Paper ID: FM-014

Development of a Pump Test Bed

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Abstract

In this study a pump test bed has been designed for characterization of both centrifugal and submersible pumps of capacity up to 6 cusec. The pump test bed will be installed in the Fluid Mechanics Lab of Mechanical Engineering Department, Rajshahi University of Engineering & Technology, Bangladesh. Complete two sets of pump test setup will be therein. One for small pumps of capacity up to 3 cusec and other up to 6 cusec. The each complete setup are comprised of Mild Steel (MS) pipe, elbow, tee joints, gate valves, motorized flow control valve, check valves, water flow meter and pressure gages in their proper position and alignment; and with supplying and welding 25 mm thick MS flanges to pipe bend/joint and supplying 2 Nos. 3 mm thick rubber gasket in each joints for making the joints water tight.

Keywords: Centrifugal and submersible pumps, Pump test bed, Technical specifications

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1. Introduction

Pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in certain industrial plant operations [1]. Pumping systems are widespread; they provide domestic services, commercial and agricultural services, municipal water/wastewater services, and industrial services for food processing, chemical, petrochemical, pharmaceutical, and mechanical industries. The energy and materials used by a pump depend on the design of the pump, the design of the installation, and the way the system is operated. These factors are interdependent [1-3].

The demand for submersible pumps has been rising recently. World leading pump companies are continually building up the share of submersible pumps in their production volumes. While 50 years ago submersible pumps with air-filled electric motors were produced by only one company, by the 1990s all of the ten leading manufacturers of pumps produced submersibles. These companies, which together account for a third of the world market, dictate their policy to the remaining 10000 pump manufacturers [2-3].

During the draught season, the ground water goes down at lower level. It is generally caused when the groundwater heads in an aquifer fall below a critical level over a certain period of time due to natural or human induced causes and inventions. In the recent past, there was increased frequency of draughts in Bangladesh. Particularly, the Northern region of the country was severely affected by the occurrence of draughts and high variability in rainfall. At that time, farmers had to face tough situation due to scarcity of water and they had to dependent on ground water for irrigation. As the ground water level is declining day by day, it is almost impossible to lift water by low lift pump like centrifugal pump for irrigation, drinking and industrial purposes today. It has become urgent to lift water by high lift pump like submersible pump for irrigation and other purposes. Barind Multipurpose Development Authority (BMDA) takes initiatives for irrigation using ground water by installing deep well and supply drinking water in barind area where the depth of ground water level is high [4-5].

There are variety brands of centrifugal/submersible pumps available in the market place. Some of them are cheap but shorter lifespans and high maintenance and energy consumption costs. These cheapest brands pump draw primary interest of the most customers. Some other brands have comparatively longer lifespan with low maintenance and energy costs. The customers do not feel interest for high price of these pumps that is very smaller than the energy consumption cost during its life. Under these circumstances it is crucial to obtain an optimum solution for selecting a good pump and also operation of submersible pumps. However, the main objectives of the present study is to develop a pump test bed for characterization of both centrifugal and submersible pumps in the Fluid Mechanics Lab of Mechanical Engineering Department, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh.

2. Basis of Design

The BMDA and Rajshahi WASA are using submersible pumps to supply water mainly for irrigation in sixteen districts of Northern part of Bangladesh and for house hold affairs in Rajshahi City Corporation respectively. Most of them are of pumping capacity of two cusec. Sometimes they uses centrifugal pumps of capacity up to 5 cusec for transferring surface water and hence a pump test bed has been designed of capacity up to 6 cusec for characterization of pumps under head of 335ft.

