US 20140044543A1

(19) United States
(12) Patent Application Publication
Jokela
(10) Pub. No.: US 2014/0044543 A1
(43) Pub. Date: Feb. 13, 2014

(54) HYDRAULIC TURBINE AND HYDROELECTRIC POWER PLANT

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(21) Appl. No.: **14/113,544**

(22) PCT Filed: **Apr. 27, 2012**

(86) PCT No.: **PCT/EP12/57870**

§ 371 (c)(1), (2), (4) Date: **Oct. 23, 2013**

(30) **Foreign Application Priority Data**

Apr. 27, 2011 (CH) 00717/11

Publication Classification

(51) **Int. Cl.**
F01D 1/26 (2006.01)
F03B 3/08 (2006.01)

(52) **U.S. Cl.**
CPC ***F01D 1/26*** (2013.01); ***F03B 3/08*** (2013.01)
USPC **416/128**

(57) **ABSTRACT**

The present disclosure relates to a turbine for hydraulic power generation comprising two bladed wheels (**11**, **12**, **31**, **32**) successively arranged in a turbine tube section (**10**, **21**) as a fore wheel (**11**, **31**) and an after wheel (**12**, **32**) with respect to the water flow direction (**23**) along a common rotation axis (**30**) extending in the water flow direction (**23**), the wheels (**11**, **12**, **31**, **32**) being configured to rotate in opposite directions driven by the water flow, and to a corresponding hydroelectric power plant. In order to improve the turbine characteristics for hydraulic power generation, in particular in view of low head power generation, the invention suggests that a first gear (**46**) and a second gear (**47**) are arranged along the rotation axis (**30**), each connected to a wheel (**11**, **12**, **31**, **32**) and mutually connected via an engagement gearing (**48**) such that the fore wheel (**11**, **31**) and the after wheel (**12**, **32**) are coupled to each other with respect to their rotation speed, the engagement gearing (**48**) being connectable to a power generator.

