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Pump design and Development for High Shear Grout Mixing Applications

Professional paper

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Abstract: The aim of this project was to design and develop a new pump for the mixing and pumping of grout cement. The initial design consisted of a cantilevered supported pump housing containing a centrifugal mill with a series of plate seals, gaskets, flanges and a single tapered bearing. To date, the initial pump has failed as evident from bearing and seal wear. Extensive research of the design features of grout mixing units from various competitors and suppliers was conducted [1]. Based on research undertaken a paddle pump design was developed incorporating dual end support, direct grout feed and improved sealing. Design calculations were used to size the hydraulic motor, the impeller shaft diameter, dynamic loading on bearings and their operational lifetime. The new pump unit, based on testing, delivers a suitable head of pressure for the mixing and shearing of the grout mix, leading to a consistent grout mix product. The performance of the pump was measured both physically and experimentally via the use of an industrial hydraulic power pack, capable of delivering the required power and pressure to enable the pump operate at industrial flow rates. Performance tests consisted of varying the flow rates of the grout material through the pump and measuring pressure head at the outlet. Results of the performance testing indicated that the pump operated to design specifications. The dual bearing system design proved satisfactory, with smooth operation even at higher ranges of industrial flow rates. The mechanical seals, selected for aggressive wear and corrosive environments remained leak proof as required. The new pump design features include a widened pumping impeller for increased shearing of the grout and gives higher volumetric flow rates. This offers advantages to the end user as it is more efficient, robust, maintainability and lest costly to manufacture. Figure 1. shows the assembled unit of the pump, hydraulic motor, holding tank, and the inlet and outlet ducts.

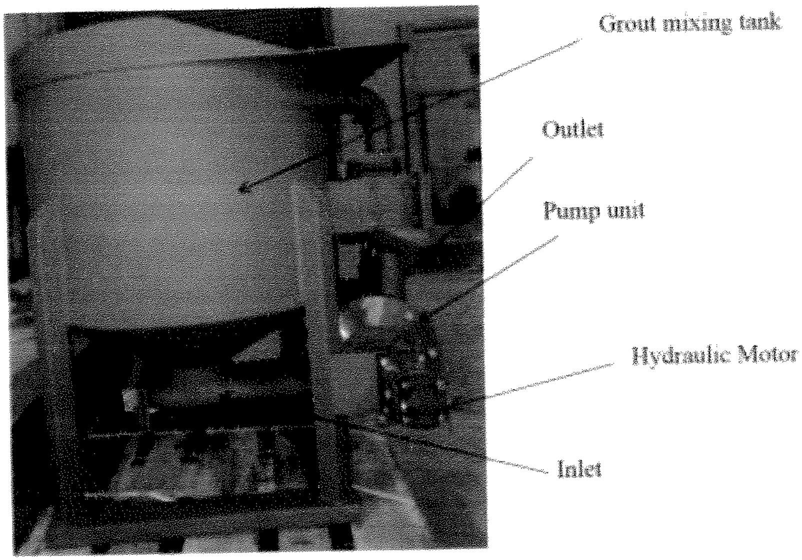

Figure 1. Pump unit with Hydraulic motor and mixing tank

1. Introduction

The main aim of this research was to design and develop a high shear colloidal mixing pump for grout material. Grout is used extensively in the construction industry for fixing foundations, re-setting sunken foundations, repairing culverts, preventing rising damp, and arresting subsoil movement/ landslides on a local basis. The formation of crack systems and voids in the subsoil reduces the load bearing capacity of a building's foundation, which may result in structural instability. Mixing grout involves shearing cement, water, sand and accelerating agents into a fine colloidal suspension. Wetting is necessary for batch quality and pumping involves transferring the slurry mix to the point of use. The technique involves circulating water in a vessel via a pump and adding the correct quantities of cement, sand and agents to produce a consistent paste. A vortex mixing effect is used to assist with the mixing as shown in Figure 2. This is generated by pumping the liquid tangentially into the mixing tank. The mix is then supplied to a second vessel where it is injected under high pressure through a hose and into the location underground or for culvert repairing.