2.1 Pipeline

The pump test bed will be fabricated by fitting, fixing and installation of MS pipes inside and outside of the Fluid Mechanics and Energy Lab including cutting, shaping, trimming and clearing the ends of the pipes. The minimum wall thickness of the pipes is considered 6mm by the supporting calculation bellow [6-7]. The pipe shall be capable to withstand a working pressure of 10 bar that is equivalent to 335ft head. Before installation the pipes and other components shall be coated with tar epoxy resin for the internal part and for the external part with bitumen reinforced with an inner layer of fiber glass tissue and an outer wrapping of bitumen impregnated reinforced glass tissue excepting exposed pipe work. The 6 inch (150mm) diameter pipe is considered for smaller pump test bed and 10 inch (250mm) pipe is considered for bigger pump test bed for reducing the thrust on the pipe and pipe fittings.

The free body diagram for bursting force in the pipeline is shown in Fig. 1. The total bursting force *F*, acting normal to the cutting plane A-A, is resisted by equal forces acting on each cut surface of the pipe wall. Applying a horizontal summation of forces,

$$[\Sigma F_x = 0]; \quad F = pDL = 2P \tag{1}$$

Here the left half of the cylinder is occupied by water, from the accompying free body diagram it is apparent that the bursting force *F* acting over the flat surface of the fluid equals the pressure intensity *p* multiplied by the area *DL* over which it acts as *pDL*.

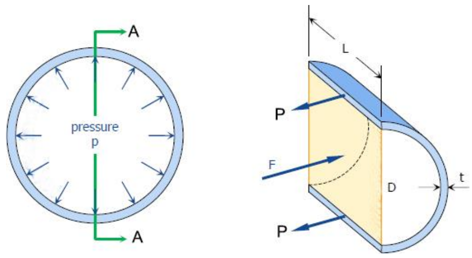

Fig.1: Direct evaluation of bursting force

The stress in the longitudinal section that resist the bursting force *F* is obtained by area of two cut surfaces. This gives,

$$[\sigma_t = \frac{F}{A}]; \quad \sigma_t = \frac{PD}{2t} \tag{2}$$

This stress is tangential stress or hoop stress or girth stress, it is practically equal to the maximum stress at inside surface. If we consider that the pumps work under 335 ft head with 10 inch dia pipe then the resulting pressure inside the pipe line is 10 bar that is calculated by the well-known equation $p = \rho g h_T$. Thus, the designed pipe wall thickness for mild steel (σ_t = 248MPa) with safety factor 3 is obtained by using Eq^n. (2):

$$t = \frac{pD}{2\sigma_t} = \frac{\rho g h_T D}{2\sigma_t} = \frac{1000\times9.81\times102.74\times0.250}{2\times\frac{248}{3}\times10^6} \qquad \text{Where, } h_T = h + V^2/2g)$$

$$= 0.0015\text{m}$$

$$= 1.15\text{mm}$$

In similar way the minimum wall thickness for 6 inch dia pipe is found as 0.92mm.

Bursting force on a transverse section**:** If we consider free body diagram of Fig. 2 of a transverse section, we can see that the bursting force acting over the end of the cylinder is resistant by the resultant P of tearing forces acting over the transverse section.

The bursting force on traverse section is calculated by the following Eq^n.
Bursting force for 10inch (250mm) diameter Pipe:

$$F_B = PA_1 = \rho g h_T A_1 \qquad (\text{here } h_T = h + V^2/2g)$$

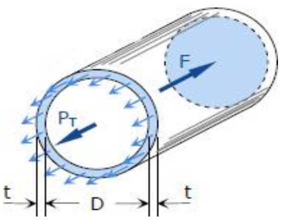

Fig.2: Bursting force on transverse section

$= 1000 \times 9.81 \times 102.13 \times .04909 = 49183$ N

The yield strength of traverse section, $\sigma_t = F/A_2$; Where, $D_2 = D_1 + 2t$

$= 49183/0.0502 = 979741$ N/M^2

In similar way the bursting force and yield strength for 6 inch dia pipe is found as 17733 N and 979723 N/M^2, respectively.

