

Development of Compact Transverse Flux Motor with a New Magnetic Circuit Configuration

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ABSTRACT

Size reduction is a significant requirement for hybrid vehicle motors. To meet this requirement, a small new-structure transverse flux (T.F.) motor has been developed, with efforts focused on coil end elimination and a higher motor torque density. The new structure is characterized by a stator core with a three-dimensional flux path configuration.

A prototype motor was also designed and produced using ring coils and stator cores made of soft magnetic composites (SMC). The prototype performance was tested to verify the validity of the new magnetic circuit configuration.

INTRODUCTION

As a measure to prevent global warming caused by greenhouse gases, automobile manufacturers are now required to enhance fuel efficiency and thereby reduce CO₂ emissions. The electrification of powertrains is an approach to improving automobile fuel economy, and a hybrid electric vehicle (HEV) is an example of electrification. Motors employed in the electric powertrain are required to be small, lightweight, and capable of high output. In a type of HEV, in which a single motor is mounted between the gasoline engine and the transmission, the powertrain is installed in the engine compartment. This means that a shorter axial length is of great significance for the motor.

Several reports were made on the use of salient-pole concentrated windings in the stator to shorten coil ends and reduce the axial length^{[1],[2],[3]}. However shorter axial lengths of motors are required, depending on the type of car body and engine-transmission combination. To meet this requirement, we have developed a new-structure transverse flux (T.F.) motor with a much shorter axial length. This

motor is configured from ring coils and three-dimensional flux-path stator cores that create a common flux path to whole coils.

Similarly to other previously reported 3D flux-path motors^{[4],[5]}, the developed motor core is made of soft magnetic composites (SMC), instead of electrical steel sheets, because it is difficult to configure a 3D flux path using a regular laminated steel sheets.

This paper describes the basic principle of the new-structure T.F. motor and the results of performance tests conducted on the prototype.

APPROACH TO SHORTENING MOTOR AXIAL LENGTH

The motor axial length can be effectively shortened by removing parts that do not contribute to motor torque generation. Motor torque is generated by interlinks between rotor magnet flux and energized coil flux. Figure 1 shows the breakdown of the axial length of a salient-pole concentrated winding motor. Figure 2 shows the coil-end of a salient-pole concentrated winding stator. The coil end does not interlink with the flux generated by the rotor and therefore does not contribute electromagnetically to motor torque generation. Accordingly, removing these coil ends would effectively shorten the motor axial length. The elimination of the coil ends would also allow surrounding parts, other than the laminated core, to be removed, making an even shorter axial length possible.

Figure 3 shows a conventional three-phase claw-teeth motor, that is, a type of T.F. motor with no coil end^[5]. Although it has no coil end, this motor uses only one third of magnetic

flux per phase compared with the conventional type. This is because coils are stacked up separately for the three phases in the axial direction, which makes it difficult to effectively utilize the flux. As a result, the axial length is not shortened in this motor.

The following presents the magnetic circuit configuration of the new-structure T.F. motor that effectively uses magnetic flux.

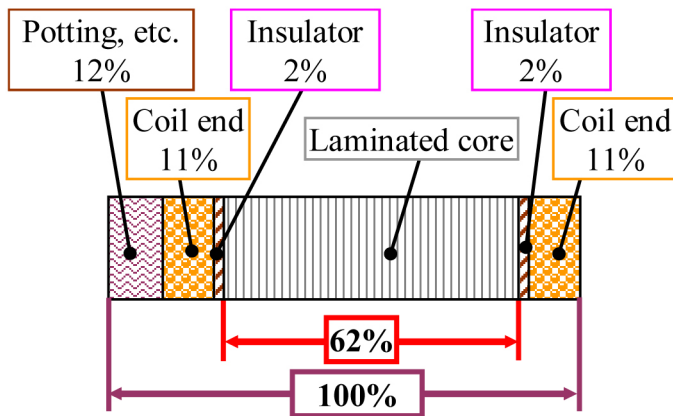


Figure 1. Breakdown of the axial length of a salient-pole concentrated winding motor

