Chapter 1
Introduction

1.1 Background

The electric motor has been the horse power of the industrial world from the time it was commercialised almost a century ago to today. The design of the electric motor varies according to the need, however the most used electric motor is the induction motor and in particular the squirrel cage induction motor. This is because of its ruggedness in design and versatility in operation.

This project was focused on the retrofit design and local manufacture proposition of the electric motor-the squirrel cage induction motor. The motor derives its name from its rotor construction which appears like a squirrel cage set in an iron core. The cage is a cylindrical rung of bars shorted on either end. The type of motor considered in this work is the three phase type commonly referred to as polyphase. This type of motor has many uses ranging from domestic to industrial applications. Some of its uses are as a driving unit for pumps engaged in de-watering systems such as in underground mining or in domestic clean water supply; farming as in irrigation or in industrial machines like lathes and drilling machine, hammer mills or extruders.

Since its discovery around the 1800 the induction motor has been developed into a highly efficient machine which has seen a reduction in actual physical size and can be made to suit almost any application from the biggest in concentrator crushing units in the mines to small motors in toys. However even though the induction motor has seen great strides in its development more work is still being carried out to improve further it's performance. This work is going on in the design of the rotor using copper and copper alloys or aluminium with the aim to reduce stator, rotor and frictional losses. With further improvement in performance still smaller motors of equal rating will be realised. This Thesis outlines the steps taken in coming up with a retrofit electric motor and its manufacturing possibility to equip the University of Zambia (UNZA) pump [1].

The UNZA pump is a centrifugal vertical submersible pump designed by Nyirenda in his Thesis "Redesign and Manufacture of the Centrifugal Pump [1]". The overall objective was to come up with a centrifugal pump which can be manufactured locally. In line with this objective, there was need to design a retrofit electric motor drive the pump and manufactured in Zambia.

Nyirenda's work was centred on producing a vertical submersible pump with an open impeller. He came to this conclusion after an extensive market research into the sales of pumps from retailers in Zambia. He designed a simplified open impeller centrifugal pump using concurrent engineering and CAD-CAM software (Master Cam and Solid Works) by eliminating some components and yet also by merging some components. He also employed the Computer Numerical Control (CNC) technology to produce permanent moulds for casting the diffuser casings, impeller, and the bearing housing. As a result Nyirenda designed a pump with the following parameters:

1. Discharge $Q = 32\ m^3 / hr$ (1-1)
2. Head $H = 40m$ (1-2)
3. Speed $n_r = 2890$ rpm (1-3)
4. Pump efficiency $\eta = 0.66$ (1-4)

Though Nyirenda did not physically produce the pump his objective to design a simplified version of the vertical submersible centrifugal pump was achieved.

Steman [2] on the other hand looked at the manufacturability and marketability of the pump designed by Nyirenda. He carried out an extended market survey on pumps imported into Zambia directly by the user. Steman came to the same conclusion as Nyirenda that the most commonly applied pump in the country was the Vertical Submersible Pump with an Open Impeller. Steman therefore looked at the Product Technology and Production Technology of this pump. He showed that capacity existed in Zambia for both Product Technology and Production Technology at the main Foundries in Zambia. He singled out Scaw Foundries Ltd in Kitwe and Zambia Railways workshops in Kabwe as some of the foundries that possessed enough know how and equipment to produce the pump parts like the impeller, vane diffuser, pump casing, bearing houses and end covers. He also identified machining workshops in Zambia to work the rotor shaft, bearing seats and overall diameters and mating faces of the cast parts of the pump and motor. He however stated that the simplified pump would be no match for the imported advanced pumps if the cost of production was high. Overall the retail price of a complete University of Zambia (UNZA) pump was priced at US $ 1680-1750 [2]. Out of which production costs were US$600-800.
Therefore Steman concluded that the advantage of the UNZA pump should be the price, spares availability and good after sales service.

1.1.1 Centrifugal Pump History in Zambia

The two studies mentioned above are not the only studies carried out on the pump in Zambia. There is actually a history to the study of the centrifugal pump at the University of Zambia. Attempts at studying and working on the horizontal centrifugal pump had been carried out in the Department of Mechanical Engineering at the University of Zambia for years as final year projects.

1. In 1986 Wakalala Partrick worked on the Process Development for Centrifugal Pump.
2. In 1995 Malisawa Mulubwa did work on the Manufacture of a Centrifugal Pump.
3. In 1996 Nyirenda Paulos did work on the Centrifugal Pump Manufacture.

However all the final year project work in 1, 2, and 3 above were on the horizontal centrifugal pump and not on the vertical submersible centrifugal pump as in the case of the studies carried out by Nyirenda [1] and Steman [2] in their master's work. Also the works carried out in 1, 2, and 3 above were attempts at reproducing an existing pump and not reengineering of a pump as done in Nyirenda's Master of Engineering work [1].

1.1.2 Problem Statement

Even though advanced works on the pump in Zambia had been achieved culminating into the redesign of the vertical submersible centrifugal pump by Nyirenda, no attempt at designing the drive unit, the electric motor, had been made. In all these attempts the electric motor, that is the stator and rotor, was considered as an item to be imported complete to fit into the pump [1, 2]. For example both Nyirenda [1] and Steman [2] considered the electric motor powering the Flygt B2102.041 pump [3] as suitable for the UNZA pump. The Flygt B2102.041 was an imported pump and therefore could not give the advantage required for a wholly locally produced pump.
This project therefore is the first attempt to look into the manufacture of the electric motor to retrofit the University of Zambia pump.

1.1.3 Polyphase Induction Motor

The pedestal polyphase induction motor is shown in Figure 1-1 showing part 29, the rotor and part 30, the stator which were the focus of this study.

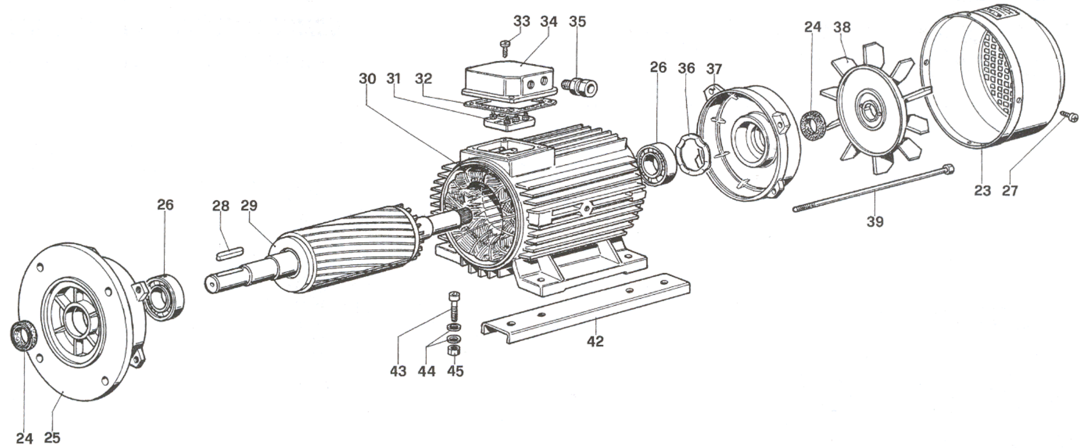


Figure 1-1 Exploded View of the Pedestal Polyphase Induction Motor

Pump parts:

24-Seal ring, 25-Flange, 26-Bearing, 27-Screw, 28-Key, 29-Rotor, 30-Casing with wound stator, 31-Terminal board, 32-Terminal board cover, 33-Screw, 34-Terminal board cover, 35-Fairlead, 36-Ring, 37-Driving cap, 38-Fan, 39-Tie-rod, 42-Support foot, 43-Screw, 44-Washer, 45-Nut.

1.1.4 The Vertical Submersible Centrifugal Pump

The vertical submersible pump is shown in Figure 1-2. The rotor is mounted on the shaft labelled 5 and the stator is labelled 3. The pump in Figure 1-2 is the likeness of Nyirenda's design. Nyirenda's design provided most of the parts shown in Figure 1-2, except parts 3 the stator and the rotor which constitutes the induction motor within the submersible pump.

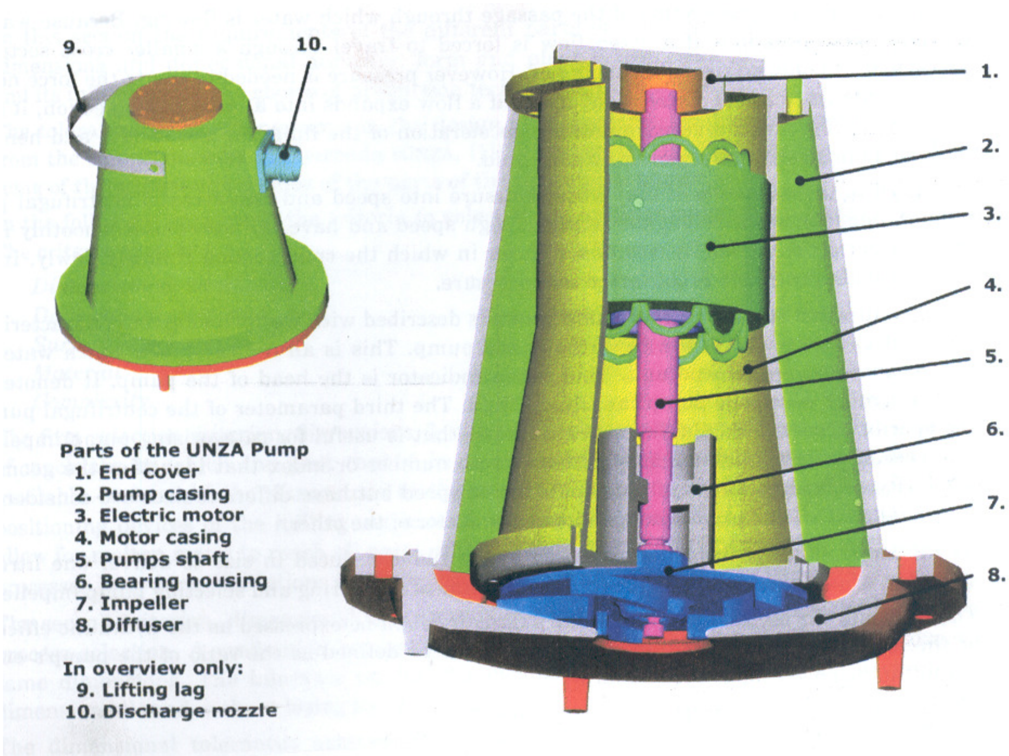
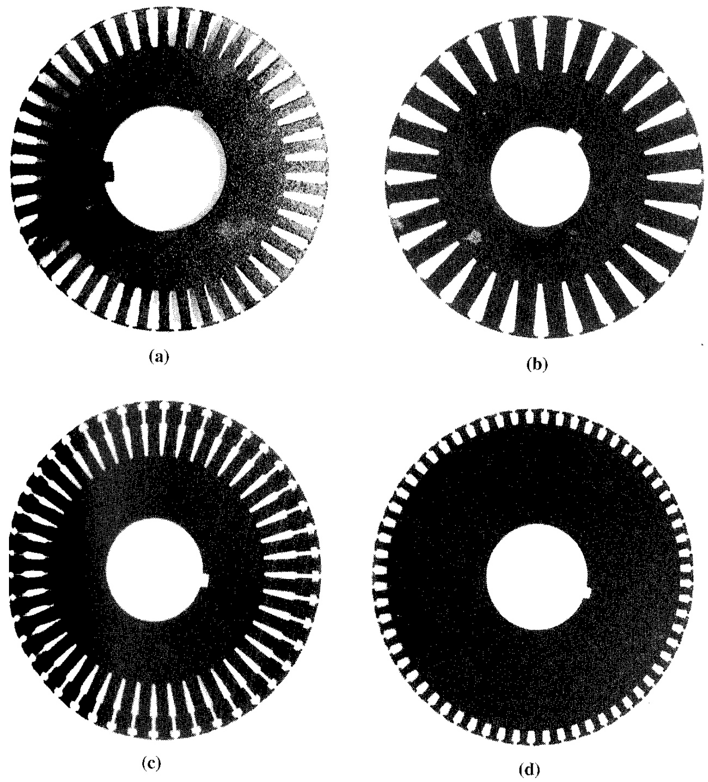


Figure 1-2 UNZA Pump [2]

The induction motor is classified in four categories as NEMA class A, B, C, and D, of which NEMA class B is the most common and is found in general application. The other classes are designed for special application depending on need.

The real difference in the design of the different induction motors lies in the design of the rotor. Figure 1-3 shows the slot designs of an induction motor which distinguishes the various classes and therefore determines the important characteristics of a motor like starting torque, and other performance criteria.

1.1.5 Induction Motor Rotor Slot Designs



Laminations from typical cage induction motor, cross section of the rotor bars

(a) NEMA class A – large bars near the surface
(b) NEMA class B – large, deep rotor bars
(c) NEMA class C – double-cage rotor design
(d) NEMA class D – small bars near the surface

Figure 1-3. Rotor Slot Designs of the Induction Motor

Figure 1-4 Cut away View of the Squirrel-Cage Class B Rotor for Induction Motor showing imbedded Aluminium Rotor Segments (Courtesy of UTH maintenance workshop)

As can be seen from Figure 1-3 NEMA class B motor has a deep bar design allowing it to start direct on line which is one of the most desirable performance criteria of a submersible pump. Its other quality is a relatively high starting torque suitable for many applications.

1.1.6 Induction Motor Performance Curves

The performance curves shown in Figure 1-5 are for the rotor designs shown in Figure 1-3 above. The curves show that NEMA class B which corresponds to curve B is the most desired performance. It has good starting torque, good pullout torque, and good breakdown torque. It is therefore sufficient to drive a centrifugal load.

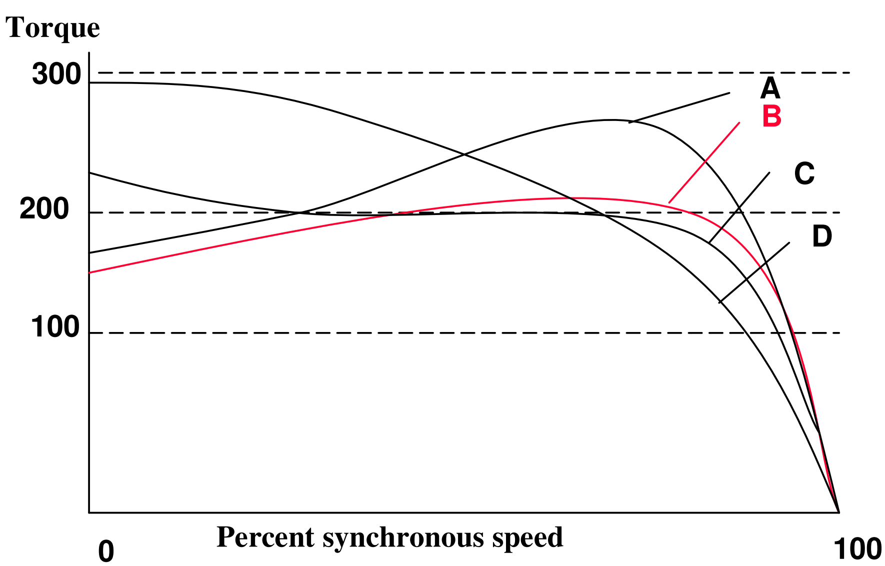
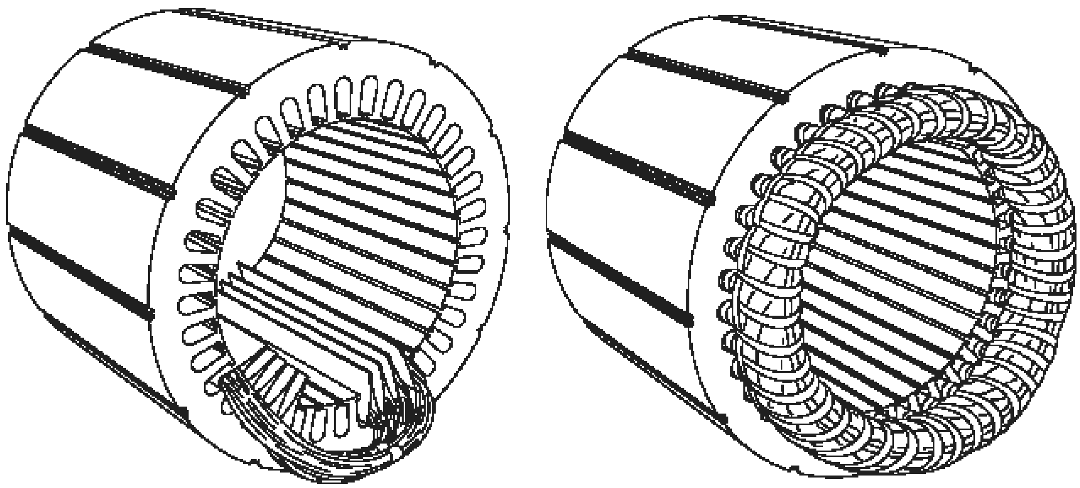


Figure 1-5 Typical Torque-Speed Curves for Class A, B, C, and D Rotors

1.1.7 Electric Motor Construction

The electric motor is divided in two major components, the stator made up of the copper winding embedded in an iron core, and in the case of the squirrel cage motor Aluminium or Copper bars cast or driven in an iron core. The stator and rotor are shown in Figures 1-6 and 1-7 respectively.



a) b)

Figure 1-6 Stator Core (a) and Stator Winding (b)

Figure 1-7 Stator Core showing a typical Stator Slot (Courtesy of UTH Workshop)

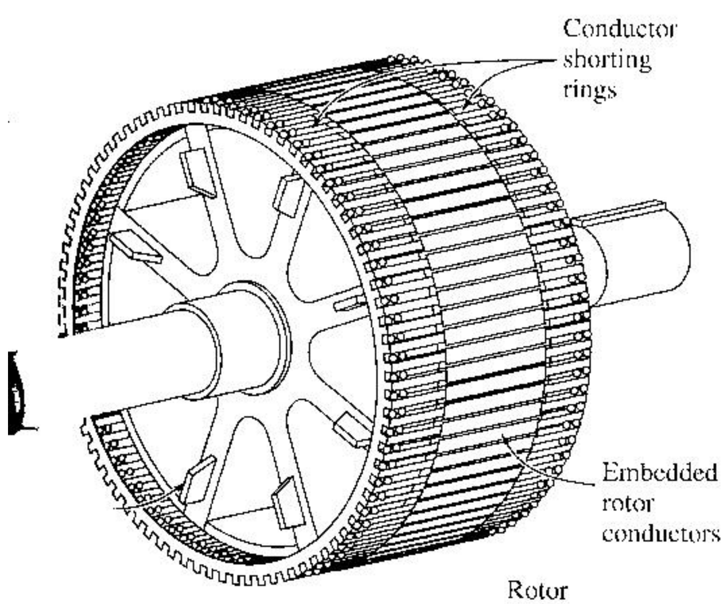


Figure 1-8 Sketch of Cage Rotor

1.1.8 Electric Motor Manufacturing Plant

The plant was designed after the process flow of the product [4, 5] shown in chapter 3 combining both cellular and process layouts [6]. This plant combines both the cellular and process layout. The financials of the plant were also done to show the viability of production of the electric motor and pump in Zambia. In designing this plant, the annual production was based on three scenarios of 105 pumps production, 500 pumps production and 3000 pumps production. The three considerations were necessary to determine the most optimal production quantities; the driver being the price of the product and the starting figure of 105 electric motors being the determined market of Zambia. The calculation of the plant viability at 500 electric motors and 3000 electric motors was to calculate the profitability of the plant seeing that at 105 units the plant was not viable. The figures of 500 units and 3000 units per annum were selected at random to see which production levels can produce an affordable electric motor. At 3000 units per annum the retail price of the electric motor was K1500000. The price was considered reasonable on the Zambian market for this size of motor.
In this work though the physical stator and rotor were not produced the main machinery to do so was identified (AppendixE) as listed below:

1. Manual Punching Machine for production of stator and rotor laminations,
2. Lamination Machine for stacking the laminations,

3. Welding Machine for welding the laminations together,
4. Winding Machine for production of stator coils,
5. Bending Machine for rolling Motor casings (Motor casings may be cast [1, 2]),
6. Lathe Machine for production of motor shafts,
7. Vertical Drilling for general purposes,
8. Lamination Dies for production of stator and rotor laminations, and
9. A Foundry for casting rotor bars (Not included in Appendix E)

The pump casing, impeller, diffuser, end covers and bearing houses were to be cast and machined to finish on the lathe and other parts like seals and bearings were to be imported [1, 2].
In determining the profitability of the plant the income statement and the balance sheet were prepared using formats in International accounting standard 1[7]. The cash flow statement was prepared using basic format used in Finance and decision making [8, 9]. Further, Return on Investment [10], Payback period [11] and Internal Rate of Return [11] were calculated.

The benefits of the UNZA pump and electric motor in comparison to imported units are:

1. Shorter time to bring the product to market,
2. Smoother transition into market,
3. Fewer components in the final product,
4. Easier assembly,
5. Lower costs of production,
6. Higher product quality, and
7. Greater customer satisfaction.

1.2 Project Justification

Zambia needs to become a middle earning country by 2030. In its quest to achieve this position Zambia needs to industrialise. To do so deliberate programmes meant to drive the country towards industrialisation must be put in place. The University of Zambia, Department of Mechanical Engineering wanting to be part of this target put in place projects which can help elevate the country to the status of a middle earning country. The projects were “Redesign and Manufacturing of a Centrifugal Pump [1]”, and the “Electric Motor Retrofit design and Local Manufacture Proposition”, among others.

The University of Zambia pump when built and the electric motor retrofit when manufactured in Zambia will trigger many auxiliary industries which could start an industrial revolution in the country.

The simplified University of Zambia pump was designed to suit the pocket of the majority of Zambian peasant farmers so that they can be encouraged to embark on farming through irrigation and contribute to the food basket of the country throughout the year. In this way the food basket of the country will be enhanced and in turn help to eliminate poverty in Zambia.

It is clear therefore that the benefits of the two projects are immense and beneficial to Zambians and Zambia as a country.

In a questionnaire conducted as part of this work, it came out clearly that electric motor users in Zambia would be ready to purchase motors made in Zambia as long as the product was good. Therefore the market for the University of Zambia pump and the electric motor is guaranteed.

1.3 Research Objectives

The overall objective of the research was to design an electric motor retrofit for the UNZA pump that could be locally manufactured.

The specific objectives were to:

- 1.3.1 Design a retrofit induction motor for the UNZA pump.
- 1.3.2 Develop a manufacturing process plan for the designed retrofit induction motor.
- 1.3.3 Investigate the feasibility for local production and operations costs for local manufacture of the designed retrofit induction motor.

1.4 Methodology

The design of the electric motor was realized by the methodology flow chart shown in Figure 1-8.

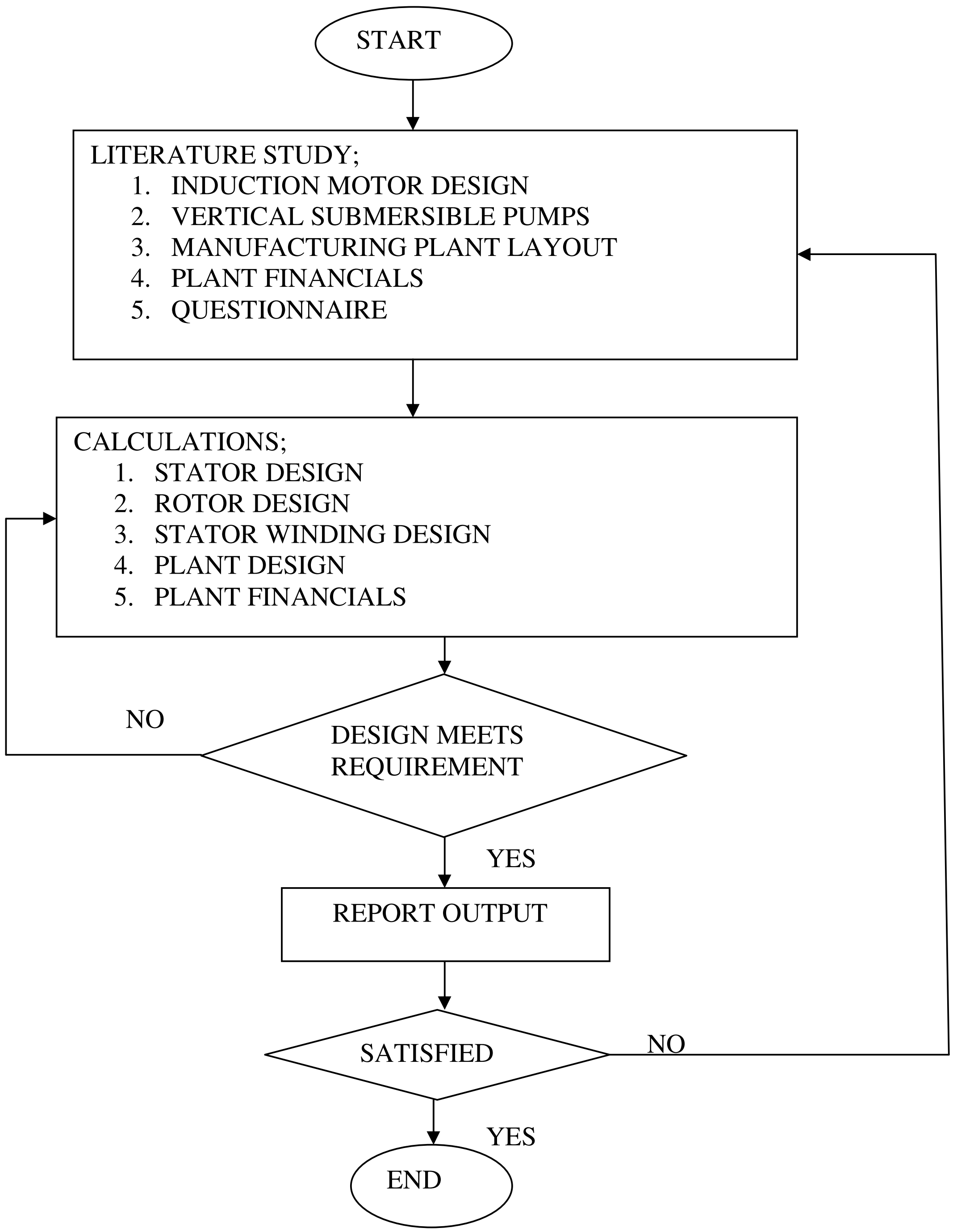


Figure 1-9 Methodology Flow Chart

1.4.1. Validation of Electric Motor Retrofit Design

The Flygt B2102.041 pump characteristics [3] (see Appendix D) were used to validate the electric motor parameters of the developed electric motor (Table 2-3). The motor data of the Flygt pump B2102.041 were obtained from the internet. The interest in this motor was because it was the preferred drive for the UNZA pump. This motor was then used as the benchmark for the locally designed motor.

1.4.2. Literature review

An extensive search of published works and books was undertaken. The references are given in section 6.

Chapter 2
Electric Motor Design

2.1 Introduction

Development of any new three-phase motor design begins with selection of basic overall stator and rotor dimensions, then the number of stator slots, N_1 and rotor slots N_2 [12]. Together with the number of magnetic poles in the stator winding, the N_1 and N_2 values-what is called the "slot combination" influence the winding alternatives. This chapter therefore deals with the electric motor design starting with the determination of the stator and rotor dimensions and then the slot dimensions and slot combination and lastly the winding from the given motor design specifications.

2.2 Design Specifications

The design specifications are from the UNZA pump parameters and approximate desired values.

- Rated Power P_s = 5.28 kW
- Speed n_r = 2890 rpm
- Synchronous speed n_s = 3000 rpm
- Line voltage V_1 = 380 V
- Supply frequency f_1 = 50 Hz
- Number of phases = 3
- Phase connections : star
- Targeted power factor = 0.85
- Targeted efficiency: η_n = 0.85
- Rated slip S_n = 3.7%
- Number of poles P = 2
- Number of pole pair P_1 = 1
- Environment conditions: standard (no derating)
- Configuration (vertical or horizontal shaft etc.): Vertical shaft
- Service factor load: 1.0
- Insulation class: F; temperature rise; class B
- Motor casing dimensions D_{out} = 180 mm
- Rotor seat length R_{SL} = 90 mm

2.3 The Algorithm

The algorithm Figure 2.1 shows the main steps in designing the induction motor [13]. The process started with (1) the design specifications given in 2.1 and assigned values of flux densities and current densities and in (2) the stator bore diameter D_{sbd}, the stack length L, stator slots N_1, and stator outer diameter D_{out}, were calculated, after which the stator and rotor currents were found.

In step (3) all dimensions were adjusted to standardised values (stator outer diameter D_{out}, stator bore diameter D_{sbd}, etc.). Then in (4), the actual magnetic and electric loadings (current and flux densities) were verified. At this stage the results of the magnet saturation coefficient $(1 + K_{sc})$ of the stator and rotor tooth were compared to assigned values. This is a decision point upon which if the values differ then the whole process starting with (1) starts with adjusted values of tooth flux densities until convergence is obtained in $1 + K_{sc}$. When this condition was met steps (5) to (8) were followed calculating the magnetisation current I_o (5); the equivalent circuit parameters in (6), losses, rated slip S_n, and efficiency in (7) and then power factor, locked rotor current and torque, breakdown torque, and temperature rise in (8).

In (9) all this performance was checked. This step was crucial because if the values are not satisfactory then the whole process is restarted at (1) with new values of flux densities and/or current densities and stack aspect ratio $\lambda = L/\tau$ (L = length of stack, τ = pole pitch).

The stator winding design did not fall into this algorithm and was done independent of it. As such it is not cast in any of the steps outlined above.

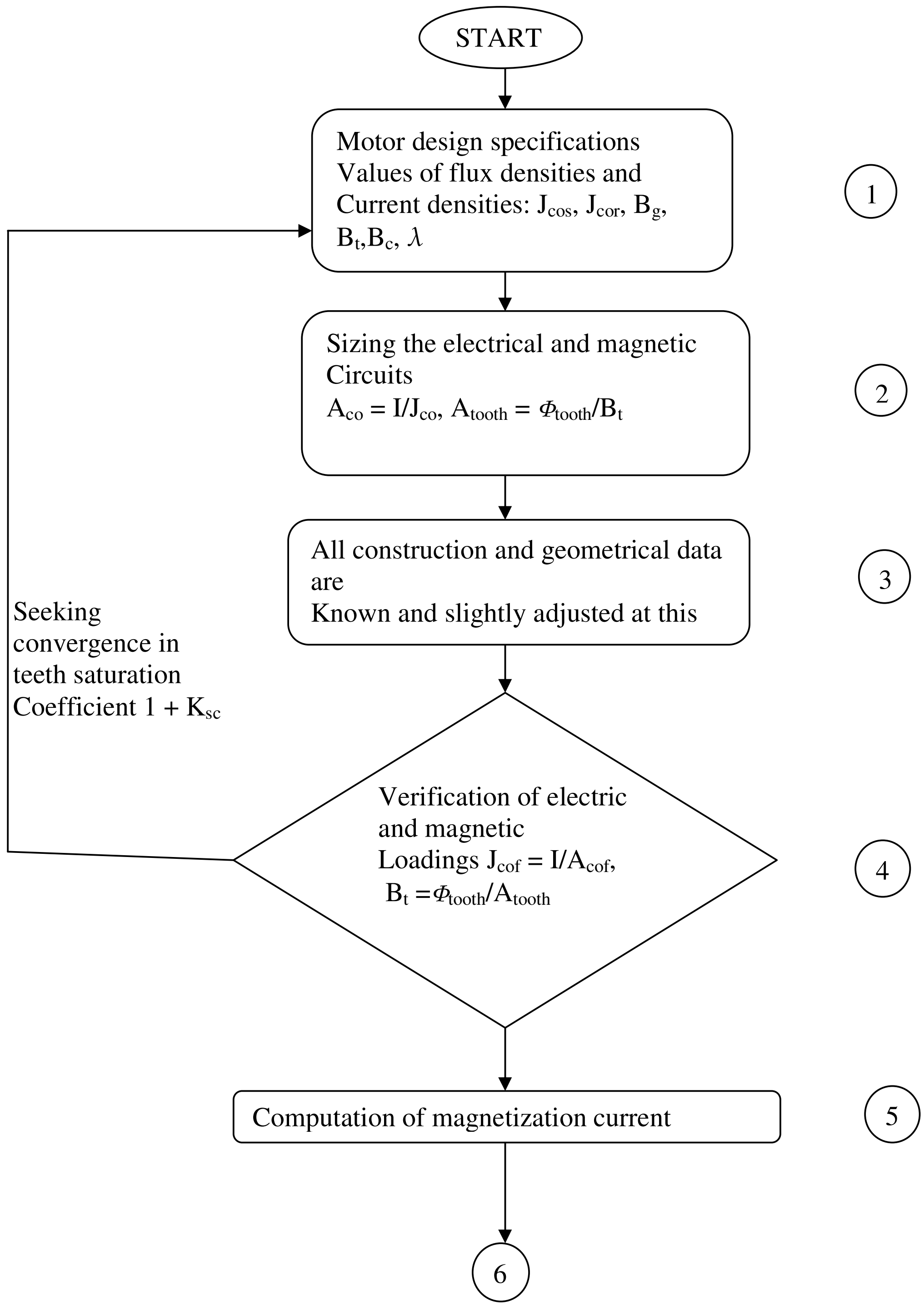


Figure 2.1 Design Algorithm

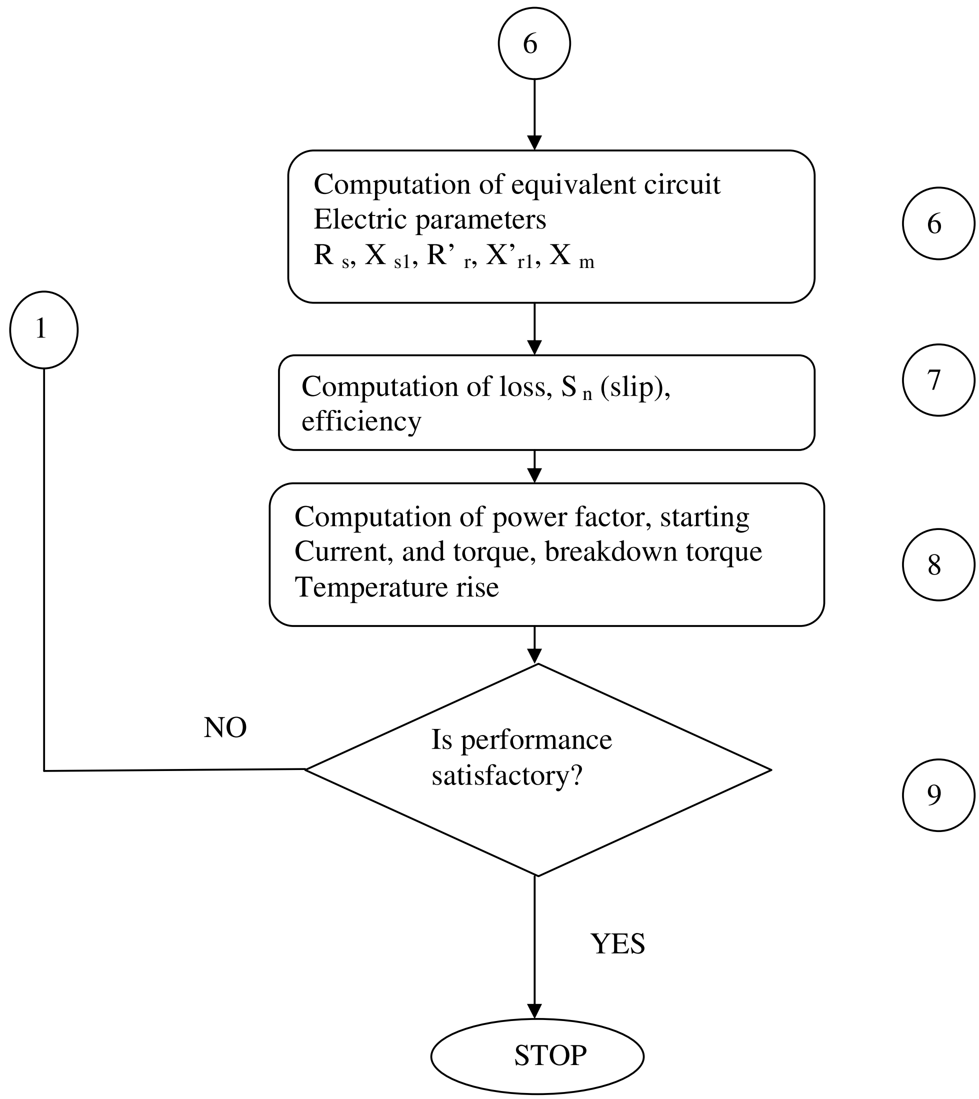


Figure 2.1 Design Algorithm (cont'd)

2.4 Determination of Stator Core main Dimensions.

There are many ways of designing the induction motor stator and rotor dimensions. The most common being;

1. The D_{sbd}^2L output constant concept and
2. The rotor tangential stress concept.

The D_{sbd}^2L output constant concept is the most widely accepted method [13, 14] and was therefore used in this project. The rotor tangential concept is used for completely new designs [13], and was not therefore considered.

Based on the advanced reasons, the stator bore diameter D_{sbd} [13] is given by

$$D_{sbd} = \sqrt[3]{((2P_1 \text{ x } P_1 \text{ x } S_{gap}) / (\pi \text{ x } \lambda \text{ x } f_1 \text{ x } C_o))} \qquad (2\text{-}1)$$

And from Equation (2-2) K_E the ratio between the generated electromotiveforce (emf) E_1 and input voltage V_{in} is given by

$$K_E = E_1 / V_{1n} = 0.98 - 0.005 \text{ x } P_1 \qquad (2\text{-}2)$$

For $P_1 = 1$, $K_E = 0.975$

The air-gap apparent power S_{gap} [13] is given as

$$S_{gap} = 3 \text{ x } E_1 \text{ x } I_{1n} \qquad (2\text{-}3)$$

The input apparent power S_{1n} [13] is given as

$$S_{1n} = 3 \text{ x } V_{1n} \text{ x } I_{1n} = P_n / (\eta_n \text{ x } \cos \varphi_{1n}) \qquad (2\text{-}4)$$

And from Equation 2-1, 2-2, 2-3 and 2-4, the air-gap apparent power is given as

$$S_{gap} = (K_E \text{ x } P_n) / (\eta_n \text{ x } \cos \varphi_{1n}) \qquad (2\text{-}5)$$

The stack aspect ratio λ [13] is given as

$$\lambda = L\ ((2 \text{ x } P_1 / \pi \text{ x } D_{sbd})) = L / \tau \qquad (2\text{-}6)$$

Past experience has shown that the stack aspect ratio λ fall in the range shown in table 2-1

Table 2-1 Stack Aspect ratio λ

$2P_1$	2	4	6	8
λ	0.6 – 1.0	1.2 – 1.8	1.6 – 2.2	2 - 3

From Equation 2-5, the apparent air-gap power S_{gap} is

$$S_{gap} = (0.975 \text{ x } 5.28 \text{ x } 10^3) / (0.85 \text{ x } 0.85) = 7125.26 \text{ VA}$$

Using the value of S_{gap} calculated, C_o is obtained graphically [13], so for $S_{gap} = 7125.26$ VA, $C_o = 144.5 \text{ x } 10^3 \text{ J / m}^3$. Since this is a 2 pole motor, $P_1 = 1$, and from Table 2-1, we select $\lambda = 0.6$, $f_1 = 50$ Hz, therefore the stator bore diameter D_{sbd} from Equation 2-1 is

$$D_{sbd} = {}^3\sqrt{}\ ((2 \text{ x } 1 \text{ x } 1 \text{ x } 7125.26) / (\pi \text{ x } 0.6 \text{ x } 50 \text{ x} 144.5 \text{ x } 10^3)) = 0.1015 \text{ m}$$

From Equation 2-6 the stack length L is

$$L = (0.6 \text{ x } \pi \text{ x } 0.1015) / (2 \text{ x } 1) = 0.0957 \text{ m}$$

From Equation 2-6 the pole pitch τ is

$$\tau = (\pi \text{ x } D_{sbd}) / (2 \text{ x } P_1) = (\pi \text{ x } 0.1015) / (2 \text{ x } 1) = 0.1594 \text{ m}$$

The slot pitch τ_s for q = 6 is

$$\tau_s = \tau / (3 \text{ x } q) \qquad (2\text{-}7)$$

$$= 0.1594 / (3 \text{ x } 6) = 0.008865 \text{ m}$$

The guide as to the ratio of internal to external stator diameter D_{sbd} / D_{out} is given in table 2-2.

Table 2-2 Ratio of Internal and External Stator Diameter

$2 \times P_1$	2	4	6	8
D_{sbd} / D_{out}	0.54 – 0.58	0.61 – 0.63	0.68 – 0.71	0.72 – 0.74

For $2 \times P_1 = 2$, $D_{sbd} / D_{out} = K_{DD} = 0.56$ was selected, therefore

$$D_{out} = D_{sbd} / K_{DD} \qquad (2\text{-}8)$$

$$D_{out} = 0.1015 / 0.56 = 0.180 \text{ m}$$

The air-gap value g [13] is given as

$$g = (0.1 + 0.02 \times \sqrt[3]{P_n}) \times 10^{-3} \text{ m for } 2P_1 = 2 \qquad (2\text{-}9)$$

$$g = (0.1 + 0.012 \times \sqrt[3]{P_n}) \times 10^{-3} \text{ m for } 2P_1 \geq 2$$

For this design therefore $2P_1 = 2$ and g was given as

$$g = (0.1 + 0.02 \times \sqrt[3]{5280}) \times 10^{-3} = 0.45 \times 10^{-4} \text{ m}$$

2.5 The Stator Winding

The number of slots N_1 is given as

$$N_1 = 2 \times P_1 \times q \times m \qquad (2\text{-}10)$$

$$= 2 \times 1 \times 6 \times 3 = 36$$

In a two layer winding with chorded coils: $y / \tau = 0.8$, is chosen. Therefore the motor is of the fractional pitch of 10 / 12 = 0.833. This pitch would reduce the effect of the 5th and 7th harmonics [15]. The 3rd harmonics are self eliminating by virtue of the three phase design of the stator [15].

