# Fractional-Slot Concentrated-Windings: A Paradigm Shift in Electrical Machines

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***Abstract*--** **Fractional-slot concentrated-winding (FSCW) synchronous permanent magnet (PM) machines have been gaining a lot of interest over the last few years. This is mainly due to the several advantages that this type of windings provides. These include high power density, high efficiency, short end turns, high slot fill factor especially when coupled with segmented stator structures, low cogging torque, flux-weakening capability, and fault-tolerance**

**This paper is going to provide an update of the key activities and research trends in this area over the past few years. These include efforts to reduce losses especially rotor losses in FSCW machines, exploring FSCW for machine topologies other than PM machines as well as some of the commercial products that utilize FSCW.**

***Index Terms--concentrated, distributed, fractional-slot, generators, integral-slot, machines, motors, permanent magnet, synchronous, windings.***

**Nomenclature**

## I. Introduction

The winding configurations which are most commonly employed for 3-phase radial-field Permanent Magnet (PM) brushless machines, can be classified as [1]:

- Overlapping, either distributed, Fig. 1(a) (2 slots/pole/phase), or concentrated, Fig. 1(b) (1 slot/pole/phase);
- Non-overlapping i.e. concentrated, with either all teeth wound, Fig. 1(c), or alternate teeth wound, Fig. 1(d).

Non-overlapping windings will be referred to as Fractional-Slot Concentrated-Winding (FSCW) for the rest of the paper. All teeth wound winding will be referred to as Double-Layer (DL), while alternate teeth wound will be referred to as Single-Layer (SL). Figures 2a, and 2b show actual prototypes of both types of windings [2].

Since a distributed overlapping winding generally results in a more sinusoidal MMF distribution and EMF waveform it is used extensively in PM ac machines.

On the other hand FSCW synchronous PM machines have been gaining a lot of interest over the last several years. This is mainly due to the several advantages that this type of windings provides. These include high power density, high efficiency, short end turns [3,4], high slot fill factor especially when coupled with segmented stator structures, low cogging torque, flux-weakening capability, and fault-tolerance. Table I summarizes the key differences between distributed windings and FSCW.

In [5] a comprehensive review of what has been published in literature as well as a detailed discussion of the opportunities and challenges of FSCW has been presented. Since then a significant amount of work has been done to address some of the key challenges associated with FSCW as well as trying to expand the application of FSCW to various types of electrical machines. This paper is going to provide an update of the key areas and publications related to FSCW.

It has been well-established in literature that one of the key challenges of using FSCW configurations is the significant rotor losses (including magnet losses, rotor core losses, and sleeve losses in case of conductive sleeve) especially at high speeds due to the various sub- and super-space harmonic components inherent to such winding configurations that are not in synchronism with the rotor. Section II will cover the most recent key papers addressing the various aspects of rotor losses in PM synchronous machines using FSCW. Some of these papers address the end effects in terms of losses on both the stator and rotor sides. Some papers address the AC losses in the stator windings. Some address ways to reduce the rotor losses but in most case at the expense of making the winding configuration relatively more complicated (winding will be somewhere in between true FSCW and distributed windings).

There has been continued interest in FSCW PM machines. Section III will provide an update of the recent activities in this area. There are several papers focusing more on IPM machines. Other papers focused on multi-phase FSCW PM machines. Also there are some papers addressing axial-flux PM machines.

There have been some attempts to evaluate FSCW in induction machines. Section IV will summarize the key papers addressing induction machines with FSCW. Both squirrel-cage as well as wound-rotor induction machines are being considered.

In general, the main focus so far has been on radial-flux FSCW PM machines. There is a growing interest in other types of PM machines equipped with FSCW. Section V will cover the key papers addressing the use of FSCW in

