Hybrid Transverse Magnetic Flux Motors — AKA Stepper Motors and Hybrid Servos

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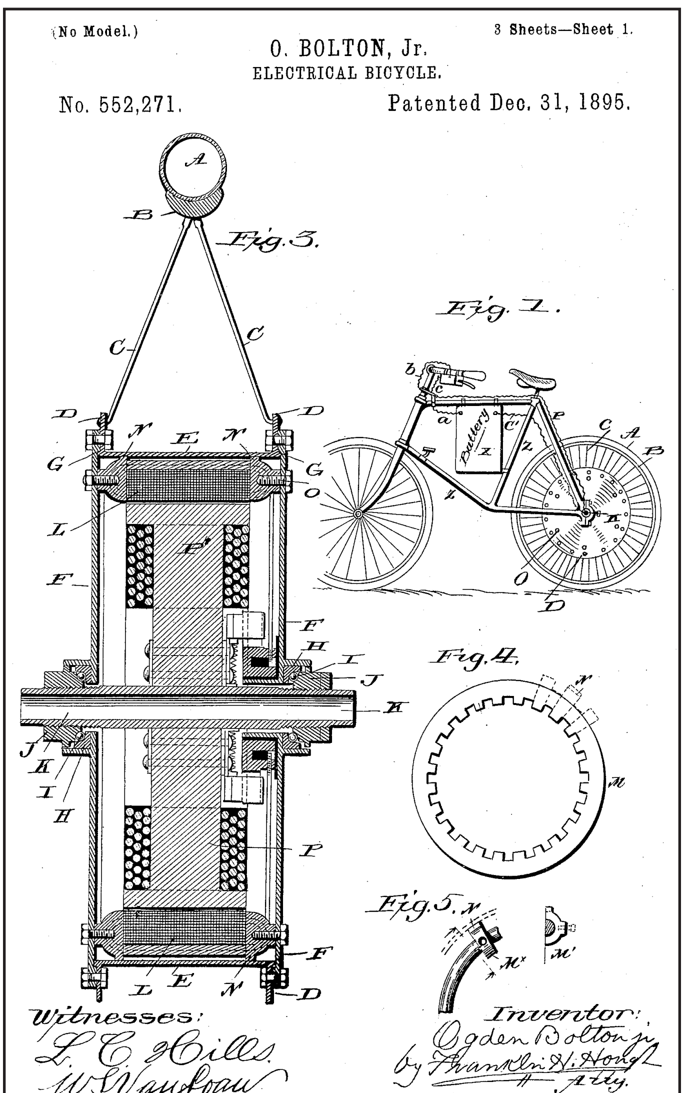
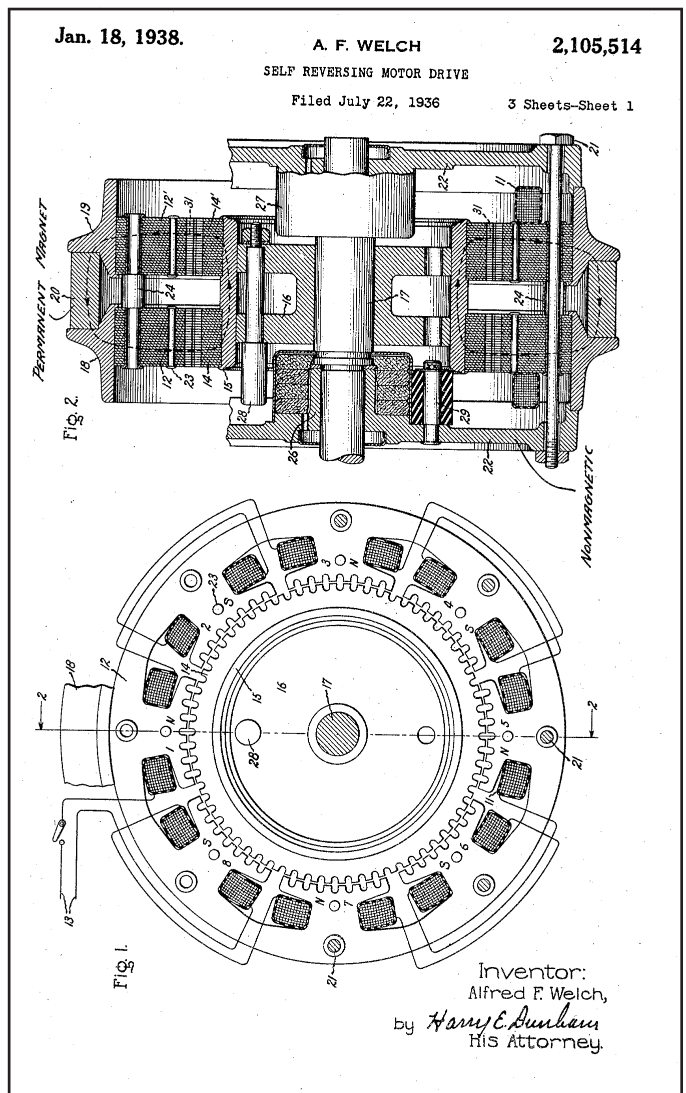
This is the first of a series of articles on permanent magnet transvers magnetic flux motors — AKA step motors. These articles will be covering the development history and the various drive technologies used with these motors — both open and closed loop. There is a long history of interest in this motor type, as it has a very high continuous torque density and a very high motor quality factor (torque/square-root of power) for a given form. Their simple construction helps reduce costs while also improving reliability. This first article covers the development of the motor over more than a century.

