“ I hereby declare that I have read through this report entitle “Investigation of Noise Generation in SRM and Method of Reduction”and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Power Electronics and Drive)”

Signature : .......................................................

Supervisor’s Name : Ir. Dr. Md Nazri Bin Othman

Date : .....................................................

# INVESTIGATION OF NOISE GENERATION IN SRM AND METHOD OF REDUCTION

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**A report is submitted in partial fulfilment of the requirements for the degree of Electrical (Power Electronics and Drive)**

**Faculty of Electrical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2013**

I declare that this report entitles“Investigation of Noise Generation in SRM and Method of Reduction” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ...........................................................

Name : SITI NURUL HUSNA BINTI AHMAD TAJUDIN

Date : ..........................................................

To my beloved mother and father

"AHMAD TAJUDIN BIN SALLEH and HALIJAH BT OSMAN"

## ACKNOWLEDGEMENT

Alhamdulillah, thanks to Allah SWT, who with His willing, I am succeed in finishing my final year project without failure. Truthfully, in completing this project, there is a lot of stage that I have been through. The bad and good things that I have faced for this few month have brought me to a new phase of my life in dealing and applying what I have learnt for four year in UTeM. First and foremost, I would like to express my deepest thanks to Prof Zulkiflie bin Ibrahim, Dean of faculty of electrical engineering. Then, my special thanks go to Ir Dr Md Nazri B. Othman, my beloved supervisor that has guided me in completing this project. He who had never failed to answer and help me with any problem that I have faced really is the best inspiration in completing my project. Not forgotten, to both my panel, Dr Auzani B. Jidin and Puan Syaharfor their valuable guidance and advice. They have inspired me greatly throughout this project. Their willingness to motivate me contributed tremendously to my work. I also would like to thank all thelecturers and staffs of University Technical Malaysia, Malacca for their cooperation during this period by giving valuable information, suggestions and guidance. Not forgotten, an honorable mention to both my parents, Ahmad Tajudin Bin Salleh and Halijah Bt Osman which, without them, surely I would not be able to continued with my project at the challenging time. Finally, special and unforgotten thanks go to my siblings and friends for their understandings and supports on me in completing all of the projects. Without helps of the particular person above, I would surely face many difficulties while going through.

# ABSTRACT

Noise is displeasing to any mankind or any living things ever existed.Same with motor application, motor drive that produce noise excessively will cause damage to the motor itself. One of the examples of DC motor that greatly affected by this noise is Switch reluctance motor or known as SRM. Construction of SRM is simple witha salient pole stator having concentrated excitation windings and a salient pole rotor that have no conductors or permanent magnets, but SRM also are commonly reviewed by its main problem of vibration and noisethat are caused by the radial force and torque pulsation between stator and rotor which resulted in torque ripple. In view of that scenario, SRM is less popular due to that drawback. In this thesis, the main study is about the investigation of noise generation in SRM and methods of reduction that have been done on the relationship of construction, winding and flux with the emission of noise and vibrations. The effect of SRM geometry in noise generation have been analysed based on three main parameters that are the pole embrace, number of phase and air gap length. An analysis by using Maxwell 2-D of Finite Element Analysis (FEA) has been used throughout this thesis so that a precise result of noise torque production can be obtained. At the end of the thesis, an optimum design that present the best motor with the lowest torque ripple production have been proposed. The outline used to develop the design is general enough for further investigation by either evaluating other designs of its components or by extending its application to other problems.

