + \cos\theta_2) / \sin\theta_2 + (lw^2 - lm^2)^{1/2}$ is obtained by putting the relationship in order.

Consequently, when the edge section c of the permanent magnet 4 is apart from the second cross line b so that the distance lr satisfies the above formula, a negative magnetic field never converge the edge sections of the permanent magnet 4 and the negative magnetic field is applied uniformly to the permanent magnet 4 in its entirety. As a result, demagnetization due to convergence of the negative magnetic field is prevented from occurrence without increase of thickness of the permanent magnet 4. Performance of a built in DC motor is sufficiently realized. An increase in cost of a built in DC motor due to enlarging the permanent magnets in their sizes is prevented from occurrence.

Fig. 4 is a diagram illustrating lines of magnetic flux within a rotor when the embodiment illustrated in Fig. 3 is employed, while Fig. 5 is a diagram illustrating lines of magnetic flux within a conventional rotor.

In Fig. 5, a magnetic flux of a permanent magnet is suppressed in edge sections of the permanent magnet due to

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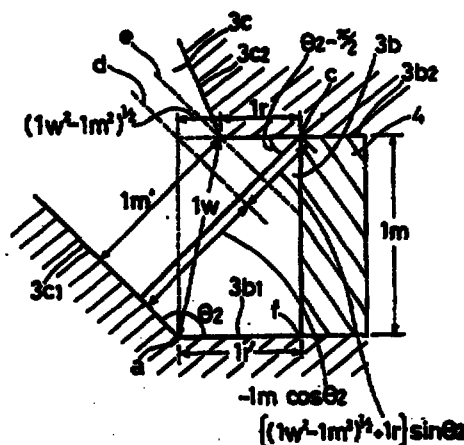
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(21) 国際出願番号 (22) 国際出願日 PCT/JP95/01489 1995年7月25日(25.07.95) (30) 優先権データ 特願平6/172909 1994年7月25日(25.07.94) JP (71) 出願人 (米国を除くすべての指定国について) ダイキン工業株式会社 (DAIKIN INDUSTRIES, LTD.)[JP/JP] 〒530 大阪府大阪市北区中崎西2丁目4番12号 梅田センタービル Osaka, (JP) (72) 発明者; および (75) 発明者/出願人 (米国についてのみ) 山際昭雄(YAMAGIWA, Akio)[JP/JP] 大山和伸(OOYAMA, Kazunobu)[JP/JP] 小島浩明(KOJIMA, Hiroaki)[JP/JP] 〒525 滋賀県草津市岡本町字大谷1000番地の2 ダイキン工業株式会社 滋賀製作所内 Shiga, (JP) (74) 代理人 弁理士 津川友士(TSUGAWA, Tomoo) 〒536 大阪府大阪市城東区中央2丁目7番7号 ライオンズマンション野江1201号 Osaka, (JP)		(81) 指定国 CN, JP, SG, US, 欧州特許(AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). 添付公開書類 国際調査報告書

(54) Title : BRUSHLESS DC MOTOR

(54) 発明の名称 ブラシレスDCモータ



(57) Abstract

A permanent magnet housing (3b) and a magnetic gap (3c) are formed in a rotor (3), and a permanent magnet (4) and its position are set designed so that the minimum value of the distance from a portion of a boundary surface of the permanent magnet housing (3b) on the rotor outer peripheral side corresponding to an end portion of the permanent magnet (4) in a transverse direction to a boundary surface of both spaces (3b, 3c) on the rotary shaft side becomes greater than the distance of the permanent magnet housing (3b) at a transverse end portion of the permanent magnet (4) in the direction of thickness. Thus, initial performance can be maintained by preventing demagnetization of the permanent magnet resulting from a reverse magnetic field, and the cost of a brushless DC motor can be reduced by reducing the volume of the permanent magnet.

回転子3に永久磁石收容空間3bおよび磁束短絡防止用空間3cを形成し、永久磁石4の幅方向端部に対応する永久磁石收容空間3bの回転子外周側境界面の部位から上記両空間3b、3cの回転軸側境界面までの距離の最小値が、永久磁石4の幅方向端部における永久磁石收容空間3bの上記厚み方向の距離よりも大きくなるように永久磁石4の幅、および收容位置を設定して、逆磁界に起因する永久磁石の減磁を未然に防止して初期性能を維持させるとともに、永久磁石の体積を小さくしてブラシレスDCモータのコストダウンを達成する。

情報としての用途のみ

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