2.2 Elbow

MS elbow inside and outside of the Fluid Mechanics and Energy Lab will be fitted in their proper position including cutting, shaping, trimming and clearing the ends of the elbow. The minimum wall thickness of the elbow is also considered as 6mm. The elbow shall be capable to withstand a working pressure of 10 bar as minimum. Before installation the elbow shall be coated with tar epoxy resin for the internal part and for the external part with bitumen reinforced with an inner layer of fiber glass tissue and an outer wrapping of bitumen impregnated reinforced glass tissue excepting exposed elbow work.

Thrust on elbow, for 10 inch (250 mm) dia pipe: Fluid flow and internal pressure in a piping system may create intolerable forces and tensions without adequately supporting of the piping structure.

The thrust on elbow for discharge of 6 cusec and using 10 inch (250mm) diameter pipe can be expressed as,

$F_T = m\,(V_1 - V_2)$

$= \rho AV\,(V - V\cos\alpha)$

$= \rho A\, V^2\,(1 - \cos\alpha)$

$= \rho AV^2$ (for $\alpha = 90^0$)

$= 1000 \times 0.04909 \times (3.46)^2$ ($V = Q/A$)

$= 588.02$N

Similarly, for discharge of 3 cusec and 6 inch diameter pipe the thrust on elbow is found as 406.11N

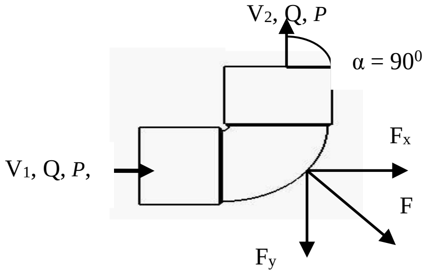

Fig. 3: Thrust force on elbow

2.3 Gate valves of diameter 150mm and 250mm

All valves shall be flanged, cast iron with gun metal wedge and rings, mornings with gun metal or stainless steel spindle and nuts. In order to ensure easy manual operation, valves should have hand wheel for closing in clockwise rotation marking “To close” and for opening in anti-clockwise rotation marking “To open” during casting, indicating with arrow. Provision should also be there for indicating the degree of opening. Designed working pressure shall be 10 bars as minimum.

2.4 Flanges of diameter 150mm and 250mm

The relevant requirement of BS 4504 is applicable to the 25mm thick (minimum) flanges. Jointing materials e.g., nuts-bolts, gasket, glands, sealants shall be provided for flanges where required to ensure proper joining and minor adjustment of pipe installation against the leakage. For easy replacement, packing of gland shall be arranged. In the first type flanged ends of the pipes or fittings are brought together and cotton fiber reinforced gaskets or rubber washers are placed in between the flanges to ensure water tightness and both the ends of the pipes are flanged with wholes in order to fix the bolts; the whole arrangement is finally tightened with the nuts. In the second type rubber gasket is pressed tightly between the annular space of spigot and socket with the aid of bolts, the socket end is flanged with cast iron or steel ring to slide freely on the spigot part and extra care is required during tightening of the bolts.

Stud bolt design**:** For 10 inch (250 mm) dia pipe, the dia. of the bolt is found by the following Eq^n. considering 12 nos of bolts to be used in a flange

$$\sigma_t = \frac{F}{A \times 12} = \frac{(F_{T+}F_B)}{A \times 12}$$

Diameter of stud bolt, $$d = \sqrt{\frac{F_{T+}F_B}{\pi \times \frac{\sigma_t}{4} \times 12}} = \sqrt{\frac{588.02+49183}{\pi \times \frac{248 \times 10^6}{4 \times 3} \times 12}} = 8 \text{ mm}$$

Considering 8 nos of bolt for 6 inch dia flange, in similar way the bolt dia. is found as 4.83mm. Nominal size of bolt dia. to be used in flange for 10 inch and 6 inch pipes are 20mm and 15mm, respectively. Thus, the design is in safe condition.