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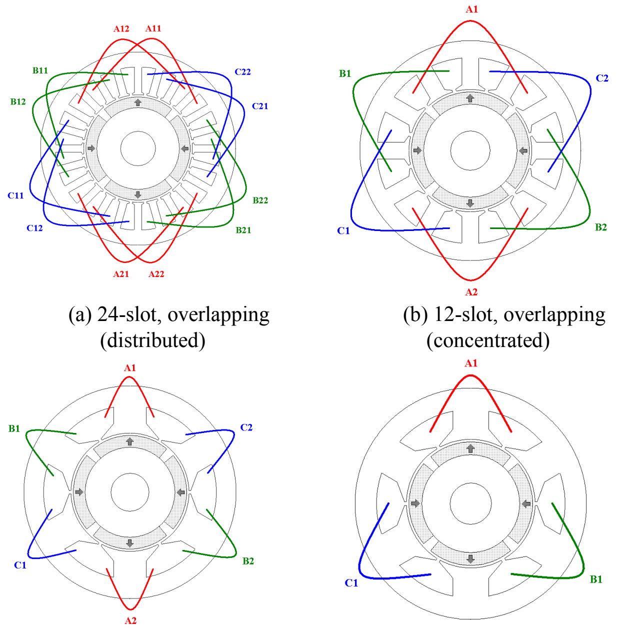
other types of machines mainly flux-switching machines.

Section VI will cover some of the papers addressing sensorless control of FSCW PM machines. Parasitic effects such as noise, vibration, unbalanced magnetic forces, and torque ripple are always a concern when designing an electrical machine. These parasitic effects can potentially be higher in FSCW PM machines due to the additional harmonic contents Section VII will cover the key papers addressing parasitic effects in FSCW PM machines.

Section VIII will provide an update of some of the commercial applications that involve FSCW PM machines.



(a) 24-slot, overlapping (distributed)

(b) 12-slot, overlapping (concentrated)

(c) 6-slot, non-overlapping, all teeth wound

(d) 6-slot, non-overlapping, alternate teeth wound

Fig. 1. Typical stator winding configurations (4-pole) [1]

Fig.2a. 12-slot/10-pole design with SL winding [2]

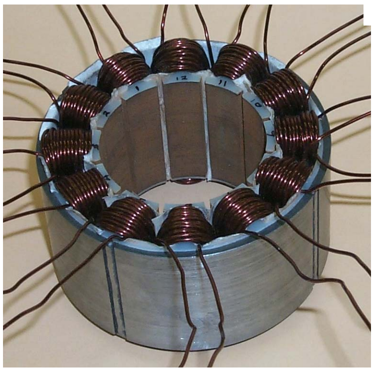


Fig.2b. 12-slot/10-pole with DL winding [2]

TABLE I
COMPARISON OF DISTRIBUTED AND CONCENTRATED WINDINGS

| | Distributed Windings | Concentrated Windings |
|---|---|---|
| Typical copper slot fill factor | 35%-45% | 50%-65% (if coupled with segmented stator structures) |
| Stator structure | Continuous laminations | Continuous laminations or segmented structures |
| End turns | Long overlapping | Short non-overlapping |
| Torque-producing stator space harmonic component | Fundamental | In most cases (except for 0.5 slot/pole/phase) a higher order harmonic |

## II. LOSSES

As previously mentioned, the additional losses generated in FSCW machines especially on the rotor side due to all the additional sub- and super-harmonic components are considered one of the key challenges of this type of windings. This section will provide an update of the most recent work done in this area.

### A. End Losses

Most of the papers focused on losses in the active portions of the machine. In [6], eddy-current losses in the rotor clamping rings of a FSCW PM machine were investigated. The loss in rotor nonmagnetic shaft with the option of i) metallic, ii) nonmetallic, and iii) metallic with shielding laminations was also estimated. The study is based on FEA. Desirable slot/pole combinations for different number of phases were investigated. Also, both single- and double-layer windings were investigated. Experimental results for a three-phase 12 slot/10 pole IPM design (Figs 3 and 4) are presented in detail. The results confirm that the losses in the rotor clamping rings can be very significant in case of FSCW machines and should not be overlooked during the design phase.

