

Development of Dry Permanently Induced Roller Magnetic Separator for The Concentration of Barkin-Ladi Columbite Ore

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Abstract

The development of a permanent induced magnetic separator aims to achieve an innovative, cost-effective, and locally sustainable solution for separating columbite ore into magnetic and non-magnetic fractions. The separation of magnetic and non-magnetic ores is a critical process in various industries, including mining, recycling, resource recovery and mineral processing. The conventional methods of separation often rely on large-scale and energy-intensive equipment, making them economically prohibitive, especially for small-scale operations. Researchers and Engineers have conducted numerous studies to comprehend how different types of paramagnetic minerals behave when separated using various separator technologies. However, despite these efforts, these separators have not been widely adopted for processing different paramagnetic minerals. This paper examines the current state of these separators, providing an overview of their operational mechanisms, practical uses, and theoretical models. It goes further to develop an induced roller magnetic separator after considering various factors such as magnetic susceptibility cost and performance, while observing certain industry specifications. The resulting design was found to produce a substantial strength of the magnetic field of about 2.2 Tesla that can be used to separate certain minerals for a reasonable period of time. 2 Kg samples of the crude Barkin-Ladi columbite ore was charged into the machine hopper at 0.05 tons per hour to evaluate the effectiveness of the fabricated machine. The efficiency of the machine was found to be about 85%. Further implementation and modification of this design will hope to yield an increase in the extraction and processing of various minerals internally within Nigeria, providing jobs and improving the economic status of the Nation.

Keywords: Induced; Magnetic; Roller; Minerals; Separation.



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1. Introduction

A permanent induced magnetic separator is a device that uses magnetic fields to separate and concentrate magnetic materials from non-magnetic ones. The design and fabrication of a permanent induced magnetic separator involves the use of strong magnets and various mechanisms to ensure efficient separation ([Maqsood et al., 2017](#)).

The World today is facing a growing environmental crisis, as pollution and waste continue to accumulate and threatens the health of our planet. One of the major sources of pollution is the industrial waste, which includes various types of hazardous materials and pollutants that are harmful to the environment and human health. One such pollutant is magnetic particles, which are commonly found in industrial waste streams and pose serious threat to the environment. According to [Yi Fan et al., \(2020\)](#) permanent induced magnetic separators are designed to address this issue by effectively separating magnetic particles from waste streams, and also reducing the negative environmental impact of industrial waste coupled with its unlimited application in metallurgical separation.

[Kim et al., \(2017\)](#) shared that magnetic particles are often found in industrial waste stream which can be harmful to the environment and human health. Magnetic particles are often found in ore deposits and can make mining process less efficient if they are not separated from the ore. Permanent induced magnetic separator is an important tool for various industrial applications, including mining, recycling, water treatment, food industry and medical industry ([Rao et al., 2019](#)).

However, [Rath and Bhattacharyya \(2014\)](#) stressed that traditional magnetic separators, such as permanent magnets, have limitations in terms of their magnetic field strength and their ability to separate weakly magnetic materials. Permanent induced magnetic separators, on the other hand, used an electromagnet to create a magnet field, which is stronger than that of a permanent magnet. This allows for more efficient separation of magnetic materials from non-magnetic materials, including weakly magnetic materials. In addition, permanent induced magnetic separators can be developed to meet specific industrial requirements, such as the size and shape of the separator, the strength of the magnetic field, and the type of materials being separated ([Lee et al., 2020](#)).

The problem addressed in this study is the need for a more efficient and cost-effective method of separating magnetic materials from non-magnetic materials in different industries, such as mineral processing and recycling. A small number of minerals that are paramagnetic and ferromagnetic—that is, contain iron, nickel, and cobalt—benefit from this approach. Most metals, including gold, silver, and aluminum, are diamagnetic. Magnetic separation techniques are used in many industries, such as mineral beneficiation, food, plastic, textile, and ceramic.

Factories have been under a lot of pressure to survive since the implementation of stricter global environmental protection policies; hence, processing plants and scientific researchers have become interested in dry permanently induced magnetic separators as an energy-saving and environmentally friendly separation technology. The general public is intended to gain insight from this study. The objective of this effort is to develop a permanent roller magnetic separator for engineering and industrial applications that will separate magnetic minerals from non-magnetic materials.

