

# Prototyping of a Claw Pole Machine Using 3D Modeling

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## Abstract

This article is the result of a hobby project. The article is going thru the iterative developing process of a claw pole machine. In this developing process, simulating the magnetic flux density and back EMF waveform have been used to validate geometrical changes to the machine.

**Keywords:** Claw Pole, Iron powder, 3D Modeling, Livelink for Solidworks, Quick Prototyping

## 1. Introduction

This article describes the journey and end result of a hobby project created by the author. The goal of the project was to create a claw pole machine with a limited set of available machining tools. Machines available were a small 3-axis CNC mill and a manual lathe.

The findings could also be applied on prototyping for small companies with limited resources were cost for prototypes have to be low and the developing process fast.

In a common series production method called powder metallurgy an iron powder material is used as the bulk material to build products. This method gives a repeatable process for a relative low cost, scaling upwards depending on geometry. The Swedish company Höganäs AB have developed an iron powder composite material called "Somaloy Prototyping Material" (Höganäs, 28 06 2014). This material was chosen to the project since it is suitable for the machines that were available.

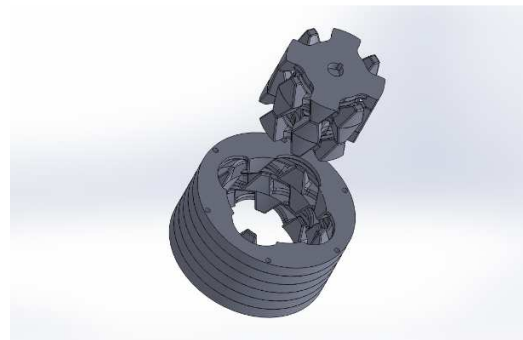
### 1.1 The claw pole topology

A claw pole machine is a transversal flux machine, which means that the magnetic flux is operating in 3D. Each phase of a claw pole have two claws surrounding the magnetic transmitter. The claws will get opposite magnetization. The rotor uses a permanent magnet to get static magnetization, the stator claws will have a winding, seen as the outer toroid in Figure 1, were the current will change the polarization to create a rotating force. An Exploded view on one phase of a claw pole machine is shown in Figure 1.



**Figure 1:** Exploded view of 1 phase claw pole.

Figure 2 and 3 shows the phase view of a claw pole. The stator phases are shifted 120 electrical degrees and the middle phase of the rotor is turned upside down to generate a higher torque. (LUNDMARK, 2005).



**Figure 2:** 3 phase claw pole stator and rotor.

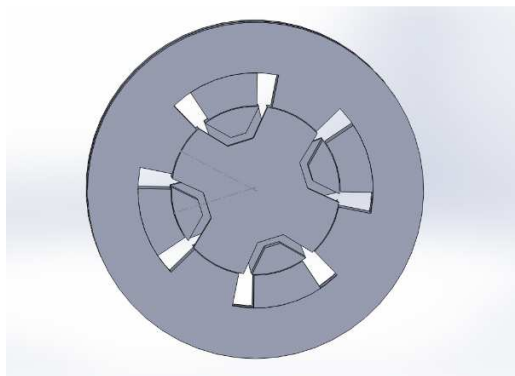
## 2. Method

Since the flux in the claw pole machine is in 3D and the conventional simulation tools for electrical machinery is based in a 2D space, a more advanced simulation environment which can handle a complex 3D geometry was needed. To be able to verify the geometry of the claw pole machine, a Comsol Multiphysics simulation with

the Magnetic Field feature (found under the AC/DC module) was used together with the live link for Solidworks. This made it possible to iterate the geometry. Since the geometry was created in Solidworks, the effort to convert the design to a manufacturing machining language (G-code) will be small.

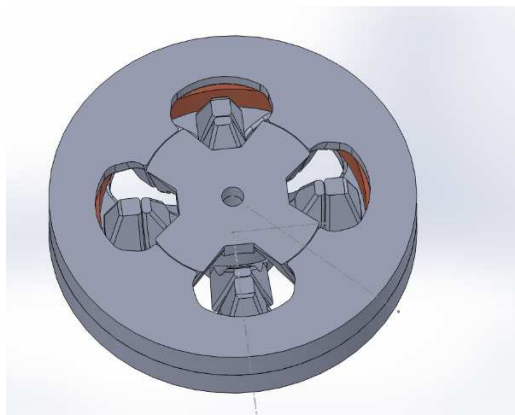
## 2.1 Geometry

The first stage of the geometry was set as straight angles with no fillets, see figure 3.



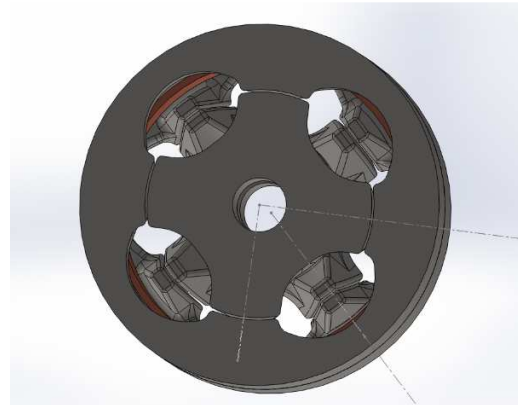
**Figure 3:** First simple geometry.