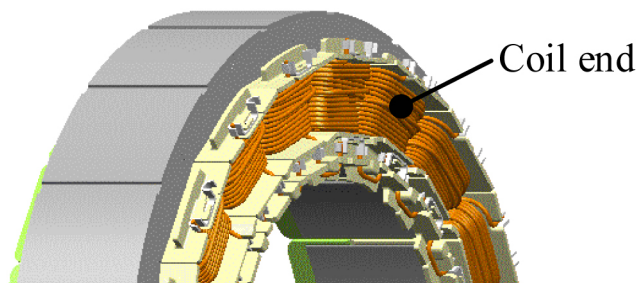


Figure 2. Salient-pole concentrated winding stator

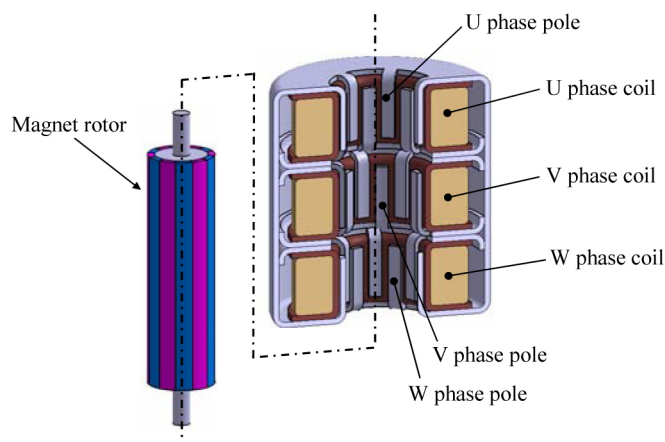


Figure 3. Conventional three-phase claw-teeth motor

MAGNETIC CIRCUIT CONFIGURATION OF T.F. MOTOR

In the radial gap-type rotating machine with salient-pole concentrated windings shown in [Fig. 2](#), a stator magnetic circuit is shared by three phases, and the flux of the rotor magnet interlinks with the windings of all the phases. On the other hand, the conventional claw-teeth motor shown in [Fig. 3](#) has a separate magnetic circuit for each phase so that only part of the flux generated by the rotor magnet interlinks with the winding of each phase.

We therefore modified the structure of the salient-pole concentrated winding stator to create a flux path that can be shared by the three phases, in the same manner as in a radial gap-type rotating machine with salient-pole concentrated windings. The developed T.F. motor has a new magnetic circuit configuration in which all the flux of the rotor magnet interlinks with the winding of each phase.

[Figure 4](#) is a schematic view of the structure of the salient-pole concentrated winding stator. For the purpose of simplification, the schematic illustrates the winding of each phase as a single-turn closed coil.

First, the teeth for each phase of the salient-pole concentrated winding stator (in [Fig. 4](#)) were shifted in the axial direction, as shown in [Fig. 5](#). [Figure 6 \(a\)](#) shows the relation between flux path and windings for U-phase and V-phase. The arrows in the figure indicate flux flow between the U and V phases. To interlink with a winding, a flux must form a closed path around the winding. In [Fig. 6 \(a\)](#), portions of the windings interlinking with the U-V phase flux are indicated in solid lines. Portions of the windings in broken lines are ineffective because they do not interlink with the flux.

[Figure 6 \(b\)](#) and [\(c\)](#) show the V-W phase flux and the W-U phase flux, respectively, as well as the relations between these fluxes and the windings. Next, [Fig. 7](#) shows the structure in which ineffective winding portions are eliminated, and the effective portions of adjacent windings in the same phase are connected in series. The structure shown in [Fig. 7](#) has the same flux linkage as in the salient-pole concentrated winding stator structure. Also extending the tip of the tooth of each phase in the axial direction, as shown in [Fig. 8](#), makes it possible to interlink all the flux of the rotor magnet with the windings.

