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REACTIVATION OF FORCED VORTEX APPARATUS FOR FLUID MECHANICS LABORATORY

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ABSTRACT

In view of poor funding of education and the passion to ensure that students continue to get the right practical skill in Nigeria, there is the need for various institutions to adequately maintain their practical equipment. Reactivation of Forced Vortex Apparatus for Fluid Mechanics Laboratory was necessary because of the bad state of the apparatus which has prevented students from using it for experiment. Physical and operational examinations were carried out on the apparatus and it was discovered that some component parts such as the electric motor, the piezometer and the regulator were in bad working condition. Some of the faulty parts were repaired while some were replaced. Performance evaluation of the reactivated apparatus was carried out. The results of the experiment performed using the apparatus were recorded at various speed of the electric motor. The results showed parabolic trend of a vortex for radius against pressure head at varying speed. Reynolds Number (Re) based on the calculated results, showed that the flow was turbulent since it was greater than 4000.

KEYWORDS: Forced vortex; Parabolic; Piezometer; Reactivation; Reynolds Number; Turbulent flow

INTRODUCTION

The study of fluid flow on which the vortex apparatus is based, is one of the few areas within engineering field that truly crosses the boundaries between the various engineering disciplines. The concept of vortex flows is important in many engineering applications of fluid mechanics. It is of equal importance to mechanical, civil, chemical and processing, aeronautic and environmental and building services engineers.

A vortex is described as the mass of whirling fluid or wind. An ideal flow is a pure theoretical concept as such flows possess no viscosity, compressibility, surface tension or vaporization pressure limit. However, the mathematical analysis of such flows was fundamental in the development of aerofoil lift, fan/pump blade design and ground water flow predictions. The flow circulates about a fixed centre and the streamlines are concentric circles. The classification of vortex flows depends upon the functional relationship between the flow velocity and radius.

Majorly, there are two classifications which are: free vortex and forced vortex. The free vortex is a rotating body of fluid whose streamlines form concentric circles. No force is exerted to sustain the free vortex (Olu, 2005). The flow velocity is inversely proportional to the radius and the total head in the flow field remains constant. In the forced vortex, the whole body of the fluid rotates as if it is a solid and the velocity is directly proportional to the radius (Wikipedia, 2014).In this type of flow, the fluid mass rotates at a constant angular velocity (ω). This paper shows the experiment of an idealized flow. The application of ideal theory is found in aerodynamics in acceleration flow, tides and waves. When the type of flow is such that the streamlines are concentric circles, they are known as vortex flows (Fox *et al,* 2004). It occurs around a cylinder for any fluid provided there is a Reynolds Number (Re) of between 49 and 10^7. A very low Re flow is sometimes called a creeping flow (Mohanty, 2014).

Reynolds Number (Re) is a dimensionless number that gives a measure of the ratio of inertia forces to the viscous forces and consequently quantifies the relative importance of these two types of forces for a given flow condition. The concept was introduced by George Gabriel Stokes in 1851 but the Reynolds Number is named after Osborne Reynolds (1842-1912) who popularized its use in 1883.

Theoretical background

The tangential velocity of any fluid particle is given by:

$$v = \omega r \quad (1)$$

(Where r = radius of the fluid particle from the axis of rotation).

Therefore, angular velocity

$$\omega = \frac{v}{r} = \text{(constant)}.$$

Reynolds Number frequently arises when performing dimensional analysis of fluid problems and as such can be used to determine dynamic similitude between different experimental cases (Zagarola & Smith, 1996).