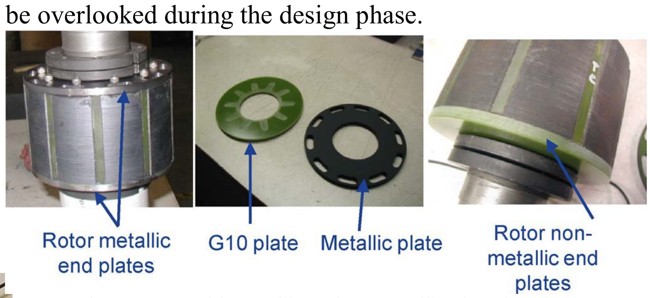



Fig. 3. Rotor with metallic and nonmetallic clamping rings [6]

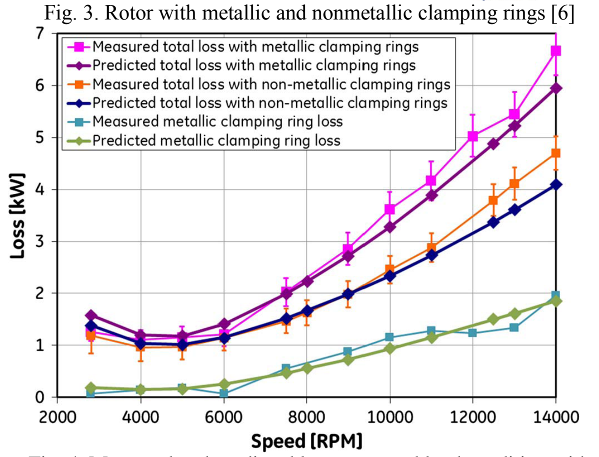



Fig. 4. Measured and predicted losses at rated load condition with metallic and nonmetallic clamping rings and losses in metallic clamping rings [6]

In [7], the focus has been on losses in the support structure including the frame, clamping rings (magnetic or nonmagnetic), and end shields. Both single-layer (SL) and double-layer (DL) windings have been analyzed. Also, the effect of different number of phases has been investigated.

As expected, SL windings produce significantly higher losses compared to DL windings. The lower order space harmonics contribute most to the losses. The main bulk of the losses are in the ESs; that is why the axial clearance has a significant impact on reducing the losses. Going to higher number of phases could have a detrimental effect in terms of increasing the losses or increasing the support-structure size and weight along with other dynamics challenges

*B. Loss Reduction*

In [8], a novel method for reduction of sub-harmonics for the FSCW by using winding coils with different number of turns per coil side has been presented. Using the proposed technique the specific sub-harmonics can be reduced without influencing the working harmonic. The presented technique is available for different m-phases FSCW. Simulation results showed potentially significant reduction of eddy-current rotor losses of more than 60%.

In [9], a new method is presented to simultaneously reduce the sub- and super-harmonics of the 12slot/10pole FSCW MMF. The method is based on doubling the number of stator slots, using two identical winding systems connected in series, and shifted to each other for a specific angle, using stator core with different tooth width and/or using different turns per coil for the neighbouring phase coils. It was shown that the new proposed winding topology can have better performances compared to the standard distributed winding. The complexity of winding is less than that of a distributed winding but more than that of a tooth winding. In this concept, the coil pitch is always two, which can greatly reduce the endwinding length compared to a distributed winding, while being able to achieve better performance than the tooth windings.

In [10], a more general definition and approach for stator shifting (that was presented in [9]) has been presented. This paper investigated a method of cancellation of harmonics in FSCW. The concept of stator shifting is introduced and its effect on the machine performance in terms of the power density, efficiency, torque ripple and flux weakening performance was evaluated. It was shown that the concept of stator shifting introduced in FSCW IPM machines is an effective way of improving the power density and efficiency. The concept is shown to be effective also in improving the saliency and the maximum electromagnetic power available from the machine at higher speeds. The final *optimal shift angle* is identified for each configuration and depends on the slot/pole combination chosen along with the number of layers. Finally the concept of stator shifting is seen to be more effective in designs with a single sub-harmonic. In slot/pole combinations with multiple sub-harmonic, the improvement is curtailed by the effect of these harmonics.
The key novelty in the paper is that it explored the effect of shift angle in more general way by scanning a wide range of angles. The paper also highlighted the fact that once high-speed operation under flux-weakening operation is taken into consideration, this can affect the choice of the shift angle in terms of maximizing efficiency at high speeds. Even though it can be seen that an improvement in power density can be seen in IPM machines due to the improvement in saliency, in surface PM machines, it is expected that the shifting would reduce the harmonics and hence only reduce the rotor losses but will simultaneously reduce the power

In [11], the introduction of non-magnetic flux barriers in the stator as a means of reducing or even cancelling the impact of the lower order sub-harmonics has been presented. The proposed geometry as well as the built prototypes are shown in Figs 5 and 6. The proposed flux barriers can also be combined with axial cooling passages.