# ABSTRAK

Bunyi bising adalah sesuatu yang tidak menyenangkan bagi manusia atau benda hidup yang wujud. Keadaaan yang sama juga berlaku kepada motor applikasi, dimana pemacu motor yang mengeluarkan bunyi yang melampau akan menyebabkan kerosakan kepada motor itu sendiri. Salah satu contoh motor berkadar terus yang mempunyai kesan yang teruk disebabkan bunyi adalah "*Switch Reluctance Motor*" atau dikenali sebagai SRM. Pembinaan motor SRM adalah mudah dimana dibahagian *stator*, terdapat belitan pengujaan pekat atau *concentrated winding excitation* manakala di bahagian *rotor* pulatidak mempunyai konduktor atau magnet kekal, tetapi SRM kebiasaanya dikaji berdasarkan masalah utama getaran dan bunyi bising yang disebabkan oleh daya jejarian dan *torque*denyutan antara *stator* dan *rotor* yang menyebabkan *torque ripple*. Senario ini justeru menyebabkan penggunaan SRM adalah kurang popular. Dalam tesis ini, kajian utama adalah mengenai penyiasatan bunyi yang terhasil pada SRM dan kaedah pengurangan yang telah dilakukan ke atas hubungan pembinaan, *windings* dan fluks dengan pengeluaran bunyi bising dan getaran. Kesan geometri SRM dalam penjanaan bunyi telah dianalisis berdasarkan tiga parameter utama iaitu*pole embrace*, nombor fasa dan beza jurang panjang udara. Satu analisis dengan menggunakan *Maxwell 2-D Finite Element Analisis (FEA)* telah digunakan sepanjang tesis ini supaya hasil yang tepat mengenai sebab berlakunya *noise torque* boleh diperolehi. Satu reka bentuk motor yang paling optimum yang menghasilkan *ripple torque* paling rendah telah dicadangkan. Sepanjang tesis ini, garis panduan yang umum untuk membangunkan reka bentuk telah digunakan supaya siasatan lanjut sama ada dengan menilai reka bentuk lain komponen atau dengan memanjangkan permohonan kepada masalah-masalah lain dapat dilakukan pada masa hadapan.

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# CHAPTER 1

# INTRODUCTION

Noise is displeasing to any mankind or any living things ever existed. In understandable word, noise can be interpreted as excessive sound that may disrupt the activity or balance of human or animal life. One type of noise is indoor noise that is caused by machines, building activities, music performances, and especially in some workplaces. Meanwhile, the source of outdoor noise is machines, transportation systems, motor vehicles, aircrafts, and trains. In some type of motor applications, noise is a major concern that always being investigated. While, in medical applications like infusion pumps or prosthetic devices, the noise disturbance might be sometimes being very sensitive to the patient [1]. Meanwhile, noise is a danger to animals because noise can increase the risk of death by altering predator or prey detection and avoidance that will interfere with their reproduction and navigation thus contribute to permanent hearing loss.

Same with motor application, motor drive that produce noise excessively will cause damage to the motor itself. The worse is when dealing with large machine, where combination of hundreds of DC motors and gears operating simultaneously can be very loud and distracting to the employees who have to work in close proximity to the machine. Therefore, good design practice is badly needed so that our daily routine will not affect, since human are now living in a life that mostly use technologies as the mover of live. One of the example of DC motor that greatly affected by this noise is Switch reluctance motor or known as SRM because even SRM is one of the simple and low cost motor that have ever invented, but it is not widely used in industry or drive because of its high production of noise and vibration.

## 1.1 Problem Statement

As being reported in many papers, construction of Switch Reluctance Motor (SRM) is simple with a salient pole stator having concentrated excitation windings and a salient pole rotor that have no conductors or permanent magnets. Beside of its simple characteristics, this construction also make SRM as robust, low cost manufacturing, high torque density and relatively simple to control. In contrast with that, the disadvantage of this motor is its high production of noise and vibration. The major problem that contributes to this problem is when phases are turned on at unaligned position. At this time, radial forces are very small and are turned off around aligned position where the radial forces are at maximum. In order to avoid from motor from generate negative torque the phase current has to be shut down as fast as possible. This sudden shut down of current is somehow produce high rate of change in radial forces. Another problem is that the control is quite complex due to its highly nonlinear electromagnetic property and the coupled relationship among rotor position, phase current and torque.