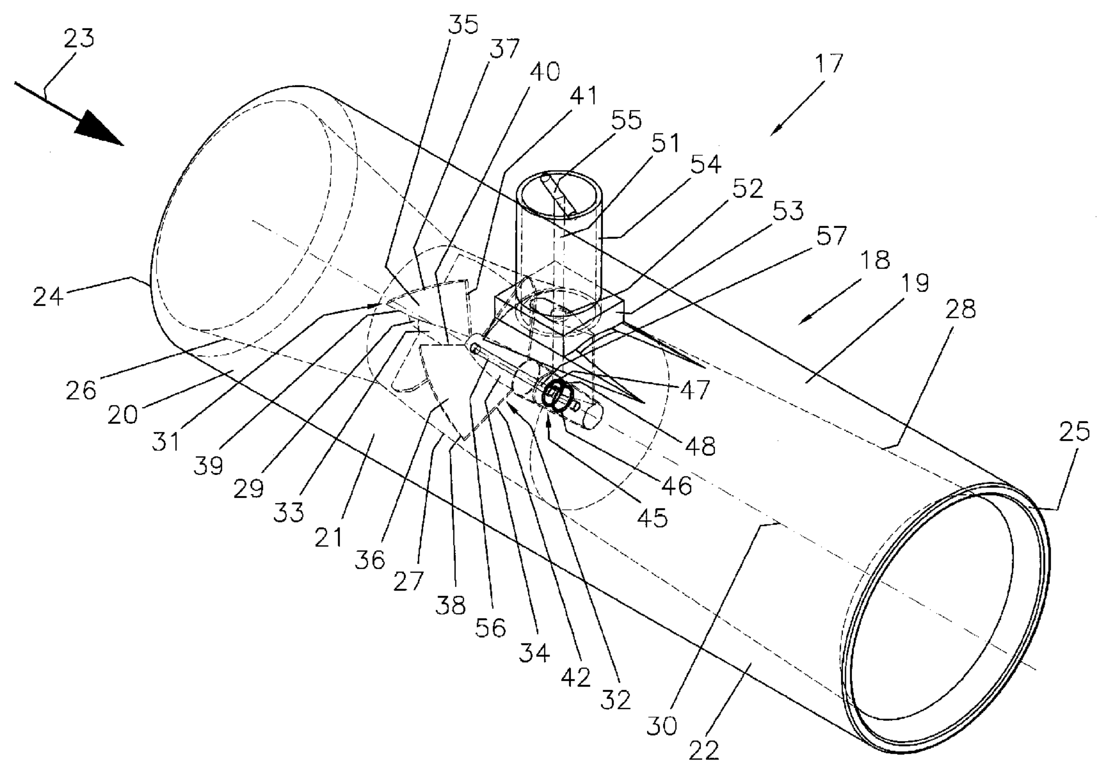


FIG. 1

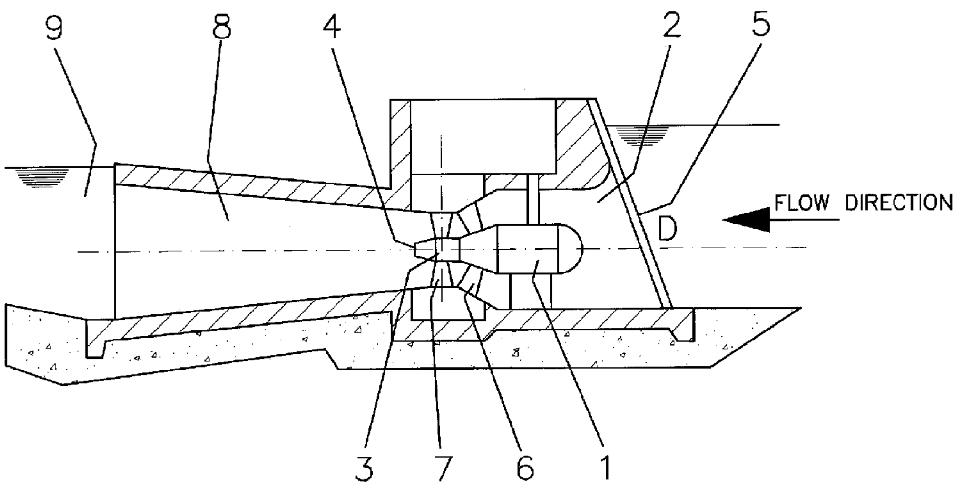


FIG. 2

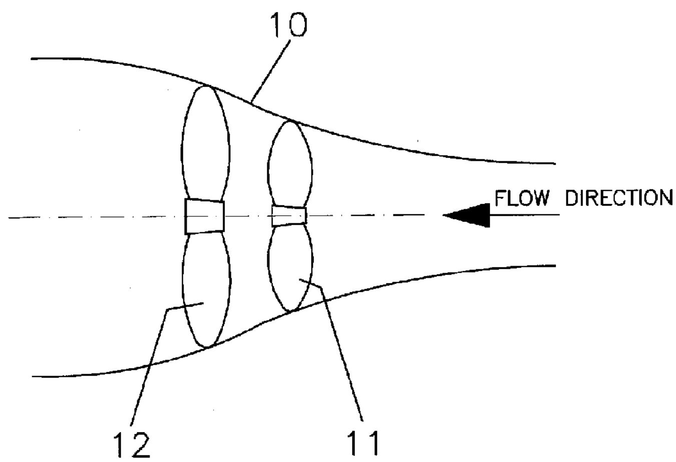
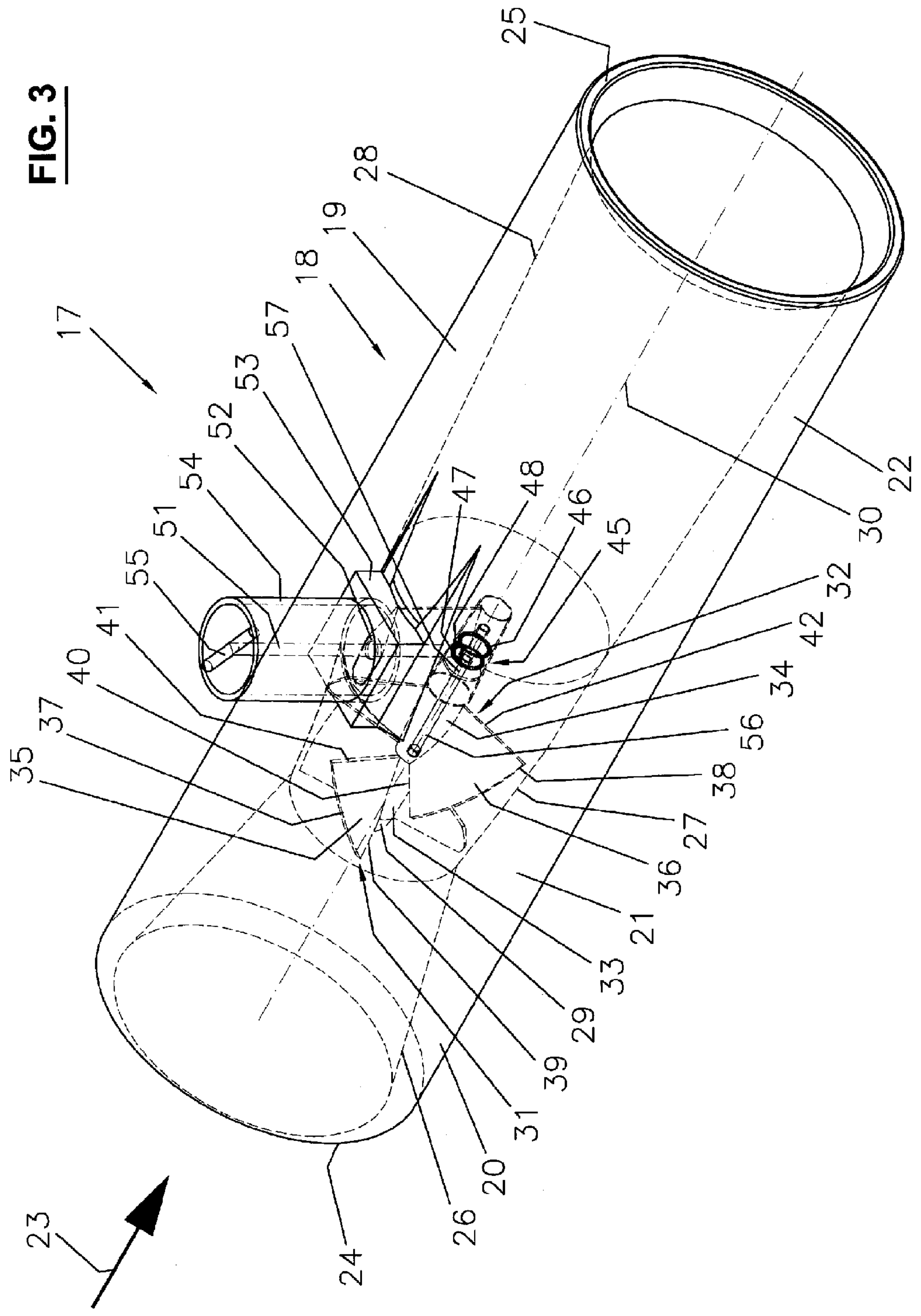


