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Spent Flow Discharge Apparatus for Instream Hydro Power Turbine

I. A fundamental challenge of design

Downeast Turbines has been working since 2009, designing, modeling, building, and testing multiple turbine prototypes while observing and analyzing fluid flows, in nature directly and through reference videos and photographs, in order to meet a fundamental challenge of design. Finding a means to discharge effectively the spent flow of an instream hydro power turbine constitutes a problem of universal concern in the hydropower industry, yet few in the industry seem to have it resolved.

An instream hydropower turbine is immersed in a tidal flow, or other ocean stream, to harvest some of its power. Energy exists in the stream’s pressure and speed, and for an instream hydropower turbine that energy is primarily kinetic, due to the motion or flow of the stream. The hydropower turbine has blades or vanes that rotate, turn a shaft, and power a useful load. The power is derived from a portion of the stream flow that enters in the turbine and pushes against its blades.

The portion of stream flow that enters into the turbine and pushes against its blades gives up, or “spends,” some of its energy to power the turbine’s load. Having less energy, that portion of flow now “spent,” is discharged back to the ambient stream. Spent flow must be removed speedily and effectively from within the turbine to let new, energetic flow enter in. By improving the spent flow discharge of a turbine immersed in a stream, a greater amount of energy can be obtained from the stream.

United States Patent Application, Pub. No.: US2015/0086327 A1, Pub. Date: March 26, 2015, “Spent Flow Discharge Apparatus for an Instream Fluid Power-Extraction Machine,” (Ref. 1), summarizes the problem:

“A … problem [at an instream hydropower turbine] is that the spent fluid must be discharged back into the ambient fluid stream that is flowing around the immersed machine, but the spent fluid has a lower total pressure and lower total energy, in comparison to the surrounding ambient flow because some of the captured fluid’s energy has been extracted by the machine.”

Finding a means to discharge effectively the spent flow of an instream hydro power turbine constitutes a fundamental challenge of design. A spent flow discharge apparatus to meet that challenge is presented here.

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II. The problem defined

Before interacting with an instream hydropower turbine an ocean current has kinetic energy contained in its momentum of flow. As a portion of the flow passes through the machine, the turbine blades, of whatever form they might be, draw upon that energy and reduce it in proportion to the power that is obtained. After passing through the machine the portion of flow with kinetic energy reduced, the "spent flow," is discharged from the machine. The term, "discharge," refers to the removal of spent flow from the machine and its re-entrainment back into the ocean stream. As the momentum of spent flow has been diminished in the machine, the forces that carried fluid into the machine are not available in the same degree for carrying that fluid away. The speed and pressure are less. The paradox is depicted in a clever cartoon in a Wikipedia entry entitled "Betz's Law." Two molecules, full of energy, approach a wind turbine rotor. One goes through the turbine and does its job but won't get out of the way to allow the second one through because, it says, "I'm tired." (Ref. 3)

Again, from the patent application (Ref. 1):

"How can you most efficiently and effectively energize the spent flow that comes from the machine, and reintroduce it back into the stream? The need for solving this problem is common to all fluid power-extraction machines."

Conventional hydropower turbines operate in connection with a dam that has a basin upstream. A flow of fluid in a river, tidal flow, or other ocean current is stopped at the dam and begins to fill the basin upstream. As the basin fills, the difference in surface level height across the structure of the dam constitutes a static pressure difference or "head" that can be applied to create useful power. A turbine nearby is fed with a portion of stopped up flow that falls from the basin down through a penstock, or pipe, and powers the turbine's load. That portion of flow becomes spent, and it falls away from the turbine through a tail race, or downstream channel, to the river (or ocean) below. A conventional hydropower turbine operates with the substantial benefit of gravity to carry spent flow away.

Water moves from high pressure regions to low – it flows downhill – which fact serves pretty well to explain the operation at a conventional hydropower dam. An instream hydropower turbine, however, because it is immersed in the stream flow that powers it, does not have the benefit of gravity to carry its spent flow away. As noted above, a portion of flow from the ambient stream powers the instream turbine's blades and thereby "spends" energy. In the ambient stream that passes by outside the machine, the pressure and speed does not appreciably change, yet spent flow from within the machine, having less pressure and speed, must re-enter the energetically undiminished ambient stream. How does spent flow climb back up that hill?