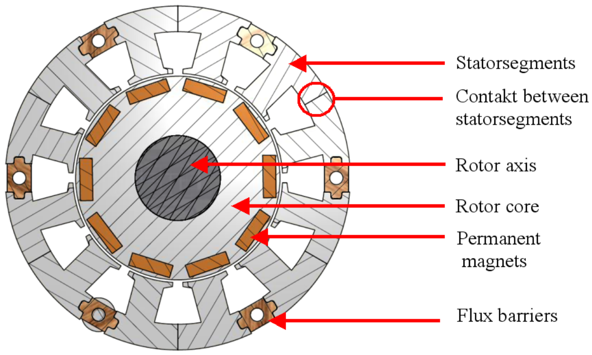



Fig. 5 Geometry of proposed PM design with flux barriers [11]

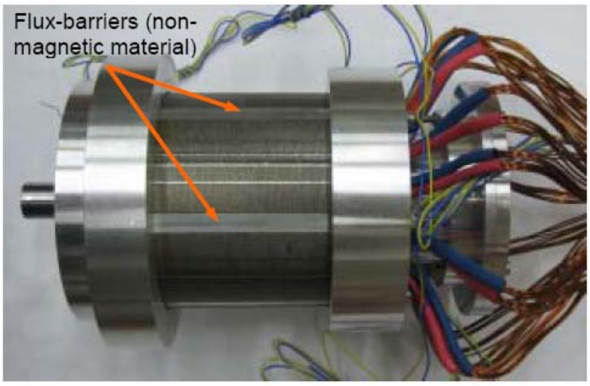



Fig. 6 Prototype with flux barriers [11]

*C. Higher Number of Layers*

Typically, the focus has been on single-layer (SL) and double-layer (DL) windings. In recent years higher number of layers especially four layers have been investigated.

In [12], the effect of increase in number of winding layers (Fig.7) on the winding factors of the torque-producing and the first loss-producing harmonics in FSCW interior PM machines is studied. The optimum slot/pole/phase (spp) combinations with a high winding factor for a torque-producing harmonic, but low harmonic content, with four winding layers are identified. The paper shows an improvement in power density, reluctance torque, efficiency and torque ripple going from single to double to four layer winding configurations.

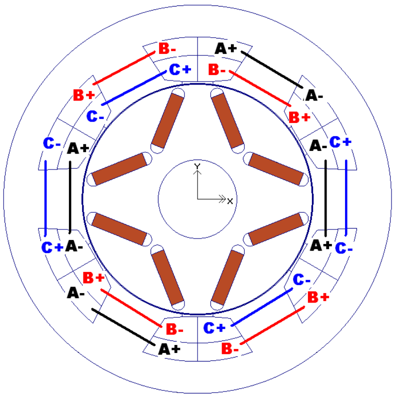



Fig. 7 Four-layer winding [12]

In [13], the general theory of the multilayer m–phase winding is presented. General rules to design such a type of winding are given. Higher number of phases is included. Different types of machines have been evaluated. It was shown that 4-layer windings did not show significant improvement in the case of SPM machines. In case of IPM machines, there was significant reduction in torque ripple. In the case of induction machine, it was shown that 4-layer windings make FSCW more feasible with IM even though the torque ripple was fairly high.

### *D. AC Losses in the Windings*

In [14], AC armature losses in FSCW SPM machines designed for a wide speed range of constant power operation have been investigated. Key conclusions include the following:

- The number of winding layers does not have a significant effect on the AC losses.
- The magnet type has a significant effect on the AC losses since it affects the machine effective air gap and hence the slot leakage flux. As a result, machines using bonded magnets are vulnerable to higher AC losses than machines using sintered magnets.
- Machines with lower pole numbers tend to have lower AC losses compared to the machines belonging to the same family but with higher pole numbers due to the higher excitation frequencies in high-pole-number machines.
- Higher levels of magnetic saturation in the stator tooth tips decreases the AC losses in the conductors because the saturation tends to reduce the effective leakage flux across the slot opening.
- Terminal conditions (series vs. parallel connections) do not have a significant effect on the AC losses provided that the strand size and the current in each strand is not changed.

