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DESIGN AND CONSTRUCTION OF ELECTROMAGNETIC METAL CHIPS COLLECTING MACHINE USING LOCALLY SOURCED MATERIAL

Ikwuebene Benjamin Chukwutem and Kebodi Chiedu Lawrence Ekene.
Department of Mechanical Engineering, Delta State Polytechnic Ogwashi Uku
Delta State Nigeria

Email:chuksejiro@yahoo.com, chikarotonx73@gmail.com

ABSTRACT

An Electromagnetic metal chip collecting trolley has been designed and fabricated to reduce the labour and time involved in metal chips collection. The machine is incorporated with an electromagnet made up of an insulated enamelled wire wound on three iron rod bolted on a metal plate. The magnetized metal plate having total field strength of 2084.5 AT/m is required to pick total of 1kg of metal chips when the system is connected to a 12 volts, 40Amperes DC power supply. The DC battery also powers a 12 volts dc motor with the torque of 5.34Nm required to turn the electromagnet housing for discharging the collected metal chips. The drive mechanism is achieved via the help of four contact bearings and a bevel gear arrangement. The whole mechanisms are controlled by the operator via switches fitted on the machine handle. This machine is four wheeled with the two front wheels having two degrees of freedom (DOF) for easy directional movements.
Keywords: Sensors ,

INTRODUCTION

In machine shops, some cutting processes which involve metal processes produce metal chips. Most common machining processes which produce chips are turning, milling and drilling operation. These tiny and sharp edged metal chips produced during machining processes make the working environment unsafe because metal machining generates large amounts of extremely hot metal chips as they come out of the tool bit and the work piece. The chip remains a safety concern even after cooling because of their sharpness and accumulation in the immediate work area. These chips on the floor of the work areas can cut machine hoses if stepped on or if machinery is rolled over them and can also cause severe cuts on the operators during machining process or manual cleaning process. Therefore even with good condition of machineries in the production line; the operator is still exposed to extreme danger if the metal chips are not properly handled and managed. The use of broom to collect the metal chips is not enough because not all the chips will be collected. Also the use of permanent magnet as a chip collector makes it difficult for easy removal of the collected chip.

Therefore, it is a good reason for the design and fabrication of the electromagnetic metal chip collecting trolley to provide a better way of metal chip removal and improve the ability of the operator to work in a safe environment. The electromagnetic feature of this trolley enables the metal chip segregation from other wastes for the benefit of metal reprocessing. We are adopting the faraday’s law of electromagnetic induction for the working principle of the electromagnet that collects the chips. The electromagnetic coil wound around a ferromagnetic iron rod fitted in the trolley induces a magnetic flux in a plate attached to the bottom of the electromagnetic cylinder container. The magnetized plate attracts the metal chips on the floor which is later collected in the chip bucket when the coil is demagnetized by cutting off the power supply through a switch. We are using trolley for driving the components to enable the collection of the metal chips from every comer of the workshop with ease. The trolley is driven manually with holding handles which is incorporated with switches for the control of the electromagnet and the drive motor which drives the lifting mechanism of the electromagnet through gear arrangement.

Chip formation is part of the process of cutting materials by mechanical means using tools such as saws, lathes and milling cutters. A clear understanding of the theory and engineering of chip formation is advantageous to the aspects of development of material removing machines and their cutting tools (Atkins, 2008).

Chip formation study was encouraged formally around World War II. Later, chip formation increased faster as well as more powerful cutting machines for metal cutting with the new high speed steel cutters. Chip formation pioneering work was carried out by Kivima (1952) and Franz (1958). Chip formation is usually described and explained according to a three-way model developed by Franz. This: "Franz model" is best known within the field of machine tool design and also used for wood working.

MATERIALS AND METHOD

Methodology

The methods includes

a. Conceptual design
b. Selection of appropriate material for each of the component
c. Testing of result

Fabrication and machining processes selected

Some machining processes were used to fabricate some components like the frame, the chip bucket, the handle while the other components that were sourced from the market includes, cylindrical pipe housing the electromagnet, the bevel gear, the dc |Motor drive, and the rechargeable dc battery. The following Fabrication and machining processes were involved

a. Marking out process
b. Cutting process
c. Drilling process
d. Welding process
e. Assembly process

Assembly process

Various components of the electromagnetic metal chip collecting trolley were installed on the already fabricated frame. This process involves the following:

a. Installation of the iron core wound with copper coil to the electromagnetic cylinder container.
b. Installation of the cylinder to the bearing support at the extreme end of the frame.
c. Mounting of the dc motor on the bevel gear arrangement.
d. Installation of the dc rechargeable battery
e. Electrical wiring of the whole component.