2. Materials and Methods

The following is the steps of materials and methods adopted in the study:

2.1 Design Considerations

To create a functional and effective induced magnetic separator, the following factors were taken into considerations:

- A minimal noisy design
- Cost-effective assembly
- Material's magnetic properties
- Ergonomical ease of operation taken into account anthropometric data of Human Height
- Portability

2.2 Selection of Materials

The permanent induced magnetic separator was designed with considerations for its mechanical, magnetic, and cost characteristics. The different parameters that make up the design of a permanent roller magnetic separator are presented in [Table 1-7](#).

Table 1. Details of the conveyor belt of the induced roller magnetic separator.

Parameter	Unit	Value
The length of Belt	mm	3650
The thickness of Belt (A ₄)	mm	0.55
The width of the Belt	mm	295
Service Factor		1.25

Table 2. Details of the hopper of the induced roller magnetic separator.

Parameter	Unit	Value
Hopper's Volume	mm ³	1060620.050
Hopper's Surface Area	mm ²	823142.555
Hopper's Height	mm	526.830

Table 3. Details of the roller of the induced roller magnetic separator.

Parameter	Unit	Value
The Diameter (A ₂)	mm	110
The Length of (Magnetic B ₄ & Non-Magnetic A ₁₅)	mm	360
Thickness of Magnetic Disc	mm	5
Thickness of Steel Disc	mm	2.5
Diameter of Roller Shaft	mm	20
Length of Roller Shaft	mm	50

Table 4. Details of conveyor frame (iso 657-1 50 x 5, hot rolled steel of equal angle).

Parameter	Unit	Value
The Length of the Separator	mm	1850
The Width of the Separator	mm	400
The Height of the Separator	mm	1075
Height of the Separator Frame	mm	800
Height of Separator Collector	mm	275

Table 5. Details of belt drive (synchronous type) of the induced roller magnetic separator.

Parameter	Unit	Value
The Driver Pulley Diameter	mm	111.5
The Driven Pulley Diameter	mm	225
The Belt's Width	mm	5
The Length of the Belt	mm	600
The Centre Distance	mm	126.5

Table 6. Details of the material retrieval (5 mm thick) of the induced roller magnetic separator.

Parameter	Unit	Value
Width of the Container	mm	280
Length of the Container	mm	280
Height of the Container	mm	200

Table 7. Details of the electric motor of the induced roller magnetic separator.

Parameter	Unit	Value
Wattage	W	2.5
The Rated Horsepower	Hp	0.5
Service factor	-	1.3
The Design Horsepower	Hp	0.65
Voltage	V	220
Speed	Rpm	1430

2.3 Analysis of the Induced Magnetic Separator Component Parts

Equations (1) to (15) were used in the design of the machine's separate parts, such as hopper, belt

drives, machine frame and the electrical unit.

a. Hopper

A, the feed hopper's volume is calculated as follows:

$$V_{frustum} = \frac{l_b w_b h_b - l_s w_s h_s}{3} \quad (1)$$

b. Pulley

The diameter of the motor pulley divided by the diameter of the conveyor pulley is known as the speed ratio when carrying out pulley design.

$$\frac{n_2}{n_1} = \frac{D_1}{D_2} \quad (2)$$

Let n_1 represent the driver pulley's speed, n_2 the driven pulley's speed, D_1 the driver pulley's diameter and D_2 driven pulley's diameter.

c. Belt Drive

The belt thickness is taken into consideration when calculating the belt velocity (v) for a particular driver magnetic roller.

$$V = \frac{\pi(2D) N}{60} \quad (3)$$

Thus, the motor power required is calculated as follows:

$$P_m = T_e \times V \quad (4)$$

The minimal motor power, P_{min} to operate the permanent induced magnetic roller is calculated as follows:

$$P_{min} = \frac{P_m}{\eta}$$

Where 5% motor losses are accounted for by η is 0.95.

The magnetic field gradient required is calculated as:

$$F_m = \frac{1}{\mu_0} (\chi_p - \chi_f) m_p B \Delta B \quad (6)$$

Where $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$, χ_p is the particle's magnetic susceptibility and χ_f is the fluid's magnetic susceptibility which is 0 for air (dry magnetic separation). Kopp (1984) states that the following relation is used to determine B and ΔB for permanent magnetic rollers.

$$B = B_0 \exp\left(\frac{-z}{t}\right) \quad (7)$$

$$B \Delta B = \frac{B_0^2}{t} \exp\left(\frac{-2z}{t}\right) \quad (8)$$

According to [Khurmi and Gupta](#) (2005) the length and Centre distance of the belt transporting materials from the hopper to the magnetic zones were determined by calculating the energy transferred by the driving pulley through the electric motor to the drums in order to rotate the conveyor belt.