The grout sets to provide structural rigidity and sealing against rising damp. Upon successful grouting, structural integrity is fully restored [2].

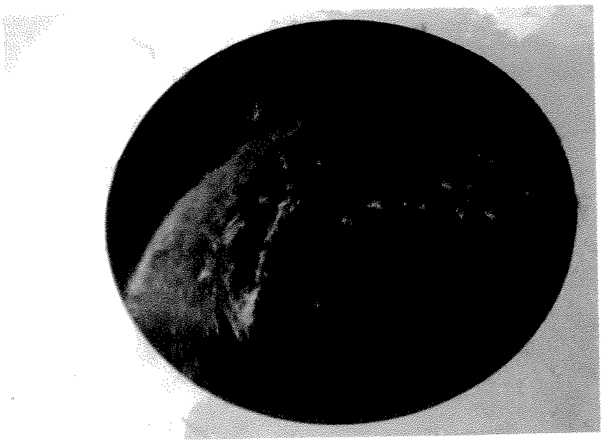

Figure 2. Vortex effect

2. Pump design

The pump was designed based on on-site mixing performance and industry knowledge coupled with faults identified with the existing pump unit and design calculations. The final design had to overcome initial design defects of the original pump and enhance technical capability with regard to performance, reliability, ease of maintenance and manufacturability. The initial pump had failed in terms of bearing performance, poor sealing, and high maintenance and manufacturing costs. The initial pump unit consisted of a modified centrifugal type pump, cantilevered impellor with one supporting bearing. The failed pump is shown in Figure 3. Figure 4. shows the component parts of this pump.

