Electromagnetic-Mechanical Design of Synchronous Reluctance Rotors with Fine Features

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This paper explores the trade-off between electromagnetic and mechanical performance when regarding the design of a synchronous reluctance machine rotor with fine features in the lamination profile – the analyzed machine consists of four rotor poles and its stator is equipped with single tooth coils. The change in the electromagnetic characteristics of the *d* and *q* axis reactance is explored for variation in radial and tangential rib width and the impact of increased rib width on the saliency ratio of the machine. It is shown that increased radial and tangential rib width impairs electromagnetic performance, with the tangential rib having the most pronounced effect on performance in this rotor design. The mechanical performance of the design is also explored in a similar manner, where it is shown that the high stress concentration in the rotor radial & tangential ribs limits the maximum speed of the machine in the field weakening region. The radial rib is found to have the dominant impact on supporting the flux guides. It is shown that the prototyped machine can achieve good electromagnetic performance while maintaining mechanical integrity up to a 25% over speed of 10,000rpm with features as small as 0.3mm. Additionally, the challenges associated with manufacturing, selecting a higher rotor pole number and the possibility of mechanical failure are also discussed in the context of electromagnetic-mechanical design of such rotors, with important avenues of further research suggested.

Index Terms— **AC motor drives, finite element method, single tooth wound, synchronous reluctance machine, mechanical design**

I. Introduction

Electromagnetic design of synchronous reluctance machine rotors has been addressed at some length in the literature. The design of the rotors usually encompasses the selection of rotor topology, either the axially laminated variant [1] or transversely laminated variant [2], the latter being the most popular. When designing the transversely laminated variant, the number of flux barriers and their shape (otherwise known as 'guides') [3], the ratio of iron to air in the barrier windows [4], known as the *insulation ratio*, or the barrier placement [5] is typically investigated. Other authors have also investigated various analytical and computational barrier optimization techniques [6,7]. Materials selection has also become an increasingly popular areas for research [8,9] with high-speed synchronous reluctance machine design being of little consideration. Attention is lacking in the design of the very important radial and tangential ribs that link the flux guides, with respect to their electromagnetic and mechanical performance. The synchronous reluctance machine relies on a high saliency ratio for high efficiency and power factor and this can only be achieved with good rotor designs, which consists of the aforementioned design parameters (barrier number, shape, location etc.) but also the radial and tangential rib design, to ensure good performance. Centripetal loading under normal operating speeds of the relatively heavy flux barriers supported by thin rib-like structures in the transversely laminated variant must be investigated. This presents a multi-disciplinary study regarding both the electromagnetic performance and the mechanical integrity of a novel single tooth wound synchronous reluctance motor, designed for operation up to 8000rpm. In high speed permanent magnet machines, studies have been conducted on mechanical integrity issues [10], however, the rotor features tend to be larger in comparison to the synchronous reluctance motor. Low speed industrial machines

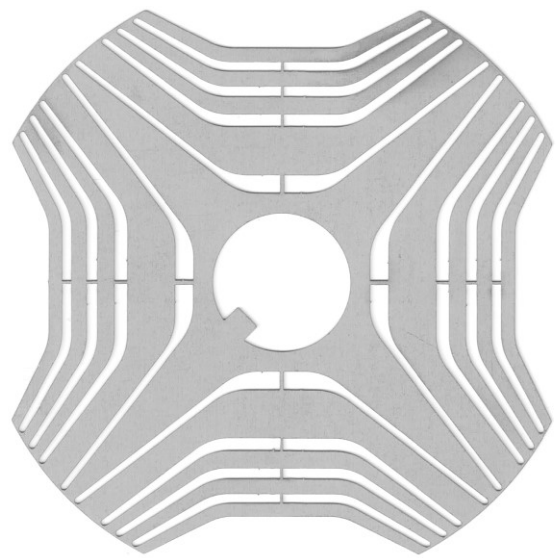

Fig. 1. 4-pole synchronous reluctance rotor with fine features

inherently experience a reduced centripetal loading, but the features required to maximize electromagnetic performance (maximize d-axis flux and minimize q-axis flux) are generally smaller and of increased number, in comparison (see Fig. 1). To the author's knowledge, an explicit study cannot be found in the literature that presents a concise study of the electromagnetic-mechanical design of synchronous reluctance rotors with fine features. This paper explores the trade-off between electromagnetic and mechanical performance, issues surrounding manufacturing and pole number selection. Both electromagnetic and mechanical finite element analysis is employed in this paper based on a previously published and experimentally verified machine design [11] producing 21Nm of torque at 1500rpm equal to 3.5kW with an efficiency of over 90%, which is facilitated by high fill factor stator coils, where the achieved fill factor is ~60%.

II. Single Tooth Wound SynRM

The base synchronous reluctance machine model used in the FEA studies is form a novel single tooth wound synchronous reluctance motor previously published by the authors (see Fig. 1 for rotor lamination profile). The rotor was designed as a research machine and to reduce torque ripple caused by the 2nd order even harmonics generated by the stator MMF distribution with single tooth coils (6 tooth, 4 pole design). The rotor is of the transversely laminated variant with shaped flux barriers webbed with radial and tangential ribs. In this design, the radial ribs are central in the flux barrier and each flux barrier has a radial rib. The analyzed single tooth wound synchronous reluctance motor consists of 6 stator slots and 4 rotor poles, the winding is of the single tooth double layer type, as shown in Figure 2.