III. The scope of the problem

The need for a solution is not specific to one or just a few ocean applications, but is more general of scope. A useful analogy to consider is the diesel engine, a ubiquitous source of power that might be found in an old fishing boat, a log skidder, a bull-dozer, or a truck, even in stationary electricity generators. The diesel engine is a prime mover suitable for a number of different power applications with only modest modifications of the general design. Similarly, a hydropower turbine is a stationary power source that can be configured to serve a variety of purposes. Though confined in its location to the stream that gives it power, it can be used in electrical, mechanical and hydraulic applications, and it can be sized big or small.

Instream hydropower turbines might be used for:

- Grid-connected power – large scale electricity generation
- Micro-hydro ("off the grid"), small scale electricity generation
- Island communities' power, medium scale electricity generation
- Fresh water production by reverse osmosis (a high pressure pumping application)
- Fresh water irrigation for farms (a low pressure pumping application)
- Energy storage by ammonia fuel production
- Thermal energy storage using molten salt

Increasing volume flow is the key to increasing power of a hydropower turbine. Volume flow is defined as the volume amount of water that passes through the turbine per unit time. Volume flow increases with swept area of the turbine blades – bigger is better when it comes to production of power. However, increase in size comes with an increase in cost. Larger turbine rotors require more structural support and more robust design to resist the operational forces on their cantilevered, overhanging blades.

Another approach to increasing power is to site the turbine in a region of fastest flow. Volume flow also increases with the speed of the fluid that passes through the machine. The drawback is, again, cost. Siting options are limited and it is more difficult and more expensive to deploy a turbine in a region of fastest flow.

The spent flow discharge apparatus that is the subject of this paper proposes a new approach to increasing volume flow through an instream hydropower turbine that offers an opportunity, industry-wide, to increase turbine power without increasing cost.

IV. <u>What is being done in the industry?</u>

Every hydropower turbine discharges spent flow, some more efficiently than others, perhaps.

Propeller type turbines have a percent solidity determination in their designs. The flow that passes between blades carries spent flow away, creating a three-figured spiral of vortexes, one behind each blade, that travel together, swirling about each other, far downstream. There's no mixing surface in the downstream path to smear the vortexes and speed up their decay. A limitation on propeller type turbines is that blades have to be spaced far enough apart to let energized flow pass through.

Another aspect to the spent flow discharge of propeller type turbines is the centrifugal flinging action of their whirling blades. It presumably helps reduce the presence and amount of backflow that can come in from behind the circle of the blades. Maybe that's why propeller type turbines don't have tip deflectors on their long, skinny blades. The blade bases do have a great deal more solidity which functions perhaps to drive flow out along the blades where the mechanical advantage is greater for powering the rotation.

Cross flow turbines create spent flow discharge streamlines that are too complex for comment here. Maybe if each blade had its own discharge channel, that would offer something for analysis, but that's not what they are. The fundamental challenge still applies.

Some turbines incorporate a shroud with a diffuser, an expanding channel for the spent flow, but a diffuser is not sufficient to re-energize spent flow from an instream hydropower turbine. From the patent application again (Ref. 1):

"The pressure prevailing at the discharge outlet(s) of the machine specifies the pressure at which the spent fluid must be discharged. If a diffuser, barrier, or other structure is provided to reduce ambient pressure at the outlet, in an effort to "suck" more captured fluid through the machine, then such reduced pressure would just as much "suck" downstream ambient fluid backwards into the discharge outlet, thereby impeding the discharge of the spent fluid."

The shroud of an instream hydropower turbine limits the centrifugal flinging action of the blades that could aid in promoting spent flow mixing with the ambient stream. The blades cannot be made more solid to be more effective at picking up the power without also reducing the amount of energized flow that passes through the spaces between blades. The efficiency of the shrouded turbine does not appear to benefit from the presence of a diffuser as much as would be desired. Maybe that's why the shroud with a diffuser is not seen automatically as a benefit, on the whole.

V. <u>Purpose of the Spent Flow Discharge Apparatus</u>

Benefits to improving spent flow discharge include improving operational efficiency, reducing operational costs, improving consistency of performance in varying flow conditions, improving predictability of outcome of design, and increasing rate of return for money needed to build and install a variety of turbine designs.