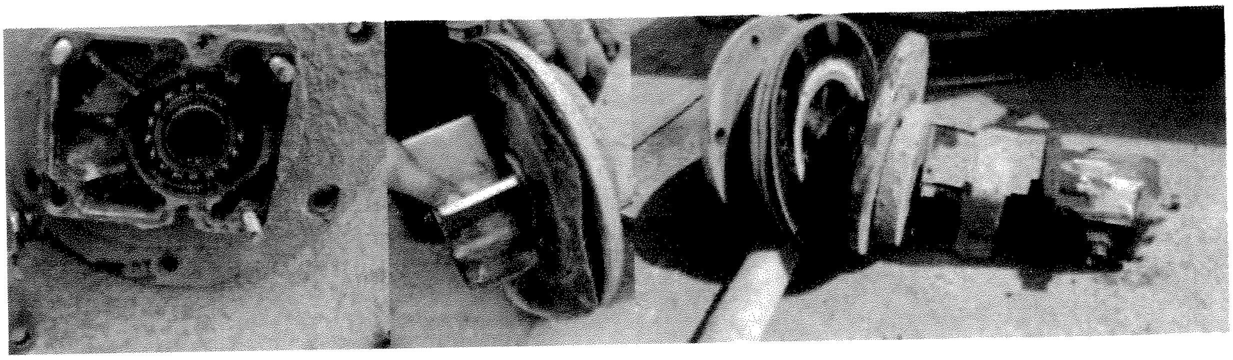

Figure 3. Pump bearing and component parts

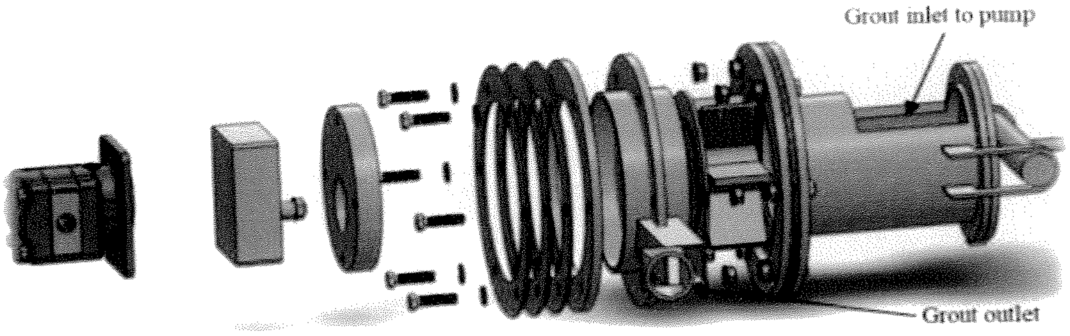

Figure 4. Exploded view of original pump unit

The Figures show the excess parts, seals, flanges and gaskets, supported by the bearing. The impellor is supported as a cantilever by the bearing and the overall pump unit is supported by the base of the mixing tank. The outlet from the pump is considerably smaller than the pump inlet which has the effect of causing back pressure in the pump. The new design overcame this by matching the cross sectional area of the outlet to the inlet. In order to improve the pump design and performance, a number of key design features were considered such as dual bearing support of the impellor shaft, direct impellor feed from the mixing tank, increased shearing areas, balancing inlet and outlet ducts, correct sizing of the motor for performance and efficiency and specifying components for operating conditions and loads. A key requirement of the design was to allow access to the pump for maintenance and inspections as this reduces downtime and increased availability. Figure 5 shows the pump impellor design, supported at each end and its accessibility on the grout pump equipment.

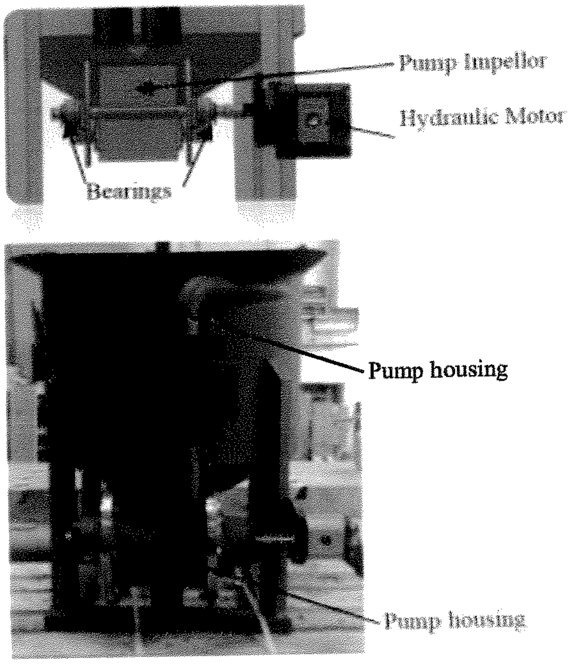

Figure 5. Redesigned pump

3. Operating conditions

The machine must be capable of mixing grout to meet the following specifications:

- Water/cement ratio = 0.4
- Mixing time of one minute (Multiple passes through pump)
- Impeller rpm > 1500
- The grout volume, based on the size of the mixing tank is 0.155m3
- Water and cement are added to the mixing drum to give a w/c ratio of 0.4
- Three bags of cement (150 kgs) added to 60l of water, giving a slurry mass of 210 kgs and overall 100 litre volume of grout mix.

The industry standard for recirculation flow rates in high shear colloidal mixing varies between 1000-1500 litres per minute and all calculations were based on the higher end of this range. The pump must deliver flow rates that produce turbulent, aggresive mixing.

Therefore the design flow rate: $= 1500\frac{litres}{min} = \frac{90\,m^3}{hour}$ and the viscosity of the grout was 0.06 Pa.s [4].

- The System Flow rate $= Q = \frac{90}{60\times60} = \mathbf{0.025\ m^3/s}$

The entire mixing system consists of pipes/ducts and fittings of differing cross sectional areas as outlined in Figure 6. The flow rate of Q = 0.025 m^3/s remains constant through the entire system.