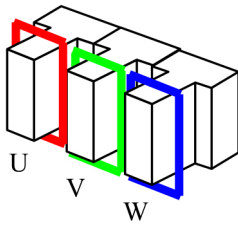


Figure 4. Schematic view of salient-pole concentrated winding stator

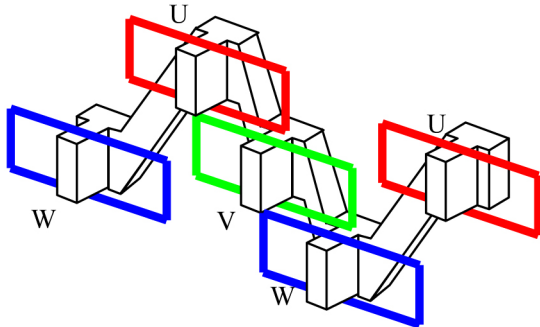
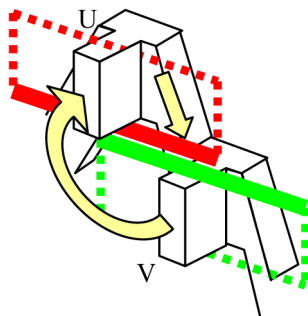
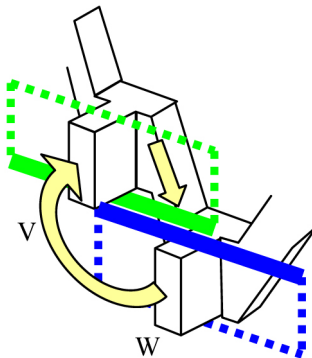


Figure 5. 3D magnetic circuit

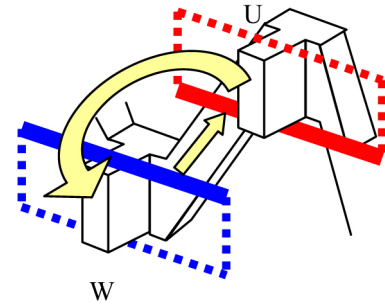


(a). U-V flux



(b). V-W flux

Figure 6. Flux between phases and effective parts of windings



(c). W-U flux

Figure 6 (cont.). Flux between phases and effective parts of windings

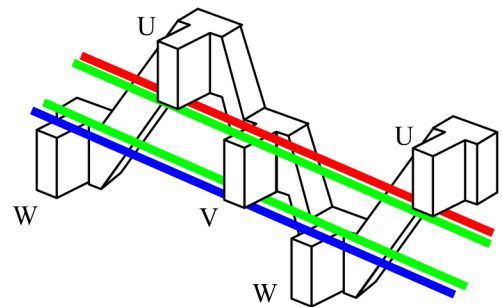


Figure 7. Windings of all phases connected in series

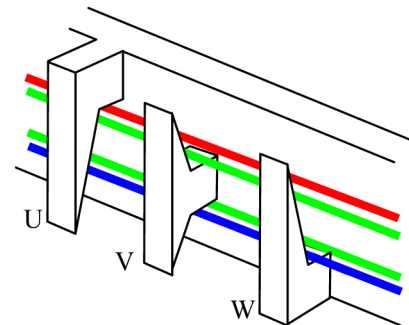


Figure 8. Claw teeth

Figures 9 and 10 show the magnetic equivalent circuit of salient-pole concentrated windings and that of the T.F. motor, respectively.

In the salient-pole concentrated winding structure, the U-, V-, and W-phase teeth and windings are laid out in the circumferential direction, as shown in Fig. 9. Flux linkage Ψ_u , Ψ_v and Ψ_w of U-, V-, and W-phase windings are obtained by Eq. (1), where the flux between W-phase and U-phase teeth is Φ_a , and U-V phase flux is Φ_b and V-W phase flux is Φ_c .