In [15], thermal analysis of a segmented stator winding design has been presented. A thermal model for a single tooth was developed and supported by tests to identify key heat transfer coefficients. A number of winding assemblies were compared, and the most promising was selected for the final motor prototype. The results from the approach are compared with thermal test results from the complete machine.

### *E. Miscellaneous*

More accurate analytical models for predicting the losses have been developed [16, 17]. Rotor losses in FSCW axial-flux PM machines have been analyzed and measured [18, 19]. Losses in the case of higher number of phases have been also investigated [20, 21]

## III. Permanent Magnet Machines

Even though the initial interest in FSCW has been focused on SPM machines, there has been a lot of work done over the past few years focusing on IPM machines.

In [22], it was demonstrated that a well-designed magnetic circuit model provides a promising method of predicting the cores losses of FSCW-IPM machines that pose special challenges because of their nonlinear electromagnetic characteristics and basic repeating unit that can include several machine poles. Despite the fact that FE analysis uses a much finer mesh that captures the localized variations in flux density more accurately than the MCM, the permeance models in the MCM are sufficiently good to provide core loss estimates that closely match the FE results under open-circuit operating condition and as well as in the presence of armature reaction.

In [23], it was shown that the FSCW-IPM machine can be designed to achieve appealingly high values of torque and power density, taking advantage of the known advantages of fractional-slot concentrated windings and IPM machines. This includes the opportunity to design PM machines that are can achieving wide ranges of constant-power operation, a valuable feature in some applications. On the other hand, the investigation has also highlighted the fact that FSCW-IPM machines are not generally compatible with achieving high values of magnetic saliency that are required for delivering large contributions of reluctance torque to the total machine torque production. Closer inspection indicates that this conclusion is not that surprising since the wide stator poles that are typical of fractional-slot winding configurations serve as spatial low-pass filters that span large angular pitches. In fact, this slot pitch exceeds one full pole pitch when spp is less than 1/3, filtering out magnetic permeance differences along the orthogonal d- and q-axes.

It is shown that, with increase in saliency, gamma angle at which the maximum torque occurs tends towards 45 degrees and machine configurations with higher saliency will have higher gamma angle magnitude. Observations made in-terms of design with double layer winding had higher saliency when compared to corresponding design with single layer winding are seconded in the later section with the help of detailed design torque comparisons. Along with this another set of design comparison is made by changing the SPP while keeping same rotor also indicated that the another important conclusion in-terms of machines with higher SPP value have higher saliency and confirm that wider stator tooth acts as a saliency filter and reduces the resultant saliency.

In [24], a comparison of IPM and SPM machines equipped with FSCW and designed for a wide CPSR has

been presented (Figs 8-11). It was shown that both machines can provide high performance and meet several of the very challenging FreedomCar 2020 specifications. Two machines, one IPM and the other SPM, were designed to meet these specifications. The analytical and experimental results for both machines have been compared and the design tradeoffs have been highlighted.
The performance characteristics of both machines have also been compared to those of State-of-Art (SoA) traction motors. Based on the test results of the prototype machines built to date, the 30/55-kW14 000-r/min advanced IPM- and SPM-FSCW machine architectures achieve significant improvements in full-load power density and efficiency compared to the SoA machines.

Fig. 8 Stator of FSCW IPM design [24]

Fig. 9 Stator of FSCW SPM design [24]

Fig. 10 Rotor of FSCW IPM design [24]

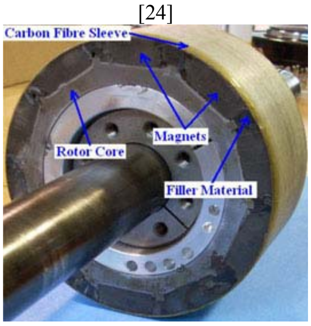



Fig. 11 Rotor of FSCW SPM design [24]

One of the challenges with IPM machines in general is the separation of the various torque components (reluctance vs. PM torque). This task becomes even more challenging in the case of FSCW IPM machines due to the presence of all the sub- and super-harmonic components. Several papers tried to tackle this issue.