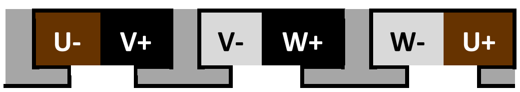

Fig. 2. 6 slot, 4 pole FSCW layout (repeated twice for full winding)

This slot pole combination is chosen due to the limited number of slot-pole combinations that support single tooth windings with 4 rotor poles. Section V discusses the issues surrounding pole number section and the manufacture of these machines with numerous fine features per rotor pole. In motors that have a slot/pole/phase of 0.5 or lower, such as the present machine topology, the main flux path in the air gap region over one pole pitch may consist of one slot and one tooth or less. Thus, flux distribution can be asymmetrical, this and the discrete placement of coils around the air-gap periphery manifests significant space harmonics, causing parasitic effects in the machine which have been previously analyzed and discussed previously.

The rationale for replacing the traditional distributed wound stator (as seen in all commercially available synchronous reluctance motors and in the literature) with a fraction slot-concentrated winding (otherwise known as a *single tooth* winding) is as follows [11,12,15];

- Segmented stators can be used (single tooth segments)
- Higher slot fill factors can be obtained ($S_{FF} \sim 60\%$)
- The winding joule losses are reduced according to $\left(\frac{1}{S_{FF}}\right)$ and energy conversion efficiency is increased
- The end winding mass, loss and axial length can be reduced
- Raw material cost can be reduced

The machine can produce 21Nm of torque at 1500rpm equal to 3.5kW with an efficiency of over 90% in a 150mm OD and 150mm stack. There are some associated disadvantages such as increased torque ripple [12] and low power factor [11], which are discussed in other publications. It is beyond the scope of this paper to provide extensive design details and it is used here only as a base design for a means of comparison, Table I outlines its key design parameters. Figures 3 and 4 show the general flux barrier arrangement and the radial rib thickness of the prototyped machine.

TABLE I
Key Rotor Design Parameters

Parameter	Value
Air-gap Length [mm]	0.5
Active stack length [mm]	150
Rotor OD [mm]	88
Rotor Poles	4
Flux Barriers Per Pole	4
Radial Rib Thickness [mm]	0.3-0.5
Tangential Rib Thickness [mm]	0.3

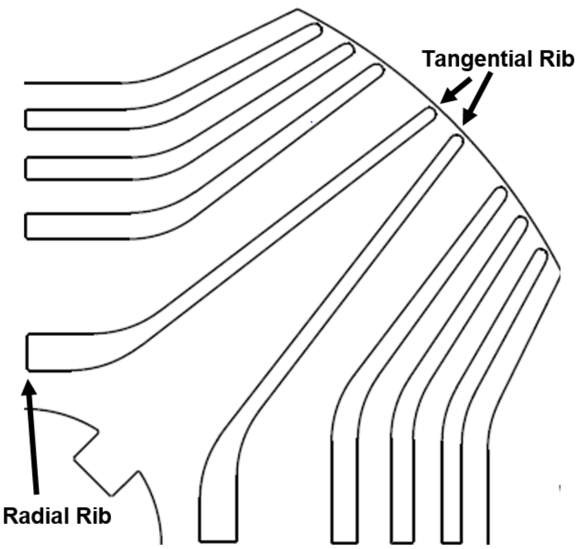

Fig. 3. General flux barrier arrangement showing the 'fine features'

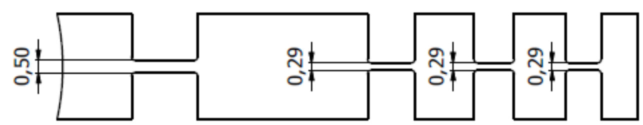

Fig. 4. Radial rib thicknesses (rotor cross section view)

The 'fine features' are defined to be the small radial and tangential ribs (Figure 3) that are required for mechanical integrity of the transversely laminated type of synchronous reluctance rotor, commonly found in the literature and now commercially available to purchase. In this machine, the feature size is small, with the minimum rib thickness at 0.3mm, which is smaller than the lamination thickness of 0.35mm. The machine has been constructed and validated, the laminations were manufactured using electro-discharge machining techniques.

III. Electromagnetic Performance

The electromagnetic design of synchronous reluctance rotors is principally concerned with maximizing the magnetic permeance of the direct-axis, $\wp_d$, and minimizing the magnetic permeance of the quadrature-axis, $\wp_q$. It can be shown that the key electromagnetic figure of merit for the synchronous reluctance motor can be derived from these permeance values - the saliency ratio, ξ.

This figure of merit determines the overall performance of the machine as all key performance criteria improve as the saliency increases. Therefore, this saliency ratio must be maximized to obtain maximum performance [13]. The saliency ratio is defined as follows;

$$\xi = \frac{\wp_d}{\wp_q} \tag{1}$$

The saliency is usually defined in the literature [14] using the orthogonal axis reactance, $X_d \propto \wp_d$ and $X_q \propto \wp_q$. The rotor designer seeks a high d-axis inductance and a low q-axis inductance, these are a complicated function of the rotor steel and air. Due to magnetic saturation, the orthogonal axis reactance and therefore the saliency are a function of phase current. Figure 5 shows the measured (using the instantaneous flux linkage method) and 3D FEA derived orthogonal axis reactance for the lamination profile in Figure. 1, good agreement between the numerical solution and the experimental results is seen, the unsaturated saliency ratio $\xi \approx 4$. Further information on the comparative performance of this motor can be found in [15].

