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Design and Field Testing of Bulb Turbine for Utilization of Ultra Low Head Energy

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Abstract

Hydro power is an important form of clean energy. Most turbines in Nepal are medium and high head which can work efficiently only where high head water resources are available. Nepal being a topographically challenging, much of the low water head sites are not utilized. Ultra-Low head(below 3m) turbine can be used in the low water head sites. This can help in rural electrification and may aid to compensate increasing energy demand in society.

This research gives brief introduction to the design procedure of the bulb turbine. Prototype of Bulb Turbine was designed for 1.2 m of hydraulic head at prototype flow rate of 38 lps. The 349 W turbine was designed and tested. The runway speed of 354 rpm was attained at the design flow rate of 23.71 lps.The testing of the turbine was done in the Bagmati river with the measurement of torque using brake dynamo meter. As the test site did not provide design flow rate of 38 lps, the prototype was tested at flow rate of 23.71 lps at part load of Qo/Qmax equal to 0.624 and the resulting maximum overall efficiency was 23.37% at 354 rpm. By this finding, the full load efficiency of turbine could be approximated to be greater than 23.37% as maximum efficiency of turbine is full load flow.

Keywords

Bulb Turbine, Ultra-Low Head, Axial Flow, Efficiency, Micro-Hydro Power

Acronyms

[MW]	Mega Watt
[KW]	Kilo Watt
[mm]	millimeter
[m]	meter
[m/s]	meter per second
[rpm]	rotation per minute
[N]	Newton
[Nm]	Newton meter
[g]	Acceleration due to gravity
[Q]	Flow rate

1. Introduction

Nepal is mountainous country with number of streams, rivulets and rivers from which 40,000 MW can be economically extracted [1]. For generation of the large electric power plant, the unit cost of electricity and geographical condition of the Nepalese villages, transmission and distribution cost is very high. Hence small hydro is a good solution for the Nepalese rural area electrification. Further, different micro hydro sites offer different combination of head and flow configuration, there is a need for a wide range of technologies that are able to respond to these diverse configurations.

The bulb turbine is a reaction turbine is used for extremely low heads. The characteristic feature of this turbine is that the turbine components as well as the generator are housed inside a bulb, from which the name is developed [2]. Most of the turbines used in Nepal are medium or high head turbines. These types of turbines are efficient but limited for rivers and streams in the mountain and hilly region which have considerably high head.

Hydraulic head below 3m is termed as ultra low head [3]. Ultra low head turbines can be used in the plain regions where head of water resources is low [2]. This helps in the rural electrification and decentralized units in community, reducing the cost of construction of national grid and also to its dependency, in already aggravated crisis situation. As numerous sites with ultra-low head and high flow which are yet to be exploited as the cross flow, pelton turbine, francis turbine are not suitable in these conditions. Furthermore, having ultra-low head, bulb turbine are economically feasible. Besides these ultra-low head turbine will have the added advantage of exploiting in existing irrigation canal or reusing the water from the tail race of an existing power plant.

In particular, Bulb turbine shows extraordinary flexibility in its application. From small to large, from run-of-river to tidal, and from fixed to variable-speed, bulb turbine can efficiently extract energy from head within range of 0.5m to 30m.

Since, Nepal is rich in water resources and has great potentiality to generate electric energy. Nepal has great import of petroleum products from foreign countries. Nepal's main source of energy is fossil fuel and bio-mass which is environmentally unfriendly and have adverse effect on health and environment. We should research clean, cheaper and environment friendly technologies and find ways to adopt these technologies for progress and development of country.

The use of the bulb turbine can be a good idea for harnessing the water potential in the Terai region. Micro hydro plants are easy to construct and they don't need huge amount of money for their construction and operation. Use of bulb turbine in the micro hydro plants further reduces the cost and technical difficulty as this turbine reduces the civil works. Size of plants using bulb turbine is small and civil works for the plant using bulb turbine is much less. Higher full-load efficiency and higher flow capacities of bulb turbines can offer many advantages over vertical other turbines. Bulb turbine is also suitable for the streams with high silt load and more eco-friendly than other types of turbine.

