OPTIMIZATION OF COIL AND PERMANENT MAGNET OF LINEAR OSCILLATORY ACTUATOR FOR HIGH THRUST PERFORMANCE

AZHAR BIN AHMAD

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AZHAR BIN AHMAD

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FACULTY OF ELECTRICAL ENGINEERING

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In The Name of Allah the Most Merciful and Most Compassionate

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Thank you.

ABSTRACT

This final year project is about doing analysis of the performance of the Linear Oscillatory Actuator (LOA). Today's linear motion applications are more demanding than ever before. Faster throughput, more exact positioning, longer life, less maintenance, fewer moving parts, and the list are never ending. LOA is popular due to advantages offered by such as flexibility in size and design, and deliver high performance for applications requiring linear motion. Therefore, this project takes the opportunity to make an analysis based on the performance of the LOA. Definitely, LOA has several variable in varying its performance that are, coil size, permanent magnet size, current supplied, value of impedance, coil material, length of the coil and etc. By varying these entire variables, we can have a different performance of LOA. However, in this project, the focus will be given on finding the optimal coil and permanent magnet size. It is because, the two component playing a major role for the high performance of the LOA. Thus, this project will try to design and analyze the coil and permanent magnet size to find out the optimal value for both components.

ABSTRAK

Projek tahun akhir ini ialah mengenai analisis terhadap prestasi Motor Penggetar Linear atau MPL. Pada hari ini, aplikasi pergerakan linear mendapat permintaan yang tinggi berbanding sebelumnya. Kepantasan respon, tahan lama, kurang penyelenggaraan, kurang komponen yang bergerak dan senarai ini tidak pernah berakhir. MPL menjadi popular kerana kelebihannya yang fleksibel dalam saiz dan rekabentuk dan memberikan prestasi yang tinggi dalam aplikasi yang menggunakan pergerakan linear. Maka, projek ini cuba mengambil kesempatan untuk membuat analisis terhadap prestasi motor jenis ini. Secara pasti, MPL ini mempunyai beberapa pemalar dalam menentukan prestasinya antaranya saiz lingkarannya, saiz magnet kekal, nilai arus yang diberikan, nilai impedans, bahan lingkaran, panjang lingkaran dan sebagainya. Walaubagaimanapun, projek ini hanya member tumpuan terhadap saiz lingkaran dan saiz magnet kekal yang optimal. Hal ini disebabkan kedua-dua komponen tersebut memainkan peranan penting terhadap prestasi MPL. Maka dengan itu, projek ini akan mencuba merekabentuk dan menganalisis saiz lingkaran dan magnet kekal untuk mendapatkan nilai yang optimum untuk kedua-dua komponen tersebut.

DECLARATION

"I hereby declared that I have read through this report entitle "Optimization of coil and permanent magnet size of linear oscillatory actuator for high thrust performance" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronic Engineering"

Signature : ....

Supervisor's Name : Mr. Fairul Azhar Bin Abdul Shukor

Date : 12/05/2010

DECLARATION

"I hereby declared that this report entitle "Optimization of coil and permanent magnet size of linear oscillatory actuator for high thrust performance" is the result of my own work 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 : Azhar Bin Ahmad

Date : 12 MAY 2010

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, most of the local industries obtain the motor from other countries and seldom develop their own motor. Therefore there are limited knowledge and technology in the development of motor in Malaysia. The local industries usually use rotational motor in their operations even though in driving the linear motion load. In this case, it wills involves using of intermediate gears, screws, bearing or crank shaft to change the rotational motion to the linear motion. This will cause the mechanical losses in the operation and may be affect the performance of the motor. Therefore, the best solution is about to produce a motor with linear motion. One of the examples of the linear motor is Linear Oscillatory Actuator (LOA). LOA is a direct short stroke device that produces linear motion at a specific frequency without using any mechanical transmission motion that converts rotary motion into linear motion [1]. Simply, it gives a rapid linear motion either in term of forward or backward direction depending on the polarity of given power supply [2]. It has been used in various applications such as refrigerators and vibrator. Definitely, for high thrust performance, there are some elements plays an important role in designing the LOA. Size of coil and the size of permanent magnet (PM) are the two important elements that must be considered in designing the LOA. However, the size of these two elements will affect the LOA size and weight. Usually, it makes the LOA comes heavy and overweight. Hence, this project will be done to optimize the size of the coil and permanent magnet for the great performance of LOA. The size of coil and permanent magnet will be set with certain range during modeling the design and followed by simulation using Finite Element Method (FEM) techniques. Then, the data will be analyzed and some parameter will be obtained from the calculation. Finally, the best design of the LOA with high thrust performance will be chosen.

