Design Optimization and Installation of Induction Furnace Over Oil Fired Furnace

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Abstract—By installing the induction furnace in place oil fired furnace the productivity increased and production cost is decreased. Due to high cost saving its payback period is very short. Optimization of induction furnace is done carefully in area of billet feeding. The stress given on to minimize the human labor and to gain more automation. While designing various components economy, compactness, cost reduction and weight reduction are kept in mind. Cost estimation of each component done suitably. In the end cost analysis done between oil fired and induction furnaces in order to observe differences obtained in production cost and productivity.


1. INTRODUCTION

The induction furnaces are more beneficial than the oil fired furnaces. So is necessary to design, optimize and install the induction furnace over the oil fired furnace in order to gain more efficiency. In this paper we have designed automatic billet feeder system for the optimization of the induction furnace. By using the automatic billet feeder system the quantity of human workers can be minimized also it contributes towards to increased productivity with time savings. The automation can be increased by adapting the automatic billet system.

2. PROBLEM STATEMENTS

Following are the problems in oil fired furnace as compared to the induction furnace:
1. High initial startup time.
2. More cycle time and less productivity.
3. Temperature cannot control precisely.
4. Effects on material properties.
5. Non-uniform flame distribution.
6. Oxidation of metal, scale formation.

To overcome all these problems the induction furnace should be used in place of oil fired furnaces. They should be designed, optimized and installed properly in order to reduce production cost and increase productivity.

3. DESIGN OF VARIOUS COMPONENTS

Density ($\rho$) =7850 kg/m$^3$

3.1 Design of Drum:-

Material C45

$\rho$ (Density) =7850 kg/m$^3$

$S_{bt}$ (Tensile Strength) =600 N/mm$^2$

$S_{yt}$ (Yield Strength) = 380 N/mm$^2$

3.1.1 Load Calculations

1. Mass of cylinder:-

$L$ (Length of sheet) =1000 mm
$h$ (Thickness of sheet) =5 mm

$V_1$ = Volume of Cylinder

$m_1$ = Mass of cylinder

$m_1$ =79.16 kg

2. Mass of pipes (24 pipes):-

Weight of pipe/m =8.10 kg
Total weight of pipe ($m_2$) =8.10×24
$m_2$ =194.4 kg

3. Mass of plates (forward and backward):-

$V_3$ = Volume of Plates

$m_3$ = Mass of plates

$m_3$ =17.526 kg

4. Mass of drum shaft:-

$V_4$ = Volume of Drum shaft

$m_4$ = Mass of drum shaft

$m_4$ =54.25 kg

5. Mass of ring gear (approximate):-

$V_5$ = Volume of Ring gear

$m_5$ = Mass of ring gear

$m_5$ =34.62 kg

6. Load:-

Mass of 1 billet=3 kg
Total no of billets can be loaded=144
Mass of 144 billets=144×3
$m_6$ =432 kg

7. Total mass of system in loaded condition or working load:-

$m=m_1+m_2+m_3+m_4+m_5+m_6$

=79.16+194.4+17.526+54.25+34.62+432

BHN (Brinell hardness number) =145

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m=830 kg
As, Weight (W) =mg
=830×9.81
W=8136.7 N

8. Torque requirement:-
T (Torque) =W×r
Where w =load acting on system.
r = pitch circle radius of ring gear.
T =8136.7×0.321
=2611.88 N-m

3.2 Design of Cover Plate:-
Material C45
ρ =7850 kg/ m³
Sut=600 N/ mm²
Syt=380 N/ mm²
B.H.N. =145
Dimensions-
PCR (Pitch circle radius) =277.721 mm
OD (Outer diameter) =642mm
Thickness of plate=10mm
Internal diameter=60mm
Diameter of slots=75mm
No. of slot = 1