The geometry in figure 3 was cut to take away the unnecessary material and give large enough air gap between stator and other stator piece.



**Figure 4:** Second stage of the geometry in the iterative process.

As shown in Figure 4 the teeth in the stator was larger than needed. The material cutout around the stator teeth was too small. This gives unnecessary material which was shaped off.



**Figure 5:** Geometry in the middle of the iterative process.

From the geometry shown in Figure 5 to the final geometry, the rotor diameter have been shortened with 5 mm. This was done to give more material in the stator and makes the manufacturing process easier since the alignment of the material in the mill will not be critical. The material of the fillet between teeth and teeth with the same magnetization in the rotor have been increased, to give a more even distributed flux.

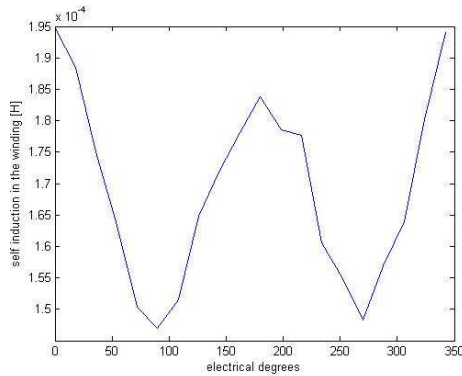
## 2.2 Simulations

Under the geometry iteration Comsol livelink for Solidworks has been used. This simulation allowed for the possibility to change the angle between the stator and rotor to simulate steps in rotation of the motor, to make sure that no extreme cases were missed. If a geometric point had a high magnetic flux density, the geometry were changed to lower the flux in this point. Same method applied if a geometric point had a low flux density. This helped to lower the material needed for the machine, without creating extra losses.

To lower the influence of the harmonics and improve the efficiency of the drive system, the Back EMF in one phase was calculated. This was done by stepping the rotor an electrical turn and calculating the self-inductance of the winding for the given rotor angle. The self-inductance were calculated using Equation 1. Where  $L$  represents the inductance,  $W$  the magnetic energy measured in Comsol and  $I$  the current in the coil.

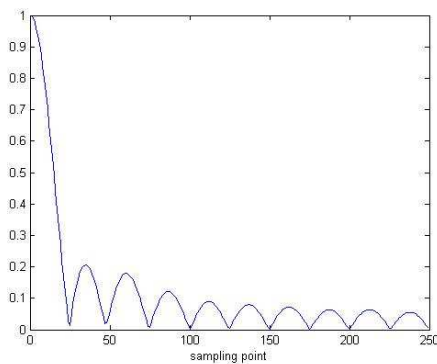
$$L = 2 * \frac{W}{I^2} \quad (1)$$

The plot of the self-induction dependent of the angle between rotor and stator is shown in figure 6.



**Figure 6:** The self inductance depending on the electrical angle, in one phase.

The back EMF was calculated using a FFT of the inductance values. This was then used to change the fillets on the teeth to get the Back EMF shown in Figure 7. This shows where each top is harmonic with the first top being the fundamental frequency.



**Figure 7:** Normalized FFT of the Back EMF in one phase.

The torque for 3 phases were calculated using Equation 2. Where  $T$  is the torque,  $D_{rotor}$  the diameter of the rotor,  $B$  the magnetic flux density in the air gap between rotor and stator.  $L$  the length of the motor,  $A$  the electrical loading.

$$T = 3\pi D_{rotor}^2 * \frac{ABL}{2} \quad (2)$$

The input power for 3 phases is calculated by Equation 3.

$$P = I * V \quad (3)$$

The losses were approximated by calculating the resistive losses and using the given value for magnetic losses per kilo at 1 T and 1 kHz in the stator (Höganäs (07 08 2014)).

The resistance were calculated using Equation 4. Where  $R$  is the resistance,  $\rho_{cu}$  the resistivity for copper,  $l$  the length of the wire and  $A$  the cross-section area of the wire.

$$R = \frac{\rho_{cu} * l}{A} \quad (4)$$

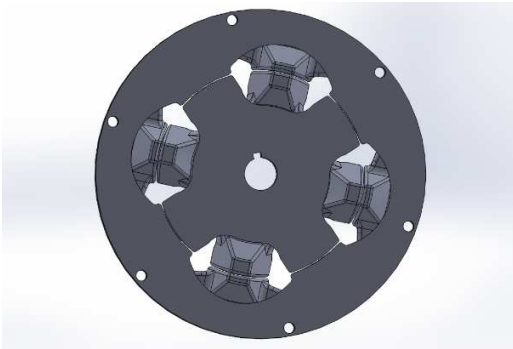
### 2.3 Environmental aspects

The brittle iron powder material allows for easy recyclability by crushing the electrical machine and separating the materials (LUNDMARK, 2005). This will make the recycle of the machine a lot easier than with a conventional laminated machine.