Design/selection of some major components

DC motor

For the purpose of this project the design of an electric motor was based on the speed and torque required to turn the weight of electromagnet housing / cylinder under load and no load conditions efficiently.

Calculating the weight of the cylinder contents

Weight of the cast iron rods (magnetic core)

Length of one rod (L) = 0.16m

Diameter of one rod (D) = 0.013m

Density of cast iron (p) = 7207kg/m^3
Volume (V) = π /4 x D^2 x L (1)
= π /4 x $(0.013)^2$ x 0.16
= 2.124 x 1 O'[5] m^3
Weight (W) = V x p (2)
= 2.124 x 10'[5] x 7207
= 0.15306 kg
Therefore, for the three cast iron rod, the total weight = 0.15306 x 3
= 0.459 kg

Weight of copper wire

1 pound weight = 0.454kg

Weight of cylindrical pipe (poly carbonate pipe)

Outer diameter (OD) = 18mm = 0.018m
Inner diameter (ID) = 14mm = 0.014m
Length (L) = 0.27m
Density of polycarbonate (p) = 1300kg/m^3
Volume (V) = π /4 **x** [$(OD)^2$- $(ID)^2$] x L (3)
= π /4 x [$(0.018)^2$- $(0.014)^2$] x 0.27 = 2.71 x 10'[5] m^3 Weight (W) = V x $_p$ = 2.71 x I0'[5]x
1300 = 0.035kg

Weight of bottom steel plate

Diameter (D) = 18mm = 0.018m
Thickness (t) = 0.5mm = 0.0005m Density of steel (p) **=** 7850kg/m^3
Volume (V) **=** π /4x $(D)^2$ x t (4)
= π /4 x $(0.018)^2$ x 0.5 =
1.272 x $10^{-7}$$m^3$
Weight (W) = Vx p
= 1.272 x I0'[7]x 7850
= 9.988 x I0'[4]kg
The weights of the two circular ply wood fitted at the electromagnets section are estimated to weigh the same as the steel plate.
Therefore, for the three plates weight = 3 x 9.988 x 10'[4]
= 0.003 kg

Weight of chips

The extreme designed weight for chips is estimated at 1kg

Total weight of the cylinder

The total weight of the components of the electromagnetic cylinder equals the sum of all the weights acting at that section;
0.459kg + 0.035kg + 0.003kg + 0.454kg + 1kg = 1.95kg

Power required to overcome a load of 1.95kg

Radius (r) = 13.5mm = 0.0135m
Linear velocity (v) = lm/s
Angular velocity (w) = v/r (5)
(w)= 1 /0.0135 = 74.074 rad /sec
But 1 radian = 9.5493 rpm
Therefore, Rotational speed required = 707.36 rpm
Therefore Power required to overcome the cylinder load;

P(req) = 74.074 x 1.95 = 144.44 watts.

Torque required to turn the cylinder

Torque = (60 x $P_{(req)}$)/ (2π x rpm) (6)

= (60 x 144.44) / (2 π x 707.36) = 1.95 N/M.

Based on the above results, a motor of $^3/_4$ horse power with l000rpm was selected.

Torque of the DC motor selected

Torque = (60 x p) / (2 π x rpm)

Where P = rated power of the motor

Therefore, torque = (60 x (3/4 x 746)) / (2 π x 1000) = 5.34 N/M

The torque (1.95N/M) required to move the load is well within the torque (5.34N/M) of the motor selected

Motor Efficiency

Motor efficiency is given by; P_{out} - $P_{,oad}$ / P_{in} (7)

Where, P_{in} = 40 x 12 = 480 W

P_{out} = % HP = $^3/_4$ X- 746 = 559.5 W

P_{load} = 144.44 W

Motor Efficiency = (559.5 - 144.44) / 480

= 0.86 = 86%

Design of bevel Gear

Type, size (number of teeth) and the arrangement of gear was based on

- The shaft to be connected
- Rpm of the motor
- Speed reduction
-

Properties

Number of gear teeth (T_G) = 14 teeth Number of pinion teeth (T_P) =10 teeth Motor power = 3/4 horse power = 559.5 watts Motor speed = 1000 Rpm Pitch circle diameter of the gear (D_G) = 70 mm Pitch circle diameter of the pinion (D_P) = 60 mm Speed of the pinion = 1000 rpm Face width =10mm

Design Calculations

Determination of the velocity ratio.