2. Literature Review

The bulb turbine is a reaction turbine used for extremely low heads. Many research works have been conducted in bulb turbines. [4]The author published a paper on bulb turbine design, selecting design details and calculations methods of the Igarapava, project in Latin America. The paper concludes bulb turbine concepts and developments of nineties. [5] The author carried out the work in improving the operation reliability of bulb turbine. It was indicated that value of axial hydrodynamic force depends on discharge and the opening of turbine control.[6]In 2010, the author tested model and performed CFD calculation of a cavitation on bulb turbine. The study found that the CFD can be seen as a valuable tool in the early design phase with respect to cavitation. An exact determination of operating limits of the prototype is, however beyond the capacity of nowadays CFD-simulations. [7] devised a modification method on runner blades in a Bulb turbine. In this paper a modification method of the runner blades in a Bulb turbine was proposed, in which the main scale of the runner being maintained. [8] In 2011, the author published a paper on Design of the rotor blades of a mini hydraulic bulb-turbine. The author study showed that the rotor blades produce with very good approximation the desired turbine head at the design condition of zero angular momentum at the exit section.In 2012, the author [9] published paper and studied performance of a bulb turbine suitable for low prototype head through model test and transient numerical simulation. The study shows that head loss in outflow channel occupies more than 50% proportion of turbine hydraulic loss, where flow separation and secondary flow occurs severely.

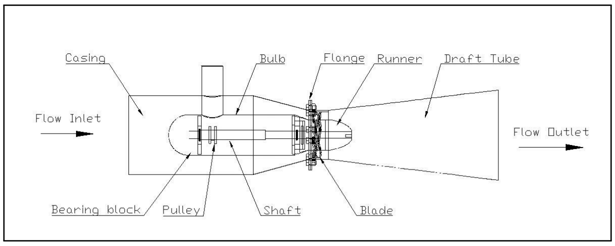

Figure 1: Drawing of Designed Turbine

3. Design Summary

The Bulb turbine is a reaction turbine which is used for the extraction of energy from low head water resource. As the generator resides inside bulb or generator hatch from which the name of turbine is developed. A main difference from the Kaplan turbine is moreover that the water flows with a mixed axial-radial direction into the guide vane cascade and not through a scroll casing. A general design procedure prepared by Robert Simpson and Arthur Williams is used for turbine runner design for this research as a reference and some modification is done in the design as per requirement of research[10].

At first key parameters were selected for the design of turbine i.e Head (H), Flow Rate (Q), and rotational speed of generator shaft (N) for design of bulb turbine. The design of bulb turbine is done mathematically for flow rate of 38 l/s at 1.2 m head according to test site. Rotational speed of generator shaft was taken 1500 rpm.

Runner Design:
Propeller runner without camber and twist was designed for bulb turbine. As design parameters were fixed hydraulic efficiency was assumed to be 78%. Using parameters of turbine, the power was calculated as 349W by using equation 1.

$$\text{Output Power} = \eta * \rho * g * Q * H = 349Watt \quad (1)$$

$$K_{(ug)} = -5*10^{-6}N_q^2 + 0.00647N_p + 0.651786 = 1.97 \quad (2)$$

$$r_{(tip)} = \frac{K_{(ug)} * \sqrt{2*g*H}}{w} = 0.06 \quad (3)$$

$$\frac{D_{(hub)}}{D_{(tip)}} = 0.66 \quad (4)$$

Using equation 2 based on Demetriades thesis based on Bohl graph [10], Ratio of velocity of tip to velocity of hub (Kug) was found to be 1.97, where Nq and Np are specific speed based on flow and speed respectively. The ratio of hub diameter to tip diameter was found to be 0.66. The tip to tip diameter of runner was calculated by using equation 3. Since ratio of hub diameter to tip diameter was known to be 0.66, hub diameter was found to be 0.08m. The number of blade was taken as five from graph .

The blades without camber and twist were designed for fabrication ease. The dimension of runner and blade are shown in figure 2 and figure 3 respectively.