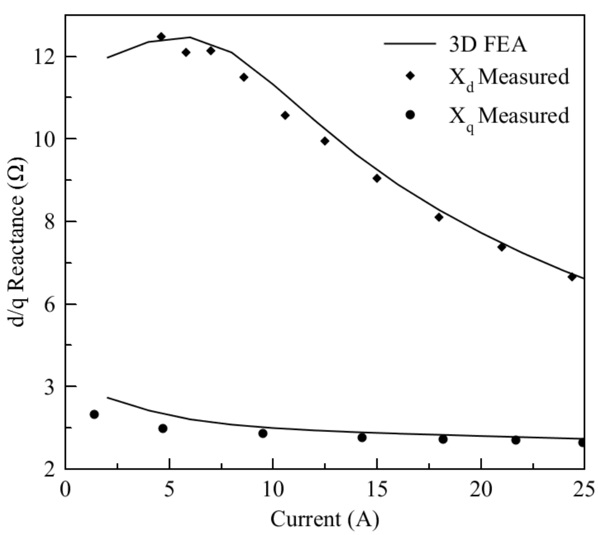

Fig. 5. 3D FEA and Measured orthogonal axis reactance

Key to the operation of the designed motor is saturation of the radial and tangential ribs (Figure 6). The radial and tangential ribs provide a flux path for both the d and q-axis fluxes to flow within the rotor magnetic circuit. Ideally, the q-axis flux linkage must be minimized as much as possible in a high performance design such that the saliency ratio is maximized. Saturation of the thin ribs limits the q-axis flux circulating via the radial and tangential ribs, reducing the q-axis inductance and hence improving the saliency ratio of the motor.

Inclusion of these radial ribs promotes q-axis flux flow and the thickness of the rib must be investigated to ensure adequate saturation of the rib during normal operation, thus 'choking off' the any q-axis flux, whilst maintaining mechanical integrity of the rotor. To observe the electromagnetic effects of the rib thickness, the orthogonal axis reactance, X_d and X_q are computed for the prototype machine design using non-linear 2D FEA studies whilst the radial and tangential rib widths are varied in the steps 0.1, 0.3, 0.5, 0.75 and 1mm (see Figure 7). In any set of studies, only a single rib width is varied, the other

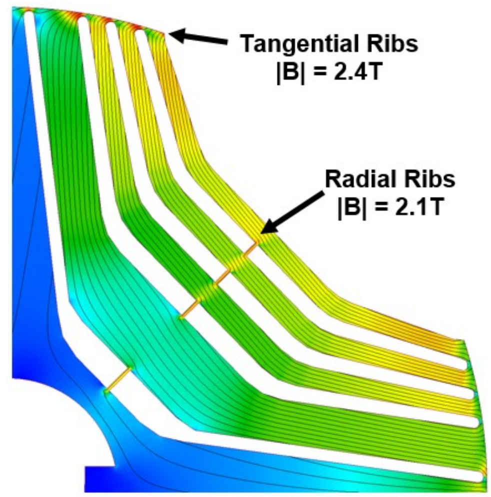

Fig. 6. **A** and |**B**| plot showing rib saturation

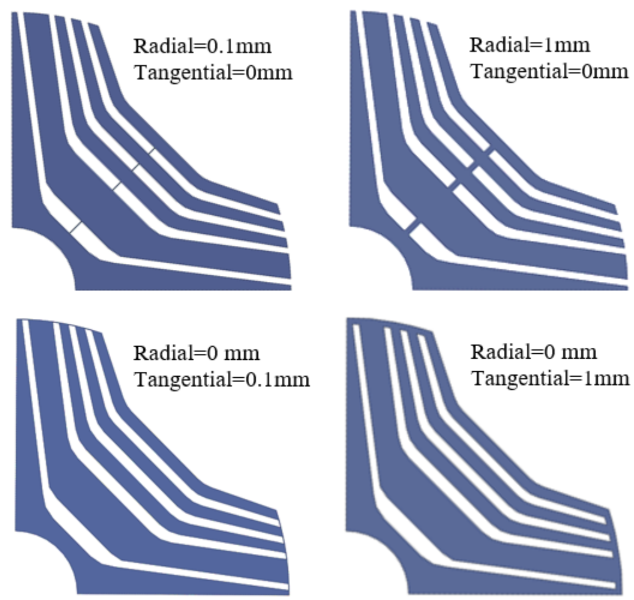

Fig. 7. Rib width variation (minimum = 0.1mm to maximum = 1mm)

rib is eliminated from that study set (width set to zero). The axis reactance and the saliency ratios are computed and compared for a range of currents to 25A – deep into the saturation region.