3.3 Design of Drum shaft:-
d (Outer diameter of the shaft)=642mm
dg (Diameter of gear)=720mm
G (gear ratio) =6
L (Length of the shaft) =1000 mm
W (Total weight) =8×10³ N
V (Speed) =6.33m/s
τs (Shear stress)=50 N/ mm²
σt (Tensile stress)=115 N/ mm²
k0 (Load correction factor)=2
k0 (Theoretical stress concentration factor)=1.5
ϕ=20°
Ft (Tangential force) =7255 N
Fr (Radial force) =2640.60 N
F (Resultant force) =720060 N

M (Maximum bending moment on shaft) =1158.81 N-mm
Te (Equivalent torque) =4551.16×10³ N-mm
Me (Equivalent bending moment) =3434.39×10³ N-mm

By maximum shear stress theory
τmax=16Τe/πd³
50=16×4551.16×10³/πd³
d=77.39mm

By maximum principal stress theory.
σmax=32Me/πd³
115=32×3434.39×10³/πd³
d=61.55mm

From above equations greater value is selected.
d=77.39mm
Take d=80mm
Material selection.
Alloy steel 50Cr1V23
Sut=190-240 kgf/ mm²
Syt=180 kgf/ mm²
BHN=500-580

3.4 Design of Ring Gear and Drum Pinion
T (Torque) =2611.88 N-m
N=100rpm
M (Module) =6mm
Zp (Number of teeth on pinion) =20
Zg (Number of teeth on gear) =120
P (Power) =7500 W
Nf=1.5
ϕ (Pressure angle) =20°
e (Tooth error)=15×10⁻³mm
c (Dynamic factor)=11400e
Material selected C45.
Sut=600 N/ mm²
Syt=380 N/ mm²
BHN=460

Effective load
V (Speed) =0.628 m/ s
Ft (Tangential load) =P/ V =11936.62 N
C=11400e =11400×15×10³
Beam strength.
As both gear and pinion are made of some material, pinion is weaker than gear in bending. Hence it is necessary to calculate the beam strength of pinion teeth.

\[ Y_p = 0.484 - (2.87 / Z_p) \]

\[ Y_p = 0.3405 \]

\[ \sigma_b = \frac{S_{ut}}{3} = \frac{600}{3} = 200 \text{ N/mm}^2 \]

\[ F_b = \sigma_b \times b \times m \times y_p = 200 \times 60 \times 6 \times 0.3405 \]

\[ F_b = 24516 \text{ N} \]

The factor of safety available against bending failure is given by

\[ N_f = \frac{F_b}{F_{eff}} = \frac{24516}{13741.658} = 1.784 \]

Since available factor of safety is greater than required therefore design is safe against bending failure. Thus material selected C45 \((S_{ut} = 600 \text{ N/mm}^2 \text{ BHN} = 460)\) is suitable for design.

Dimension of gear pair.
\( m \) (Module) = 6mm

\( Z_p \) (Number of teeth on pinion) = 20

\( Z_g \) (Number of teeth on gear) = 120

\( b \) (Face width) = 10 \times m = 10 \times 6 = 60mm

\( d_p \) (Diameter of pinion) = \( m \times Z_p \times 6 \times 20 = 120 \text{mm} \)

\( d_g \) (Diameter of gear) = \( m \times Z_g \times 6 \times 120 = 720 \text{mm} \)

\( a \) (Centre distance) = \( (d_p + d_g) / 2 = 420 \text{mm} \)

\( h_a \) (Addendum) = 6mm

\( h_r \) (Dedendum) = 1.25 \times m = 7.5mm

3.5 Design of Pinion Shaft
Material C45

\[ S_{ut} = 600 \text{ N/mm}^2 \]

\[ S_{yt} = 600 \text{ N/mm}^2 \]

\[ K_b = 1.5, K_t = 1, N_f = 1.5 \]

\[ \sigma_{all} = \frac{S_{yt}}{N_f} = 400 \text{ N/mm}^2 \]

\[ \sigma_{all} = 400 \text{ N/mm}^2 \]

\[ \sigma_{all} = 0.55 \times S_{ut} / N_f = 200 \text{ N/mm}^2 \]

Maximum bending of shaft.
\[ M = F_L / 4 = 8188.95 \times 380 / 4 \]

\[ M = 2305.08 \times 10^3 \text{ N-mm} \]

