DESIGN OF HYDRAULIC LADLE TILTING DEVICE AT PIG CASTING MACHINE

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ABSTRACT-Pig iron casting is carrying out in pig casting machine. After complete production of alloy steel as per customer requirement, remaining molten pig iron is transferred to pig casting machine. To cast pig iron, ladle has to be tilt in order to pour pig iron constantly. During ladle tilting, several problems are facing such as, more effort required to tilt the ladle because more mass is concentrated at the bottom of ladle so when ladle is tilting from its top position it will not tilt properly. Since more mass is concentrated at the bottom, gear slip may occur, so chances of overflow of molten pig iron. Also initial tilting of ladle takes more time around 30 to 45 minutes and also after complete pouring lifting of ladle also takes place in the same manner as of tilting that consumes more time. In order to overcome all these problems, ladle tilting and lifting operation through hydraulic system is preferred.

Keywords-**Pig casting machine (PCM), Ladle, Hydraulic cylinder, Piston, Piston rod.**

1. INTRODUCTION

In blast furnace hot molten metal called pig iron is produced. Produced pig iron is used in steelmaking shop for the production of alloy steel based on the customer requirement. Once steel production is completed as per customer demand, remaining hot molten pig iron is transferred to pig casting machine in ladle to cast pig iron. Casted pig iron is stored and it is reused during future production of pig iron in blast furnace.

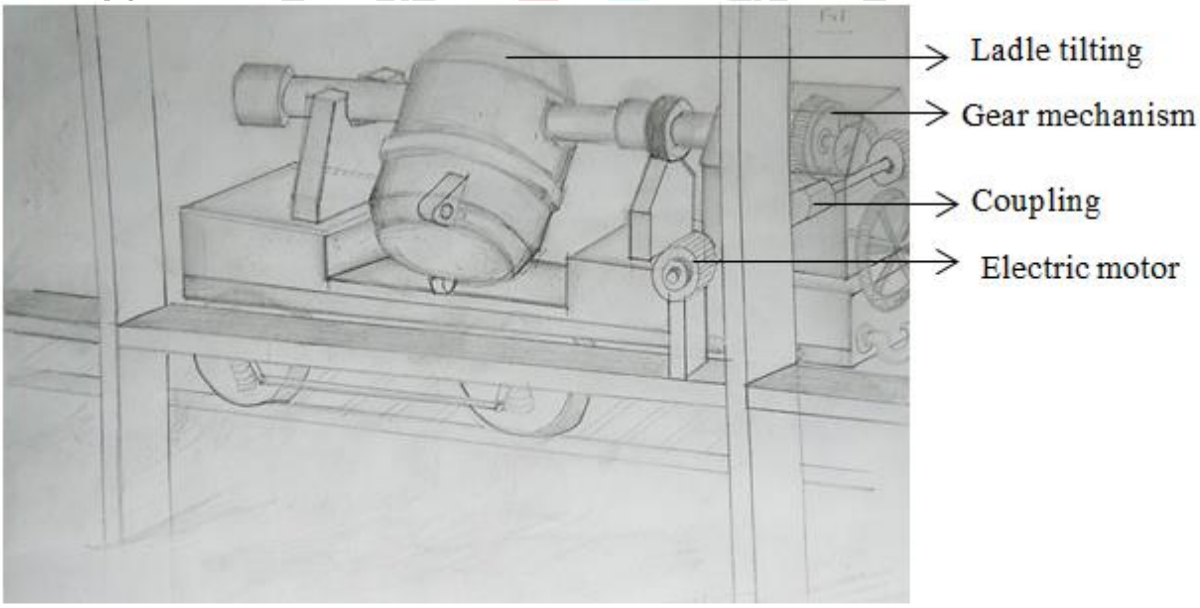

Figure 1: Ladle tilting arrangement at PCM

2. PROBLEM ANALYSIS AND SOLUTION

To cast pig iron in PCM, the remaining molten pig iron from steel making shop is used. Pig iron is carried in ladle and this ladle is tilted to pour the pig iron into the pig casting machine and after complete pouring of pig iron, ladle is lifted back to its initial position. During this operation following drawbacks are observed.