Figure 8 shows the orthogonal axis reactance family of curves for varying tangential rib width across the current range. Clearly at approx. 7A the d-axis begins to saturate and the reactance drops with further increase in current. The same is true with the q-axis, however it is less pronounced. Clearly, there is an increase in q-axis reactance with increasing rib width, which is most pronounced in the unsaturated region, but perhaps the most interesting result is concerned with the d-axis. There is an initial increase in d-axis reactance when the 0.1mm tangential rib is introduced due to the flux capturing capability of the rotor. With increasing tangential rib width the *d*-axis reactance remains relatively unchanged from the value at 0.1mm rib thickness, however the *q*-axis reactance increases with rib width. This is to be expected. The negative impact on electromagnetic performance can be seen in Figure 9 which shows the family of saliency ratio curves, clearly illustrating that the increased tangential rib thickness reduces the achieved saliency ratio which is in agreement with the literature [3-5]. While it is obvious that the saliency ratio decreases with tangential rib width, most of the difference is in the unsaturated region, which the saliency ratio converging with increased saturation. This is when the saturation conditions in the flus guides and tooth tips of the machine begin to play a dominant role in the reactance characteristic. Similar magneto-static analysis was performed for the variation in radial rib thickness, the orthogonal axis reactance variation is shown in Figure 10. It is clear that the effect on the *q*-axis reactance with tangential rib thickness is slightly more pronounced due to *q*-axis flux that can circulate around the tips of the flux barriers in a low reluctance path. The potential flux path along the radial ribs is complicated by the existence of the flux guides providing potential exit points. The *d*-axis reactance is found to be relatively unchanged with radial rib thickness. Again, due to the increase in *q*-axis reactance with radial rib thickness, the saliency ratio decreases accordingly, presented in Figure 11.

In summary, the radial and tangential ribs should be small enough to provide maximum electromagnetic performance, i.e. to minimize the *q*-axis reactance and maximize the *d*-axis reactance, but still function to maintain the structural integrity of the rotor segments under mechanical stress caused by centripetal loading. The mean unsaturated saliency ratio of the prototyped machine is around 4.5 which is in-line with the results presented in Figure 9 and 11 for tangential and radial rib thicknesses of 0.3mm. It must be noted that this is a low saliency ratio for a synchronous reluctance motor, where usually a saliency greater than 7-8 is desired, however the saliency is limited here by high stator leakage inductance.