It might seems normal to have a motor that produces sounds, but if the noise and vibration is produce continuously and excessively, it is actually can be the main cause that contributes to the loss of torque production. In any motor existed, torque is one of the main parameter that will determine the motor performance. Therefore, an early precaution is needed to overcome the problem, in order to avoid any long term damage to the motor or immediate failure. Ignoring motor vibration and noise issues may contribute to bad impact motor reliability.

## 1.2 Objective (s) of The Project

Basically, the overall objective of this project is to investigate the generation of noise and vibrations in SRM which can be analyzed by identify the parameters that greatly contribute to the problem. The principal objectives of this research are:

1. To investigate the generation of noise in SRM.
2. To identify the parameter that contributes to the generation of noise.
3. To develop simulation model of SRM using Finite Element Analysis (FEA) software.
4. To evaluate the proposed noise reduction in SRM.

## 1.3 Project Scope

The scope or limitations of these projects is;

1. To study the effect of SRM geometry in noise generation using Finite Element Analysis.
2. To propose the optimum SRM geometry parameters in noise reduction

# CHAPTER2

# LIFERATURE REVIEW

Switch reluctance motor or simply known as SRM is a doubly-salient singly-excited reluctance motor, that has salient poles on both rotor and stator sides. Construction of SRM at the rotor part is without windings, magnet or cage winding. But, it is built up with a stack of salient pole laminations and the rotating motion is generated due to the difference of variable reluctance in the air gap between rotor and stator [2].

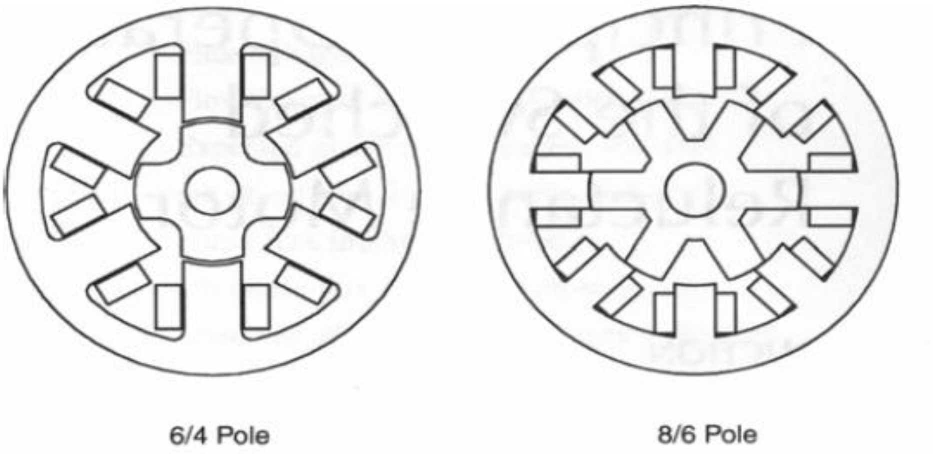



Figure 2.1: Diagram of 6/4 and 8/6 pole of SRM motor [5]

Switched reluctance motors can be classified as shown as in figure 2.2.