FIG. 3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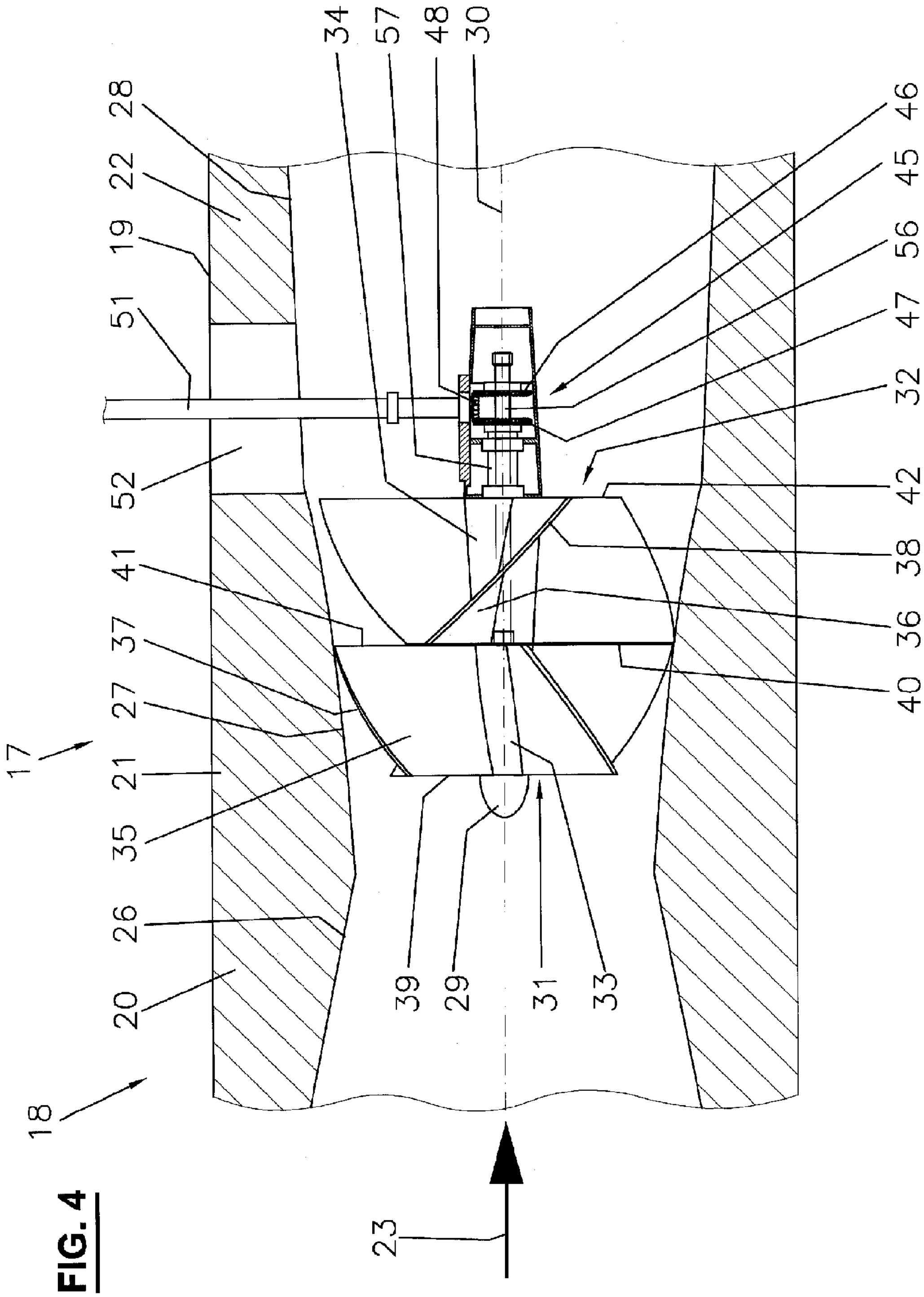
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FIG. 4