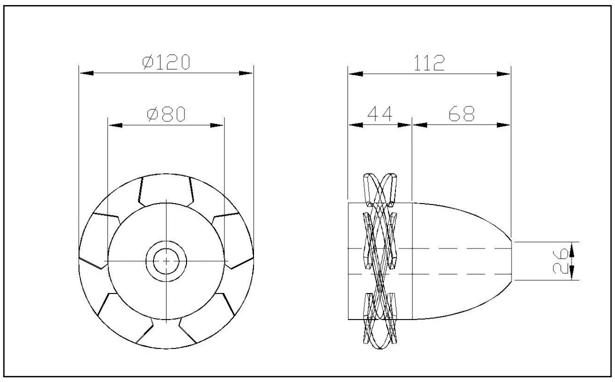

Figure 2: Turbine Runner

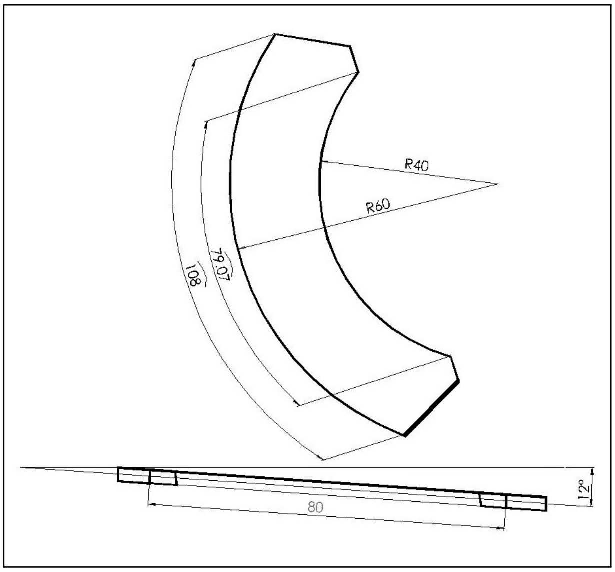

Figure 3: Runner Blade

Generator Hatch:
Bulb turbine arrangement consist of bulb shaped watertight housing in which generator is and shaft is mounted which is called generator hatch of bulb. But in this research generator was not mounted in generator hatch because objective of research was to measure shaft output power. Dimensions of generator hatch are shown in figure 4.

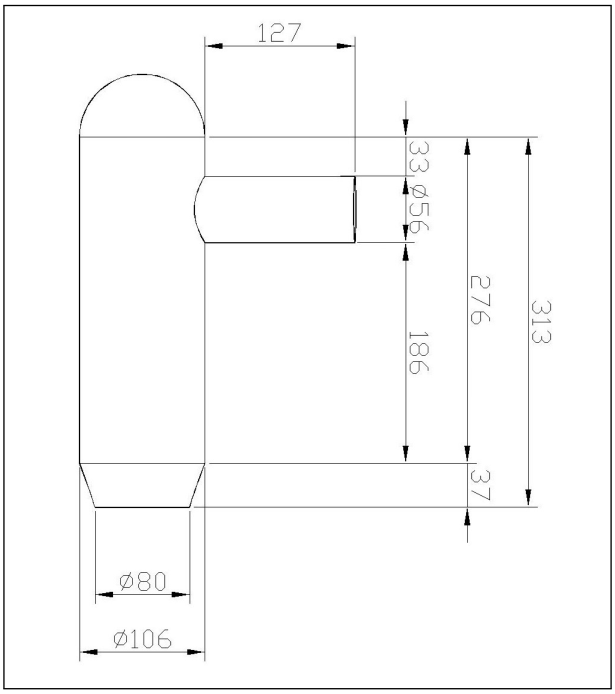

Figure 4: Generator Hatch

Turbine Casing:
Casing is an arrangement that forms case around the

bulb turbine from which water enters in the turbine. Casing was designed such that it can allow smooth and required flow for the runner. Dimensions of turbine casing are shown in figure in 5.

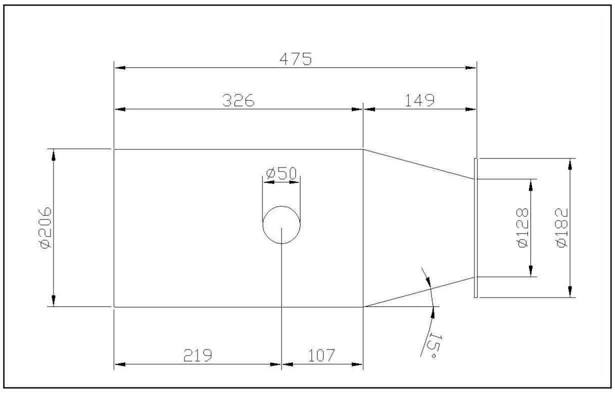

Figure 5: Turbine Casing

Draft Tube Design:
Draft tube converts kinetic energy of exit water from runner into pressure head which increases the overall efficiency of turbine. It also helps to reduce cavitation in the runner. Dimensions of turbine casing are shown in figure in 6.