In [25], alternative techniques for segregating the calculated torque values in FSCW-IPM machines have been investigated. It is shown that the previously-established frozen permeability technique does a very good job of predicting the nonlinear effects of saturation on the machine flux linkages, building confidence in the meaningfulness of its resulting PM and reluctance torque component predictions. Unfortunately, the frozen permeability technique is very computation intensive since it depends so heavily on FE analysis for its execution.

A new modified torque segregation technique based on capturing the effects of the combined *q*- and *d*-axis currents in a single saturation variable dependency has been proposed. Predicted PM and reluctance torque values for this new model match the results of the baseline frozen permeability technique very well. It is an appealing alternative because it provides an attractive tradeoff between accuracy and computation time for this torque segregation task as it is necessary to freeze the permeance and perform linear simulations.

In [26], The frozen permeability method has been used to analyze the influence of saturation due to PM, d- and q-axis currents on the different parameters, such as the PM flux linkage, d- and q-axis inductances of fractional-slot PM machines having concentrated windings. The analysis shows that the q-axis PM flux linkage, the influence of d-axis current on the d-axis PM flux linkage, and the cross-coupling effect on the dq-axis inductance can be neglected in the calculation of the torque speed characteristics of such machines. A proposed partial cross-coupling model has been compared to FEA and experimental results. The proposed model proved to be fairly accurate and a much faster analysis tool.

## IV. Induction Machines

After the extensive work that has been done in the area of FSCW PM over the past decade or so, it was a logical step to evaluate the potential of FSCW in other types of machines especially induction machines (IM) that are still considered the main workhorse for several applications.

In [28], this was the first time attempt to quantitatively address the tradeoffs involved in using FSCW in induction machines. It focused on squirrel-cage induction machines. Based on the analysis results presented, the traditional distributed lap winding is proven to be superior to FSCW in terms of torque production and rotor bar losses for induction machine applications. The 1/2 spp shows some promising results in terms of torque production, in addition to significant reduction and simplification of end turns with lower number of coils albeit with more turns/coil. (12 slots vs. 48 slots.) The penalty is the additional rotor bar losses due to the 2$^{nd}$ and 4$^{th}$ harmonic mmf components. The 2/5 spp is not promising for torque production. The transient simulation results that simultaneously take into account the effects of all space harmonics and magnetic saturation showed comparable trends compared to the harmonic analysis results. It has also been shown that FSCW tend to have higher torque ripple compared to distributed windings.

In [29], the analysis, design and tests of a wound-rotor FSCW IM have been presented. An airgap analytical model has been used to evaluate the various slot/pole combinations as well as the number of poles. Higher number of layers (more than 2) have been evaluated on both the stator and rotor side (Fig. 12).

Both 2- and 4-layer machine prototypes have been built and tested. It has been shown that the 4-layer exhibits better performance compared to the 2-layer winding. This is kind of expected due to the reduction of some of the harmonics. Even though the torque ripple as lower compared to the

20layer, it was still fairly high. This paper showed that potentially there is a path to use FSCW with low-speed high pole-count IM.

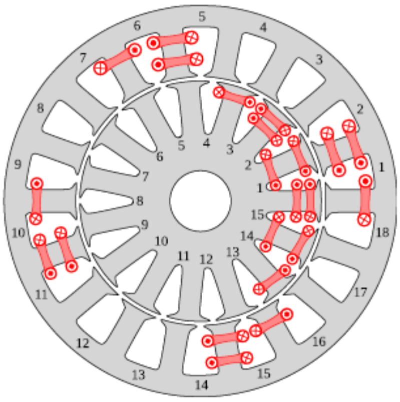


Fig. 12 Winding layout for a wound-rotor FSCW induction machine design [29]

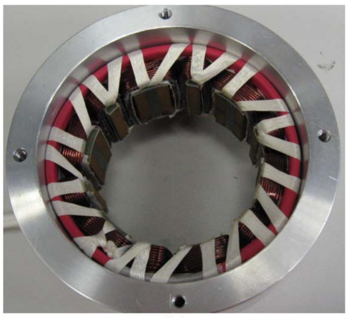
## V. Flux-Switching Machines

There has been growing and continued interest in flux-switching machines (FSM). These machines have the advantage of having a passive rotor (similar to that of a switched-reluctance machine (SRM)), lower torque ripple compared to SRM, it can be fed by a standard 3-phase inverter, and the fact that the permanent magnets are on the stator side means that there are no magnet-retention challenges and the magnet are easier to cool.