The earliest transverse magnetic flux motor (of which I am aware) is described in U.S. patent 552271, which was designed as a brush motor for an electric bicycle hub motor — patented Dec. 31, 1895. It uses 6 driven coils that are mechanically commutated. The motor is "inside-out" with the center being the stator electrically wired through the ends of the center mounting rod, while the outside armature (rotor) connects to the bicycle wheel. This is a variable reluctance design, as it has no permanent magnets being used, nor a field winding. The coil windings for transverse flux motors are relatively simple and concentrated, thus minimizing copper losses, while the magnetic flux follows a more complex path in three dimensions. Many smaller teeth are used to increase the pole count, which helps trade torque for speed. This is typical of the "transverse flux" design.

US2105514 from July 1936 looks closer to a modern step motor, except that the biasing magnet is placed axially in a



Early variable reluctance transverse flux motor (US552271)



Early 50:50 laminate Transverse magnetic flux – Stator PM design (US2105514)

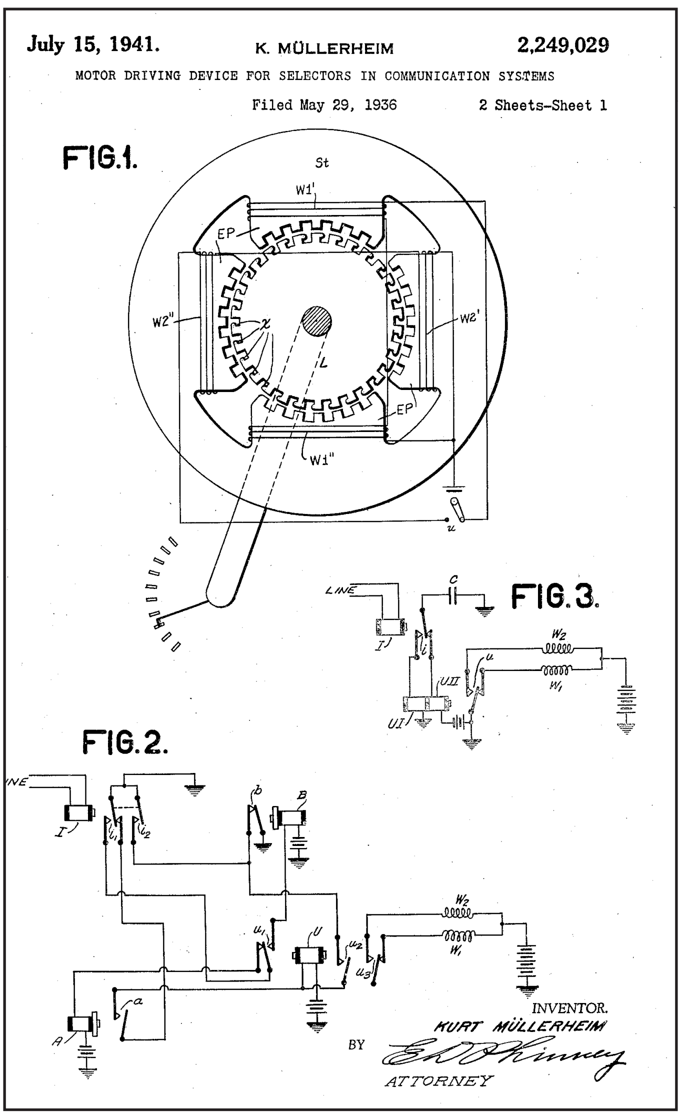