Fig.4: Flange and stud bolt

2.5 Motorized flow control valve of diameter 150mm with range up to 500 m^3/h and 250mm with range up to 1000 m^3/h

Motorized flow control valves of any reported international brand with the following requirements will be installed: valve material: stainless steel 304/316, connection type: flange connection, operating pressure: 0 to 10 bar, operating temperature: 15 to 150° C, valve opening indication: provision should also be there for indicating the degree of opening. , actuator type: electric motor, actuating time: 1 sec/mm (approximate), actuating thrust: 10-15 kN, power supply: 220-240 VAC, frequency: 50/60 Hz, electronic type: input signal 4-20mA, feedback signal 4-20mA, enclosure protection: IP 54.

2.6 Water flow meter of diameter 150mm and 250mm

Water flow meter of any international brand with maximum working Pressure: 10 bar, connection type: flange connection , flow rate: 50 m^3/h to 1000 m^3/h , accuracy: about ±3% f.s. the materials for the main components of the water flow meter comply with the following requirements:, housing: stainless steel (AISI 316L) with IP65-coated aluminum, scale plate: coated aluminum, window: polycarbonate , closing disk: stainless steel (AISI 316L), magnet group: stainless steel (AISI 316L) +alnico (coated) bearing: poly tetra fluoro ethylene (PTFE) / bronze, shaft support disk: stainless steel (AISI 316) ,spring: stainless steel (AISI 304), shaft: stainless steel (AISI 316). disk stop: stainless steel (AISI 316L) , disk: stainless steel (AISI 316Lbody: polyamide coated steel (AISI 316L).

2.7 Check valve of diameter 150mm and 250mm

Double door type compact design check valve shall be fitted between flanges. The doors of check valve to be spring loaded, closed by means of one or more heavy duty stainless steel torsion springs. Door is opened with the flow from the pump and when shut down, the torsion spring shuts the door before reverse flow stars at the point of nil velocity, for non-slain close. The seating shall be watertight and resilient. Provision for lifting hook is required. The deigned working pressure shall be 10 bar as minimum. Cast iron body conforming to BS 5153 clasic-16. Aluminum bronze doors conforming to BS 1400, grade LG-2 T 136 steel shall be used for stop pins and hinges. Buna-N molded to the body to be used as scaling element. Similarity with either No. 9000 series or mission style-B shall be maintained for construction. These are suitable for installation between BS 4504 class NP 10 flanges.

2.8 Tee joint of diameter 150mm and 250mm

Fitting, fixing and installation of MS Tee joints inside the Fluid and Energy Lab including cutting, shaping, trimming and clearing the ends of the Tee joint. The minimum wall thickness of the Tee joint is 6mm. The Tee joints shall be capable to withstand a working pressure of 10 bar as minimum. Before installation the Tee joint shall be coated with tar epoxy resin for the internal part and for the external part with bitumen reinforced with an inner layer of fiber glass tissue and an outer wrapping of bitumen impregnated reinforced glass tissue excepting exposed Tee joint work .

2.9 Pressure gages of range 0 to 10 bar

Supplying, fitting and fixing pressure gages with the following requirements: pressure element: bourdon tube (stainless steel 316L, C-type or helical type), dial: aluminum, white of 15cm dia (minimum), black/red lettering, NS 63 with pointer stop pin., pointer: aluminum, black/red, case: stainless steel, window: laminated safety glass (NS 63: polycarbonate), ring: cam ring (bayonet type), stainless steel ,accuracy: 1.5 (minimum), case filling: with glycerin.

2.10 Vacuum pressure gages of 0 to -1 bar

Supplying, fitting and fixing vacuum pressure gages with the following requirements: pressure element: Bourdon tube (AISI 316L seamless tube), dial: Aluminum, white of 13cm dia (minimum), black/red lettering, NS 63 with pointer stop pin, pointer: Aluminum, black/red, case: Bayonet ring, 1.4301 (304 stainless steel),window: Laminated safety glass, ring: Cam ring (bayonet type), stainless steel, accuracy: 1.5 (minimum),case filling: with glycerin.

