Contents

2D Planar Motors -- a literature survey

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Abstract: This paper presents an overview the development of different types of planar motors. The features and defects are summarized and compared accordingly. The schemes of power electronics and control theory for the corresponding motors are also outlined.

Keywords: 2D planar motor, Surface motor, 2D direct drive

1. INTRODUCTION

In modern industrial world, precise two-dimensional planar motions are required. Examples are the manufacturing of parts assembling, component insertion, and electrical wiring. Most of these high-performance manufacturing machines use cascaded X-Y tables with rotary motors and rotary-to-linear mechanical couplings. Though this is the most widely used method, it has the disadvantages of complex mechanical structure, frequent mechanical adjustments, high manufacturing/maintenance cost, and low reliability.

Planar motors, also known as surface motors, X-Y motors or two-dimensional linear motors, are essentially different from X-Y tables in that the mover can be directly driven and controlled in both X and Y directions. The use of electronic control systems with accurate position detection and rapid response allows two dimensional motions of to be performed. This paper investigates several kinds of planar motors and examines their characteristics and drawbacks.

2. SAWYER MOTOR

The Sawyer planar motor [SAWYER, 1969, 1973] is the first type of two dimensional motor widely available to industry. It was first developed as a linear motor to produce a linear motion instead of a rotary output. It provides fast response, high speed and acceleration, long motion capability and the unique ability to position itself precisely in space without the need for a closed-loop system.

Fig.1 shows the construction of a two-phase Sawyer motor [SHALOM, 1994]. The forcer which contains permanent magnets and driving cores is the moving part. The platen is made of ferromagnetic material to provide the return path for the magnetic field of the forcer. The function of the driving coil is to commute the permanent magnetic flux of the forcers, in conjunction with the relative position of pole and the platen teeth. In this way, one-axis motion can be achieved.

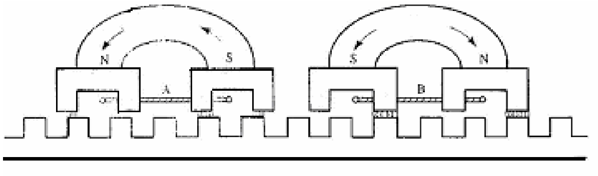


Fig. 1 Basic structure of a two-phase single-axis motor.

Two-axis motion can be obtained by assembling two identical forcers on a single motor frame, but with their axes perpendicular to each other (Fig.2).

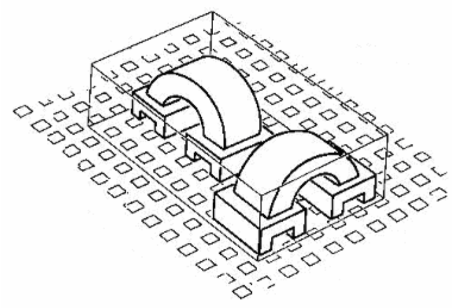


Fig.2 Sawyer motor with two-axis motion

The output force equation neglecting saturation and iron losses is given below.

$$F_x = \frac{KR_0\phi_m\phi_c}{2\tau} \times \sin\phi \qquad (1)$$

where R_0=average reluctance over a pitch,

K=reluctance per unit variation

τ =pole pitch

ϕ=the force angle or phase shift between the flux and the reluctance function

ϕ_m, ϕ_c are the permanent magnetic flux and the coil flux respectively. For excitations of each pole, $\phi_{ca} = \phi_c \times \sin(wt + \varphi)$, $\phi_{cb} = \phi_c \times \cos(wt + \varphi)$.

(1) indicates that the output force, neglecting saturation and iron losses, is constant and proportional to the product of magnetic flux times the coil flux, and inversely proportional to the motor and platen pitch. For the motors to achieve high acceleration, iron saturation in the reluctance of the iron path, is no longer negligible. Moreover, if the phases are driven with sine wave currents, the two-phase forcer has cyclic errors, which occur with a period of one-fourth of a tooth pitch, i.e. fourth harmonic errors. One method of reducing the above errors is by using a four-phase motor, combined with two two-phase motors, displaced one eighth of a pole pitch from each other and driving the two forcers with 45 degree phase separation. Another method is to use the transformer action in a motor-winding to synchronize the ± 45 degree signals required for the extra phases. This is called the hybrid arrangement.