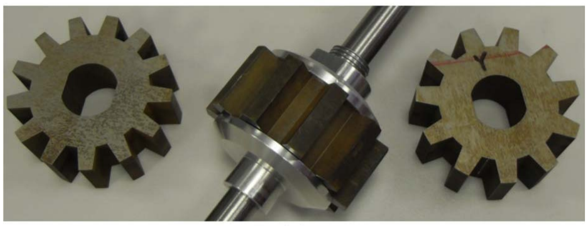
There continue to be many papers addressing various aspects of FSMs. In [31], a novel E-core FSM shown in Fig. 13 has been presented. A prototype has been built and tested.

In [32], a comparison of FSM vs. SPM in the context of high-speed embedded power generation has been presented. It has been shown that FSM can be superior in such applications because it has a passive rotor. In the case of an SPM, the sleeve required for magnets retention poses a significant penalty in terms of machine electromagnetic performance.

(a)



(b)



(c)

Fig. 13 Photographs of E-core SFPM prototype machines. (a) Stator lamination.(b) E-core six-pole stator. (c) 10-, 11-, and 13-pole rotors [31]

There are other papers addressing FSM with DC filed windings [33,34], FSM with hybrid excitation [35], FSM with modular rotor structure [36], axial-flux FSM [37], and proximity losses in FSM [38].

## VI. Sensorless Control

In many applications, the position sensor can be one of the main sources of unreliability. Over the past few years, some of the sensorless control concepts that were developed for the more conventional distributed-winding designs have been evaluated for different FSCW PM designs.

In [39], two ringed–pole (Figs 14, 15) SPM motors are compared in terms of sensorless control at zero speed. One has a distributed coil winding, the other has FSCW. It is shown that a ring around each rotor pole represents an effective method to create a high frequency saliency in both cases.. The effect of eddy currents in the magnets due to the high frequency injected signal is also investigated. It is shown that eddy currents in the PMs contribute additional increase in saliency but in presence of the ring.

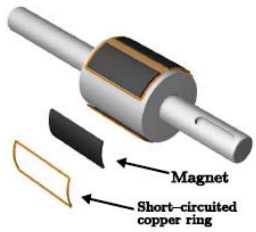



Fig. 14 Scheme of the coil around the magnet of an SPM motor [39]

Fig. 15 SPM rotor with short circuited rings around the poles [39]

In [40], it is shown that a dual three–phase IPM machine, equipped with two sets of 3-phase FSCW( Fig 16,17) can be properly operated using sensorless algorithm based on high frequency injection. The experimental tests confirm the machine is suitable for sensorless control in either cases of supplying the two 3-phase winding sets or only one of them. FEA as well as experimental results confirmed that the machine exhibits significant saliency even when only one set of windings is supplied.

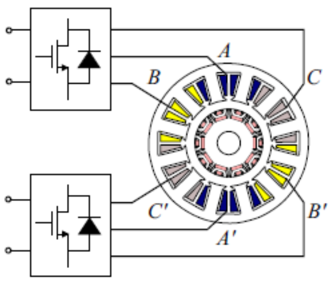


Fig. 16 General scheme of the dual three–phase motor drive [40]

(a) Coils (b) Rotor

Fig. 17 12 slot/ 10 pole IPM design [40]

## VII. Parasitic Effects

Parasitic effects such as noise, vibration, unbalanced magnetic forces, and torque ripple are always a concern when designing an electrical machine. These parasitic effects can potentially be higher in FSCW PM machines due to the additional harmonic contents.

In [42], a simplified analytical model for FSCW IPM with two flux barrier per pole and a fractional– slot winding has been presented. The model has been used to come up with an optimized design with minimum torque ripple. The full FEA results showed that at nominal load condition, the optimized design exhibits a very low torque ripple with a slightly higher torque to PM volume ratio. Additionally, the torque ripple map computed with FEA has highlighted that the percent torque ripple remains limited even at both lower and higher current amplitude.