The objects of the invention disclosed in the referenced patent application (Ref. 1) are:

1. Develop a scalable, efficient, cost-effective technology that converts a high proportion of captured stream flow into useful power;
2. Purposely create an accelerated exterior fluid flow pattern and/or turbulence pattern and exploit such flow patterns for energizing the removal of spent flow from the apparatus;
3. Provide a structure that prevents backflow effects in a downstream wake of a machine from negatively influencing the discharge of spent fluid flow through one or more discharge outlets;
4. Provide and configure a structural component to act as a mixing surface against which the spent flow discharged from the machine can be effectively mixed with an accelerated external flow;
5. Provide a downstream structural component as a tail to reduce or minimize wake turbulence and downstream turbulence of the ambient flow field downstream of a machine, and be able to arrange multiple turbines more closely to one another in a

"turbine farm" arrangement, while avoiding or minimizing the influence of wake turbulence of one such machine on adjacent machines downstream.

The spent flow discharge apparatus could benefit any type of shrouded turbine – propeller, cross flow, or Downeast Turbines' patented design (Ref. 2).

VI. Description of the Spent Flow Discharge Apparatus, and how it works

The spent flow discharge apparatus that is the subject of this paper provides a means of re-energizing spent flow so that it can be discharged and carried away with the ambient stream, to allow a new portion of ambient flow to enter in and power the machine. The only forces available to make that happen derive from the ambient stream itself. The spent flow discharge apparatus consists of an ambient flow deflector and a downstream body. The downstream body comprises a backflow preventer and mixing surface that operate together with the ambient flow deflector to create conditions of pressure and speed in the stream flow outside the machine that will help draw spent flow away.

A description is summarized in the abstract of the patent application (Ref. 1, Exhibit 1):

"*A fluid power-extraction machine is immersed in the ambient flow of a fluid, captures (and extracts energy from) a portion of the fluid, and discharges it back into the ambient flow. The machine includes a housing bounding a fluid intake inlet and including an ambient flow deflector, a downstream body arranged rearwardly from the deflector and forming a discharge outlet between the deflector and the downstream body, and a power-extraction device in a fluid flow channel communicating from the fluid intake inlet to the discharge outlet. The deflector outwardly deflects and accelerates a portion of the ambient flow adjacent to the discharge outlet. A mixing surface of the downstream body extends outwardly and rearwardly from the discharge outlet, mixing the accelerated flow, the discharge flow and the ambient flow together along the mixing surface. A backflow preventer of the downstream body prevents wake backflow from impeding discharge of spent flow at the discharge outlet."*

Included in the figure (Exhibit 1) is a schematic, axial, sectional diagram of a representative example embodiment of an instream fluid power-extraction machine with a spent flow discharge apparatus, and includes schematic streamlines to indicate fluid flow patterns inside and outside of the machine, and labels.

Labels #1-4 indicate schematic structural components of the turbine, its forward housing or shroud, and the downstream body of the representative example embodiment:

1 is the ambient flow deflector portion of the forward housing 15;
1A is the outer edge of the ambient flow deflector 1;
2 is the fluid flow channel of the forward housing 15;
3 is the backflow preventer portion of the downstream body 16;
4 is the spent flow discharge outlet.

Labels #5-7 indicate schematic streamlines of fluid flow inside and outside the machine:

5 is streamlines of ambient flow passing around the machine;

5A is streamlines of accelerated ambient flow near the discharge outlet;
6 is spent flow within the machine which is free to circulate and flow without constraint except upon reaching the curved flange 10 and the outer portion of the inner channel wall of the ambient flow deflector 1 leading to its outer edge 1A;
#7 is the turbulent downstream wake.

Labels #8-9,10,12,14-16 indicate schematic structural components of the turbine's fluid flow channels and spent flow discharge apparatus:

8 is the fluid intake inlet portion of the forward housing 15;
9 is the turbine rotor;
10 is the curved flange of the spent flow discharge outlet 4;
12 is mixing surface of the downstream body 16;
14 is the widest part of the downstream body 16, rearwardly located from the spent flow discharge outlet 4;
15 is a forward housing, or turbine shroud;
16 is the aft or downstream body.