circumferential gap in the stator, while the rotor has the two toothed rotor poles. This motor is a single-phase motor and must be manually started up in the desired direction; it automatically reverses when it encounters a blockage. A rewiring of this motor would yield a step motor — operating very similarly to the planar Sawyer motor.

US2249029 shows both 2- and 3-phase step motors used to direct the dialing of the old rotary phones (now quite obsolete), which sent out the number dialed as a series of clicks. The motor responded to these current pulses by moving a contactor across a set of contacts. This machine is a variable reluctance design, as no axial magnet in the rotor is described in the patent.

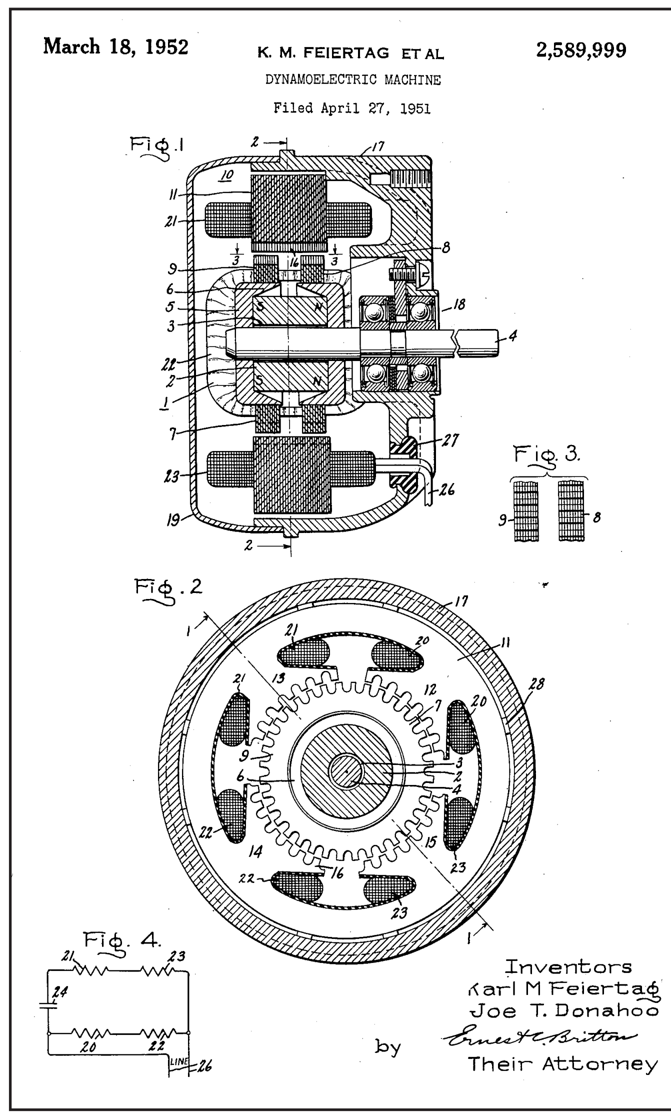
US2589999 is the first patent (I have documented that) that shows all the elements of the modern hybrid step motor. It has only 4 stator poles, arranged as 2 phases, to be driven from the AC line with a split capacitor design to generate sine and approximately cosine waveforms. The rotor has a single disk magnet that is oriented in the axial direction between two rotor pole pieces, with the teeth offset between the two halves of the rotor. The teeth of the rotor and the stator have the same pitch, so this motor would be similar to a full-step motor, i.e. — the design would not support effective microstepping.

