IMPROVING THE EFFICIENCY OF STATIONARY CONCRETE PUMPS USING WHITWORTH QUICK RETURN MECHANISM

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Abstract. The objective of this paper is to study the working of concrete pumps and to establish an alternative mechanism that would enhance their efficiency. A concrete pump is a machine used for transferring semi-solid, ready-mix concrete by pumping. As observed from the analysis of their functioning, it was evident that the transition of energy from mechanical to hydraulic, and back to mechanical during the process was accompanied with significant energy loss, which comprehensively reduced the efficiency of the concrete pump. A great proportion of this energy was lost through heat dissipation. Reducing the number of energy conversions posed to be a promising concept, for which the usage of hydraulic system in the current setup was to be withdrawn. The Whitworth Quick Return mechanism sufficed as a suitable alternative for the required purpose. It was observed from the mathematical analysis of the new mechanism that the theoretical flow rate increased from 45m³/h to 73m³/h, indicating a higher volume of concrete being pumped at the same input energy supply.

Keywords: Concrete Pump, Efficiency, Energy Conversion, Hydraulic System, Whitworth Quick Return Mechanism.

1. INTRODUCTION

A concrete pump is a machine used for transferring semi-solid ready-mix concrete by pumping. There are two types of concrete pumps. The first type of concrete pump is attached to a truck or longer units are on semi-trailers. It is known as a boom concrete pump because it uses a remote-controlled articulating robotic arm (called a boom) to place concrete accurately. Boom pumps are used on most of the larger construction projects as they are capable of pumping at very high volumes and because of the labor saving nature of the placing boom.

The second main type of concrete pump is either mounted on a truck or placed on a trailer, and it is commonly referred to as a line pump or trailer-mounted concrete pump. This pump requires steel or flexible concrete placing hoses to be manually attached to the outlet of the
machine. Those hoses are linked together and lead to wherever the concrete needs to be placed. Line pumps normally pump concrete at lower volumes than boom pumps and are used for smaller volume concrete placing applications such as swimming pools, sidewalks, and single family home concrete slabs and most ground slabs. The pump works by one piston drawing concrete into a cylinder from a hopper while the other one simultaneously pushes its concrete out into the discharge pipes. A valve which determines which cylinder is open to the concrete hopper and which one is open to the discharge pipes switches over each time the pistons reach the end point and the process continues with the first cylinder now discharging and the second drawing fresh concrete from the hopper. To be able to perform this, the concrete pumps utilize high amounts of energy which they obtain through simple energy conversions. A diesel engine provides mechanical energy to run the hydraulic unit, which in turn regulates the fluid flow in the cylinders by supplying adequate liquid pressure on the pistons. The pistons then move synchronously and push out the concrete at the necessary rate. This conversion of energy from mechanical (engine) to hydraulic (hydraulic unit) and again to mechanical (pistons) is accompanied by many losses. The losses can be in the form of heat, wearing, and bends which lead to pressure drop. It may thus be inferred that the concrete pumps which make use of the above mechanism do not perform at high efficiencies.

At a time where industrialization and construction is at peak, a lot of investment in monetary terms and in energy is made on concrete pumps. This paper addresses the problem seen in the conventional mechanism and suggests an alternative mechanism to counter the energy losses. A method of approach was to reduce the number of energy conversions that took place. In the process, the Whitworth Quick Return mechanism posed as a suitable opportunity to replace the previously used mechanism. Following this, the hydraulic unit was dropped from the system and replaced by the Whitworth mechanism, providing the means to run the concrete pumps solely on mechanical energy.

2. MODEL INVESTIGATION

2.1 Model Type and Specifications

For the purpose of this paper, the model analyzed was SP1200D and all calculations, inferences and results were obtained in regards to the model’s specifications. SP1200D is a stationary concrete pump which is manufactured at SCHWING Stetter GmbH. The organization deals with a large variety of concrete pumps, both stationary and boom type. Some examples of their other models include SP 1420, SP 8800, SP 4800 and SP 4507. These models differ on the basis of the volume of concrete they can function with. Due to its simplicity, SP 1200 D was chosen as the specimen for this paper. With their due permission, data pertaining to the specified concrete pump was obtained and investigated. The specifications of the model are mentioned in Table 1:

| Property                  | Uni  | SP 1200 |
|---------------------------|------|---------|
| Versio                    | -    | Diese   |
| Motor/Engine rating       | kW   | 49      |
| Nominal Speed             | RP   | 210     |
In order to proceed with the Whitworth Quick Return mechanism, it is necessary to determine the efficiency of the concrete pumps that follow the current method and then compare it with the results obtained with the alternative mechanism.

| Pumping cylinder Diameter X | mm | 180 X |
|--------------------------|----|-------|
| Differential cylinder drive | -  | RS    |
| Max. stroke count per     | -  | 24    |
| Max. theoretical output   | m³/h| 45    |
| Max. concrete pressure    | bar| 70    |