How it works, in part, is recited from the patent application (Ref. 1):

"The ambient flow deflector 1 is configured and arranged to intercept and deflect outwardly a portion of the ambient flow 5 thereby forming accelerated flow 5A as the fluid streams outwardly and rearwardly from the outer edge 1A of the ambient flow deflector 1. Here the accelerated flow 5A further interacts with the ambient flow 5 that streams axially downstream. This causes the accelerated flow 5A to also curve toward the downstream axial direction, thereby forming a convex curvature of the flow directly outside adjacent to the discharge outlet 4, with a concave inner side of the curved flow facing inwardly toward the discharge outlet …. This creates an area of reduced static pressure along with increased dynamic or velocity pressure of the accelerated flow 5A. This area of reduced static pressure drives, i.e. "sucks" the spent flow 6 outwardly through the discharge outlet 4. While the reduced static pressure in the area of the discharge outlet 4 also has an influence to draw in the accelerated flow 5A, the outward momentum of the accelerated flow 5A deflected by the ambient flow deflector 1 continues to carry the accelerated flow 5A outwardly and then rearwardly away from the discharge outlet 4 so that the accelerated flow 5A does not tend to vortex or curl into the discharge outlet 4 …. The discharge of the spent fluid 6 is….achieved by accelerating and re-energizing the spent fluid 6 by inducting and mixing the discharged fluid into the accelerated fluid 5A outside of the outlet 4. The resulting mixed fluid flows at a now acute glancing angle along the mixing surface 12. Here, the axial downstream ambient flow 5 also drives the mixed fluids against the mixing surface 12 and provides further energy and further mixing by a boundary layer shearing effect along the mixing surface and/or a laminar flow shearing effect of the ambient flow meeting the discharged fluid and the accelerated fluid. This mixing effect can be considered by analogy to a physical mechanical mixing of two viscous components with each other, for example the mixing of a polymer resin with a hardener to form a thermosetting polymer compound. To achieve this, it is typically known to smear or wipe a quantity of hardener onto and together with a quantity of resin along a mixing plate using a putty knife or spatula at a relatively narrow acute glancing angle. The putty knife smears and mixes the hardener into and with the resin by pressing and drawing the putty knife over the mixing plate. In the context of the present invention, the ambient flow 5 presses, draws, smears and mixes the accelerated flow 5A together with the discharged spent flow 6 coming out of the discharge outlet 4 as a mixture along the mixing surface 12. The ambient fluid 5 is similar to the putty knife as it presses the other two components (the

accelerated fluid and the discharged fluid) into intimate mixture with one another along the mixing surface 12 …. The mixing surface 12 can be considered to extend rearwardly to the widest part 14 of the downstream body 16, while mixing may continue somewhat beyond the widest part 14 or already end somewhat upstream from the widest part 14. At some point rearwardly or downstream from the widest part 14, increased flow separation and formation of a turbulent downstream wake 7 may occur. This downstream wake 7 is displaced sufficiently rearwardly and downstream, however, so that it does not influence the flow conditions at the discharge outlet 4 and thereby does not hinder the discharge of spent fluid 6 through the discharge outlet 4."

The spent flow discharge apparatus disclosed in the patent application (Ref. 1) is based on theory. Much work still needs to be done to turn the theory into a marketable product.

VII. The gap from theory to product – what still needs to be done?

Since 2009, Downeast Turbines has accomplished many things. In addition to proposing an apparatus for spent flow discharge (Ref. 1) , Downeast Turbines has achieved:

- Awarded US Patent No. US 8,506,244 B2, "Instream Hydro Power Generator," granted by the USPTO on Aug. 13, 2013 (Ref. 2)
- A design method of streamlines and ratios for modeling a water flow turbine
- Built and tested multiple turbine prototypes
- Designed and built "on the water" test fixtures – culvert-mount, work-boat mount, and double-hulled floating platform

With respect to marketing the spent flow discharge apparatus, two types of products are planned.

First is the IP, intellectual property that will be offered for license. The award of the pending patent (Ref. 1) awaits the time the when the USPTO (Patent and Trademark Office) will review it. Disclosure will not change in the patent application, but claims might be revised. Approval of the patent application ultimately rests with the USPTO.

When and if the patent is allowed, Downeast Turbines will make a decision on how to proceed among three licensing alternatives: 1) Turn the IP over in its entirety to someone with more capital to improve it; 2) Create exclusive licenses to different market segments (geographical, wind/water power, fresh/salt water, large/small, electricity/pumping applications); and 3) Non-exclusive licenses for use.

The second type of product is an actual turbine generator for micro hydro power that combines Downeast Turbines' patented instream hydropower generator (Ref. 2) with the spent flow discharge apparatus that is presented here (Ref. 1). Choice of application initially is to generate electricity or for pumping water.