The electrical angle between emfs in neighbouring slots α_{ea} is

$$\alpha_{ea} = (2 \times \pi \times P_1) / N_1 \qquad (2\text{-}11)$$

$$= (2 \times \pi \times 1) / 36 = \pi / 18$$

The pitch factor K_{P1} [13] is

$$K_{P1} = \sin (P^{\circ} / 2) \quad (2\text{-}12)$$
$$= \sin (150 / 2) = 0.924$$

Where P° is the span of the coil in electrical degrees

The distribution factor K_{d1} [13] is

$$K_{d1} = \sin (q \times d^{\circ} / 2) / q \times \sin (d^{\circ} / 2) \quad (2\text{-}13)$$
$$= \sin (6 \times 10 / 2) / (6 \times \sin (10 / 2)) = 0.956$$

Where $d^{\circ} = \alpha_{ea}$

Therefore the stator winding factor K_{W1} [13] is

$$K_{W1} = K_{P1} \times K_{d1} = 0.924 \times 0.956 = 0.907$$

Now the number of turns per phase is determined on the value of the pole flux ϕ, where flux ϕ is

$$\phi = \alpha_1 \times \tau \times L \times B_g \quad (2\text{-}14)$$

where B_g is the air-gap flux density [13] and is specified in intervals as follows:

$$B_g = (0.5 – 0.75)T \text{ for } 2 \times P_1 = 2$$
$$B_g = (0.65 – 0.78)T \text{ for } 2 \times P_1 = 4 \quad (2\text{-}15)$$
$$B_g = (0.7 – 0.82)T \text{ for } 2 \times P_1 = 6$$
$$B_g = (0.75 – 0.85)T \text{ for } 2 \times P_1 = 8$$

The spanning coefficient α_1 [13] depends on the tooth saturation factor $1 + K_{sc}$. For $1 + K_{sc}$ = to 1.4, $\alpha_1 = 0.729$, $K_f = 1.085$, and for a 2 pole motor $B_g = 0.5T$.

Therefore $\phi = 0.729 \times 0.1594 \times 0.0957 \times 0.58 = 6.45 \times 10^{-3}$ Wb

The number of turns per phase W_1 [13] is

$$W_1 = (K_E \times V_{1ph}) / (4 \times K_f \times K_{w1} \times f_1 \times \phi) \quad (2\text{-}16)$$

$$W_1 = (0.975 \text{ x } 380 / \sqrt{3}) / (4 \text{ x } 1.085 \text{ x } 0.907 \text{ x } 50 \text{ x } 6.45 \text{ x } 10^{-3})$$
$$= 168.641 \text{ turns / phase}$$

Therefore the number of conductors per slot N_c is

$$N_c = (a_1 \text{ x } W_1) / (P_1 \text{ x } q) \tag{2-17}$$
$$N_c = (1 \text{ x } 168.641) / (1 \text{ x } 6) = 28.107$$

The number of conductors must be even, therefore $N_c = 28$.

Hence the adjusted value of $W_1 = W_{1A} = P_1 \text{ X } q \text{ x } N_c = 1 \text{ x } 6 \text{ x } 28 = 168$

Therefore the actual flux density $B_g = 0.5 \text{ x } (W_1 / W_{1A})$ (2-18)

$$B_g = 0.5 \text{ x } (168.641 / 168) = 0.58\text{T}$$

The rated current I_{1n} [13] is

$$I_{1n} = P_n / (\eta_n \text{ x } \cos\varphi_n \text{ x } \sqrt{3} \text{ x } V_1) \tag{2-19}$$

Therefore $I_{1n} = 5280 / (0.85 \text{ x } 0.85 \text{ x } \sqrt{3} \text{ x } 380) = 11.103 \text{ A}$

The recommended current densities [13] are

$$J_{cos} = (4 – 7) \text{ A / mm}^2 \text{ for } 2P_1 = 2, 4 \tag{2-20}$$
$$J_{cos} = (5 – 8) \text{ A / mm}^2 \text{ for 2P1} = 6, 8$$

For this design the value of current density $J_{cos} = 7 \text{ A / mm}^2$ was chosen.

Now the magnetic wire cross section A_{Co} is

$$A_{Co} = I_{1n} / (J_{cos} \text{ x } a_1) \tag{2-21}$$

Therefore $A_{Co} = 11.103 / 7 = 1.586 \text{ mm}^2$

From the conductor area A_{Co} the conductor diameter d_{Co} [13] is

$$d_{Co} = \sqrt{(4 \times A_{Co} / \pi)} \quad (2\text{-}22)$$

$$d_{Co} = \sqrt{(4 \times 1.586 / 3.14)} = 1.421 \text{ mm}$$

therefore $d_{Co} \approx 1.3$ mm

In general if $d_{Co} \geq 1.3$ mm in low power induction motors, a few conductors may be used in parallel [13] in which case a_1 becomes $a_P > 1$. Since $d_{Co} = 1.4$ mm is approximately equal to $d_{Co} = 1.3$ mm the conductor diameter of $d_{Co} = 1.3$ mm was used to avoid designing a motor with conductors in parallel. With this reduction however, the conductor temperature was expected to be slightly higher than it would otherwise be and this turned out to be 4 degrees higher on maximum temperature. The design of the stator winding is shown in Figure 2-8.

2.6 Stator Slot Sizing

In calculating the slot sizing a factor known as slot fill K_{fill} with the known values of N_c and a_P were used. For round wire the slot fill, $K_{fill} \approx 0.35$ to 0.4 below 10 kW, and 0.4 to 0.5 above 10 kW [13]. Therefore the useful slot area A_{su} is

$$A_{su} = (\pi \times d_{CoP}^2 \times a_P \times N_c) / (4 \times K_{fill}) \quad (2\text{-}23)$$

Therefore for $K_{fill} = 0.4$, A_{su} is

$$A_{su} = (3.14 \times 1.3^2 \times 1 \times 28) / (4 \times 0.4) = 111.03 \text{ mm}^2$$

$$A_{su} = 111 \text{ mm}^2$$

For this design a trapezoidal shape was used. For this type of shape the stator tooth is rectangular see Figure 2-2. In Figure 2-2 the variables b_{os}, h_{os}, h_w are assigned values from accepted practice as, $b_{os} = 2$ to 3 mm $\leq 8g$, $h_{os} = (0.5$ to $1.0)$, wedge height $h_w = 1$ to 4 mm.

Now assuming that all the air-gap flux passes through the stator teeth, then

$$B_g \times \tau_s \times L = B_{ts} \times b_{ts} \times L \times K_{Fe} \quad (2\text{-}24)$$

Where $K_{Fe} \approx 0.96$ for 0.5 mm thick lamination, and B_{ts} is given as

$$B_{ts} = 1.5 - 1.65\text{T}. \quad (2\text{-}25)$$

Therefore $B_{ts} = 1.6$T was chosen.

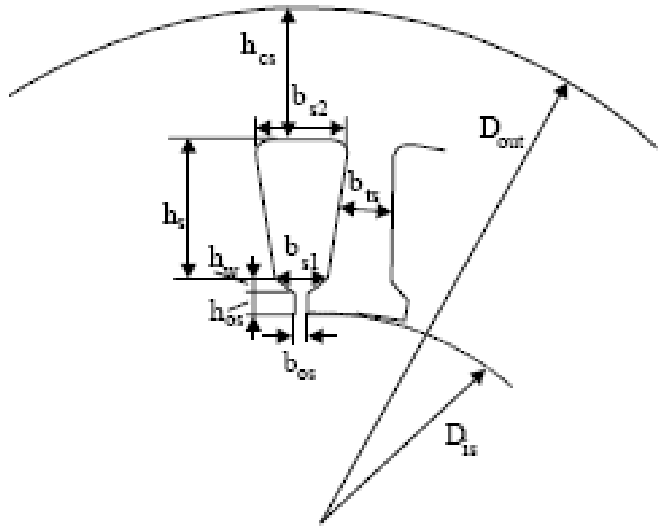


Figure 2-2 Stator Slot Geometry

From Equation 2-24 b_{ts} is

b_{ts} = (0.58 x 8.8565 x 10^{-3}) / (1.6 x 0.96) = 3.344 x 10^{-3} m

From acceptable practice the value of tooth width b_{ts} > 3.5 x 10^{-3} m [13] therefore the value of b_{ts} = 3.3 x 10^{-3} m, being just below the lower limit is acceptable.

Now from the assigned value ranges of b_{os}, h_{os} and h_w, the following values are assigned, b_{os} = 2.4 x 10^{-3} m, h_{os} = 1.0 x 10^{-3} m, h_w = 1.5 x 10^{-3} m, therefore the slot lower width b_{s1} (Figure 2-2) is

$$b_{s1} = \pi\, ((D_{sbd} + 2 \times h_{os} + 2 \times h_w) / N_1)) - b_{ts} \qquad (2\text{-}26)$$

$$b_{s1} = 3.14((0.1015 + 2 \times 1.0 \times 10^{-3} + 2 \times 1.5 \times 10^{-3}) / 36) - 3.344 \times 10^{-3}$$

$$= 5.95 \times 10^{-3} \text{ m}$$

The useful area of the slot A_{su} (Figure 2-2) may be expressed as

$$A_{su} = h_s\, (b_{s1} + b_{s2}) / 2 \qquad (2\text{-}27)$$

And $$b_{s2} \approx b_{s1} + 2 \times h_s \times \tan(\pi / N1) \qquad (2\text{-}28)$$

From Equation 2-27 and 2-28 the unknown values of b_{s2} and h_s were computed.

Therefore $$b_{s2}^2 - b_{s1}^2 = 4 \times A_{su} \times \tan(\pi / N1) \qquad (2\text{-}29)$$

Therefore $b_{s2} = \sqrt{((4 \times A_{su} \times \tan(\pi / N1) + bs1^2)}$ (2-30)

$b_{s2} = 10^{-3} \times \sqrt{((4 \times 111.03 \times \tan(3.14 / 36) + 5.95^2))} = 8.62 \times 10^{-3}$ m

And the slot useful height h_s is

$$h_s = (2 \times A_{su}) / (b_{s1} + b_{s2}) \quad (2\text{-}31)$$

therefore $h_s = (2 \times 111) / (5.95 + 8.62) = 15.24 \times 10^{-3}$ m

$h_s = 15 \times 10^{-3}$ m

The teeth saturation factor $1 + K_{sc}$ was then calculated as follows,

$$1 + K_{sc} = 1 + (F_{mts} + F_{mtr}) / F_{mg} \quad (2\text{-}32)$$

The airgap mmf F_{mg} is

$$F_{mg} \approx 1.2 \times g \times B_g / \mu_0 \quad (2\text{-}33)$$

For $g = 0.45 \times 10^{-3}$ m (Equation 2-9)

$F_{mg} = (1.2 \times 0.45 \times 10^{-3}) \times 0.58 / (1.256 \times 10^{-6}) = 249.349$ Aturns

From Equation 2-25 $B_{ts} = 1.6$T, and from the magnetisation curve (Table A-4) $H_{ts} = 2460$ A / m.

Therefore the stator tooth mmf F_{mts} is

$F_{mts} = H_{ts} (h_s + h_{os} + h_w)$

Therefore $F_{mts} = 2460 (15 + 1.0 + 1.5) \times 10^{-3} = 43.66$ Aturns (2-34)

Now from Equation 2-32 and assuming $1 + K_{sc} = 1.4$, rotor tooth mmf F_{mtr} was calculated.

$$F_{mtr} = K_{sc} \times F_{mg} - F_{mts} \quad (2\text{-}35)$$

$F_{mtr} = 0.4 \times 249.349 - 43.66 = 56.0796$ Aturns

The value of F_{mtr} is approximately equal to that of F_{mts}, therefore $F_{mtr} \approx F_{mts}$, and this satisfies step 4 of the algorithm. Therefore no further iterations are necessary.

After closing step 4 in the flow chart (Figure 2-1) the stator back iron height h_{cs} (Figure 2-2) was calculated.

$$h_{cs} = (((D_{out} - ((D_{sbd} + 2(h_{os} + h_w + h_s))) / 2 \qquad (2\text{-}36)$$

$$h_{cs} = (((180 - ((101.5 + 2(1 + 1.5 + 15.2))) / 2 = 21.5 \text{ mm}$$

Having calculated h_{cs}, the back core flux density B_{cs} was verified using the calculated value of flux $\phi = 5.5603 \times 10^{-3}$ Wb (Equation 2-14).

$$B_{cs} = \phi / (2 \times L \times h_{cs}) \qquad (2\text{-}37)$$

$$B_{cs} = 6.45 \times 10^{-3} / (2 \times (95.65 \times 21.5) \times 10^{-3}) = 1.6\text{T}$$

This value of B_{cs} is within the range for B_{cs} = 1.4 to 1.7T. If this had not been the case it would have been necessary to adjust either of the following; increase the stator outside diameter D_{out}, or use a bigger stack aspect ratio λ which would reduce the stator bore diameter D_{sbd}, or increase the back iron height h_{cs}, to lower B_{cs}. The other alternative is to increase the current density which would result in the reduction of h_s. In this work this did not apply since is within range, B_{cs} = 1.6T. The developed stator design is shown in Figure 2-6.

2.7 Rotor Slot Sizing

The selection of the number of rotor slots N_2 was based on theoretical analysis dating back as far as 1909 plus proven experience on the rules for slot combination of which the most prominent is that N_2 should be either below or above N_1 by 15 to 20% of N_1 [13]. In this particular design N_2 was taken to be 15% below N_1, therefore,

$$N_2 = N_1 - 0.15 \times N_1 \qquad (2\text{-}38)$$

$$N_2 = 36 - 0.15 \times 36 = 30$$

The other rule is that N_2 must be an even number therefore N_2 = 30 is acceptable.

Now the value of rated rotor bar current I_b [13] is

$$I_b = K_1 \times (2 \times m \times W_1 \times K_{w1} / N2) \times I_{1n} \qquad (2\text{-}39)$$

When K_1 = 1, the stator and rotor mmfs are equal and yet in reality the stator mmf is larger than the rotor mmf, therefore K_1 is,

$$K_1 \approx 0.8 \cos\varphi 1n + 0.2 \qquad (2\text{-}40)$$

$$K_1 = 0.8 \text{ x } 0.85 + 0.2 = 0.88$$

Therefore the rotor bar current I_b (Equation 2-39) is

$$I_b = 0.88 \text{ x } (2 \text{ x } 3 \text{ x } 168 \text{ x } 0.907 / 30) \text{ x } 11.103 = 298.78 \text{ A}$$

For high efficiency, the current density in the rotor bar $J_b = 3.42$ A / mm^2. The rotor slot area is

$$A_b = I_b / J_b \qquad (2\text{-}41)$$
$$A_b = 298.78 / 3.42 = 87.36 \text{ x } 10^{-6} \text{ m}^2$$

The end ring current I_{er} is

$$I_{er} = I_b / (2 \text{ x } \sin(\pi \text{ x } P_1 / N2)) \qquad (2\text{-}42)$$
$$I_{er} = 298.78 / (2 \text{ x } \sin(3.14 \text{ x } 1 / 30)) = 1429.903 \text{ A}$$

The current density in the end ring J_{er} is

$$J_{er} = (0.75 - 0.8) \text{ x } J_b \qquad (2\text{-}43)$$

Whereby the selection of J_{er} is

$$J_{er} = 0.75 \text{ x } J_b = 0.75 \text{ x } 3.45 \text{ x } 10^6 = 2.57 \text{ x } 10^6 \text{ A/m}^2$$

Therefore the end ring cross section A_{er} is

$$A_{er} = I_{er} / J_{er} \qquad (2\text{-}44)$$
$$A_{er} = 1429.903 / (2.57 \text{ x } 10^6) = 557.5 \text{ x } 10^{-6} \text{ m}^2$$

Figure 2-3 below shows the variables of the rotor slot.

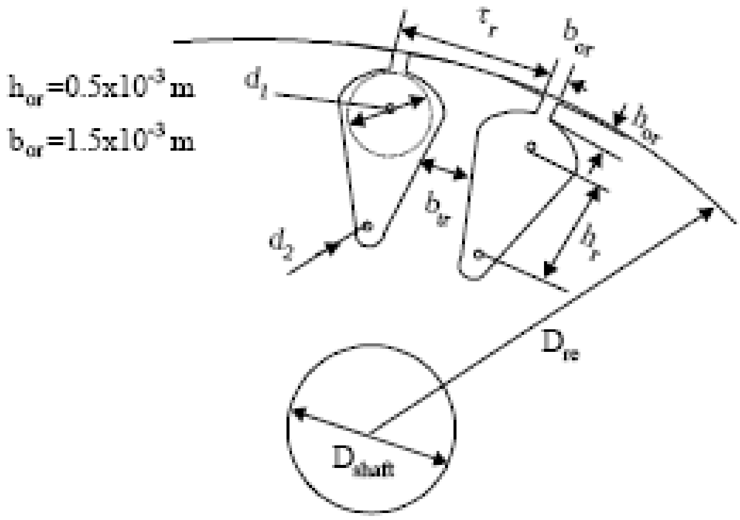


Figure 2.3 Rotor Slot Geometry

The rotor slot pitch is given by the Equation

$$\tau_r = \pi\ (D_{sbd} - 2g)\ /\ N_r \qquad (2\text{-}45)$$

Therefore

$$\tau_r = \pi\ (0.1015 - 2 \text{ x } 0.45)\ /\ 30 = 10.5 \text{ x } 10^{-3} \text{ m}$$

Now b_{tr} the tooth width is

$$b_{tr} \approx (B_g\ /\ K_{Fe} \text{ x } B_{tr}) \text{ x } \tau_r \qquad (2\text{-}46)$$

From Equation 2-25 B_{tr} = 1.6T, therefore

$$b_{tr} = (0.58\ /\ 0.96 \text{ x } 1.6) \text{ x } 10.5 \text{ x } 10^{-3} = 3.99 \text{ x} 10^{-3} \text{ m}$$

To determined d_1 (the top rotor diameter) following the formula was used (Note $D_{re} = D_{sbd}$)

$$\pi\ (D_{sbd} - 2 \text{ x } h_{or} - d_1)\ /\ N2 = d_1 + b_{tr} \qquad (2\text{-}47)$$

Therefore d_1 is

$$d_1 = (\pi (D_{re} – 2 \times h_{or}) – N2 \times b_{tr}) / (\pi + N2) \qquad (2\text{-}48)$$

Therefore

$$d_1 = (\pi (101.5 – 2 \times 0.5 – 0.9) – 30 \times 3.99) / (3.14 + 30) = 5.9 \times 10^{-3} \text{ m}$$

to calculate the value of d_2 and h_r the following formulas of the slot area were applied

$$A_b = \pi / 8 (d_1^2 + d_2^2) + ((d_1 + d_2) \times h_r)) / 2 \qquad (2\text{-}49)$$

$$d_1 – d_2 = 2 \times h_r \times \tan (\pi / N2) \qquad (2\text{-}50)$$

Using Equation 2-49 and making $h_r = 15.2 \times 10^{-3}$ m, same as h_s

$$d_2 = 5.9 \times 10^{-3} – 2 \times 15.2 \times 10^{-3} \times \tan (3.14 / 30) = 2.7 \times 10^{-3} \text{ m}$$

This value of $d_2 = 2.7 \times 10^{-3}$ m did not satisfy A_b (Equation 2-41) = 87.36×10^{-6} m^2, so a series of iterations were done using Equation 2-49 and 2-50 and at $h_r = 19.4 \times 10^{-3}$ m, $d_2 = 1.8 \times 10^{-3}$ m and $A_b = 87.54 \times 10^{-6}$ m^2, this was satisfactory.

Therefore the values of h_r and d_2 are

$h_r = 19.4$ mm

$d_2 = 1.8$ mm

At this value of h_r, d_1 and d_2 the rotor tooth mmf F_{mtr} was calculated to see how it compares with the earlier calculated value of $F_{mtr} = 56.09$ Aturns. At $B_{tr} = B_{ts} = 1.6T$ (Table A-4), $H_{tr} = 2460$ Aturns and F_{mtr} is

$$F_{mtr} = H_{tr} \times (h_r + h_{or} + ((d_1 + d_2) / 2)) \qquad (2\text{-}51)$$

$$= 2460 \times (19.4 + 0.5 + ((5.9 + 1.8) / 2)) \times 10^{-3} = 58.43 \text{ Aturns}$$

This calculated value (Equation 2-51) of $F_{mtr} = 58.43$ Aturns is very close to the earlier calculated value (Equation 2-35) of $F_{mtr} = 56.09$ Aturns. Therefore the design is acceptable.

The next parameter to calculate was the rotor back core height h_{cr}. For this calculation a value of B_{cr} = 1.4 was used since the range of B_{cr} = 1.4 – 1.7T. Therefore the h_{cr} is

$$h_{cr} = \phi / (2 \times L \times B_{cr}) \tag{2-52}$$
$$= 6.45 \times 10^{-3} / (2 \times 9.56 \times 10^{-3} \times 1.6) = 20.4 \text{ mm}$$

The maximum shaft diameter D_{shaft} is

$$D_{shaft} \leq D_{sbd} - 2 \times g - 2 \times (h_{or} + ((d_1 + d_2) / 2) + h_r + h_{cr}) \tag{2-53}$$
$$= 101.5 - 2 \times 4.5 \times 10^{-4} - 2 \times (0.5 + ((5.9 + 1.8) / 2) + 19.4 + 20.4)$$
$$= 12.0 \text{ mm}$$

The shaft diameter must correspond to the rated torque T_{en} given by the tables and often by comparison from past designs. The rated torque is

$$T_{en} = P_n / (2 \times \pi \times (f_1 / P_1) \times (1-S_n)) \tag{2-54}$$
$$= 5280 \times (2 \times 3.14 \times (50 / 1) \times (1 - 0.05) = 17.7 \text{ Nm}$$

For this design the 14 mm left for shaft diameter suffices. However the shaft diameter of 22 mm given by Nyirenda [1] might be on the high side and therefore a shaft diameter of D_{shaft} = 14 mm is recommended. The developed rotor design is shown in Figure 2-7.

The end ring cross section is shown in Figure 2-4 below.

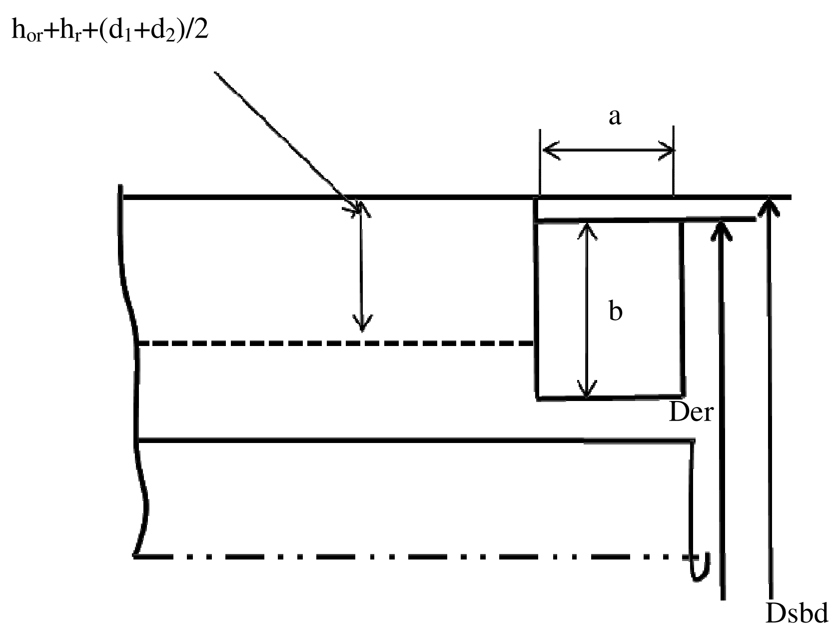


Figure 2-4 End Ring Cross-Section

In general $D_{sbd} - D_{er} = (3 - 4) \times 10^{-3}$ and also (2-55)

$$b = (1.0 - 1.2) \times ((h_r + h_{or} + (d_1 + d_2) / 2 \quad (2\text{-}56)$$

From Equation 2-56 b is

$$b = 1.0 \times (h_r + h_{or} + (d_1 + d_2) / 2) \quad (2\text{-}57)$$

$$b = 1.0 \times (19.4 + 0.5 + (5.9 + 1.8) / 2) = 23.9 \text{ mm}$$

the dimension a is

$$a = A_{er} / b \quad (2\text{-}58)$$

$$a = 557.5 \times 10^{-6} / 23.9 \times 10^{-3} = 23.3 \text{ mm}$$

The Magnetisation current I_o is

$$I_o = (\pi \times P1 \times (F_{1m} / 2)) / (3 \times \sqrt{2} \times W_1 \times K_{w1}) \quad (2\text{-}59)$$

where F_{1m} is

$$F_{1m} = 2 \times (K_c \times g \times B_g / \mu_o + F_{mts} + F_{mtr} + F_{mcs} + F_{mcr}) \quad (2\text{-}60)$$

And K_c, F_{mcs} and F_{mcr} are calculated as follows

K_c is called Carter's coefficient and is calculated as follows

$$\gamma_1 = b_{os}^{\ 2} / (5 \times g + b_{os}) \quad (2\text{-}61)$$

$$\gamma_1 = (2.2 \times 10^{-3})^2 / (5 \times 4.5 \times 10^{-4} + 2.2 \times 10^{-3}) = 1.09 \times 10^{-3} \text{ m}$$

$$\gamma_2 = b_{or}^{\ 2} / (5 \times g + b_{or}) \quad (2\text{-}62)$$

$$\gamma_2 = (1.5 \times 10\text{-}3)2 / (5 \times 0.45 \times 10^{-3} + 1.5) = 0.60 \times 10^{-3} \text{ m}$$

Where K_{c1} and K_{c2} are given by the formulas involving γ_1 and γ_2 as follows

$$K_{c1} = \tau_s / (\tau_s - \gamma 1) \quad (2\text{-}63)$$

$$K_{c1} = 8.865 \times 10^{-3} / (8.865 - 1.09) \times 10^{-3} = 1.14$$

$$K_{c2} = \tau_r / (\tau_r - \gamma_2) \quad (2\text{-}64)$$

$K_{c2} = 10.5 \times 10^{-3} / (10.5 - 0.6) \times 10^{-3} = 1.061$

Therefore $K_c = K_{c1} \times k_{c2}$ (2-65)

$K_c = 1.14 \times 1.061 = 1.21$

Now F_{mcs} and F_{mcr} are given by the following

$$F_{mcs} = C_{cs} \times \pi \times ((D_{out} - h_{cs}) / 2 \times P_1) \times H_{cs}(B_{cs}) \quad (2\text{-}66)$$

And

$$F_{mcr} = C_{cr} \times \pi \times ((D_{shaft} + h_{cr}) / 2 \times P_1) \times H_{cr}(B_{cr}) \quad (2\text{-}67)$$

Where

$$C_{cs} = C_{cr} \approx 0.88 \times e^{-0.4xBcs,r^2} \quad (2\text{-}68)$$

And for $B_{cs} = 1.5T$, $H_{cs} = 1340$ A/m, $B_{cr} = 1.65T$, $H_{cr} = 3460$ A / m (2-69)

Therefore from Equation 2-66 F_{mcs} is

$$F_{mcs} = 0.88 \times e^{-0.4x1.5^2} \times 3.14 \times ((180 - 21.5) / 2 \times 1) \times 1340 = 119.32 \text{ Aturns}$$

$$F_{mcr} = 0.88 \times e^{-0.4 \times 1.65^2} \times ((12 + 20.4) / 2 \times 1) \times 3460 = 57.45 \text{ Aturns}$$

Therefore from Equation 2-60 F_{1m} is

$$F_{1m} = 2 \times ((1.21 \times 0.45 \times 10\text{-}3 \times 6.45 \times 10\text{-}3 / 1.3 \times 10\text{-}6) + 43.66 + 56.08 + 119.32 + 57.45)$$

$$F_{1m} = 1055.60 \text{ Aturns}$$

The total saturation factor K_s is

$$K_s = (F_{1m} / (2 \times F_{mg})) - 1 \quad (2\text{-}70)$$

$$K_s = (1055.60 / (2 \times 249.349)) - 1 = 1.1167$$

From Equation 2-59 the magnetisation current I_o is

$$I_o = (3.14 \times 1 \times (1055.60 / 2)) / 3 \times \sqrt{2} \times 168 \times 0.907) = 2.55 \text{ A}$$

And the unit per unit value io is

$$i_o = I_o / I_{1n} \quad (2\text{-}71)$$

$$i_o = 2.55 / 11.103 = 0.23$$

2.8 Resistances and Inductances

Resistances and inductances are shown in Figure 2-5 below.

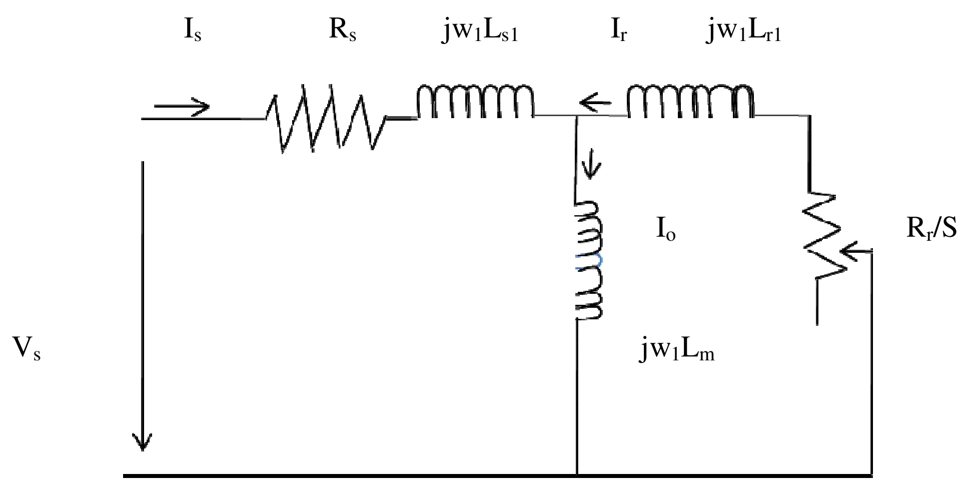


Figure 2-5 The Equivalent Circuit of an Induction Motor (Core Losses ignored)

The stator phasor resistance R_s is

$$R_s = \rho_{Co} \text{ x } ((I_c \text{ x } W_1) / A_{Co} \text{ x } a_1) \quad (2\text{-}72)$$

Where I_c is

$$I_c = 2 \text{ x } (L + I_{end}) \quad (2\text{-}73)$$

The coil end connection depends on the coil span y. Number of poles P, shape of coils, and number of layers in the winding.

Therefore $I_{end} = 2 \text{ x } y - 0.04$ m for $2 \text{ x} P_1 = 2$ (2-74)

And the ratio $y / \tau = \beta$ called the chording factor = 15 / 18 (2-75)

Where the acceptable values of β are $2 / 3 \leq \beta \leq 1$ (2-76)

Therefore $\beta = 15 / 18 = 0.833$ is acceptable and therefore

$$y = \beta \times \tau \tag{2-77}$$

$$y = 0.83333 \times 0.1594 = 0.13285 \text{ m}$$

and from Equation 2-74 I_{end} is

$$I_{end} = 2 \times 0.13285 - 0.04 = 0.2457 \text{ m}$$

And from Equation 2-73 I_c is

$$I_c = 2 \times (0.0957 + 0.2457) = 0.6828 \text{ m}$$

Now induction motor of high efficiency are desired and in designing for this requirement the winding temperature is regard important and must not be large even if the insulation class is F. In this design therefore similar caution was observed. To achieve this the motor was designed for copper resistivity $(\rho_{Co})_{80°C}$ at 80°C. Now for copper resistivity at 20°C, $(\rho_{Co})_{20°C}$ = 1.78 x 10-8 Ωm. And at 115°C, $(\rho_{Co})_{115°C} = 1.37 \times (\rho_{Co})_{20°C}$.

Therefore at copper resistivity = 80°C, $(\rho_{Co})_{80°C}$ is

$$(\rho_{Co})_{80°C} = (\rho_{Co})_{20°C} \times (1+(1 / 273) \times (80 - 20)) \tag{2-78}$$

$$(\rho_{Co})_{80°C} = 1.78 \times 10^{-8} \times (1 + (1 / 273) \times (80 - 20)) = 2.171 \times 10^{-8} \ \Omega\text{m}$$

Therefore the stator phasor resistance R_s (Equation 2-72) is

$$R_s = 2.171 \times 10\text{-}8 \times ((0.6828 \times 168) / (1.586 \times 10\text{-}6 \times 1)) = 1.570 \ \Omega$$

And the rotor bar-end ring equivalent resistance R_{be} is

$$R_{be} = \rho_{A1} \times ((L / A_b) \times K_R + (\iota_{er} / (2 \times A_{er} \times \text{SIN}^2(\pi \times P_1 / 2))) \tag{2-79}$$

Where ρ_{A1} is the cast aluminium resistivity and at 20°C $(\rho_{A1})_{20°C} = 3.1 \text{ X } 10^{-8}$ Ωm (2-80)

The end-ring length $\iota_{end} = \pi \times (D_{er} - b) / N_2$ (2-81)

Now from Equation 2-55 $D_{er} = D_{sbd} - 2 \times g - 2 \times 3 \times 10^{-3}$ m (2-82)

$$D_{er} = 94.64 \times 10^{-3} \text{ m}$$

And from Equation 2-81 the end-ring length ι_{end} is

$$\iota_{end} = 3.14 \text{ x } (94.64 – 23.9) / 30 = 7.36 \text{ mm}$$

In Equation 2-79, K_R is the approximate skin effect resistance coefficient, for a rectangular slot, and is

$$K_R = \xi \text{ x } (SINH(2 \text{ x } \xi) + SIN(2 \text{ x } \xi)) / (COSH(2 \text{ x } \xi) – COS(2 \text{ x } \xi)) \approx \xi \qquad (2\text{-}83)$$

And

$$\xi = \beta_s \text{ x } h_s \text{ x } \sqrt{S} \text{ , where } S = 1 \qquad (2\text{-}84)$$

And

$$\beta s = \sqrt{((\omega_1 \text{ x } \mu_o) / (2 \text{ x } \rho_{A1})} \qquad (2\text{-}85)$$

$$\beta s = \sqrt{((314 \text{ x } 1.3 \text{ x } 10^{-6}) / (2 \text{ x } 3.1 \text{ x } 10^{-8}))} = 80 \text{ (m)}^{-1}$$

And from Equation 2-83

$$\xi = 80 \text{ x } 19.4 \text{ x } 10^{-3} \text{ x } \sqrt{1} = 1.56$$

From Equation 2-83

$$K_R = \xi = 1.56 \qquad (2\text{-}86)$$

Now from Equation 2-79, $R_{be80°C}{}^{S=1}$ is

$$(R_{be80°C})^{S=1} = 3.1\text{x}10^{-8}\text{x}(1+1/273\text{x}(80\text{-}20))\text{x}((95.7\text{x}10^{-3}/87.36\text{x}10^{-6})\text{x}1.56+(7.36\text{x}10^{-3}/(2 \text{ x } 557.5\text{x}10^{-6}$$

$$\text{x } SIN(3.14 \text{ x } 1/30))$$

$$(R_{be80°C})^{S=1} = 6.612 \text{ x } 10^{-5}\ \Omega$$

The rotor cage resistance reduced to the stator R_r' is

$$(R_r')_{s=1} = ((4 \text{ x } m) / N2) \text{ x } (W_1 \text{ x } K_{W1})^2 \text{ x } R_{be80°C} \qquad (2\text{-}87)$$

$$= ((4 \text{ x } 3) / 30) \text{ x } (168 \text{ x } 0.907)^2 \text{ x } 6.612 \text{ x } 10^{-5} = 0.614\ \Omega$$

The stator phase leakage reactance X_{s1} is

$$X_{s1} = 2 \text{ x } \mu_o \text{ x } \omega_1 \text{ x } L \text{ x } (W_1{}^2 / (P_1 \text{ x } q)) \text{ x } (\lambda_s + \lambda_{ds} + \lambda_{ec}) \qquad (2\text{-}88)$$

Where λ_s, λ_{ds}, λ_{ec} are the slot differential and end ring connection coefficients:

And $\lambda_s = ((((2 / 3) x (h_s / (b_{s1} + b_{s2})) + ((2 x h_w) / (b_{os} + b_{s1})) + (h_{os} / b_{os})) x$

$((1 + 3 x \beta) / 4)$ (2-89)

$\lambda_s = (((2/3)x(15 x 10\text{-}3 / (5.95 + 8.62) x 10\text{-}3) + ((2 x 1.5 x 10\text{-}3/(1.5 + 5.95)x10\text{-}3) +$

$(1 / 1.5)) x ((1 + 3 x (15 / 18)) / 4) = 1.331$

And $\lambda_{ds} = (0.9 x \tau_s x q^2 x K_{w1}^2 x C_s x \gamma_{ds}) / (K_c x g x (1 + K_{st}))$ (2-90)

Where $C_s = 1 - 0.033 x (b_{os}^2 / (g x \tau_s))$ (2-91)

$= 1 - 0.033 x ((1.5 x 10^{-3})^2 / (0.45 x 10^{-4} x 8.865 x 10^{-3}) = 0.960$

And $\gamma_{ds} = (0.11 x SIN\varphi_1 + 0.41) x 10\text{-}2$; for q = 6 (2-92)

Where $\varphi_1 = \pi x (6 x \beta - 5.5)$ (2-93)

From Equation 2-93 $\varphi_1 = 3.14 x (6 x 0.8333 - 5.5) = -1.57$

From Equation 2-92 $\gamma_{ds} = (0.11 x SIN(-1.57) + 0.41) x 10\text{-}2 = 3 x 10^{-3}$

From Equation 2-90 $\lambda_{ds} = (0.9x8.865x10^{-3}x6^2x0.907^2x0.96x3x10^{-3}/(1.21x0.45x10^{-4}x1.4) = 0.8948$

This design being a two layer winding, the end connection specific geometric permeance coefficient λ_{ec} is

$\lambda_{ec} = 0.34 x (q / L) x (I_{end} - 0.64 x \beta x \tau)$ (2-94)

$= 0.34 x (6 / (95.7 x 10^{-3})) x (245.7 x 10^{-3} - 0.64 x 0.8333 x 159.4 x 10^{-3})$

$= 3.427$

From Equation 2-88 $X_{s1} = 2x1.3 x 10^{-6} x 139 x 95.7 x 10^{-3} x (1682 / (1 x 6))+1.331+0.8948+ 3.427)$

$X_{s1} = 2.021\ \Omega$

The equivalent rotor bar leakage reactance X_{be} is

$X_{be} = 2 x \pi x f_1 x \mu_o x L x (\lambda_r x K_x + \lambda_{dr} + \lambda_{er})$ (2-95)

Where λ_r, λ_{dr}, λ_{er} are the rotor slot differential and end ring permeance coefficient,

$$\lambda_r = 0.66 + (2 \text{ x } h_r / (3 \text{ x } (d_1 + d_2))) + h_{or} / b_{or} \quad (2\text{-}96)$$

$$\lambda_r = 0.66 + (2 \text{ x } 19.4 \text{ x } 10\text{-}3 / (3 \text{ x } (5.9 + 1.8))) + 0.5 / 1.5 = 2.679$$

And the differential coefficient λ_{dr} is

$$\lambda_{dr} = ((0.9 \text{ x } \tau_r \text{ x } \gamma_{dr}) / (K_c \text{ x } g)) \text{ x } (N_r / (6 \text{ x } P_1))^2 \quad (2\text{-}97)$$

and $\gamma_{dr} = 9 \text{ x } (6 \text{ x } P^1 / N2)^2 \text{ x } 10^{-2}$ (2-98)

Therefore $\gamma_{dr} = 9 \text{ x } (6 \text{ x } 1 / 30)^2 \text{ x } 10^{-2} = 0.36 \text{ x } 10^{-2}$

From Equation 2-97 $\lambda_{dr} = ((9 \text{ x } 10.5 \text{ x } 10^{-3} \text{ x } 0.36 \text{ x } 10^{-2}) / (1.21 \text{ x } 0.45 \text{ x} 10^{-4})) \text{ x } (30 / (6 \text{ x } 1)^2$

$= 1.574$

And the end-ring coefficient λ_{er} is

$$\lambda_{er} = ((2.3 \text{ x } (D_{er} - b))/N2 \text{ x } L \text{ x } 4 \text{ x } SIN^2(\pi \text{ x } P_1/N2)) \text{ x } \log((4.7 \text{ x } (D_{er} - b) / (b + 2 \text{ x } a)) \quad (2\text{-}99)$$

$=((2.3 \text{ x } (94.64 - 23.9) \text{ x } 10^{-3}) / 30 \text{ x } 95.7 \text{ x } 10^{-3} \text{ x} 4 \text{ x } SIN^2(3.14 \text{ x } 1 / 30)) \text{ x}$

$\text{Log}((4.7 \text{ x } (94.64 - 23.90 \text{ x } 10^{-3}) / (23.9+2\text{x}23.3) \text{ x } 10^{-3}) = 0.8691$

The skin coefficient for the leakage reactance K_x ($\xi = 1.56$) is

$$K_x = (3/(2 \text{ x } \xi)) \text{ x } ((SINH(2 \text{ x } \xi) - SIN(2 \text{ x } \xi) / (COSH(2 \text{ x } \xi) - COS(2 \text{ x } \xi))) = 3 / (2 \text{ x} \xi) \quad (2\text{-}100)$$

$K_x = (3 / (2 \text{ x } 1.56)) = 0.964$

From Equation 2-95 X_{be} is

$$X_{be} = 2 \text{ x } 3.14 \text{ x } 50 \text{ x } 1.3 \text{ x } 10^{-6} \text{ x} 95.7 \text{ x } 10^{-3} \text{ x } (2.679 \text{ x } 0.964 + 1.574 + 0.8691)$$

$$= 1.9 \text{ x } 10^{-4}\ \Omega$$

The rotor leakage reactance X_{r1} is a function of X_{be} and is given as

$$X_{r1} = 4 \text{ x } m_1 \text{ x } ((W_1 \text{ x } K_{w1})^2 / N2) \text{ x } X_{be} \quad (2\text{-}101)$$

$$X_{r1} = 4 \text{ x } 3 \text{ x } ((168 \text{ x} 0.907)2 / 30) \text{ x } 1.9 \text{ x } 10^{-4} = 1.7597\ \Omega$$

At standstill S = 1, both stator and rotor leakage reactance are reduced due to leakage flux path saturation. For power levels in semi-closed stator and rotor slots, therefore

$$(X_{s1})^{S=1}{}_{sat} = X_{s1} \text{ x } (0.7 - 0.8) \approx X_{s1} \text{ x } 0.75 \quad (2\text{-}102)$$

$$= 2.021 \text{ x } 0.75 = 1.516\ \Omega$$

$$(X_{r1})^{S=1}{}_{sat} = X_{r1} \text{ x } (0.6 - 0.7) \approx X_{r1} \text{ x } 0.65 \quad (2\text{-}103)$$

$$= 1.7597 \text{ x } 0.65 = 1.144\ \Omega$$

For rated slip (speed), both skin and leakage saturation effects are undesirable and must be eliminated by making $K_R = K_x = 1$

Therefore from Equation 2-79 $(R_{be80°C})_{Sn}$ is

$$(R_{be80°C})_{Sn} = 3.1 \text{ x } 10^{-8} \text{ x } (1 + (1/273) \text{ x } (80\text{-}20)) \text{ x } ((95.7 \text{ x } 10^{-3}/8.736 \text{ x } 10\text{-}5) \text{ x } 1 +$$

$$7.4 \text{ x } 10^{-3}/(2 \text{ x } 557.5 \text{ x } 10\text{-}6 \text{ x } \text{SIN2}(3.14 \text{ x } 1/30)) = 6.43 \text{ x } 10\text{-}5\ \Omega$$