Reynolds number computation can be carried out using equation 2 as given by

$$Re = \frac{\rho d V}{\mu} = \frac{Vd}{\nu} \text{ (Rajput ,2013)} \quad 2$$

Where, Re = Reynolds Number

ρ = density of water ($\frac{kg}{m^3}$)

d= diameter of the cylinder (mm)

V = linear velocity (m^2/s)

μ = dynamic viscosity (pa.s or N.s/m^2)

v=Kinematic viscosity= $\frac{\mu}{\rho}$

Taking kinematic viscosity of water to be 10^{-6}m^2/s

But, v =$\boldsymbol{\omega}$r

Where, $\boldsymbol{\omega} = \frac{2\pi N}{60}$, v = $\frac{2\pi N r}{60}$

Therefore, Re = $\frac{2\pi N r d}{60\, v}$

Where, (r =$\frac{d}{2}$) and d = 2r

Therefore; Re = $\frac{2\pi N r.2r}{60\, v}$

$$Re = \frac{4r.r\pi N}{60\, v} \text{ (Fox et al., 2004)} \quad (3)$$

MATERIALS AND METHODS

Dismantling of the Apparatus.

The apparatus was dismantled to remove damaged parts. Some of these parts were repaired; some were fabricated, while some were purchased from the market.

The Piezometer

The piezometer, as shown in fig 1, consists of stand, plywood board, and capillary tubes with meter rules on both sides. The stand is made from flat bar of 2300mm long and 35mm wide. This flat bar is bent at 75^0 to form a right angle triangle. The vertical side of each triangle is drilled at two points at 50mm to each other. These serve as a means of bolting the plywood board on the stand. The plywood board is 960mm by

500mm in dimension and white Formica is gummed to the front, back and the sides. Four holes are drilled on the board, which coincides with the holes on the stand so that the board can be bolted on the stand through the holes. The capillary tubes made of plastic, each with outside and inside diameter of 6mm and 4mm respectively, are fixed to the board by means of two small planks of size 300mm x 20mm. Each plank has 12 grooves so that, the tubes can be held in it without slipping down. The planks are screw to the board at the top and bottom to hold the tubes in position. The piezometer is the part of vortex apparatus, which is used for measuring the pressure head at different radius of the water in the cylinder. This pressure head is developed by the centrifugal force of the impeller.

The Impeller

An impeller is a device through which energy is transferred to a fluid through rotation or by which energy is transferred from a fluid to set that device into rotation. In the operation of a vortex apparatus, it requires that the impeller transfer energy to a fluid. Out of the three types of impeller that are available i.e the simplified radial flow (centrifugal blower), tangential flow (impulse turbine), and axial flow (engine turbine). It is simplified radial flow that can easily achieve the desired result. Also, the impeller is a form of centrifugal pump, which will allow water to be pumped into the small opening under the cylinder which serves as the pressure tapping point where the piezometer is connected so that the pressure head can be read directly on the piezometer tube stand. The impeller shaft is made from a mild steel rod which is 30mm diameter and 250mm long. 200mm of the rod is turned to 12mm diameter and 30mm long is threaded from the other side as shown in Figure 2.

The Speed Control System

Since the equipment is mainly dependent on the speed, it is necessary to know the speed of the electric motor and how it is stabilized by the regulator. A wire is connected to the armature supply and the field supply in the electric motor from the regulator, another wire is connected to the input voltage from the regulator, thus, making the regulator acts as an intermediary between the electric motor and the input voltage (mains)

The regulator operates to stabilize the electric voltage going into the electric motor causing a balance of voltage in the electric motor, when it is at work. The regulator also operates to increase or decrease the speed of the rotating impeller by reducing or increasing the amount of voltage entering the electric motor. The connection diagram for the control of the regulator is as shown in Figure 3.

Electric motor

The electric motor of the forced vortex apparatus was rewound and serviced. Proper connections were made on the armature and the field supply. The electric motor is rated 0.25 horse powers, 50Hz, having a maximum speed of 1400 r.p.m.

Assembly of the apparatus

The parts of the apparatus are assembled together with bolt and nuts. The cylinder is bolted to the frame and the electric motor is bolted to the base of the frame. The gear box is couple to the electric motor by means of a flange coupling and the output end of the gear box is coupled to the impeller shaft by a hollow shaft which has holes on it at both end so that the gearbox output shaft and the impeller shaft can be connected together by using pins which pass through the holes and through the holes that are on both shaft. The piezometer is bolted to its stand and its tubes are connected to the pressure tapping radius by hose.