FIG. 5

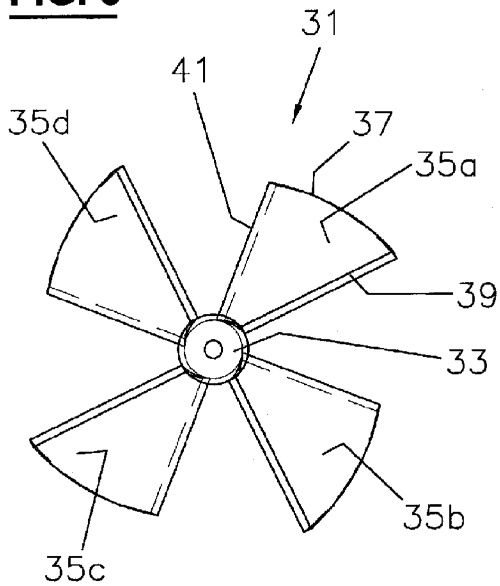


FIG. 6

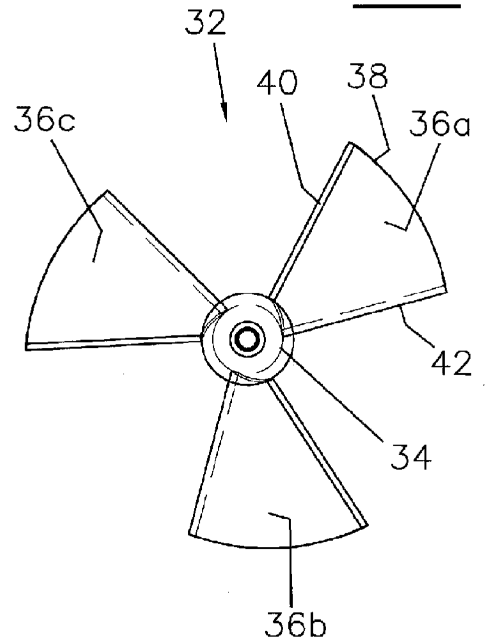


FIG. 7

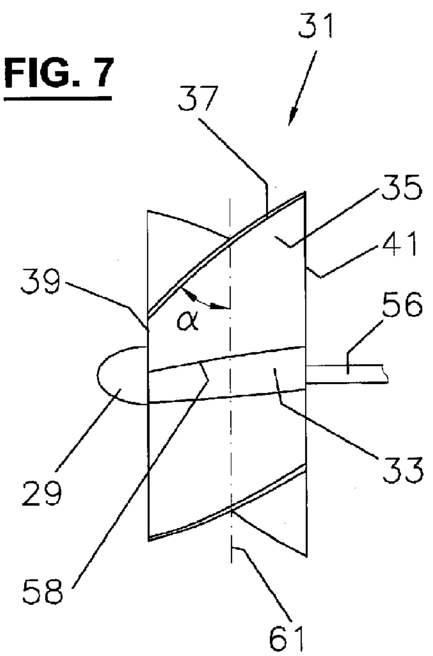


FIG. 8