US2982872 shows a motor with the rotor and stator teeth designed to have different pitches. This reduces the torque ripple by not having all the teeth simultaneously align between rotor and stator. The rotor has an axially polarized magnet with two pole caps that have the teeth offset to produce a gap on one side pole and a tooth on the opposite pole. Again, the split capacitor design drives one phase of the coil from the line voltage and the other through a capacitor to generate a phase shift to set the direction of motion. Reversing which coil is directly driven and which is phase-shifted by the capacitor determines the direction of motion. This motor could be run synchronously from the AC line voltage for applications like record players, thus all but eliminating most of the gearing.

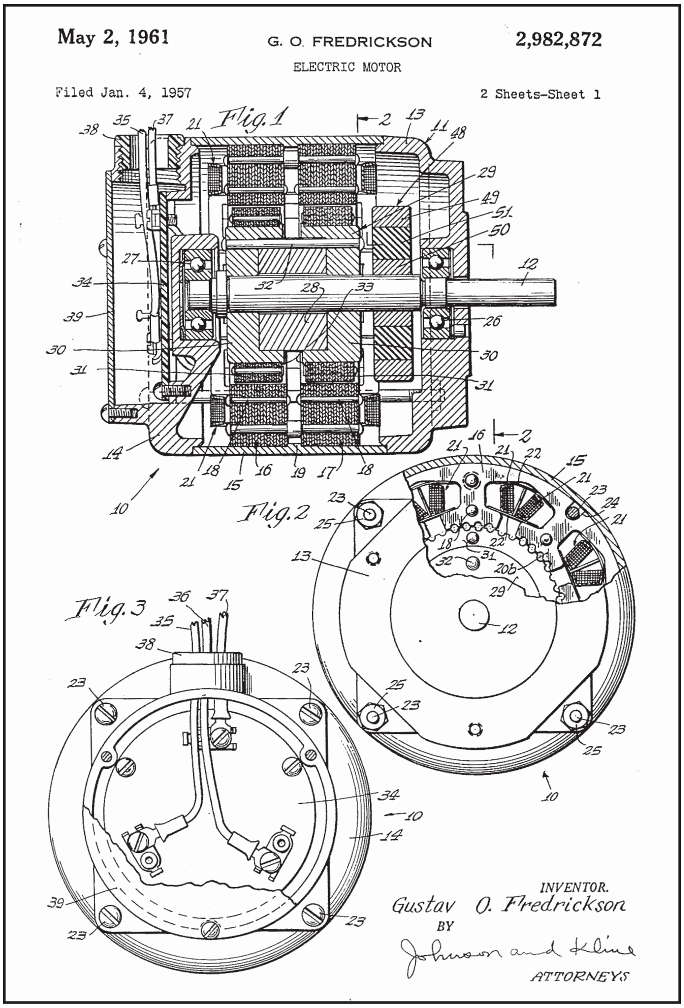
US3343014 refers to the above motor design, but finally takes the “step” to driving this with a motor with a bipolar square wave drive circuit to cause the motor to move 1.8 degrees at each successive switch combination in the sequence