$$L_b = 2CD + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4CD} \quad (9)$$

Where;

$$CD = \frac{B + \sqrt{B^2 - 32(D_2 - D_1)^2}}{16} \quad (10)$$

c. Belt tension

The following relation, which accounts for the total resistance and models belt friction in accordance with [Yardly and Stale \(2005\)](#) was used to calculate the belt tensions. This is the effective belt tension of the magnetic roller.

$$\frac{T_1}{T_2} = e^{\mu\theta} \quad (11)$$

According to Dunlop (2009) for horizontal conveyor belts with bare pulleys and dry condition $\mu = 0.3$.

d. Variable frequency drive (VFD) speed control

The synchronous speed or the constant speed at which VFD makes the electric motor to rotate at a specific frequency is:

$$N_s = \frac{120f}{P} \quad (12)$$

Where N_s represents the synchronous speed, f the supply frequency, P the number of poles of the motor. The electric motor rating and parameters determines the VFD requirement ([Kuphaldt, 2023](#)).

e. Bearing service life/rating

According to [Shigley \(2007\)](#) the rating of the service life of a bearing is given as

$$L_b = \left[\frac{C}{P_d} \right]^k \times 10^6 \quad (13)$$

Where C is the dynamic load rating, P_d is the design load. K is 3 for ball bearings and for roller bearings it is 3.33.

A deflected beam can support the following critical load calculated as:

$$P_{cr} = \frac{\pi^2 EI}{L_e^2} \quad (14)$$

The relation for maximum allowable load applied is given as

$$P_a = \frac{P_{cr}}{N} \quad (15)$$

Where P_{cr} represents the critical load, P_a the allowable load, N the factor of safety, E the Modulus of elasticity, I the Moment of inertia, and L_r is the slenderness ratio.

2.4 Detailed Drawing and Picture of the Developed Induced Magnetic Roller Separator

[Figure 1, 2](#) and [3](#) present the detailed drawing and picture of the developed induced magnetic separator. [Table 8](#) present the Part Description.

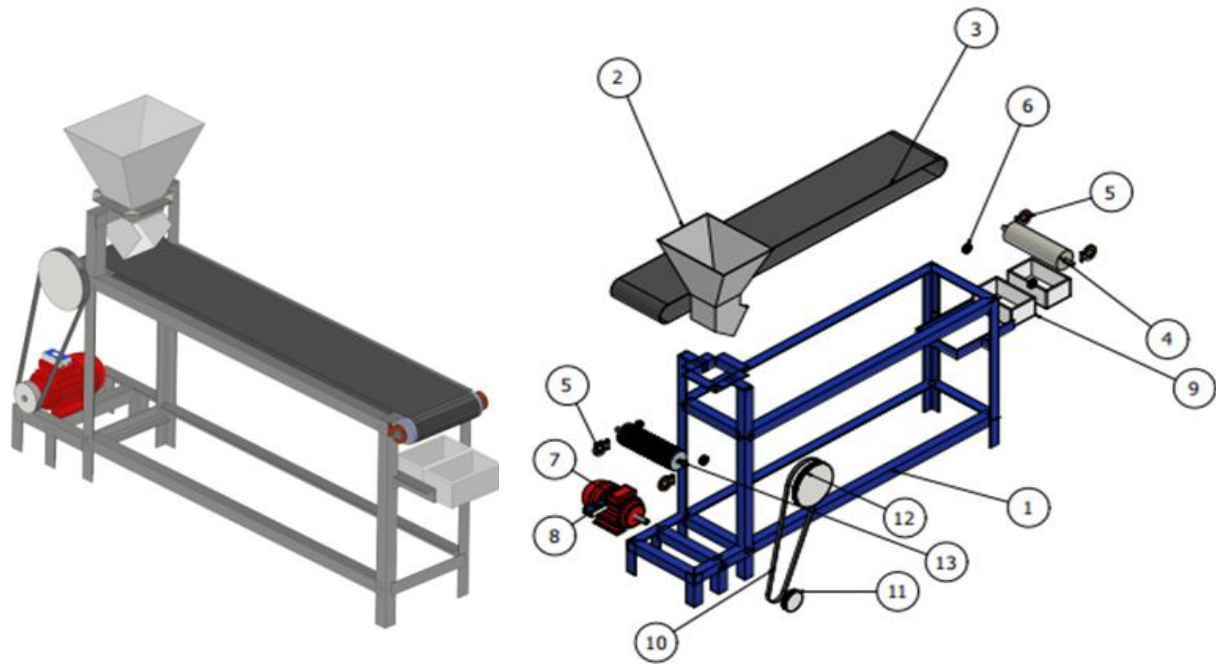


Figure 1. Dry Induced permanent roller magnetic separator.