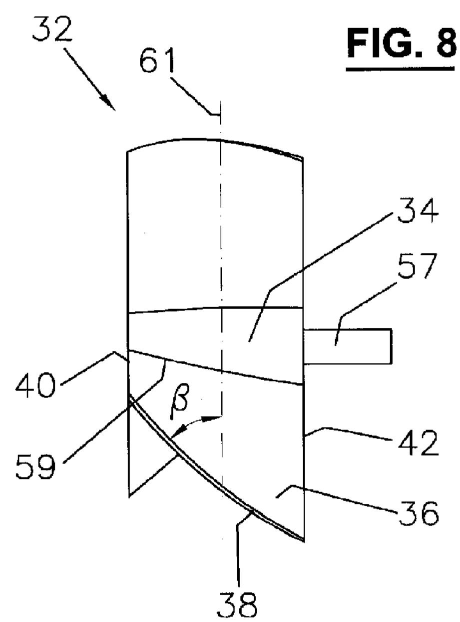


FIG. 10

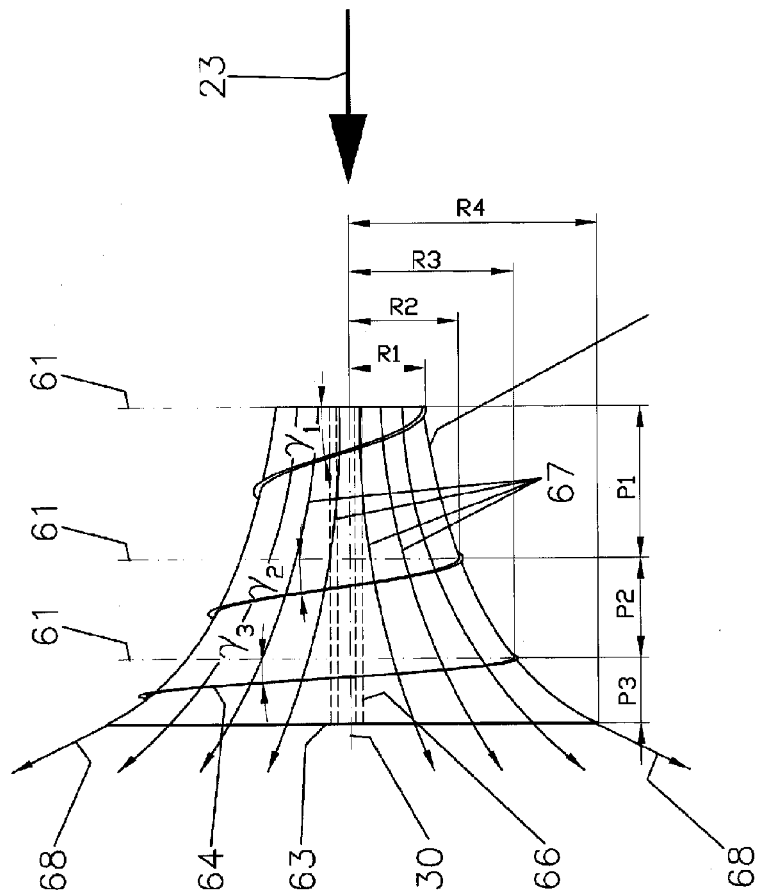


FIG. 9

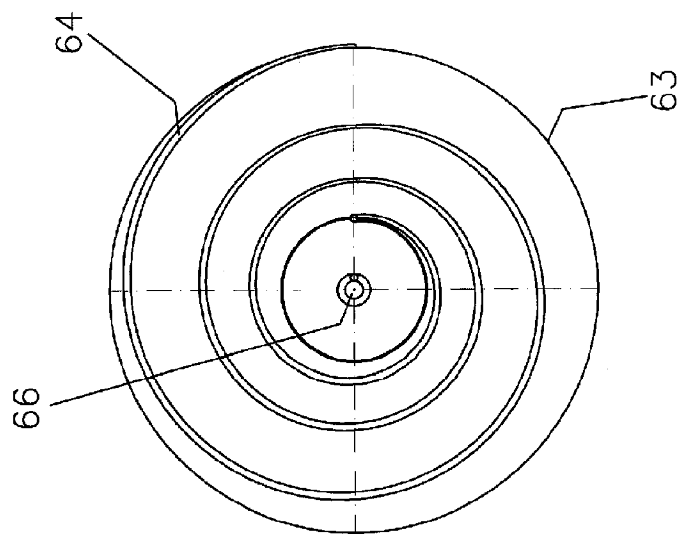
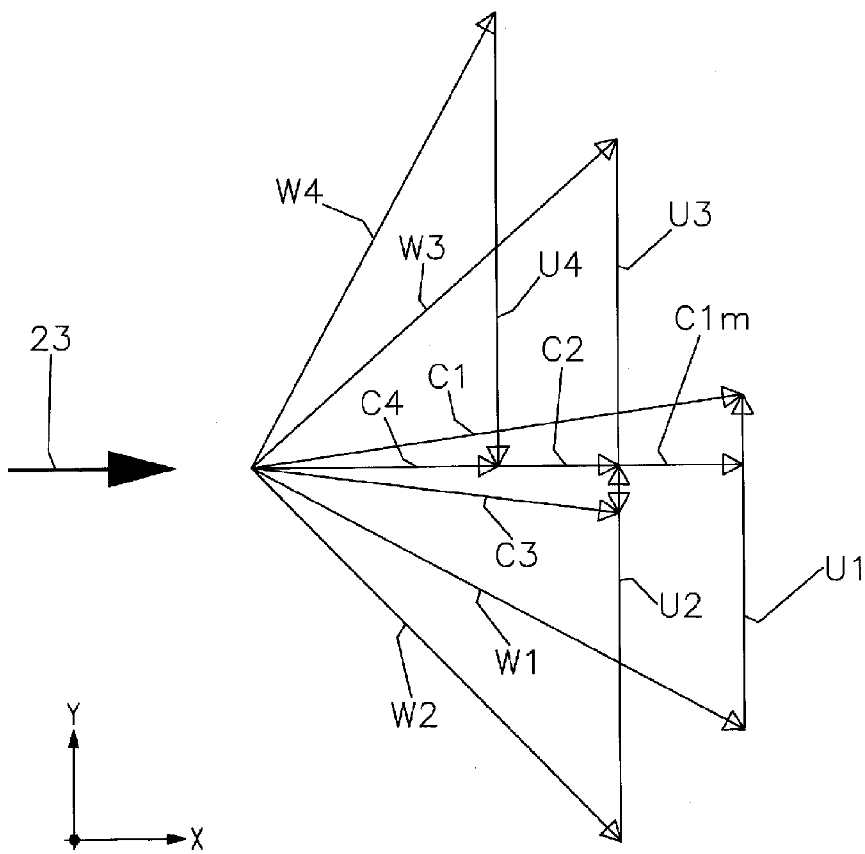