1.2 Problem Statement

Recent advances in magnetic material, power electronics, and control strategy increase the demands of LOA for several of applications such as aerospace, automotive and industrial [3]. Current designs of LOA with high thrust performance sometimes are too heavy. Therefore, the matter comes to worst problem because it is not really suitable and compatible for recent market products which are more compact and simple. It really had urged the LOA technologies to overcome the problems in a way to increase or maintain the demands of the LOA. Thus, it needs some studies to design a new high thrust LOA with small in size. Usually, the two components inside the LOA take an important part in defining the thrust and the size of the LOA. For this reason, this project will be done to studies about the LOA and try to optimize the size of coil and permanent magnet by adjusting the dimension of the two components and come out with the great performance of LOA.

1.3 Objectives

There are several objectives or the aims of the project. These objectives are the goal of the project and must be achieved at the end of the analysis. Objectives also referred as a guidance of any project. Thus, the objectives of the analysis based on the title optimization of coil and permanent magnet size of linear oscillatory actuator for high thrust performance are listed below:

1. To model a Linear Oscillatory Actuator (LOA).
2. To simulate the model by using the Finite Elements Method (FEM)
3. To obtain the optimum size of coil and permanent magnet for high thrust performance and light in weight of LOA

1.4 Scope

The size and the performance of LOA come as one of the issues on their marketing level. Commonly, the performance of LOA did not satisfy with their size. As have been done by other researcher, the LOA is designed with a bigger size to produce a high thrust performance. From that, it can conclude that the higher the performance, the bigger the size of LOA. Thus, this project will try to overcome the issues by optimizing the size of LOA without neglecting the thrust performance. In this case, the parts that have been controlled are the size of coil and the size of the permanent magnet of the LOA. Both parts are the most important parts in determine the size and the performance of LOA. The size of coil and permanent magnet will be set in a specific range. Based on the ranges, the data will be analyzed to find the optimum size for the high thrust performance of LOA.

1.5 Report Layout

Obviously, this report consists of five main chapters; begin with introduction to the main idea of the project followed by literature review chapter. Next is a methodology, results and discussions and the report will be finalized with the conclusions chapter. Basically, on the first chapter is some information about main idea of the project, the objectives or the aims of the project. It also definitely explains about the scope of the project. Second chapter will discuss based on the readings, searching and understanding any related information. This chapter will explain some concepts that used in the project research. Come on the next chapter is a methodology which shows the steps or the methods used to complete the project. Then, the result or data collected will be analyzed on the fourth chapter and some discussion for overall progress. Finally, a conclusion will be made on the fifth chapter. This chapter totally discussed about the achievement of the early target or objectives of the project. It also comes out with related suggestion, recommendation or any improvement of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to linear motor

Motor is defined as a machine, especially one powered by electricity or internal combustion that supplies motive power for a vehicle or other device [4]. There are many types of motor in the recent market and can be divided by referring to the principle and the way its function. In figure 2.1 below, there are several types of motor that comes familiar to the engineering level which is AC motor, DC motor, electrostatic motor, and servo motor.