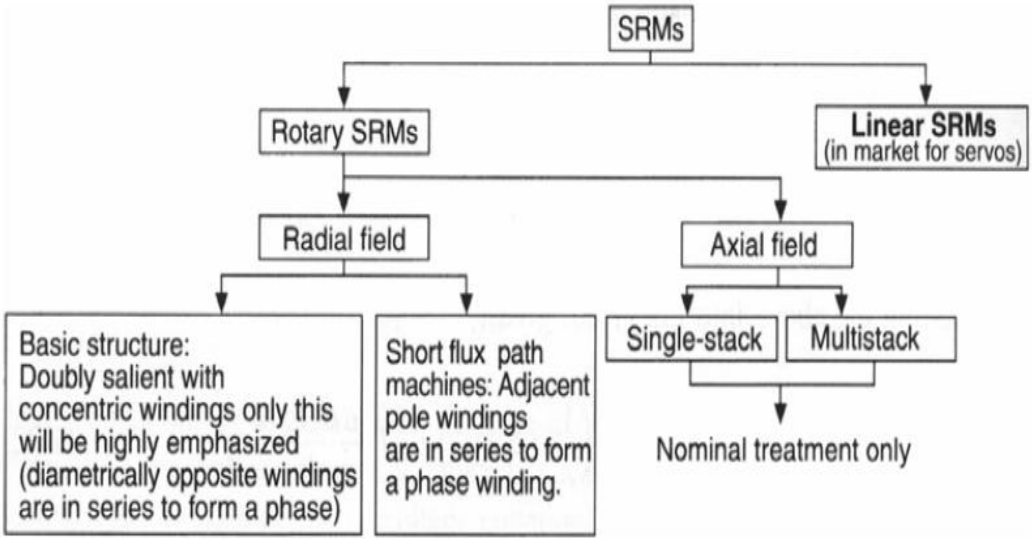



Figure 2.2: Classification of SRM motor [5]

## 2.1 CONSTRUCTION

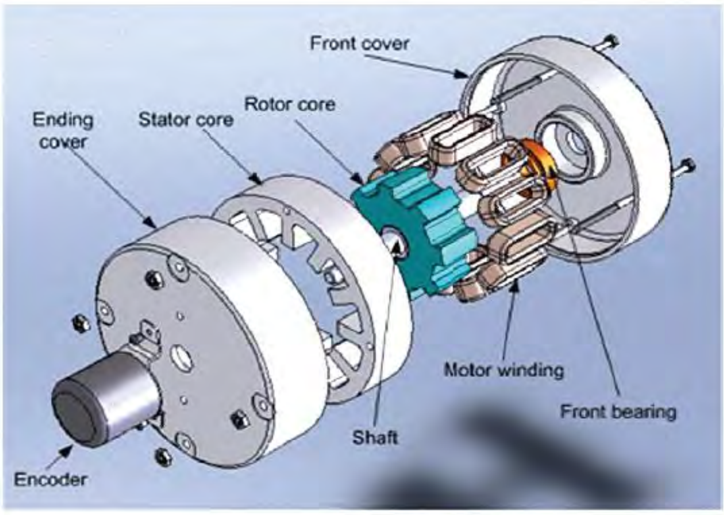



Figure 2.3: Construction of SRM motor [8]

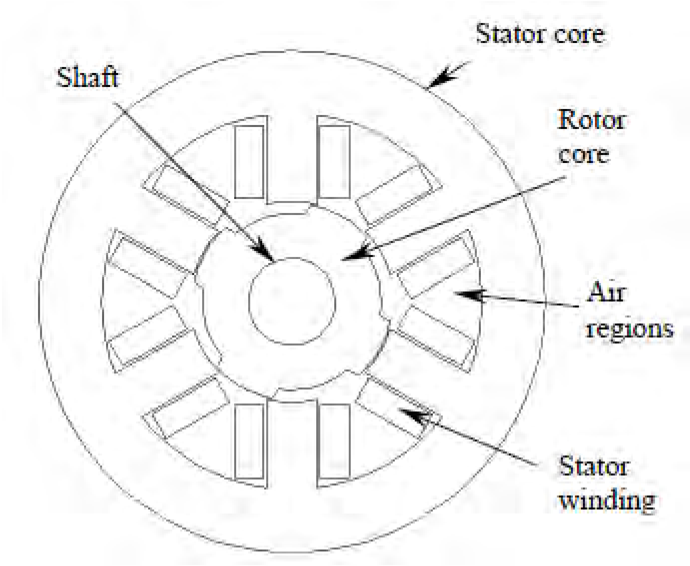



Figure 2.4: Construction of SRM [8]