The rotor resistance $(R_r')_{Sn}$ is

$$(R_r')_{Sn} = (R_r')^{S=1} \text{ x } R_{be80°C}{}^{S=Sn} / R_{be80°C}{}^{S=1} \quad (2\text{-}104)$$

$$(R_r')^{Sn} = 0.614 \text{ x } 6.44 \text{ x } 10^{-5} / 6.612 \text{ x} 10^{-5} = 0.598\ \Omega$$

The magnetisation X_m is

$$X_m = \sqrt{}\ ((V_{ph} / I_o)^2 - R_s^2) - X_{s1} \quad (2\text{-}105)$$

$$= \sqrt{}\ ((\ 219.393 / 2.55)^2 - 1.57^2 - 2.021 = 84\ \Omega$$

The skewing effect on reactances

In most designs rotor slots are skewed. The topic of skewing is however not the subject of this design. Nevertheless it is sufficient to know that a skewing factor C of one stator slot pitch τ_s is typical ($C = \tau_s$)

The effect of skewing on X_m is

$$(X_m)_{skew} = X_m \text{ x } K_{skew} \quad (2\text{-}106)$$

And $K_{skew} = SIN(\pi / 2 \times C / \tau) / (\pi / 2 \times C / \tau) = SIN(\pi /2 \times \tau_s / \tau) / (\pi / 2 \times \tau_s / \tau)$(2-108)

Therefore $K_{skew} = SIN(3.14 / 2 \times 8.865 \times 10\text{-}3 / 159.4 \times 10\text{-}3) = 0.9987$

Therefore from Equation 2-106 $(X_m)_{skew}$ is

$$(X_m)_{skew} = 84 \times 0.9987 = 83.73\ \Omega$$

The rotor leakage inductance is augmented by a new term X'_{r1skew} equal to

$$X'_{r1skew} = X_{mskew} \times (1 - K_{skew}^2) \quad (2\text{-}107)$$

$$= 83.73 \times (1 - 0.9987^2) = 0.2121\ \Omega$$

The final values of rotor reactance at S=1 and $S = S_n$ respectively are

$$(X_{r1})_{skew}^{S=1} = (X_{r1})_{sat}^{S=1} + X'_{r1skew} \quad (2\text{-}108)$$

$$= \quad 1.144 + 0.2121 = 1.356\ \Omega$$

$$(X_{r1})_{skew}^{S=Sn} = X_{r1} + X'_{r1skew} \quad (2\text{-}109)$$

$$= 1.7597 + 0.2121 = 1.972\ \Omega$$

2.9 Losses and Efficiency

Efficiency η is defined as the output divided by the input power and is given by the expression,

$$\eta = P_{out} / P_{in} = P_{out} / (P_{in} + \sum \text{losses}) \quad (2\text{-}110)$$

The loss components are

$$\sum \text{losses} = P_{Co} + P_{A1} + P_{iron} + P_{mv} + P_{stray} \quad (2\text{-}111)$$

Where P_{Co} is the stator winding losses and is equal to

$$P_{Co} = 3 \times R_s \times I_{1n}^2 \quad (2\text{-}112)$$

$$= 3 \times 1.575 \times 11.103^2 = 580.642\ \text{W}$$

And P_{A1} is the rotor cage losses, therefore

$$P_{A1} = 3 \text{ x } (R_r)_{Sn} \text{ x } I_{rn}^2 = 3 \text{ x } R_r \text{ x } K_I^2 \text{ x } I_{1n}^2 \quad (2\text{-}113)$$

$$= 3 \text{ x } 0.598 \text{ x } 0.88^2 \text{ x } 11.103^2 = 170.826 \text{ W}$$

The mechanical/ventilation losses $P_{mv} = 0.03 \text{ x } P_n$ (2-115)

Therefore for $P_1 = 1$,

$$P_{mv} = 0.03 \text{ x } 5280 = 158.4\text{W}$$

The stray losses $P_{stray} = 0.01 \text{ x } Pn$ (2-114)

Therefore $P_{stray} = 0.01 \text{ x } 5280 = 52.8 \text{ W}$

The iron core losses are complicated and are composed of the fundamental P^1_{iron} and additional P^h_{iron} (harmonics) loss. The fundamental core losses occur only in the teeth and back iron (P_{t1}, P_{y1}) of the stator as the rotor (slip) frequency is low ($f_2 < (3 – 4)$ Hz). (2-115)

Therefore $P_{t1} = K_t \text{ x } P_{10} \text{ x } (f_1 / 50)^{1.3} \text{ x } B_{ts}^{1.7} \text{ x } G_{t1}$ (2-116)

Where P_{10} is the specific losses in W / Kg at 1.0 Tesla and 50 Hz (P_{10}=(2-3)) W / Kg , γ_{iron} =

7800 and K_t = (1.6 – 1.8) is the core loss augmentation for mechanical working. (2-117)

The stator tooth weight Gt1 is

$$G_{t1} = \gamma_{iron} \text{ x } N_s \text{ x } b_{ts} \text{ x } (h_s + h_w + h_{os}) \text{ x } L \text{ x } K_{Fe} \quad (2\text{-}118)$$

$$= 7800 \text{ x } 36 \text{ x } 3.344 \text{ x } 10^{-3} \text{ x } (15 + 1.5 + 1) \text{ x } 10^{-3} \text{ x } 95.7 \text{ x } 10^{-3} \text{ x } 0.96$$

$$= 1.5304 \text{ Kg}$$

From Equation 2-116 P_{t1} is

$$P_{t1} = 1.7 \text{ x } 2 \text{ x } (50 / 50)^{1.3} \text{ x } 1.6^{1.7} \text{ x } 1.5304 = 11.569 \text{ W}$$

Similarly the stator back iron (yoke) fundamental losses Py1 is

$$P_{y1} = K_y \text{ x } P_{10} \text{ x } (f_1 / 50)^{1.3} \text{ x } B_{cs}^{1.7} \text{ x } G_{y1} \quad (2\text{-}119)$$

Where K_y = 1.6 -1.9 takes care of the influence of mechanical machining. Let K_y = 1.6. And Gy1 is

$$G_{y1} = \gamma_{iron} \text{ x } (\pi / 4) \text{ x } (D_{out}^2 - (D_{out} - 2 \text{ x } h_{cs})^2) \text{ x } L \text{ x } K_{Fe} \quad (2\text{-}120)$$

$$= 7800 \text{ x } (3.14 / 4) \text{ x } (180^2 - ((180 - 2 \text{ x } 20.4) \text{ x } 10^{-3})^2) \text{ x } 95.7 \text{ x } 10^{-3} \text{ x } 0.96$$

$$= 7.658 \text{ Kg}$$

Now from Equation 2-119 P_{y1} is

$$P_{y1} = 1.6 \text{ x } 2 \text{ x } (50 / 50)1.3 \text{ x } 1.51.7 \text{ x } 7.658 = 45.515 \text{ W}$$

Therefore the fundamental iron losses P^1_{iron} is

$$P^1_{iron} = P_{t1} + P_{y1} \quad (2\text{-}121)$$

$$= 11.569 + 45.515 = 53.084 \text{ W}$$

The stray losses P^S_{iron} are made up of the tooth flux pulsation losses, therefore P^S_{iron} is

$$P^S_{iron} = 0.5 \text{ x } 10^{-4} \text{ x } ((N2 \text{ x } (f_1/P_1) \text{ x } K_{ps} \text{ x } B_{ps})^2 \text{ x } G_{ts} + (N_s \text{ x } (f_1/P_1) \text{ x } K_{pr} \text{ x } B_{pr})^2 \text{ x } G_{tr}) \quad (2\text{-}122)$$

Where the quantities K_{ps}, B_{ps}, G_{ts}, K_{pr}, B_{ps} and G_{tr} are as follows,

$$K_{ps} = 1 / (2.2 - B_{ts}) \quad (2\text{-}123)$$

Therefore $K_{ps} = 1 / (2.2 - 1.6) = 1.667$

$$B_{ps} = (Kc2 - 1) / B_g \quad (2\text{-}124)$$

$$B_{ps} = (1.061 - 1) / 0.58 = 0.0353 \text{ T}$$

And $K_{pr} = 1 / (2.2 - B_{tr})$ (2-125)

$$K_{pr} = 1 / (2.2 - 1.6) = 1.667$$

$$B_{pr} = (Kc1 - 1) / Bg \quad (2\text{-}126)$$

$$B_{pr} = (1.140 - 1) / 0.58 = 0.0817 \text{ T}$$

The rotor teeth G_{tr} is

$$G_{tr} = \gamma_{iron} \text{ x } L \text{ x } K_{Fe} \text{ x } N2 \text{ x } (h_r + ((d_1 + d_2) / 2) \text{ x } b_{tr} \quad (2\text{-}127)$$

$$G_{tr} = 7800 \times 95.7 \times 10^{-3} \times 0.96 \times 30 \times (19.4 + ((5.9 + 1.8)/2) \times 10^{-3} \times 3.99 \times 10^{-3}$$

$$G_{tr} = 2.043 \text{ Kg}$$

And $$G_{ts} = G_{t1} = 1.530 \text{ Kg}$$

Therefore from Equation 2-122 P^S_{iron} is

$$P^S_{iron} = 0.5\times10^{-4} \times ((30 \times (50/1) \times 1.667 \times 0.0353)^2 \times 1.53 + (36 \times (50/1) \times 1.667 \times 0.0817)^2 \times 2.043$$

$$P^S_{iron} = 6.7 \text{ W}$$

Therefore the total core loss P_{iron} is

$$P_{iron} = P^1_{iron} + P^S_{iron} \qquad (2\text{-}128)$$

$$P_{iron} = 53.084 + 6.7 = 59.8 \text{ W}$$

And from Equation 2-111 the summation of all losses $\sum$ losses is

$$\sum \text{losses} = 580.642 + 170.826 + 158.4 + 52.8 = 1022.480 \text{ W}$$

From Equation 2-110 the efficiency η is

$$\eta = 5280 / (5280 + 1022.480) = 0.84$$

The efficiency η_n used in the design of the motor was $\eta_n = 0.85$ which is very close to the calculated efficiency $\eta = 0.84$, therefore the design is acceptable. However it should be noted that if the calculated efficiency η had been much smaller than the design efficiency η_n then the design would not have been accepted and design calculations would have started right from step one of the algorithm.

2.10 Operation Characteristics

Operating characteristics were calculated to see if the design power factor Cos φ_{1n} was achieved.

The operation characteristics are the active no load current I_{0a}, rated slip S_n, rated torque T_n, breakdown slip and torque S_k, T_{bk}, current I_s and power factor versus slip, starting current, and torque I_{LR}, T_{LR}.

The no load current I_{0a} is given by the no load losses as follows;

$$I_{0a} = (P_{iron} + P_{mv} + (3 \times I_0^2 \times R_s)) / (3 \times V_{ph}) \qquad (2\text{-}129)$$

$$I_{0a} = (59.8 + 158.4 + (3 \times 2.55 \times 1.57)) / (3 \times 219.393) = 0.350 \text{ A}$$

The rated slip S_n is

$$S = P_{A1} / (P_n + P_{A1} + P_{mv} + P_{stray}) \qquad (2\text{-}130)$$

$$S = 170.826 / (5280 + 170.826 + 158.4 + 52.8) = 0.03$$

The value of the design slip is $S_n = 0.05$, therefore the design is acceptable since the calculated value $S < 0.05$.

The rated shaft torque T_n is

$$T_n = P_n / (2 \times \pi \times (f_1 / P_1) \times (1 - S) \qquad (2\text{-}131)$$

$$T_n = 5280 / (2 \times 3.14 \times (50 / 1) \times (1 - 0.03) = 17.34 \text{ Nm.}$$

The torque versus slip expression is given by the equation,

$$T_e = (3 \times P_1 / \omega_1) \times ((V_{ph}^2 \times (R_r / S)) / ((R_s + C_m \times (R_r / S))^2 + (X_{s1} + C_m \times X_{r1})^2) \qquad (2\text{-}132)$$

Where $C_m = 1 + X_{s1} / X_m$ (2-133)

$$C_m = 1 + 2.021 / 84 = 1.0241$$

Therefore from (2-132) the breakdown torque T_{bk} is

$$T_{bk} = (3 \times P_1 / 2 \times \omega_1) \times ((V_{ph}^2) / (\sqrt{}(R_s^2 + (X_{s1} + C_1 \times X_{r1})^2) \qquad (2\text{-}134)$$

And $C_1 = 1.1658 \times C_m$ (2-135)

$$C_1 = 1.1658 \times 1.0241 = 1.1939$$

From Equation 2-134 T_{bk} is

$$T_{bk} = (3 \times 1 / (2 \times 314)) \times ((219.393)2 / (\sqrt{}1.5702 + (2.021 + 1.1939 \times 1.7597)2)$$

$$T_{bk} = 38.74 \text{ Nm}$$

The starting current I_{LR} is

$$I_{LR} = (V_{ph} / \sqrt{}((R_s + R_r^{S=1})^2 + (X_{s1}^{S=1} + X_{r1}^{S=1})^2 \quad (2\text{-}136)$$

$$I_{LR} = (219.393 / \sqrt{}((1.570 + 0.614)^2 + (1.516 + 1.145)^2) = 63.75 \text{ A}$$

The starting torque T_{LR} is

$$T_{LR} = ((3 \text{ x } R_r^{S=1} \text{ x } I_{LR}^2) / \omega 1) \text{ x P1} \quad (2\text{-}137)$$

$$T_{LR} = ((3 \text{ x } 0.614 \text{ x } 63.75^2 / 314) \text{ x } 1 = 23.83 \text{ Nm}$$

The rated power factor Cos φ_{1n} is

$$\text{Cos } \varphi_{1n} = P_n / (3 \text{ x } V_{ph} \text{ x } I_n \text{ x } \eta) \quad (2\text{-}138)$$

$$\text{Cos } \varphi_{1n} = 5280 / (3 \text{ x } 219.393 \text{ x } 11.103 \text{ x } 0.84) = 0.86$$

The calculated power factor Cos φ_{1n} = 0.86 is above the design value of Cos φ_{1n} = 0.85. Therefore the design is acceptable.

The other quantities of interest are the ratios of breakdown torque to rated torque t_{bk}, the starting torque to the rated torque t_{LR} and the starting current to the input current i_{LR}, therefore,

$$t_{bk} = T_{bk} / T_n \quad (2\text{-}139)$$

$$t_{bk} = 38.74 / 17.34 = 2.2$$

$$t_{LR} = T_{LR} / T_n \quad (2\text{-}140)$$

$$t_{LR} = 23.89 / 17.34 = 1.4$$

$$i_{LR} = I_{LR} / I_{1n} \quad (2\text{-}141)$$

$$i_{LR} = 63.75 / 11.103 = 5.7$$

2.11 Temperature Rise

The temperature rise of the induction motor in operation was is very important and it was calculated to prove that it was below that of insulation class F, even though the motor was designed for class F insulation. The temperature rise must not exceed the design class for the design to be thermally valid.

To start with the temperature differential between the conductors in slots and the slot wall $\Delta\theta_{co}$ was calculated as follows;

$$\Delta\theta_{co} = P_{co} / (\alpha_{cond} \text{ x } A_{1s}) \quad (2\text{-}142)$$

The frame temperature rise $\Delta\theta_{frame}$ with respect to ambient air was determined as follows;

$$\Delta\theta_{frame} = \sum \text{losses} / (\alpha_{cond} \text{ x } A_{frame}) \quad (2\text{-}143)$$

Where $\alpha_{cond} = \lambda_{ins} / h_{ins}$ (2-144)

And $\lambda_{ins} = 0.25$ is the insulation thermal conductivity in (W / m^2 x K) (2-145)

$h_{ins} = 3 \text{ x } 10^{-4}$ is the total insulation thickness from the slot middle to the teeth of the wall (2-144)

and α_{cond} is the slot insulation conductivity plus its thickness lumped together.

Therefore from (2-144) α_{cond} is

$$\alpha_{cond} = 0.25 / 3 \text{ x } 10^{-4} = 833 \text{ W / m}^2\text{K}$$

The stator slot lateral area A_{1s} is

$$A_{1s} = (2 \text{ x } h_s + b_{s2}) \text{ x L x N1} \quad (2\text{-}146)$$

$$A_{1s} = (2 \text{ x } 15.2 + 8.62) \text{ x } 10^{-3}) \text{ x } 95.7 \text{ x } 10^{-3} \text{ x } 36 = 134.7 \text{ x } 10^{-3} \text{ m}^2$$

The frame area A_{frame} is

$$A_{frame} = \pi \text{ x } D_{out} \text{ x } (L + \tau) \text{ x } K_{fin} \quad (2\text{-}147)$$

Where $K_{fin} = 2.0$, is the frame area multiplied by number of fins.

Therefore from Equation 2-147 A_{frame} is

$$A_{frame} = 3.14 \text{ x } 180 \text{ x } 10^{-3} \text{ x } (95.7 + 159.4) \text{ x } 10^{-3} \text{ x } 2 = 432.5 \text{ x } 10^{-3}\text{m}^2$$

From Equation 2-112, 2-144 and 2-146 $\Delta\theta_{co}$ is

$\Delta\theta_{co} = 580.642 / (833 \times 134.7 \times 10^{-3}) = 5.17°C$

From Equation 2-142, $\alpha_{cond} = P_{co}/(60$ (for 2P1=2) X $\Delta\theta_{frame})$ $\Delta\theta_{frame}$ is

$\Delta\theta_{frame} = 1022.480 / (60 \times 432.5 \times 10^{-3}) = 39°C$

Now if ambient temperature $\theta_{amb} = 40°C$, then θ_{co} is

$$\theta_{co} = \theta_{amb} + \Delta\theta_{co} + \Delta\theta_{frame} \qquad (2\text{-}148)$$

Therefore $\theta_{co} = 40 + 5.17 + 39 = 84.17°C > 80°C$

The conductor temperature $\theta_{co} = 84.17°C$ is above class F insulation by 4.17°C, which is acceptable and therefore the design is acceptance. In most instances the desire is to design for a conductor temperature less than the insulation allowable temperature. In this design too this can be achieved by reducing the ambient temperature or increasing the area of cooling.

2.12 Shaft Power and Input Power calculations

The pump driving power P is the energy E imparted on the fluid equal to the flow rate Q multiplied by the pressure difference H [16]. Therefore energy E is

$$E = \rho \times g \times H \times Q \qquad (2\text{-}149)$$

Now $E = P = 0.163 \times s \times H \times Q$ (2-150)

$g = 9.8$, s is the specific gravity, $H = 40$ m (1-2), $Q = 32\ m^3/hr$ (1-1)

Therefore $P = 0.163 \times 1 \times 40 \times 32 / 60 = 3.48$ kW

Now the shaft power P_s = P / Pump efficiency, pump efficiency = 0.66 (Equation 1-4) (2-151)

Therefore $P_s = 3.48 / 0.66 = 5.272$ kW

The motor capacity P_m [16] is equal to the input power P_{1n}. Therefore P_m ($=P_{1n}$) is

$$P_m = (1 + d) \times P_s \text{ [16]} \qquad (2\text{-}152)$$

Where d = 0.25 [16], therefore P_{1n} is

$P_{1n} = (1 + 0.25) \times 5272 = 6.6$ kW

2.13 Motor Speed

The motor speed n is

$$n = n_s \times (1 - 0.06) \text{ for a type 6 motor [16]} \quad (2\text{-}153)$$

Where n_s is synchronous speed and is equal to ns = 120 x f1 / 2 (2-154)

Therefore $n_s = 120 \times 50 / 2 = 3000$ rpm

Therefore $n = 3000 \times (1 - 0.06) = 2820$ rpm

2.14 Rotor Inertia

Rotor inertia is made up the shaft and rotor core components;

The shaft dimensions are

Diameter = 22 mm (2-155)

Length = 244.3 mm (2-156)

Therefore Weight = 0.7287 Kg [10]

Now center of gyration = $(\text{Radius})^2 = (22 / 2 \times 10^{-3})^2$ (2-157)

Moment of Inertia I = Weight x $(\text{Radius})^2$ (2-158)

Therefore $I_{ns} = 0.7287 \times (11 \times 10^{-3})^2 = 0.00008817\ K_{gm}^2$

The core dimensions are

Diameter = 101.5 mm (2-159)

Length = 95.7 mm (2-160)

Therefore Weight = 6 Kg

And center of gyration = $(101.5 / 2 \times 10^{-3})^2$ (2-161)

Then I_{nc} = 6 x (50.75 x 10-3)2 = 0.01545337 K_{gm}^2

The value of the core inertia I_{nc} = 0.0155 K_{gm}^2 is with the assumption that the whole rotor core is made of steel, but this is not so. Almost half of the core will be made of aluminium which is much lighter than steel. Therefore if the weight of aluminium is considered insignificant compared to steel then the rotor inertial is only half the calculated value therefore Inc = 0.00775 K_{gm}^2

Therefore the rotor inertia $I_{nr} = I_{nc} + I_{ns}$ (2-162)

$$I_{nr} = 0.00775 + 0.00008817 = 0.007838\ K_{gm}^2$$

2.15 Induction Motor Design Validation

The motor parameters calculated in this design were compared to that of the electric motor of Flygt 2102.041 pump (Appendix D). Below is the comparison.

Table 2-3 Flygt Pump 2102.041 Motor Parameters versus UNZA Pump Motor Parameters

	Electric motor parameters		Flygt 2102.041	UNZA motor
1	Frequency	Hz	50	50
2	Poles		2	2
3	Number of phases		3	3
4	Rated speed	rpm	2810	2820
5	Rated voltage	Volts	400	380
6	Rated current	A	10.0	11.10
7	Rated output power	kW	5.2	5.28
8	Rated input power	kW	6.7	
	The values are valid at 75°C		Flygt 2102.041	UNZA motor
1	Output power	kW	5.2	5.28

2	Input power	kW	6.7	6.6
3	Efficiency	%	77	84
4	Current	A	10	11.1
5	Power factor		0.93	0.86
6	Torque	Nm	18.0	17.4
7	Speed	rpm	2810	2820
8	No load current	A	2.0	2.55
9	Power factor at no load		0.28	
10	Break away starting current	A	66	63
11	Starting torque	Nm	28	24
12	Max: torque / Rated torque	Nm	40	38
13	Speed at max torque	rpm	2060	
14	Rotor inertial	Kgm2	0.0077	0.0078
15	Iron losses	W	130	53
16	Friction losses	W	75	
17	Max: torque / Rated torque t_{bk}		2.3	2.2
18	Starting torque / Rated torque t_{LR}		1.6	1.4
19	Starting current / Rated current i_{LR}		6.3	5.7

The objective of this Master's work which was to design a motor with a rated power of 5280 W, rated speed of 2890 and rated slip of 3.6% was met. However a few assumptions were made in the process for example the requirement to have the teeth width greater than 3.5 mm fell short and the actual achievable value of 3.3 mm was acceptable being very close to 3.5 mm.

The conductor temperature exceeded the limit value by 4°C which is not desirable, but acceptable since this is a very small rise in temperature and it is in very rare times that the motor will be expected to operate at maximum temperatures.

In table 2-3 it is clear that the UNZA pump motor is very close to the Flygt pump B2102.041 motor. The Flygt pump B2102.041 motor was recommended by both Nyirenda [1] and Steman [2] to retrofit the UNZA pump. The electric motor designed in this Master's work therefore meets the expectations and should be developed into a physical motor by later studies.

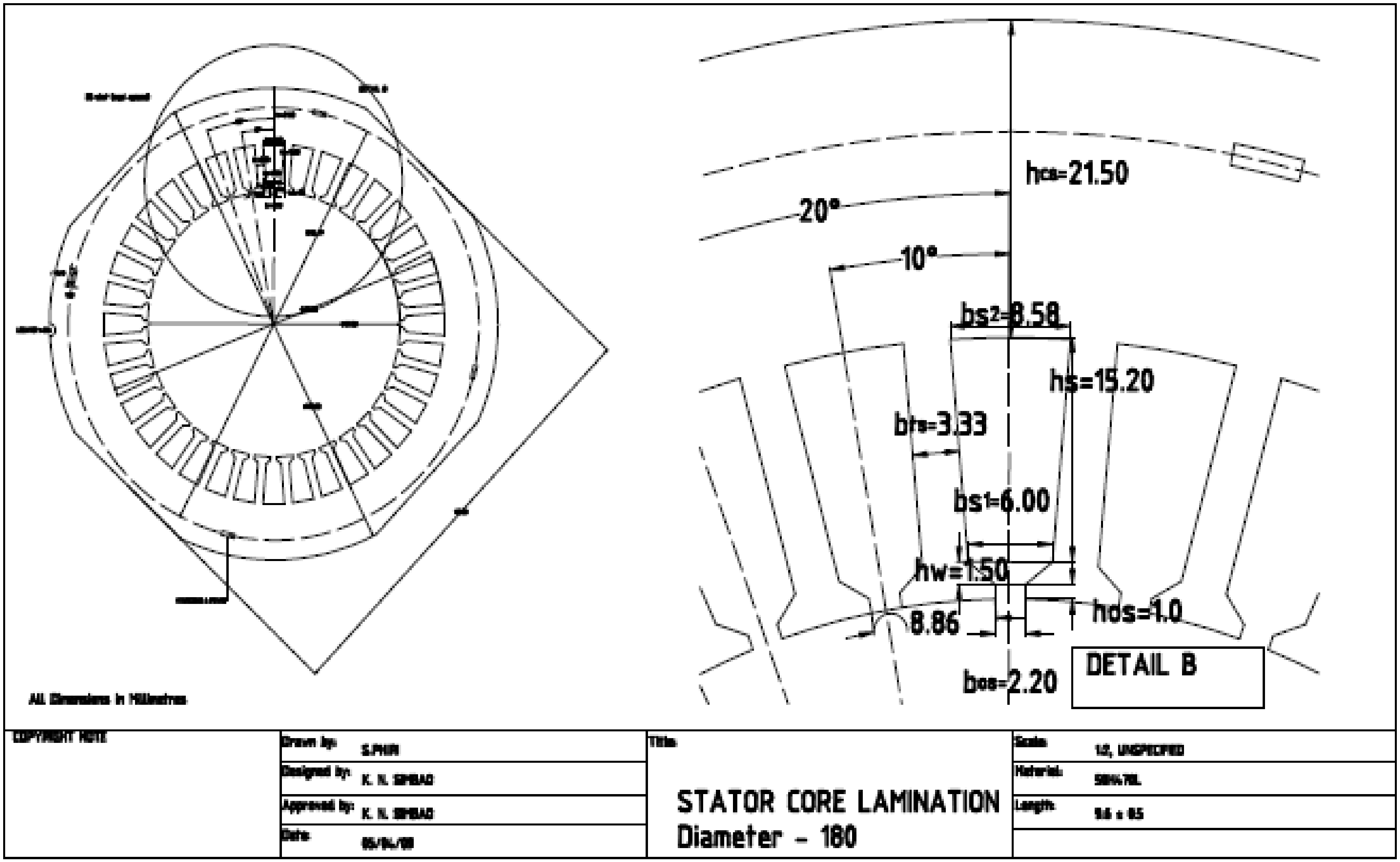


Figure 2-6 Stator Lamination

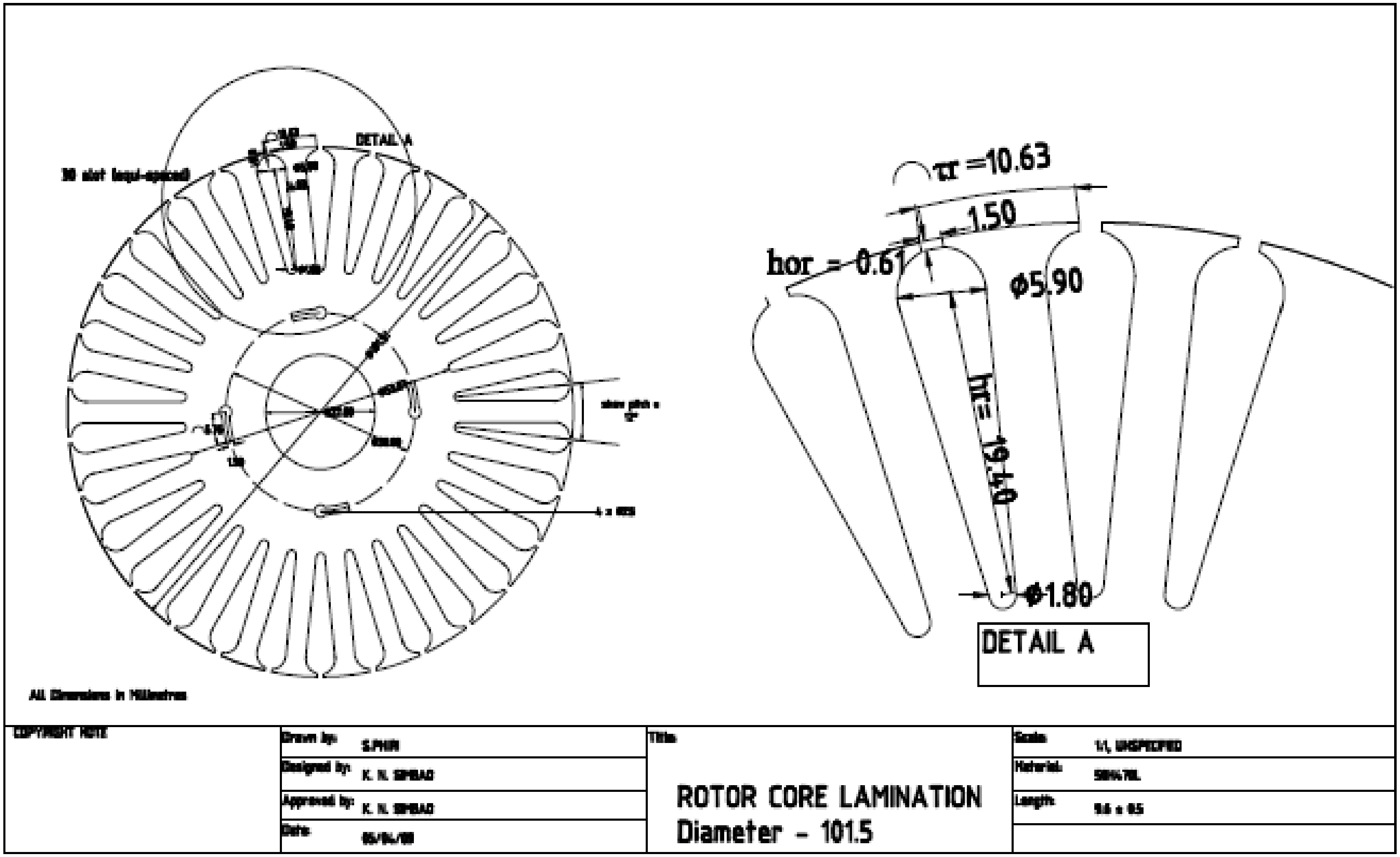


Figure 2-7 Rotor Lamination

2.17 The Wiring Diagram

The wiring diagram of the motor was designed with a pitch factor of 15/18 [15]. This was to reduce significantly the 5^{th} and 7^{th} harmonics of the motor to such a level that they have negligible effect on the generated voltage. The pitch factor of 15/18 also made the span of the coils equal to 15 instead of 18 slots. This design is called fractional pitch and is preferred over the full pitch because the generated waveform closely approximates the sinusoidal waveform.

In designing the wiring of the induction motor, the following steps were followed:

1. The number of slots was determined, as explained in the design of the stator lamination.

2. A whole-coiled lap winding configuration was used. In this winding there are as many coils as there are slots.

3. The coil span was determined by using a pitch factor of 15/18 as explained above.

4. The number of coils per phase which is the same as the slots per phase was determined.

5. The number of coils in each pole group per phase equals to slots/(poles x phases) was determined.

6. The motor was designed for a star connection so as to automatically eliminate third harmonics and all its multiples.

7. This electric motor being designed for a two pole machine, the coils were connected for simplex lap winding.

The wiring diagram for this motor is shown in Figure 2-8.

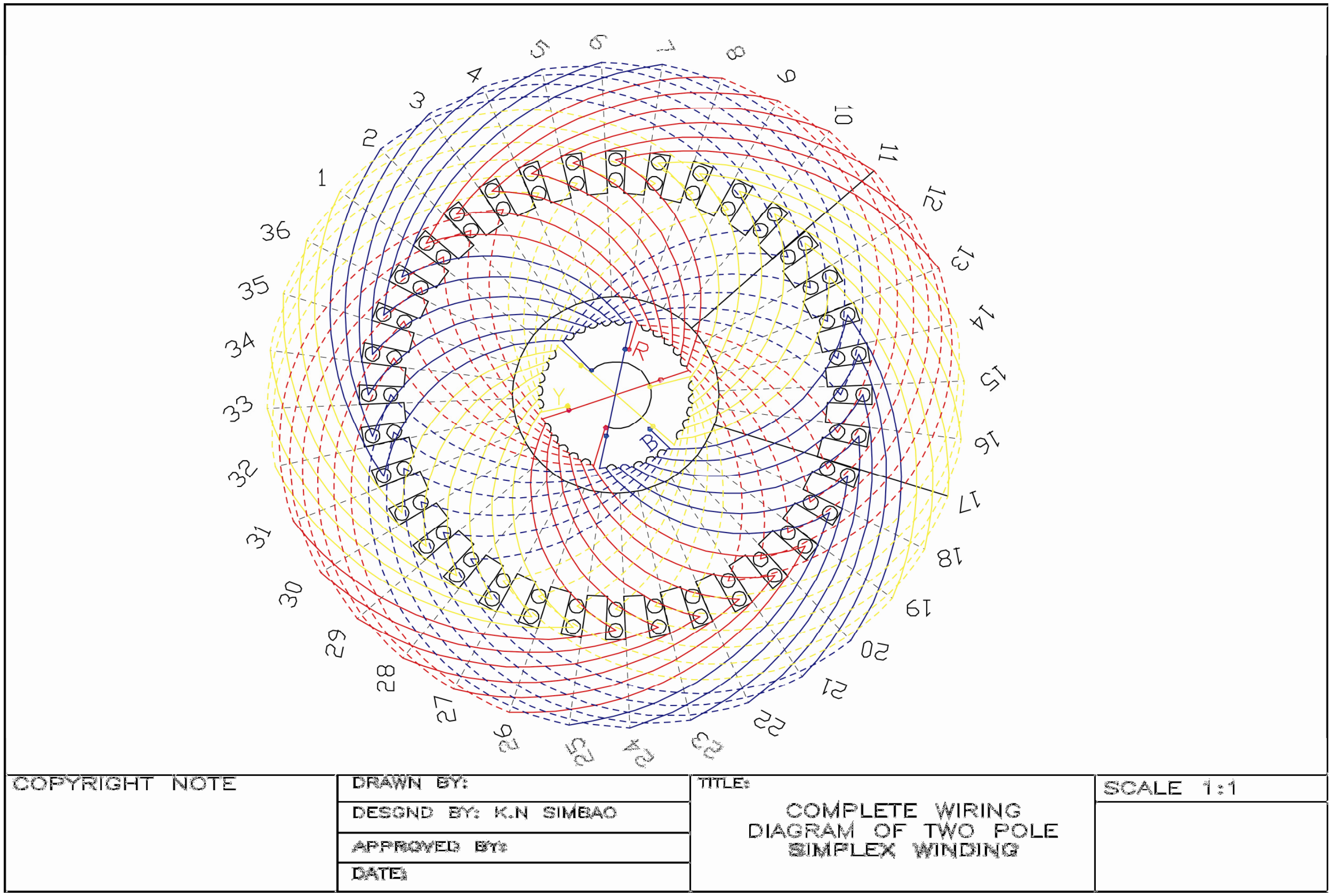


Figure 2-8 Wiring Diagram of the Stator Winding

The wiring diagram in Figure 2-8 above is for the 5.28 kW 2 pole 380 volts 50 hertz 2820 rpm electric motor design for the UNZA pump. The diagram also shows the simplex lap connections of the coils and the three phase star connection.

The diameter of the stator in Figure 2-6 is bigger than the allowed space in the design of the pump by Nyirenda [1]. It was therefore necessary to redesign the outer cover, motor casing, the bottom bearing housing section and the shaft, see Figures 2-9, 2-10, 2-11, 2-12, and 2-13.

1. Figure 2-9 gives the original dimensions of the electric motor casing design [1].
2. Figure 2-10 gives the original pump-motor unit casing assembly and dimensions for the UNZA pump [1].
3. Figure 2-11 gives the modified dimensions of the electric motor casing.
4. Figure 2-12 gives the modified pump-motor unit casing assembly and dimensions for the UNZA pump unit.
5. Figure 2-13 gives the modified centrifugal pump casing.