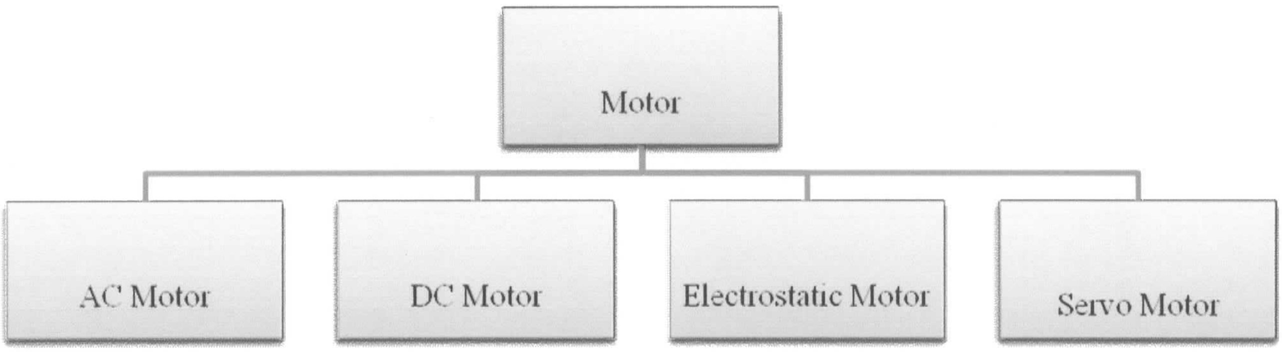

Figure 2.1: Types of Motor

All of the motor also can be classified by comparing the way of its function such as rotational or linear motion. The motor that used a linear motion principle called as linear motor. Linear motor can be divided into three types as shown below

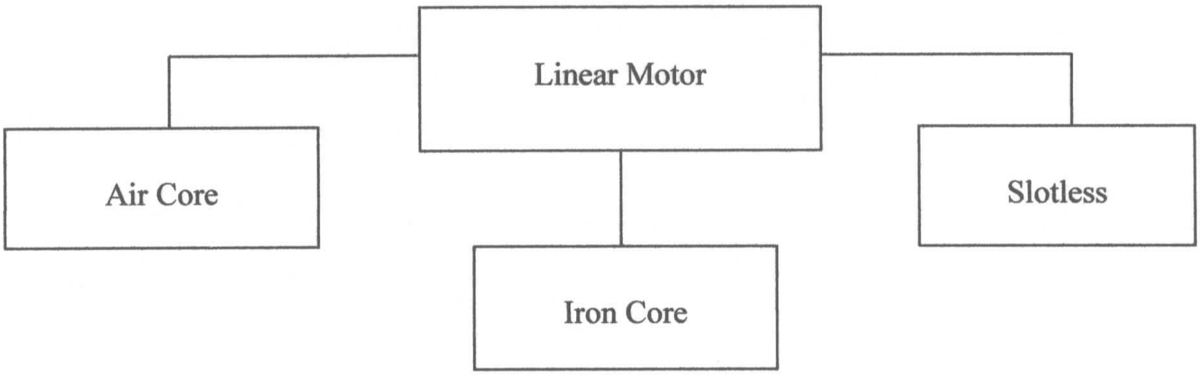

Figure 2.2: Types of linear motor

Linear motor can be classified into three types; iron core linear motor, air core linear motor and slot less linear motor [5]. Iron core linear motor takes its design straight from a brushless rotary motor. The motor consists of a flat iron rail to which rare earth permanent magnets are bonded. The Forcer is constructed of laminations and coil's wound around the teeth of the laminations. Several advantages of this motor are highest force per size, lower cost due to lower weight rail, and good heat dissipation.

Air core linear motor design is referred to as AirCore or Ironless [5]. Two magnet rails oppose each other. A spacer bar between them keeps the two sides from closing together. The forcer is constructed of coils wound and held together with epoxy. This winding assembly is then topped off with an aluminum bar. This bar is used for mounting the load and also for heat removal. The Winding itself has no iron in it, thus the names AirCore or Ironless. The advantages of this type of linear motor are no attractive forces, no cogging and low weight forcer.