Velocity ratio = number of teeth of gear teeth /number of teeth of pinion teeth. VR=T_G/T_P (8)

VR= 14/10= 1.4

Pitch angle for the gear and pinion

But T_g / T_P= N_P / N_g (9)

Therefore, 1.4 = 1000 / N_g

N_G = 1000/1.4

=714.3 Rpm

Since the shafts are at right angle angles, therefore pitch angles for the pinion, θPi= Tan^{-1} (1/VR) (3.10) = (1/1.4) = 35.5°

And pitch angle for the gear,

θp_2= 90-36 = 54°

Calculation of the formative number of teeth for the pinion and the gear

Formative number of teeth for pinion = T_{EP} =T_P sec θpi (10)

10 sec 36 = 12.4

And the formative of teeth for the gear = T_{EG} =T_G sec θp_2 (11)

14 sec 54 = 23.8

Tooth form factor
Tooth form is taken as composite system 141/2°
For the pinion
Y'P = (0.124-0.684) (12)
(0.124 - 0.684) / 12.4 = 0.0689
For the gear
Y'G = 0.124 - 0.684 / 23.4 = 0.0953

Calculating the Strength of the bevel gear
The strength of the bevel gear tooth is obtained by using the modified form of the Lewis equation for the tangential tooth load as shown below:
WT = (σ_9 x Cv)b.n.m.y^1 (1-b/l) (13)
Where WT= tangential tooth load
Cv = velocity factor= 6 / 6+v, for the teeth generated with precision machines
V= peripheral speed in m/s
B= face width
Y'=tooth form factor (Lewis factor) for the equivalent number of teeth
L= slant height of the pitch cone (cone distance) =
√V (DG / 2) + (DP/2)

Pitch line velocity
v = $\pi t D_p Np$ / 60 (14)
v- (3.142 x 0.06 x 1000)/60v
= 3.142 m/s
Taking velocity factor, Cv = 6/ 6 + v = 6/ 6 + 3.142 Cv = 0.6563
Therefore allowable static stress for cast iron heat treated = 70mpa are the same since the allowable stress for the both pinion and gear is same. Thus, the pinion is weaker and the design should be based on the pinion.

Calculating the Length of the pitch cone element or slant height of the pitch cone.
L = V (70 / 2) + (60 / 2) = 46.09 mm
Torque on the pinion
T= (P x 60) / (2π x N_P) (15)
(559.5 x 60) / (2π **x** 1000) =
33570 / 6284 = 5.34 N-m or 5342 N-mm
Tangential load on the pin
WT=((T/Dp)/2) (16)
(5.34/60) x 1) / 2 = 0.0445 N
Gear module
94.97 = 70x0.65 x l0 x πt x $_m$x0.0689(46.09-10/46.09)
m = 94.97 / 77.88
m = 1.24 says m = 2mm
Checking gears for wear
Load stress factor = σes = SinΦ) / 1.4(l/E_p+l/E_g) (17)
From table, σes = 630 Mpa, E_p and E_G = 84 Mpa
Therefore,
K= (630) sin14 / 1.4 (1 / 84 x 10 x 1/84 x 10)
K= 1.687

And ratio factorΦ
$= 2T_{EG} / T_{EG} + T_{EP}$ (18)
2 x 23.8/23.8 + 12.4= 1.31
And maximum limiting load for wear
Ww = (60 x 10 x l.3l x 1.687)/cos35.5 Ww= 1628.7 N
Since the maximum load wear is much than the tangential load, the design is satisfactory from the consideration of wear.