- Initial tilting of ladle up to pouring point takes around 30-45 minutes and also ladle lifting takes place in the same manner as that of tilting which consumes more time.
- Continuous tilting of ladle is not required as it needs time to pour pig iron to PCM, so controlled tilting operation becomes difficult.
- Since more mass concentrated at the bottom of ladle, gear slip may occur so chances of overflow of pig iron and also proper ladle tilting becomes difficult.
- After complete pouring of pig iron to the PCM, ladle lifting also takes place in the same manner as that of tilting so this consumes more time unnecessarily.

Solution:

To overcome all these problems hydraulic system can be replaced. In this, piston rod is linked to the ladle at its bottom position as shown in the Figure 2. Design of hydraulic system includes design of hydraulic cylinder, piston and piston rod, selection of mounting system, selection of hydraulic pump, selection of valves, selection of pipes and design of tank.

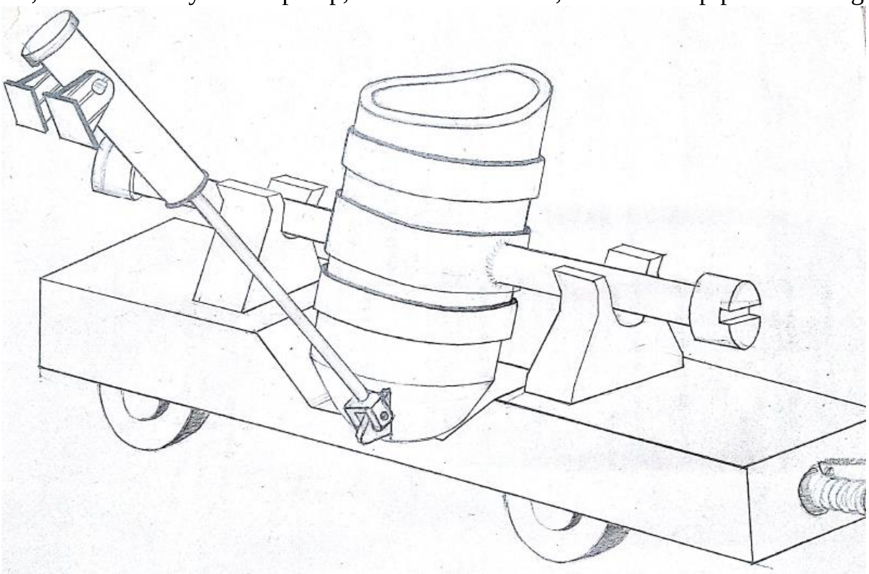

Figure 2: Hydraulic ladle tilting arrangement

3. DESIGN OF HYDRAULIC SYSTEM

Design of hydraulic system involves design of hydraulic cylinder, piston and piston rod, selection of mounting system, selection of hydraulic pump, selection of valves, selection of pipes and design of tank.

3.1 Design of piston rod

The material selected for piston rod is carbon steel casting (Grade 20–40). The tensile stress of the selected material is 400 MN/m² and factor of safety selected as 5.

We know that,

$$\text{FOS} = \frac{\text{Maximum stress}}{\text{Working stress}}$$

$$5 = \frac{400}{\delta}$$

$$\sigma = 80 \text{ MN/m}^2$$

Therefore, working stress of carbon steel casting material is found to be 80 MN/m². From the determined value of working stress, area of piston rod can be determined as

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

Where, F is the force which is found to be 50 tonnes.

$$F = 50000 \text{ kg} = 50000 \text{ X } 9.81$$

$$= 490.5 \text{ X } 10^3 \text{ N}$$

$$\therefore \quad A = \frac{490.5 \text{ X } 10^3}{80 \text{ X } 10^6}$$

$$A = 6.131 \text{ X } 10^{-3} \text{ m}^2$$

$$\text{Now, } \frac{\pi d^2}{4} = 6.131 \text{ X } 10^{-3}$$

d = 88.35 mm is the diameter of piston rod.

3.2 Design of hydraulic cylinder

In order to design cylinder, the pressure at which cylinder has to be operate should be known. Operating pressure will be around 160 bar but to have cylinder with maximum capacity, the operating pressure is selected as 200 bar.