Another linear motor, slotless linear motor is designed by the Compumotor and Daedal Division of Parker Hannifin, the motor takes its operating principle from Parker's rotary slotless motors that have grown popular over the past few years [5]. The rail is the same as those used for the IronCore design. Simply a flat iron plate with magnets bonded to it. The Forcer is unique. It begins with a coil similar to those used in the AirCore. A backiron plate is placed behind the coil. This assembly is placed inside an aluminums housing with an open bottom. The housing is then filled with epoxy, securing the winding and back-iron into the housing.

2.2 Basic Principle of Linear Oscillatory Actuator

An actuator is a device that produces small movements. An actuator creates mechanical motion by converting various type of energy to mechanical energy. Linear actuator is a type of actuator that uses a single axis system to provide linear motion. For the LOA, the oscillatory effect occurs when the movement is repeated to and forth periodically. This can be achieved when AC supply is given to the linear actuator [6].

The structure of LOA in figure 2.3 consists of a stator part and a mover part. The stator part is composed of stator yoke, coil and cover. The coil is embedded inside the stator yoke. The coil is used to provide the external magnetic field that will generate the attracting and repulsive forces. The permanent magnet is combined with the moving yoke and together they are attached to the shaft to construct the mover part. The magnetization of the permanent magnet is in the thickness of the magnet [1]. The assembly of the moving part and the static part are stated in the figure 2.3:

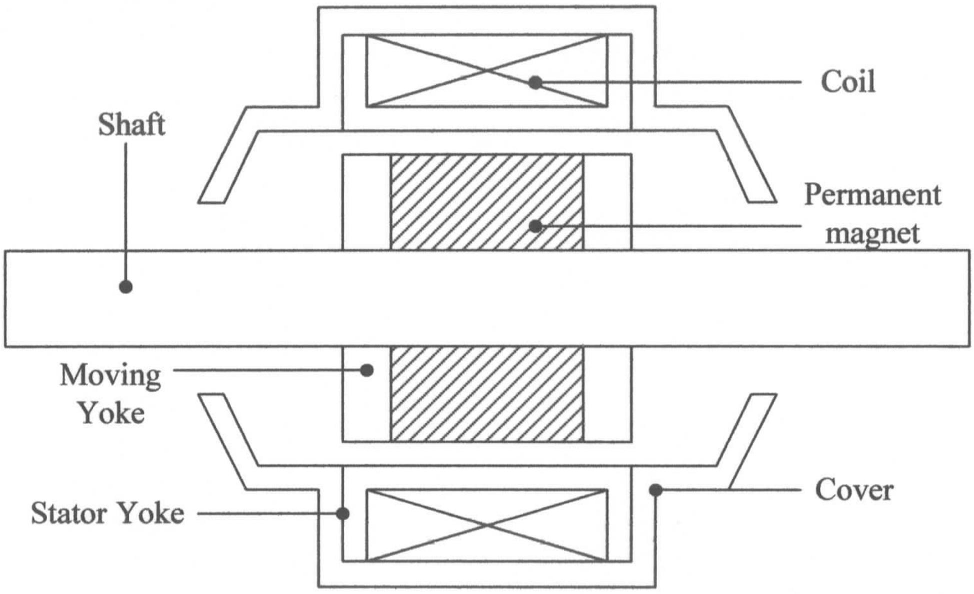

Figure 2.3: Cross-section of Linear Oscillatory Actuator

2.3 Basic Structure of LOA

The structure of LOA in this project consists of one rod shaft, permanent magnet, coil, moving yoke, stator yoke and cover. As have been stated before, all the component of LOA have been separated into 2 which is moving part and static part. Figure 2.4 show the assembled of the LOA:

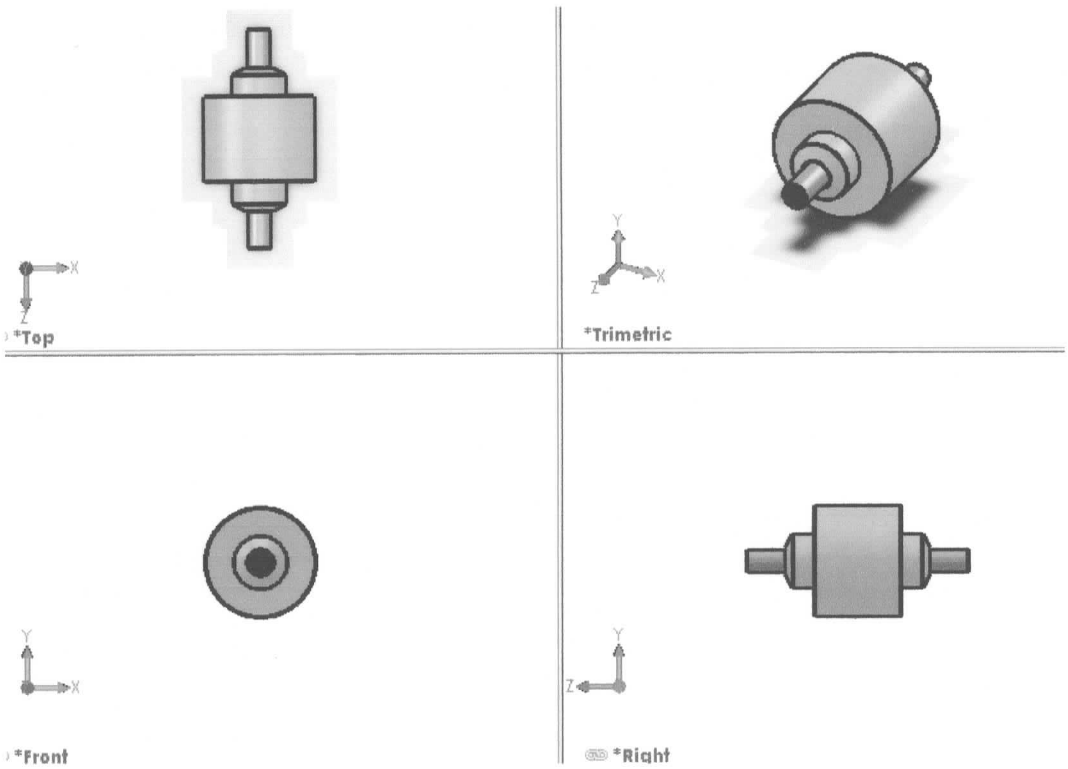

Figure 2.4: Assembled of the LOA

In the designed concept of LOA, there are two types which slot type and another one is slot less. For this structure of LOA, it uses the slot-less as a designed concept. By referred to the reference [3], slot-less type has higher average of thrust along the shaft displacement compare to slot type of LOA. More than that, slot-less of LOA applicable for application that require almost constant thrust at every positioning of shaft.

2.4 Comparison of the Analysis Method

In designing the electrical machine, there are two methods that can be used. First method is Permeance Analysis Method (PAM). In this method it is necessary to assume the magnetic path of the motor as a whole, and in particular the analytical results are conspicuously influenced by the assumption of the fringing magnetic flux distribution of the air gap. As things now stand, it is being applied only to a simple model which the teeth of both the stator and the mover are represented by rectangular periodic structures, with the influence of the magnetic field intensity on the fringing magnetic flux distribution being neglected. Such being the case, it is difficult to apply PAM to models with complicated shaped and to take into consideration the influence of the magnetic field intensity on the fringing magnetic flux distribution [8].

The finite element method (FEM) is a technique that makes it possible to obtain the magnetic forces, the torques and other characteristics of electromagnetic equipment with a high degree of accuracy because it gives an approximation of the magnetic flux distribution on a microscopic scale. In addition, FEM requires the minutely subdivided meshes in order to improve its-analytical accuracy [8]. At the same time it requires structure modeling and high memory capacities of computer which in the end give more computational time drawback [9].