Equivalent torque on shaft.
\[ T_e = 3054.20 \times 10^3 \text{ N-mm} \]

Design of shaft by Max-shear stress theory.
\[ \tau_{max} = \frac{16T_e}{\pi d^3} \]

\[ 200 = 16 \times 3054.20 \times 10^3 / (\pi d^3) \]

\[ d = 43.26 \text{mm} \]

Design of shaft by maximum principle stress theory.
\[ \sigma_c = 32M_e / (\pi d^3) \]

\[ 400 = 32 \times 2305.08 \times 10^3 / (\pi d^3) \]

\[ d = 30.06 \text{mm} \]

Taking larger value from above two equations.
\[ d = 45 \text{mm} \]
3.6 Design of Square Key:-

As, d=45mm

Nf=1.5

Material C45

Sy=600N/ mm²

Sut=600N/ mm²

W=h=d/4=45/4

=11.25

Taking w=h=12mm

\[\tau_{al} = 0.5 \times \frac{S_{ut}}{N_f}\]

\[= (0.5 \times 600) / 1.5 \]

=200 N/ mm²

\[\sigma_c = \frac{S_{yt}}{N_f}\]

=400 N/ mm²

Crushing of key:-

Considering Crushing of key

L=46.735mm

Shearing of key

L=48.68mm

Taking larger of above equations.

L=48.68mm

Taking L=50mm

Dimensions of key.

w=13mm

h=13mm

l=50mm

Quantity=5(nos)

3.7 Selection of Bearings:-

1) For drum shaft

Given data, d=80mm

Load=830 kg

Weight=3727.8 N

Axial load (F_a) =3727.8 \times \sin 45° = 2396.18N

Radial load (F_r) =3727.8 \times \cos 40° = 2855.7 N

Bearing life in hours (Lh10) =8000 hrs. (from catalog based on application).

N=100rpm

Type- taper roller bearing

For taper roller bearing (from catalogue)

X=0.4

Y=0

Load factor (ka) =1.2

Equivalent dynamic load.

\[P_e = F_r \times k_a\]

=3426.8N

\[L_{10} = 48 \text{ million revolutions.} \]

C=10.946kN

From catalogue bearing available with 60mm bore diameter are:

<table>
<thead>
<tr>
<th>Bearing no.</th>
<th>Basic dynamic capacity (C), kN</th>
<th>Outer diameter (mm)</th>
<th>Width “B” (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30215</td>
<td>99</td>
<td>110</td>
<td>23.75</td>
</tr>
<tr>
<td>32212</td>
<td>125</td>
<td>110</td>
<td>29.75</td>
</tr>
<tr>
<td>30312</td>
<td>168</td>
<td>130</td>
<td>33.5</td>
</tr>
<tr>
<td>32312</td>
<td>229</td>
<td>130</td>
<td>48.5</td>
</tr>
</tbody>
</table>

Table No 1 (Bearings for drum shaft)

So, bearing no. 30215 is most economic for our application therefore bearing no. 30215 is selected.

Quantity=2(nos).

2) For Pinion Shaft

Type –taper roller bearing

Axial load (Fa) =2396.18N

Radial load (Fr) =2855.7 N

Bearing life in hrs. =8000 hrs (from catalogue based on application)

\[L_{10} = 48 \text{ million revolutions.} \]

C=10.946kN

From catalogue bearing available with 50mm bore diameter for calculated dynamic load are

<table>
<thead>
<tr>
<th>Bearing no.</th>
<th>Basic dynamic capacity (C), kN</th>
<th>Outer diameter (mm)</th>
<th>Width “B” (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30210</td>
<td>76.5</td>
<td>90</td>
<td>21.75</td>
</tr>
<tr>
<td>32210</td>
<td>82.5</td>
<td>90</td>
<td>24.75</td>
</tr>
<tr>
<td>30310</td>
<td>12.5</td>
<td>110</td>
<td>29.75</td>
</tr>
<tr>
<td>32310</td>
<td>172</td>
<td>110</td>
<td>42.25</td>
</tr>
</tbody>
</table>

Table No 2 (Bearings for pinion shaft)

Bearing no. 30210 is most economical and suitable for our application.