We know that,

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$200 \text{ X } 10^5 = \frac{490.5 \text{ X } 10^3}{A}$$

$$A = 24.525 \text{ X } 10^{-3} \text{ m}^2$$

$$\frac{\pi}{4}(D^2 - d^2) = 24.525 \text{ X } 10^{-3}$$

$$\frac{\pi}{4}(D^2 - 0.088352^2) = 24.525 \text{ X } 10^{-3}$$

D = 197.56 mm is the diameter of cylinder.

From the available standard, cylinder diameter is selected as 200 mm. From the safety and strength point of view diameter of piston rod is selected as 110 mm from the below Table 1.

Table 1: Standard cylinder and piston rod diameter [1]

Bore diameter (mm)	Piston rod diameter (mm)
100	56
100	70
125	70
125	90
160	90
160	110
200	110
200	140
250	140
250	180

3.3 Buckling load

Length of piston rod is 3000 mm, as it is long there will be chances of bend of piston rod during operation. Hence it is necessary to find out the buckling load of piston rod from safety point of view.

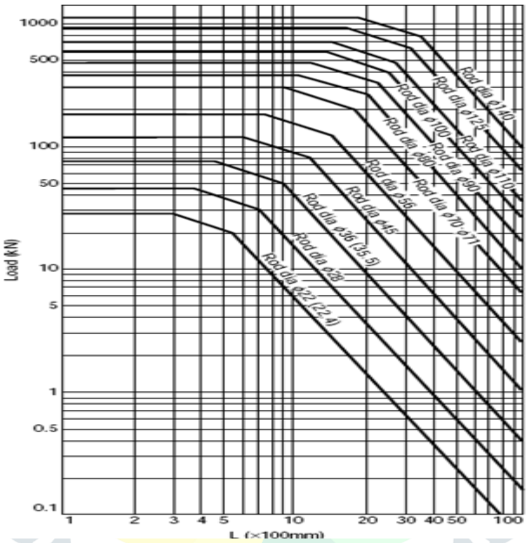

Figure 3: Buckling chart [3]

From the above chart, it is found that the value of buckling load for piston rod of 110 mm diameter is 380 kN, which is less than actual load (490.5 kN). But from the safety point of view buckling load should be greater than actual load acting on the piston rod. Thus for cylinder bore of 200 mm, piston rod diameter is selected as 140 mm from Table 1. Now for piston rod of 140 mm diameter, buckling load is 850 kN, which is greater than actual load. Hence it is safe to select piston rod diameter as 140 mm.

3.4 Design of piston thickness

Piston diameter is assumed as 1 mm less than cylinder bore.

∴ Diameter of piston = 199 mm

We know that,

$$A_P = \frac{\pi Dp^2}{4}$$

$$A_P = \frac{\pi\,(0.199)^2}{4}$$

$$A_P = 31.102 \text{ X } 10^{-3} \text{ m}^2$$

Stress induced in piston,

$$\sigma_P = \frac{F}{A_P}$$

$$\sigma_P = \frac{490.5 \text{ X } 10^3}{31.102 \text{ X } 10^{-3}}$$

$$\sigma_P = 15.77 \text{ MN/m}^2$$

The material selected for the piston is cast steel (Grade 25) and the allowable stress of selected material is 57.6 MN/m². As stress induced in the piston is less than the allowable stress, hence the design is safe.

Piston thickness is calculated by using the relation,

$$\sigma_P = \frac{P \text{ X } Dp}{2 \text{ X } tp}$$

$$15.77 \text{ X } 10^6 = \frac{200 \text{ X } 10^5 \text{ X } 0.199}{2 \text{ X } tp}$$

tp = 126.18 mm is the thickness of piston.

3.5 Velocity of flow

Stroke length i.e., distance that piston has to travel is 3000 mm and time taken to travel this distance is approximated as 45 minutes.

