Apparatus for Cleaning Ferrous Chips using Magnetic Brush

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Abstract: ***The invention relates to a standard cleaning brush with the novel addition of an electromagnetic core within itself to enable it to clean ferrous materials more efficiently.***

Keywords: Magnet, brush, cleaning, manufacturing

1. Introduction

When charged particles stay stationary, they produce electric forces and display the general characteristics of electrostatics. However when these particles, like electrons, are accelerated or moved, they display and exhibit magnetism.

In daily life, we can take the example of a charged electron moving through ordinary power lines. These wires exhibit magnetism due to the current passing through them, a phenomenon discovered by Hans Christian Ørsted, improved upon by William Sturgeon and Joseph Henry in later years. We do not feel the presence of a magnetic field in our homes because the current passing through the wires is flowing in the least efficient orientation possible to obtain a magnetic field. However, if we were to take a wire and coil it in a spiral manner and pass a current through this wire, it will exhibit magnetism. The application of current to produce a magnetic field is called electromagnetism and a mechanism or apparatus which converts electrical energy to magnetic energy is called an electromagnet.

2. Electromagnets

An electromagnet is a practical application of the above discussed property of charged electrons in motion. An electromagnet involves a coiled wire of any material that can conduct electricity freely, in the shape of a spiral. Due to this particular shape and orientation, the magnetic field generated by each coil individually adds up to produce a comparatively strong magnetic field.

Traditional permanent magnets are pieces of Iron, Nickel or Cobalt that have been magnetized by physical action of a previously magnetized material (essentially, a magnet). This physical action can include being in the presence of a strong magnet, or continuous rubbing action with a magnet.

3. Advantages

In a standard magnet, we obtain a magnetic field which is of a constant value and cannot be altered unless we diminish its magnetic field with physical means such as deformation, melting or strongly magnetizing it in the opposite polarity. We cannot easily increase its magnetic field intensity either. Electromagnets overcome these difficulties. If we provide more or less current to the electromagnet, the magnetic field consequently produced also has its intensity increased or decreased.

Another technical difficulty that the electromagnet overcomes is the direction of magnetic field. Magnetic field is a vector quantity i.e. it has a direction and subsequent magnitude. The magnitude can be varied as discussed above. The direction of the magnetic field cannot be changed in a permanent non-electric magnet, but in an electromagnet, we can reverse the direction of magnetic field by connecting the power supply in the opposite direction as before, to the electromagnet. Yet another difficulty that the electromagnet overcomes is the difficulty faced by a permanent non-electric magnet. A standard permanent magnet can only be made out of materials that can themselves be magnetized. This however is not the case with electromagnets, because the magnetic field is produced by the action of moving electrons in the wire. This means that electromagnets can have any metal as their core, and still operate as a magnet (provided there are multiple turns of the conducting wire, and it is carrying current)

4. Diagrams

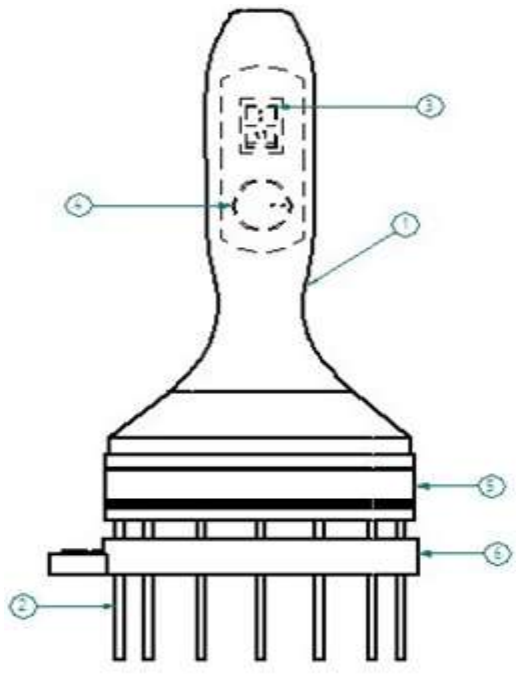

Figure 1

With reference to the above figure 1, we define the following elements of the brush:

1) Handle of the brush
   This component enables the worker to properly grip brush and use it as per convenience. It is made of thermoplast plastic.
2) Bristles
   This component is the part of the brush that gets magnetised and attracts the ferrous chips. It is made out of soft iron.
3) Switch
   This acts as the component that lets current flow in the circuit when required and blocks the current when not.
4) Regulator
   This is the component that alters the amount of magnetic field in the brush, by altering the amount of current that flows in the circuit. Regulators are components that can be set to multiple levels of resistances, thus changing the amount of current in the circuit.
5) Core housing
   This part of the brush contains the soft iron cores and their wiring.
6) Separator
   The separator is a plate of thermoplast plastic. When the chips have been picked up by the magnetised brush, they will still tend to stick to the soft iron bristles after demagnetisation due to temporary magnetism. To remove these leftover chips, we use the separator. The separator is essentially a plate with holes, such that it fits over the bristles and pushes anything that is not the profile of the bristles cross-section.

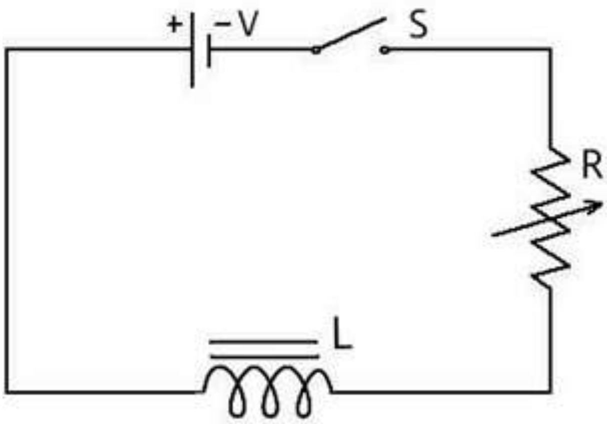

Figure 2

With reference to the above figure 2, we define the following various elements of the circuitry concerning the connections of the brush:

1) Voltage supply V
   This component supplies the voltage across the circuit to generate a current, which powers the entire brush. We use a 3 volts cell-battery setup.
2) Copper wiring
   We make use of copper wire which is enamelled, such that there is no undesirable passage of current between the curved surfaces of the wire. The wire we use for the brush is of 0.5 millimeters diameter. The copper wire connects all the main components of the brush as seen in figure 2, depicted by the line connecting all the major components in figure 2. Additionally, most of the length of the copper wire is wound around the two soft iron cores, to generate electromagnetism. This electromagnetism is governed by laws as given in later sections of this paper.
3) Switch S
   The switch governs the passage of current in the circuit. If the switch is in the ON position, current flows in the circuit, and if the switch is in the OFF position, then there is no current in the circuit. We use a standard Single Pole Single Throw switch.
4) Variable Resistor R
   The variable resistance is the method to control the amount of current flowing in the circuit. The amount of current flowing in the circuit also flows in the turns of wire around the soft iron core, for the purpose of magnetisation. If the value of variable resistance has been set to a low value, then the amount of current in the circuit will be high, and the subsequent magnetic field generated will be large in intensity as well. If the value of variable resistance is high, then the current flowing in the circuit will be low, and the subsequent magnetic field produced will of a relatively lower intensity. We use a variable resistance whose range of resistance varies from 0 to 100 ohms.
5) Soft Iron Core L
   The Soft Iron Core is a major part of the brush. Susceptibility of a material describes the materials tendency to become magnetic due to the application of an external magnetic field. Retentivity of a material describes its ability to retain or lose its magnetism when the cause of its magnetisation has been removed. Soft iron is a material that has high susceptibility and low retentivity. This means that soft iron gets magnetised quickly in an external magnetic field, but upon removal of that field, it loses the magnetic properties it displayed when in the presence of the external magnetic field. These properties indicate that soft iron is a strong temporary magnet, which makes it the ideal material to be used in the brush, since the brush requires a strong magnetic field, and requires that this magnetic field disappear upon removal of the power supply. We use a core in the electromagnet because due to the coils of current in the magnet, the core also gets magnetised, thus enhancing the magnetic field strength of the electromagnet.