Comparing to any others machine, construction of SRM is the simplest between all. SRM is said as simple, robust, low cost manufacturing, high torque density and relatively simple control and converter structure motor due to its construction with a salient pole stator with concentrated excitation windings and a salient pole rotor with no conductors or permanent magnets. Research and studied done for this latest years have shown that SRM has gained popularity as a variable speed drive due to several advantages compared to conventional AC and DC motors. Due to its low cost, fault tolerance and safety characteristics, SRM have been the most suitable choice in replacing many adjustable speed ac and dc drive in aerospace, manufacturing and domestic applications. In term of its operation, SRM is strongly influenced by the nonlinear magnetic characteristics with high levels of saturation which occurred as the rotor continuously moves from unaligned to aligned positions with reference to the energized stator phase. SRM has applications in low power servomotor to high power traction drive. It can run with either an ac or switched dc power source [3].

The saliency of the stator and rotor is necessary for the machine to produce reluctance torque. But it will causes strong non-linear magnetic characteristics, complicating the analysis and control of the SRM. Combination of perceived difficulties with the SRM, the lack of commercially available electronics with which to operate them, and the wide usage of traditional AC and DC machines in the marketplace have made the acceptance to this motor is slow. Contrary to that, SRMs however, offer some advantages along with potential low cost. For example, they can be very reliable machines since each phase of the SRM is largely independent physically, magnetically, and electrically from the other motor phases. Also, because of the lack of conductors or magnets on the rotor, very high speeds can be achieved, relative to comparable motors [4].

## 2.2 OPERATION

The operation of SRM is that, rotor is aligned whenever the diametrically opposite stator poles are excited. In a magnetic circuit, the rotating part prefers to come to the minimum reluctance position at the instance of excitation. While two rotor poles are aligned to the two stator poles, another set of rotor poles is out of alignment with respect to a different set of stator poles. The set of stator poles is then excited to bring the rotor poles into alignment.

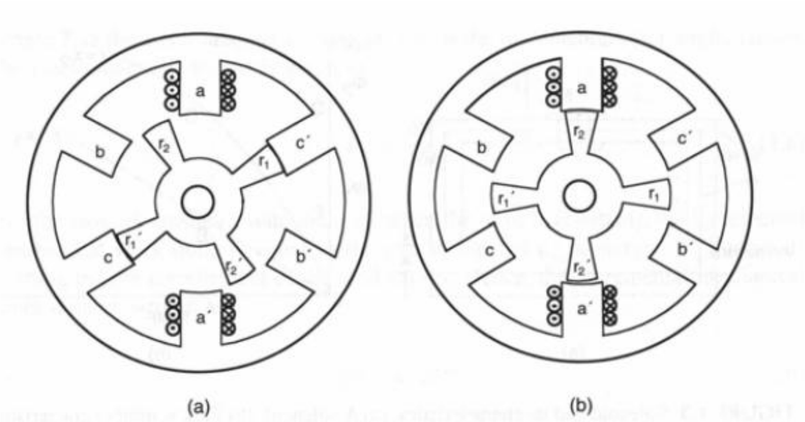



Figure 2.5: Operation of SRM [5]

(a) Phase c aligned and (b) phase a aligned

The operation can be illustrated as figure 2.5. Consider that the rotor poles $r1$ and $r1'$ and stator poles $c$ and $c'$ are aligned. When we apply current to phase $a$ with the current direction as shown in Fig. 2.5 a, a flux is established through stator poles $a$ and $a'$ and rotor poles $r2$ and $r2'$ which tends to pull the rotor poles $r2$ and $r2'$ toward the stator poles $a$ and

$a'$, respectively. When they are aligned, the stator current of phase $a$ is turned off and the corresponding situation is shown in Fig.2.5 b. Now the stator winding $b$ is excited, pulling $r1$ and $r1'$ toward $b$ and $b'$, respectively, in a clockwise direction. Likewise, energizing phase $c$ winding results in the alignment of $r2$ and $r2'$ with $c$ and $c'$, respectively [5]. This switching will cause the motor to rotate. If we want to rotate the motor in reverse direction, the switching current will be in sequence of $acb$.