Velocity at which piston has to travel is calculated by using the formula,

$$\text{Velocity} = \frac{\text{Distance}}{\text{Time}}$$

$$= \frac{3000}{45 \text{ X } 60}$$

$$= 1.111 \text{ X } 10^{-3} \text{ m/s}$$

3.6 Flow rate or discharge required

Flow rate of the fluid is calculated by using the relation,

$$\text{Discharge} = \text{Area of cylinder X Velocity of fluid}$$

$$Q = \frac{\pi\,(0.2)^2}{4} \text{ X } 1.111 \text{ X } 10^{-3}$$

$$Q = 34.9 \text{ X } 10^{-6} \text{ m}^3\text{/s}$$

$$= 34.9 \text{ X } 10^{-3} \text{ lps}$$

3.7 Power required

Power required for the motor to provide required flow rate is calculated by using the relation, Power = $\frac{\text{P X Q}}{\eta\text{hyd X }\eta\text{mech}}$

$$= \frac{200 \text{ X } 10^5 \text{ X } 34.9 \text{ X } 10^{-6}}{0.95 \text{ X } 0.95}$$

$$= 773.4 \text{ W}$$

3.8 Pump selection

Selection of pump involves the following factors,

- Selection of actuator based on loads.
- Determination of flow rate requirements to drive the actuator to move the load to a specified distance in a time limit.
- Determination of system pressure based on the actuator size and magnitude of resistance force on the system by external load.
- Determination of total power to be delivered by the pump.
- Determination of pump speed and selection of prime mover.
- Selection of pump type based on variable displacement.

To select pump, several brand company pumps are available in the market. YUKEN brand pump is selected because it offers low noise, high efficiency and swash plate type variable displacement piston pump. It offers three series namely, AR series, A series and A3H series variable displacement piston pump. In these, AR series variable displacement piston pump is selected because it is compact and light in weight, it has high power to mass ratio, low noise and less expensive.

3.9 Hydraulic piping

It is mainly used for supply of hydraulic fluid from hydraulic cylinder to actuating cylinder to perform specific function. These piping should be rigid enough to withstand damage due to sudden impact of loads on pipes and also it should have high resistance to the thermal conductivity and fire proof. These piping should be seamless type and should be made with less number of bents throughout its length. There are 3 hydraulic piping's are available namely, carbon steel piping (16-420 bar), stainless steel piping AISI (16-420 bar) and stainless steel piping, ice class -50℃ (16-420 bar) [2]

In hydraulic system flow lines are recommended to maintain a predefined, standard limit of velocity of flow as shown in the Table 2.

Table 2: Velocity of fluid at different flow lines [2]

Sl No.	Flow line	Velocity should not exceed (m/s)
1	Suction	1.3
2	Return	3

Based on these limits, diameters of pipe at different flow lines are calculated.

At suction line:

$$Q = \text{A X V}$$

$$34.9 \text{ X } 10^{-6} = \frac{\pi d^2}{4} \text{ X } 1.3$$

d = 0.584 cm, for this value pipe size is selected as ¼″.

At return line:

$$Q = \text{A X V}$$

$$34.9 \text{ X } 10^{-6} = \frac{\pi d^2}{4} \text{ X } 3$$

d = 0.384 cm, for this value pipe size is selected as ¼″.

3.10 Mechanical design

To design the piping system some factors have to be taken into considerations like pipe and tube material, connection technology which includes fitting, flanges and couplings, hoses and hose couplings and pipe supports.

Table 3: Carbon Steel 210 bar / 3000 psi [2]

Outside diameter [mm]	10	12
Wall thickness [mm]	2	2
Material	E235N	E235N
Nominal diameter [mm]	6	8
NPS/ASME B36.19M-2004	1/8″	¼″
Class	S-Series (Heavy)	
Standard	ISO 8434-1 (DIN 2353)	
Connection technology	All piping connections with nonwelded technology	

3.11 Hydraulic valves

In hydraulic system, valves are mainly used to control the flow, direction and pressure of the fluid. Different types of valves are used in the hydraulic system like check valve which allows the flow of fluid in one direction and opposes flow in another direction, direction control valve which directs the flow in particular direction, pressure reducing valve and loading vale used to reduce excess pressure to required pressure and solenoid actuated valve used to shut off the flow when flow is not required.. Based on pipe diameter valve size is selected. The size of the valve should be greater than 0.584 cm at suction line and 0.384 cm at return line.