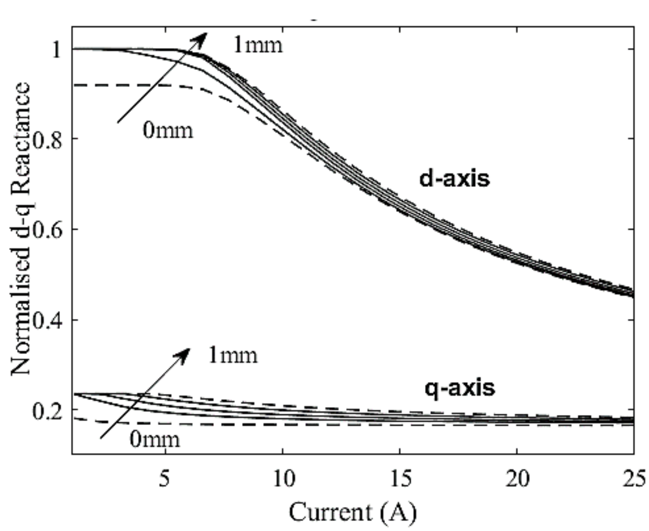

Fig. 8 *d-q* Reactance with tangential rib thickness

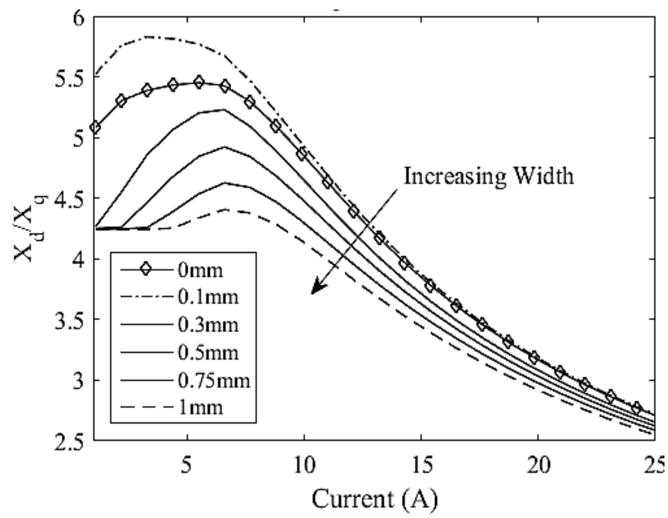

Fig. 9. Machine saliency ratio with tangential rib thickness

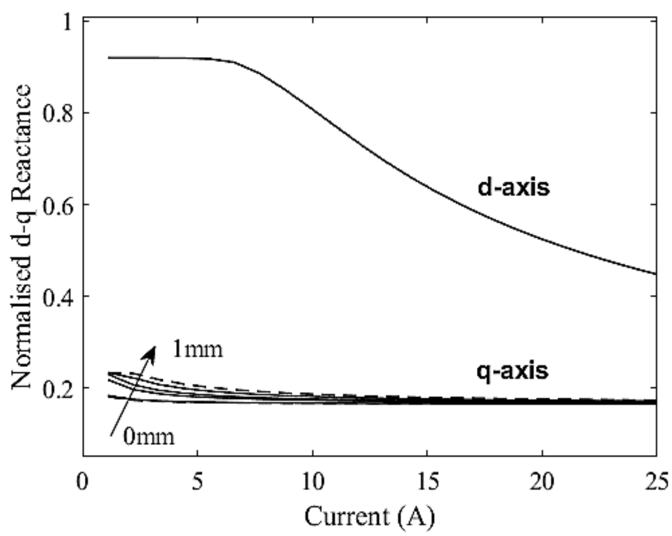

Fig. 10. *d-q* Reactance with radial rib thickness

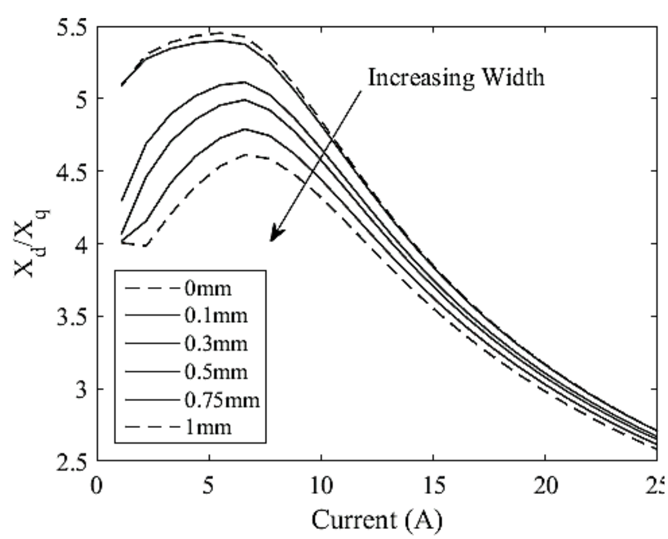

Fig. 11. Machine saliency ratio with radial rib thickness

IV. Mechanical Performance

The radial and tangential ribs do not only play a role in the electromagnetic design aspects of the machine, they are key to the mechanical integrity of the rotor. Without the tangential ribs the rotor flux guides would be unsupported. The role of the radial and tangential ribs is to support the flux guides under operation, preventing the centripetal loading that the flux guides experience under normal operation from exploding into the stator inner bore. Here the effect of rib thickness on the maximum mechanical loading and hence maximum achievable speed is explored.

A. Centripetal Loading of Flux Barriers

It is evident that the ribs, particularly the radial ribs, hold the flux guides together under mechanical loading when the rotor is operating under variable frequency control across its designed speed range. Each i^{th} flux guide has a mass;

$$m_i = \rho l \iint dA_i \tag{2}$$

Where ρ is the mass density of the lamination material, l the stack length and $\iint dA$ is the cross-sectional area of the i^{th} flux guide, which has a complex shape. It is typical that a transversely laminated rotor has between 4 and 6 flux guides. When the motor is operating and the rotor has an angular velocity ω, the i^{th} flux guide experiences a centripetal loading that acts on its center of gravity at a radius of r_i;

$$f_i = m_i r_i \omega^2 \tag{3}$$

The critical mechanical property of the lamination material is its yield strength, σ_y, the stress the rotor experiences is a function of ω^2. At this yield point, the lamination material begins to deform plastically – a suitable safety factor should be used in sizing the radial ribs, where the 'worst case' is if the tangential ribs are eliminated from the design. For the lamination material M250-35A, as used in the prototyped machine and considered in this study, the yield stress is 455 MPa and the material has a mass density of 7650 kg/m^3. From Eq. 2 & 3, it is possible to 'size' the radial ribs, assuming that the tangential ribs are zero thickness using the following equation;

$$t_i = \frac{\rho r_i \omega^2}{S_F \sigma_y} \iint dA_i \tag{4}$$

The angular velocity should be chosen as 20-25% over-speed and/or the factor of safety S_F chosen, to give confidence in safe rotor operation. The rib thickness t_i will be a minimum value depending on the lamination manufacturing process, if 'punched', that value is typically the lamination thickness (0.35mm for M250-35A), and with electro-discharge machining this value can be smaller.

Mechanical FEA of the stress distribution provides a convenient method of analyzing the centripetal loading in the complex geometry of a synchronous reluctance rotor. Figure 12 shows the stress distribution in the prototyped machine at 10,000rpm – the machine has a maximum achievable speed of 8,000 rpm in the field weakening region and hence this mechanical operating point represents a 25% over-speed. It is evident that the highest stress concentrations are in the radial and tangential ribs, specifically the inner-most radial rib – it is important therefore that this rib is sized correctly.