Therefore bearing no. 30210 is selected for system

Quantity=2(nos)

3.8 Material for Base Plate:-

Cast iron

ISI grade-GCI 20

Overseas nearest equivalent=DIN 1691/ GG22

Tensile strength=200 N/ mm² (minimum)

BHN =179-223

Bending stress=3kgf/ mm²

Pressure=10 kgf/ cm²

3.9 Slope of Drum / Inclination Angle of Drum:-

Material of pipe=Mild steel
\[ \mu = \text{static/ kinetic friction co-efficient} \]
\[ \mu = 0.61 \text{ (For mild steel)} \]
We know that.
\[ \theta = \tan (0.61) = 31.38^\circ \]
Taking \( \theta = 40^\circ \)

3.10 Specifications of Motor:-
Type-stepper motor [6].
Type code=ACS550-01-031A-2
Frame size=R2
Number of steps=24.
Power (Pn) = 7.5kW or 10 hp
Current (I) = 31 A
Electronic equipments like controller (8051) and photo sensor may be used in system for positioning purpose.

3.11 Complete Assembly:-

4 CONSTRUCTION AND WORKING
1) Mount drum assembly on frame in inclined position
2) Place small frame in front and large frame at rear
3) Mount drum assembly in such a way that ring gear comes in front (near to smaller frame).
4) Then assemble pinion and stepper motor.
5) Assembly of pinion and stepper motor should be below the drum to make system compact.
6) Mount light emitter at rear end in such a way that light beam passes through the axis of pipe when pipe is at lowest bottom position.
7) Also mount receiver in same line of action at front end.
8) Mount drum assembly on frame in inclined Working.
9) Load the drum with billets.
10) Start the machine.
11) As soon as machine starts conveyor also starts to move then billets from pipes starts to slide on conveyor automatically by gravity.
12) When last billet of pipe fall on conveyor then light beam fall on receiver.
13) When light beam fall on receiver then it sends signal to controller to rotate stepper motor by 1 step (in case of 24 step motor) i.e 15 degree.
14) After receiving signal from controller, motor rotates by 1 step (15 degree) and next billet loaded pipe comes in front of light beam and it obstruct the beam to fall on receiver till last billet of pipe falls on conveyor.
15) In this way process goes on.
16) Controller program is programmed in such a way that after receiving 24 such signals m/c will stop automatically for reloading.

5 COST ESTIMATION
It is the art of finding the cost which is likely incurred on the manufacturers of the article before its actually manufactured thus if the calculation of probable cost of an article before manufacturing the tool. It also includes predetermination of quality and quantity if material and labor required.

5.1 Aims of estimation-
1. To help in deciding the methods of manufacturing.
2. To decide about the amount of overheads.
3. It helps to decide whether and particular material should be purchased from the market or from manufacturer. Etc.

5.2 Cost estimation-
Present market rate of raw material-
- C45= 60 Rs/ kg
- Alloy steel (50Cr1V23) = 72 Rs/ kg
- Cast iron (GCI20) = 40 Rs/ kg
- Mild steel (pipe) = 60 Rs/ kg

5.3 Machine operation cost per hour: (Rs/hr)
- Lathe m/c- 60/80
- Milling m/c- 80/90
- Grinding m/c- 70/75
- Drilling m/c- 40/45
- Surface grinding-85
- Counter boring-45
- Tapping-30
- Welding-80
- Cutting-40
- Rolling-60