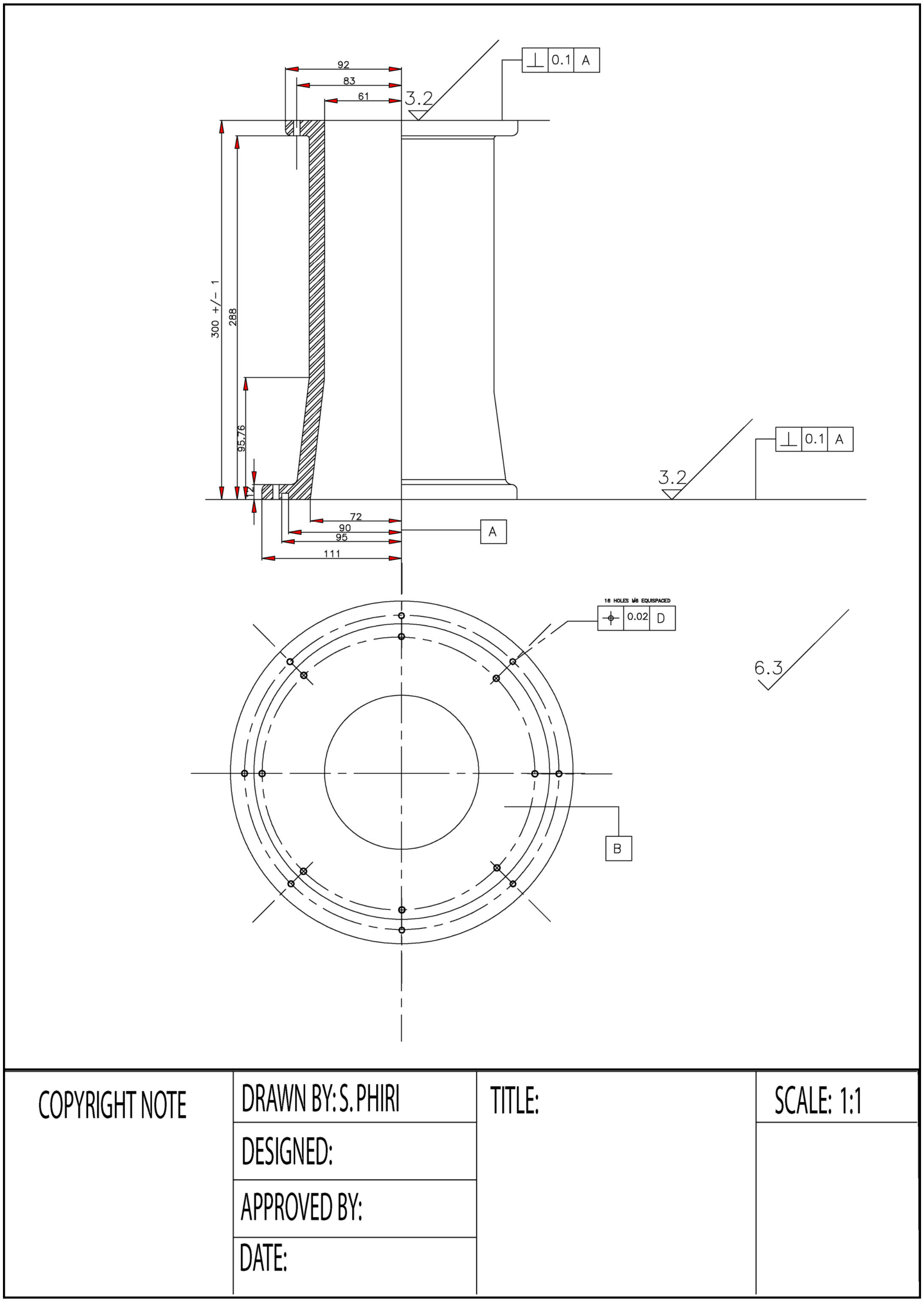


Figure 2-9 Original Electric Motor Casing

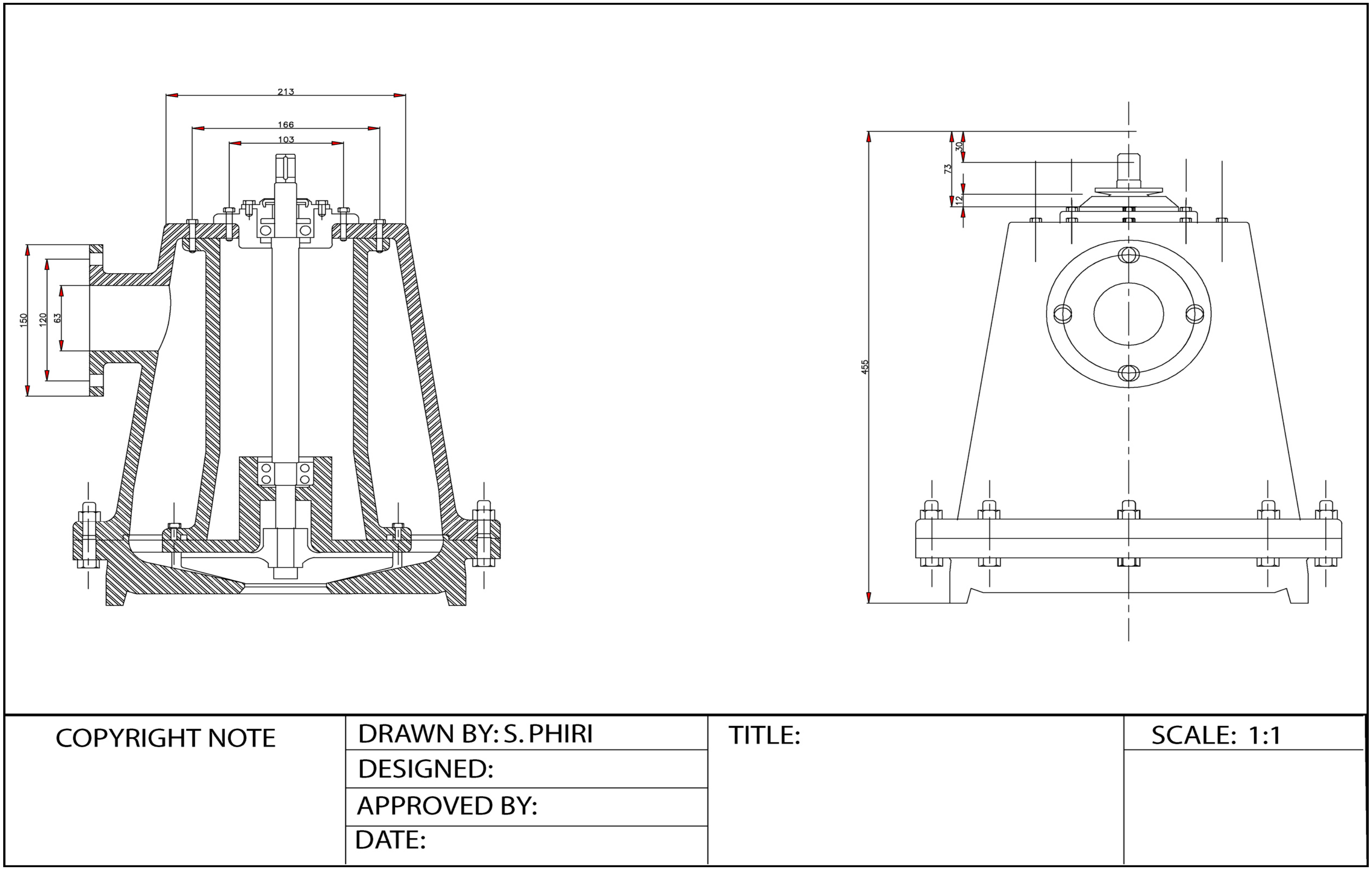


Figure 2-10 Pump and Motor Casing Dimensions

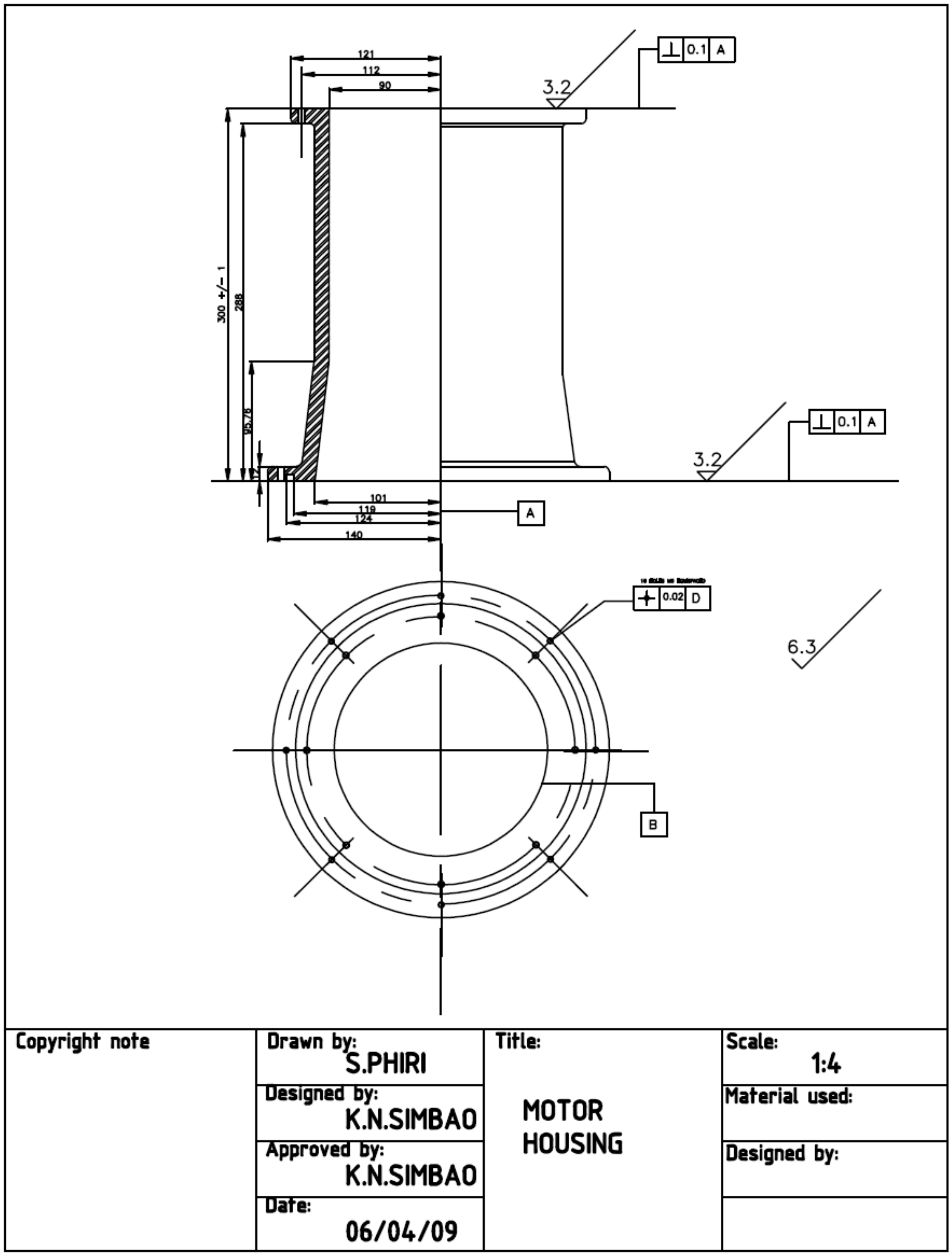
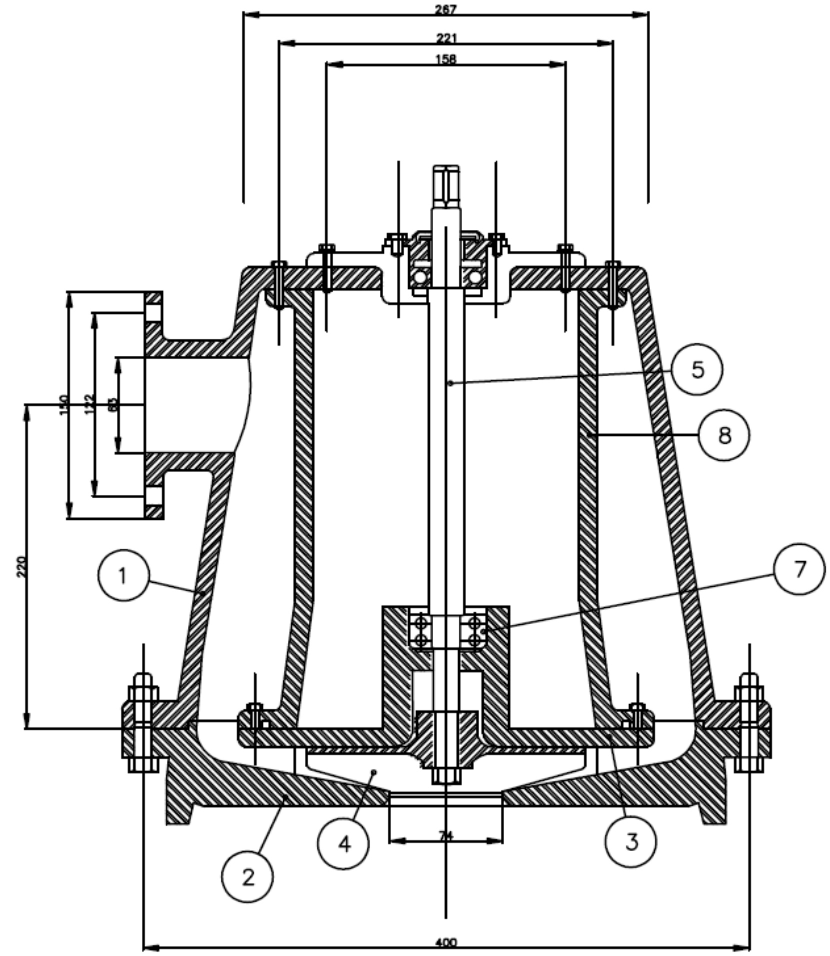


Figure 2-11 Modified Electric Motor Casing to suit the New Stator Dimensions Requirements



POS	ITEM	DRAWING NO.	MATERIAL	NOTICE
8	MOTOR BOUSING	3	ALUMINIUM	
7	BEARING	ANGULAR CONTACT		SKF 3304–2FF
6	MECHANICAL SEAL			
5	SHAFT	7	EN 8	
4	IMPELLER	1	ALUMINIUM	
3	BEARING BOUSING	4	STEEL	
2	DIFFUSER CASING	2	ALUMINIUM	
1	OUTER COVER	5	ALUMINIUM	

Copyright note	Drawn by: S.PHIRI	Title: MOTOR HOUSING	Scale: 1:4
	Designed by: K.N.SIMBAO		Material used:
	Approved by: K.N.SIMBAO		
	Date: 06/04/09		

Figure 2-12 Modified Pump-Motor Casing for the New Stator Dimension Requirements

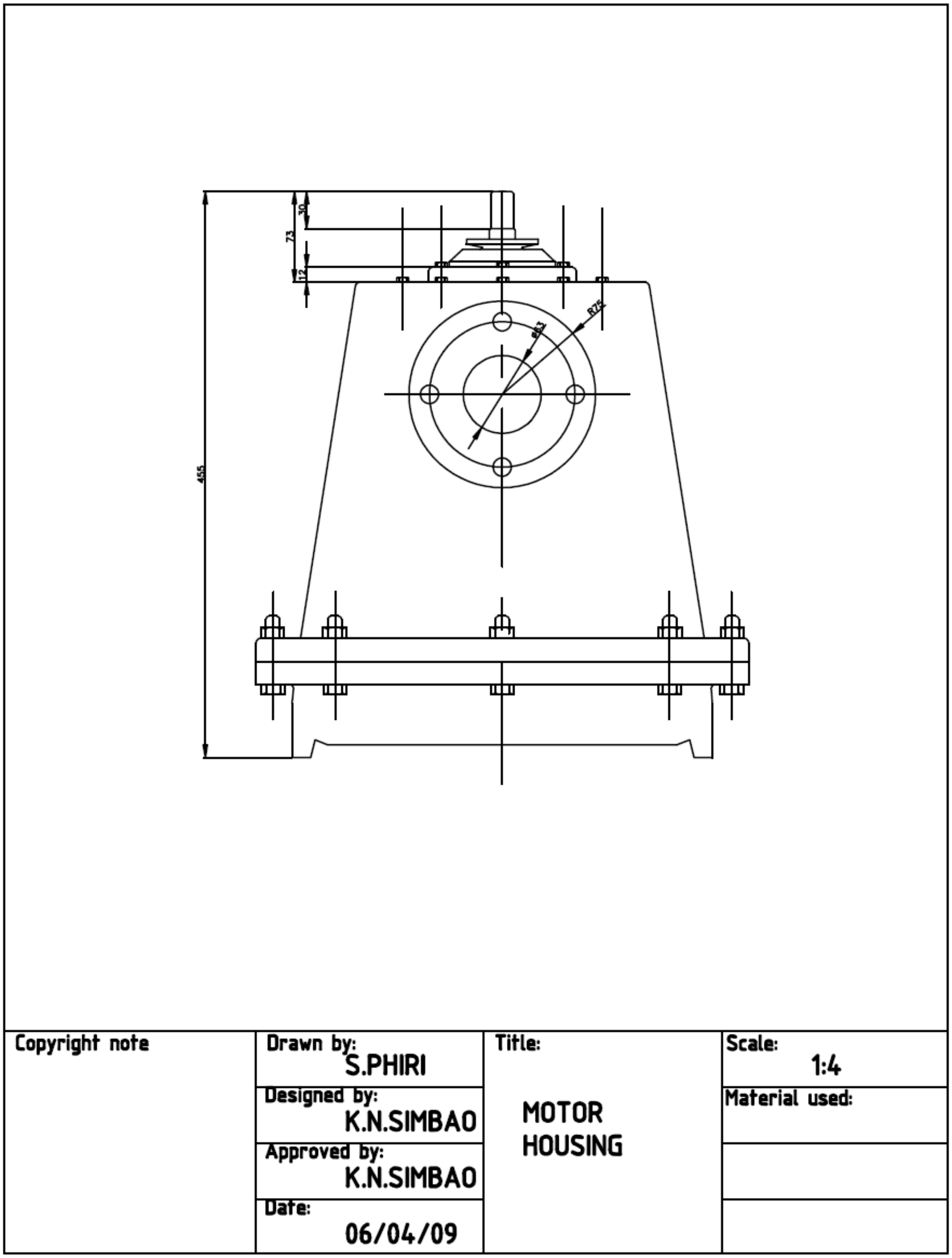


Figure 2-13 Modified Centrifugal Pump Casing

Chapter 3
Electric Motor Manufacture Proposition

3.1 Introduction

This chapter deals with the set up and operation of the electric motor manufacturing plant. It shows in detail the plant set up and personnel requirements. It also shows the expected cash flow for the plant.

It is important to note that a factory of this kind operates well as a hybrid layout combining cellular and process layouts.

In the beginning, the factory will produce squirrel cage electric motors by manufacturing in house, motor shafts, winding wire coils, and rotor and stator laminations from imported round bar steel stock, magnet wire and steel sheet respectively. Other items to be imported are the bearings. End covers, fans and fan covers will be outsourced from the foundries within Zambia.

The rotor will be made of a copper bar cage or an aluminium bar cage. In Zambia, therefore, with abundant copper, it is obvious that a copper bar cage rotor will be the most preferred but this is not so because aluminium carries a big advantage of weight and therefore is the front runner in rotor design. This design therefore will concentrate on production of aluminium squirrel cage rotors. The production of the aluminium cage rotors will require setting up a die casting foundry.

Later, the production of motor casings will entail putting up a foundry unit to cast motor casings and end covers [2].

The production of rotor and stator laminations will require the purchase of a laminate puncher. This is a press that carries a design die according to the laminate design and punches out laminates of rotor and stator design simultaneously from a roll of steel sheet.

The stator core windings will be formed on wire winders. These are machines which will carry a former according to the required coil pitch upon which the windings will be formed from a drum of magnet wire.

The factory will also have a machine shop with lathes, boring machines, electric power saws for cutting steel, arc and gas welding machines and vertical drilling machines for the manufacture of motor shafts and machining of motor casings and end covers.

The raw materials for the manufacture of the electric motor are:

1) sheet steel rolls,
2) magnet wire (winding wire),
3) aluminium bars,
4) copper bars,
5) round steel bar stock.
6) Varnish.

The outsourced components are:

1) bearings,
2) end covers,
3) motor casings and
4) end fans.

The basic processes involved in the manufacture of the electric motor are:

1) form coils from the magnet wire,
2) make rotor and stator perforated laminations from the sheet steel strip and
3) make shafts from the steel round bar stock.

The primary processes involve:

1) stacking the laminations into rotor and stator cores and welding the same,
2) winding the stator core using the preformed magnet wire coils,
3) place copper bars in the rotor slots, or cast aluminium in the rotor slots,
4) machine rotor to the right diameter,
5) shrink fit rotor on to the shaft.

The secondary processes involve:

1) placing the stator into the motor casing,
2) fitting the bearings on the shaft,
3) placing the rotor in the stator,
4) putting both end covers on the shaft and bolting it to the motor casing,
5) placing the end fan on to the shaft,
6) fixing the fan cover onto the shaft.

The final process involves:

1) meggering to ensure that the insulation on the wires has not been damaged,
2) connecting the three phase power supply to the motor terminals to check the performance by measuring load current and speed.

3.2 Work Flow Diagram

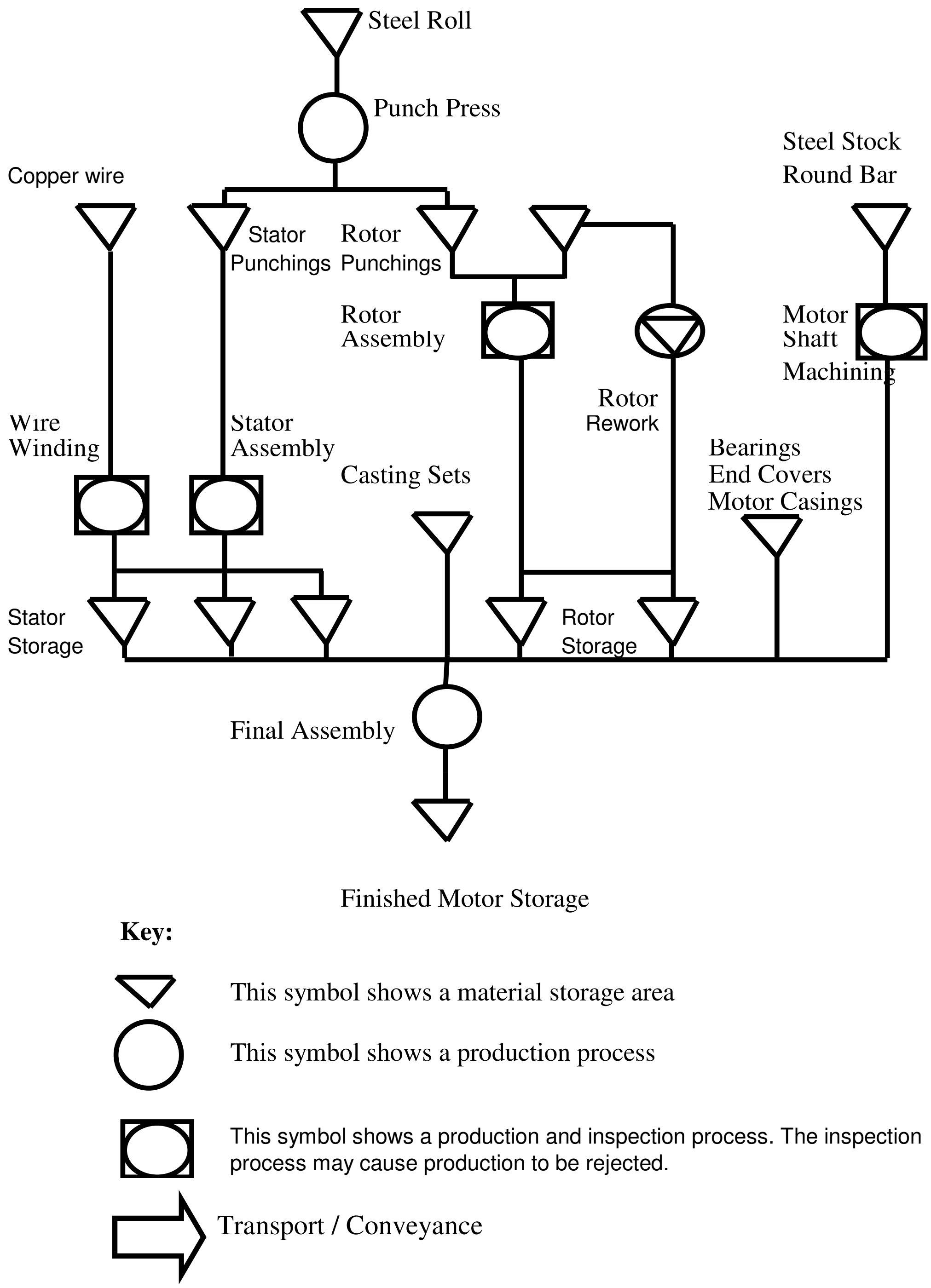


Figure 3-1 Work Flow Diagram for Electric Motor Manufacture

The work flow diagram in Fig. 3-1, gives the actual flow of raw materials and work in progress in the whole factory [4]. A loop for rework is provided in the rotor path at die-casting stage. This is because poor casts are sometimes made and therefore a rework is ordered. To avoid poor casts however, the aluminium bar stock must be kept clean in storage and handling.

In house produced parts are:

1. Stator core made of steel laminates
2. Rotor core made of steel laminates
3. Rotor shaft made of EN8 steel
4. Stator winding coils made from magnet wire
5. Aluminium bars cast or forced into the rotor

Parts ordered from other sources are:

1. Motor housing
2. Bearing housing
3. End covers
4. Bearings

3.2.1 Stator and Rotor Core Process Flow

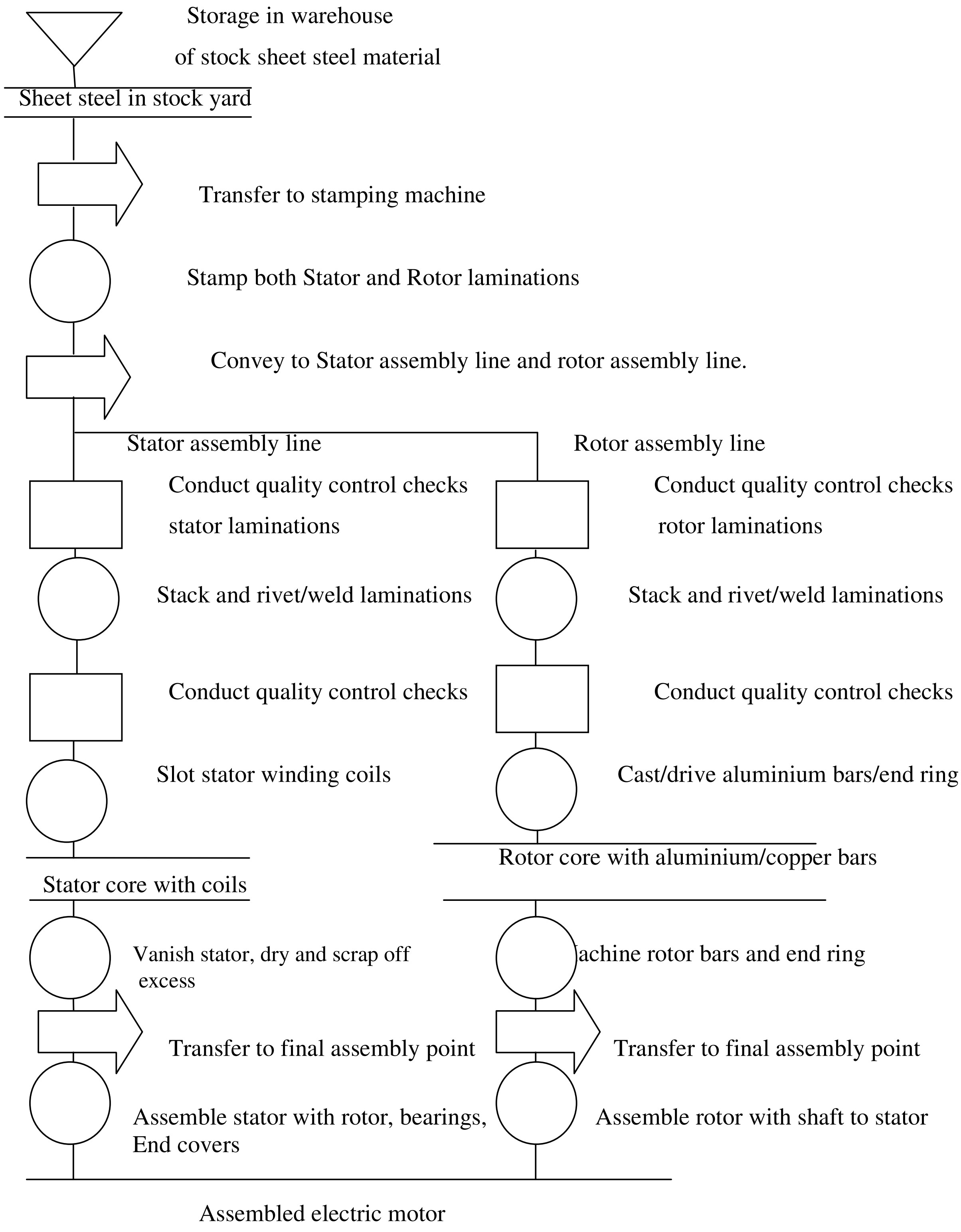


Figure 3-2 Stator and Rotor Process Flow

3.2.2 Rotor Shaft Process Flow

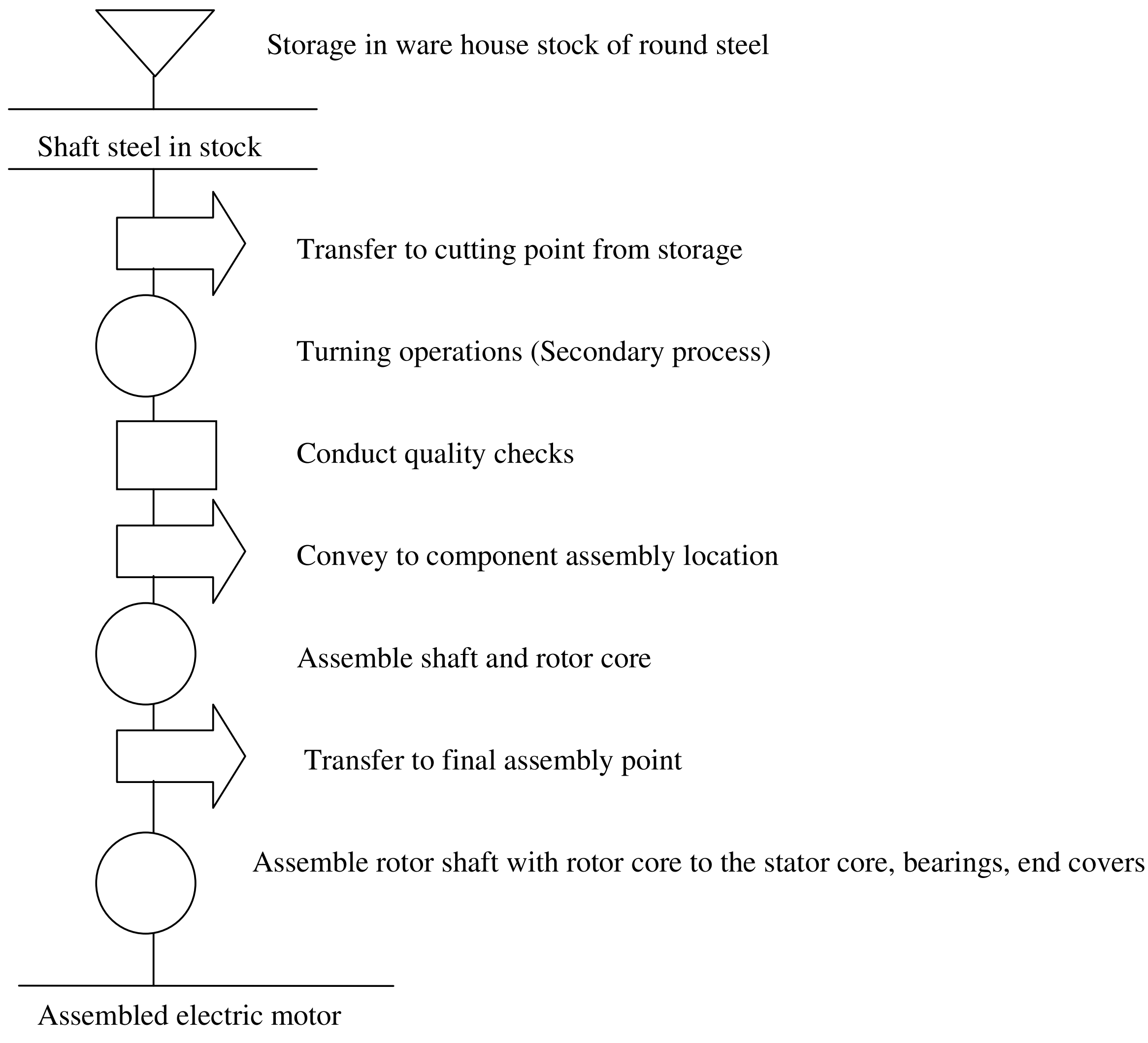


Figure 3-3 Rotor Shaft Process Line to Final Assembly Stage

3.2.3 Magnet Wire Coil Forming

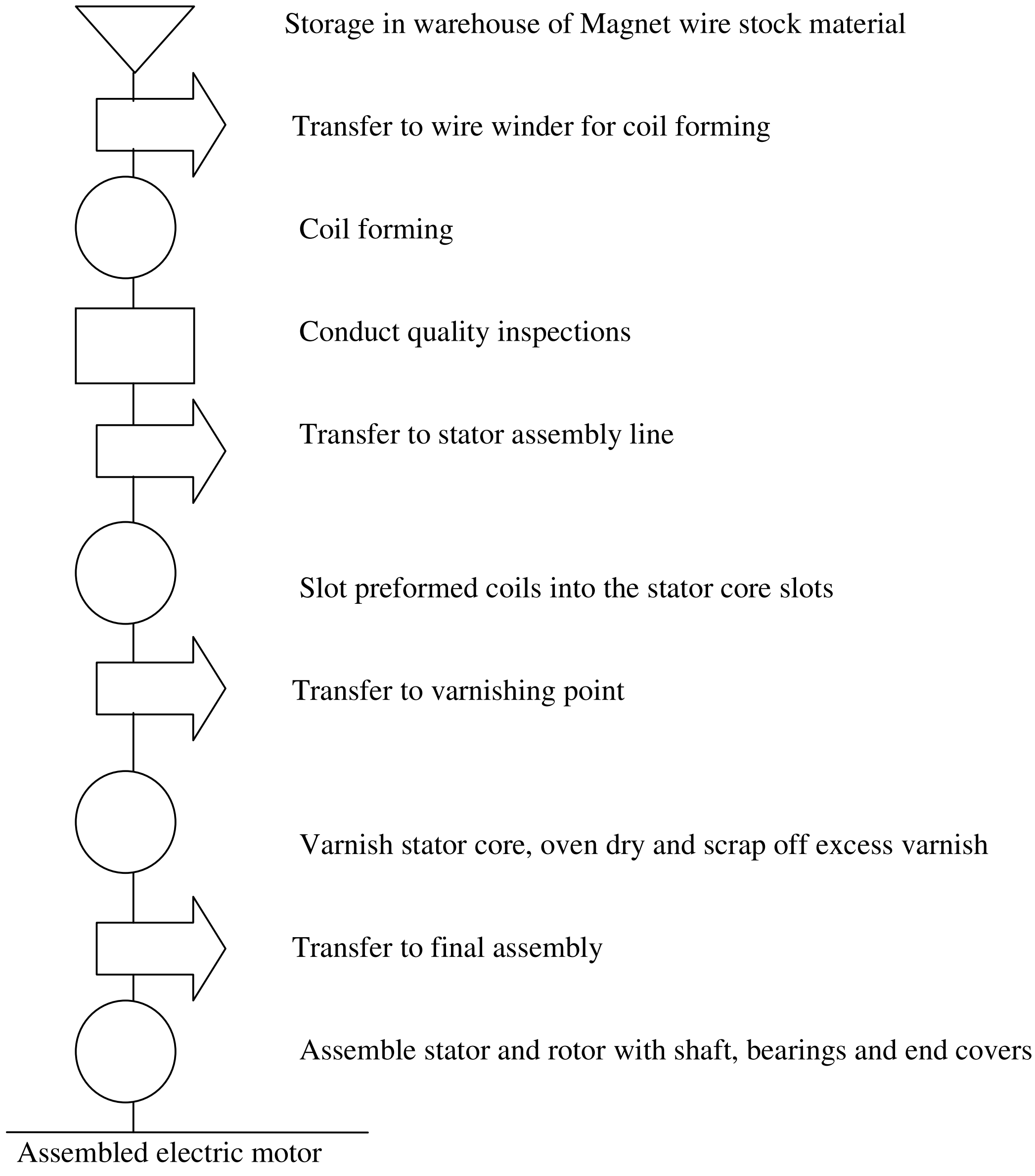


Figure 3-4 Magnetic Wire Coil Forming Process Flow to the Final Product

3.3 The Plant.

The Plant is a place where manufacturing takes place. A combination of cellular and process layout of the plant to be constructed for the manufacture of the squirrel cage induction motor in Zambia is as below.

3.3.1 The Combined Cellular and Process Plant Layout.

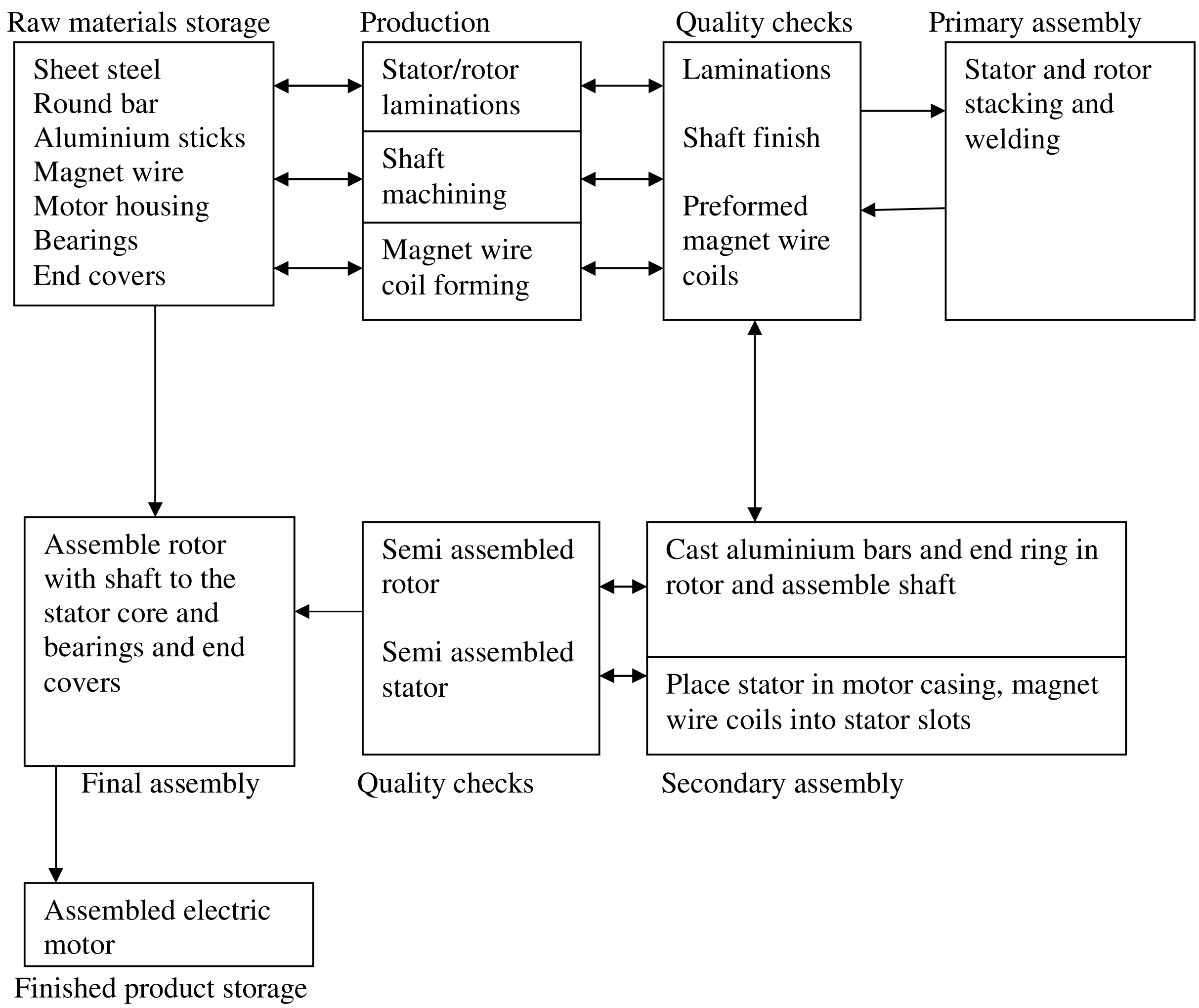


Figure 3-5 Plant Cellular and Process Layout.

The combined plant layout as shown in Figure 3-5 is the best set up in an electric motor manufacturing plant of this kind. This is because semi-finished products flow downstream for assembly and are checked for compliance and quality [5, 6].

3.4 The Organization

The company is organized in two sections, the administration and the plant.

3.4.1 The Administration.

The administration makes up the core management team of the company. It is the amalgamation of all the functions of the company at the top level and it is made up of the following officers:

1. The Chief Executive Officer

   The Chief Executive officer is the highest ranking corporate officer of the company and is responsible for its operations. The Chief Executive Officer oversees all the functions of the company especially Manufacturing, Finance, Marketing, Procurement and Human Resources.

2. The Plant Manager

   The Plant Manager reports to the Chief Executive Officer and is responsible for manufacturing. The Plant Manager oversees the departments of Production, Production Planning and Materials Control, Engineering and Quality Control.

3. The Chief Accountant

   The Chief Accountant reports to the Chief Executive Officer and is responsible for finances of the company.

4. The Marketing Manager

   The Marketing Manager reports to the Chief Executive Officer and is responsible for the marketing functions of the company. The Marketing Manager oversees the functions of sales, product promotion and customer relations.

5. The Purchasing Manager

   The Purchasing Manager reports to the Chief Executive Officer and is responsible for all procurements of the company.

6. The Personnel Manager

   The Personnel Manager reports to the Chief Executive Officer and is responsible for recruitments and public relations of the company.

3.4.2 The Plant Manning.

The Plant is the manufacturing arm of the company. It is headed by the Plant Manager who reports directly to the Chief Executive Officer. The Plant Manager is the Plant main representative in management. The Plant management is made up of the following managers:

1. The Plant Manager

   As explained in 2 above.

2. The Engineering Manager

   The Engineering Manager reports to the Plant Manager and is responsible for plant maintenance of machinery and buildings.

3. The Quality Control Manager

   The Quality control Manager reports to the Plant Manager and is responsible for product quality control.

4. The Production Manager

   The Production Manager reports to the Plant Manager and is responsible for production of electric motors.

5. The Production Planning and Materials Control Manager

   The Production Planning and Materials Control Manager reports to the Plant Manager and is responsible for planning of plant operations and ordering of all raw materials and outsourced components.

6. Cost Accountant

   The Cost Accountant reports to the Chief Accountant and is responsible for costing of the production of the electric motor.

In addition to the above mentioned officers, the Plant also employs all the direct labour and most of the indirect labour. These are the operators, various technicians and workmen.

3.5 The Organisation Chart

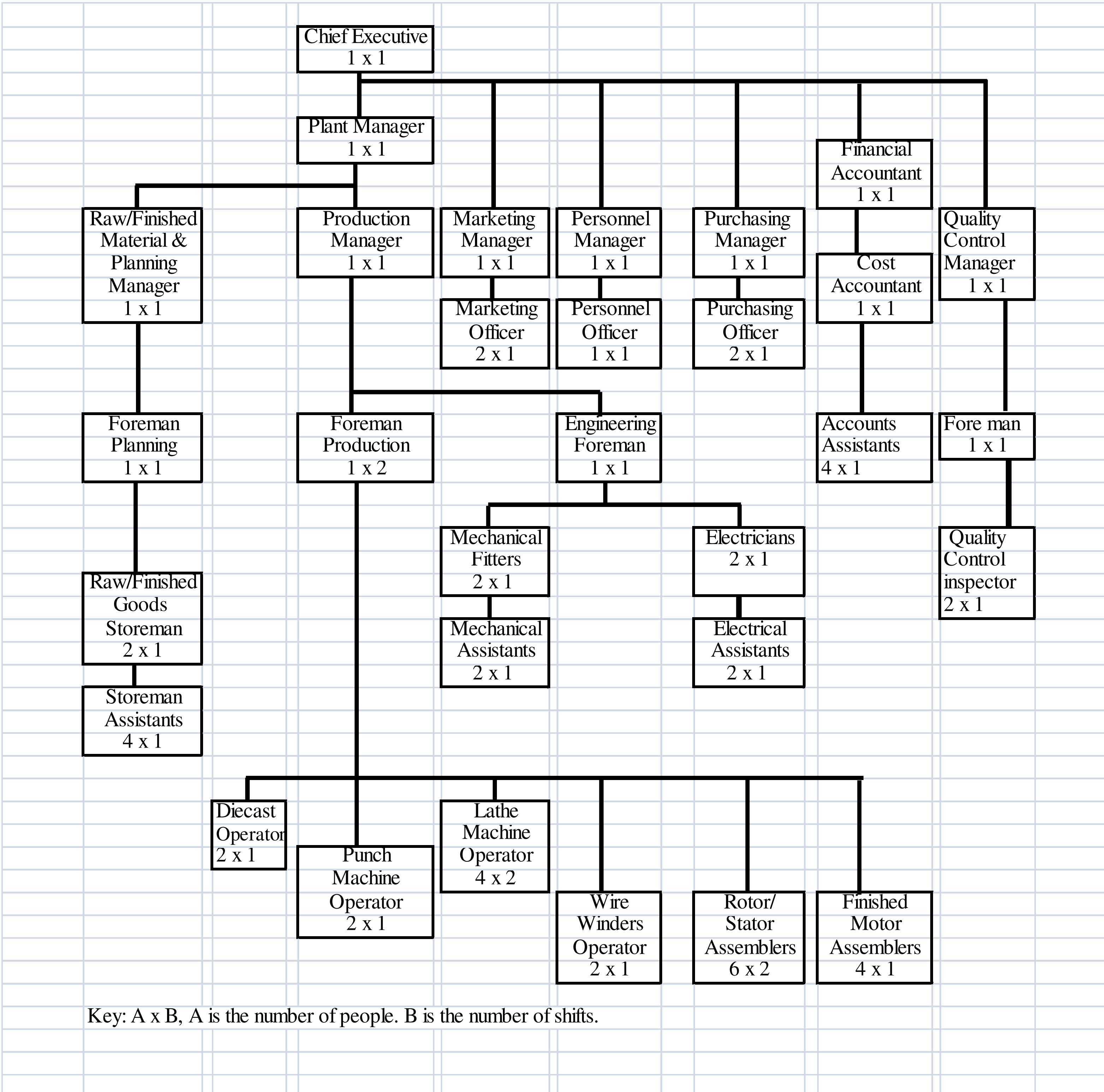


Figure 3-6 Company Organisation Chart

3.6 The Product

The product is a 5.28 kilo watt (kW) squirrel cage electric motor, but the factory can also be set up to manufacture other sizes when required, since the process is the same for all squirrel cage induction motors.

As per design, the squirrel cage electric motor is made up of a squirrel cage rotor and a wound stator. The squirrel cage rotor winding is made up of either copper bars driven into the rotor slots or aluminium bars cast into the rotor slots. On the other hand the stator is made up of formed enamelled wire slotted into the stator slots.

The squirrel cage electric motor is designed to operate on 380 volts, at 50 hertz frequency.

The work station manning in the diagram in Figure 3-1 is as follows:

Station	**Personnel**
Raw/Finished Material Stores:	9
Machine shop	2
Punch Press	2
Winding Machine	2
Die casting	2
Rotor assembly	7
Stator assembly	5
Motor assembly	4
Testing	2

3.7 Production Processes

There are five major production processes in the manufacture of the polyphase induction motor. These are: coil forming, steel punching, stator assembly, rotor assembly and final assembly [4].

3.7.1 The Steel Punching Assembly

This is a process consisting of a steel punching machine for rotor and stator punching. The steel punching for both rotor and stator are then insulated, stacked and pressed to make the stator or rotor core. The stator core is welded to keep the punching (laminations) in place and compressed.
Input material: **Silicon steel sheet rolls**.

3.7.2 Coil Forming

The magnet wire (enamel insulated copper wire) is preformed into a coil that fits the stator slot span. This step is done by using two winding machines. The set up for the coils is eight hours per set up. Since this factory is set up to produce one type of motor only, the set up is done once a week. The only other time a set up is done or checked is when a departure in coil size is noticed or suspected. Each machine is manned by one operator and the coils are tagged as per the machine that produced it. This is to ensure easy traceability of a problem on the coil.