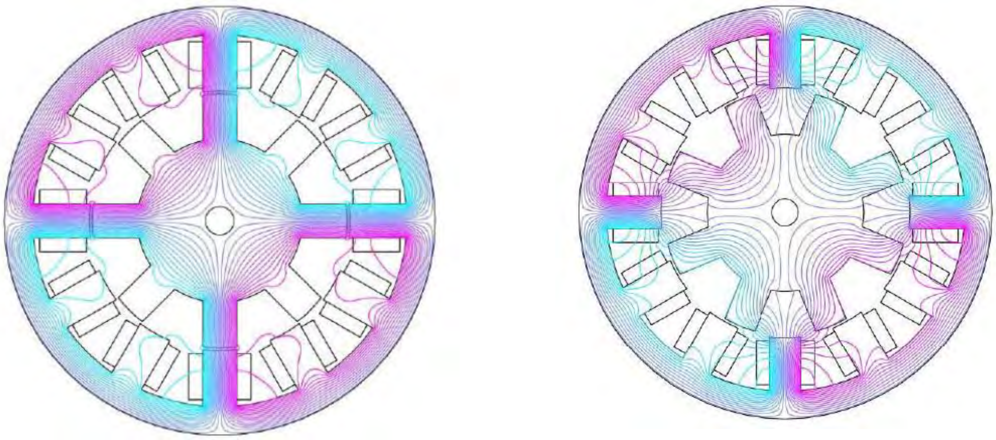
The conventional way to operate a SRM is by supplying unidirectional current pulses sequentially to each of the SRM phase coils. Due to low back emf, the source voltage is sufficient to impose a rather rectangular current pulse though the excited phases coil at low and intermediate rotor speeds. Meanwhile, at high speeds, the back emf becomes quite large, that will result the current pulse to be no longer rectangular but becomes rather triangular. The equation of voltage can be shown as below;

$$V_{dc} = R_i + L\frac{d\theta}{dt} + i\frac{dl(\theta)}{dt} \tag{1}$$

The mechanical torque on the rotor is due to the force exerted by the excited phase of the stator on the rotor salient poles. The force, mechanical torque and average torque produced in SRM depend on the number of stator and rotor salient poles, their geometrical dimensions, and the number of stator phases, and also the phase current intensity and on/off timing. These parameters are also contributes to the instantaneous profile of the torque that would determine the torque ripple characteristic of the SRM. Generally, the demand for a high average torque is contradictory to the demand for a low torque ripple. It seems that any approach producing a lower torque ripple would produce also a lower average torque and vice versa, any approach intended to produce a larger average torque would produce also a higher torque ripple [6].

## 2.3 CHARACTERISTICS

The SRM is an electric machine that converts the reluctance torque into mechanical power. The number of poles on the SRM's stator is usually unequal to the number of the rotor to avoid the possibility of the rotor being in a state where it cannot produce initial torque, which occurs when all the rotor poles are aligned with the stator poles.



(a) SRM with aligned position (b) SRM with unaligned position

Figure 2.6: Magnetic Flux at aligned and unaligned position [6]

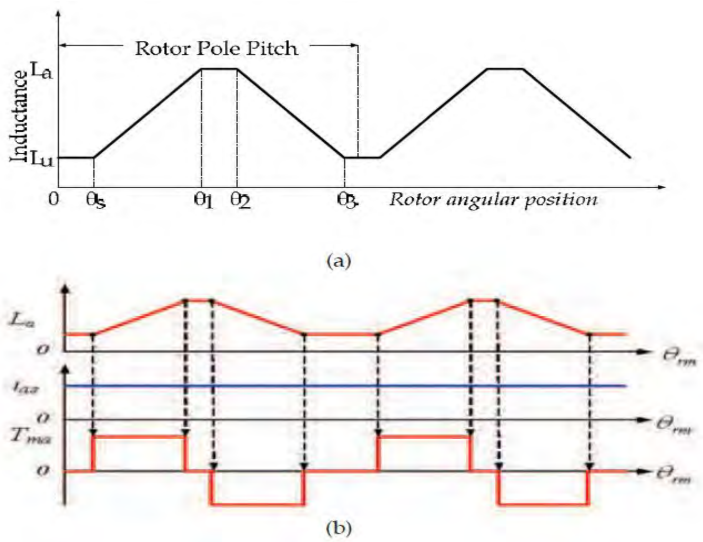



Figure 2.7: (a) Inductance and (b) torque in SRM [6]