FIG. 11



HYDRAULIC TURBINE AND HYDROELECTRIC POWER PLANT

[0001] The invention relates to a turbine for hydraulic power generation comprising two bladed wheels successively arranged in a turbine tube section as a fore wheel and an after wheel with respect to the water flow direction along a common rotation axis extending in the water flow direction. The wheels are configured to rotate in opposite directions driven by the water flow. The invention also relates to a hydroelectric power plant in a flowing or falling water comprising such a turbine.

[0002] Hydraulic turbines are used for the production of electrical power by converting the energy of a water flow offered from water falling or flowing through the gravitational force. The hydraulic head and the rate of the water flow are determining parameters. Current low head hydraulic turbines use a fall of water of less than 20 meters, often less than 5 meters, for power production.

[0003] Concerns remain about the environmental impact of low head hydropower applications. Large construction sizes of low head dams, weirs, drop structures as well as large water energy dissipaters and velocity controllers to ensure erosion control lead to a disturbance of a natural and paddler safe river environment and of fish migration. Indeed, it would be highly desirable to harness low head hydropower without the need of separate fish-ladder constructions and a division of the main flow for a bedload transportation past the hydroelectric power plant, such that the fish and residual water could pass alongside the turbine.

[0004] French patent application FR 2 787 522 refers to a power generator employing an aerodynamic and also a liquid current flow. To this end, at least one bladed rotor wheel is arranged in a housing traversed by the current flow. A fixed rotation speed is imposed on the wheel by an external regulation means, such as a regulated mechanical brake or electric brake or flap gate, to achieve a current flow speed at the exit of the housing that corresponds to $1/\sqrt{3}$ of the current flow speed at the housing entry. In one embodiment, two rotor wheels with an opposed rotation direction are successively arranged in the housing, each comprising a separate brake and operating independent of each other. By the external regulation of the rotation speed of the wheels, however, aerodynamic power gets lost.

[0005] International patent application WO 2006/016360 A2 describes a device enabling a rotor and a stator to rotate in opposite directions which can be used for generation of electrical power. To this end, a generator is arranged in between the rotor and the stator along the rotation axis such that the rotor and stator can rotate independently. The arrangement is disposed in a water flow pipe formed of concrete at the bottom of a dam with a cross-sectional area narrowing in the water flow direction. The device is not well suited for low head hydropower applications.

[0006] British patent application GB 1,132,117 discloses a speed increaser for an axial flow hydraulic turbine. To this end, the power turbine wheel has blades which are radially shorter than the inner diameter of the surrounding housing and which are provided with an inner shroud to provide an annular passage between the shroud and the turbine housing. Where a relatively high ratio of speed increase is required, contra-rotating pairs of freely rotating bladed wheels are provided in the turbine housing. Such an arrangement can lead to large construction sizes and a sacrifice of turbine efficiency due to the shortened turbine blades cannot be fully avoided.

[0007] It is an object of the present invention to remedy at least one of the above mentioned deficiencies and to provide the initially addressed turbine with an improved performance characteristics for hydraulic power generation. It is another object of the invention to allow a reduction of the construction size required for such a turbine and/or for a corresponding hydroelectric power plant comprising at least one such turbine. It is a further object of the invention to provide the turbine with the capability to be used in a hydroelectric power plant working with a comparatively low or very low head.