Figure 1. SP 1200 D Stationary Concrete Pump Outlay

2.2 Calculation of Efficiency

All the technical data relevant to the calculation of efficiency is listed below (as observed from Table 1):

Engine/Motor Capacity, Pin = 49 kW
Bore Diameter x Stroke Length = 180 mm (D) x 1200 mm (S)
Max. Strokes per minute, N = 24 Claimed
Max. Theoretical Concrete Output = 45 m³ /h
Actual Output Rate of Concrete = Qb
Volumetric Efficiency in Cylinder, $\eta_v = 60\%$
3. PROPOSAL OF ALTERNATIVE PUMPING MECHANISM

3.1 Ideology

The hydraulic system is responsible for the losses of energy in the concrete pumping mechanism as it is apparent from the calculations made in the previous section. In order to improve the efficiency with which concrete is pumped, an idea of approach to the problem is to remove the hydraulic system completely and replace it with a suitable alternative that would produce the same output with a greater efficiency. The reduction in the number of energy conversions occurring during the process would imply a lesser wastage in energy. Therefore, it is necessary that only one energy type is used throughout the entire process of pumping. Since mechanical energy obtained from the diesel engine is the initiator of the entire process, abiding to it throughout seemed ideal. Hence, an alternative mechanism is sought after that would be driven purely by mechanical energy and simultaneously sucks in and pushes out concrete with better efficiency. Not only should this mechanism produce better output, but is should also consume lesser energy for its functioning. This way, the efficiency of the pump would increase significantly. The Whitworth Quick Return Mechanism posed as a substitute for the current mechanism.

3.2 Whitworth Quick Return Mechanism and its Working Principle

Whitworth quick return mechanism is an apparatus that converts circular motion (rotating motion following a circular path) into reciprocating motion (repetitive back-and-forth linear
motion) in presses and shaping machines, which are utilized to shape stocks of metal into flat surfaces. Unlike the crank and slider, the forward reciprocating motion is slower rate than the return stroke. At the bottom of the drive arm, the peg only has to move through a few degrees to sweep the arm from left to right, but it takes the remainder of the revolution to bring the arm back. This is why it is called quick return mechanism. Figure 3 shows a simple Quick Return Mechanism’s link arrangement.

![Whitworth Quick Return Mechanism](image)

**Figure 3.** Whitworth Quick Return Mechanism

In the conventional mechanism of pumping, a rocker valve was made use of at the output of the two cylinders. This valve would timely change its position from one cylinder to another. While it closes the opening of one cylinder, the other cylinder pushes out the concrete. Meanwhile, the piston inside the cylinder whose opening was closed sucks in concrete from the hopper with the aid of vacuum pressure. To make the output flow of concrete regulated, the two cylinders as well as its rocker valve were retained from the previous mechanism. However, that would mean that both the cylinders couldn't have the same time periods for the strokes, which would imply that the actuators wouldn't move synchronously. To solve this synchronization problem of the actuators, the requirement of two rams of opposite speeds i.e. one with a quicker returning motion and another with a quicker forward motion was needed.

### 3.3 Basic Working Principle of Concrete Pump

The objective remains to pump concrete through the cylinders. Two cylinders are being made use of in such a manner that while one pushes the concrete through the outlet, the other sucks concrete through the hopper. The mechanism, however, is initiated without the usage of hydraulics. The power of the engine is directed to only rotate the bull gear at desired RPMs to achieve the exact motion sequence.

The cylinder motions are defined as follows:

- **Forward: Pump out Concrete**
- **Backward: Suck in Concrete**

**Cylinder 1:**
- 1 second to move forward, 2 seconds to return back

**Cylinder 2:**
- 2 seconds to move forward, 1 second to return back
Following this time period allotment, the cylinders always remain in sync with one another despite having different ram speeds. While one pushes out concrete, the other sucks it in and in the same definite amount of time.

![Figure 4](image_url). Schematic Diagram of ram movement inside cylinders

### 3.4 Dimensions of the CAD Model

| Feature                      | Notation | Unit | Value |
|------------------------------|----------|------|-------|
| Inner Cylinder Diameter      | D₁       | mm   | 180   |
| Outer Cylinder Diameter      | D        | mm   | 200   |
| Stroke                       | L        | mm   | 120   |
| Ram                          | D₁       | mm   | 180   |
| Width/Thickness of Piston Head | Tᵣ     | mm   | 60    |
| Bull Gear/ Wheel Diameter    | D        | mm   | 600   |
| Bull Gear/ Wheel Thickness   | T        | mm   | 20    |
| Distance between Cylinder    | Dᶜ       | mm   | 100   |