Accordingly computations are being carried out by reducing the analytical region as much as possible through effective use of symmetrical conditions and periodic boundary conditions. Finite Element Method has been used for the analysis of an induction motor. The analysis of the induction motor using Finite Element Method provides flux distribution, flux density, magneto motive force, eddy currents, and torques, etc. Finite Element Method is very flexible for new shapes even it has a long equation due to detail region of calculation [7,8].

From other research about the electrical machine, some of them had chosen the PAM as the method of analysis. Such in [3], the author used the PAM method in their analysis on effect of thrust constant, spring constant, electrical time constant, mechanical time constant to vibration displacement of slot-less linear oscillatory actuator. The analytical solution of the research was obtained mathematically which is essential for repetitive calculation in their analysis.

It is different for the research in the reference paper [9], the author using a combined technique employing the FEM and PAM in the thrust calculation of linear pulse motor. In this paper proposes a general purpose technique that makes it possible to obtain the thrust of linear pulse motors in an accurate and easy way through the combined technique employing FEM and PAM. This technique is applied to double-sided linear pulse motors, which the teeth of both the stator and the mover have simple rectangular shapes, to obtain its thrust.

From the characteristics that have been stated for both method above, it jump to the conclusion that FEM method is the most suitable for this analysis due to FEM provides more accuracy in calculating the parameters of LOA, easy to implement using computer calculation and FEM has flexibility in calculating the parameters for the new shapes of LOA [8].

2.5 Magnetic material

In physics, the term magnetism is used to describe how materials respond on the microscopic level to an applied magnetic field; to categorize the magnetic phase of a material [7]. Magnetic material can be divided into three types as shown in the figure below:

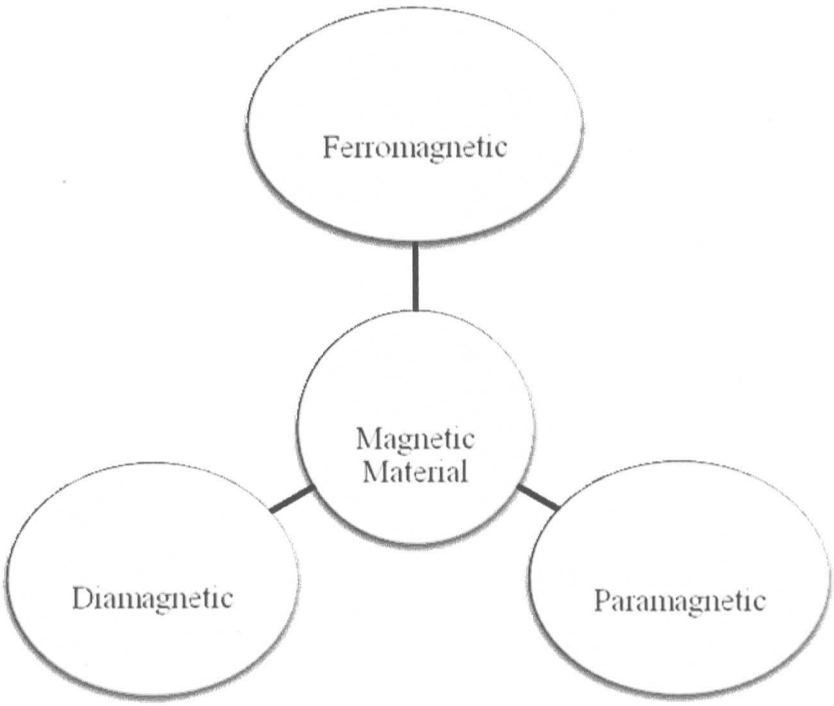

Figure 2.5: Types of magnetic material

The most well known form of magnetism is ferromagnetism such that some ferromagnetic materials produce their own persistent magnetic field. Some well-known ferromagnetic materials that exhibit easily detectable magnetic properties (to form magnets) are nickel, iron, cobalt gadolinium and their alloys. However, all materials are influenced to greater or lesser degree by the presence of a magnetic field. Some are attracted to a magnetic field (paramagnetism); others are repulsed by a magnetic field (diamagnetism); others have a much more complex relationship with an applied magnetic field [10]. Substances that are negligibly affected by magnetic fields are known as non-magnetic substances. They include copper, aluminium, water, and gases. The magnetic state (or phase) of a material depends on temperature (and other variables such as pressure and applied magnetic field) so that a material may exhibit more than one form of magnetism depending on its temperature, etc.