5. Construction and Working

The main elements of the magnetic brush circuit are:

- Soft iron core
- Copper wire
- Switch
- Variable Resistive regulator
- Separating plate
- Bristles
- Power Supply

We connect a 1.5 Volts DC power Supply to the simple 2-way switch. This is connected to a variable resistive regulator which has resistance ranging from 0 to 100 ohms, in series. There are 2 cylindrical soft iron cores, of radius 1.25cm and height 2.5cm, and are kept side by side with their axes of rotation parallel to each other. The copper wire from the variable resistance regulator is wound around these cores separately, 50 turns per core for a total of 200 turns (both cores, twice wound). The wire in then connected back to the power supply. The wire used for this purpose is of diameter 0.5mm and length approximately 16m.

The steps of operations are as follows:
1) The switch is changed to 'ON' position. Due to this, the circuit is closed and current passes through the coil of wire, thus creating a magnetic field.
2) The regulator (variable resistance) can then be used to alter the amount of current being supplied to the coil of wire, thus varying the intensity of the magnetic field accordingly.
3) The magnetized brush is then brought sufficiently close to the ferrous particles on the machine to be rid of the ferrous particles. Due to the field generated by the brush, the ferrous particles get attracted to the brush, leaving the surface of the machine clean.
4) Once all the particles have been collected on the brush, the brush is taken to the waste metal stock and is switched off, thus becoming demagnetized. When this happens, the ferrous particles fall off the brush and into the waste metal stock.
5) In case there are still some metal particles stuck to the brush, we make use of the separator plate to push any remaining particles off the brush and into the waste metal stock.

6. Equations

Given below are the equations used and the corresponding calculations associated with them.

Ampere's Law:

$$B = u_0 NI/L_1$$

Where B is the magnetic field produced (Tesla)
I is the current in the coil (Amperes)
u_0 is a constant, called permeability of free space and value $4\pi*10^{-7}$ (Henry per meter)
N is the Number of turns on the Soft iron core
$L_1$is Length of the Soft iron core (meters)

Lorentz's Force Law:

$$F=BIL_2$$

Where
B is magnetic field (Tesla)
F is the magnetic force (push or pull) exerted by a magnet on ferrous chips (Newtons)
I is the current in the coil (Amperes)
L_2 is the distance of the magnet from the ferrous chips (meters)

Resistance equation:

$$R= \rho L_3/A$$

Where
R is the resistance of the wire (Ohms)
ρ is the resistivity of the wire (Ohm meter)
L_3 is the length of the wire (meters)
A is the cross-sectional area of the wire, calculated as A= πr^2, where r is the radius of the wire in meters (meter square)

Ohm's Law:

$$V=IR$$

Where
V is the voltage (volts)
I is the current (amperes)
R is the resistance (ohms)

Newton's Second Law of Motion for weight, and density formula:

$$\rho=M/V$$

and

$$W=Mg$$

Where
ρ is the density (kg/m^3)
M is the mass (kg)
V is the volume (m^3)
W is the weight (Kg-f or Newton)
g is the acceleration due to gravity (m/s^2)

7. Calculations

We first make a few assumptions and approximations about the chips formed during machining operations. These are:
- The average chip thickness is about 0.5mm
- The average chip width is about 1mm
- The average chip length is about 10mm
- The chips are made of mild steel, with a density of 7850 kg/m^3
- Most number of chips picked up per pass is 20
- Average distance between brush and chip is 10cm (value of L_2)
- Thickness of copper wire (which is being used for winding, 2*r) is 0.5mm
- Length of soft iron core is 2.5cm (value of L_1)

1) Length of the copper wire is calculated as,
Perimeter of the iron core is

$$p= 2*\pi*r$$

or $p= 2*\pi*1.25*10^{-2}$
or **p= 0.0785 meters**
Then, total amount of wire equals

$$L_3= p*N$$
$$L_3= 0.0785*200$$

or **L_3= 15.707 meters**
We will round off this value to **16 meters** to account for the additional wiring for making the circuit connections.