## 4. Results

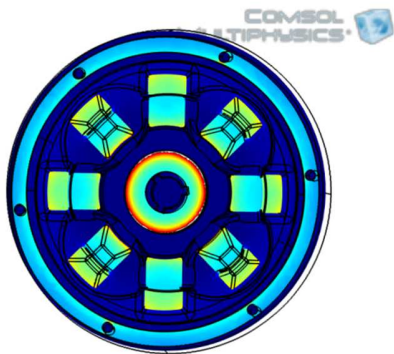
Geometry of the final machine is shown in Figure 8. This geometry have a rotor diameter of 75 mm, a stator diameter of 120 mm and a length of 60 mm, a material volume of 0.5 dm<sup>3</sup>. Which gives a weight of approximately 3.7 kg.

The average 3 phase current were set to be 120A and the voltage were set to be 48 V. The wire resistance was calculated to be 17.7 mΩ with the magnetic losses calculated to be 97.5 W at max power load. This gave the max output power approximated to be 5.2 kW with an efficiency at 90.5 %. The electrical loading crudely approximated to be 7 kA/m. The magnetic flux density  $B$  in the air gap is simulated to be 0.7 T. This gives a torque equal to 7.8 Nm.

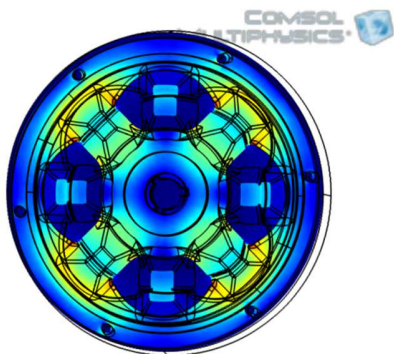


**Figure 8:** The finished geometry in the iterative process.

The magnetic flux density shown at max load is shown in Figure 9 and Figure 10 with same scale. The maximum magnetic flux density will be in the outer radius and centered in height of the magnet, as shown in Figure 9.



**Figure 9:** Magnetic flux density in center of the height.



**Figure 10:** Magnetic flux density 75% of the height.

## 5. Conclusions

A claw pole machine with a suitable iron powder core would give the possibility to build a prototype machine for a low cost.

This machine shows a torque per weight ratio of 2.1 Nm/kg, and torque per volume ratio of 15.6 Nm/dm<sup>3</sup>. The magnet would suffer a small magnetic reduction under a short circuit scenario, which could have been solved by increasing the magnets cross-section area. In Figure 10 a small max can be seen at the corner of the teeth in the stator. This could also be solved if the rotor was designed to be smaller.

## 6. Future work

### 6.1 Refine the sample points for the self-inductance.

Because of time- and resource constraints the resolution of the data in figure 6 does not show as high granularity as initially intended. This data should be reevaluated with shorter step angles to give a more precise data.

### 6.2 Calculating the 3 phase Back EMF.

The Back EMF for 3 phases needs to be calculated to get an equivalent schematic over the machine.

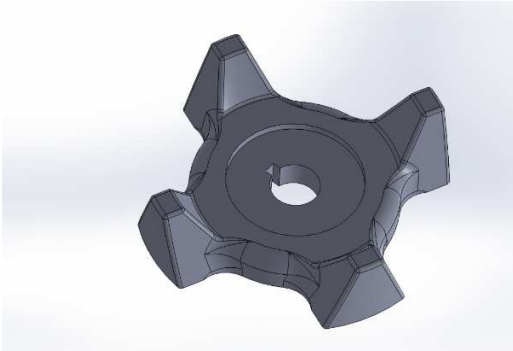
### 6.3 Building the machine.

Build the machine has to be done to verify the simulation and calculations.

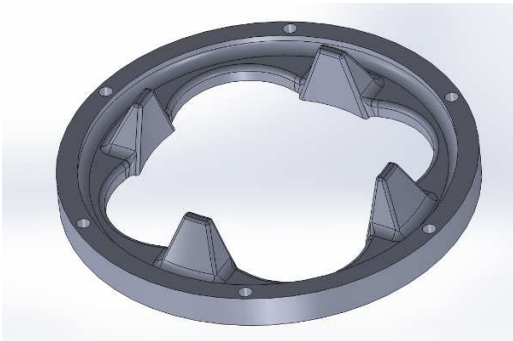
## 7. References

1. Höganäs. (28 06 2014) Höganäs Somaloy; <http://www.hoganas.com/en/Segments/Somaloy-Technology/Home/>
2. Höganäs. (07 08 2014) Höganäs Somaloy; [http://www.hoganas.com/Documents/Segmentbrochures/Somaloy/Somaloy\\_Prototyping\\_Material\\_May\\_2014\\_0805HOG.pdf](http://www.hoganas.com/Documents/Segmentbrochures/Somaloy/Somaloy_Prototyping_Material_May_2014_0805HOG.pdf)
3. S. Lundmark (2005). *Application of 3-D Computation of Magnetic Fields to the Design of claw pole motors*. Göteborg: Chalmers University of Technology.

## 8. Appendix



**Figure 11:** The rotor of the finished geometry.



**Figure 12:** The stator of the finished geometry.