Ferromagnetism is the basic mechanism by which certain materials (such as iron) form permanent magnets [11]. And/or exhibit strong interactions with magnets; It is responsible for most phenomena of magnetism encountered in everyday life (for example, refrigerator magnets). The attraction between a magnet and ferromagnetic material is the quality of magnetism first apparent to the ancient world, and to us today, according to a classic text on ferromagnetism. All permanent magnets (materials that can be magnetized by an external magnetic field and which remain magnetized after the external field is removed) are either ferromagnetic or ferrimagnetic, as are other materials that are noticeably attracted to them.

Historically, the term ferromagnet was used for any material that could exhibit spontaneous magnetization: a net magnetic moment in the absence of an external magnetic field. This general definition is still in common use. More recently, however, different classes of spontaneous magnetization have been identified when there is more than one magnetic ion per primitive cell of the material, leading to a stricter definition of ferromagnetism that is often used to distinguish it from ferrimagnetism. In particular, a material is ferromagnetic in this narrower sense only if all of its magnetic ions add a positive contribution to the net magnetization. If some of the magnetic ions subtract from the net magnetization (if they are partially antialigned), then the material is ferrimagnetic. If the moments of the aligned and antialigned ions balance completely so as to have zero net magnetization, despite the magnetic ordering, then it is an antiferromagnet.

All of these alignment effects only occur at temperatures below a certain critical temperature, called the Curie temperature (for ferromagnets and ferrimagnets) or the Néel temperature (for antiferromagnets). Among the first investigations of ferromagnetism are the pioneering works of Aleksandr Stoletov on measurement of the magnetic permeability of ferromagnetics, known as the Stoletov curve. There are a number of crystalline materials that exhibit ferromagnetism (or ferrimagnetism). The table below lists a representative selection of them, along with their Curie temperatures, the temperature above which they cease to exhibit spontaneous magnetization.

Material	Curie temperature (K)
Co	1388
Fe	1043
$FeOFe_2O_3$	858
Ni	627
MnAs	318

Table 2.1: Material with their Curie temperature

Ferromagnetism is a property not just of the chemical makeup of a material, but of its crystalline structure and microscopic organization. There are ferromagnetic metal alloys whose constituents are not themselves ferromagnetic, called Heusler alloys, named after Fritz Heusler. One can also make amorphous (noncrystalline) ferromagnetic metallic alloys by very rapid quenching (cooling) of a liquid alloy. These have the advantage that their properties are nearly isotropic (not aligned along a crystal axis); This results in low coercivity, low hysteresis loss, high permeability, and high electrical resistivity. A typical such material is a transition metalmetalloid alloy, made from about 80% transition metal (usually Fe, Co, or Ni) and a metalloid component (B, C, Si, P, or Al) that lowers the melting point. A relatively new class of exceptionally strong ferromagnetic materials is the rare-earth magnets. They contain lanthanide elements that are known for their ability to carry large magnetic moments in well localized forbitals [13,14].

Paramagnetism is a form of magnetism which occurs only in the presence of an externally applied magnetic field [13]. Paramagnetic materials are attracted to magnetic fields; hence have a relative magnetic permeability of ≥1 (1 or more, a positive magnetic susceptibility). The magnetic moment induced by the applied field is linear in the field strength and rather weak. It typically requires a sensitive analytical balance to detect the effect and modern measurements on paramagnetic materials are often conducted with a SQUID magnetometer. Unlike ferromagnets, paramagnets do not retain any magnetization in the absence of an externally applied magnetic field, because thermal motion causes the spins to