Various views of the assembled apparatus are shown in plate 1 to 4.

Experimental Procedure

Water is admitted into the cylinder through the drain hole to a noted level which is above half the depth of the cylinder but it should not be up to the brim to avoid spillage during the experiment. After this, the drain hole is closed and the desired speed is selected on the speed regulator. Then the electric motor is switch on and left to run to its full speed. The piezometer is observed until there is no more increase or decrease in water level in the tubes before any reading is taken. When taken readings the total head corresponding to each radius is measured, i.e. the height of water at each point using the base of the cylinder as the datum.

RESULTS AND DISCUSSION

The result of the experiment performed with the reactivated apparatus is as presented in Table 1. By substituting the value of the speed into equation (3), when N = 60 r.p.m,

$$Re = \frac{4\ x 0.0215\ x\ 60\ x 3.142}{60\ x\ 10^{-6}} = 270{,}212.1$$

Also, when N = 50 r.p.m

$$Re = \frac{4\ x 0.0215\ x\ 50\ x\ 3.142}{60\ x\ 10^{-6}} = 225{,}176.70$$

Table 1 showed clearly that at a speed of 60 rpm, as the radius increases from 20mm to 120mm, the measured head reduces from 480mm to 50mm but, as from the radius of 140mm to 240mm the measured head increases from 70mm to 480mm.

Also, at a speed of 50 rpm, the measured head at the radius of 20mm was 480mm.This value decreases to 250mm at a radius of 120mm but, the head started rising from 260mm at a radius of 140mm to 470mm at a radius of 240mm. These cases were also shown graphically in fig 3 and 4. In both cases, the figures showed clearly the parabolic shape of a vortex and since the Reynolds number in each case as calculated above was greater than 4000, the flow in each case according to Osborne Reynolds, was turbulent.

CONCLUSIONS

The forced vortex apparatus was reactivated and tested. The results of the experiment conducted using the reactivated apparatus showed that the Reynolds number (Re), at each speed of the electric motor, was greater than 4000.This value according to Osborne Reynolds, implies that the flow in the cylinder was turbulent hence, the reactivated apparatus is efficient and suitable for Laboratory experiments.

REFERENCES

Fox, R.W., McDonald, A. T., & Pritchard, P. J. (2004). *Introduction to Fluid Mechanics.* (6th ed.). Hoboken, London, United Kingdom: John Wiley and Sons.

Mohanty, A. K. (2014). Fluid Mechanics. (2nd ed.) Delhi, India: PHI Learning Private Limited.

Olu, O. (2005). *Fluid Mechanics*. Development of Learning Materials in Engineering Education (DELTMEE), UNESCO Africa Regional Project, University of Lagos Press, Akoka, Lagos, Nigeria.

Rajput, R. K. (2013). Fluid mechanics and hydraulic mechanics. (5th ed.). New Delhi, India: S. Chand Limited.

Wikipedia (2014). *Free-forced-vortex flow.* Retrieved from html://eeepune.tradeindia.com/free-forced-vortex flow apparatus (29th Sept., 2014)

Zagarola, M.V., & Smith, A. J. (1996). Experiment in high Reynolds number turbulent pipe flow. *34th AIAA Aerospace sciences meeting, Reno, Nevada*, 0096-0654.

