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Design and Development of Magnetic Separator for foundry

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Abstract- **casting industry is one of the large contributors in India's industrial sector. Sand casting is one of the important type of casting processes. The major raw material in casting industry in cast iron or cast steel which contains pure iron along with other alloying materials like carbon, manganese, magnesium etc. In the sand casting process, the molten metal is poured into the sand mould and after solidification that mould is broken and part is taken out. The sand is then reused after filtering and it contains the small particles of the ferrous particles. This paper focuses on design and development of a machine which can efficiently separates these ferrous particles from sand, thus saving material cost of the Industry. This machine can separate large as well as mini particles from sand by using basic property of ferrous material, i.e. magnetism.**

Index terms- **Casting, Ferrous Particles, Foundry sand, Magnetic Drum, Separator**

I.INTRODUCTION

Casting is a manufacturing process in which a liquid material is usually poured into a mould, which contains a hollow cavity of a desired shape and then allowed to solidify. The solidified part is called casting, which is ejected or broken out of the mold to complete the process. Sand casting is one of the mostly used casting process in which the moulds are made up of sand.

While pouring the molten metal in the mould and while breaking the mould, the metal particles get trapped in the sand. These ferrous particles are price worthy and can be reused for casting after remelting. Large particles can be removed manually but it is difficult to remove small particles and they are many in numbers so picking them manually from sand is difficult work. These small particles of ferrous material must be removed otherwise wasted along with coarse sand.

The case study about the percent of ferrous material in coarse sand is done at M/s Bharat Auto Industries, Kolhapur, India by using manual method and results of the tests are tabulated below-

Table No. I- Testing the % of ferrous material in mixture

Test No.	Weight of Mixture (Kg)	Weight of Sand (Kg)	Weight of ferrous material (Kg)	% of ferrous material in mixture
1	5	2.7	2.3	46
2	5	2.3	2.7	54
3	5	2.9	2.1	42
4	5	2.4	2.6	52
5	5	2.9	2.1	42
6	5	2.5	2.5	58
7	5	2.1	2.9	58
8	5	3.2	1.8	36
9	5	2.8	2.2	44
10	5	2.6	2.4	48

From above table we can understand that in the filtered coarse sand which cannot be used for molding and scraped, about 50% is the ferrous particles by weight. The machine described in this paper eliminates the manual work and separates all major and minor particles from the sand.

II. LITERATURE REVIEW

Arnold Peterson, Brad Deuerling, Adam Love and Jason Tift patented Material separation and transfer conveyor. It is a sorting conveyor for separating ferromagnetic materials from a stream of material includes a conveyor having an input end and output end. The sorting conveyor also includes a conveyor drive system for driving the conveyor component to move the stream of materials from the input end to the output end for discharge. A magnetic separator is located adjacent the conveyor component and adapted to divert ferromagnetic material from stream of material. [1]

Leonard Williams and James R. Steele patented a magnetic separator comprising a vibratory conveyor for vibratory flowing nonferrous articles and articles containing ferrous material within the magnetic field of a transverse extending magnet to magnetically capture the articles containing ferrous material while allowing others to flow there past.[2]

The drum separator consists of a nonmagnetic drum fitted with 3%- 6% magnets composed of ceramic or rear earth magnetic alloys in the inner periphery. The drum rotates at uniform motion over a moving stream of preferably wet feed. The ferromagnetic and paramagnetic minerals are picked up by the rotating magnets and pinned to the outer surface of the drum. As the drum moves up, the concentrate is compressed, dewatered and discharged leaving gangue in the trailing compartment. Drum rotation can be clockwise or anticlockwise and the collection of concentrate is designed accordingly. A drum separator produces extremely clean magnetic concentrate. It is suitable for the recovery of precious material from beach sand [3]

III. METHODOLOGY

There are several methods available for separating the ferrous particles from sand. These methods have their own advantages and disadvantages. Some of the popular methods use electromagnet for the process. In some applications, a conveyor with magnetic pulley or overhead magnetic separator is used. These methods are having huge capacity but also require more capital cost. Keeping the small foundries in focus, these methods are more costly and require some infrastructure changes also.

It is desirable to develop a small scale separator for small scale foundries, which is flexible with place and also do not require much cost for purchasing and operating.