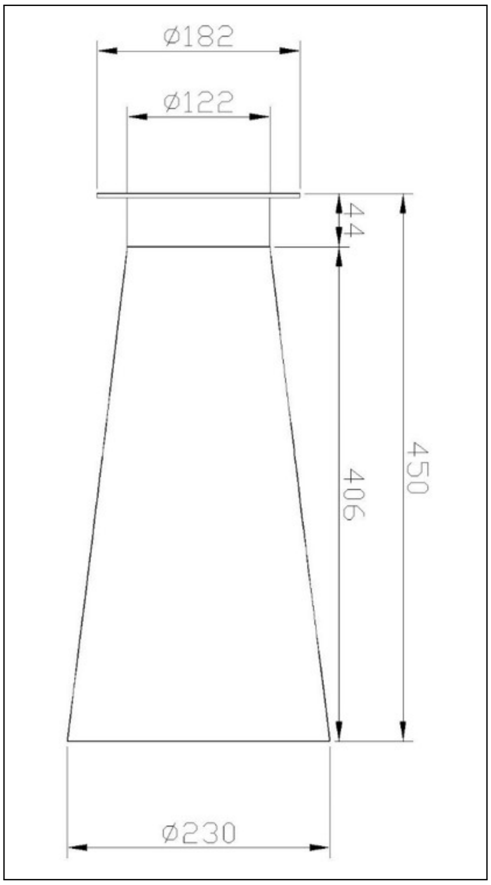

Figure 6: Draft Tube

4. Fabrication

First market study was analyzed to find the suitable place with efficient cost to fabricate our turbine. Locally available workshop was selected for fabrication of bulb turbine assembly. Two labours were used during fabrication process and it took nearly one month to fabricate the complete assembly as there was lack of availability machine for fabrication which has to be done manually and lots of changes and optimization was done during fabrication.

Figure 7: Turbine Runner

4.1 Components and their fabrication procedure

Turbine Runner:
Runner without camber and twist was chosen for the research. Runner hub was fabricated by using lathe machine from cylindrical steel block and point wise grinding method was used to produce parabolic part of runner. Blades were made from cutting 3mm thickness mild steel plate and finally arc welded to hub. Fabricated turbine runner for this research is shown in figure 7.

Runner Shaft:
The stepped shaft was fabricated using lathe machine through turning of the shaft for the respected design dimension.Fabricated turbine runner for this research is shown in figure 8.

Figure 8: Turbine Shaft

Generator Hatch:
At first surface development of the bulb was done and mild steel sheet was cut according to surface development Cylindrical and conical part of bulb of turbine was fabricated by roll bending machine. Semi-hemispherical part was made available from the market because of manufacturing complexity. Fabricated turbine runner for this research is shown in figure 9.

Figure 9: Generator Hatch

Turbine Casing:
At first surface development of the casing was done and mild steel sheet was cut according to surface development. Casing was fabricated with the help of roll bending machine and arc welded according to specified design. Fabricated turbine runner for this research is shown in figure 10..

Figure 10: Turbine Casing

Draft Tube:
At first surface development of the draft tube was done and mild steel sheet was cut according to surface development. Draft tube was fabricated with the help of roll bending machine and arc welded according to specified design. Fabricated turbine runner for this research is shown in figure 11.

Figure 11: Draft Tube

5. Testing and Analysis

5.1 Test Preparation Tools and site

On the basis of required head and flow rate, river was found to be suitable for testing of fabricated bulb turbine. Head of the test site was 1.2m. Test was performed on the concrete stepping of having 1.2m height. Tools used for test preparation are as below:

1. Penstock
2. Tachometer
3. Brake Dynamo-meter
4. Elbows
5. Planks
6. Rocks
7. Rope
8. Mild steel Angles

For test arrangement, Turbine was fixed under the river stepping with the help of rocks. Pipe of 6 inch diameter was connected with inlet of turbine with elbow and reducer as penstock. River water was diverted in penstock inlet with the help of planks. Suitable arrangement was made to position two brake dynamo-meter to measure the brake force of turbine shaft. Turbine shaft was fixed with pulley and rope was used to apply braking force to shaft of pulley. Tachometer was used to measure rpm of the shaft.