Speed reduction effect of the gear on the motor Rpm

Motor speed / V.R (19)
1000/ 1.4 = 714.28 rpm
Therefore, the gear reduces the rpm of the motor from 1000 to an output speed of 714.28rpm

Design of Electromagnet

The design of an electromagnet in this context was based on:

- Weight to be lifted
- Field strength required to lift the weigh

Materials for Electromagnet

- Gauge copper wire
- Cast iron rod
- DC battery

Power required to lift the weight of chips (1kg)

Power = (distance (cm) / time (s) * weight (kg)) (20)
Desistance = 5cm (distance between the electromagnet and chips)
Time = 1 second (time of attraction)
Weight = 1kg (metal chips)
Therefore;
Power = 5cm / lsec x (1kg) =
5watts-kg.cm/sec

Magnetic field strength required to lift the weight

But, $P = B^2 / 2p_0$ n/m^2 (21)
F =$B^2A / 2p_0$
5 = B^2/2x4nxl0"^{7} (22)
B = 0.3511
F = $(0.3511)^2$ x (3x6.7999x10'^{3})/2x47cx10'^{7}
F = 1000.56N
MMF = NI = F (23)
H = MMF / L (24)
L = 0.16 m x 3 = 0.48m
H = 1000.56N/ 0.48m = 2084.5At/m
Number of turns of wire required

Combining equation 3.24 and 3.25

H = NI/L (25)
But I = P/V (26)
1 = 5/12
= 0.417Amperes From
equation 3.26 N = HL/I
= (2084.5x0.48)/0.417
2399 turns

Design of Dc source (battery)

The design of a DC source are based on:

- Capacity

- Hours of operation
- Discharge rate

Rated capacity of the battery
Capacity = 480 watts

Hours of operation

Total loads on the battery;
Motor power = 144.44 watts
Electromagnetic power = 5 watts
Total load = 149.44 watts
Therefore,
Capacity = loads x hours (27)
Hr = capacity / loads
Hr = 480/ 149.44 = 3.211 hours

Efficiency of the Battery

Efficiency = loads x hours / capacity (28)
battery = (149.44 x3.211)/ 480 = 96.9%

Battery discharge rate

Discharge (Q) =Load in ampere **x** Time in hours (29)
Loads in Ampere = 0.416Amp + 12 Amp =12.416 Amperes
Therefore,
Discharge rate per hour = 12.416AmpHr.

MATERIAL SELECTION

Factors considered during the process of selecting best materials that can give the optimum design and performance of the electromagnetic metal chip collecting trolley include:

a. Availability of the material to be selected.
b. Cost of the material.
c. The suitability of the materials for the working conditions in service
d. Availability of design and test data.
e. Mechanical properties of the material, including its strength, toughness and rigidity, resistance to wear etc.
f. Magnetic properties of the material.
g. The environmental conditions in which they will function.
h. The machining and surface finishing of the materials were considered.

Table 1: Various components of the machine and their selection criteria.

Material component	Material used for the design	Reasons for selecting the material
Frame	Mild Steel	• Cost effectiveness: least expensive of all steel type. • Weld able: unlike high carbon steel, mild steel can be coalesced with far greater ease. • Ductile: it is able to bend, stretch and have relatively large forces applied to it. That is making it easier to form shape and to weld.
Bevel gear	Heat treated cast iron	• Good wear resistance. • Low cost. • Smooth action.

	• Market availability.	
Battery	Lend acid	• Low cost • Rechargeable • Reliable • Low maintenance • Low self-discharge
Electromagnetic cylinder base	Galvanized steel	• Ferromagnetic material thus have strong magnetic effect. • Low cost • Prevent rust due to zinc coating.
Dc motor		DC power supply

Table 2: Various components of the electromagnet an their selection criteria

S/N	Component	Material	Property requirement
1.	Magnetic wire	Copper	Excellent conductor of electricity. Have low resistance. Very affordable
2.	Magnetic core	Iron rod	• It has a greater magnetic permeability. • It produces a strong magnetic field. • It has a low retentively. • Therefore when current is switched off, the remaining field strength is very weak.
3.	Power source	DC Battery	• Supply the appropriate current required to induce the wound coil • Mobility
4.	Circuit breaker	Switch	Regulates the induction of wound copper wire

Three essential properties that influenced the choosing of these material for an electromagnet include;

a. The magnetic wire and magnetic core should be an excellent conductor of electricity
b. It should not be susceptible to becoming permanently magnetized as that would defeat the only advantage of an electromagnet over permanent magnet. This and its high electrical resistance, usually eliminate iron wire as a candidate for the coil material
c. Cost consideration.

Electromagnet assembly

Gather the materials that have been selected during the material selection which includes the copper magnetic wire, the iron magnetic core, the DC battery and the circuit breaker.

Remove a few centimeter of the insulations on both ends of the copper wire to expose it to a good electrical connection with the battery.