### 3.5 CAD Model of Suggested Mechanism

![Figure 5](image_url). Front View of suggested mechanism

![Figure 6](image_url). Top View of suggested mechanism
3.6 Calculation of Efficiency

Mass of Ram
Material = Mild Steel (Density, ρ_r = 7000 kg/m³)
Mass of Ram, $M_r = \text{Density} \times \text{Volume}$

\[ M_r = \rho_r \times \pi \times \left( \frac{D_r^2}{4} \right) \times T_r \]

\[ M_r = 7700 \times 3.14 \times \left( \frac{0.18^2}{4} \right) \times 0.06 \]

\[ M_r = 11.756468 \text{ kg} \]  

Mass of Concrete
Material = Concrete (Density, ρ_c = 2400 kg/m³)
(Assumption: 100% of the volume is included during motion.)
Mass of Concrete, $M_c = \text{Density} \times \text{Volume}$

\[ M_c = \rho_c \times \pi \times \left( \frac{D_c^2}{4} \right) \times L \]

\[ M_c = 2400 \times 3.14 \times \left( \frac{0.18^2}{4} \right) \times 1.2 \]

\[ M_c = 73.287073 \text{ kg} \]

Acceleration of Ram

The ram uniformly accelerates for half the displacement and then uniformly retards towards the end.
Let us assume:
Displacement of Ram = s
Initial Velocity = u
Time duration = t
Acceleration in forward direction = af
Acceleration in backward direction = ab

Taking Cylinder 1 (one second for forward motion and two seconds for backward motion) into consideration: During Forward Stroke:
Similarly, Retardation = 1.2 m/s²

For the ram to complete one cycle of motion (i.e.) from one end to another and then back, the bull gear completes one rotation and the time taken to do so is 3 seconds.

Therefore, required RPM for Bull Gear;

\[ N_{eq} = \frac{60}{3} = 20 \text{ RPM} \]

Now, in 3 seconds, both the pumps have pushed out Concrete once.

### 4. OBSERVATIONS AND RESULTS

Taking into consideration that the volumetric efficiency of the concrete filling the cylinder is around 60% (as observed), the actual concrete output amounts to 13.2 m³/hr/cylinder, or 26.4 m³/hr for the entire system. Calculating the Fluid Power using this flow rate and the pressure on the piston head on concrete side and using this, an efficiency of 52.35% was obtained.

As observed from the above calculations, the Whitworth Quick Return Mechanism seeks to pump out concrete much quicker, at a theoretical output rate of approximately 73.3 m³/hr, as opposed to the theoretical output supplied by the existing model, which amounted to approximately 45 m³/hr.
With only the CAD model in hand and no physical prototype to support the theoretical findings, it is difficult to assess the volumetric efficiency of the Whitworth Mechanism and this is left for the future scope of analysis of the mechanism.

5. CONCLUSION

It is clear that the concrete output rate that the current mechanism offers can be theoretically bettered with the help of the Quick Return Mechanism that was designed. With the notion that an increased output for the same amount of input power results in an improved efficiency, it is easy to assume that the efficiency increases in the new mechanism.

However, mechanical engineering is a field of study where assumptions need to be proven before they can be accepted. It is critical to calculate the pressure on the ram heads, which can be best performed experimentally. Such an experiment would prove to be very capital-intensive and time-consuming. Support obtained from organizations may help in carrying out the execution of the theoretical model and verifying its correctness as obtained on paper.

Further advancements can be achieved, mainly in lines with selection of alternative power sources which could replace the diesel engine. This is desirable, owing to the fact that diesel, like many other fossil fuels, is a depleting entity. Moreover, consumption of diesel contributes to release of greenhouse gases, such as carbon dioxide, which are essentially the main culprits of the alarming rise in the global average temperatures. Taking these into consideration, one can always select a suitable replacement, probably a chemically or an electrically running device, that is not only sustainable for the machine but also for the environment.

The scope of research in this area is limitless. Further enhancements in the model can be achieved, in terms of its basic body outlay, the mechanism and other aspects, which would benefit both economically and functionally.

REFERENCES

[1]. Ye. Koshkarev, Influence of Engine Load on Concrete Pump Operating Parameters, In International Conference on Industrial Engineering, Surat, India, 21-23 December 2017. Procedia Engineering, 2017, pp.1684-1689.

[2] Chipperfield A J and Fleming P J 1995 IET The MATLAB genetic algorithm toolbox.

[3] Yokota T, Taguchi T and Gen M 1998 A solution method for optimal weight design problem of the gear using genetic algorithms Computers & industrial engineering Elsevier Vol 35 Issues 3–4 pp 523-526

[4] Wang H and Wang H 1994 Optimal engineering design of spur gear sets Mechanism and machine theory Elsevier Vol 29 Issue 7 pp 1071-1080

[5]. https://www.schwingsetterindia.com/products/stationary-pump/sp-1200