2.11 Foundation/base for complete pump test setup

Each of the two complete pump test setup should be mounted at proper position/elevation by making suitable foundation/base. The position/elevation of pipeline, valves, all meters etc. should be suitable for taking reading easily. The foundation/based must be made by 100mm dia and 6mm thick MS pipe with concrete base.

2.12 Star-Delta control panel including capacitor bank

45 kW Star Delta 3 phase pump motor starter with voltage control coils fitted with panel board complete for up to 60 HP pumping system comprising of incoming circuit breaker of sufficient capacity, ammeter with ASS, volt meter with VSS, C/T of proper current ratio and burden, indication light for three phase indicator, comprising main contractor, auxiliary contractors, thermal over load relay, timer, ON/OFF push button, indicating light for ON/Trip, electronic relay for protection against phase failure, phase reverse and dry run, complete with necessary wires, cable lugs, cable ties, connectors capacitor bank. The start delta unit is provided with a timer for automatic changeover of star delta to reduce the voltage and current of motor starting.

2.13 Trolley cum base for centrifugal pump

The centrifugal pump and motor shall have to be mounted on a rectangular trolley cum base. Then the pump and motor will be coupled and fixed through coupling flanges and flexible disc. The required coupling flanges, disc, coupling pin and nut-bolts etc. are to be supplied by the bidder/supplier. The trolley/base is to be fabricated out of new mild steel channel section. The cross sectional dimension of the trolley/base will be as follows: frame: 1530mm×460mm×125mm/matching with pump motor set (should be made of 150mm×75mm×8mm channel) , steel angle (all through), wheel size: dia.38 cm, width10 cm and disc thickness 9mm., foot Bars: 51mm×25.4mm-2 nos. at diagonal ends., tow bar: A detachable tow bar fabricated out of min 40mm diameter with mild steel (M.S.) shall have to be provided., dimension of the trolley cum base must be suitable for mounting of the different size of pump coupled with motor. The trolley cum base should be designed by the supplier and get it approved by the authorized representative of the purchaser before fabrication.

2.14 Welding work

Desired welding rods having about 2.5 kg/sq.cm tensile strength shall be used for all welding works. To handle high pressure welding sufficiently experienced welders shall be selected. In order to ensure perfect penetration of metals during welding, shims may be used. For carrying out butt-welding base plate joints should be placed face to face. With a view to avoiding and wrapping due to over-heat, continuous single in welding must not be done. Precautions to be taken in course of subsequent runs which has to be executed after a thorough cleaning, chipping and grinding the previous welding. Disc grinder for penetrated side finishing and for final finish, light welding to be provided. The steel pipes including fittings shall be welded quality.

When all component have been jointed together completely hydraulic tests to be started on the full length of the complete setup. Two sets of centrifugal and submersible pump motor will be provided for testing both of two setups. The pumping is done at a pressure of 6 bars (minimum), it is kept steady for 4 hours and finally the loss of water in the tank is detected. The maximum leakage shall be maximum 0.1 liter/mm of pipe diameter per kilometer per 24 hours for the applied pressure. If the losses are more, the pipeline shall be declared unacceptable and shall have to be re-laid. Care should be taken that the pipeline and pipe work shall be tested immediately after installation and before it is covered with filling materials.

2.15 Painting

Painting pipes and other fittings with super gloss enamel paint of two coats over a red oxide primer after proper cleaning of surface as per direction of the Engineer in charge.

3. Assembly and trial run

Basically this setup is considered of two circuit and the water flow is controlled by three valves in each circuit. The complete assembled pump test bed is presented in Fig. 5. Two of them are gate valves and denoted by V_1 and V_2. These gate valves which is used to vary internal pressure of flow by changing the gate opening which is ultimately used directly to calculate the head. Another one is motorized flow control valve .This valve is denoted by V_3. The flow diagram for one set of pump test bed is shown in Fig. 6. The discharge is measured by flow meter. When centrifugal pump is attached to the setup, valve V_2 is kept close and valve V_1 and V_3 remains open to flow the water from pump to measuring tank. When submersible pump is attached to the setup, valve V_1 is kept close and valve V_2 and V_3 remains open to flow the water from submersible pump to measuring tank.