In [43], a comprehensive investigation of the characteristics of the unbalanced magnetic force (UMF) in FSCW SPM machines having diametrically asymmetric windings by using an analytical method based on the FE predicted airgap flux densities has been presented. It shows that the UMF is strongly determined by the canceling and additive effects between two UMF sources from the radial and circumferential stresses. It is found that the UMF components due to the radial and circumferential traveling stresses are additive for machines having pole number $2p = 3k - 1$, e.g., 8-pole/9-slot and 8-pole/6-slot (single-layer winding), but partially canceling for machines having $2p = 3k + 1$, e.g., 16-pole/15-slot and 16-pole/18-slot (single-layer winding). Furthermore, due to the additive and canceling effects, for the same slot number, the machine having the smaller pole number may have a larger UMF when the slot/pole numbers differed by one, whereas the machine having a larger pole number may have a larger UMF when the slot/pole numbers differed by two and the slot number is higher than 6. For the same pole number, machines employed with slot/pole numbers differed by two have a smaller UMF than machines employed with slot/pole numbers differed by one. It is also found that, if $2p = 3k + 1$, the UMF diminishes to 0 with the increase in pole number. Otherwise, i.e., when $2p = 3k - 1$, it reduces to a certain value with the increase in pole number. The experimental results are provided to verify the analysis.

In [44], the airgap field and magnetic radial force density between 12slot/10pole FSCW SPM and IPM machines designed to have the same torque capability have been compared. FEA incorporating frozen permeability technique is used to account for saturation effects. It is shown that the lowest harmonic of radial force for 12slot/10pole configuration both for SPM and IPM machine is 2, which is mainly caused by the interaction between 5th harmonic of open-circuit field and 7th harmonic of armature reaction field, not because of the 1st harmonic of armature reaction field itself, and also by the interaction between armature reaction field harmonics in IPM machine which is much more significant than the case of SPM machine due to significantly higher armature reaction. It also shows that to reduce the (2p)th harmonic of radial force density on both open-circuit and load, higher ratio of magnet pole-arc/pole-pitch is desirable, ideally being 1, i.e. full arc magnet. However, due to the mechanical restriction, the effective ratio of magnet pole-arc/pole-pitch is impossible to reach 1 for IPM machine. Thus, the (2p)th harmonic of radial force in IPM machine will be normally higher than that in SPM machine.

## VIII. Commercial

FSCW continue to find their way in commercial products. Hybrid Electric Vehicles (HEV) traction motors is a growing area where new FSCW PM machines have been recently commercialized. A good example is the Prius 2010 generator shown in Figs 18 and 19 [46]. The full dimensions and ratings of this machine can be found in [46]

Fig. 18 Prius 2010 FSCW PM generator [46]

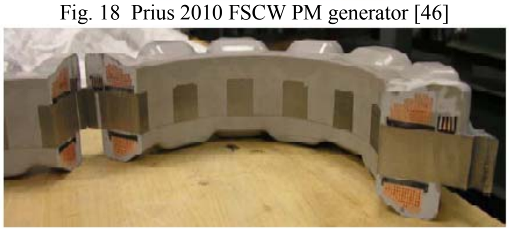


Fig. 19 Cutout of the Prius 2010 FSCW PM generator stator winding [46]

Another good example is “Motor A” in the Chevy Volt’s Voltec 4ET50 electric drive system. This machine is mainly used as a generator. This is a FSCW IPM machine with 24 stator slots and 16 rotor poles (1/2 spp). The machine has a segmented stator structure as shown in Figs 20 and 21 and an IPM rotor as shown in Fig 22. More details about this machine can be found in [47].

Fig. 20 One tooth assembly of the Voltec motor A [47]

Fig. 21 Machine A assembly diagram [47]

Fig. 22 Machine A rotor with the end ring removed to show the magnet arrangement [47]

## IX. Conclusions

This paper provides an update of the recent research activities in the area of FSCW machines. These include evaluating and trying to reduce various loss components, more focus on IPM, multi-phase and axial flux machines, induction machines, flux-switching machines, sensorless control and noise and vibration.

Also an update of some of the commercial examples where FSCW PM machines are used has been presented.

This paper in addition to the comprehensive review previously presented in [5] will provide engineers and researchers interested in the area of synchronous PM machines equipped with FSCW a comprehensive reference that will help them come up to speed with what has been done in this fast-growing area.

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