For this purpose a permanent magnetic drum based separator is a perfect machine, which include a magnetic drum which having a magnetic field on its half circumference. That drum will rotate and mixture of sand and ferrous metal will be poured onto it through the hopper. Material flow rate will be adjusted by using vibratory feeder. As the mixture will come in contact with the rotating drum, ferrous material will stick to the drum and will be carried away and thrown to other side of the drum whereas the sand will get down directly.

This machine will be simple, robust, less costly and flexible. Also it will not include many electronic or electrical parts and rotating part so it's running and maintenance cost will be low. This machine is suitable for small scale foundries.

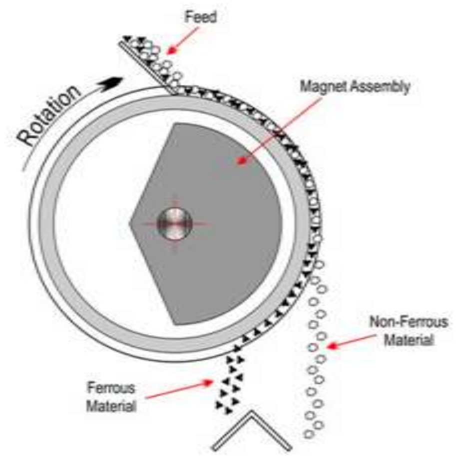


Fig. I. - Principle of operation of Magnetic separator using magnetic drum. [4]

IV. DESIGN OF MACHINE ELEMENT

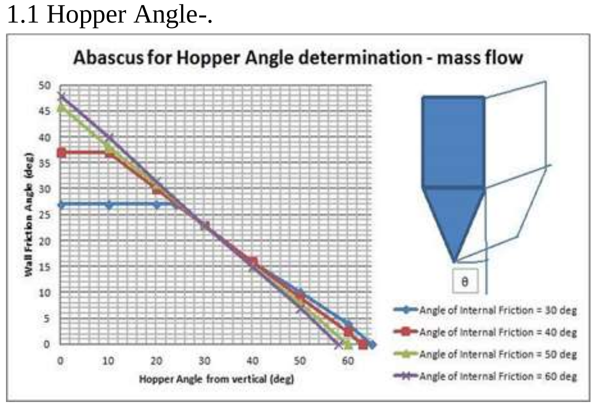
Designing the machine considering required capacity of 2 Tones/ Hr.

1. Design of Hoppper-

Available Data-

- Material Name- Sand and ferrous particles mixture
- Wall friction angle with M.S. = 27.5°
- Internal Friction Angle = 41°
- Type of Hopper and outlet = Wedge shaped hopper with rectangular outlet.
- Density of material= 1280 kg/m3

1.1 Hopper Angle-.



From above graph, calculated hopper angle is 27°
For manufacturing purpose, Angle of Hopper is 30°

1.2 Size of Hopper outlet [5]-
The material size is not uniform, as it carries lump and non-uniformly sized ferrous particles, so the design is based on the maximum lump size.
As per IS 9178-3 (Design of steel bins for storage of bulk material)

- Maximum Size of Lump/ Particle-

Maximum Area of Lump considered is 25mm x 25mm
Calculating hydraulic diameter using this area, $d = \frac{4a}{p}$
Where a= Area of lump
p= Perimeter of lump

$$d = \frac{4 \times [25 \times 25]}{2[25 + 25]} \tag{1}$$

Hence, d= 25mm

- Width of Outlet (b) = 3*d= 3*25= 75mm

Hence selected Width of outlet is 80mm

- Length of Outlet (l)= 6*b = 6*80 = 480mm

Hence selected Length of outlet is 500mm

1.3 Discharge through hopper-
Using Beverloo Equation[5] for hopper discharge for coarse, non uniform particles

$$W = C.Pb.\sqrt{g}.(do - k.dp)^{5/2} \tag{2}$$

Where,
W= Discharge rate in kg/s
C= Empirical discharge coefficient= 0.58
Pb= Density of material= 1280kg/m^3
g= Acceleration due to gravity= 9.81m/s^2
do=Outlet diameter = $\frac{4a}{p} = \frac{4 \times (80 \times 500)}{2(80+500)} = 137.93\text{mm}$
dp= Particle diameter = 25mm
k= Empirical shape coefficient= 2.9 for sand
Upon putting the values in the above equation,
W= 2.5kg/sec
It is found that the value obtained from equation is generally 1/3 to ½ of the calculated.
So, Actual flow rate expected is 0.8kg/sec.