2) Resistivity of the copper is

$$\rho=1.7*10^{-8} \text{ ohm meter}$$

From resistance formula,

$$R= \rho L_3/A$$
$$\text{Where } A= \pi r^2$$
$$A= \pi*(0.25*10^{-3})^2= \mathbf{1.963*10^{-7}\ m^2}$$

Therefore $R=(1.7*10^{-8}*16)/1.963*10^{-7}$

$$\mathbf{R=1.3856\ ohms}$$

3) Now, the volume of each chip is

$$1mm*0.5mm*10mm$$

$=5*10^{-9}\ m^3$
Then, mass of each chip is given by density formula,

$$5*10^{-9}*7850= \mathbf{3.925*10^{-5}\ kg}$$

Then, weight of each chip is given by Newton's second law of motion,

$$3.925*10^{-5}*9.8065=\mathbf{3.849*10^{-4}\ N}$$

For 20 chips, the total weight to be lifted is

$$3.849*10^{-4}*20=\mathbf{7.698*10^{-3}\ N}$$

4) We know that $F=BIL_2$ and $B= u_0NI/L_1$
Equating B in both, we get

$$\mathbf{F= (u_0NI*IL_2)/L_1} \ ...(1)$$

5) Thickness of copper wire (which is being used for windings) is 0.5mm. Thus, along the length of the soft iron core, we can accommodate

$$(2.5*10^{-2})/(0.5*10^{-3})=\mathbf{50\ turns}$$

We use 2 cores, and both cores can be wrapped with two sets of turns. Therefore, total number of turns is

$$50*2*2=\mathbf{200\ turns}$$

6) Therefore, making use of equation (1) and all the calculated and known values,

$$7.698*10^{-3}=(4\pi*10^{-7}*200*I^2*10*10^{-2})/(2.5*10^{-2})$$

or $I^2=(7.698*10^{-3}*2.5*10^{-2})/(4\pi*10^{-7}*200*10*10^{-2})$
or $I^2=7.65$
or **I=2.767 amperes**

This value of current is the highest amount of current that is needed in the apparatus, because we have carried out the above calculations for the assumed value of most number of chips. When the cleaning process required is less, the number of chips will be lesser, and thus magnetic field required to life them will be lesser as well. This means the current supplied is also lesser, which indicates a need for a resistance of higher value than the resistance we used for maximum number of chips.

7) Voltage Supplied= 3V
Maximum current= 2.767 Amperes

Thus, from Ohm's Law,

$$V=IR$$

or R=V/I
therefore R=3/2.767

=**1.08 Ohms**

This is the least amount of resistance the circuits needs to produce the required amperage of 2.767 amperes. Thus, the circuit must have a resistance of 1.08 ohms to produce maximum amount of magnetic field. The variable resistance we use must have least resistance of 0 ohms and must increase in resistance.

8. Conclusion

In conclusion, it can be said that the magnetic brush that has been developed will be very effective in small time machine shops, where cleaning of metal chips is generally very tedious. The entire process of cleaning becomes much easier when the brush is used, due to its magnetic effect on the ferrous chips produced in small time machine shops.

9. Acknowledgment

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References

[1] Sturgeon, W. (1825). "Improved Electro Magnetic Apparatus". Trans. Royal Society of Arts, Manufactures, & Commerce. London. 43: 37–52. *cited in* Miller, T.J.E (2001). *Electronic Control of Switched Reluctance Machines*. Newnes. p. 7. *ISBN 0-7506-5073-7*.
[2] http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/curloo.html
[3] https://www.pa.msu.edu/courses/2000fall/PHY232/lectures/ampereslaw/solenoid.html
[4] http://science.howstuffworks.com/electromagnet.htm
[5] http://resources.schoolscience.co.uk/cda/16plus/copelech2pg1.html