Table 8 . Part Description

ITEM	PART NUMBER	DESCRIPTION	QTY
1	Steel frame (ISO 657-1)	Hot-rolled steel section	1
2	Hopper feederz	Sheet Metal	1
3	Rubber Belt	Elastic material for conveyor Mechanism	1
4	Non-magnetic Roller	Machined Steel	1
5	Bearing Housing	Rotating elements support	1
6	NSK 7004C	High precision Angular contact Ball Bearing (standard series)	4
7	AC Induction Motor	Electro-Mechanical device	4
8	VFD	Electronic device	1
9	Collecting Box for magnetic and non- magnetic material	Plastic	1
10	Synchronous Belt	Rubber	1
11	Synchronous Pulley1	Aluminum	1
12	Synchronous pulley 2	Aluminum	1
13	Assembly of the magnetic Roller	Interleaved arrangement of steel and magnetic discs over a shaft	1

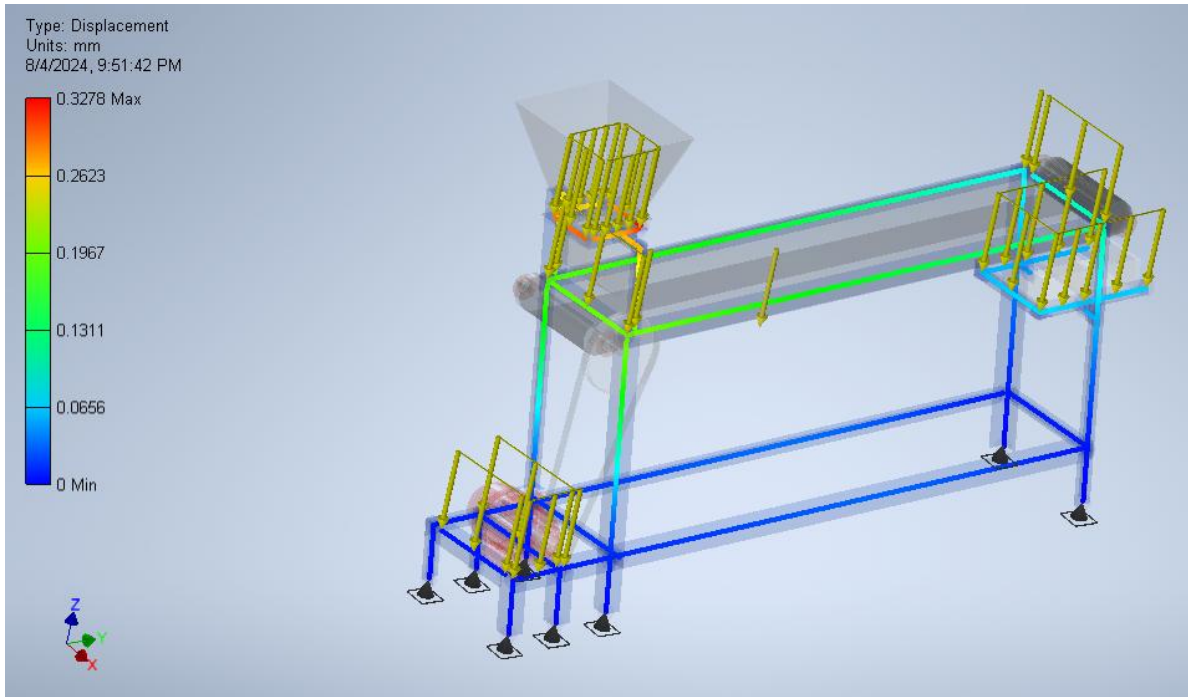


Figure 2. Simulation of the load applied to the frame of the machine.



Figure 3. Picture of the developed permanent induced magnetic separator.