Platen iron losses also cannot be neglected if the motor is accelerated to high velocities, for example, 30 inch/sec or more. The platen losses translate into a drag force opposing the motor motion, proportional to the velocity. So the force equation should be implemented as below:

$$F_x = \frac{KR_0\phi_m\phi_c}{2\tau} \times \sin\phi - F_d \qquad (2)$$

where F_d is the drag force at that particular speed.

The sawyer motors were initially used as open-loop, step motors. However, until now, more and more types of sensors are implemented to provide closed-loop control. The accelerometer feedback system was first proposed [PELTA, 1987] to provide velocity or tachometer feedback. Using the platen as a reference, several other means to sense position are also available. The means are: (a) magnetic [SAWYER, 1973, 1974], [BRENNEMANN et al, 1992], (b) capacitive [MILLER, 1990] and (c) optical [SAWYER, 1973], [NICOLSON, 1993].

The magnetic method has the potential of extremely high resolution but it requires adding additional coils to measure the position. It is also sensitive to the motor which induced strong magnetic field. The capacitive method uses the large area of the motor's teeth for sensing and thus being able to average the non-uniformity of the platen. The drawback is that the teeth give the sensor the same angular sensitivity as the motor. The optical one is insensitive to coupling from the motor's field but it is very sensitive to platen surface imperfections, which demands careful manufacture of the platen.

3. PERMANENT MAGNETIC PLANAR MOTOR

The two-axis linear motion described above is achieved by the combination of two linear motors in orthogonal directions. However, in the permanent magnetic (PM) motors proposed in [EBIHARA, 1989], there is only one mover and it can be directly driven and controlled in both X and Y axis.

Fig.3 (a) shows the basic structure of the motor. The mover is composed of eight core coils and the stator is a checkerboard arrangement of N- and S- pole magnets, laid atop a back iron plate.

The operating principle of PM surface motor originates from the interaction between the permanent magnet and the induction coils. The layout of mover poles is shown in Fig.3 (b). Phase A is completely opposite to the N pole, while phase B is pitched $\tau/4$ out of phase along X axis; phase C, $\tau/4$ along Y axis, phase D, $\tau/4$ along both X and Y axis. These coils are positioned in such a way that by selecting among different combinations of excitation phases, the mover can move in both X and Y directions. For example, if phase A is changed to phase B excitation, then phase B is positioned half the magnetic width along X axis, it will generate the magnetic force so that the mover will move half the magnetic width along X axis only.

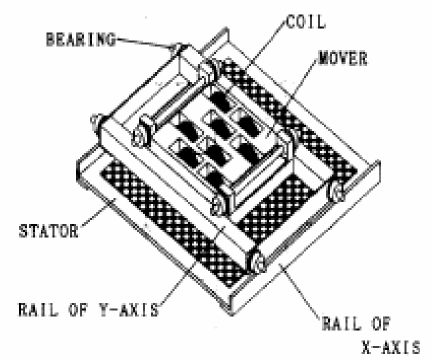


Fig. 3 (a) Overall structure of the PM planar motor

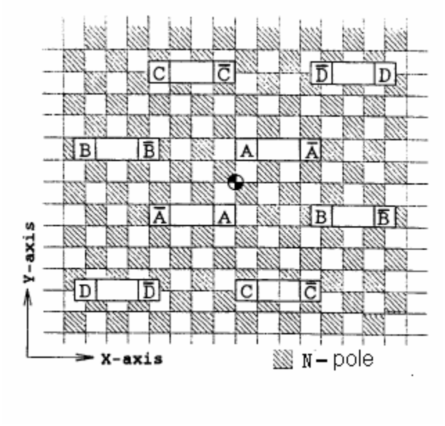


Fig. 3 (b) Stator layout of the PM planar motor

The above planar motor uses permanent magnets as the stator and the electromagnets as the mover, [FILHO, et al, 1998], however, proposed a totally inversed structure. The structure of the stator is a stationary slotless armature with orthogonal windings. The mover is composed of two high-efficient permanent magnets (Fig.4). The orthogonal windings have no electric connections and they are produced in such a way that on top of one layer of the X-coil there will be a layer of the Y-coil, and so on. Each winding is divided into twelve independent phases and has the same width as the permanent magnets. For driving the motor, only necessary coil sections will be excited for a short time. The disadvantages of this structure are the significant presence of end effects and the normal force that reduced the actuator performance.