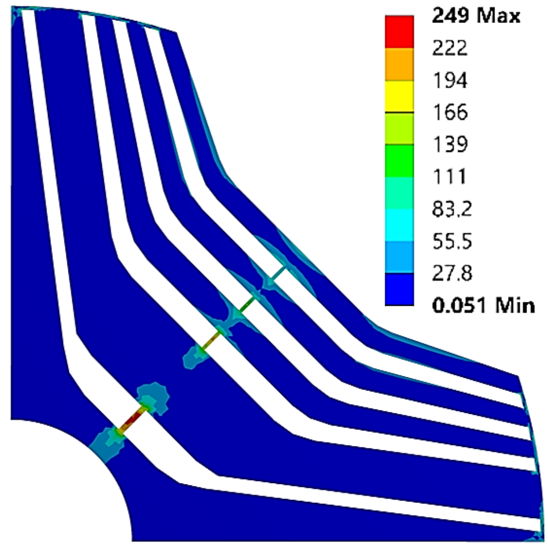

Fig. 12. Stress distribution showing stress concentration (MPa) in ribs

B. Radial & Tangential Rib Thickness

To observe the mechanical effects of the rib thickness, the maximum stress, σ_{max} and the minimum safety factor $S_{F,min}$ are computed for the prototype machine design using FEA studies whilst the radial and tangential rib widths are varied in the steps 0.1, 0.3, 0.5, 0.75 and 1mm (Figure 7). Again, in any set of studies, only a single rib width is varied, the other rib is eliminated from that study set (width set to zero). The maximum stress and minimum safety factor are computed for a range of speeds up to and including 10,000rpm, the 25% over-speed condition. Figure 13 shows the maximum stress in the rotor with varying tangential rib thickness. Clearly, if no radial ribs exist within the design, the maximum stress exceeds the stress required for the material to yield, causing plastic deformation and ultimately material fracture. The FEA results presented in Fig. 13 agrees with Eq. 3 that the stress in the supporting ribs varies as a square law. As expected (Eq. 4), increasing the thickness of the radial ribs reduces the stress in the tangential ribs for a given centripetal load. From the results, it is concluded that prototype machines base speed, 1500rpm, can be achieved in all designs and thus should maintain mechanical integrity, however, the maximum speed, before yielding of the tangential ribs, is severely limited. This is shown in Figure 14, which presents the minimum safety factor family of curves for each rib thickness over the speed range. By selecting an engineering safety factor $S_F = 2$, the results predict that the machines maximum speed of 8000rpm *can not* be achieved by implementing the tangential ribs alone, unless their thickness is approximately greater than 2mm, which would be unacceptable form an electromagnetic view point.

The radials ribs provide improved mechanical support compared to the tangential ribs. Figure 15 shows the family of maximum stress curves with varying radial rib thickness, it is immediately evident that the magnitude of the maximum stress, even with 0.1mm rib width, is significantly lower than in the tangential ribs, even though in this study the tangential rib width is set to zero. This is due to the location of the tangential ribs and the shearing behavior at these locations due to the mass of the flux guides. The positive results are reflected in Figure 15 that shows the minimum safety factor family of curves for each rib thickness over the speed range. Clearly the curves have been shifted towards the right, when compared to the results of the tangential ribs, the resultant is that with a rib thickness 0.3mm, the 25% over-speed condition can be reached before yielding of the rib material and the maximum speed in the field weakening region can be achieved with $S_F \approx 2$. Only when the radial rib thickness is slender at 0.1mm does material yielding become an issue.

The results show that the radial ribs are more effective than the tangential ribs in this rotor design at maintaining mechanical integrity at high speeds within the field weakening region. The lamination profile of the prototyped machine in Figure 1 is also analyzed at 10,000rpm. The inner radial rib is 0.5mm as this experiences the greatest load, with the remaining radial rib thicknesses set to 0.3mm as with the tangential ribs. The maximum calculated stress at this speed is 213 MPa, which is located at the inner radial ribs. As expected, other points of high stress are throughout the radial and tangential ribs, but to a lesser degree. The maximum calculated deformation of the rotor is 21μm, which is 4% of the airgap (0.5mm) and it does not occur at the air-gap periphery. The maximum air-gap closure at 10krpm is predicted to be 10μm, or approximately 2% of the airgap length. The minimum safety factor with M250-35A silicon steel 10krpm is predicted to be 2.1, which is within allowable limits – typical safety factors between 1.8 and 2.2.

C. *Note on Rib Radii*

If there is no radius on the inner corner edges of the radial and tangential ribs, the stress concentration at these corners will be high due to the sharp edges of the lamination. The stress concentrations are not only a cause of early yielding of the material, but pose a potential mechanical integrity hazard. By including small radii, the stress concentration can be reduced and any plastic deformation due to yielding localized to a smaller area. An interesting area of research is the reduction in relative permeability within the radial and tangential ribs due to high mechanical stress concentrations experienced under normal operation. The mechanical design of the ribs is a complex task and many variations on rib design and placement can be conceived, only this simplest of forms is presented here.