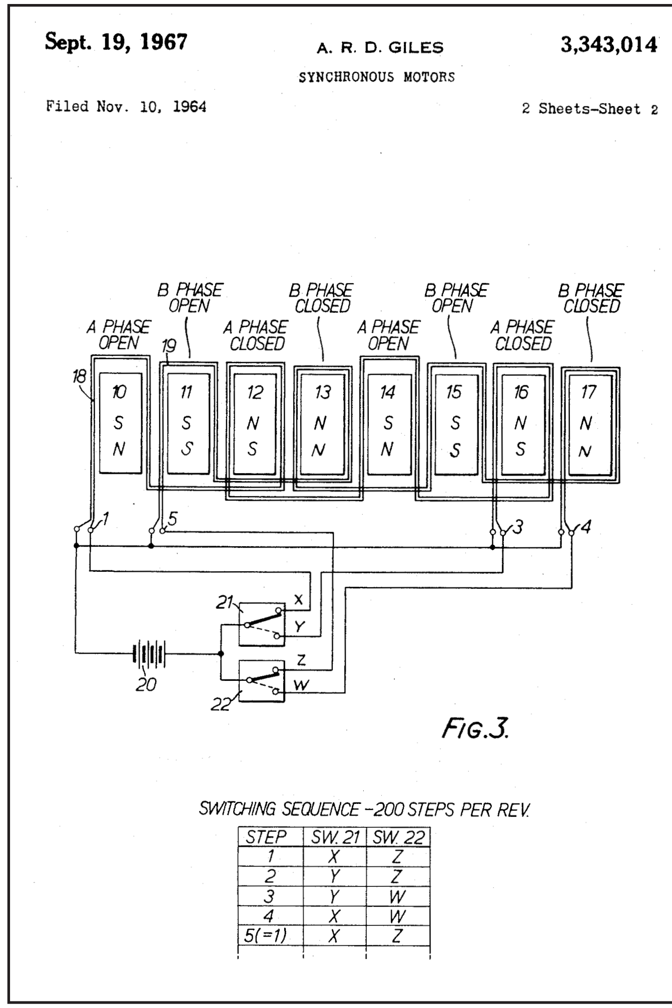
Early Variable reluctance Transverse magnetic flux step motor (US2249029)



2-Phase Permanent Magnetic Transverse Magnetic Flux Motor (US2589999)



48:50 Low Cog 2-Phase Permanent Magnet Transverse Magnetic Flux Motor (US2982872)



Operation of Traditional Full-Step Stepper (US3343014)

table, i.e. — 200 steps per revolution.

There have continued to be many improvements in this motor type — more than 100 additional patents — but I will stop here as it brings us very close to the modern step motor designs.

Summary

The history of the transverse magnetic flux motor shows that this design was motivated by the need for high torque in direct-drive operations. The transverse magnet flux design allows for many more rotor poles than there are windings by putting multiple teeth on the stator pole piece associated with each winding. The resulting high pole count of the motor enables the design to produce high torque

The permanent magnet transverse flux motor uses a single rotor magnet in a 100-pole motor design. A 100-pole face magnet non-transverse-flux design would require one- or two-magnets-per-electrical-pole, and would need a much more complex stator as well. The transverse magnetic flux motor uses a simple stacked rotor and stator design with few, compact coils. This makes for a simpler and lower-cost design. The transverse design, which uses three dimensions for flux flow, brings the iron to the copper rather than the other way around. This reduces the non-productive end turns in the coils, which only contribute copper losses and do not assist in torque generation. **PTE**

For more information. Questions or comments regarding this article? Contact Don Labriola at *don_labriola@quicksilvercontrols.com.*


Donald P. Labriola II, president and founder of QuickSilver Controls, Inc., specializes in servo controllers and motors, with a special focus on cost-effective motion control. He has been granted eleven US patents as well as numerous international patents. His background includes over 40 years of motion control including 20 years in medical instrument design. He enjoys gardening, camping and Ham radio - and motion control!