Figure 2.6 shows the illustration of magnetic flux at aligned and unaligned position. Figure 2.7 shows the relationship between inductance and torque production according to rotor position. The aligned position of a phase is defined to be the situation when the stator and rotor poles of the phase are perfectly aligned with each other ($\theta_1 - \theta_2$), attaining the minimum reluctance position and at this position phase inductance is maximum (La) as shown in the figure 2.7. The phase inductance decreases gradually as the rotor poles move away from the aligned position in either direction. When the rotor poles are symmetrically misaligned with the stator poles of a phase ($\theta_3 - \theta_s$), the position is said to be the unaligned position and at this position the phase has minimum inductance (Lu) [6].

**The aligned position (**La**)**

This position can be illustrated by considering a pair of aligned rotor and stator poles. When current is applied phase flux will be establishes through stator and rotor poles. The rotor will stay remain in this position if current continues to flow through this phase. This position is called aligned position, and the phase inductance is at its maximum value (Lmax or La) as the magnetic reluctance of the flux path is at its minimum.

**Intermediate rotor positions (**Lint**)**

Intermediate positions can be seen when rotor pole is between two stator poles. In this case the induction is intermediate between the aligned and unaligned values. If there is any overlap at all, the flux is diverted entirely too the closer rotor pole and the leakage flux path starts to increase at the base of the stator pole on one side [7].

**The unaligned position (**Lu**)**

In the unaligned position, the magnetic reluctance of the flux path is at its highest value as a result of the large air gap between stator and rotor. The inductance is at its minimum (Lmin or Lu). There is no torque production in this position when the current is flowing in one the adjacent phases. However, the unaligned position is one of unstable equilibrium.

## 2.4 DRAWBACK

Besides being well known in the aspects of its high efficient, reliable, robust, easy manufacturing and inexpensive characteristics, but SRM also are commonly reviewed by its main problem of vibration and noise. Many investigations founds that the main noise in SRM is the electromagnetic noise that are caused by the radial force and torque pulsation between stator and rotor which resulted in torque ripple. With further research, it has been shown that the magnitude and the rate of change of radial forces are functions of rotor position and phase current [8].

High level of torque at low speeds is a major problem in SRM that contributes to the speed ripple and vibration in stator. Basically, main problem in SRM is the alignment of phase that is turned on at unaligned position, where radial forces are very small and are turned off around aligned position where the radial forces are maximum [8]. On the other hand, noise in SRM is the result of harmonic frequency of radial noise that resonates with natural frequency of stator. Generally, this radial vibration is initiated at commutation point, when the magnetic radial force reaches a maximum value. Forces that are produced is due to highly localized flux-lines on the stator poles excites various circumferential mode shapes of the stator geometry. The stator subsequently resonates with a damped vibration at its natural mode frequency and radiates acoustic noise into the air, [9 - 11].

Major drawbacks of this motor are the necessity of a rotor position sensor and presence of large torque ripple. The primary disadvantage of SRM is the higher torque ripple compared to conventional machines. In high performance servo application or in any application, torque ripple is the most unwanted one. In the case of SRM, it does have this problem that is vibration and acoustic noise. Originally, higher torque pulsation is due to the non-linear and discrete torque production mechanism. The total torque in SRM is the sum of the torque produced by each of the stator phases. The torque pulsation is significant during the commutation when the torque production shifts from one active phase to the other.