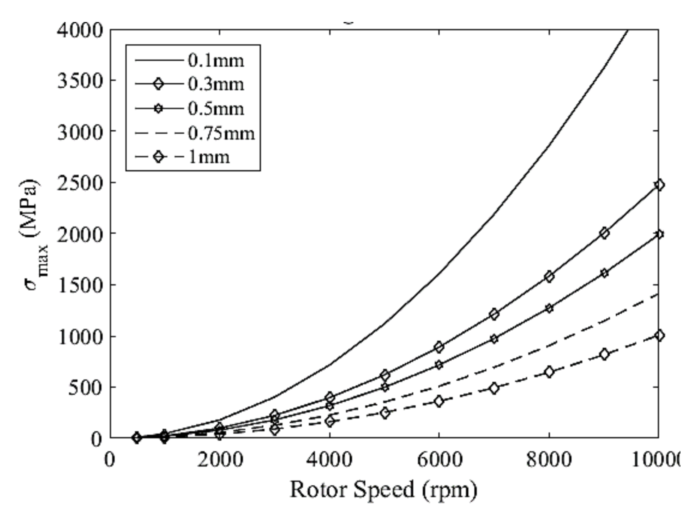

Fig. 13. Peak stress with tangential rib thickness

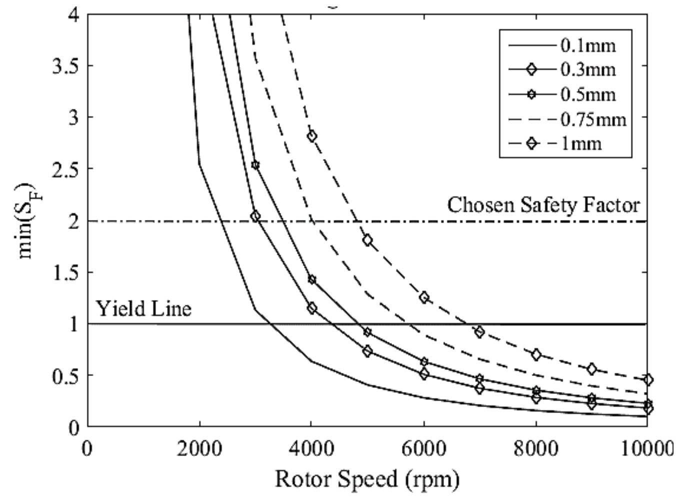

Fig. 14. Minimum safety factor with tangential rib thickness

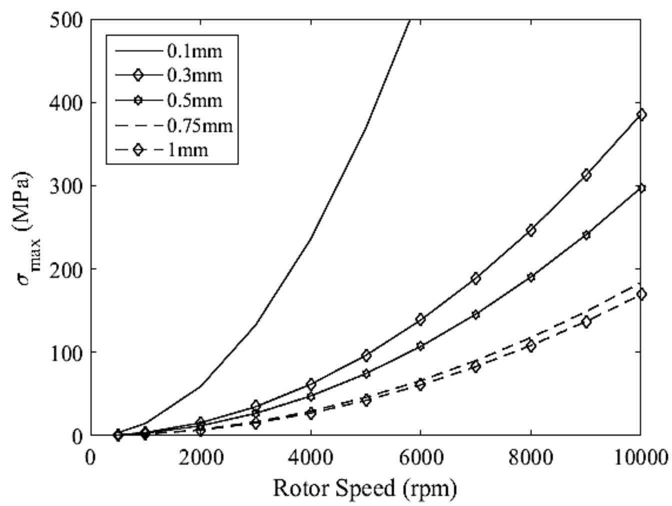

Fig. 15. Peak stress with radial rib thickness

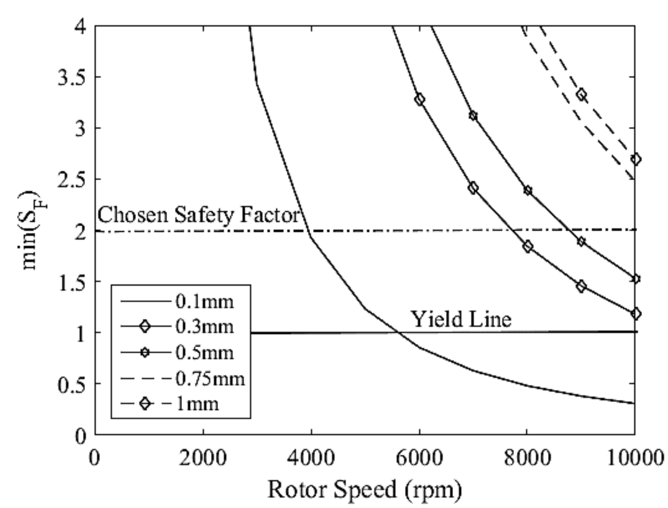

Fig. 16. Minimum safety factor with radial rib thickness

V. Manufacturing & Design Considerations

When considering the electromagnetic and mechanical design of synchronous reluctance rotors, the production volume and rotor pole number has a considerable influence in the design process. Here, a discussion regarding rotor manufacturing and the challenges designing higher pole number machines (p>2) is presented.

A. Prototyping vs. High Volume Manufacture

Prototyping of synchronous reluctance rotor laminations can be performed electro-discharge machining techniques – the prototyped laminations (Figure 1) were cut using this technique. This high precision lamination cutting technique is only suitable for low production volumes due to the long processing times and therefore cost. This technique also does not cause any 'magnetic damage' to the laminations which is associated with increased iron loss and lower permeability – this could be catastrophic for the d-axis inductance. However, high production volumes of electrical machines usually requires 'punching' or 'stamping' of the laminations form a sheet. It is well known that magnetic damage occurs due to the mechanical impact of the punching process [16]. This magnetic damage is usually unwanted in electrical machines due to its negative effects, however, the punching of synchronous reluctance machine rotors could potentially be beneficial. If the ribs are narrow enough, the magnetic damage caused to the edges of the laminations will destroy the permeability of those ribs, somewhat equivalent to permanent magnetic saturation, whilst allowing increased rib thickness for improved mechanical integrity. It is unclear as to whether this magnetic damage is significant enough to somewhat improve electromagnetic performance, even minimally, in 'punched' rotors, and further research is warranted. Additionally, if higher pole numbers are produced (p>2), the number of flux barriers per pole does not decrease and as a consequence the number of stamped sections increases linearly with the number of poles resulting in increased tooling complexity, capital tooling cost and maintenance cost due to increased tool wear.