Figure 12: Test Site

5.2 Data Calculation

It was decided to conduct the test of turbine in river by making suitable arrangement to measure the output shaft power by using brake dynamo-meter. Rotational speed(speed) of shaft was measured with tachometer. Braking force was applied in the pulley attached to turbine shaft using brake dynamo-meter.

Required Parameters:

$$\text{Breaking Torque (T)} = (F_1 - F_2) * R \quad (5)$$

$$\text{Angular Speed (w)} = \frac{2 * \pi * N}{60} \quad (6)$$

$$OutputPower(P_{out}) = T * w \quad (7)$$

$$InputPower(P_{in}) = \eta * \rho * g * Q * H \quad (8)$$

$$Overallefficiency(\eta) = \frac{P_(out)}{P_(in)} * 100\% \quad (9)$$

Where,
F1, F2 are force reading in first and second brake dynamo-meters.
R is radius of the pulley fixed in runner shaft where the brake is applied.
N is rotation per minute(rpm) of the runner measured by tachometer.

Turbine Installation at Test Site:
Bulb turbine was tested in Bagmati river by making suitable arrangements. Wooden planks were used to accumulate the flowing river water at the inlet of penstock. The outlet of penstock was connected to the casing of turbine with the help of elbow. Braking force was applied in the runner shaft by dynamo-meter and measured by spring balances Runner shaft rotational speed(rpm) by measured by tachometer.

Input Parameters and test result:
Due to unavailability of flow for full load, turbine was tested at part load of 0.624Qmax i.e. 21.71L/s. Test parameters of bulb turbine are as below:

Design flow rate(Q_{max}) = 38 L/s

Test flow rate (Q) = 23.71 L/s

Design Head (H) = 1.2 m

Input power (P_{in}) = 279 W

Radius of Pulley (R) = 0.023 m

Table 1: Test Results

F1	F2	T(Nm)	rpm	P_{out}(W)	Eff. (η)
0.00	0.00	0.00	900	0.00	0.00
2.65	4.80	0.79	700	35.60	12.75
2.10	6.00	0.88	550	50.68	18.16
2.30	7.50	1.17	455	55.90	20.03
1.80	8.00	1.40	431	63.14	22.62
0.12	7.80	1.73	356	64.64	23.17
2.10	10.00	1.76	354	65.24	23.37
2.10	11.00	2.01	288	60.56	21.70
1.10	12.00	2.46	200	51.51	18.45