3.7.3 Stator Assembly

The slots of the welded stator core are insulated with Mylar and paper insulation and pre-formed copper coils are slotted in them. The entire assembly is then immersed in vanish and oven dried.
Input material: **Stator core**
Preformed magnet wire coils
Mylar insulation
Paper insulation
Mica strips
Mica sheets

3.7.4 Rotor Assembly

The stacked rotor punching is compressed and taken to the foundry for die-casting if the rotor is of aluminium bar cage. The molten aluminium is poured into the slots to form the bars and end rings. The cast rotor is then checked for defects and sent for further processing.
Input material: **Rotor core**
Aluminium bar stock or copper bars
Shaft

3.7.5 Final Assembly

The stator is pressed into the housing; the rotor on the shaft is assembled into the stator. The end covers carrying bearing are then bolted to the stator housing. The bearing in the end covers provides the seat for the rotor shaft.

Input components: **Stator assembly**
Rotor assembly
Stator housing
End covers
Bearings
Miscellaneous parts

3.8 Accounting Information

All costs and wages are expressed in Kwacha, at the exchange rate of US $1= K3, 500.

3.8.1 Plant wages-Direct Staff

Direct staff comprises of what is known as direct labour force. Direct labour force is the personnel described as directly linked to the manufacture of the product. This group of labour is mainly made up of operators but the group can be enlarged to include other related personnel like store men.

Table 3-1 Monthly Plant Wages for direct labour staff showing the Cost of One Unit

Station	**Number of staff**	**Basic pay/month**	**Total/month**	**Total/year**
Raw material				
Supervisor	1	2,500,000	2500000	30000000
Work men	2	800,000	1600000	19200000
Assistant Storemen	2	700,000	1400000	16800000
Punch Press				
Operator	2	1,500,000	3000000	36000000
Machine shop				

Machinists	8	1,500,000	12000000	144000000
Winding Machines				
Operators	2	900,000	1800000	21600000
Diecasting				
Operator	2	1,500,000	3000000	36000000
Rotor assembly				
Stackers	2	1,200,000	2400000	28800000
Loaders	1	900,000	900000	10800000
Assemblers/Balancers	4	1,300,000	5200000	62400000
Stator assembly				
Welders	1	1,500,000	1500000	18000000
Insulation	2	900,000	1800000	21600000
Assemblers/Testing	2	1,200,000	2400000	28800000
Final assembly				
Assemblers/Testing	4	2,500,000	10000000	120000000
Finished product				
Store men	2	800,000	1600000	19200000
Assistant Storemen	2	700,000	1400000	16800000
Total	39	20,400,000	52500000	**630,000,000**
Cost of 1 unit				**6000000**
Motor production/year				105

The wages shown in Table 3-1 above include all allowances. This is a normal week operation of 5 days 8 hours a day and therefore does not attract overtime.

Table 3-1 gives the cost of direct labour contribution to the cost of production. It is seen that for 105 units the cost of direct labour is ZK 6,000,000 per unit.

3.8.2 Plant Wages - Indirect Staff

Indirect labour is the group of employees who are not very closely linked to the product but work to assist the direct labour continue with manufacturing with minimum interruption. Indirect labour staff can do many other jobs not related to the product.

Table 3-2 Indirect Staff

Station	**Number of staff**	**Basic pay/month**	**Total/month**	**Total/year**
Maintenance				
Supervisor	1	1500000	1500000	18000000
Mechanics	2	900000	1800000	21600000
Electricians	2	900000	1800000	21600000
Assistant Electricians	4	750000	3000000	36000000
Total	9	4050000	8100000	**97,200,000**
Cost per unit				**925714.28**
Number of units				105

Table 3-2 gives the cost contribution of indirect labour towards production. It is seen that the cost contribution of indirect labour is ZK 925,714 per unit.

3.8.3 Administration

Administration is another group of indirect labour. This group of people is detached from the direct manufacture of the product and does not need to be near the plant. And yet this is the group that carries out all the planning of the entire factory and also work hard towards the success of the factory. Though this group looks far from the product and yet they are very near to ensure its success in the plant and its success in the market.

Table 3-3 Administration Costs (Source: Teamskill [4])

Station	**Number of staff**	**Basic pay/month**	**Total/month**	**Total/year**
Chief Executive	1	15000000	15000000	180000000
Plant Manager	1	10000000	10000000	120000000
Financial Accountant	1	10000000	10000000	120000000
Marketing Manager	1	8000000	8000000	96000000
Purchasing Manager	1	6000000	6000000	72000000
Personnel Manager	1	5000000	5000000	60000000
Technical Manager	1	5000000	5000000	60000000

Production Manager	1	5000000	5000000	60000000
Raw Materials Manager	1	4000000	4000000	48000000
Cost Accountant	1	3000000	3000000	36000000
Accounts office	4	2500000	10000000	120000000
Marketing office	2	2000000	4000000	48000000
Personnel office	1	1500000	1500000	18000000
Technical Foreman	1	1000000	1000000	12000000
Purchasing office	2	1500000	3000000	36000000
Quality Control Inspectors	2	900000	1800000	21600000
Total	22	80400000	92300000	**1,107,600,000**
Cost per unit				**10548571.43**
Number of units				105

From table 3-3 the cost contribution of administration cost is ZK 10,548,571 per unit. This is the biggest component of labour costs.

3.8.4 Material Costs.

Table 3-4 Material Costs, Landed (source of information: LME, Steman [2])

Material	K/Kg	Quantity	Total per year
Copper	23800	630	14994000
Aluminum	8655.5	157.5	1363241.25
Mylar insulation	1000	52.5	52500
Paper insulation	1000	52.5	52500
Stator housing cast	3500	966	3381000
End cover	3500	63	220500
Bearings	102725	105	10786125
Silicon sheet steel	3500	1050	3675000
Shaft	3500	95	330750
Total			**34,855,616**
Cost per unit			**331958.25**
Number of units			105

Table 3-4 gives the cost contribution of raw materials to the product. The material requirement was worked over the production of 105 electric motors, but as seen in appendix C the material requirements is the same per unit no matter the number of motors produced. The cost of materials is ZK 331,958 per unit.

Table 3-5 Standard Cost of the Electric Motor Per Unit.

Year	Plant wages	Indirect staff	Administration	Material	Other Fixed Costs	Total
1	6000000	925714.2857	10548571.43	331958.25	1571428.571	**19377672.54**

Table 3-5 summarises the cost of production of 105 motors at ZK 19,377,672.54. And at a profit mark up of 15% the sales price of the electric motor is ZK 22,284,323.42. This cost is without the other costs like land and equipment. These have been dealt with in Appendix C, where the entire cost and values of Return on Investment, Payback period and Internal Rate of Return (IRR) are dealt with.

3.8.5 Equipment Cost, Landed

Table 3-6 Equipment Cost (Source: infoprod@direct-industry.com.)

Broomfield winding machine		K 45,000,000
Broomfield winding machine		K 45,000,000
Punch Press stamping machine		K 250,000,000
Megger		K 5,000,000
Arc welding machine		K 10,000,000
Caterpillar Folk truck		K 60,000,000
Lathe machine		K 50,000,000
Lathe machine		K 50,000,000
Riveting machine		K 5,000,000
Tachometer		K 2,000,000
Multimeter		K 1,500,000
Multimeter		K 1,500,000
Multimeter		K 1,500,000
Multimeter		K 1,500,000
Steel cutter		K 5,000,000
Trolley		K 1,000,000
Trolley		K 1,000,000
Wire cutter		K 200,000
Wire cutter		K 200,000
Wire cutter		K 200,000
Wire cutter		K 200,000

The equipment in Table 3-6 is the barest requirement for the factory to produce laminations and stator coils. The Megger and the Multimeter are for the quality certification of the coils and the motor after assembly.

3.9 After Sales Maintenance

After sales maintenance is cardinal for the UNZA pump. Availability of spares is very critical, shops for spares must be located in all important towns close to the users. This is the only way the pump can have an advantage over imported pumps like the Flygt pump B2102.041 and others as noted by Steman [2].

3.10 Plant Finances

Appendix C provides the calculation scenario for three levels of production of 105, 500 and 3000 electric motors per year. From Table 3-7 it is clear that the plant can break even at any level of production, but the differentiating factor is the cost of the unit. The cost of the unit is seen to be very high with lower production than with higher production. The reason is because the fixed costs are very high at low production as compared to when production is very high. It is therefore clear that for this plant to be competitive production should be above 2000 units per year at which level the price of the motor is K 2,000,000. Table 3-7 also shows that the payback period for all the levels of production is the same, 2.4 years, but this is so because of varying prices of the motor at different production levels. In reality the cost of a motor at K 29,000,000 per unit as is the case in the 105 units is unrealistic and cannot be sold. Therefore this plant was designed for 3000 electric motors production per year at which the price of a 5.28 kW electric motor is K 1,497,837. At this price the motor is definitely affordable.

Table 3-7 Table of Comparison for Different Production Units

Number	Production / year	ROI %	IRR %	PBP (Yr)	BEP (Units)	Price / Unit (KW)
1	105	5	11.6	2.4	60	29,066,509
2	500	5	18	2.4	279	6,497,337
3	2000	8	32	2.4	1,014	1,997,787
4	3000	8	37.6	2.4	1,433	1,497,837

In Table 3-7: ROI = Return On Investment

IRR = Internal Rate of Return

PBP = Payback Period

BEP = Breakeven Point

3.11 Summary

Chapter 3 proves the fact that manufacturing of the polyphase 5.28 kW induction motor in Zambia is feasible. The financial figures in Appendix C and Table 3-7 show that and give a good performance of the plant by posting a good return on investment and a reasonable breakeven point for higher production of electric motors than low production. However, major observations must be noted and these are that the production of 3000 units per year will require an aggressive marketing and sales division. This is due to the fact that by the market survey conducted by both Nyirenda [1] and Steman [2], the Zambia market is very small. It is only capable of absorbing about 4 percent of the annual production of 3000, meaning that the remainder of the production will have to be marketed outside Zambia. This being the case the pump and motor will have to compete with other imported units in these countries and this could prove difficult as the manufacturers of the other brands already on the market will try to close out the UNZA pump unit. However, the design of the UNZA pump unit is such that it will be the cheapest pump unit on the market as it contains fewer parts and will be easier to maintain compared to the European and Asian pumps. The cost component therefore will be the strength of the UNZA pump to market it within the region.

Chapter 4
Results and Discussion

4.1 Introduction

The development of the electric motor to drive the University of Zambia pump became a necessity upon Nyirenda [1] development of the pump. The objective of this study therefore was to come up with a retrofit electric motor which would be lifted off the shelf and fitted into the pump or develop a motor suitable to the pump. Both objectives were met.

4.2 Results

The study to develop an electric motor suitable for the University of Zambia pump achieved its objectives. The main parts of the motor like the stator and rotor laminations were designed and the physical size of the motor was determined by specifying the diameters of stator and rotor and by determining the number and size of laminations for both stator and rotor by determining the lengths of both the stator and rotor and also by determining the thickness of the laminations.

It was shown that the Flygt pump B2102.041 could retrofit the University of Zambia pump as the parameters of the Flygt B2102.041 pump motor [17] matched well with the parameters of the motor calculated using the University of Zambia pump characteristics (see Table 2-3). Indeed any electric motor that would match these parameters other than the Flygt B2102.041 pump motor would equally suit.

4.3 Discussion

The problem faced in this design was one of the diameters allotted in the University of Zambia pump. The diameter of 120 mm provided [1] for the stator was too small and resulted in an otherwise long stator and rotor which is undesirable due to magnet problems of the motor and would result in unnecessary vibration of the motor in operation. The diameter requirement for this kind of motor is in the range of 170 mm to 200 mm. Therefore the diameter of 120 mm as provided by Nyirenda [1] was not sufficient and was enlarged to accommodate a stator of 180 mm diameter and 95.7 mm long.

To accommodate a stator of 180 mm the casing of the motor was redesigned (see Figure 2-11, 2-12, 2-13). The new design however did not change the volume requirements of the water passage from the empeller to the outlet pipe as designed by Nyirenda [1].

The electric motor developed for the University of Zambia pump will go a long in re-vitalising the collapsed industry of this country. With the local production of the electric motor and pump a breath of life will be given to a lot of other economic sectors like agriculture and water and sewerage services.

The electric motor development is good progress for Zambia. There is need for Zambia to embark on import substitution industries like the pump but also must develop industries targeting the abundant export market within the region.

Chapter 5
Conclusion and Recommendations

5.1 Conclusion

The development of the electric motor involved the design of the stator and rotor laminations. This was successfully achieved as evidenced by the drawings of stator and rotor laminations in Figures 2-6, 2-7, 2-8, 2-11, 2-12 and 2-13. The study also determined the diameters and the lengths for both stator and rotor cores.

This study though carried out to develop the electric motor for the University of Zambia pump applies to any three phase squirrel cage electric motor. Therefore pedestal motors, or flange mounted motors will be manufactured from the same parameters used in designing the electric motor for the University of Zambia pump, the only difference therefore appearing in the mode of base mounting and hence a different motor casing design.

The selection of the type of factory and machinery is very important in this case. And for this factory a hybrid plant layout of process and cellular layouts was recommended.

5.2 Recommendations

This study on the development of a three phase induction motor is the first carried out on the manufacture of an electric motor in Zambia. It was conducted purely on the premise of equipping the University of Zambia pump. It is therefore important to extend it to other useful forms of electric motors like the single phase electric motor which is generally used for domestic purposes.

The issue of the motor casing size also needs to be seriously re-looked into. The provision in Nyirenda [1] study is not enough and if used will cause motors to rattle and heat up resulting into premature failure.

Chapter 6
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Appendix A
The Electric Motor Design

A-0 Introduction

Development of any new three-phase motor design begins with selection of basic overall stator and rotor dimensions, then the number of stator slots, N_1 and rotor slots N_2. Together with the number of magnetic poles in the stator winding, the N_1 and N_2 values-what is called the “slot combination” influence the winding alternatives [12]. This chapter therefore deals with the electric motor design starting with the determination of the stator and rotor dimensions and then the slot dimensions and slot combination and lastly the winding from the given motor design specifications.

A-1 Determination of Stator Core Main Dimensions.

There are many ways of designing the induction motor stator and rotor dimensions. The most common being;

1. The $D_{sbd}{}^2L$ output constant concept and
2. The rotor tangential stress concept.

The $D_{sbd}{}^2L$ output concept is the most widely accepted method and was therefore used in this project [13, 14]. The rotor tangential concept is used for completely new designs [13], and was not therefore considered.

Based on the above advanced reasons, the stator bore diameter D_{sbd} is given by

$$D_{sbd} = \sqrt[3]{((2P_1 \times P_1 \times S_{gap}) / (\pi \times \lambda \times f_1 \times C_O))} \qquad \text{(A-1)}$$

Where P_1 = the number of pole pairs

S_{gap} = the apparent power in the air gap

λ = the stack aspect ratio

C_o= Esson’s constant

f_1 = supply frequency

K_E is the ratio between the generated electromotiveforce (emf) E_1 and input voltage V_{1n} and is given by

$$K_E = E_1 / V_{1n} = 0.98 - (0.005 \times P_1) \qquad \text{(A-2)}$$

The air-gap apparent power S_{gap} is given as

$$S_{gap} = 3 \times E_1 \times I_{1n} \qquad \text{(A-3)}$$

Where E_1 = generated emf

I_{1n} = input current

The input apparent power S_{1n} is given as

$$S_{1n} = 3 \times V_{1n} \times I_{1n} = P_n / (\eta_n \times \cos \varphi_{1n}) \qquad \text{(A-4)}$$

Where V_{1n} = input voltage

I_{1n} = input current

P_n = the shaft power

η_n = the assigned design efficiency

Cos φ_{1n} = the assigned design power factor

And from Equation 2-1, 2-2, 2-3 and 2-4, the air-gap apparent power S_{gap} is given as

$$S_{gap} = (K_E \times P_n) / (\eta_n \times \cos \varphi_{1n}) \qquad \text{(A-5)}$$

The stack aspect ratio λ is given as

$$\lambda = L \times ((2 \times P_1 / \pi \times D_{sbd})) = L / \tau \qquad \text{(A-6)}$$

where L = length of stator core

τ = pole pitch

Past experience has shown that the stack aspect ratio λ falls in the range shown in Table A-1

$2P_1$	2	4	6	8
λ	0.6 – 1.0	1.2 – 1.8	1.6 – 2.2	2 – 3

Table A-1 Stack Aspect Ratio λ

Using Equation A-5 to calculate the value of S_{gap}, C_o is then obtained from Figure A-1.

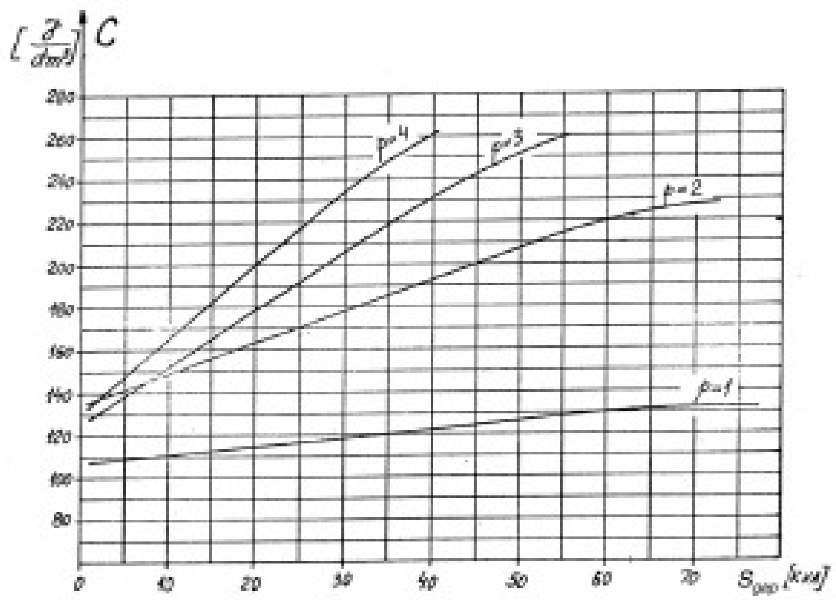


Figure A-1 Esson's "Constant" C_o versus S_{gap} (Air-Gap Apparent Power)

From A-6 the pole pitch τ is

$$\tau = (\pi \times D_{sbd}) / (2 \times P_1) \qquad \text{(A-7)}$$

And the slot pitch τ_s is

$$\tau_s = \tau / (3 \times q) \qquad \text{(A-8)}$$

Where q = the number of slots per pole per phase.

The guide to the ratio of internal to external stator diameters D_{sbd} / D_{out} is given in Table A-2.

$2 \times P_1$	2	4	6	8
D_{sbd} / D_{out}	0.54 – 0.58	0.61 – 0.63	0.68 – 0.71	0.72 – 0.74

Table A-2 Ratio of Internal and External Stator Diameter

And the ratio of internal to external diameters $K_{DD} = D_{sbd} / D_{out}$, therefore output diameter D_{out} is

$$D_{out} = D_{sbd} / K_{DD} \qquad \text{(A-9)}$$

The air-gap value g is given by the following equations and depending on the number of pole pairs 2 x P1 [13].

$$g = (0.1 + 0.02 \times \sqrt[3]{P_n}) \times 10^{-3} \text{ m for } 2 \times P_1 = 2 \quad \text{(A-10)}$$

$$g = (0.1 + 0.012 \times \sqrt[3]{P_n}) \times 10^{-3} \text{ m for } 2 \times P_1 \geq 2$$

A-2 Stator Winding

The number of stator slots N_1 is

$$N_1 = 2 \times P_1 \times q \times m_1 \quad \text{(A-11)}$$

Where m_1 = number of phases

In a two layer winding with chorded coils: $y / \tau = 0.8$, is chosen. This pitch reduces the unwanted 5th and 7th harmonics [15]. The 3rd harmonics are automatically removed by a balanced circuit or a star connected circuit.

The electrical angle between emfs in neighbouring slots α_{ea} is

$$\alpha_{ea} = (2 \times \pi \times P_1) / N_1 \quad \text{(A-12)}$$

The pitch factor K_{P1} is

$$K_{P1} = \sin (P^{\circ} / 2) \quad \text{(A-13)}$$

Where P° = the span of the coil in electrical degrees

The distribution factor K_{d1} is

$$K_{d1} = \sin (q \times d^{\circ} / 2) / q \times \sin (d^{\circ} / 2) \quad \text{(A-14)}$$

Where $d^{\circ} = \alpha_{ea}$ (Equation A-12)

Therefore the stator winding factor K_{W1} is

$$K_{W1} = K_{P1} \times K_{d1} \quad \text{(A-15)}$$

Now the number of turns per phase is determined on the value of the pole flux ϕ, where flux ϕ is

$$\phi = \alpha_1 \times \tau \times L \times B_g \quad \text{(A-16)}$$

Where B_g is the air-gap flux density [13] and is specified in intervals as follows

$$B_g = (0.5 - 0.75)\text{T for } 2 \times P_1 = 2$$

$$B_g = (0.65 - 0.78)\text{T for } 2 \times P_1 = 4 \quad \text{(A-17)}$$

$B_g = (0.7 - 0.82)T$ for $2 \times P_1 = 6$

$B_g = (0.75 - 0.85)T$ for $2 \times P_1 = 8$

As for the spanning coefficient α_1, this is obtained from Figure A-2 and depends on the tooth saturation factor $1 + K_{sc}$.

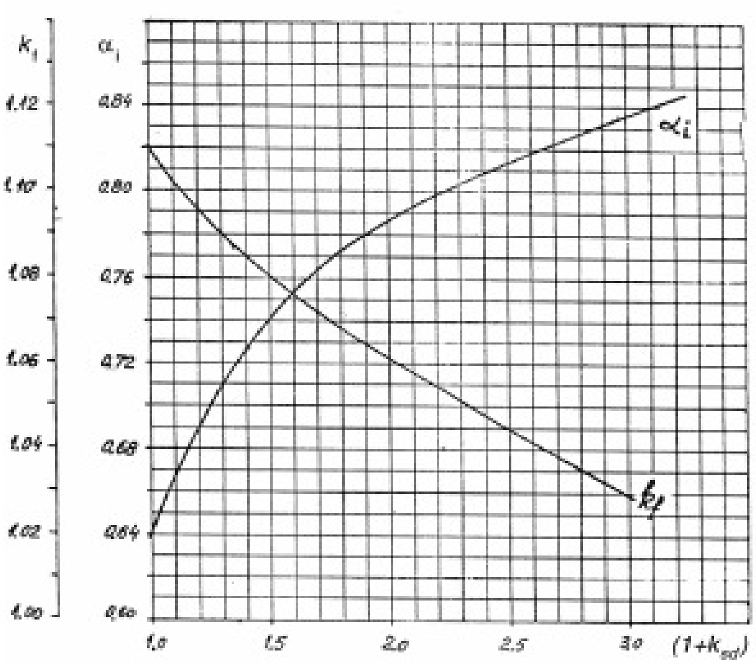


Figure A-2 Form Factor K_f and Flux Density Shape Factor α_1 versus Teeth Saturation

The number of turns per phase W_1 is given as

$$W_1 = (K_E \times V_{1ph}) / (4 \times K_f \times K_{w1} \times f_1 \times \phi) \quad \text{(A-18)}$$

Therefore the number of conductors per phase N_c is

$$N_c = (a_1 \times W_1) / (P_1 \times q) \quad \text{(A-19)}$$

N_c must be made an even number if it is not. Hence the adjusted value of W_1 becomes

$$W_1 = W_{1A} = P_1 \times q \times N_c \quad \text{(A-20)}$$

Therefore the actual flux density $B_g = 0.5 \times (W_1 / W_{1A})$ (A-21)

The rated current I_{1n} is

$$I_{1n} = P_n / (\eta_n \times \cos\varphi_n \times \sqrt{3} \times V_1) \quad \text{(A-22)}$$

The recommended current densities [13] are

$$J_{cos} = (4 - 7)\ A / mm^2 \text{ for } 2P_1 = 2, 4 \quad \text{(A-23)}$$

$$J_{cos} = (5 - 8)\ A / mm^2 \text{ for } 2P1 = 6, 8$$

Now the magnetic wire cross section A_{Co} is

$$A_{Co} = I_{1n} / (J_{cos} \text{ x } a_1) \quad \text{(A-24)}$$

Where $a_1 = 1$

From the conductor area A_{Co} (Equation A-24) the conductor diameter d_{Co} is

$$d_{Co} = \sqrt{(4 \text{ x } A_{Co} / \pi)} \quad \text{(A-25)}$$

The values of standardised diameter sizes are given in Table A-3.

Rated diameter [mm]	Insulated diameter [mm]
0.3	0.327
0.32	0.348
0.33	0.359
0.35	0.3795
0.38	0.4105
0.40	0.4315
0.42	0.4625
0.45	0.4835
0.48	0.515
0.50	0.536
0.53	0.567
0.55	0.5875
0.58	0.6185
0.60	0.639
0.63	0.6705
0.65	0.691
0.67	0.7145
0.70	0.742
0.71	0.7525
0.75	0.749
0.80	0.8455
0.85	0.897
0.90	0.948
0.95	1.0
1.0	1.051
1.05	1.102
1.10	1.153
1.12	1.173
1.15	1.2035
1.18	1.2345
1.20	1.305
1.25	1.305
1.30	1.356
1.32	1.3765
1.35	1.407
1.40	1.4575
1.45	1.508
1.5	1.559

Table A-3 Standardised Diameter Sizes.

In general if $d_{Co} \geq 1.3$ mm in low power induction motors, a few conductors may be used in parallel in which case a_1 becomes $a_P > 1$[13].

A-3 Stator Slot Sizing

In calculating the slot sizing a factor known as slot fill K_{fill} is used in a formula of values of N_c and a_P. For round wire the slot fill, $K_{fill} \approx 0.35$ to 0.4 below 10 kW, and 0.4 to 0.5 above 10 kW [13]. Therefore the useful slot area A_{su} is

$$A_{su} = (\pi \times d_{CoP}^2 \times a_P \times N_c) / (4 \times K_{fill}) \quad \text{(A-26)}$$

There are main types of shapes of slots but in general a trapezoidal shape design is used for motors < 10 kW as shown in Figure A-3.

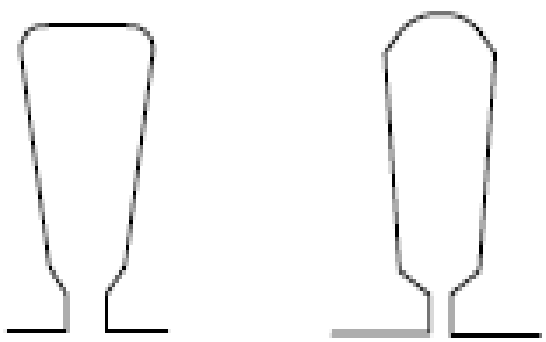


Figure A-3 Recommended Stator Slots

The slot shown in Figure A-3a is further detailed in Figure A-4. For this kind of slot the shape of the stator tooth is rectangular. In Figure A-4 the variables b_{os}, h_{os}, h_w are assigned values from accepted practice as, b_{os} = 2 to 3 mm ≤ 8g, h_{os} = (0.5 to 1.0), wedge height h_w = 1 to 4 mm [13].

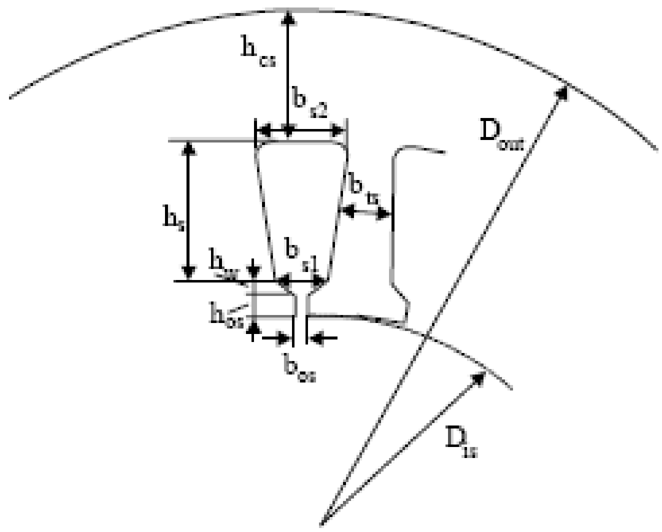


Figure A-4. Stator Slot Geometry

Now assuming that all the air-gap flux passes through the stator teeth, then

$$B_g \text{ x } \tau_s \text{ x } L = B_{ts} \text{ x } b_{ts} \text{ x } L \text{ x } K_{Fe} \quad \text{(A-27)}$$

Where $K_{Fe} \approx 0.96$ for 0.5 mm thick lamination, constitutes the influence of lamination insulation thickness and B_{ts} is given as

$$B_{ts} = 1.5 - 1.65\text{T}. \quad \text{(A-28)}$$

From Equation A-27 b_{ts} is

$$b_{ts} = (B_g \text{ x } \tau_s) / (B_{ts} \text{ x } K_{Fe}) \quad \text{(A-29)}$$

From acceptable practice the value of tooth width $b_{ts} > 3.5 \text{ x } 10^{-3}$ m is acceptable.

From Figure A-4 the slot lower width b_{s1} is

$$b_{s1} = \pi\ ((D_{sbd} + 2 \text{ x } h_{os} + 2 \text{ x } h_w) / N1)) - b_{ts} \quad \text{(A-30)}$$

The useful area of the slot A_{su} (Figure A-4) may be expressed as

$$A_{su} = h_s\ (b_{s1} + b_{s2}) / 2 \quad \text{(A-31)}$$

And $$b_{s2} \approx b_{s1} + 2 \text{ x } h_s \text{ x } \tan\ (\pi / N1) \quad \text{(A-32)}$$

From Equation A-31 and A-32, the unknown values of b_{s2} and h_s are computed.

Therefore $b_{s2}^2 - b_{s1}^2 = 4 \text{ x } A_{su} \text{ x } \tan(\pi / N1)$ (A-33)

Therefore $b_{s2} = \surd\ ((4 \text{ x } A_{su} \text{ x } \tan(\pi / N1) + bs1^2)$ (A-34)

And the slot useful height h_s is

$$h_s = (2 \text{ x } A_{su}) / (b_{s1} + b_{s2}) \quad \text{(A-35)}$$

The teeth saturation factor $1 + K_{sc}$ is calculated as follows,

$$1 + K_{sc} = 1 + (F_{mts} + F_{mtr}) / F_{mg} \quad \text{(A-36)}$$

The airgap mmf F_{mg} is

$$F_{mg} \approx 1.2 \text{ x } g \text{ x } B_g / \mu_0 \quad \text{(A-37)}$$

The stator tooth mmf F_{mts} is

$$F_{mts} = H_{ts}\ (h_s + h_{os} + h_w) \quad \text{(A-38)}$$

And from (A-36) F_{mtr} is

$$F_{mtr} = K_{sc} \text{ x } F_{mg} - F_{mts} \quad \text{(A-39)}$$

At this point the value of F_{mtr} must equal that of F_{mts}, If this requirement is not met then the calculation must start again right from the beginning. But if $F_{mtr} \approx F_{mts}$, then the design is acceptable and no further iterations are necessary.

The next step is to calculate the stator back iron height h_{cs} (Figure A-4).

$$h_{cs} = (((D_{out} - ((D_{sbd} + 2(h_{os} + h_w + h_s))) / 2 \quad \text{(A-40)}$$

Having calculated h_{cs}, the back core flux density B_{cs} must be verified using the calculated value of flux ϕ from Equation A-16. Therefore B_{cs} is

$$B_{cs} = \phi / (2 \text{ x } L \text{ x } h_{cs}) \quad \text{(A-41)}$$

B_{cs} must be within the range 1.4 to 1.7T. If B_{cs} is outside this range then it is necessary to adjust either of the following; increase the stator outside diameter D_{out}, until B_{cs} gets into range. Or use a bigger stack aspect ratio λ which would reduce the stator bore diameter D_{sbd}. Or increase the back iron height $h_{cs,}$ to lower B_{cs}. The other alternative is to increase the current density which would result in the reduction of h_s but this compromises efficiency. All these measures would lead to bringing B_{cs} within the range.

A-4 Rotor Slot Sizing

The selection of the number of rotor slots N_2 was based on theoretical analysis dating back as far as 1909 plus proven experience on the rules for slot combination of which the most prominent is that N_2 should be either below or above N_1 by 15 to 20% of N_1[12]. In this particular design N_2 was taken to be 15% below N_1. (A-42)

Now the value of rated rotor bar current I_b is

$$I_b = K_1 \text{ x } (2 \text{ x } m \text{ x } W_1 \text{ x } K_{w1} / N_2) \text{ x } I_{1n} \quad \text{(A-43)}$$

When $K_1 = 1$, the stator and rotor mmfs are equal and yet in reality the stator mmf is larger than the rotor mmf, therefore K_1 is

$$K_1 \approx 0.8 \cos\varphi 1n + 0.2 \quad \text{(A-44)}$$

For high efficiency, the current density in the rotor bar $J_b = 3.42$ A / mm^2. The rotor slot area is

$$A_b = I_b / J_b \quad \text{(A-45)}$$

The end ring current I_{er} is

$$I_{er} = I_b / (2 \text{ x } \sin(\pi \text{ x } P_1 / N2)) \quad \text{(A-46)}$$

The current density in the end ring J_{er} is

$$J_{er} = (0.75 - 0.8) \text{ x } J_b \quad \text{(A-47)}$$

Therefore the end ring cross section A_{er} is

$$A_{er} = I_{er} / J_{er} \quad \text{(A-48)}$$

A-5 Rotor Slot Sizing

Figure A-5 below shows the variables of the rotor slot.

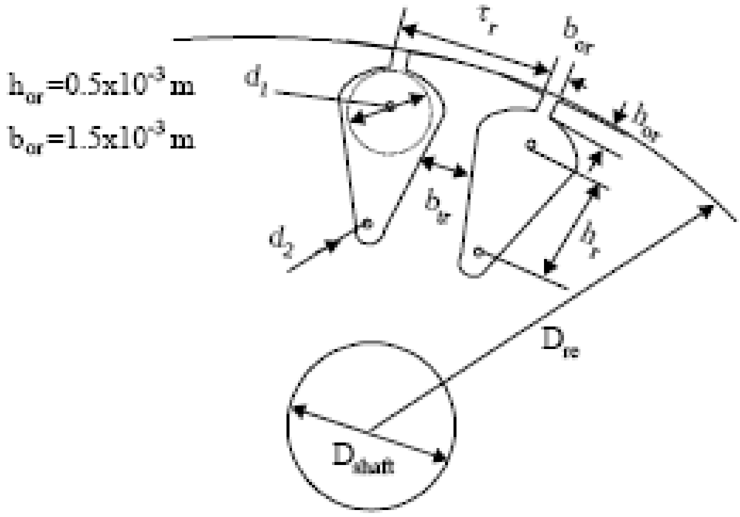


Figure A-5 Rotor Slot Geometry

The rotor slot pitch τ_r is given by the Equation

$$\tau_r = \pi (D_{sbd} - 2g) / N_r \tag{A-49}$$

Now b_{tr} the tooth width is

$$b_{tr} \approx (B_g / K_{Fe} \text{ x } B_{tr}) \text{ x } \tau_r \tag{A-50}$$

To determined d_1 the top rotor slot diameter ($D_{re} = D_{sbd}$)

$$\pi (D_{sbd} - 2 \text{ x } h_{or} - d_1) / N2 = d_1 + b_{tr} \tag{A-51}$$

Therefore d_1 is

$$d_1 = (\pi (D_{re} - 2 \text{ x } h_{or}) - N2 \text{ x } b_{tr}) / (\pi + N2) \tag{A-52}$$

To calculate the value of d_2 and h_r the following formulas apply

$$A_b = \pi / 8 (d_1^2 + d_2^2) + ((d_1 + d_2) \text{ x } h_r)) / 2 \tag{A-53}$$

$$d_1 - d_2 = 2 \text{ x } h_r \text{ x } \tan (\pi / N2) \tag{A-54}$$

At this point the rotor tooth mmf F_{mtr} is calculated using the values of h_r, d_1 and d_2 and compared to the earlier calculated value of F_{mtr} (Equation A-39), therefore F_{mtr} is

$$F_{mtr} = H_{tr} \text{ x } (h_r + h_{or} + ((d_1 + d_2) / 2)) \quad \text{(A-55)}$$

The values of H_{tr} depends on the values of B_{tr} as shown in Lamination magnetisation curve of Table A-4

B[T]	H[A/m]	B[T]	H[A/m]
0.05	22.8	1.05	237
0.1	35	1.1	273
0.15	45	1.15	310
0.2	49	1.2	356
0.25	57	1.25	417
0.3	65	1.3	482
0.35	70	1.35	585
0.4	76	1.4	760
0.45	83	1.45	1050
0.5	90	1.5	1340
0.55	98	1.55	1760
0.6	106	1.6	2460
0.65	115	1.65	3460
0.7	124	1.7	4800
0.75	135	1.75	6160
0.8	148	1.8	8270
0.85	162	1.85	11170
0.9	177	1.9	15220
0.95	198	1.95	22000
1.0	220	2.0	34000

Table A-4 Lamination Magnetisation Curve B_{tr} (H_{tr})

At this point if F_{mtr} (Equation A-39) ≈ F_{mtr} (Equation A-55), then the design is acceptable.

The next parameter to calculate is the rotor back core height h_{cr}.

$$h_{cr} = \phi / (2 \text{ x } L \text{ x } B_{cr}) \quad \text{(A-56)}$$

The maximum shaft diameter D_{shaft} required is

$$D_{shaft} \leq D_{sbd} - 2 \text{ x } g - 2 \text{ x } (h_{or} + ((d_1 + d_2) / 2) + h_r + h_{cr}) \quad \text{(A-57)}$$

The shaft diameter must correspond to the rated torque T_{en} given by the tables and often by comparison from past designs. The rated torque is

$$T_{en} = P_n / (2 \text{ x } \pi \text{ x } (f_1 / P_1) \text{ x } (1-S_n) \quad \text{(A-58)}$$

The end ring cross section is shown in Figure A-6 below.

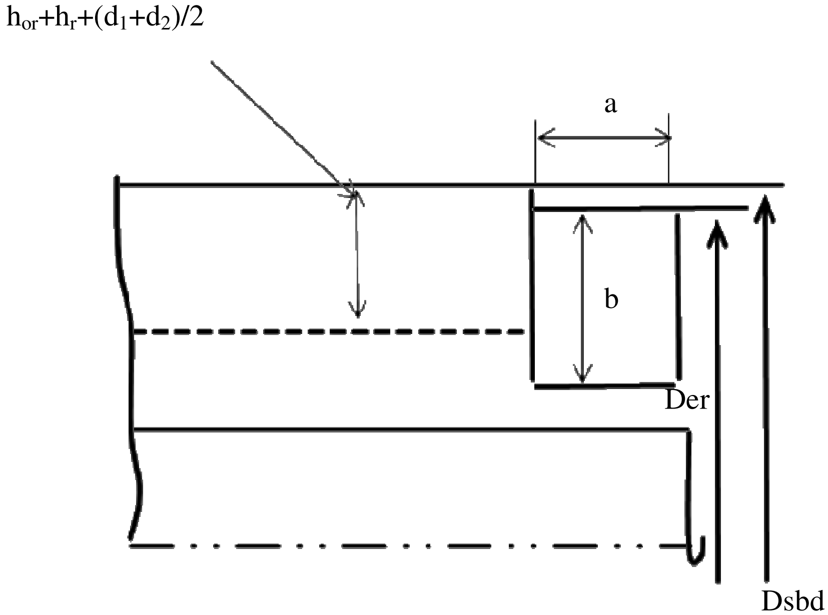


Figure A-6 End Ring Cross-Section

In general $D_{sbd} – D_{er} = (3 – 4) \times 10^{-3}$ and also (A-59)

$$b = (1.0 – 1.2) \times ((h_r + h_{or} + (d_1 + d_2) / 2 \quad \text{(A-60)}$$

From Equation A-60 b is

$$b = 1.0 \times (h_r + h_{or} + (d_1 + d_2) / 2) \quad \text{(A-61)}$$

the dimension a is

$$a = A_{er} / b \quad \text{(A-62)}$$

The Magnetisation current I_o is

$$I_o = (\pi \times P1 \times (F_{1m} / 2)) / (3 \times \sqrt{2} \times W_1 \times K_{w1}) \quad \text{(A-63)}$$

where F_{1m} is

$$F_{1m} = 2 \times (K_c \times g \times B_g / \mu_o + F_{mts} + F_{mtr} + F_{mcs} + F_{mcr}) \quad \text{(A-64)}$$

And K_c, F_{mcs} and F_{mcr} are calculated as follows

K_c is called Carter's coefficient and is calculated as follows

$$\gamma_1 = b_{os}^2 / (5 \times g + b_{os}) \quad \text{(A-65)}$$

$$\gamma_2 = b_{or}^2 / (5 \text{ x } g + b_{or}) \tag{A-66}$$

Where K_{c1} and K_{c2} are given by the formulas involving γ_1 and γ_2 as follows

$$K_{c1} = \tau_s / (\tau_s - \gamma 1) \tag{A-67}$$

$$K_{c2} = \tau_r / (\tau_r - \gamma_2) \tag{A-68}$$

Therefore $$K_c = K_{c1} \text{ x } k_{c2} \tag{A-69}$$

Now F_{mcs} and F_{mcr} are given by the following

$$F_{mcs} = C_{cs} \text{ x } \pi \text{ x } ((D_{out} - h_{cs}) / 2 \text{ x } P_1) \text{ x } H_{cs}(B_{cs}) \tag{A-70}$$

And

$$F_{mcr} = C_{cr} \text{ x } \pi \text{ x } ((D_{shaft} + h_{cr}) / 2 \text{ x } P_1) \text{ x } H_{cr}(B_{cr}) \tag{A-71}$$

Where

$$C_{cs} = C_{cr} \approx 0.88 \text{ x } e^{-0.4xBcs,r\mathbf{2}} \tag{A-72}$$

The total saturation factor K_s is

$$K_s = (F_{1m} / (2 \text{ x } F_{mg})) - 1 \tag{A-73}$$

And the unit per unit value i_o is

$$i_o = I_o / I_{1n} \tag{A-74}$$

A-6 Resistances and Inductances

Resistances and inductances are shown in Figure A-7.

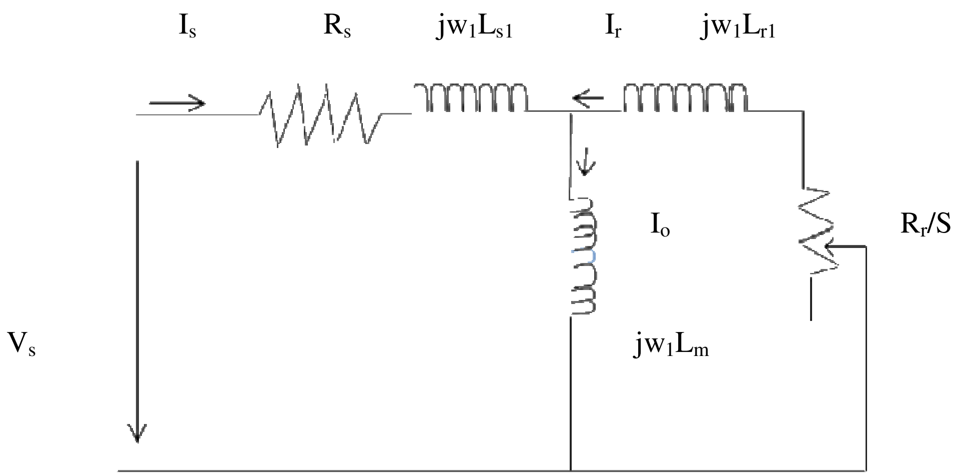


Figure A-7 Equivalent Circuit of an Induction Motor (Core Losses ignored)

The stator phasor resistance R_s is

$$R_s = \rho_{Co} \text{ x } ((I_c \text{ x } W_1) / A_{Co} \text{ x } a_1) \quad \text{(A-75)}$$

Where I_c is

$$I_c = 2 \text{ x } (L + I_{end}) \quad \text{(A-76)}$$

The coil end connection depends on the coil span y. Number of poles P, shape of coils, and number of layers in the winding.