[0008] At least one of these objects is attained by the turbine according to claim **1** and the hydroelectric power plant according to claim **19**. The dependent claims define preferred embodiments.

[0009] Accordingly, in a turbine according to the invention, a first gear and a second gear are arranged along the rotation axis, wherein the first gear is connected to the fore wheel and the second gear is connected to the after wheel such that each of the first and second gear is configured to rotate around the rotation axis driven by the respective wheel. The first gear and the second gear are connected via an engagement gearing such that the fore wheel and the after wheel are coupled to each other with respect to their rotation speed, wherein the engagement gearing is connectable to a power generator.

[0010] Thus, due to the connection of the first gear and the second gear via the engagement gearing, a drivenly fixed connection between the fore wheel and the after wheel can be established, in which the relative rotation speed of the wheels is synchronized according to a predetermined ratio. In this way, a more reliable running performance of the turbine can be achieved, wherein an advantageous feedback between the wheels is preferably provided to a certain extent via the engagement gearing.

[0011] As a further advantage, the nominal rotation speed of the wheels can be effectively reduced for extracting a desired power output. Thus, a higher friendliness to living water organisms can be provided due to a more peacefully changing water pressure which may be combined with a more open inner tube structure.

[0012] Moreover, an advantageous power extraction from the turbine can be provided, in which both wheels can equally contribute to the power generation. Furthermore, the engagement gearing allows to feed the power extracted from both wheels to a single generator. In particular, small output powers delivered from a single wheel can thus be advantageously enhanced by the contribution of the second wheel to sufficiently supply the generator.

[0013] it is to be noted that in the context of the present patent application, the term "water flow" can refer to the movement of flowing and of falling water.

[0014] For power extraction, the engagement gearing is preferably fixed to a transmission shaft for connecting the engagement gearing to the power generator, wherein the transmission shaft extends through an outer wall of the turbine tube section or of a tube section before or behind the turbine tube section. In this way, all kinds of power generators regardless the respective sizes can be disposed externally with an arbitrary lateral distance to the water flow. It is also conceivable, however, to provide the power generator before or behind the water flow tube comprising the turbine tube section. It is further conceivable to provide the power generator and its connection to the engagement gearing inside the turbine tube section or a tube section further upstream or downstream.

[0015] To drive the gear arrangement, the first gear is preferably connected to the fore wheel via a first shaft and the second gear is preferably connected to the after wheel via a second shaft, wherein one of the shafts is a hollow shaft and the other shaft extends concentrically through the hollow shaft along the rotation axis. In this way, the gears can be advantageously provided at any position along the rotation axis and the wheel and gear design and location can be chosen to minimize the disturbance to the water flow. For this purpose, the first gear and the second gear are preferably disposed downstream with respect to the location of both wheels. A gear arrangement upstream with respect to the location of the wheels is also conceivable. A gear location in between the wheels is further conceivable, wherein both shafts can be arranged in a mutually opposed manner and no hollow shaft is needed. Preferably, the gears are successively arranged along the rotation axis. More preferred, the gears are arranged in a mutually opposing manner on the rotation axis.

[0016] According to a preferred embodiment, the engagement gearing is constituted by a single gear, in particular a conical gear, that is preferably disposed in between the first gear and the second gear. This allows a direct power extraction from the turbine and losses can be minimized. According to another preferred embodiment, the engagement gearing is constituted by a gearing assembly comprising several gears. This can be used, for instance, for a power extraction from a turbine in which the rotation speed of the wheels is synchronized to a value differing from each other, i.e. to a rotation speed ratio that is not equal to one. This can also be used to provide a desired transformation ratio of the rotation speed to a generator.

[0017] In order to allow a synchronized running of the wheels, the geometry of the turbine tube section and/or the wheels is preferably adapted to produce a desired ratio of the relative rotation speed of the wheels. In a preferred embodiment, the turbine tube section and/or the wheels are configured in such a way that the fore wheel and the after wheel can be driven by the water flow at substantially the same rotation speed. In this way, a stable running of the wheels and good power extraction can be accomplished. However, other ratios of the rotation speed are also conceivable. Moreover, various measures are conceivable to adapt the turbine tube section and/or the wheels accordingly. Some preferred measures are summarized below.

[0018] Preferably, the turbine tube section is provided with an inside diameter increasing in the water flow direction. In this way, the kinetic energy of the water can be lowered already inside the turbine tube section in which the bladed wheels are provided. In consequence, the dimensioning of a draft tube section that is needed to reduce the water flow speed behind the turbine tube section can be effectively reduced. Moreover, due to the increasing tube diameter, the flow area through the after wheel is preferably increased with respect to the flow area through the fore wheel. By an increase of the respective flow area, the rotation speed of the after wheel can be approached to a desired rotation speed of the fore wheel to avoid scarifying of output power or turbine efficiency.