3.12 Tank design

Stroke = 3000 mm

Cylinder bore = 200 mm

$$\therefore \text{Area of cylinder} = \frac{\pi D^2}{4}$$

$$A = \frac{\pi \times 0.2^2}{4}$$

$$= 31.41 \times 10^{-3}\ m^2$$

$$\text{Volume of cylinder} = A \times L$$

$$= 31.41 \times 10^{-3} \times 3$$

$$= 94.23 \times 10^{-3}\ m^3$$

$$= 94.23 \text{ liters}$$

Additional fluid storage must be there in order to use during emergency period. Therefore, total volume required is taken as 1.25 times the actual volume.

$$\text{i.e., total volume required} = 1.25 \times 94.23$$

$$= 117.8 \text{ liters}$$

Generally tank filling capacity should be 1.5 to 2 times the fluid storage.

3.13 Hydraulic circuit

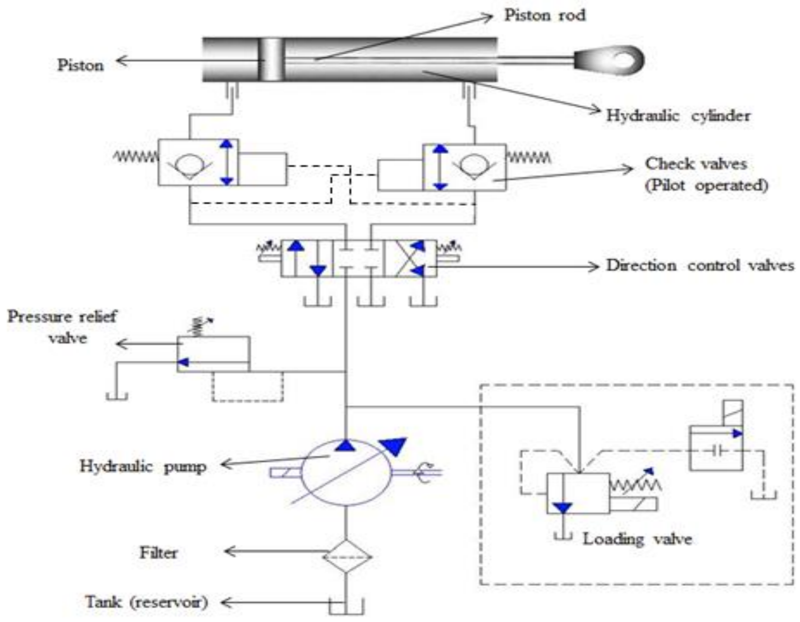

Figure 4: Hydraulic circuit

4. CONCLUSION

To cast pig iron, ladle is tilted and after complete pouring of molten pig iron to the pig casting machine ladle is lifted back to its initial position. This initial tilting of ladle up to pouring point takes around 30-45 minutes and the ladle lifting is in the same manner as that of tilting which consumes more time, this wastage of time can be reduced by the installation of hydraulic system. As piston rod is linked to the ladle at its bottom, tilting can be done properly with ease and much less effort is required. As there is no gear mechanism in hydraulic system, so there will be no gear slip that leads to less chance of overflow of molten pig iron into casting machine.

NOMENCLATURE

Symbol	Meaning	Unit
σ	Working stress	N/m^2
F	Force	N
P	Pressure	N/m^2
A	Area	m^2
D	Cylinder diameter	m
d	Piston rod diameter	m
D_p	Piston diameter	m
A_p	Area of piston	m^2
t_p	Piston thickness	m
Q	Discharge	m^3/s
Q_T	Total discharge	m^3/s
V	Velocity of fluid	m/s
η_{mech}	Mechanical efficiency	%
η_{hyd}	Hydraulic efficiency	%

REFERENCES

[1] Catalogues of Yuken, Parker, Dayton and Vickers.
[2] GS hydro “Hydraulic piping standard handbook-Revision-1”.
[3] “OIL_02_210C1” Buckling chart by cylinder mounting style.