2. Design of Vibrating Feeder-
2.1 Feeder Mechanism [6]-
The reciprocating motion is provided by the eccentric cam, which is driven by the motor with belt and pulley mechanism.

- Eccentricity= 5mm
- Stroke= 10mm
- Mass at instant (m) = 1 kg
- Stiffness of Steel strip= 250N/m
- No. of strips = 4

When the vibrations are not provided, the sand does not move down the tray unless it fills fully. When the vibrations are provided, the sand moves down in series of small hops. The rate of flow is depend upon the frequency of vibrations
By trial and error method, the speed of shaft selected is= 160 RPM

2.2 Frequency -

$$\omega = \frac{2\pi n}{60} = \frac{2\pi \times 160}{60} = 16.75\ \text{rad/sec} \tag{3}$$

2.3 Power required-
Four steel strips with stiffness of 250N/m are arranged in parallel way, so equivalent spring stiffness will be [7]
Ke= 1000 N/m
We Know,

$$F = K \times \delta = 1000 \times 0.01 = 10\ \text{N} \tag{4}$$

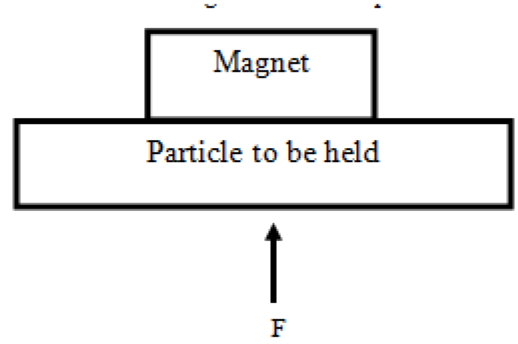
Considering Cam radius (r)= 0.1m
Torque required =

$$T = F \times r = 10 \times 0.01 = 1\ \text{N} - \text{m} \tag{5}$$

Power Required (P) =

$$P = n \times T/5252 = 0.03\text{HP} \tag{6}$$

3. Calculation of Magnetic Flux
For proper selection of the magnetic drum, the calculation of magnetic flux is required



Magnetic holding force, which is given by,

$$F = \frac{Dm^2 \times Am}{8\pi \times 10^{-7}} \tag{7}$$

Where,
F= Holding force for given mass (Considering mass=1kg, F= 9.81N)

Dm= Magnetic flux in Tesla
Am= Area of contact of particle with magnet= 0.025*0.025= $6.25*10^{-4}$
Putting above values in equation,
Dm= 0.19 Tesla= 2000 Gauss
Required Flux= 0.2 Tesla

4. Selection of Magnetic Drum-
Standard magnetic drum is selected with following specification-
Diameter=450 mm
Length= 500 mm
Speed= 30-50 RPM
Capacity= 2 TPH
Weight= 300 kg

5. Design of Motor [8]
We know, the torque required to rotate the drum is given by,

$$T = I.\alpha \tag{8}$$

Where,
T= Torque in N/m
I= Mass moment of Inertia (kg/m^2)
α= Acceleration (rad/s^2)
m= Mass of drum (kg)
r= Radius of drum (m)

$$I = \frac{mr^2}{2} \tag{9}$$

As per table,
Speed of drum considered is n= 40RPM
m= 300kg
d= 450mm= 0.45m
r= 225mm= 0.225m
So, I= 7.60 kg/m^2

$$\omega f = \frac{2\pi N}{60} \tag{10}$$

wf= 4.71 rad/s

$$\propto = \frac{wf - wi}{t} \tag{11}$$

Assuming wi=0
α= 4.71 rad/s^2
T= 35.81 N-m
Power required for driving the drum
Power in HP= n.T/5252

$$P = \frac{n \times T}{5252} = \frac{40 \times 35.81}{5252} \tag{12}$$

Power = 0.30 HP
Total Power = Power required to drive the drum + Power required for vibratory motion
P = 0.30+0.03 = 0.33 HP
Considering Factor of safety=2
Power= 0.66 HP
Motor Selected= 1HP= 0.75KW

6. Selection of Gearbox [9]
Gearbox is required to reduce the speed of motor as per requirement
Speed reduction is required at 2 applications; i.e. for rotating drum and for vibratory feeder.