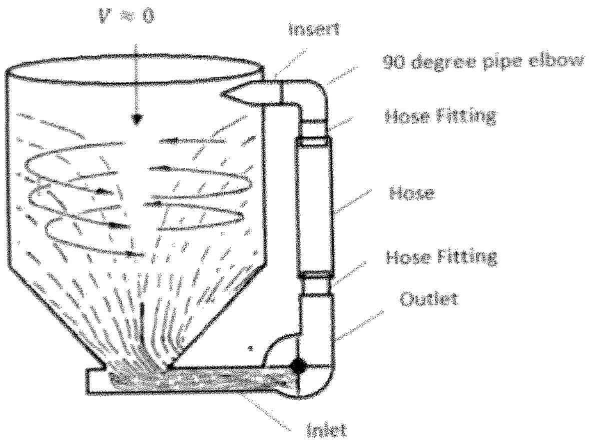

Figure 6. Schematic of mixing tank with variable cross sections

Major losses in the system are highlighted in Table 1. and the values derived in Column 8.

Table 1. values to determine head losses in the mixing system

Component	Relative Roughness	Length (m)	Hydraulic Diameter (m)	f_{moody} (Friction factor)	Reynolds Number	Velocity (m/s)	h_f (m) $\left(f\frac{L}{D}\frac{V^2}{2g}\right)$
Main tank	-	-	-	-	-	-	-
Inlet Duct	0.000526	0.365	0.095	0.032	11704	3.51	0.077
Outlet Duct	0.000526	0.07	0.095	0.032	11704	3.51	0.0148
Hose fitting	0.00607	0.046	0.0428	0.035	26017	17.36	0.577
Rubber Pinch hose	0.000147	0.282	0.068	0.0285	16374	6.88	0.285
Pipe elbow (90°)	0.00607	0.116	0.0428	0.035	26017	17.39	1.45
Insert pipe	0.00607	0.228	0.0428	0.035	26017	17.36	2.85

The overall design power required for the Grout pump for the mixing and pumping unit is was determined to be 12.56 kW.

4. Key Design improvements

The aim of this project was to improve the technical performance associated with a grout pump and mixing rig. To achieve this, a number of key objectives were addressed:

- To provide design documentation for the grout pump
- To design and develop a stationary mixing unit for testing machine performance
- To design and develop a high shear colloidal mixing pump
- To design for maintenance and accessibility
- To improve bearing performance problems and seal issues

The new design utilizes a twin bearing, positive displacement mixing unit with a widened impeller to provide increased shearing area and higher volume flow rates. The widened impeller is one of the key features of the mixing unit. It accounts for increased shearing area, and therefore more cement particles are wetted. In addition, the wider impeller displaces more volume per revolution, therefore increasing flow rates. Vortex formation is enhanced which improves mixing, wetting and turbulent flow in the mix. As a mixing unit, this new design has improved reliability, enhanced mixing capacity (due to high shearing area) and employs a better sealing system to cope with aggressive environments as shown in Figure 7. With the new design, the time taken for maintenance has been reduced from 1 day to 30 minutes. This is due to the simplified design of the new mixing unit. With only a flange to remove from the mill, access to the blades is immediate. The original machine suffered bearing failure as a result of a cantilevered impeller. Deflection of the impeller translated into additional dynamic loading on bearings, resulting in premature bearing fatigue and failure. This problem was solved with the use of a dual bearing system and eliminating the cantilever effect. The calculated value of dynamic loads on the bearings was found to be 5.41 kN which is well under the rated value of 14.6 kN [6]. The seal included a Tungsten Carbide shaft seal designed for abrasive environments.