From common practice the following empirical formulas are used in determining I_{end} [13].

$$I_{end} = 2 \text{ x } y - 0.04 \text{ m for } 2 \text{ x} P_1 = 2 \quad \text{(A-77)}$$

$$I_{end} = 2 \text{ x } y - 0.02 \text{ m for } 2 \text{ x } P_1 = 4$$

$$I_{end} = \pi / 2 \text{ x } y + 0.018 \text{ m for } 2 \text{ x } P_1 = 6$$

$$I_{end} = 2.2 \text{ x } y - 0.012 \text{ m for } 2 \text{ x } P_1 = 8$$

And the ratio $y / \tau = \beta$ called the chording factor usually equal to 0.8. (A-78)

Where the acceptable values of β is $2 / 3 \leq \beta \leq 1$ (A-79)

From Equation A-77 the coil span y is

$$y = \beta \text{ x } \tau \quad \text{(A-80)}$$

Now in designing an induction motor of high efficiency the winding temperature is regarded important and must not be large even if the insulation class is F. In any design therefore caution must be observed to design a motor below the maximum insulation temperature.. To achieve this the motor is designed for copper resistivity $(\rho_{Co})_{80°C}$ at 80°C. Now for copper resistivity at 20°C, $(\rho_{Co})_{20°C}$ = 1.78 x 10-8 Ωm. And at 115°C, $(\rho_{Co})_{115°C} = 1.37 \text{ x } (\rho_{Co})_{20°C}$.

Therefore at copper resistivity = 80°C, $(\rho_{Co})_{80°C}$ is

$$(\rho_{Co})_{80°C} = (\rho_{Co})_{20°C} \text{ x } (1+(1 / 273) \text{ x } (80 -20)) \quad \text{(A-81)}$$

And the rotor bar-end ring equivalent resistance R_{be} is

$$R_{be} = \rho_{A1} \text{ x } ((L / A_b) \text{ x } K_R + (\iota_{er} / (2 \text{ x } A_{er} \text{ x } SIN^2(\pi \text{ x } P_1 / 2))) \quad \text{(A-82)}$$

Where ρ_{A1} is the cast aluminium resistivity and at 20°C $(\rho_{A1})_{20°C} = 3.1 \text{ X } 10^{-8}$ Ωm (A-83)

The end-ring length $\iota_{end} = \pi \text{ x } (D_{er} – b) / N2$ (A-84)

Now from Equation 2-57 $D_{er} = D_{sbd} – 2 \text{ x } g – 2 \text{ x } 3 \text{ x } 10^{-3}$ m (A-85)

In Equation A-82, K_R is the approximate skin effect resistance coefficient, for a rectangular slot, and is

$$K_R = \xi \text{ x } (SINH(2 \text{ x } \xi) + SIN(2 \text{ x } \xi)) / (COSH(2 \text{ x } \xi) – COS(2 \text{ x } \xi)) \approx \xi \quad \text{(A-86)}$$

And

$$\xi = \beta_s \text{ x } h_s \text{ x } \sqrt{S} \text{ , where } S = 1 \quad \text{(A-87)}$$

And

$$\beta_s = \sqrt{((\omega_1 \text{ x } \mu_o) / (2 \text{ x } \rho_{A1})} \quad \text{(A-88)}$$

From Equation A-85

$$K_R = \xi \quad \text{(A-89)}$$

The rotor cage resistance reduced to the stator R_r' is

$$(R_r')_{s=1} = ((4 \text{ x } m) / N2) \text{ x } (W_1 \text{ x } K_{W1})^2 \text{ x } R_{be80°C} \quad \text{(A-90)}$$

The stator phase leakage reactance X_{s1} is

$$X_{s1} = 2 \text{ x } \mu_o \text{ x } \omega_1 \text{ x } L \text{ x } (W_1^2 / (P_1 \text{ x } q)) \text{ x } (\lambda_s + \lambda_{ds} + \lambda_{ec}) \quad \text{(A-91)}$$

Where λ_s, λ_{ds}, λ_{ec} are the slot differential and end ring connection coefficients.

And $$\lambda_s = ((((2 / 3) \text{ x } (h_s / (b_{s1} + b_{s2})) + ((2 \text{ x } h_w) / (b_{os} + b_{s1})) + (h_{os} / b_{os})) \text{ x } ((1 + 3 \text{ x } \beta) / 4) \quad \text{(A-92)}$$

And $$\lambda_{ds} = (0.9 \text{ x } \tau_s \text{ x } q^2 \text{ x } K_{w1}^2 \text{ x } C_s \text{ x } \gamma_{ds}) / (K_c \text{ x } g \text{ x } (1 + K_{st})) \quad \text{(A-93)}$$

Where $$C_s = 1 – 0.033 \text{ x } (b_{os}^2 / (g \text{ x } \tau_s)) \quad \text{(A-94)}$$

And $$\gamma_{ds} = (0.11 \text{ x SIN } \varphi_1 + 0.28) \text{ x } 10^{-2}; \text{ for } q = 8$$

$$\gamma_{ds} = (0.11 \text{ x SIN}\varphi_1 + 0.41) \text{ x } 10^{-2}; \text{ for } q = 6 \quad \text{(A-95)}$$

$$\gamma_{ds} = (0.14 \text{ x SIN}\varphi_1 + 0.76) \text{ x } 10^{-2}; \text{ for } q = 4$$

$$\gamma_{ds} = (0.18 \text{ x SIN}\varphi_1 + 1.24) \text{ x } 10_{-2}; \text{ for } q = 3$$

$$\gamma_{ds} = (0.25 \text{ x SIN}\varphi_1 + 2.6) \text{ x } 10_{-2}; \text{ for } q = 2$$

Where $$\varphi_1 = \pi \text{ x } (6 \text{ x } \beta – 5.5) \quad \text{(A-96)}$$

For a two layer winding, the end connection specific geometric permeance coefficient λ_{ec} is

$$\lambda_{ec} = 0.34 \text{ x } (q / L) \text{ x } (I_{end} – 0.64 \text{ x } \beta \text{ x } \tau) \quad \text{(A-97)}$$

The equivalent rotor bar leakage reactance X_{be} is

$$X_{be} = 2 \text{ x } \pi \text{ x } f_1 \text{ x } \mu_o \text{ x } L \text{ x } (\lambda_r \text{ x } K_x + \lambda_{dr} + \lambda_{er}) \quad \text{(A-98)}$$

Where λ_r, λ_{dr}, λ_{er} are the rotor slot differential and end ring permeance coefficient.

$$\lambda_r = 0.66 + (2 \text{ x } h_r / (3 \text{ x } (d_1 + d_2))) + h_{or} / b_{or} \quad \text{(A-99)}$$

And the differential coefficient λ_{dr} is

$$\lambda_{dr} = ((0.9 \text{ x } \tau_r \text{ x } \gamma_{dr}) / (K_c \text{ x } g)) \text{ x } (N_r / (6 \text{ x } P_1))^2 \quad \text{(A-100)}$$

and $$\gamma_{dr} = 9 \text{ x } (6 \text{ x } P^1 / N2)^2 \text{ x } 10^{-2} \quad \text{(A-101)}$$

And the end-ring coefficient λ_{er} is

$$\lambda_{er} = ((2.3\text{x}(D_{er} – b)) / N2 \text{ x } L \text{ x } 4 \text{ x } SIN^2(\pi \text{ x } P_1/N2)) \text{ x } \log((4.7 \text{ x } (D_{er} – b) / (b + 2 \text{ x } a)) \quad \text{(A-102)}$$

The skin coefficient for the leakage reactance K_x is

$$K_x = (3/(2 \text{ x } \xi)) \text{ x } ((SINH(2 \text{ x } \xi) – SIN(2 \text{ x } \xi) / (COSH(2 \text{ x } \xi) – COS(2 \text{ x } \xi))) = 3 / (2 \text{ x}\xi) \quad \text{(A-103)}$$

The rotor leakage reactance X_{r1} is a function of X_{be} and is given as

$$X_{r1} = 4 \text{ x } m_1 \text{ x } ((W_1 \text{ x } K_{w1})^2 / N2) \text{ x } X_{be} \quad \text{(A-104)}$$

At standstill S = 1, both stator and rotor leakage reactance are reduced due to leakage flux path saturation. For power levels in semi-closed stator and rotor slots, therefore

$$(X_{s1})^{S=1}{}_{sat} = X_{s1} \text{ x } (0.7 – 0.8) \approx X_{s1} \text{ x } 0.75 \quad \text{(A-105)}$$

$$(X_{r1})^{S=1}{}_{sat} = X_{r1} \text{ x } (0.6 – 0.7) \approx X_{r1} \text{ x } 0.65 \quad \text{(A-106)}$$

For rated slip(speed), both skin and leakage saturation effects are undesirable and must be eliminated by making $K_R = K_x = 1$. This condition then gives the rotor bar end resistance $(R_{be80°C})S_n$ at rated slip (A-81).

The rotor resistance $(R_r')_{Sn}$ is

$$(R_r')_{Sn} = (R_r')^{S=1} \text{ x } R_{be80°C}{}^{S=Sn} / R_{be80°C}{}^{S=1} \quad \text{(A-107)}$$

The magnetisation reactance X_m is

$$X_m = \sqrt{} ((V_{ph} / I_o)^2 – R_s{}^2) – X_{s1} \quad \text{(A-108)}$$

A-7 The Skewing Effect on Reactances

In most designs rotor slots are skewed. The topic of skewing is however not the subject of this design. Nevertheless it is sufficient to know that a skewing factor C of one stator slot pitch τ_s is typical ($C = \tau_s$).

The effect of skewing on X_m is

$$(X_m)_{skew} = X_m \text{ x } K_{skew} \tag{A-109}$$

And $K_{skew} = SIN(\pi / 2 \text{ x } C / \tau) / (\pi / 2 \text{ x } C / \tau) = SIN(\pi /2 \text{ x } \tau_s / \tau) / (\pi / 2 \text{ x } \tau_s / \tau)$(2-108)

The rotor leakage inductance is augmented by a new term X'_{r1skew} equal to

$$X'_{r1skew} = X_{mskew} \text{ x } (1 - K_{skew}^2) \tag{A-110}$$

The final values of rotor reactance at S=1 and S = S_n respectively are

$$(X_{r1})_{skew}^{S=1} = (X_{r1})_{sat}^{S=1} + X'_{r1skew} \tag{A-111}$$

$$(X_{r1})_{skew}^{S=Sn} = X_{r1} + X'_{r1skew} \tag{A-112}$$

A-8 Losses and Efficiency

Efficiency η is defined as the output divided by the input power and is given by the expression,

$$\eta = P_{out} / P_{in} = P_{out} / (P_{in} + \sum \text{losses}) \tag{A-113}$$

The loss components are

$$\sum \text{losses} = P_{Co} + P_{A1} + P_{iron} + P_{mv} + P_{stray} \tag{A-114}$$

Where P_{Co} is the stator winding losses and is equal to

$$P_{Co} = 3 \text{ x } R_s \text{ x } I_{1n}^2 \tag{A-115}$$

And P_{A1} is the rotor cage losses, therefore

$$P_{A1} = 3 \text{ x } (R_r)_{Sn} \text{ x } I_{rn}^2 = 3 \text{ x } R_r \text{ x } K_I^2 \text{ x } I_{1n}^2 \tag{A-116}$$

The mechanical/ventilation losses $P_{mv} = 0.03 \text{ x } P_n$ (A-117)

The stray losses $P_{stray} = 0.01 \text{ x } P_n$ (A-118)

The iron core losses are complicated and are composed of the fundamental $P^1{}_{iron}$ and addition (harmonics) $P^h{}_{iron}$ loss. The fundamental core losses occur only in the teeth and back iron (P_{t1}, P_{y1}) of the stator as the rotor (slip) frequency is low ($f_2 < (3 – 4)$ Hz). (A-119)

Therefore $P_{t1} = K_t \text{ x } P_{10} \text{ x } (f_1 / 50)^{1.3} \text{ x } B_{ts}{}^{1.7} \text{ x } G_{t1}$ (A-120)

Where P_{10} is the specific losses in W / Kg at 1.0 Tesla and 50 Hz (P_{10}=(2-3)) W / Kg , γ_{iron} =

7800 and K_t = (1.6 – 1.8) is the core loss augmentation for mechanical working. (A-121)

The stator tooth weight G_{t1} is

$$G_{t1} = \gamma_{iron} \text{ x } N_1 \text{ x } b_{ts} \text{ x } (h_s + h_w + h_{os}) \text{ x } L \text{ x } K_{Fe} \quad \text{(A-122)}$$

Similarly the stator back iron (yoke) fundamental losses Py1 is

$$P_{y1} = K_y \text{ x } P_{10} \text{ x } (f_1 / 50)^{1.3} \text{ x } B_{cs}{}^{1.7} \text{ x } G_{y1} \quad \text{(A-123)}$$

Where K_y = 1.6 -1.9 takes care of the influence of mechanical machining.

$$G_{y1} = \gamma_{iron} \text{ x } (\pi / 4) \text{ x } (D_{out}{}^2 – (D_{out} – 2 \text{ x } h_{cs})^2) \text{ x } L \text{ x } K_{Fe} \quad \text{(A-124)}$$

Therefore the fundamental iron losses $P^1{}_{iron}$ is

$$P^1{}_{iron} = P_{t1} + P_{y1} \quad \text{(A-125)}$$

The stray losses $P^S{}_{iron}$ are made up of the tooth flux pulsation losses, therefore $P^S{}_{iron}$ is

$$P^S{}_{iron} = 0.5 \text{ x } 10^{-4} \text{ x } ((N2 \text{ x } (f_1/P_1) \text{ x } K_{ps} \text{ x } B_{ps})^2 \text{ x } G_{ts} + (N_s \text{ x } (f_1/P_1) \text{ x } K_{pr} \text{ x } B_{pr})^2 \text{ x } G_{tr}) \quad \text{(A-126)}$$

Where the quantities K_{ps}, B_{ps}, G_{ts}, K_{pr}, B_{ps} and G_{tr} are as follows

$$K_{ps} = 1 / (2.2 – B_{ts}) \quad \text{(A-127)}$$

$$B_{ps} = (K_{c2} -1) / B_g \quad \text{(A-128)}$$

And $$K_{pr} = 1 / (2.2 – B_{tr}) \quad \text{(A-129)}$$

$$B_{pr} = (K_{c1} - 1) / Bg \quad \text{(A-130)}$$

The rotor teeth weight G_{tr} is

$$G_{tr} = \gamma_{iron} \text{ x } L \text{ x } K_{Fe} \text{ x } N2 \text{ x } (h_r + ((d_1 + d_2) / 2) \text{ x } b_{tr} \quad \text{(A-131)}$$

And $$G_{ts} = G_{t1} \quad \text{(A-132)}$$

Therefore the total core loss P_{iron} is

$$P_{iron} = P^1{}_{iron} + P^S{}_{iron} \quad \text{(A-133)}$$

A-9 Operation Characteristics

Operating characteristics are calculated to see if the design power factor Cos φ_{1n} is achieved.

The operation characteristics are the active no load current I_{0a}, rated slip S_n, rated torque T_n, breakdown slip and torque S_k, T_{bk}, current Is and power factor versus slip, starting current, and torque I_{LR}, T_{LR}.

The no load current I_{0a} is given by the no load losses as follows

$$I_{0a} = (P_{iron} + P_{mv} + (3 \text{ x } I_0^2 \text{ x } R_s)) / (3 \text{ x } V_{ph}) \quad \text{(A-134)}$$

The rated slip S_n is

$$S_n = P_{A1} / (P_n + P_{A1} + P_{mv} + P_{stray}) \quad \text{(A-135)}$$

The value of the design slip S_n used in the initial stages of the design must be equal or more than the rated slip S_n calculated in Equation A-135 for the design to be acceptable.

The rated shaft torque T_n is

$$T_n = P_n / (2 \text{ x } \pi \text{ x } (f_1 / P_1) \text{ x } (1 - S) \quad \text{(A-136)}$$

The torque versus slip expression is given by the equation

$$T_e = (3 \text{ x } P_1 / \omega_1) \text{ x } ((V_{ph}^2 \text{ x } (R_r / S)) / ((R_s + C_m \text{ x } (R_r / S))^2 + (X_{s1} + C_m \text{ x} X_{r1})^2) \quad \text{(A-137)}$$

Where $C_m = 1 + X_{s1} / X_m$ (A-137)

Therefore from Equation A-137 the breakdown torque T_{bk} is

$$T_{bk} = (3 \text{ x } P_1 / 2 \text{ x } \omega_1)\text{x}((V_{ph}^2) / (\sqrt{}(R_s^2 + (X_{s1} + C_1 \text{ x } X_{r1})^2) \quad \text{(A-138)}$$

And $C_1 = 1.1658 \text{ x } C_m$ (A-139)

The starting current I_{LR} is

$$I_{LR} = (V_{ph} / \sqrt{}((R_s + R_r^{S=1})^2 + (X_{s1}^{S=1} + X_{r1}^{S=1})^2 \quad \text{(A-140)}$$

The starting torque T_{LR} is

$$T_{LR} = ((3 \text{ x } R_r^{S=1} \text{ x } I_{LR}^2) / \omega 1) \text{ x } P1 \quad \text{(A-141)}$$

The rated power factor Cos φ_{1n} is

$$\text{Cos } \varphi_{1n} = P_n / (3 \text{ x } V_{ph} \text{ x } I_n \text{ x } \eta) \quad \text{(A-142)}$$

The calculated power factor Cos φ_{1n} must be bigger or equal to the initial assumed value of Cosφ_{1n} used in the design for the design to be acceptable.

The other quantities of interest are the ratios of breakdown torque to rated torque t_{bk}, the starting torque to the rated torque t_{LR} and the starting current to the input current i_{LR}, therefore

$$t_{bk} = T_{bk} / T_n \quad \text{(A-143)}$$

$$t_{LR} = T_{LR} / T_n \quad \text{(A-144)}$$

$$i_{LR} = I_{LR} / I_{1n} \quad \text{(A-145)}$$

A-10 Temperature Rise

The temperature rise of the induction motor in operation was is very important and it was calculated to prove that it was below that of insulation class F, even though the motor was designed for class F insulation. The temperature rise must not exceed the design class for the design to be thermally valid.

To start with the temperature differential between the conductors in slots and the slot wall $\Delta\theta_{co}$ was calculated as follows

$$\Delta\theta_{co} = P_{co} / (\alpha_{cond} \text{ x } A_{1s}) \quad \text{(A-146)}$$

The frame temperature rise $\Delta\theta_{frame}$ with respect to ambient air was determined as follows

$$\Delta\theta_{frame} = \sum \text{losses} / (\alpha_{cond} \text{ x } A_{frame}) \quad \text{(A-147)}$$

Where $\alpha_{cond} = \lambda_{ins} / h_{ins}$ (A-148)

And $\lambda_{ins} = 0.25$ is the insulation thermal conductivity in (W / m^2 x K) (A-149)

$h_{ins}= 3\text{x}10^{-4}$ is the total insulation thickness from the slot middle to the teeth of the wall (A-150)

and α_{cond} is the slot insulation conductivity plus its thickness lumped together.

The stator slot lateral area A_{1s} is

$$A_{1s} = (2 \text{ x } h_s + b_{s2}) \text{ x } L \text{ x } N1 \quad \text{(A-151)}$$

The frame area A_{frame} is

$$A_{frame} = \pi \text{ x } D_{out} \text{ x } (L + \tau) \text{ x } K_{fin} \quad \text{(A-152)}$$

Where $K_{fin} > 1.0$ is the frame cooling constant and expresses the cooling effect of the number of fins on the motor casing. (A-153)

Now if ambient temperature $\theta_{amb} = 40°C$, then θ_{co} is

$$\theta_{co} = \theta_{amb} + \Delta\theta_{co} + \Delta\theta_{frame} \quad \text{(A-154)}$$

The conductor temperature θ_{co} must fall below that of class F insulation.

A-11 Construction and Armature Windings

A motor or generator is divided into two parts namely, the stator and the rotor. The stationary part of the motor is called the stator, while the rotating part is called the rotor. Both the stator and the rotor are built up of laminated steel cores and windings. The stator core usually carries the field winding while the rotor core carries the armature windings. The windings on both the stator and the rotor are similar.

A-12 Types of Armature Windings

There are generally two types of windings, the lap-winding and the wave-winding [15, 18]. These are classified as simplex or multiplex depending on the end connection sequence.

A-13 Lap-Winding and Wave winding

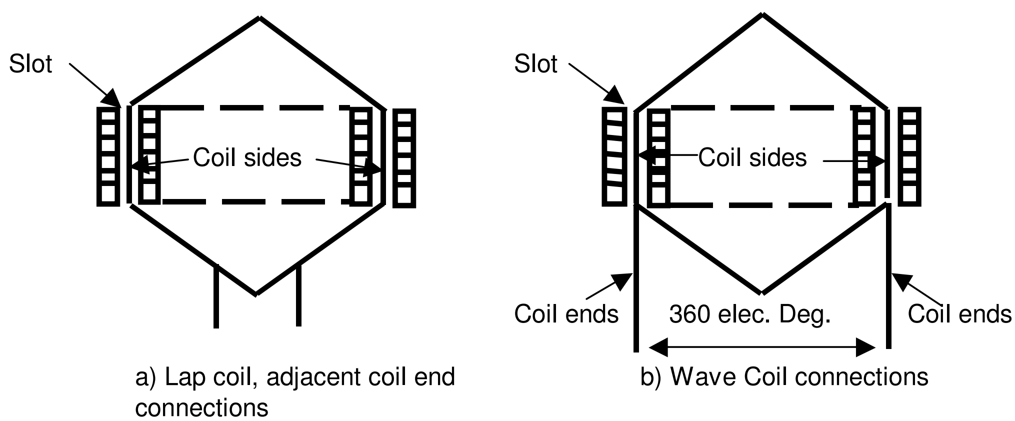


Figure A-8 Lap and Wave Coils

A-14 Simplex Lap-Winding

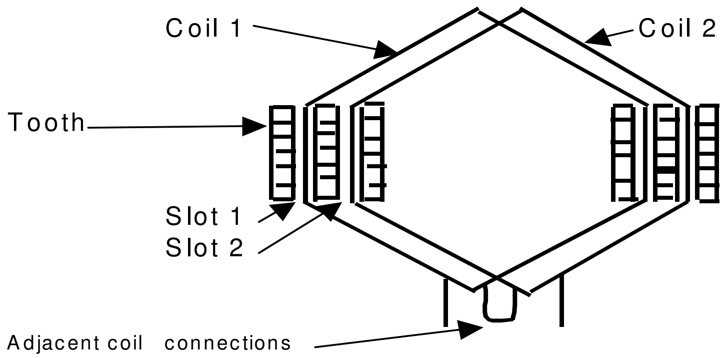


Figure A-9 Coil End Connections for Simplex Lap-Winding

In this winding the coil ends are connected to the adjacent coil ends in case of an ac machine and to the adjacent segments in case of a dc machine.
This winding was used for the development of the University of Zambia electric motor

A-15 Coil Span and the Coil Pitch

The coil span y_s is often referred to as the **coil pitch** [15] and is expressed as,

$$Y_S = \frac{S}{P} - K \qquad \text{(A-155)}$$

Where Y_S = coil pitch, in slots

S = total number of slots

P = number of poles

K = any fraction remainder of S/K that is subtracted to make Y_S an integer.

When a coil spans exactly 180 electrical degrees, the coil pitch is called **full pitch.** If the coil spans less than 180 electrical degrees, the coil pitch is called a **fractional pitch**. The ratio of the voltage generated in a fractional pitch coil to that generated in the full pitch coil is called the **pitch factor.**

A-16 Pitch Factor

$K_{p1} = \sin P° / 2$

(A-156)

where k_p = pitch factor (always a decimal for a fractional-pitch winding) [13]

$p°$= span of the coil in electrical degrees.

A-17 Distribution Factor

When coils are connected in series their resultant voltage is not equal to the voltage of individual coils (not connected) added together. The factor used to multiply to the voltage from the series connection to equal that of the sum of the unconnected coils is called the distribution factor and is expressed as,

$$K_{d1} = \mathrm{SIN}(n \times d° / 2) / (n \times \mathrm{SIN}(d° / 2)) \qquad \text{(A-157)}$$

where K_{d1} = distribution factor

n = number of slots per phase per pole

$d°$ = number of electrical degrees between adjacent slots

Induction Motor Design Formulae

Motor Parameters

S_n =	0.05		K_c =	1.21		B_{cs} =	1.5	A/m	ρ_{Co} =	1.8E-08	
q =	6		π =	3.14		a1 =	1		ω_1 =	314	
P_1 =	1		K_{DD} =	0.56		K_{fill} =	0.4		γ_{iron} =	7800	
P_n =	5280	w	η_n =	0.85		K_{Fe} =	0.96	for 0.5mm			
μ_0	1E-06		Hcs =	1340		B_{ts} = B_{tr} =	1.6	T	K_t =	1.7	
P°	150	deg	sn =	0.05		h_{os} =	0.001	m	P_{10}	2	
m_1 =	3		K_f =	1.085		h_w =	0.0015	m	K_y	1.6	
α_1 =	0.729		B_g =	0.58	T	b_{os} =	0.0022	m	λ_{ins}	0.25	
J_{cos} =	0.7	A/mm2	1+K_{st}=	1.4		H_{ts} =	2460	A/m	h_{ins}	0.0003	
f_1 =	50	Hz	Cosφ_{1n} =	0.85		η_n =	0.85		K_{fin}	3	
C_o =	144500	J/m³	λ =	0.6		K_E =	0.975		α_{cond}	60	
V_{ph} =	219.39	V	V_1 =	380	V	K_{sc}	0.4		$\Delta\theta_{amb}$	40	
J_b =	3E+06	A/m²	h_{or} =	0.0005	m	b_{or} =	0.0015	m	K_R = K_x	1	
						B_{cr} =	1.65	T			
						H_{cr} =	3460	A/m			

The airgap apparent power S_{gap} is

S_{gap} = $(K_E x P_n)/(\eta_n x Cos\varphi_{1n})$ = 7125.3 VA (B-1)

For S_{gap} = 7125.3 VA, C_o = 144500 J / m_3 obtained from Figure A-1.

The stator bore diameter D_{sbd} is

D_{sbd} = $\sqrt[3]{((2xP_1 xS_{gap})/(\pi x\lambda xf_1 xC_o))}$ = 0.10154 m (B-2)

Pole pitch τ is

$\tau = (\pi xD_{sbd})/(2xP_1)$ = 0.15942 m (B-3)

The length of the stator core L is

$L = (\lambda x\pi xD_{sbd})/(2xP1)$ = 0.09565 m (B-4)

The stator slot pitch is

$\tau_s = \tau/(3xq) =$ 0.00886 m (B-5)

From Appendix A (Table A-2) K_{DD} is

$K_{DD} = D_{sbd}/D_{out}$, (B-6)

The stator out diameter D_{out} is

$D_{out} = D_{sbd}/K_{DD} =$ 0.181 m (B-7)

Therefore $D_{out} =$ 0.18 m = 180 mm

The air-gap g is

$g = (0.1+0.02x\sqrt[3]{P_n})x10^{-3}m$, for $2xP_1=2$(i.e. 2 pole motors) (B-8)

g = 0.0004 m .= 4.50E-04 m

Stator Winding Electrical Calculations

The number of primary winding N1 is

$N1 = 2xP_1xqxm =$ 36 (B-9)

The stator electric angle α_{ea} is

$\alpha_{ea} = (2x\pi xP_1)/N1 =$ 0.174 or $\pi/18$ (B-10)

The pitch factor K_{p1} is

$K_{p1} = SIN(P^{\circ}/2) =$ 0.948 (B-11)

The distribution factor K_{d1} is

K_{d1} = SIN(qxd°/2)/(qxSIN(d°/2)) = 0.956 (B-12)

Therefore the stator winding factor K_{w1} is

$K_{w1} = K_{p1} x K_{d1}$ = 0.907 (B-13)

Flux per pole ϕ is

$\phi = \alpha_1 x \tau x B_g$ = 0.00645 Wb (B-14)

The range of B_g for a 2xP1=2 motor is

B_g = (0.5 - 0.75)T, therefore B_g = 0.58 T (B-15)

From Appendix A (Figure A-2)the tooth saturation coefficient $1+K_{st}$ is

$1+K_{st}$ = 1+0.4 From which graph α_1 = 0.729 (B-16)
and K_f = 1.085

The number of turns per phase W_1 is

$W_1 = K_E x V_{ph}/(4 x K_f x K_{w1} x f_1 x \phi)$ = 168.641 (B-17)

The number of conductors per slot N_c is

Nc = $(a_1 x W_1)/(P_1 x q)$ = 28.107 (B-18)

But N_c must be an even number, since the slot accommodates two distinct coils in a double layer winding.

Therefore N_c = 28

Therefore the number of turns per phase as to be corrected as W_{c1} and is

$W_{c1} = P_1 x q x N_c =$ 168 (B-19)

Therefore the actual flux density B_{ag} is

$B_{ag} = B_g x(W_1/W_{c1}) =$ 0.58 T (B-20)

The input current I_{1n} is

$I_{1n} = P_n/(\eta_n x Cos\varphi_{1n} x \sqrt{3} x V_1) =$ 11.103 A (B-21)

Current density range J_{cos} is

J_{cos} = (4 - 7) A/mm² for 2xP1 = 2,4, i.e. 2 pole,4 pole motor (B-22)

Therefore Jcos = 7 A/mm² was selected.

The conductor cross section area A_{co} is

$A_{co} = I_{1n}/J_{cos} =$ 1.586 mm² (B-23)

Therefore the conductor diameter d_{co} is

$d_{co} = \sqrt{(4 x A_{co}/\pi)} =$ 1.421 mm (B-24)

In general, if d_{co}>1.3 mm in low power induction motors, a few conductors may be used in parallel. But in this design d_{co}=1.4 mm is close to the maximum range = 1.3 mm therefore
$d_{co} = \sqrt{(4 x A_{co}/(\pi x a_1))} =$
= 1.421 mm

Stator Slot sizing

The stator slot area A_{su} is

$A_{su} = (\pi x d_{coc}^2 x a_1 x N_c)/(4xK_{fill}) =$ 111.03 mm² (B-25)

Assuming that all the airgap flux passes through the stator teeth, then,

$B_g x \tau_s x L \approx B_{ts} x b_{ts} x L x K_{Fe}$, where b_{ts} is the tooth width and expressed as (B-26)

$b_{ts} = (B_g x \tau_s x L)/(B_{ts} x K_{Fe}) =$ 0.00334 m (B-27)

For technological reasons b_{ts} must not be below $3.5x10^{-3}$m. But the calculated value of 3.3 x 10-3 m is acceptable as it is just below the limit.

The slot front width b_{s1} is

$b_{s1} = ((\pi(D_{sbd}+2xh_{os}+2xh_{w}))/N1)-b_{ts} =$ 0.00595 m (B-28)

The useful area of the slot may be expressed as

$A_{su} = h_s x(b_{s1}+b_{s2})/2$, also (B-29)

$b_{s2} = b_{s1}+2xh_s x Tan(\pi/N1)$ (B-30)

From the two equations the values of b_{s2} and h_s may be found as follows:

$b_{s2}^2-b_{s1}^2 = 4xA_{su}xTan(\pi/N1)$, therefore (B-31)

$b_{s2} = \sqrt{((4xA_{su}xTan(\pi/N1)+b_{s1}^2)} =$ 0.00862 m (B-32)

Therefore the slot useful height h_s is

$h_s = 2xA_{su}/(b_{s1}+b_{s2}) =$ 0.0152 m (B-33)

We then must compute the teeth saturation factor $1+K_{st}$ by assuming that stator and rotor produce the same effects in this regard. Therefore the teeth saturation factor is

$1+K_{st} = 1 + ((F_{mts}+F_{mtr})/F_{mg})$, where the airgap F_{mg} is (B-34)

$F_{mg} = 1.2xgxB_g/\mu_o =$ 249.349 Aturns (B-35)

For $B_{ts} =$ 1.6 T $H_{ts} =$ 2460 A/m (B-36)

Therefore Fmts is

$F_{mts} = H_{ts}(h_s+h_{os}+h_w) =$ 43.660 Aturns (B-37)

And F_{mtr} is

$F_{mtr} = K_{st}xF_{mg}-F_{mts} =$ 56.079 Aturns (B-38)

This value of the rotor tooth F_{mtr} is only slightly more than that of the stator tooth saturation F_{mts} therefore the design is acceptable.

The stator back iron height h_{cs} is given by the equation,

$h_{cs} = (D_{out}-(D_{sbd}+2x(h_{os}+h_w+h_s)))/2 =$ 0.0215 m (B-39)

The back core diameter B_{cs} with $h_{cs} = 0.0215$m is,

$B_{cs} = \phi/(2xLxh_{cs}) =$ 1.569 T (B-40)

The acceptable value of B_{cs} is 1.4 to 1.7T, therefore the calculated value of $B_{cs} = 1.569$T is acceptable.

Rotor Slot Calculations

In selecting the number of rotor slots care must be exercised to avoid electromagnetic noise, vibration and anomalies in the speed-torque curve. Manufacturing cost, losses, and heating are affected.

Based on past experience one general rule often used is that the number of stator slots N2 must be either below or above N1 by 15 to 20(some say 25)% of N1. Therefore in this design N2 is,

$N2 = N1-0.15xN1 =$ 30.6 (B-41)

Therefore N2 = 30

The value of the rated rotor bar current I_b is,

$I_b = K_I x(2xmxW_1xK_{w1})xI_{1n}/N2 =$ 298.78 A (B-42)

Where $K_I = 0.8xCos\phi_{1n}+0.2 =$ 0.88 (B-43)

If $K_I = 1$, the rotor and stator mmf are equal but in reality stator mmf is slightly larger.

For high efficiency, the current density in the rotor bar is $J_b = 3.45$ A/mm². The rotor slot area is,

$A_b = I_b/J_b =$ 8.7E-05 m² (B-44)

The end ring current I_{er} is,

$I_{er} = I_b/(2xSIN(\pi xP_1/N2)) =$ 1429.9 A (B-45)

The current density in the end ring $J_{er} = (0.75\text{-}0.8)J_b$. Selecting $J_{er} = 0.75J_b$, (B-46)

$J_{er} =$ 3E+06 A/m²

Therefore the end ring cross section A_{er} is

$A_{er} = I_{er}/J_{er} =$ 0.00056 m² (B-47)

Rotor Slot Sizing

The rotor slot pitch τ_r is

$\tau_r = (\pi x(D_{sbd}\text{-}2xg))/N2 =$ 0.0105 m (B-48)

With the rotor tooth flux density B_{tr} = 1.6T, the tooth width b_{tr} is,

$b_{tr} = B_g x \tau_r/(K_{Fe} x B_{tr}) =$ 0.00399 m (B-49)

The diameter d_1 is obtained from the following equation,

$$(\pi x(D_{sbd}\text{-}2xh_{or}\text{-}d_1))/N2 = d_1+b_{tr} \qquad \text{(B-50)}$$

Therefore $d_1 = (\pi x(D_{sbd}\text{-}2xh_{or})\text{-}N2xb_{tr}))/(\pi+N2) =$ 0.0059 m (B-51)

To compete the slot dimensions we apply the following slot area equations

$$A_b = \pi/8(d_1^2\text{-}d_2^2)+(d_1+d_2)h_r/2 \text{ and} \qquad \text{(B-52)}$$

$$d_1\text{-}d_2 = 2xh_r x TAN(\pi/N2) \qquad \text{(B-53)}$$

Starting with $h_r = h_s$ = 0.152m, d_2 is

$d_2 = d_1\text{-}2xh_r$ x $TAN(\pi/N2)=$ 0.0027 m (B-54)

h_r(m)	d_2(m)	A_b(m²)
0.0152	0.0027	7.7E-05
0.0194	0.0018	8.8E-05

With h_r = 0.0194m, A_b = 8.754E-05m². This value of A_b is almost equal to the earlier calculated value of A_b=8.74E-05m². Therefore the values of h_r and d_2 are,

$h_r =$ 0.0195 m

$d_2 =$ 0.0018 m

At this point the value of the rotor tooth mmf F_{mtr} was calculated to see how it compares to the earlier value of F_{mtr} = 56.09Aturns calculated. Therefore for $B_{tr} = B_{ts}$ = 1.6T, H_{tr} = 2460Aturns F_{mtr} is given by the followng equation

$F_{mtr} = H_{tr}(h_r+h_{or}+((d_1+d_2)/2)) =$ 58.69 Aturns. (B-55)

The value of F_{mtr} = 58.69Aturns is very close to the earlier calculated value of F_{mtr} = 56.09 Aturns, therefore the design is acceptable.

The rotor back core height h_{cr} is calculated for rotor core flux density B_{cr} = 1.6T, since acceptable B_{cr} = 1.4 to 1.7T. Therefore h_{cr} is,

$h_{cr} = \phi/(2xLxB_{cr}) =$ 0.0204 m (B-56)

The maximum shaft diameter D_{shaft} is,

$D_{shaft} \leq D_{sbd}-2xg-2x(h_{or}+((d_1+d_2)/2)+h_r+h_{cr}) =$ 0.012 m (B-57)

The shaft diameter must correspond to the rated torque given by the mechanical design $D_{shaftmec}$ = 22mm [1] and often from past designs. The rated torque Ten is,

$T_{en} = P_n/(2x\pi x(f_1/P_1)x(1-S_n) =$ 17.7 Nm (B-58)

In this design 22mm given as the shaft diameter by Nyirenda[1] suffices.

The dimensions a and b of the end ring cross section area were calculated from figure B-3 as follows

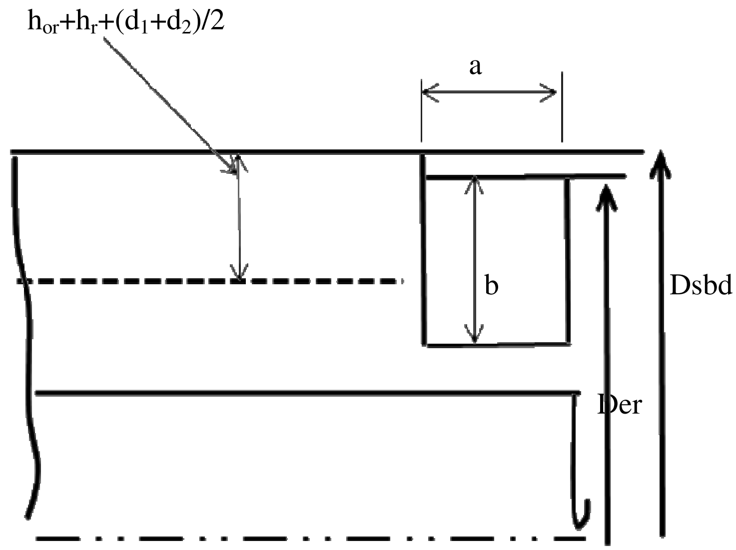


Figure B-1 End Ring Cross-Section

In general D_{sbd}-D_{er} = (3 to 4) x 10^{-3}m. Also (B-59)

$$b = (1.0 - 1.2) \times ((h_r + h_{or} + (d_1+d_2)/2)$$ from which b is

$b = 1.0x((h_r + h_{or} + (d_1+d_2)/2)) =$ 0.0239 m (B-60)

and a
is

$a = A_{er}/b =$ 0.0234 m (B-61)

The Magnetisation current I_o

The magnetisation mmf F_{1m} is

$$F_{1m} = 2x(K_c \times g \times B_g/\mu_o+F_{mts}+F_{mtr}+F_{mcs}+F_{mcr}) \quad \text{(B-62)}$$

Where K_c, F_{mcs} and F_{mcr} are calculated as follows,

K_c is called Carter's coefficient and is calculated as follows,

$\gamma_1 = b_{os}^2/(5 \times g + b_{os}) =$ 0.00109 m (B-63)

$\gamma_2 = b_{or}^2/(5 \times g + b_{or}) =$ 0.00060 m (B-64)

Where K_{1c} and K_{2c} are

$K_{1c} = \tau_s/(\tau_s - \gamma 1) =$ 1.140 (B-65)

$K_{2c} = \tau_r / (\tau_r - \gamma_2) =$ 1.061 (B-66)

Therefore $K_c = K_{1c} \times K_{2c} =$ 1.21

Now $F_{mcs} = C_{cs} \times \pi \times ((D_{out} - h_{cs})/2P1) \times H_{cs}(B_{cs})$ (B-67)

Where B_{cs} = 1.456T and $C_{cs} \approx 0.88 \times e^{-o \cdot 4 B_{cs,r}^2}$ C_{cs} = 0.358

Therefore F_{mcs} = 119.32 Aturns C_{cr} = 0.296

and $F_{mcr} = C_{cr} x(\pi x(D_{shaft}+h_{cr})/2P1)xH_{cr}$ (B-68)

Therefore F_{mcr} = 52.30 Aturns

Therefore F_{1m} = 1045.29

And the total saturation factor Ks is

$K_s = (F_{1m}/2xF_{mg}) - 1 =$ 1.0960 (B-69)

The magnetisation current I_o is

$I_o = (\pi x P_1 x(F_{1m}/2))/(3x\sqrt{2}xW_1 x K_{w1}) =$ 2.53 A (B-70)

And the relative per unit value i_o is

$i_o = I_o/I_{1n} =$ 0.228 23 % (B-71)

Resistances and Inductances

Resistances and reactances are as shown in figure B-2 below.