3. Performance Evaluation of The Induced Roller Magnetic Separator

Five kilograms of the crude columbite ore sample was source from Barkin-Ladi Mines site, Barkin-Ladi Local Government Area of Plateau State, Nigeria covering a vast area of land about 560,000 hectares of land, with a reserve estimate of about 123,000 million tons of columbite which is an ore of niobium pentoxide in association with iron oxide, silica, zircon sand, tin oxide, silver, lead oxide and

zinc oxide. The columbite ore was charged into laboratory jaw crusher of the Metallurgical and Material Engineering Department, precision laboratory, after which it was grounded using ball mill at the same laboratory to 355 μm . 2 Kg was sampled out of this using cone and quartering method and charged into the developed permanent induced magnetic separator which was switched on before the charge was carried out and set at a current of 40 Amperes, 220 Volts and a feed rate of 0.05 ton per hour. After the process, two products were received which are Magnetic and non-magnetic in nature. The products were weighed, representative sample picked using random sampling method and was taken for chemical analysis using X-ray Fluorescence Spectroscopy (X-RF), at the National Metallurgical Development Centre, Jos, Plateau state, Nigeria. The result obtained were presented in Table 9 and 10.

Table 9. Weight of Charge and Product: Crude, Magnetic and Non-Magnetic

Weight of Charge (g)	Weight of Magnetic (g)	Weight of Non-Magnetic (g)
2000	289.60	1710.36
2000	284.89	1715.11
2000	296.82	1703.18
Average (product)	290.44	1709.55

Table 10. Chemical Characterization of Barkin-Ladi Columbite Crude, Magnetic and Non-Magnetic

Compositions (%)	SiO ₂	Fe ₂ O ₃	Nb ₂ O ₅	Ta ₂ O ₅	TiO ₂	ZrO ₂	SnO ₂	PbO	CeO ₂
Crude	20.24	45.12	11.13	2.24	2.63	13.16	4.01	0.56	0.244
Magnetic	2.54	73.08	0.23	0.07	12.18	0.06	0.90	0.01	0.013
Non-Magnetic	25.78	4.09	32.08	5.05	0.91	17.76	7.12	0.98	0.211

4. Results and Discussions

Table 9 shows that the quantity of the crude Barkin-Ladi columbite ore charge on to the developed permanent magnetic separator weighing 2000 grammes; after three (3) repeated processing an average weight of 290.44 grammes of magnetic mineral was recovered, while an average of 1,709.55grammes of non-magnetic mineral was recovered. These products were sampled using cone and quartering sampling method was withdrawn and taken for compositional analysis using XRF at the Analytical chemistry laboratory of the National Metallurgical Development Centre, Jos, Plateau State, Nigeria.

The result on Table 9 shows that the columbite crude contains columbite Niobium Pentoxide, Silica, Iron oxide and other non-magnetic to the tune of 20.24% SiO₂, 45.12% Fe₂O₃, 11.12% Nb₂O₅, 2.24% Ta₂O₅, 2.63% TiO₂, 13.16% ZrO₃, 4.01% SnO₂, 0.56% PbO and 0.244% CeO₂. This shows that the crude contains a lot of Iron oxide, silica and some percentages of minerals as stated in Table 9. While material reported at the magnetic arm shows a high percentage of iron oxide with less non-magnetic to the tune of 2.5% SiO₂, 73.08% Fe₂O₃, 0.23% Nb₂O₅, 0.07% Ta₂O₅, 12.18% TiO₂, 0.06%

ZrO₃, 0.90% SnO₂, 0.01% PbO and 0.013% CeO₂, while non-magnetic arm to the tune of 25.78% SiO₂, 4.09% FeO₃, 32.08% Nb₂O₅, 5.05% Ta₂O₅, 0.91% TiO₂, 17.76% ZrO₃, 7.12% SnO₂, 0.98% PbO and 0.211% CeO₂.

The obtained results have clearly confirmed that the developed permanent induced magnetic separator truly separates magnetic material from the non- magnetic mineral effectively and very efficient. Hence, the project yields a successful result.

5. Conclusion

The machine successfully fulfilled its intended function based on the other separator characteristics, such as stability and stiffness. It is capable of separating magnetic mineral from non-magnetic mineral with a magnetic strength of about 2.2 Tesla at a feed rate of 0.05 ton per hour with about 85% efficiency. The machine's production costs are reasonable, and if it is used, it will cut down on imports and help the country save money on foreign exchange gains. As a result, it might be utilized in foundry floors and mineral processing; the machine could be useful for both experimental and educational objectives. It was observed that this separator produced a particular Magnetic Field Intensity of 2.2 Tesla and this would be limited to a few minerals that can be separated. Changing the grade of Permanent magnet will change the value of Magnetic Field Intensity and it would be advisable to get varying grades of magnets

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