While getting a product to market, Downeast Turbines has many additional upcoming tasks. Some involve expanding on work already started and these include:

1) Continue developing the spent flow discharge theory (observe/study/learn);
2) Expand fabricating facility for design/model/build (much progress has been made since 2009);
3) Continue to develop on-the-water test capability (work is still in progress);

New capabilities are required as well, that so far have not been part of Downeast Turbines' development activity. These include:

4) Purchase CFD (computational fluid dynamics) computer modeling software seat – (expensive, with a significant learning curve);
5) Develop wind tunnel testing that can substitute for some on-water testing and is quicker, cheaper, more easily performed, to accelerate the learning process (in the planning stage).

Downeast Turbines continues plugging away to develop marketable products for the spent flow discharge apparatus.

VIII. Final Words

The spent flow discharge apparatus (Ref. 1) offers a novel approach to improving turbine design that might be useful in many different instream hydropower turbines. Downeast Turbines plans to offer opportunities for license and manufacture of the spent flow discharge apparatus, and welcomes your inquiry.

Exhibits:

1. United States Patent Application Publication, Pub. No.: US2015/0086327 A1, Pub. Date: March 26, 2015, "Spent Flow Discharge Apparatus for an Instream Fluid Power-Extraction Machine." (The cover page – It includes the abstract and the schematic, axial, sectional diagram of a representative example embodiment of an instream fluid power-extraction machine with a spent flow discharge apparatus)

References:

1. United States Patent Application Publication, Pub. No.: US2015/0086327 A1, Pub. Date: March 26, 2015, "Spent Flow Discharge Apparatus for an Instream Fluid Power-Extraction Machine."
2. US Patent No. US 8,506,244 B2, "Instream Hydro Power Generator," granted by the USPTO on Aug. 13, 2013
3. Wikepedia entry, "Betz's Law," http://en.wikipedia.org/wiki/Betz's_law

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(54) **SPENT FLOW DISCHARGE APPARATUS FOR AN INSTREAM FLUID POWER-EXTRACTION MACHINE**

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(57) **ABSTRACT**

A fluid power-extraction machine is immersed in an ambient flow of a fluid, captures (and extracts energy from) a portion of the fluid, and discharges it back into the ambient flow. The machine includes a housing bounding a fluid intake inlet and including an ambient flow deflector, a downstream body arranged rearwardly from the deflector and forming a discharge outlet between the deflector and the downstream body, and a power extraction device in a fluid flow channel communicating from the fluid intake inlet to the discharge outlet. The deflector outwardly deflects and accelerates a portion of the ambient flow adjacent to the discharge outlet. A mixing surface of the downstream body extends outwardly and rearwardly from the discharge outlet, mixing the accelerated flow, the discharged flow and the ambient flow together along the mixing surface. A backflow preventer of the downstream body prevents wake backflow from impeding discharge of spent flow at the discharge outlet.

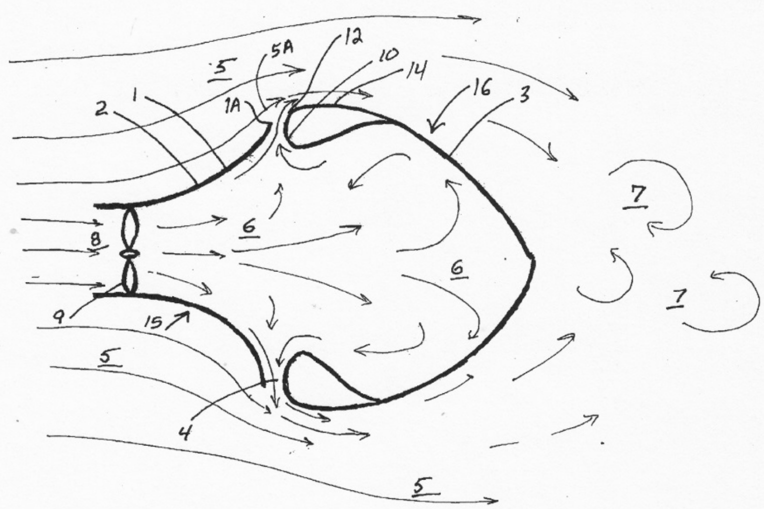

Exhibit 1