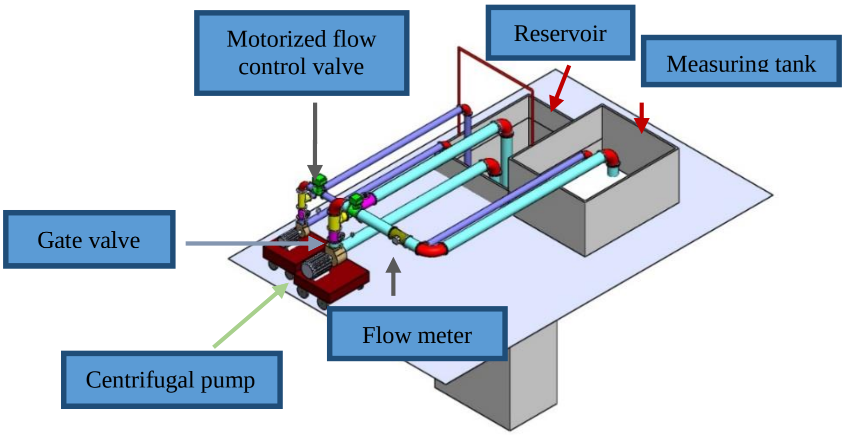

Fig. 5**:** Assembly of pump test bed

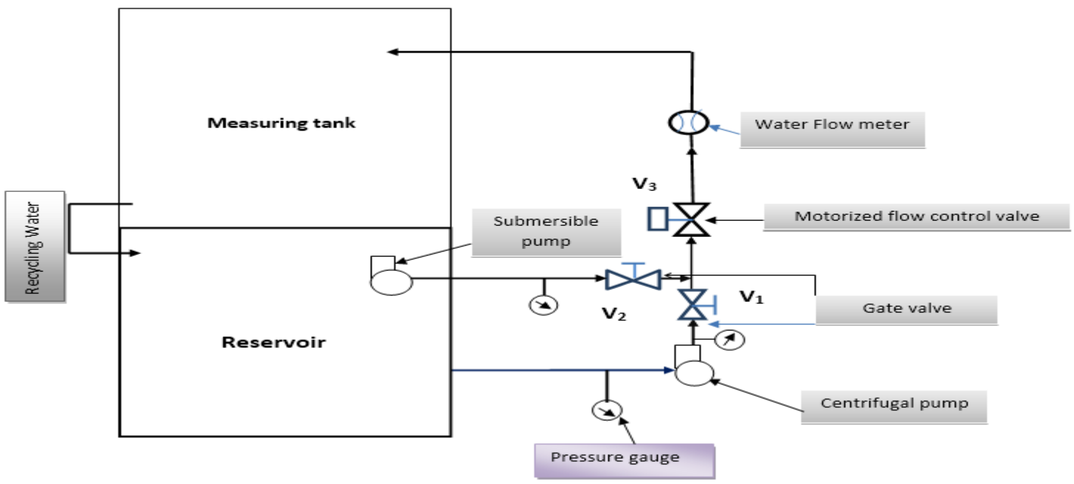

Fig.6: Flow diagram of a single set pump test bed

4. Conclusions

The total successful design has been completed considering all issues for a pump test bed. Operating requirements may sometimes override energy cost considerations; an optimum solution is still possible. A greater understanding of all the components that make up the total cost of ownership for the pumps will provide an opportunity to dramatically reduce energy, operational, and maintenance costs.

5. Acknowledgement

The work has been carried out under subproject (CP No.: 3615), financed by the Higher Education Quality Enhancement Project (HEQEP), University Grant Commission of Bangladesh (UGC). The authors would like to express their sincere gratitude and thanks to the Barind Multipurpose Development Authority (BMDA) and Rajshahi WASA for providing necessary information and opportunity to study their different water pumping sites.

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