B. Rotor Flux Barrier and Rib Design

Synchronous reluctance motors are typically 4-pole machines (p=2), this is for a variety of reasons, mainly due to their traditional deployment in low, fixed speed industrial applications where 4-pole induction machines are common and which remain the primary competitor of the synchronous reluctance motor. With increased pole numbers, come additional engineering design problems specific to the synchronous reluctance motor. They are as follows;

1. Physical space required for flux barrier shaping
2. The required radial and tangential rib thickness

For a given rotor outer diameter, the flux barriers must be optimally shaped within the rotor radial cross-section to maximize the saliency ratio via the barrier location, geometry and insulation ratio. A 2-pole or a 4-pole rotor is relatively simple to optimize, however, as the pole number increases, the rotor pole pitch becomes smaller and the window within which the barriers are to be designed within, becomes limiting. The flux barrier lamination sections become smaller and the entry and exit points at the rotor periphery increase in angle. This makes the barrier design difficult, though 6-pole designs have been realized, 4-pole is the most common. Therefore, higher pole numbers are not generally not recommended for synchronous reluctance motors due to the inability to obtain sufficient electromagnetic performance within the limitations. An increase rotor outer diameter is one solution to enable adequate shaping of the flux barriers, of course, this may not always be possible within given design criteria. Also, with increased pole numbers, the flux per pole decreases which causes a specific issue with the radial and tangential ribs. The ribs must be as narrow as possible such that the q-axis inductance is minimized and this is usually achieved by saturating these ribs. By lowering the flux per pole for a given total MMF, the rib widths becoming diminishingly small for an increasing pole number. This is fine of course if the machine is very low speed and the rotor has a small outer diameter, but for common motor sizes, this could present limiting mechanical integrity issues. Maintaining sufficient rib thickness to preserve mechanical integrity of the rotor could potentially result in poorer electromagnetic performance. Therefore, the choice of pole number has an influence on the electromagnetic/mechanical design & performance - a highly integrated electro-mechanical design approach is recommended. These are not typical issues with interior permanent magnet machines or even permanent magnet assisted synchronous reluctance machines as the majority of their torque is a magnet-current interaction torque and only rely on reluctance torque by small measure compared to the full synchronous reluctance machine.

VI. Rotor Rib Fatigue & Failure

Lamination material fatigue has not received much attention in the literature. Despite the limited studies available [17], lamination material fatigue due to repeated cyclic loading could potentially become an issue with synchronous reluctance motors. The high stress concentrations in the radial and tangential ribs warrants further investigation of the fatigue life of a rotor design if the typical operating cycle includes frequent positive and negative acceleration (such as electric vehicles or some common industrial loads). The cyclic loading patterns could cause the radial and/or the tangential ribs to suddenly fail, resulting in catastrophic destruction of the rotor, damage to the stator and subsequent electrical faults to be incurred – a different rotor topology may be required [18]. It is beyond the scope of this paper to consider fatigue life of rotors under such cyclic loading conditions further; however, it is suggested here as an important avenue of further research and the stress-endurance curve data [19] for the lamination material in use will be important for further investigation. It must also be noted that additional care when handling of the rotor of a synchronous reluctance motor must also be taken – the rotor periphery is not as solid as with the induction motor and it is prone to handling damage during rotor extraction and insertion, for example during stator rewinds or when bearing maintenance is performed.

VII. Conclusions

This paper has presented selected electromagnetic and mechanical analysis of a synchronous reluctance machine utilizing single tooth coils. Focus is placed on the electro-mechanical design trade-offs when considering the rotor design and the following conclusions can be drawn for this particular machine topology; Increasing the radial rib thickness does not change the *d*-axis inductance, however it does increase the unsaturated *q*-axis inductance, lowering the saliency ratio. The radial rib is the main supporting member of the flux barriers and has the most significant effect on increasing the minimum safety factor for mechanical integrity under steady state operation. Increasing the radial rib thickness affects both the *d*-axis inductance and the unsaturated *q*-axis inductance, by including a tangential rib, a gain in saliency ratio can be obtained. The tangential ribs have a lesser role in the structural integrity due to the centripetal loading experienced under steady state operation. With the onset of saturation, the *d/q* axis inductance characteristics converge and the influence of the rib thickness on electromagnetic performance is diminished. The design choices for the prototype machine dictate a maximum rotor speed of 10krpm with a safety factor of 2.1 resulting in an air gap closure of only 2% the air gap thickness. The saliency ratio is reported as 4. It is shown that the prototyped machine can achieve good electromagnetic performance while maintaining mechanical integrity up to a 25% over speed of with features as small as 0.3mm. It has also been discussed that care must be taken when designing rotors with fine features and the rotor pole number section, increased rotor pole number counts have a negative impact of the mechanical and electromagnetic performance and hence it is typical to see synchronous reluctance machines with no more than 4 poles. Rotor fatigue has been identified as an area for research due to the limited studies available, knowing that the high stress concentrations around the radial & tangential ribs combined some industrial processes that exhibit high frequency cyclic loadings could cause rotor failure.

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