Neatly wrap the wire around the iron magnetic core. The more the number of turns of the copper wire, the stronger electromagnetic field it produces. The wire is wrapped only in one direction because the direction of a magnetic field depends on the direction of the electric current creating it. Attach one end of the copper wire to the positive terminal of the battery and the other end of the wire to the negative terminal of the battery.

Attach a switch between one ends of the battery terminal to control the electromagnet.

Fig 1 solenoid

Fig. 2 Exploded view of electromagnetic assembly

Fig.3 Assembled View of Electromagnet

Operational procedure for the electromagnetic chip collecting trolley (EMCCT)

The usage of this EMCCT is quite clear and simple to operate. The operational procedures include:

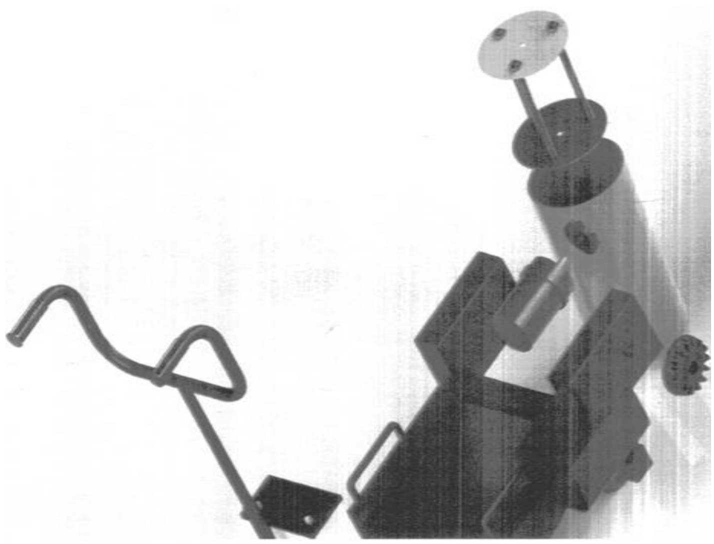
a. Fix all the accessories including the battery and the dc motor ensuring that the gear arrangement is connected firmly and appropriately to the dc motor.
b. Ensure that all the electrical parts are connected appropriately by connecting the battery to the dc motor and electromagnet through the switch.
c. Turn on the electromagnetic power switch so that the electromagnetic cylinder becomes magnetic.
d. Drive the trolley around to pick the metal chips on the working area or in workshop.
e. Switch on the clockwise switch of the motor drive to rotate the chip bucket where it drops the chip automatically after hitting the demagnetizing switch of the electromagnet.
f. Switch on the anticlockwise switch of the motor drive to rotate the electromagnetic cylinder back to the position where it continues its metal chip magnetizing function.
g. Turn off the general power supply switch connected to the battery to disconnect the power source from the working component immediately after use.
h. Dispose the chip collected in the chip bucket, clean up the machine and then keep in safe place.

3.12 Safety considerations in operating the electromagnetic metal chip collecting trolley

It is very necessary that safety measures are applied carefully in order to prevent accident to both the machine and the user. The safety precautions includes:

a. Ensure that the bevel gear arrangement are connected firmly at a right angle during mounting to avoid wobbling of the gears.
b. Ensure that the bearing are always lubricated to enhance easy movement and longer life span.
c. Turn off the power source switches immediately after use to avoid battery discharge.
d. Always charge the battery when it is discharged after use.

Fig 4 parts and components of EMMCC



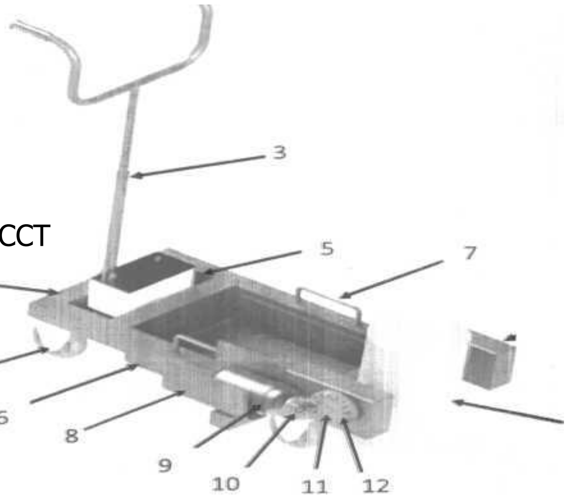


Fig 5 Exploded View of EMCCT

EMCCT modelling

1. Frame
2. Handle
3. Adjustable height
4. Roller wheel (housing)
5. 12 volts battery
6. Bucket
7. Bucket handle
8. Motor sitting
9. Motor
10. Pinion Gear Bearing Driven Gear
11. Flipping Cylinder (Electromagnet
12. Driven Gear
13. Flipping Cylinder (Electromagnet)