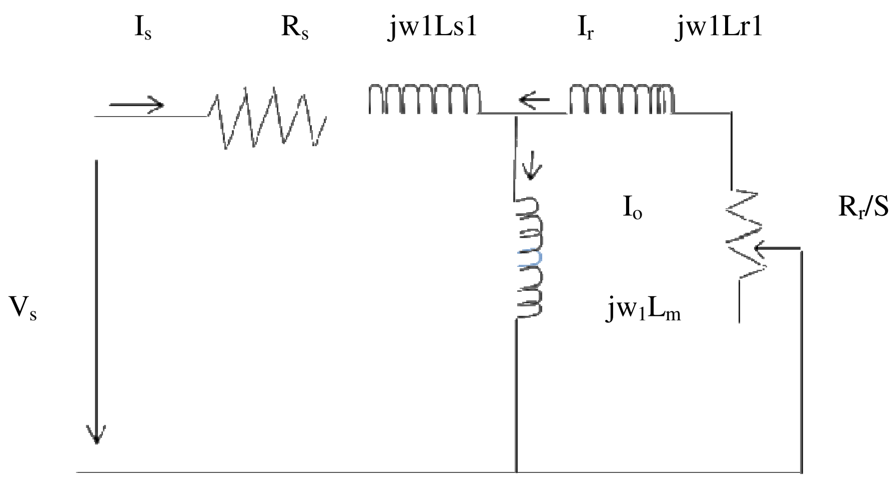


Figure B-2 Equivalent Circuit of an Induction Motor (Core Losses ignored)

The stator phasor resistance is given as

$$R_s = \rho_{Co}x((I_cxW_1)/A_{co}xa_1) \quad \text{(B-72)}$$

where $I_c = 2x(L+I_{end})$ (B-73)

The coil end connection depends on the coil span y, number of poles, shape of coils, and number of layers in the winding.

and $I_{end} = 2y - 0.04$ m for 2P1 = 2 (B-74)

Also the ratio $y/\tau= 15/18 =ß$, is called the chording factor. (B-75)

and the acceptable value of ß is the range $2/3 \leq ß \leq 1$ (B-76)

Therefore $y = (15/18) \times \tau =$ 0.13285 m (B-77)

ß = 0.8333

Therefore I_{end} = 2xy - 0.02 = 0.24570 m (B-78)

I_c = 0.6827 m

In all designs high efficiency is desired and in achieving this the winding temperature must not be large even if the insulation class if F. In this design therefore similar caution was taken. Now the copper resistivity at 20ºC is $(\rho_{Co})_{20ºC} = 1.78 \times 10^{-8}$ Ωm and $(\rho_{Co})_{115ºC} = 1.37 \times (\rho_{Co})_{20ºC}$. (B-79)

Therefore at copper resistivity = 80ºC, ρ_{Co} is

$(\rho_{Co})80ºC = (\rho Co)20ºC \times ((1+(1/273) \times (80-20)) =$ 2.171E-08 Ωm (B-80)

Therefore from (B-70) $R_s = (\rho_{Co})_{80ºC} x((I_c x W_1)/(A_{Co} x a_1)) =$ 1.570 Ω (B-81)

And the rotor bar-end ring equivalent resistance R_{be} is

$R_{be} = \rho_{A1} \times ((L/A_b) \times K_R + (\iota_{er}/(2A_{er} \times SIN^2(\pi \times P_1/N2))) =$ (B-82)

The cast aluminium resistivity at 20ºC $(\rho_{A1})_{20ºC} = 3.1 \times 10^{-8}$ Ωm.

Therefore $(\rho_{A1})_{20ºC} =$ 3.1E-08 Ωm

The end ring length ι_{er} is

$\iota_{er} = \pi(D_{er} - b)/N2$ (B-83)

From (B-57) $D_{er} = D_{sbd} - 2 \times g - 2 \times 3 \times 10^{-3}$ m 0.09464 m

From (B80) ι_{er} = 0.00741 m

In (B-79) K_R is the approximate skin effect resistance coefficient (and for a rectangular) is

$$K_R = \xi \times (SINH(2 \times \xi) + SIN(2 \times \xi))/(COSH(2 \times \xi) - COS(2 \times \xi)) \approx \xi \quad \text{(B-84)}$$

And $\xi = ß_s \times h_r \times \sqrt{S}$ where S = 1 (B-85)

And $ß_s = SQRT((\omega_1 x\ \mu_o)/(2 \times \rho_{A1}))$ 80 $(m)^{-1}$ (B-86)

From (B-82) ξ = 1.56 From (B-81) $K_R \approx \xi \approx$ 1.56

Now from (B-79) $R_{be}{}^{s=1}{}_{80°C}$ = 6.6E-05 Ω

The rotor cage resistance reduced to the stator R_r' is

$$(R_r')_{s=1} = ((4 \times m)/N2) \times (W_1 \times Kw_1)^2 R_{be80°} \quad 0.614\ \Omega \tag{B-87}$$

The stator phase leakage reactance X_{s1} is

$$X_{s1} = 2 \times \mu_o \times \omega_1 \times L \times (W_1^2/(P_1 \times q)) \times (\lambda_s + \lambda_{ds} + \lambda_{ec}) \tag{B-88}$$

where λ_s, λ_{ds}, λ_{ec} are the slot differential and end ring connection coefficients:

and $\lambda_s = ((2/3) \times (h_s/(b_{s1} + b_{s2})) + ((2 \times h_w)/(b_{os} + b_{s1})) +(h_{os}/b_{os})) \times ((1 + 3\ xß)/4)$ (B-89)

Therefore λ_s = 1.331

And $\lambda_{ds} \approx (0.9 \times \tau_s \times q^2 \times K_{W1}{}^2 \times C_s \times \gamma_{ds})/(K_c \times g \times (1 + K_{st})$ (B-90)

Where $C_s = 1 - 0.033(b_{os}{}^2/(g \times \tau_s))$ 0.960 (B-89)

For ß = 15/18 and q = 6, γds is

$$\gamma_{ds} = (0.11 \times SIN\varphi_1 + 0.41) \times 10^{-2} \tag{B-90}$$

where $\varphi_1 = \pi \times (6 \times ß - 5.5)$ = -1.57 (B-91)

From (B-90) γ_{ds} = 0.003

Therefore from (B-88) λ_{ds} = 0.89481

This design being a two layer winding, the end connection specific geometric permeance coefficient λ_{ec} is

$$\lambda_{ec} = 0.34 \text{ x } (q / L) \text{ x } (I_{end} - 0.64 \text{ x } ß \text{ x } \tau) = \quad 3.426781 \tag{B-92}$$

From (B-86) the stator phase reactance X_{s1} is

$$X_{s1} = \quad 2.02131$$

The equivalent rotor bar leakage reactance X_{be} is

$$X_{be} = 2 \text{ x } \pi \text{ x } f_1 \text{ x } \mu_0 \text{ x } L \text{ x } (\lambda_r \text{ x } K_x + \lambda_{dr} + \lambda_{er}) \tag{B-93}$$

where λ_r, λ_{dr}, λ_{er} are the rotor slot, differential and end ring permeance coefficient.
For this design λ_r is

$$\lambda_r = 0.66 + (2 \text{ x } h_r/(3*(d_1 + d_2))) + h_{or}/b_{or} = \quad 2.679 \tag{B-94}$$

And the differential coefficient λ_{dr} is

$$\lambda_{dr} = ((0.9 \text{ x } \tau_r \text{ x } \gamma_{dr})/(K_c \text{ x } g)) \text{ x } (N2/(6 \text{ x } P_1))^2 \tag{B-95}$$

and $\gamma_{dr} = 9 \text{ x } (6 \text{ x } P_1/N2)^2 \text{ x } 10^{-2} =$ 0.0036

From (B-95) $\lambda_{dr} =$ 1.574

And the end ring coefficient λ_{er} is

$$\lambda_{er} = ((2.3 \text{ x } (D_{er}\text{-}b))/(N2 \text{ x } L \text{ x } 4 \text{ x } SIN^2(\pi \text{ x } P_1/N2)) \text{ x } \log((4.7 \text{ x } (D_{er}\text{-}b)/(b+2 \text{ x } a)) \tag{B-96}$$

Therefore $\lambda_{er} =$ 0.8750

The skin effect coefficient for the leakage reactance K_x is, for $\xi = 1.56$

$K_x = (3/2 \text{ x } \xi) \text{ x } ((\text{SINH}(2 \text{ x } \xi) - \text{SIN}(2 \text{ x } \xi))/(\text{COSH}(2 \text{ x } \xi) - \text{COS}(2 \text{ x } \xi))) \approx 3/(2 \text{ x } \xi)$ (B-97)

Therefore $K_x = 3 / (2 \text{ x } \xi) =$ 0.964 (B-98)

From (B-93) $X_{be} =$ 0.00019 Ω

The rotor leakage reactance X_{r1} is a function of X_{be} and is given as

$X_{r1} = 4 \text{ x } m_1 \text{ x } ((W_1 \text{ x } K_{w1})^2/N2) \text{ x } X_{be}$ (B-99)

Therefore $X_{r1} =$ 1.7618 Ω

At stand still S=1, both stator and rotor leakage reactances are reduced due to leakage flux path saturation. For power levels in semi-closed stator and rotor slots, therefore,

$(X_{s1})^{S=1}_{sat} = X_{s1} \text{ x } (0.7 - 0.8) \approx X_{s1} \text{ x } 0.75 =$ 1.516 Ω (B-100)

$(X_{r1})^{S=1}_{sat} = X_{r1} \text{ x } (0.6 - 0.7) \approx X_{r1} \text{ x } 0.65 =$ 1.145 Ω (B-101)

For rated slip (speed), both skin and leakage saturation effects are undesirable and must be eliminated by making $K_R = K_x = 1$ (B-101)

Therefore from (B-80) $R_{be80°}$ is

$(R_{be80°})_{Sn} =$ 6.4E-05 Ω

The rotor resistance $(R_r')_{Sn}$ is

$(R_r')_{Sn} = (R_r')_{s=1} \text{ x } R_{be80°}^{S=Sn}/R_{be80°}^{S=1} =$ 0.598 Ω (B-101)

The magnetization Xm is

$X_m = \sqrt{((V_{ph}/I_0)^2 - R_s^2)} - X_{s1} =$ 84.68 Ω (B-102)

The skewing effect on reactances
In most designs rotor slots are skewed. The topic of skewing is however not the subject for this design. Nevertheless it is sufficient to know that a skewing C of one stator slot pitch τ_s is typical ($C = \tau_s$)

The effect of skewing on X_m is

$$X_m = X_m \times K_{skew} \tag{B-103}$$

And $K_{skew} = SIN(\pi/2 \times C/\tau)/(\pi/2 \times C/\tau) = SIN(\pi/2 \times \tau_s/\tau)/(\pi/2 \times \tau_s/\tau) =$ 0.9987 (B-104)

Therefore from (B-103) X_m is

$$X_m = 84.58 \quad \Omega$$

The rotor leakage inductance is augmented by a new term X'_{r1skew}

$$X'_{r1skew} = X_m(1-K_{skew}^2) = 0.2143 \quad \Omega \tag{B-105}$$

The final values of rotor reactances at S=1 and S=Sn respectively are,

$$(X_{r1})_{skew}^{S=1} = (X_{r1})_{sat}^{S=1} + X_{r1skew} = 1.359 \quad \Omega \tag{B-106}$$

$$(X_{r1})_{skew}^{S=Sn} = X_{r1} + X_{r1skew} = 1.976 \quad \Omega \tag{B-107}$$

Losses and Efficiency

Efficiency η is defined as output divided by the input power ;

Therefore $\eta = P_{out} / P_{in} = P_{out} / (P_{in} + \sum \text{losses})$ (B-108)

The loss components are

$$\sum \text{losses} = P_{co} + P_{A1} + P_{iron} + P_{mv} + P_{stray} \tag{B-109}$$

where P_{co} is the stator winding losses, P_{A1} is the rotor cage losses.

Therefore $P_{co} = 3 \times R_s \times I_{in}^2 =$ 580.642 W (B-110)

And $P_{A1} = 3 \times (R_r)_{Sn} \times I_{rn}^2 = 3 \times R_r \times K_1^2 \times I_{in}^2 =$ 171.218 W (B-111)

The mechanical/ventlation losses $P_{mv} = 0.03P_n$ for $P_1 = 1$ (B-112)

Therefore $P_{mv} =$ 158.4 W

The stray losses $P_{stray} = 0.01Pn$ is considered standard estimation (B-113)

Therefore $P_{stray} =$ 52.8 W

The iron core losses are complicated and are composed of the fundamental P^1_{iron} and addition (harmonics) P^h_{iron} loss.

The fundamental core losses occur only in the teeth and back iron (P_{t1}, P_{y1}) of the stator as the rotor (slip) frequency is low ($f_2 < (3 - 4)$ Hz). (B-114)

Therefore $P_{t1} = K_t \times P_{10} \times (f_1/50)^{1.3} \times B_{ts}^{1.7} \times G_{t1}$ (B-116)

where P_{10} is the specific losses in W/Kg at 1.0 Tesla and 50 Hz ($P_{10} = (2 - 3)$) W/Kg and $K_t = (1.6 - 1.8)$ is the core loss augmentation for mechanical working. (B-117)

G_{t1} is the stator tooth weigth and is

$G_{t1} = \gamma_{iron} \times N_s \times b_{ts} \times (h_s + h_w + h_{os}) \times L \times K_{Fe} =$ 1.5304 Kg (B-118)

From (B-116) P_{t1} is

$P_{t1} =$ 11.5689 W

Similarly the stator back iron (yoke) fundamental losses P_{y1} is

$P_{y1} = K_y \times P_{10} \times (f_1/50)^{1.3} \times B_{cs}^{1.7} \times G_{y1}$ (B-119)

where $K_y = 1.6 - 1.9$ takes care of the influence of mechanical machining. Let $K_y = 1.6$ (B-120)

And $G_{y1} = \gamma_{iron} \times (\pi/4) \times (D_{out}^2 - (D_{out} - 2 \times h_{cs})^2) \times L \times K_{Fe}$ 7.6583 Kg (B-121)

Therefore from (B-119) Py1 = 41.5148 W

Therefore the fundamental iron losses P^1_{iron} is

$P^1_{iron} = P_{t1} + P_{y1} =$ 53.0838 W (B-122)

The tooth flux pulsation core losses makes up the main components of stray losses P^s_{iron}.

Therefore $P^s_{iron} = 0.5 \times 10^{-4} \times ((N2 \times (f_1/P_1) \times K_{ps} \times B_{ps})^2 \times G_{ts} + (N_s \times (f_1/P_1) \times K_{pr} \times B_{pr})^2 \times G_{tr})$ (B-123)

where $K_{ps} = 1 / (2.2 - B_{ts}) =$ 1.6667 (B-124)

and $K_{pr} = 1 / (2.2 - B_{tr}) =$ 1.6667 (B-125)

$B_{ps} = (K_{c2} - 1) \times B_g =$ 0.0353 T (B-126)

$B_{pr} = (K_{c1} - 1) \times B_g =$ 0.0817 T (B-127)

And the rotor teeth weight G_{tr} is

$G_{tr} = \gamma_{iron} \times L \times K_{Fe} \times N2 \times (h_r + ((d_1 + d_2)/2) \times b_{tr} =$ 2.0428 Kg (B-128)

Now from (B-203), P^s_{iron} is

$P^s_{iron} =$ 6.7 W

Therefore the total core loss P_{iron} is

$P_{iron} = P^1_{iron} + p^s_{iron} =$ 59.8 W (B-129)

The summation of losses from (B-109) ∑ losses is

∑ losses = 1022.872 W

Having calculated the total losses the efficiency η from (B-108) is

η = 0.84

The targetted efficiency used in this design was $\eta_n = 0.85$. The calculated value of efficiency η = 0.84 is very close to the targetted efficiency η_n and therefore the design is acceptable.

Operation Characteristics

Operation characteristics were calculated to see from another targetted value of $\cos\varphi_{1n}$ = 0.85 if the design is acceptable.

The operation characteristics are the active no load current I_{0a}, rated slip S_n, rated torque T_n, breakdown slip and torque S_k, T_{bk}, current I_s and power factor versus slip, starting current, and torque I_{LR}, T_{LR}.

The no load current is given by the no load losses as follows:

$I_{0a} = (P_{iron} + P_{mv} + (3 \text{ x } I_{02} \text{ x } R_s)) /(3 \text{ x } V_{ph})$ 0.350 A (B-130)

The rated slip Sn is

$S_n = P_{A1}/(P_n + P_{A1} + P_{mv} + P_{stray}) =$ 0.030 (B-131)

The rated shaft torque T_n is

$T_n = P_n / (2 \text{ x } \pi \text{ x } (f_1 / P_1) \text{ x } (1-S_n))$ 17.34 Nm (B-132)

The approximate expressions of torque versus slip are

$T_e = ((3 \text{ x } P_1)/\omega_1) \text{ x } ((V_{ph}^2 \text{ x } (R_r/S))/(R_s + C_m \text{ x } (R_r/S))^2 + (X_{s1} + C_m \text{ x } X_{r1})^2)$ (B-133)

where $C_m = 1 + X_{s1} / X_m =$ 1.0239 (B-134)

From (B-210) the breakdown torque T_{bk} is

$T_{bk} = ((3 \text{ x } P_1)/2 \text{ x } \omega_1) \text{ x } (V_{ph2}/(R_s + \sqrt{}(R_s^2 + (X_{s1} + C_1 \text{ x } X_{r1})^2)) =$ 38.73 Nm (B-135)

The starting current I_{LR} is

$I_{LR} = (V_{ph}/\text{sqrt}(R_s + R_r^{S=1})^2 + (X_{s1}^{s=1} + X_{rl}^{S=1})^2$ 63.73 A (B-136)

The starting torque T_{LR} is

$T_{LR} = ((3 \text{ x } R_r^{S=1} \text{ x } I_{LR}^2)/\omega_1) \text{ x } P_1 =$ 23.81 Nm (B-137)

The rated power factor cosφ1n is

$\cos\varphi_{1n} = P_n/(3 \times V_{ph} \times I_n \times \eta) =$ 0.86 (B-138)

The calculated value of cosφ1n = 0.86 is close to the rated value of cosφ1n = 0.85. Therefore the design is acceptable and does not need any further iterations.

The other values of interest are

$t_{bk} = T_{bk} / T_n =$ 2.2 (B-139)

$t_{LR} = T_{LR} / T_n =$ 1.4 (B-140)

$i_{LR} = I_{LR} / I_{1n} =$ 5.7 (B-141)

Temperature Rise

The temperature rise of the induction motor in operation was very important to prove and compared to the design insulation class F, for the design to be thermally valid.

To start with the temperature differential between the conductors in slots and the slot wall $\Delta\theta_{co}$ was calculated as follows:

$$\Delta\theta_{co} = P_{co} / (\alpha_{cond} \times A_{1s}) \quad \text{(B-142)}$$

And the frame temperature rise Δθframe with respect to the ambient air was determined.

$$\Delta\theta_{frame} = \sum \text{losses} / (\alpha_{cond} \times A_{frame}) \quad \text{(B-143)}$$

Where $\alpha_{cond} = \lambda_{ins} / h_{ins} =$ 833 W / m^2K (B-144)

Where αconductor is the slot insulation conductivity plus its thickness lumped together and $\lambda_{ins} = 0.25$ and $h_{ins} = 3 \times 10^{-4}$ are the insulation thermal conductivity in (W / m^2K) and the total insulation thickness from the slot middle to the teeth wall respectively.

The stator slot lateral area A_{1s} is

$A_{is} = (2 \times h + b_{s2}) \times L \times N1 =$ 0.1347 m^2 (B-145)

and the frame area A_{frame} is

$A_{frame} = \pi \times D_{out} \times (L + \tau) \times K_{fin} =$ 0.4325 m^2 (B-146) where K_{fin} = 2.0, is the frame area multiplied by fins, provided to maximise heat transfer.

Now from (B-219),(B-110),(B-221),(B-222) (B-147)

$\Delta\theta_{co}$ = 5.17 °C

And from (B-220), and for α_{cond} = 60, for $2P_1$ = 2

$\Delta\theta_{frame}$ = 39 °C

Therefore if ambient temperature $\Delta\theta_{amb}$ = 40°C, then the conductor temperature θ_{cond} is

$\theta_{cond} = \theta_{amb} + \Delta\theta_{Co} + \Delta\theta_{frame}$ = 85 °C > 80°C

The conductor temperature θ_{cond} = 85°C < 80°C, which is 5°C more than the maximum. However it must be appreciated that the change in ambient tempeture can quickly change the conductor temperature accordingly. And in this case if the ambient temperature θamb = 30°C, θcond = 75°C. Another way to improve the conductor temperature is by increasing the surface area of the motor casing by increasing the number of fins.

Appendix C Financial Statements

C-1 Financial Statements for Production of 105 Electric Motors.

Income Statement

Year	1	2	3	4	5	6	7
ZMK '000	**ZMK '000**	**ZMK '000**	**ZMK '000**	**ZMK '000**	**ZMK '000**	**ZMK '000**	**ZMK '000**
Sales	1082890	1786768	2620593	3242984	4756376	5232013	5755215
Cost of sales	1122106	1230431	1356002	1482102	1665885	1809753	1970219
Gross Profit	**(39217)**	**556337**	**1264591**	**1760882**	**3090490**	**3422261**	**3784996**
Adminstration	1107600	1218360	1340196	1474216	1621637	1783801	1962181
Operating Profit	(1146817)	(662023)	(75605)	286666	1468853	1638460	1822815
Interest payable	100000	100000	100000	100000	100000	100000	100000
Profit before tax	(1246817)	(762023)	(175605)	186666	1368853	1538460	1722815
Taxation				65333	479099	538461	602985
Retained Earnings	**(1246817)**	**(762023)**	**(175605)**	**121333**	**889755**	**999999**	**1119829**

Table C-1.1 Income Statement for 105 Units

Balance Sheet

Year	1	2	3	4	5	6	7
	K' 000	**K' 000**	**K' 000**	**K '000**	**K' 000**	**K' 000**	**K '000**
Non current Assets	1911220	1753498	1610948	1482053	1365448	1259903	1164313
Current Assets							
Bank and Cash					9961	952428	1982372
Total Assets	**1911220**	**1753498**	**1610948**	**1482053**	**1375409**	**2212331**	**3146685**
Share capital	1000000	1000000	1000000	1000000	1000000	1000000	1000000
Retained Earnings	(1246817)	(2008840)	(2184444)	(2093445)	(1426129)	(676130)	163743
Long Term Liabilities							
10% Loan	1000000	1000000	1000000	1000000	1000000	1000000	1000000
Current Liabilties							
Interest	100000	100000	100000	100000	100000	100000	100000
Taxation				65333	479099	538461	602985
Proposed Dividend				30333	222439	250000	279957
Trade Payables							
Bank Overdraft	1058037	1662338	1695393	1379832			
Total Liabilities	**1911220**	**1753498**	**1610948**	**1482053**	**1375409**	**2212331**	**3146685**
Return on Investment	**-65%**	**-43%**	**-11%**	**8%**	**65%**	**45%**	**36%**

Table C-1.2 Balance Sheet for 105 Units

Cash Flow

Year	1	2	3	4	5	6	7
	K' 000	**K' 000**	**K' 000**	**K' 000**	**K '000**	**K '000**	**K '000**
Receipts							
Sales	1082890	1786768	2620593	3242984	4756376	5232013	5755215
Loan	1000000						
Sharecapital	1000000						
Total Receipts	**3082890**	**1786768**	**2620593**	**3242984**	**4756376**	**5232013**	**5755215**
Payments							
Material	55326	91289	133890	165689	243010	267311	294042
Equipment	1685800						
Administation	1107600	1218360	1340196	1474216	1621637	1783801	1962181
Direct Labour	630000	693000	762300	838530	922383	1014621	1116083
Indirect Labour	97200	106920	117612	129373	142311	156542	172196
Land and Buildings	400000						
Taxation					65333	479099	538461
Dividends					30333	222439	250000
Interest		100000	100000	100000	100000	100000	100000
Incremental Fixed Cost	165000	181500	199650	219615	241577	265734	292308
Total Payments	**4140926**	**2391069**	**2653648**	**2927422**	**3366584**	**4289546**	**4725270**
Cash at start		(1058037)	(1662338)	(1695393)	(1379832)	9961	952428
Net Cashflow	**(1058037)**	**(604301)**	**(33055)**	**315561**	**1389792**	**942467**	**1029944**
Cash at end	(1058037)	(1662338)	(1695393)	(1379832)	9961	952428	1982372

Discounting Factor26.3%	0.7918	0.6269	0.4964	0.3930	0.3112	0.2464	0.1951
Present Value	**(837717)**	**(378832)**	**(16407)**	**124014**	**432447**	**232191**	**200905**
Net Present Value	**(243399)**						

Table C-1.3 Cash Flow for 105 Units

C-1.4 Breakeven Point, Internal Rate of Return (IRR), Payback

Breakeven Point(units)	**56**	**56**	**56**	**56**	**56**	**56**	**56**
Breakeven Point(Sales)	**1920883**	**2112971**	**2324268**	**2556695**	**2812364**	**3093601**	**3402961**

Discount Factor 26.5%	0.790513834	0.624912122	0.494001677	0.39051516	0.308707636	0.244037657	0.192915144
	(804931)	(336598)	31250	169776	464147	255060	220486
	(810)						

!st Discount factor	1.263		
2nd Discount factor	1.265		
10% interest rate	26.3		
X interest rate	26.5		
IRR	26.47829708 %		26.47829708

Cumulative inflows

Project Cost	Initial	Yr	cumulative	DCH	Inflows	Pv of inflows	Cumulative
	4220525	1	1202287	0.791765637	1202287	951929	951929
		2	3186060	0.626892825	1983773	1243613	2195542
		3	6095594	0.496352197	2909534	1444154	3639696
		4	9696142	0.392994613	3600548	1414996	5054692
		5	14976946	0.311159631	5280804	1643173	6697865
		6	20785831	0.246365503	5808885	1431109	8128974
		7	27175604	0.19506374	6389773	1246413	9375387

Payback	2 years 4 months
Discounted payback	3 years 4 months

C-1.5 Inflation

PLANT WAGES	INDIRECT STAFF	ADMINSTRATION	MATERIAL COSTS
1.1	1.1	1.1	1.1

C-1.6 Plant Wages, Direct Staff

Station	Number of staff	Basic pay/month	Total/month	Total/year	Year 2(inflated)	Year 3(inflated	Year 4(inflated)	Year 5(Inflated)	Year 6(Inflated)	Year 7(Inflated)
Raw material										
Supervisor	1	2,500,000	2500000	30000000	33000000	36300000	39930000	43923000	48315300	53146830
Work men	2	800,000	1600000	19200000	21120000	23232000	25555200	28110720	30921792	34013971.2
Assistant Storemen	2	700,000	1400000	16800000	18480000	20328000	22360800	24596880	27056568	29762224.8
Punch Press										
Operator	2	1,500,000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Machine shop										
Machinists	8	1,500,000	12000000	144000000	158400000	174240000	191664000	210830400	231913440	255104784
Winding Machines										
Operators	2	900,000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Diecasting										
Operator	2	1,500,000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Rotor assembly										
Stackers	2	1,200,000	2400000	28800000	31680000	34848000	38332800	42166080	46382688	51020956.8
Loaders	1	900,000	900000	10800000	11880000	13068000	14374800	15812280	17393508	19132858.8
Assemblers/Balancers	4	1,300,000	5200000	62400000	68640000	75504000	83054400	91359840	100495824	110545406.4
Stator assembly										
Welders	1	1,500,000	1500000	18000000	19800000	21780000	23958000	26353800	28989180	31888098
Insulation	2	900,000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Assemblers/Testing	2	1,200,000	2400000	28800000	31680000	34848000	38332800	42166080	46382688	51020956.8
Final assembly										
Assemblers/Testing	4	2,500,000	10000000	120000000	132000000	145200000	159720000	175692000	193261200	212587320
Finished product										
Store men	2	800,000	1600000	19200000	21120000	23232000	25555200	28110720	30921792	34013971.2
Assistant Storemen	2	700,000	1400000	16800000	18480000	20328000	22360800	24596880	27056568	29762224.8
Total	39	20,400,000	52500000	**630,000,000**	**693000000**	**762300000**	**838530000**	**922383000**	**1014621300**	**1116083430**
Cost of 1 unit				**6000000**	**6600000**	**7260000**	**7986000**	**8784600**	**9663060**	**10629366**
Motor production/year				105	105	105	105	105	105	105
Motor production/month				9	9	9	9	9	9	9

C-1.7 Plant Wages, Indirect Staff

Station	**Number of staff**	**Basic pay/month**	**Total/month**	**Total/year**	Year 2(inflated)	Year 3(inflated	Year 4(inflated)	Year 5(inflated)	Year 6(inflated)	Year 7(inflated)
Maintenance										
Supervisor	1	1500000	1500000	18000000	19800000	21780000	23958000	26353800	28989180	31888098
Mechanics	2	900000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Electricians	2	900000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Assistant Electricians	4	750000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Total	9	4050000	8100000	**97,200,000**	**106920000**	**117612000**	**129373200**	**142310520**	**156541572**	**172195729.2**
Cost per unit				**925714.2857**	**1018285.714**	**1120114.286**	**1232125.714**	**1355338.286**	**1490872.114**	**1639959.326**
Number of units				105	105	105	105	105	105	105

C-1.8 Administration

Station	**Number of staff**	**Basic pay/month**	**Total/month**	**Total/year**	Year 2(inflated)	Year 3(inflated	Year 4(inflated)	Year 5(inflated)	Year 6(inflated)	Year 7(inflated)
Chief Executive	1	15000000	15000000	180000000	198000000	217800000	239580000	263538000	289891800	318880980
Plant Manager	1	10000000	10000000	120000000	132000000	145200000	159720000	175692000	193261200	212587320
Financial Accountant	1	10000000	10000000	120000000	132000000	145200000	159720000	175692000	193261200	212587320
Marketing Manager	1	8000000	8000000	96000000	105600000	116160000	127776000	140553600	154608960	170069856
Purchasing Manager	1	6000000	6000000	72000000	79200000	87120000	95832000	105415200	115956720	127552392
Personnel Manager	1	5000000	5000000	60000000	66000000	72600000	79860000	87846000	96630600	106293660
Technical Manager	1	5000000	5000000	60000000	66000000	72600000	79860000	87846000	96630600	106293660
Production Manager	1	5000000	5000000	60000000	66000000	72600000	79860000	87846000	96630600	106293660
Raw Materials Manager	1	4000000	4000000	48000000	52800000	58080000	63888000	70276800	77304480	85034928
Cost Accountant	1	3000000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Accounts office	4	2500000	10000000	120000000	132000000	145200000	159720000	175692000	193261200	212587320
Marketing office	2	2000000	4000000	48000000	52800000	58080000	63888000	70276800	77304480	85034928
Personnel office	1	1500000	1500000	18000000	19800000	21780000	23958000	26353800	28989180	31888098
Technical Foreman	1	1000000	1000000	12000000	13200000	14520000	15972000	17569200	19326120	21258732
Purchasing office	2	1500000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Quality Control Inspectors	2	900000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Total	22	80400000	92300000	**1,107,600,000**	**1218360000**	**1340196000**	**1474215600**	**1621637160**	**1783800876**	**1962180964**
Cost per unit				**10548571.43**	**11603428.57**	**12763771.43**	**14040148.57**	**15444163.43**	**16988579.77**	**18687437.75**
Number of units				105	105	105	105	105	105	105

C-1.9 Equipment Cost

Machine	Quantity	cost/machine(K)	Total(Kwacha)
Broomfield coil winder	2	45000000	90000000
Punch press stamp machine	1	250000000	250000000
Megger	1	5000000	5000000
Arc Welding Machine	1	10000000	10000000
Caterpillar Folk Truck	1	60000000	60000000
Lathe Machine	2	50000000	100000000
Riveting Machine	1	5000000	5000000
Tachometer	1	2000000	2000000
Multimeter	4	1500000	6000000
Steel Cutter	1	5000000	5000000
Trolley	2	1000000	2000000
Wire Cutter	4	200000	800000
Die	1	650000000	650000000
Truck	1	500000000	500000000
Total Equipment cost			**1,685,800,000**

C-1.10 Material Cost

Material	K/Kg	Quantity	Total per year	Year 2(inflated)	Year 3(inflated)	Year 4(inflated	Year 5(inflated)	Year 6(inflated)	Year 7(inflated)
Copper	23800	630	14994000	16493400	18142740	19957014	21952715.4	24147986.94	26562785.63
Aluminum	8655.5	157.5	1363241.25	1499565.375	1649521.913	1814474.104	1995921.514	2195513.666	2415065.032
Mylar insulation	1000	52.5	52500	57750	63525	69877.5	76865.25	84551.775	93006.9525
Paper insulation	1000	52.5	52500	57750	63525	69877.5	76865.25	84551.775	93006.9525
Stator housing cast	3500	966	3381000	3719100	4091010	4500111	4950122.1	5445134.31	5989647.741
End cover	3500	31.5	110250	121275	133402.5	146742.75	161417.025	177558.7275	195314.6003
Bearings	102725	105	10786125	11864737.5	13051211.25	14356332.38	15791965.61	17371162.17	19108278.39
Silicon sheet steel	3500	1050	3675000	4042500	4446750	4891425	5380567.5	5918624.25	6510486.675
Shaft	3500	105	367500	404250	444675	489142.5	538056.75	591862.425	651048.6675
Total			**34,782,116**	**38260327.88**	**42086360.66**	**46294996.73**	**50924496.4**	**56016946.04**	**61618640.65**
Cost per unit			**331258.25**	**364384.075**	**400822.4825**	**440904.7308**	**484995.2038**	**533494.7242**	**586844.1966**
Number of units			105	105	105	105	105	105	105

C-1.11 Product Cost and Contribution

Year	Plant wages	Indirect staff	Adminstration	Material	Other Fixed Costs	Total	Profit Mark up/Unit	Sale/unit	Contribution/unit
1	6000000	925714.2857	10548571.43	331258.25	1571428.571	**19376972.54**	9688486	**29065459**	22734201
2	6600000	1018285.714	11603428.57	364384.075	1728571.429	**21314669.79**	10657335	**31972005**	25007621
3	7260000	1120114.286	12763771.43	400822.4825	1901428.571	**23446136.77**	11723068	**35169205**	27508383
3	7986000	1232125.714	14040148.57	440904.7308	2091571.429	**25790750.45**	12895375	**38686126**	30259221
5	8784600	1355338.286	15444163.43	484995.2038	2300728.571	**28369825.49**	14184913	**42554738**	33285143
6	9663060	1490872.114	16988579.77	533494.7242	2530801.429	**31206808.04**	15603404	**46810212**	36613657
7	10629366	1639959.326	18687437.75	586844.1966	2783881.571	**34327488.84**	17163744	**51491233**	40275023

C-1.12 Land, Buildings and Services

	Land	Buildings							
Land and Buildings	100000000	300000000	**400,000,000**						
	Year	Electricity	Water	Maintenace of Buildings	Total	Cost/unit	Indirect wages	Admnistration	Total fixed Cost
Other Fixed Cost	1	90000000	60000000	15000000	165000000	1571428.571	97,200,000	1,107,600,000	1369800000
	2				181500000	1728571.429	106,920,000	1218360000	1506780000
	3				199650000	1901428.571	117612000	1340196000	1657458000
	4				219615000	2091571.429	129373200	1474215600	1823203800
	5				241576500	2300728.571	142310520	1621637160	2005524180
	6				265734150	2530801.429	156541572	1783800876	2206076598
	7				292307565	2783881.571	172195729.2	1962180964	2426684258

C-1.13 Non Current Asset Schedule

Year	Equipment(NBV)	Depreciation(10%)	Land and Buildings	Depreciation(2%)		Total NBV
1	1685800000	168580000	400000000	6000000		1911220000
2	1517220000	151722000	394000000	6000000		1753498000
3	1365498000	136549800	388000000	6000000		1610948200
4	1228948200	122894820	382000000	6000000		1482053380
5	1106053380	110605338	376000000	6000000		1365448042
6	995448042	99544804.2	370000000	6000000		1259903238
7	895903237.8	89590323.78	364000000	6000000		1164312914
8	806312914	80631291.4	358000000	6000000		1077681623
9	725681622.6	72568162.26	352000000	6000000		999113460.4
10	653113460.4	65311346.04	346000000	6000000		

C-1.14 Cost of Sales

	ZMK	ZMK	ZMK	ZMK	ZMK	ZMK	ZMK
Year	1	2	3	4	5	6	7
Material	134,924,500	222625425	326517290	404065146.4	592628881.4	651891769.5	717080946.4
Plant Wages	630,000,000	693000000	762300000	838530000	922383000	1014621300	1116083430
Indirect Staff	97,200,000	106920000	117612000	129373200	142310520	156541572	172195729.2
Other Fixed Costs	165000000	181500000	199650000	219615000	241576500	265734150	292307565
Depreciation: Equipment	168580000	151722000	136549800	122894820	110605338	99544804.2	89590323.78
Depreciation: Land and Buildings	6000000	6000000	6000000	6000000	6000000	6000000	6000000
Total	**1,201,704,500**	**1361767425**	**1548629090**	**1720478166**	**2015504239**	**2194333596**	**2393257994**

C-1.15 Statement of Changes in Equity

	Share Capital	Retained Earnings
Year		
1	1000000000	-1207017750
2	1000000000	-1903372038
3	1000000000	-1982663193
4	1000000000	-1833559134
5	1000000000	-1081023572
6	1000000000	-237282932.3
7	1000000000	705704889.4

C-2 Financial Statements for Production of 500 Electric Motors.

Income Statement

Year	1	2	3	4	5	6	7
ZMK '000	**K '000**	**K '000**	**K '000**	**K '000**	**K '000**	**K '000**	**K '000**
Sales	1082890	1786768	2620593	3242984	4756376	5232013	5755215
Cost of sales	1122106	1230431	1356002	1482102	1665885	1809753	1970219
Gross Profit	**(39217)**	**556337**	**1264591**	**1760882**	**3090490**	**3422261**	**3784996**
Adminstration	1107600	1218360	1340196	1474216	1621637	1783801	1962181
Operating Profit	(1146817)	(662023)	(75605)	286666	1468853	1638460	1822815
Interest payable	100000	100000	100000	100000	100000	100000	100000
Profit before tax	(1246817)	(762023)	(175605)	186666	1368853	1538460	1722815
Taxation				65333	479099	538461	602985
Retained Earnings	**(1246817)**	**(762023)**	**(175605)**	**121333**	**889755**	**999999**	**1119829**

Table C-2.1 Income Statement for 500 Units

Balance Sheet

Year	1	2	3	4	5	6	7
	K' 000	**K' 000**	**K' 000**	**K' 000**	**K' 000**	**K' 000**	**ZMK 000**
Non current Assets	1911220	1753498	1610948	1482053	1365448	1259903	1164313
Current Assets							
Bank and Cash					9961	952428	1982372
Total Assets	**1911220**	**1753498**	**1610948**	**1482053**	**1375409**	**2212331**	**3146685**
Share capital	1000000	1000000	1000000	1000000	1000000	1000000	1000000
Retained Earnings	(1246817)	(2008840)	(2184444)	(2093445)	(1426129)	(676130)	163743
Long Term Liabilities							
10% Loan	1000000	1000000	1000000	1000000	1000000	1000000	1000000
Current Liabilties							
Interest	100000	100000	100000	100000	100000	100000	100000
Taxation				65333	479099	538461	602985
Proposed Dividend				30333	222439	250000	279957
Trade Payables							
Bank Overdraft	1058037	1662338	1695393	1379832			
Total Liabilities	**1911220**	**1753498**	**1610948**	**1482053**	**1375409**	**2212331**	**3146685**
Return on Investment	**-65%**	**-43%**	**-11%**	**8%**	**65%**	**45%**	**36%**

Table C-2.2 Balance Sheet for 500 Units

Cash Flow

Year	1	2	3	4	5	6	7
	K' 000	**K' 000**	**K' 000**	**K' 000**	**K' 000**	**ZMK 000**	**ZMK 000**
Receipts							
Sales	1082890	1786768	2620593	3242984	4756376	5232013	5755215
Loan	1000000						
Sharecapital	1000000						
Total Receipts	**3082890**	**1786768**	**2620593**	**3242984**	**4756376**	**5232013**	**5755215**
Payments							
Material	55326	91289	133890	165689	243010	267311	294042
Equipment	1685800						
Administation	1107600	1218360	1340196	1474216	1621637	1783801	1962181
Direct Labour	630000	693000	762300	838530	922383	1014621	1116083
Indirect Labour	97200	106920	117612	129373	142311	156542	172196
Land and Buildings	400000						
Taxation					65333	479099	538461
Dividends					30333	222439	250000
Interest		100000	100000	100000	100000	100000	100000
Incremental Fixed Cost	165000	181500	199650	219615	241577	265734	292308
Total Payments	**4140926**	**2391069**	**2653648**	**2927422**	**3366584**	**4289546**	**4725270**
Cash at start		(1058037)	(1662338)	(1695393)	(1379832)	9961	952428
Net Cashflow	**(1058037)**	**(604301)**	**(33055)**	**315561**	**1389792**	**942467**	**1029944**
Cash at end	(1058037)	(1662338)	(1695393)	(1379832)	9961	952428	1982372

Discounting Factor26.3%	0.7918	0.6269	0.4964	0.3930	0.3112	0.2464	0.1951
Present Value	**(837717)**	**(378832)**	**(16407)**	**124014**	**432447**	**232191**	**200905**
Net Present Value	**(243399)**						

Table C-2.3 Cash Flow for 500 Units

C-2.4 Breakeven Point, Internal Rate of Return, Payback

Breakeven Point(units)	**279**	**279**	**279**	**279**	**279**	**279**	**279**
Breakeven Point(Sales)	**1814346**	**1995780**	**2195358**	**2414894**	**2656383**	**2922022**	**3214224**
Discount Factor 26.5%	0.7905	0.6249	0.4940	0.3905	0.3087	0.2440	0.19291514
	(836393)	(377635)	(16329)	123231	429039	229997	198692
	(249397)						
1st Discount factor	1.263						
2nd Discount factor	1.265						
10% interest rate	26.3						
X interest rate	26.5						
IRR	18.1839	%	18.1839				
			Cumulative inflows				
Project Cost	Initial	Yr	cumulative	DCH	Inflows	Pv of inflows	Cumulative
	4140926	1	1082890	0.7917	1082890	857395	857395
		2	2869657	0.6268	1786768	1120112	1977507
		3	5490250	0.4963	2620593	1300737	3278244
		4	8733234	0.3929	3242984	1274475	4552719
		5	13489609	0.3111	4756376	1479992	6032711
		6	18721623	0.2463	5232013	1288988	7321698
		7	24476838	0.1950	5755215	1122634	8444332
			Payback		2 years 4 months		
			Discounted payback		3 years 4 months		

C-2.5 Inflation

PLANT WAGES	INDIRECT STAFF	ADMINSTRATION	MATERIAL COSTS
1.1	1.1	1.1	1.1

C-2.6 Plant Wages, Direct Staff

Station	**Number of staff**	**Basic pay/month**	**Total/month**	**Total/year**	Year 2(inflated)	Year 3(inflated)	Year 4(inflated)	Year 5(Inflated)
Raw material								
Supervisor	1	2,500,000	2500000	30000000	33000000	36300000	39930000	43923000
Work men	2	800,000	1600000	19200000	21120000	23232000	25555200	28110720
Assistant Storemen	2	700,000	1400000	16800000	18480000	20328000	22360800	24596880
Punch Press								
Operator	2	1,500,000	3000000	36000000	39600000	43560000	47916000	52707600
Machine shop								
Machinists	8	1,500,000	12000000	144000000	158400000	174240000	191664000	210830400
Winding Machines								
Operators	2	900,000	1800000	21600000	23760000	26136000	28749600	31624560
Diecasting								
Operator	2	1,500,000	3000000	36000000	39600000	43560000	47916000	52707600
Rotor assembly								
Stackers	2	1,200,000	2400000	28800000	31680000	34848000	38332800	42166080
Loaders	1	900,000	900000	10800000	11880000	13068000	14374800	15812280
Assemblers/Balancers	4	1,300,000	5200000	62400000	68640000	75504000	83054400	91359840
Stator assembly								
Welders	1	1,500,000	1500000	18000000	19800000	21780000	23958000	26353800
Insulation	2	900,000	1800000	21600000	23760000	26136000	28749600	31624560
Assemblers/Testing	2	1,200,000	2400000	28800000	31680000	34848000	38332800	42166080
Final assembly								
Assemblers/Testing	4	2,500,000	10000000	120000000	132000000	145200000	159720000	175692000
Finished product								
Store men	2	800,000	1600000	19200000	21120000	23232000	25555200	28110720
Assistant Storemen	2	700,000	1400000	16800000	18480000	20328000	22360800	24596880
Total	39	20,400,000	52500000	**630,000,000**	**693000000**	**762300000**	**838530000**	**922383000**
Cost of 1 unit				**1260000**	**1386000**	**1524600**	**1677060**	**1844766**
Motor production/year				500	500	500	500	500
Motor production/month				42	42	42	42	42