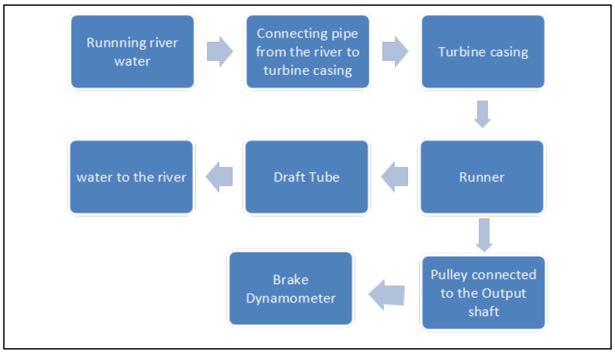

Figure 13: Block representation of test turbine rig

Figure 14: Bulb Turbine

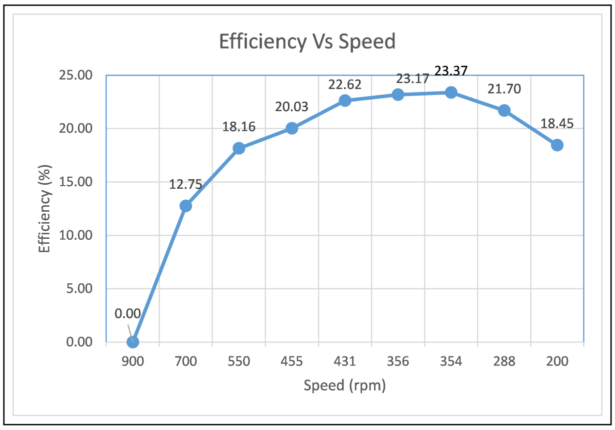

Figure 15: Graph of Efficiency Vs Speed

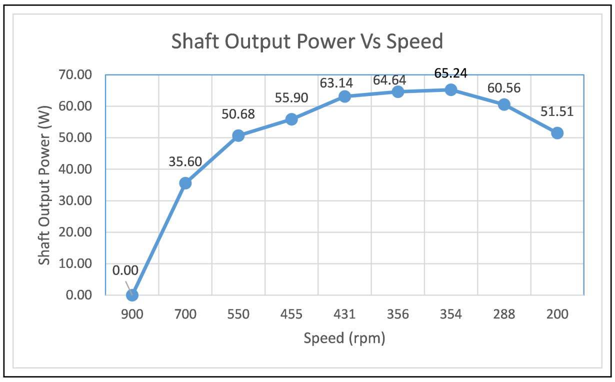

Figure 16: Graph of Shaft Output Power Vs Speed

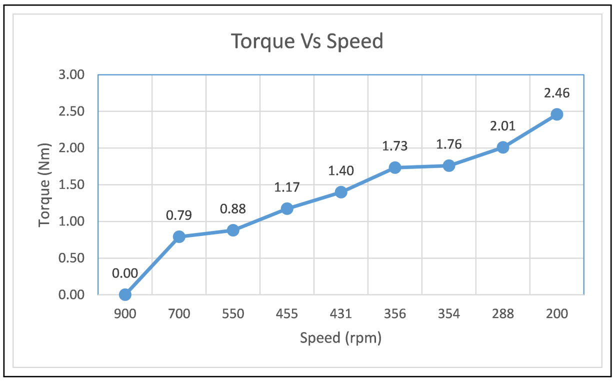

Figure 17: Graph of Torque Vs Speed

5.3 Result Discussion

Due to the unavailability of design flow, testing was conducted in part load operating conditions RPM and torque were measured multiple number of times to obtain the average power produced by the turbine and the maximum mechanical efficiency was found out to be 23.371% at 354 rpm as shown in figure 15. Input head was 1.2 m, which is as according to design and flow rate was 23.71 L/s, which is part load. Test results show lower efficiency of the turbine but efficiency of the turbine can be increased sufficiently by design optimization, precise fabrication and proper testing of turbine. The research lacked design optimization, which resulted in lower efficiency and main cause for lower efficiency was lack of fabrication according to specified design. Due to unavailability of appropriate turbine test rig was also reason for lower efficiency. The mechanical efficiency at full load cannot be estimated without proper testing procedure. Meanwhile, it can be understood that the overall efficiency of bulb turbine without guide vanes at full load is for sure greater than 22.37% because of the reason that part load efficiency is 22.37%. Maximum shaft output power was measured as

65.24W at 354 rpm of runner shaft speed as shown in figure 16. Figure 17 shows that maximum rotation speed attained by runner shaft was 900 rpm at no braking torque and as torque is applied in runner shaft runner rotational speed went on decreasing.

6. Conclusion

This research was the outcome of project for fulfillment of Bachelor in Mechanical Engineering curriculum. From this research, it can be concluded that bulb turbine can be used in hydro power plants to extract energy from low head water resources like rivers and canals by adjusting suitable head and flow. Further, prototype of bulb turbine was developed for extracting hydraulic energy from ultra-low head water resources.Bulb turbine with propeller runner without camber was designed, fabricated. Field test of bulb turbine assembly was performed.

The research paper can be further extended by part load maximum efficiency at Qo/Qmax i.e. 0.624 to obtained 22.37% at 354 rpm which is less than our expectation. Efficiency can be increased by making appropriate test arrangements, by optimizing the design by using CFD software and precise manufacturing. The full load efficiency was estimated to be more than that of obtained part load efficiency so to measure more accurate performance of turbine, turbine should be tested at full load. The actual efficiency can be higher than the test efficiency due to several losses like vibration losses, water leakage etc that were encountered while testing in this research. The draft tube should be fully submersed in the water to get maximum efficiency but during the turbine testing, the draft tube was partially submersed in the water which was also the reason for lower efficiency. For precise measurement of performance, bulb turbine should be tested in appropriate test rig for number of iterations.

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