14. Cylinder mount

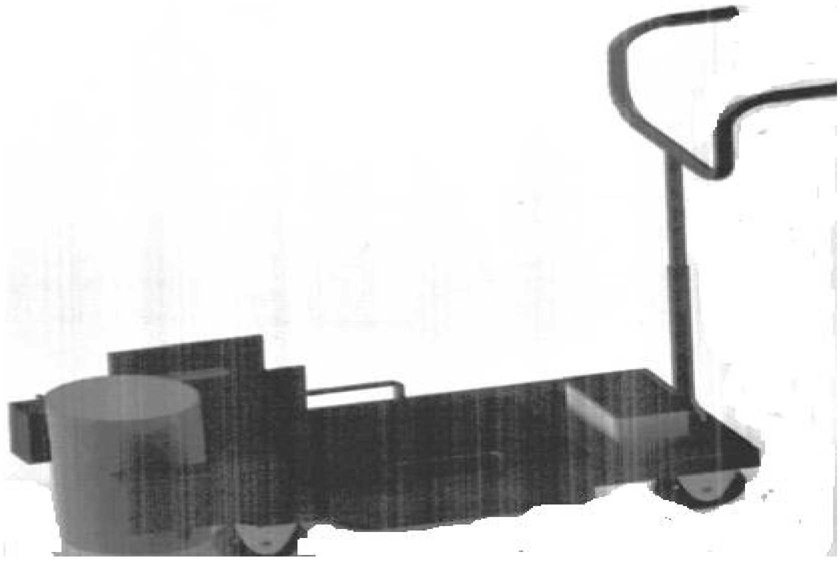


Figure 6 : Electromagnetic Metal Chip Collector Trolley (EMCCT) modelling

RESULT AND ANALYSIS

Functional Performance

The performance of the electromagnet an experiment was carried out to test its workability and magnetic effect.
The project is to study the effect of different number of turns and their corresponding magnetic-field strength of an electromagnet respectively.
Secondly, to determine the relationship between flux density β in ωb/m^2 and magnetizing force (H) in AT/m of different ferromagnetic materials respectively.

Apparatus and equipment used includes

a. Lead acid battery (12 volts, 40 amperes)
b. Solenoid
c. Cast iron rod
d. Mild steel
e. Cast steel
f. Chip metals
g. Copper wire (18 gauge)

Experimental Procedure

The project testing was carried out using cast iron rod wound with various number of turns to obtain their various magnetic field strengths.
Other test was carried using three different metals (ferromagnetic) of the same areas were used with the same number of turns to observe their magnetic field strengths. Bolt of 0.013m diameter is used and a length of 0.16m is wound with 750tums of insulated copper wire.
A 12 volts, 40 amperes lead acid battery is connected to the solenoid with a switch to connect and disconnect the system. Metal chips of various ferromagnetic materials and non-magnetic materials are dispersed evenly on the floor for electromagnetic separation.
The magnetic field strength (FI) of various ferromagnetic materials are obtained analytically, hence the length of the metal core(L), number of tums (N), and the amount of current passing through are specified.
Magnetic field strength (H) of various ferromagnetic materials are compared with the same

number of turns and same area.

CONCLUSION

The electromagnetic metal chip collecting trolley has been finally designed and constructed efficiently to operate optimally. The EMCCT was constructed using appropriate available materials that enabled it to be of less weight and size for easy movement. The EMCCT is ergonomically designed for convenient use, efficient and reliable picking and dropping of the metal chips through the action of the controlled electromagnet. The design of this electromagnetic metal chip collecting trolley is less bulky and therefore making it convenient for usage; Also, It is very affordable. The motor produced enough torque that can drive the electromagnetic cylinder through the aid of gear arrangement. Thus, resulting to effective picking and dropping of the metal chips. During the experimentation and testing of the magnetic field strength of different metals using the same number of turns of wire and same power input; it was ascertained that cast iron had the highest magnetic field strength. Finally, utilization of the electromagnetic metal chip collecting trolley will help to reduce the stress that could be encountered in simple cleaning operation in workshop.

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