5.4 Raw material cost

<table>
<thead>
<tr>
<th>Sr.no</th>
<th>Name of parts</th>
<th>Kg</th>
<th>Market rate/kg</th>
<th>Total cost of parts(Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drum shaft</td>
<td>55</td>
<td>72</td>
<td>3960</td>
</tr>
<tr>
<td>2</td>
<td>Cover plate(front and end)</td>
<td>35</td>
<td>60</td>
<td>2100</td>
</tr>
<tr>
<td>3</td>
<td>Cover plate(fixed)</td>
<td>17</td>
<td>60</td>
<td>1020</td>
</tr>
<tr>
<td>4</td>
<td>Pinion shaft</td>
<td>15</td>
<td>60</td>
<td>900</td>
</tr>
<tr>
<td>5</td>
<td>Drum cylinder</td>
<td>80</td>
<td>60</td>
<td>4800</td>
</tr>
<tr>
<td>Sr. no</td>
<td>Operation</td>
<td>Time(hr)</td>
<td>Market rate/kg</td>
<td>Cost(Rs)</td>
</tr>
<tr>
<td>-------</td>
<td>---------------</td>
<td>----------</td>
<td>----------------</td>
<td>----------</td>
</tr>
<tr>
<td>1</td>
<td>Cutting</td>
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<td>40</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>Welding</td>
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<td>400</td>
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<tr>
<td>3</td>
<td>Grinding</td>
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<td></td>
<td><strong>Total cost</strong></td>
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Table No. 8

<table>
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<th>Sr. no</th>
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<th>Time(hr)</th>
<th>Market rate/kg</th>
<th>Cost(Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cutting</td>
<td>1</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>Rolling</td>
<td>1</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>Welding</td>
<td>1</td>
<td>80</td>
<td>80</td>
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<td>4</td>
<td>Grinding</td>
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<td>70</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td><strong>Total cost</strong></td>
<td></td>
<td></td>
<td><strong>250</strong></td>
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Table No. 9

<table>
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<th>Sr. no</th>
<th>Operation</th>
<th>Time(hr)</th>
<th>Market rate/kg</th>
<th>Cost(Rs)</th>
</tr>
</thead>
<tbody>
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<td>Cutting</td>
<td>1</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>Welding</td>
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<td>3</td>
<td>Grinding</td>
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<tr>
<td></td>
<td><strong>Total cost</strong></td>
<td></td>
<td></td>
<td><strong>340</strong></td>
</tr>
</tbody>
</table>

Table No. 10

5.5.9 Total machine cost:
=360+630+315+125+250+940+570+340 =3530 Rs.
Raw material cost=61,880 Rs.
Total cost=raw material cost+ machining cost
=61880+3530 =65410 Rs
Overhead charges=15% of manufacturing cost
=9811 Rs.
Indirect expenses (material handling, transportation etc)
=10% of manufacturing cost =6541 Rs.
Inspection expenses=5% of manufacturing cost

Table No. 11
6 COST ANALYSIS

Oil-fired furnace:-
Price of furnace oil-56.66/ litre
Oil consumption-125 lit/ ton (8 hr.)
Total cost per shift-125 lit×56.66=7082.5 Rs.

Induction Furnace (400kw/hr.):-
Electricity Tariff rate-8.30/ unit
Capacity-540 kg/ hr.
Power consumption per ton-770(unit) ×8.30=6391Rs. (2hr)

6.1 Result (induction over oil fired furnace)
Cost Saving per ton: 7082-6391=691(2hrs)
Cost save per shift: 691×4=2764(8hrs)
% of cost saving per shift: (2764/7082.5) ×100=40%
Productivity per shift: 4 ton (8hrs.).
Cost saved per day- 2764×2=5528 Rs.

Annual saving=20 lakhs (approximately).
Productivity increases four times as that of oil fired furnace. At the same time production cost reduces by 40% per shift.

7 CONCLUSION

We have observed that by installing the induction furnace over oil fired furnaces the problems faced in oil fired furnaces can be minimized. Due to installation of induction furnace productivity increases four times and also there is saving in production cost of 40%. Due to 40% cost saving its payback period is very short. Optimization of induction furnace is done by installing “Automatic Billet Feeder”. It replaces human labour and feed billets in furnace automatically. Its design and manufacturing process is made simple. While designing of its components economy, compactness and weight reduction are kept in mind.

8 REFERENCES