C-2.7 Plant Wages, Indirect Staff

Station	**Number of staff**	**Basic pay/month**	**Total/month**	**Total/year**	Year 2(inflated)	Year 3(inflated)	Year 4(inflated)	Year 5(inflated)	Year 6(inflated)	Year 7(inflated)
Maintenance										
Supervisor	1	1500000	1500000	18000000	19800000	21780000	23958000	26353800	28989180	31888098
Mechanics	2	900000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Electricians	2	900000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Assistant Electricians	4	750000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Total	9	4050000	8100000	**97,200,000**	**106920000**	**117612000**	**129373200**	**142310520**	**156541572**	**172195729.2**
Cost per unit				**194400**	**213840**	**235224**	**258746.4**	**284621.04**	**313083.144**	**344391.4584**
Number of units				500	500	500	500	500	500	500

C-2.8 Administration

Station	**Number of staff**	**Basic pay/month**	**Total/month**	**Total/year**	Year 2(inflated)	Year 3(inflated)	Year 4(inflated)	Year 5(inflated)
Chief Executive	1	15000000	15000000	180000000	198000000	217800000	239580000	263538000
Plant Manager	1	10000000	10000000	120000000	132000000	145200000	159720000	175692000
Financial Accountant	1	10000000	10000000	120000000	132000000	145200000	159720000	175692000
Marketing Manager	1	8000000	8000000	96000000	105600000	116160000	127776000	140553600
Purchasing Manager	1	6000000	6000000	72000000	79200000	87120000	95832000	105415200
Personnel Manager	1	5000000	5000000	60000000	66000000	72600000	79860000	87846000
Technical Manager	1	5000000	5000000	60000000	66000000	72600000	79860000	87846000
Production Manager	1	5000000	5000000	60000000	66000000	72600000	79860000	87846000
Raw Materials Manager	1	4000000	4000000	48000000	52800000	58080000	63888000	70276800
Cost Accountant	1	3000000	3000000	36000000	39600000	43560000	47916000	52707600
Accounts office	4	2500000	10000000	120000000	132000000	145200000	159720000	175692000
Marketing office	2	2000000	4000000	48000000	52800000	58080000	63888000	70276800
Personnel office	1	1500000	1500000	18000000	19800000	21780000	23958000	26353800
Technical Foreman	1	1000000	1000000	12000000	13200000	14520000	15972000	17569200
Purchasing office	2	1500000	3000000	36000000	39600000	43560000	47916000	52707600
Quality Control Inspectors	2	900000	1800000	21600000	23760000	26136000	28749600	31624560
Total	22	80400000	92300000	**1,107,600,000**	**1218360000**	**1340196000**	**1474215600**	**1621637160**
Cost per unit				**2215200**	**2436720**	**2680392**	**2948431.2**	**3243274.32**
Number of units				500	500	500	500	500

C-2.9 Material Cost

Material	Cost per kg/unit	Quantity	Total per year	Year 2(inflated)	Year 3(inflated)	Year 4(inflated)	Year 5(inflated)	Year 6(inflated)	Year 7(inflated)
Copper	23800	3,000	71400000	78540000	86394000	95033400	104536740	114990414	126489455.4
Aluminum	8655.5	750.0	6491625	7140787.5	7854866.25	8640352.875	9504388.163	10454826.98	11500309.68
Mylar insulation	1000	250.0	250000	275000	302500	332750	366025	402627.5	442890.25
Paper insulation	1000	250.0	250000	275000	302500	332750	366025	402627.5	442890.25
Stator housing cast [2]	3500	4,600.0	16100000	17710000	19481000	21429100	23572010	25929211	28522132.1
End cover [2]	3500	300.0	1050000	1155000	1270500	1397550	1537305	1691035.5	1860139.05
Bearings [2]	102725	500	51362500	56498750	62148625	68363487.5	75199836.25	82719819.88	90991801.86
Silicon sheet steel	3500	5000	17500000	19250000	21175000	23292500	25621750	28183925	31002317.5
Shaft [2]	3500	450	1575000	1732500	1905750	2096325	2305957.5	2536553.25	2790208.575
Total			**165,979,125**	**182577037.5**	**200834741.3**	**220918215.4**	**243010036.9**	**267311040.6**	**294042144.7**
Cost per unit			**331958.25**	**365154.075**	**401669.4825**	**441836.4308**	**486020.0738**	**534622.0812**	**588084.2893**
Number of units			500	500	500	500	500	500	500

C-2.10 Product Cost and Contribution

Year	Plant wages	Indirect staff	Adminstration	Material	Other Fixed Costs	Total	rofit Mark up/Ur	Sale/unit	Contribution/unit
1	1260000	194400	2215200	331958.25	330000	**4331558.25**	2165779	**6497337**	4905379
2	1386000	213840	2436720	365154.075	363000	**4764714.075**	2382357	**7147071**	5395917
3	1524600	235224	2680392	401669.4825	399300	**5241185.483**	2620593	**7861778**	5935509
3	1677060	258746.4	2948431.2	441836.4308	439230	**5765304.031**	2882652	**8647956**	6529060
5	1844766	284621.04	3243274.32	486020.0738	483153	**6341834.434**	3170917	**9512752**	7181966
6	2029242.6	313083.144	3567601.752	534622.0812	531468.3	**6976017.877**	3488009	**10464027**	7900162
7	2232166.86	344391.4584	3924361.927	588084.2893	584615.13	**7673619.665**	3836810	**11510429**	8690178

C-2.11 Equipment Cost

Machine	Quantity	cost/machine(K)	Total(Kwacha)
Broomfield coil winder	2	45000000	90000000
Punch press stamp machine	1	250000000	250000000
Megger	1	5000000	5000000
Arc Welding Machine	1	10000000	10000000
Caterpillar Folk Truck	1	60000000	60000000
Lathe Machine	2	50000000	100000000
Riveting Machine	1	5000000	5000000
Tachometer	1	2000000	2000000
Multimeter	4	1500000	6000000
Steel Cutter	1	5000000	5000000
Trolley	2	1000000	2000000
Wire Cutter	4	200000	800000
Die	1	650000000	650000000
Truck	1	500000000	500000000
Total Equipment cost			**1,685,800,000**

C-2.12 Land, Buildings and Other Fixed Costs

100000000	300000000	**400,000,000**						
Year	Electricity	Water	Maintenace of Buildings	Total	Cost/unit	Indirect wages	Admnistration	Total fixed Cost
1	90000000	60000000	15000000	165000000	330000	97,200,000	1,107,600,000	1369800000
2				181500000	363000	106,920,000	1218360000	1506780000
3				199650000	399300	117612000	1340196000	1657458000
4				219615000	439230	129373200	1474215600	1823203800
5				241576500	483153	142310520	1621637160	2005524180
6				265734150	531468.3	156541572	1783800876	2206076598
7				292307565	584615.13	172195729.2	1962180964	2426684258

C-2.13 Non Current Asset Value

Year	Equipment(NBV)	Depreciation(10%)	Land and Buildings	Depreciation(2%)		Total NBV
1	1685800000	168580000	400000000	6000000		1911220000
2	1517220000	151722000	394000000	6000000		1753498000
3	1365498000	136549800	388000000	6000000		1610948200
4	1228948200	122894820	382000000	6000000		1482053380
5	1106053380	110605338	376000000	6000000		1365448042
6	995448042	99544804.2	370000000	6000000		1259903238
7	895903237.8	89590323.78	364000000	6000000		1164312914
8	806312914	80631291.4	358000000	6000000		1077681623
9	725681622.6	72568162.26	352000000	6000000		999113460.4
10	653113460.4	65311346.04	346000000	6000000		

C-2.14 Cost of Sales

	ZMK	ZMK	ZMK	ZMK	ZMK	ZMK	ZMK
Year	1	2	3	4	5	6	7
Material	55,326,375	91288518.75	133889827.5	165688661.5	243010036.9	267311040.6	294042144.7
Plant Wages	630,000,000	693000000	762300000	838530000	922383000	1014621300	1116083430
Indirect Staff	97,200,000	106920000	117612000	129373200	142310520	156541572	172195729.2
Other Fixed Costs	165000000	181500000	199650000	219615000	241576500	265734150	292307565
Depreciation: Equipment	168580000	151722000	136549800	122894820	110605338	99544804.2	89590323.78
Depreciation: Land and Buildings	6000000	6000000	6000000	6000000	6000000	6000000	6000000
Total	**1,122,106,375**	**1230430519**	**1356001628**	**1482101682**	**1665885395**	**1809752867**	**1970219193**

C-2.15 Statement of Change in Equity

	Share Capital	Retained Earnings
Year		
1	1000000000	-1246816813
2	1000000000	-2008839553
3	1000000000	-2184444439
4	1000000000	-2093444649
5	1000000000	-1426128680
6	1000000000	-676129593.4
7	1000000000	163742520.5

C-3 Financial Statements for Production of 3000 Electric Motors.

Income Statement

Year	1	2	3	4	5	6	7
ZMK '000	**K '000**	**K '000**	**K '000**	**K '000**	**K '000**	**K '000**	**K '000**
Sales	1497837	2471432	3624766	4485648	6578951	7236846	7960531
Cost of sales	1398738	1686873	2025451	2310545	2880936	3146308	3440430
Gross Profit	**99099**	**784559**	**1599316**	**2175103**	**3698016**	**4090538**	**4520101**
Adminstration	1107600	1218360	1340196	1474216	1621637	1783801	1962181
Operating Profit	(1008501)	(433801)	259120	700888	2076378	2306737	2557920
Interest payable	100000	100000	100000	100000	100000	100000	100000
Profit before tax	(1108501)	(533801)	159120	600888	1976378	2206737	2457920
Taxation				210311	691732	772358	860272
Retained Earnings	**(1108501)**	**(533801)**	**159120**	**390577**	**1284646**	**1434379**	**1597648**

Table C-3.1 Income Statement for 3000 Units

Balance Sheet

Year	1	2	3	4	5	6	7
	K' 000	**K' 000**	**K' 000**	**K' 000**	**K' 000**	**K' 000**	**K' 000**
Non current Assets	1911220	1753498	1610948	1482053	1365448	1259903	1164313
Current Assets							
Bank and Cash					1520681	2820069	4242626
Total Assets	**1911220**	**1753498**	**1610948**	**1482053**	**2886129**	**4079972**	**5406939**
Share capital	1000000	1000000	1000000	1000000	1000000	1000000	1000000
Retained Earnings	(1108501)	(1642302)	(1483183)	(1190250)	(226765)	849019	2047255
Long Term Liabilities							
10% Loan	1000000	1000000	1000000	1000000	1000000	1000000	1000000
Current Liabilties							
Interest	100000	100000	100000	100000	100000	100000	100000
Taxation				210311	691732	772358	860272
Proposed Dividend				97644	321161	358595	399412
Trade Payables							
Bank Overdraft	919721	1295800	994131	264348			
Total Liabilities	**1911220**	**1753498**	**1610948**	**1482053**	**2886129**	**4079972**	**5406939**
Return on Investment	**-58%**	**-30%**	**10%**	**26%**	**45%**	**35%**	**30%**

Table C-3.2 Balance Sheet for 3000 Units

Cash Flow

Year	1	2	3	4	5	6	7
	K' 000	**K' 000**	**K' 000**	**K' 000**	**K' 000**	**K' 000**	**ZMK 000**
Receipts							
Sales	1497837	2471432	3624766	4485648	6578951	7236846	7960531
Loan	1000000						
Sharecapital	1000000						
Total Receipts	**3497837**	**2471432**	**3624766**	**4485648**	**6578951**	**7236846**	**7960531**
Payments							
Material	331958	547731	803339	994132	1458060	1603866	1764253
Equipment	1685800						
Administation	1107600	1218360	1340196	1474216	1621637	1783801	1962181
Direct Labour	630000	693000	762300	838530	922383	1014621	1116083
Indirect Labour	97200	106920	117612	129373	142311	156542	172196
Land and Buildings	400000						
Taxation					210311	691732	772358
Dividends					97644	321161	358595
Interest		100000	100000	100000	100000	100000	100000
Incremental Fixed Cost	165000	181500	199650	219615	241577	265734	292308
Total Payments	**4417558**	**2847511**	**3323097**	**3755866**	**4793922**	**5937458**	**6537973**
Cash at start		(919721)	(1295800)	(994131)	(264348)	1520681	2820069
Net Cashflow	**(919721)**	**(376079)**	**301669**	**729783**	**1785029**	**1299388**	**1422557**
Cash at end	(919721)	(1295800)	(994131)	(264348)	1520681	2820069	4242626

Discounting Factor26.3%	0.7917	0.6268	0.4963	0.3929	0.3111	0.2463	0.1950
Present Value	**(728203)**	**(235762)**	**149734**	**286801**	**555429**	**320124**	**277489**
Net Present Value	**625613**						

Table C-3.3 Cash Flow

C-3.4 Breakeven Point, Internal Rate of Return (IRR), Payback

Breakeven Point(units)	**1,433**	**1433**	**1433**	**1433**	**1433**	**1433**	**1433**
Breakeven Point(Sales)	**2146440**	**2361085**	**2597193**	**2856912**	**3142603**	**3456864**	**3802550**
Discount Factor 26.5%	0.7905	0.6249	0.4940	0.3905	0.3087	0.2440	0.192915144
	(727052)	(235017)	149025	284991	551052	317100	274433
	614532						
1st Discount factor	1.263						
2nd Discount factor	1.265						
26.3% interest rate	26.3						
26.5% interest rate	26.5						
IRR	37.59	%	37.59				
			Cumulative inflows				
Project Cost	Initial	Yr	cumulative	DCH	Inflows	Pv of inflows	Cumulative
	4417558	1	1497837	0.791765637	1497837	1185936	1185936
		2	3969269	0.626892825	2471432	1549323	2735259
		3	7594035	0.496352197	3624766	1799161	4534420
		4	12079684	0.392994613	4485648	1762836	6297255
		5	18658635	0.311159631	6578951	2047104	8344359
		6	25895481	0.246365503	7236846	1782909	10127269
		7	33856012	0.19506374	7960531	1552811	11680080
			Payback		2 years 4 months		
			Discounted payback		3 years 4 months		

C-3.5 Inflation

PLANT WAGES	INDIRECT STAFF	ADMINSTRATION	MATERIAL COSTS
1.1	1.1	1.1	1.1

C-3.6 Plant Wages, Direct Staff

Station	Number of staff	Basic pay/month	Total/month	Total/year	Year 2(inflated)	Year 3(inflated)	Year 4(inflated)	Year 5(Inflated)	Year 6(Inflated)	Year 7(Inflated)
Raw material										
Supervisor	1	2,500,000	2500000	30000000	33000000	36300000	39930000	43923000	48315300	53146830
Work men	2	800,000	1600000	19200000	21120000	23232000	25555200	28110720	30921792	34013971.2
Assistant Storemen	2	700,000	1400000	16800000	18480000	20328000	22360800	24596880	27056568	29762224.8
Punch Press										
Operator	2	1,500,000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Machine shop										
Machinists	8	1,500,000	12000000	144000000	158400000	174240000	191664000	210830400	231913440	255104784
Winding Machines										
Operators	2	900,000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Diecasting										
Operator	2	1,500,000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Rotor assembly										
Stackers	2	1,200,000	2400000	28800000	31680000	34848000	38332800	42166080	46382688	51020956.8
Loaders	1	900,000	900000	10800000	11880000	13068000	14374800	15812280	17393508	19132858.8
Assemblers/Balancers	4	1,300,000	5200000	62400000	68640000	75504000	83054400	91359840	100495824	110545406.4
Stator assembly										
Welders	1	1,500,000	1500000	18000000	19800000	21780000	23958000	26353800	28989180	31888098
Insulation	2	900,000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Assemblers/Testing	2	1,200,000	2400000	28800000	31680000	34848000	38332800	42166080	46382688	51020956.8
Final assembly										
Assemblers/Testing	4	2,500,000	10000000	120000000	132000000	145200000	159720000	175692000	193261200	212587320
Finished product										
Store men	2	800,000	1600000	19200000	21120000	23232000	25555200	28110720	30921792	34013971.2
Assistant Storemen	2	700,000	1400000	16800000	18480000	20328000	22360800	24596880	27056568	29762224.8
Total	39	20,400,000	52500000	**630,000,000**	**693000000**	**762300000**	**838530000**	**922383000**	**1014621300**	**1116083430**
Cost of 1 unit				**210000**	**231000**	**254100**	**279510**	**307461**	**338207.1**	**372027.81**
Motor production/year				3000	3000	3000	3000	3000	3000	3000
Motor production/month				250	250	250	250	250	250	250

C-3.7 Plant Wages, Indirect Staff

Station	Number of staff	Basic pay/month	Total/month	Total/year	Year 2(inflated)	Year 3(inflated)	Year 4(inflated)	Year 5(inflated)	Year 6(inflated)	Year 7(inflated)
Maintenance										
Supervisor	1	1500000	1500000	18000000	19800000	21780000	23958000	26353800	28989180	31888098
Mechanics	2	900000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Electricians	2	900000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Assistant Electricians	4	750000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Total	9	4050000	8100000	**97,200,000**	**106920000**	**117612000**	**129373200**	**142310520**	**156541572**	**172195729.2**
Cost per unit				**32400**	**35640**	**39204**	**43124.4**	**47436.84**	**52180.524**	**57398.5764**
Number of units				3000	3000	3000	3000	3000	3000	3000

C-3.7 Administration

Station	Number of staff	Basic pay/month	Total/month	Total/year	Year 2(inflated)	Year 3(inflated)	Year 4(inflated)	Year 5(inflated)	Year 6(inflated)	Year 7(inflated)
Chief Executive	1	15000000	15000000	180000000	198000000	217800000	239580000	263538000	289891800	318880980
Plant Manager	1	10000000	10000000	120000000	132000000	145200000	159720000	175692000	193261200	212587320
Financial Accountant	1	10000000	10000000	120000000	132000000	145200000	159720000	175692000	193261200	212587320
Marketing Manager	1	8000000	8000000	96000000	105600000	116160000	127776000	140553600	154608960	170069856
Purchasing Manager	1	6000000	6000000	72000000	79200000	87120000	95832000	105415200	115956720	127552392
Personnel Manager	1	5000000	5000000	60000000	66000000	72600000	79860000	87846000	96630600	106293660
Technical Manager	1	5000000	5000000	60000000	66000000	72600000	79860000	87846000	96630600	106293660
Production Manager	1	5000000	5000000	60000000	66000000	72600000	79860000	87846000	96630600	106293660
Raw Materials Manager	1	4000000	4000000	48000000	52800000	58080000	63888000	70276800	77304480	85034928
Cost Accountant	1	3000000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Accounts office	4	2500000	10000000	120000000	132000000	145200000	159720000	175692000	193261200	212587320
Marketing office	2	2000000	4000000	48000000	52800000	58080000	63888000	70276800	77304480	85034928
Personnel office	1	1500000	1500000	18000000	19800000	21780000	23958000	26353800	28989180	31888098
Technical Foreman	1	1000000	1000000	12000000	13200000	14520000	15972000	17569200	19326120	21258732
Purchasing office	2	1500000	3000000	36000000	39600000	43560000	47916000	52707600	57978360	63776196
Quality Control Inspectors	2	900000	1800000	21600000	23760000	26136000	28749600	31624560	34787016	38265717.6
Total	22	80400000	92300000	**1,107,600,000**	**1218360000**	**1340196000**	**1474215600**	**1621637160**	**1783800876**	**1962180964**
Cost per unit				**369200**	**406120**	**446732**	**491405.2**	**540545.72**	**594600.292**	**654060.3212**
Number of units				3000	3000	3000	3000	3000	3000	3000

C-3.8 Material Cost

Material	Cost per kg/unit	Quantity	Total per year	Year 2(inflated)	Year 3(inflated)	Year 4(inflated)	Year 5(inflated)	Year 6(inflated)	Year 7(inflated)
Copper	23800	18000	428400000	471240000	518364000	570200400	627220440	689942484	758936732.4
Aluminum	8655.5	4500	38949750	42844725	47129197.5	51842117.25	57026328.98	62728961.87	69001858.06
Mylar insulation	1000	1500	1500000	1650000	1815000	1996500	2196150	2415765	2657341.5
Paper insulation	1000	1500	1500000	1650000	1815000	1996500	2196150	2415765	2657341.5
Stator housing cast [2]	3500	27600	96600000	106260000	116886000	128574600	141432060	155575266	171132792.6
End cover [2]	3500	1800	6300000	6930000	7623000	8385300	9223830	10146213	11160834.3
Bearings [2]	102725	3000	308175000	338992500	372891750	410180925	451199017.5	496318919.3	545950811.2
Silicon sheet steel	3500	30000	105000000	115500000	127050000	139755000	153730500	169103550	186013905
Shaft [2]	3500	2700	9450000	10395000	11434500	12577950	13835745	15219319.5	16741251.45
Total			**995,874,750**	**1095462225**	**1205008448**	**1325509292**	**1458060221**	**1603866244**	**1764252868**
Cost per unit			**331958.25**	**365154.075**	**401669.4825**	**441836.4308**	**486020.0738**	**534622.0812**	**588084.2893**
Number of units			3000	3000	3000	3000	3000	3000	3000

C-3.9 Product Cost and Contribution

Year	Plant wages	Indirect staff	Adminstration	Material	Other Fixed Costs	Total	Profit Mark Up/Unit	Sale/unit	Contribution/unit
1	210000	32400	369200	331958.25	55000	998558.25	499279	1497837	955879
2	231000	35640	406120	365154.075	60500	1098414.075	549207	1647621	1051467
3	254100	39204	446732	401669.4825	66550	1208255.483	604128	1812383	1156614
3	279510	43124.4	491405.2	441836.4308	73205	1329081.031	664541	1993622	1272275
5	307461	47436.84	540545.72	486020.0738	80525.5	1461989.134	730995	2192984	1399503
6	338207.1	52180.524	594600.292	534622.0812	88578.05	1608188.047	804094	2412282	1539453
7	372027.81	57398.5764	654060.3212	588084.2893	97435.855	1769006.852	884503	2653510	1693398

C-3.10 Equipment Cost

Machine	Quantity	cost/machine(K)	Total(Kwacha)
Broomfield coil winder	2	45000000	90000000
Punch press stamp machine	1	250000000	250000000
Megger	1	5000000	5000000
Arc Welding Machine	1	10000000	10000000
Caterpillar Folk Truck	1	60000000	60000000
Lathe Machine	2	50000000	100000000
Riveting Machine	1	5000000	5000000
Tachometer	1	2000000	2000000
Multimeter	4	1500000	6000000
Steel Cutter	1	5000000	5000000
Trolley	2	1000000	2000000
Wire Cutter	4	200000	800000
Die	1	650000000	650000000
Truck	1	500000000	500000000
Total Equipment cost			1,685,800,000

C-3.11 Land, Buildings, Other Fixed Costs

Land	Buildings							
100000000	300000000	400,000,000						
Year	Electricity	Water	Maintenace of Buildings	Total	Cost/unit	Indirect wages	Admnistration	Total fixed Cost
1	90000000	60000000	15000000	165000000	55000	97,200,000	1,107,600,000	1369800000
2				181500000	60500	106,920,000	1218360000	1506780000
3				199650000	66550	117612000	1340196000	1657458000
4				219615000	73205	129373200	1474215600	1823203800
5				241576500	80525.5	142310520	1621637160	2005524180
6				265734150	88578.05	156541572	1783800876	2206076598
7				292307565	97435.855	172195729.2	1962180964	2426684258

C-3.12 Non Current Asset Schedule

Year	Equipment(NBV)	Depreciation(10%)	Land and Buildings	Depreciation(2%)		Total NBV
1	1685800000	168580000	400000000	6000000		1911220000
2	1517220000	151722000	394000000	6000000		1753498000
3	1365498000	136549800	388000000	6000000		1610948200
4	1228948200	122894820	382000000	6000000		1482053380
5	1106053380	110605338	376000000	6000000		1365448042
6	995448042	99544804.2	370000000	6000000		1259903238
7	895903237.8	89590323.78	364000000	6000000		1164312914
8	806312914	80631291.4	358000000	6000000		1077681623
9	725681622.6	72568162.26	352000000	6000000		991113460.4
10	653113460.4	65311346.04	346000000	6000000		

C-3.13 Cost of Sales

	ZMK	ZMK	ZMK	ZMK	ZMK	ZMK	ZMK
Year	1	2	3	4	5	6	7
Material	331,958,250	547731112.5	803338965	994131969.2	1458060221	1603866244	1764252868
Plant Wages	630,000,000	693000000	762300000	838530000	922383000	1014621300	1116083430
Indirect Staff	97,200,000	106920000	117612000	129373200	142310520	156541572	172195729.2
Other Fixed Costs	165000000	181500000	199650000	219615000	241576500	265734150	292307565
Depreciation: Equipment	168580000	151722000	136549800	122894820	110605338	99544804.2	89590323.78
Depreciation: Land and Buildings	6000000	6000000	6000000	6000000	6000000	6000000	6000000
Total	1,398,738,250	1686873113	2025450765	2310544989	2880935579	3146308070	3440429916

C-3.14 Statement of Changes in Equity

	Share Capital	Retained Earnings
Year		
1	1000000000	-1108500875
2	1000000000	-1642302319
3	1000000000	-1483182636
4	1000000000	-1190249790
5	1000000000	-226765338.2
6	1000000000	849019079.2
7	1000000000	2047255057

FLYGT PUMP 2102.041

MOTOR CHART	MOTOR NO: 19-09-2AA	ISSUE: 11 Date: 85 02 08

2102.041

NOMINAL VALUES:

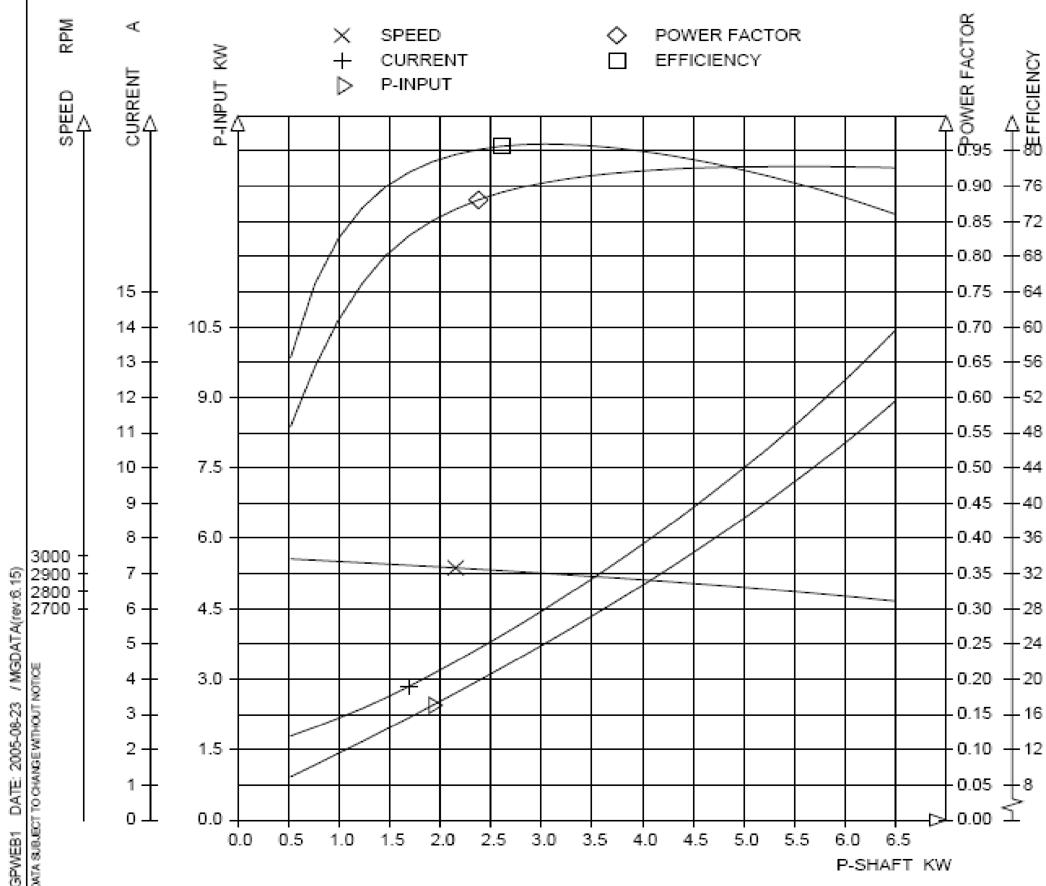
VOLTAGE: 3 * 400 V	FREQUENCY: 50 HZ	POLES: 2	STATOR: 44 D
P-INPUT: 6.7 KW	P-SHAFT: 5.2 kW	CURRENT: 10 A	SPEED: 2810 RPM

TORQUE (NM / QUOTIENT COMPARED TO TORQUE AT NOMINAL SPEED)

START:	PULL-UP:	BREAK-DOWN:	MOMENT OF INERTIA:
28 / 1.6	21 / 1.2	40 / 2.3	0.0077 KGM^2

LOAD	1/1	3/4	1/2
POWER FACTOR	0.93	0.92	0.89
EFFICIENCY %	77.0	80.0	80.5
CURRENT A	10	7.6	5.2

BREAKAWAY STARTING CURRENT (LOCKED ROTOR CURRENT ACC. TO NEMA)	66
BREAKAWAY STARTING POWER FACTOR	0.74
NO LOAD CURRENT	2.0
NO LOAD POWER FACTOR	0.28
INSULATION	CLASS H



THE VALUES ARE STATED WITH TOLERANCES ACC. TO IEC 34-1
AT 75°C TOTAL TEMPERATURE AND 75 W FRICTION LOSSES. PP04.C

Figure D-1 Flygt Pump 2102-041 Motor Chart

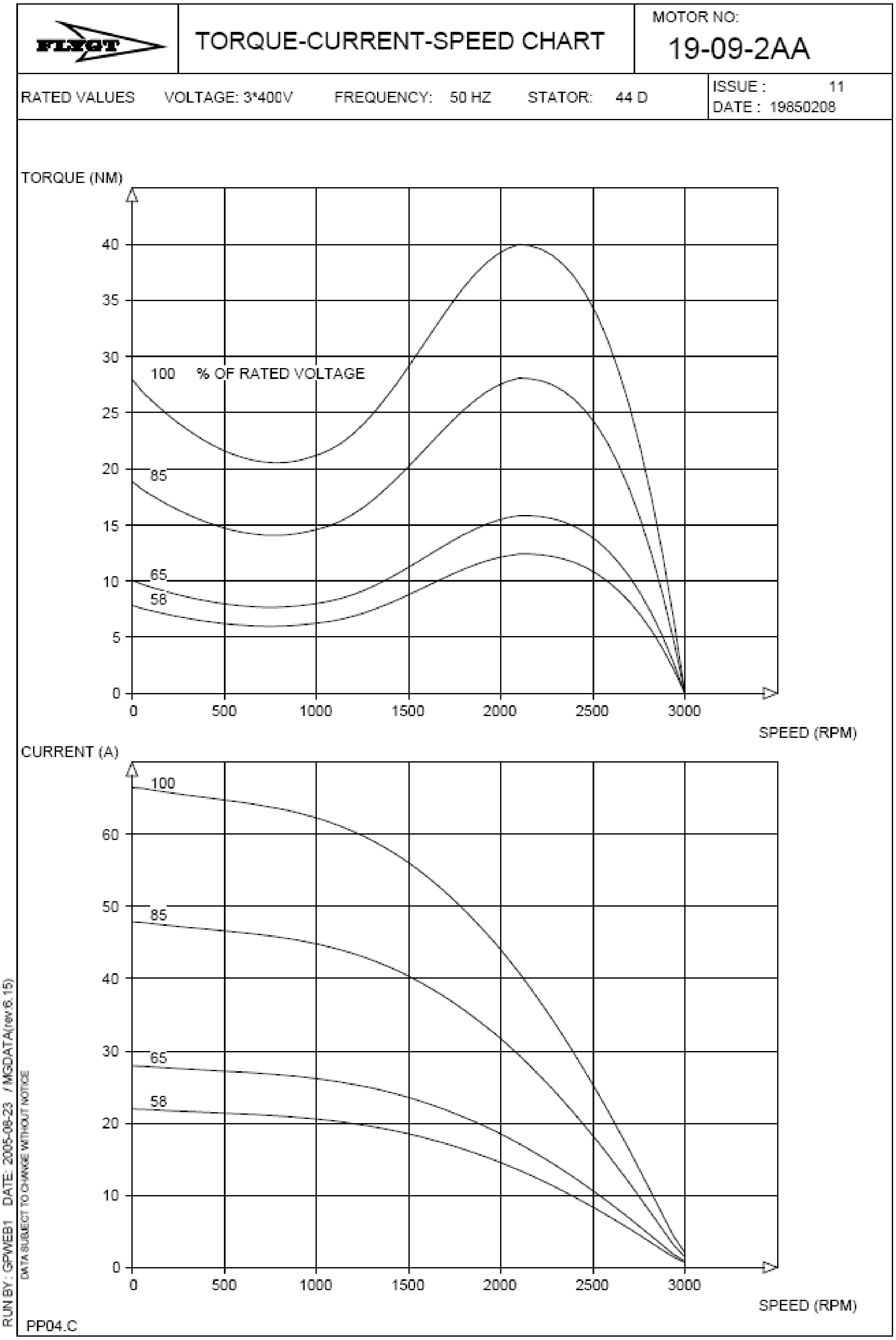


Figure D-2 Torque-Current-Speed-Chart

VARIOUS LOAD TABLE	MOTOR NO: 19-09-2AA
	ISSUE : DATE : 19850208

Frequency	50 Hz
Poles	2
Number of phases	3
Rated speed	2810 Rpm
Rated voltage	400 V
Rated current	10 A
Rated output power	5.2 kW
Rated input power	6.7 kW
Stator variant	44 D

The values are valid at 75 deg. C

		125%	110%	100%	90 %	75 %	50 %	25 %	10 %
Output power	kW	6.5	5.7	5.2	4.7	3.9	2.6	1.3	0.5
Input power	kW	8.9	7.6	6.7	6.0	4.9	3.2	1.7	0.9
Efficiency	%	72.5	75.5	77.0	78.5	80.0	80.5	74.0	56.5
Current	A	14.0	12.0	10.0	9.3	7.6	5.2	3.3	2.4
Power factor	-	0.93	0.93	0.93	0.93	0.92	0.89	0.78	0.56
Torque	Nm	23.0	20.0	18.0	16.0	13.0	8.5	4.2	1.7
Speed	Rpm	2740	2785	2810	2835	2870	2915	2960	2980

No load current	2.0 A		
Power factor at no load	0.28		
Breakaway starting current	66 A	Break. starting/Rated current	6.3
Breakaway start. power factor	0.74		
Starting torque	28 Nm	Starting torque/Rated torque	1.6
Max. torque/Rated torque	40 Nm	Max. torque/Rated torque	2.3
Speed at max. torque	2060 -		
Rotor inertia	0.0077 kgm2		
Iron losses	130. W		
Friction losses	75.0 W	(at synchronous speed)	
Pull up torque	21 Nm		

PP04.C

Figure D-3 Various Load Table

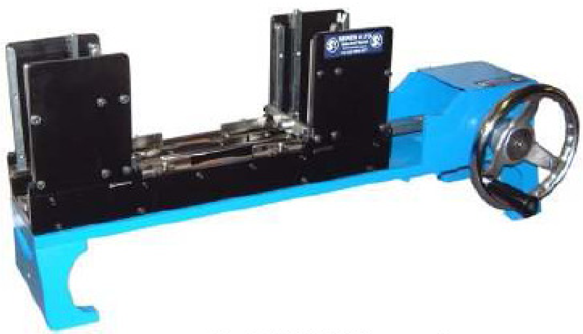
LAMINATION MACHINE
TRANSFORMER HAND TYPE LAMINATION STACKING MACHINE

The HEI Superior range of Hand Lamination Machines are fast and easy to use.

On the smaller models they use a clutch system that prevents the operator from inadvertently over process and damage the laminations.

These machines are available in all the sizes below and specials are available on request.

Full spares and service are also provided by Series 4.



Model HEI-96 Shown above

Metric			Imperial	
Model	Lamination Size			
	X (mm)	Y (mm)	Model	Pattern
HEI-28	28	25	HEI-42.88	18
HEI-30	30	*	HEI-52.39	74
HEI-35	35	29.5	HEI-57.15	35
HEI-38	38	*	HEI-66.68	147
HEI-41	41	33	HEI-76.20	29
HEI-48	48	40	HEI-85.73	196
HEI-54	51	45	HEI-95.25	78
HEI-57	57	47.5	HEI-114.30	120
HEI-60	60	50	HEI-133.35	248
HEI-66	66	55	HEI-161.93	638

HE1-96 PRICE
NEW: 945.00 GBP

www.series4.co.uk

Figure E-1 Lamination Machine

COIL WINDING
BENCH TYPE
MODEL No. 74


Illustrates Model Number 74

AUTOMATIC STOP

A Bi-Directional single level preset counter counts from 1 to 999,999 turn counts. Registers turn count whether adding or subtracting turns. The counter displays the turn count and tachometer reading. It stops the winder at the preset number. The stopping position can be advanced up to one full turn to compensate for inertia over-ride under various loads and speeds.

LIGHT DUTY WINDER

Constant torque winding machine. A permanent magnet DC motor drives a gear reducer. Engineered for those who require a coil winder with limited pulling power, and a wide infinitely variable speed range.

PERMANENT MAGNET DC MOTOR DRIVE

Gives you soft, smooth starting and stopping. Controlled acceleration and deceleration from zero to full speed prevents shock loads, which could break the wire. The drive is reversible and can operate continuously at rated toque throughout the specified speed range.

SPEED CONTROL

Speed is controlled by the foot pedal. The operator has full control of acceleration and deceleration of the entire speed range by use of the remote foot pedal. The winder will accelerate to the same speed every time the foot pedal is depressed.

SAFETY FEATURE

The operator may stop the machine instantly at any desired turn count by removing pressure from the foot pedal. Starting and stopping remains in control of the foot pedal.

COIL WEIGHT CAPACITY

Loads up to 240 Lbs. when used with an outboard support.

IMPORTANT

When ordering, be sure to specify: Voltage and clockwise or counter-clockwise rotation of the face plate.

SPEED AND TORQUE RANGES

MODELS	RPM SPEED	LB. FT. TORQUE	H.P. DRIVE
74	0-490	7	3/4 HP.
74A	0-490	10	1 HP.

ace
Since 1919
ACE Equipment Company
4725 Manufacturing Road
Cleveland, Ohio 44135
800-255-1241*PH216-267-6366*FAX216-267-4361
email: info@armaturecoil.com
www.armaturecoil.com

Medium Duty Model 3-VAS Automatic Stop
Price USD 17,010.00

Figure E-2 Coil Winding Machine

LAWSON HIS

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Catalogue / Welding / Arc Welding Machines

UP

SEALEY - 210XTD - ARC WELDER 210AMP C/W ACCESSORY KIT (DUAL VOLTAGE 230V & 415V) 210XTD

- Manufactured in Europe this Sealey 210XTD welder meets all relevant CE standards.
- Dual voltage input for use with 230v or 415v supply.
- Complete accessory kit including electrode holder, cables, earth clamp, chipping hammer/wire brush and welding mask.
- Suitable for electrodes 2.0-5.0mm. Welding current range 75-210A(230V), 80-210A(415V).
- Usually despatched within 1 day
- Details of our carriage charges.

List Price: ~~£299.95~~ (~~£352.44~~ inc VAT)
Our Price: £159.95 (£187.94 inc VAT)

More from Lawson-HIS:

For more information or if you would like a quote on any item not already listed, please contact us by e-mail: enquiries@lawson-his.co.uk, by telephone: **08709 907038** or by fax: **08709 907031**.

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Figure E-3 Welding Machine

Home Back

LatheMaster model: HD250X750

9 x 30 Lathe

For Purchase Information Price:$1100.00

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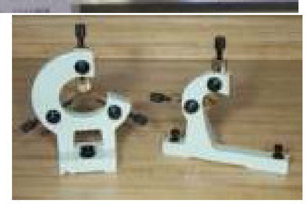
ORDER MACHINES Page!

Specifications:

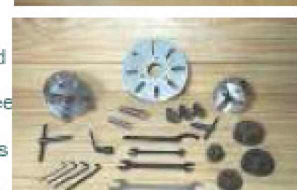
- Swing over Bed: 9 "
- Swing over Cross Slide: 5 7/8"
- Distance between centers: 30"
- Carriage Travel: 25"
- Spindle speeds: 6
- (125, 210, 450, 620, 1000, 2000 rpm)
- Longitudinal Feeds: 2 (.005,.010)
- Inch Threads: 12 (8 - 40TPI)
- Metric Threads: 12 (.4 - 3mm)
- Cross Slide Travel: 4 1/2"
- Compound Travel: 2 5/16""
- Tailstock Spindle Travel: 2 3/4"
- Tailstock Taper MT2
- Spindle Bore: 20mm (3/4")
- Spindle Taper: MT3
- Motor: 3/4 HP, 110V/60Hz
- Machine Size: 56"x19"x18 1/2"
- Machine weight: 330lbs.
- Shipping weight: 388lbs.

STANDARD ACCESSORIES INCLUDED:

5" - 3 JAW CHUCK	5" - 4 JAW CHUCK
FACEPLATE	4 WAY TOOLPOST
MT2 DEAD CENTER	WRENCH SET
MT3 DEAD CENTER	THREADING DIAL
INCH CHANGE GEARS	METRIC CHANGE GEARS
STEADY REST	FOLLOW REST
FEED REVERSE GEAR	



FEATURES:



The Lathemaster 9 x 30" Lathe is the highest quality lathe in it's size and

Unlike some on the market today, this is a true, ready to machine, no nee

Removing the protective grease, lubrication, and installing the drive belts ning with precision.

It is a solid machine (330lbs.) with induction hardened, precision ground, dy reinforced frame.

The spindle is constructed with quality tapered bearings.

Spindle speeds up to 2000 RPM for turning small parts.

Feed ratio and thread selection are a simple task of changing a few easily removed gears!

Figure E-4 Lathe Machine