- Speed of Motor (N) = 1440 RPM
- Speed of Drum (n) = 40 RPM
- Speed of Vibrator's shaft = 160 RPM
- Speed reduction ratio for drum = 1440/ 40 = 36
- Speed reduction ratio for Vibrator's shaft = 1440/160 = 9

As the reduction is required to be done for 2 applications as well as the gearbox was unable to connect directly to drum; by considering that factor, the gearbox speed reduction ratio selected is 30:1
Gearbox output speed= 1440/30= 48 RPM.

Table No.II- Summary of Design and Parts

Sr.No	Part Name	Specification	Qty.
1	Hopper	Angle- 30° Width-80mm Length-500mm	1
2	Vibrating feeder	Tray length-350mm Tray width -450mm Inclination- 25° Frequency-16.75 rad/s	1
3	Shaft[10]	Material-30C8 O.D.-25mm	1
4	Bearings[10]	Manufacturer-SKF Bearing No.-6205	2
5	Magnetic Drum	Diameter-450mm Length-500mm Flux Density-0.2 Tesla	1
6	Motor	Make- Techno Drive Power-1 HP Speed-1440 RPM	1
7	Gearbox	Ratio-30:1 Output Speed- 48RPM	1
8	Belt (Pulley to drum)	Type-V-Belt Cross Section-A type	1
9	Belt (Pulley to vibrator)	Type-V-Belt Cross Section- A type	1
10	L- Section Bar	Cross Section-45*45mm Thickness- 5mm	-

V. ASSEMBLY DRAWING

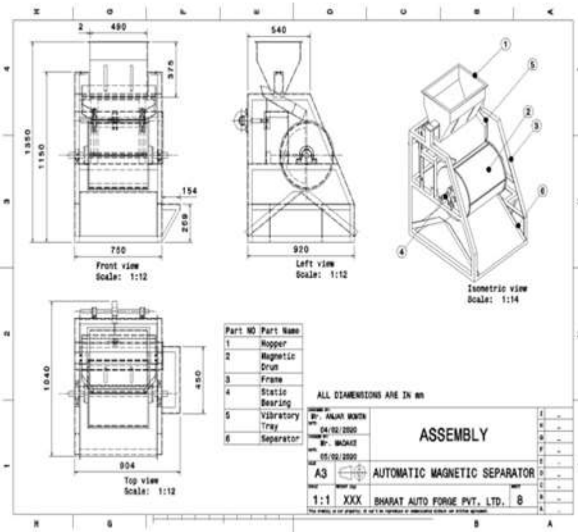


Fig. III- Assembly Diagram

Fig. IV- Photo of Assembly

VI. TESTING AND RESULTS

After completing the assembly, testing is done with the samples of mixture of coarse sand and ferrous particles and results are tabulated below-

Table No.III-Testing results of the machine

Sr.No.	Weight of Mixture (Kg)	Weight of Metal (Kg)	Metal Separated Manually (Kg)	Metal separated by Machine (Kg)	% Increase in separation
1	5	2.3	1.8	2.25	20
2	5	2.7	2.1	2.65	21
3	5	2.1	1.5	2.08	28
4	5	2.6	2.0	2.58	22
5	5	2.1	1.6	2.05	22
6	5	2.5	1.9	2.47	23
7	5	2.9	2.2	2.85	23
8	5	1.8	1.4	1.78	21
9	5	2.2	1.8	2.18	17
10	5	2.4	2.0	2.37	16

Results-

1. As per test, almost 98% of ferrous particles separate from the sand by using this machine
2. The particles separated by using the machine are almost 20% more than that of separated manually
3. No human work except pouring mixture into the hopper

VI. CONCLUSION

Design and development of magnetic separator is successfully carried out and all required objectives are fulfilled. Compensating for the shortcomings of the other methods, this work is more feasible, efficient and robust.

Objectives accomplished-

1. The main purpose of this work is to remove all ferrous particles from sand without any manual work.
2. All small as well as mini ferrous particles are removed by using this machine.
3. Develop a machine which is suitable for small scale foundry industries with less investment.
4. This machine is simple and robust and also do not require much running cost.
5. This machine requires less maintenance and also parts of the machine are easily available.

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