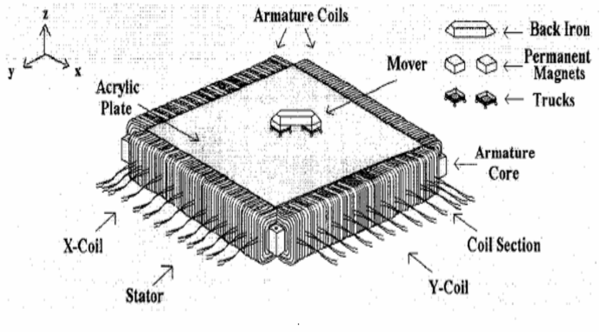


Fig. 4 Perspective view of the planar actuator

Another PM planar motor is proposed in [TSUCHIYA, et al, 2001]. The mover is free from wire connections and it can rotate itself，in addition to performing motions in two directions on the X-Y plane.

Fig.5 shows the structure of this motor. The stator is composed of multiple electromagnets and a yoke. The mover consists of several permanent magnets, a back iron with four bearings. A glass board is inserted in between to support the mover and adjust the air gap.

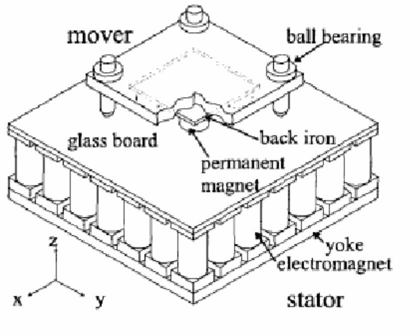
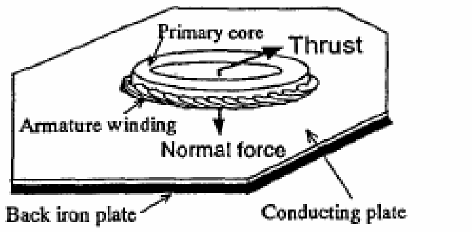


Fig. 5 Structure of the planar motor

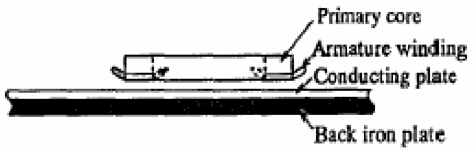
4. PLANAR INDUCTION MOTOR

The prototype of planar induction motor is the X-Y linear induction type, which does not have the drawbacks of many armature windings or magnetic field poles for the structure of planar PM motors. It has the same composition as a single-sided linear induction motor (LIM). However，the two windings for X and Y direction have to be perpendicularly intersected to each other. Due to the complicate configuration of core, it is difficult to form a good magnetic circuit [OHIRA, et al, 1989].

An induction type of circular shaped planar motor is proposed [FUJII, et al, 1998], which has a toroidal core as a primary core (Fig.6). The secondary surface is composed of a flat conducting plate and back iron plate. The mover can perform rotation in addition to linear motion on the surface and it can obtain the thrust for any direction.



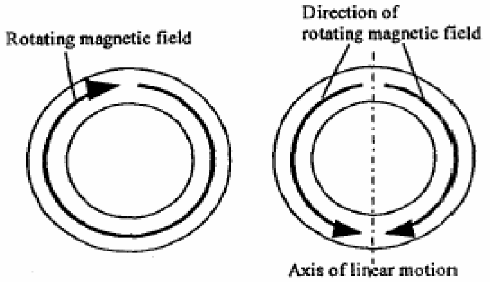
(a) General view



(b) Side view

Fig. 6 Surface induction motor

For rotating the drive, all the coils are used to generate the ordinary rotating magnetic field in the same as an axial gap type rotating motor, as shown in Fig.7 (a). For linear drive, the winding is separated into two groups every half of toroidal core for a desired direction of motion, then the partial rotating magnetic field is generated every winding group, as shown in Fig.7 (b) [FUJII, et al, 1999], [FUJII, et al, 1999].



(a) For rotating drive (b) For linear drive

Fig. 7 Principle of operation

Planar induction motors have smooth force output. Generally they are difficult to develop for high air gap flux density. However，their simple conducing plate ensures wide area of movement.

5. CONCLUSION

Several planar motors of different structures have been studied in this paper. Unfortunately, only the Sawyer stepper motor has a steady output performance. It is the only type of planar motor that can be commercialized. There is still a long way to go for other types of planar motors. Due to the complex distribution of magnetic field, finite element analysis is not mature enough to fully solve three-dimensional problems; more advanced software package in magnetic field analysis is needed.

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