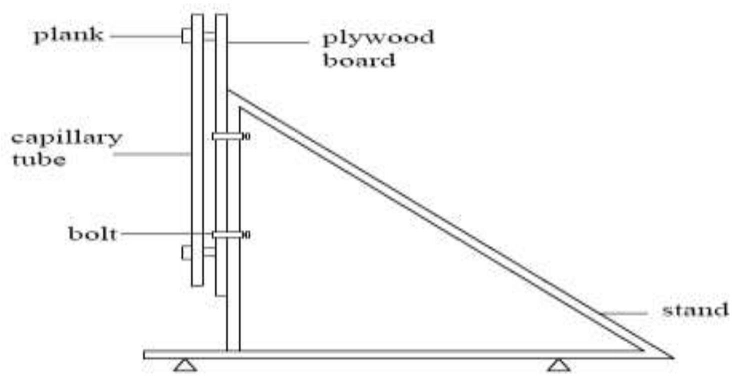

Figure 1. The piezometer stand and Plywood carrying the capillary tube.

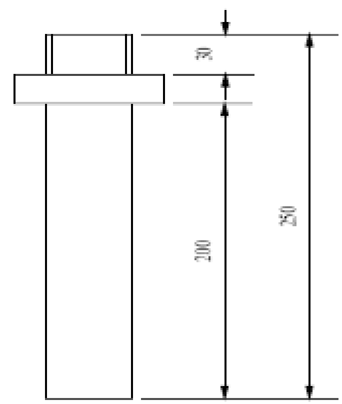

Figure 2. The Impeller shaft

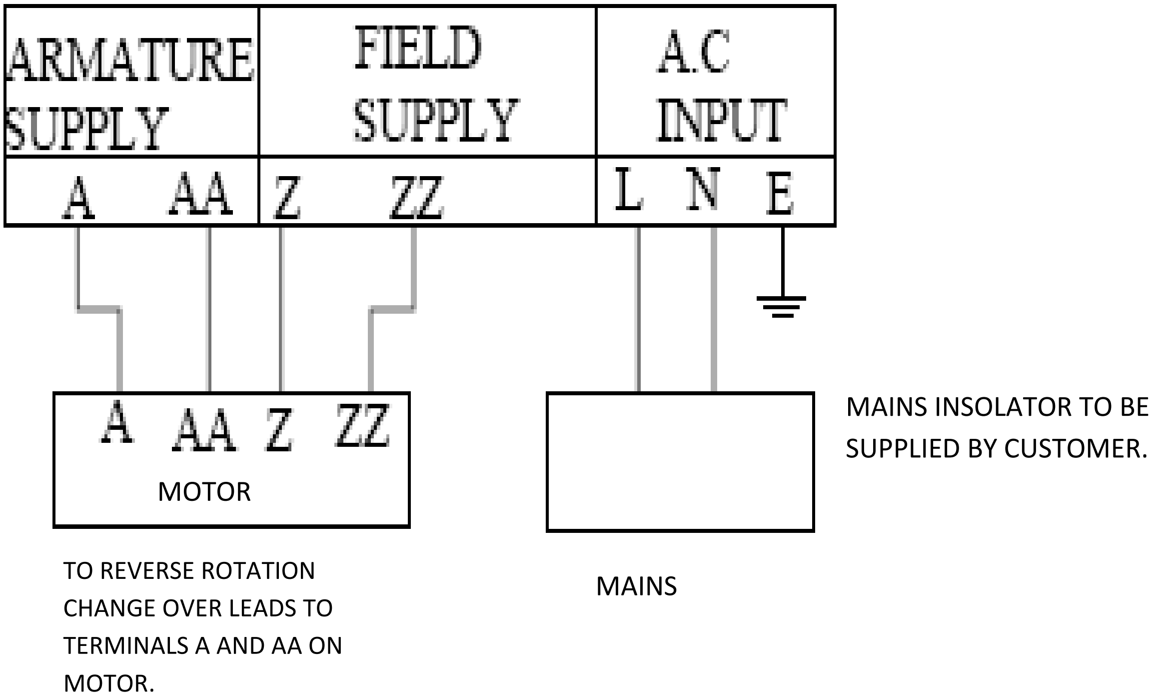

Figure 3. Connection diagram of the speed controller. (Source: Navy Electronic Commerce Online Europe limited)

Table 1: Results from the experiment.