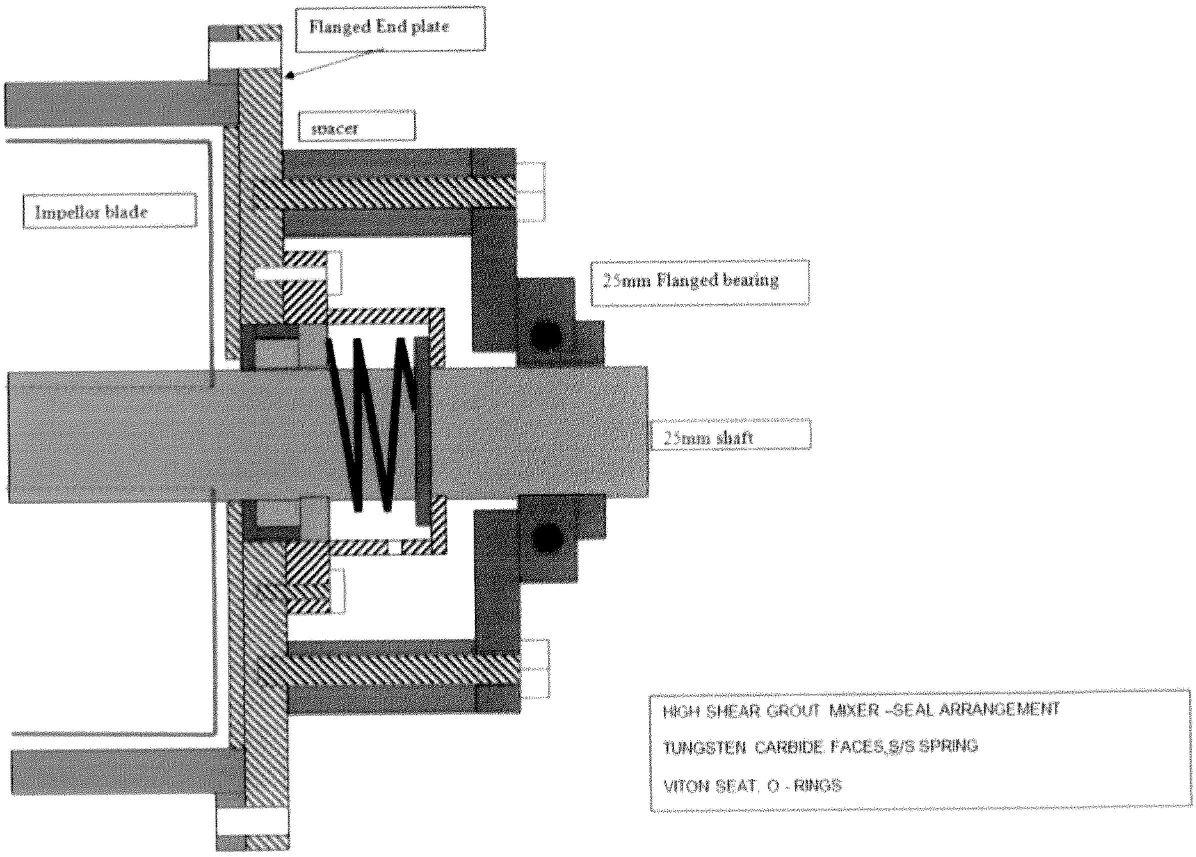

Figure 7. Bearing and seal system for grout pump

5. Testing and results

Preliminary operations with water proved satisfactory, generating a high speed and a vortex effect as required. This indicated that mixing should occur to requirements for the company involved. With the addition of cement and sand, the results of mixing was positive with a thourough homogenous mix obtained for a w/c ratio of 0.4 for grout. No leaks or part failure was observed. The power required to drive the impeller for mixing was calculated to be 12.56 kW. The overall torque on the impeller was calculated to be 66.63 Nm. The system was sized to cope with the highest industry standard flow rate of 1500 litres/min. Further testing is ongoing at the manufacturers plant and these involve standard cube tests of grout to determine strength and performance of the mixed product.

Acknowledgements

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