Speed rpm) N	Measuring positions, r												
	1	2	3	4	5	6	7	8	9	10	11	12	
	20	40	60	80	100	120	140	160	180	200	220	240	Radius r mm
60	480	350	262	184	100	50	70	150	210	300	392	480	Measured H mm
50	480	403	365	310	284	250	260	275	320	355	410	470	Measured H mm

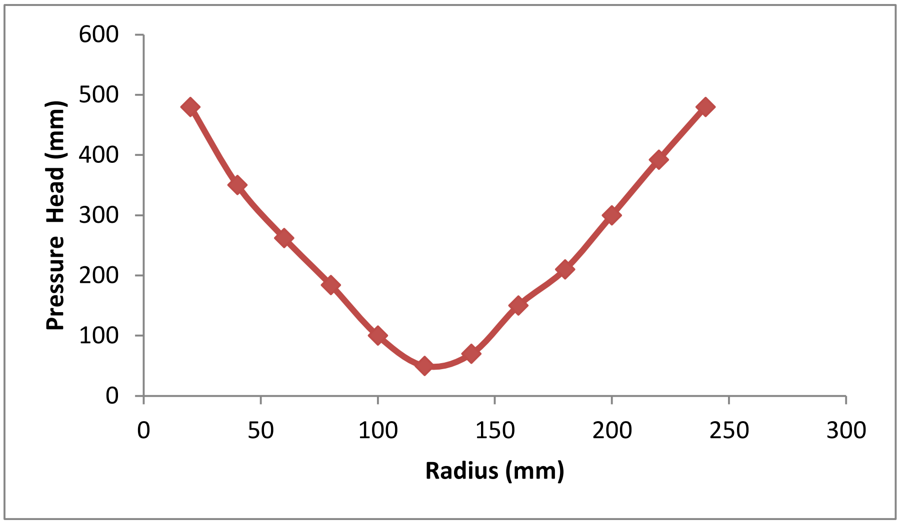

Figure 4. Pressure head at 60r.p.m

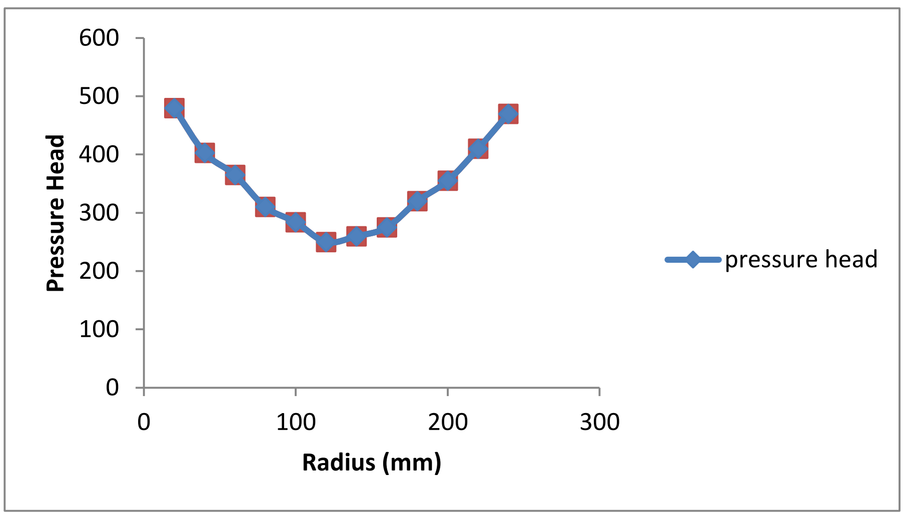

Figure 5: Pressure head at 50 r.p.m

Plate 1. Isometric view, showing the piezometer

Plate 2. Side view of the forced vortex apparatus

Plate 3. Isometric view of the forced vortex apparatus

Plate 4. Front view of the speed control system