[0019] Preferably, the change of the inside diameter of the turbine tube section is chosen such that the water flow speed is reduced by at least 6%, more preferred by at least 20%, at the cross-sectional area at which the water flow exits the after wheel as compared to the cross-sectional area at which the water flow enters the fore wheel. In particular, an optimum turbine performance could be demonstrated in a preferred configuration which comprises a change of the inside diameter of the turbine tube section such that a decrease of the water flow speed of in between 40% to 60% is achieved at the cross-sectional area at which the water flow exits the after wheel as compared to the cross-sectional area at which the water flow enters the fore wheel. The water flow speed is preferably defined as the average of the velocity profile of the water passing through the respective cross-sectional area.

[0020] A particularly efficient reduction of the water velocity inside the turbine tube section combined with a synchronization of the rotation speed of the wheels can be achieved when the inside diameter of the turbine tube section increases with a slope continuously increasing from the position at which the water flow enters the fore wheel to the position at which the water flow exits the after wheel. More preferred, the inner side wall of the turbine tube section exhibits a convex curvature along which the cross-sectional area widens in the water flow direction.

[0021] Preferably, the size and shape of the wheel blades is adapted to the inner wall geometry of the turbine tube section, such that the outer edges of the blades are substantially directly adjoining to the inner wall of the turbine tube section. Thus, the turbine efficiency can be maximized.

[0022] Preferably, the fore wheel or the after wheel or both have a diameter at a leading edge at which the water flow enters the wheel which is smaller as compared to the diameter at a leaving edge at which the water flow exits the respective wheel. This can further contribute to a synchronization of the rotation speed of the wheels. More preferred, the difference between the leaving edge diameter and the leading edge diameter of the after wheel is larger as compared to the difference between the leaving edge diameter and the leading edge diameter of the fore wheel.

[0023] Preferably, the diameter of the fore wheel comprises a value in between 60% to 97% of the diameter of the after wheel to achieve synchronization of the rotation speed of the wheels. According to a preferred configuration, the leading edge diameter of the fore wheel is at most 97%, more preferred at most 90% and most preferred at most 80%, of the leaving edge diameter of the after wheel. According to a specific example, an optimum turbine performance could be shown in a preferred configuration which comprises an increase in diameter of the leaving edge of the after wheel as compared to the leading edge of the fore wheel of in between 65% to 75%.

[0024] Preferably, both wheels are arranged along the rotation axis before or after the gears with respect to the water flow direction. The fore wheel and the after wheel are preferably arranged in immediate proximity to each other, in particular such that the leaving edge of the fore wheel is substantially directly followed by the leading edge of the after wheel. In this way, the turbine efficiency can be further improved and misrouted currents or leakage currents at an intermediate volume or disruption between the wheels can be avoided. Preferably, the leaving edge diameter of the fore wheel substantially corresponds to the leading edge diameter of the after wheel.

[0025] According to a preferred configuration, an equal number of blades is provided on the fore wheel as compared to the number of blades on the after wheel. According to another preferred configuration, a different number of blades is provided on the fore wheel as compared to the after wheel. More preferred, the blade number on the fore wheel is larger as compared to the blade number on the after wheel. According to a specific example, one additional blade is preferably provided on the fore wheel. In particular, four blades in total are preferably provided on the fore wheel and three blades in total are preferably provided on the after wheel.

[0026] Preferably, the length in the water flow direction of the after wheel is different than the length in the water flow direction of the fore wheel. In this way, the rotation speed of the after wheel can be approached to a desired rotation speed of the fore wheel according to a desired output power or turbine efficiency. Preferably, the length of the after wheel differs from the length of the fore wheel by at least 5%, more preferred at least 10%, of its length. Thereby, different wheel configurations are conceivable.

[0027] According to a preferred configuration, the fore wheel exhibits a larger length in the water flow direction as compared to the after wheel. Such a wheel configuration can be advantageous to balance the energy of the fore wheel and after wheel transmitted from the water flow to a desired value, in particular to an equal value. Such a wheel configuration is preferably employed when an equal number of blades is provided on the fore wheel as compared to the after wheel.

[0028] According to another preferred configuration, the after wheel exhibits a larger length in the water flow direction as compared to the fore wheel. Such a wheel configuration can be advantageous to extend the length of the after wheel in order to provide a desired value of pitch of the wheel blades with respect to a line perpendicular to the rotation axis at the leaving edge of the after wheel. Such a wheel configuration is preferably employed when a larger number of blades is provided on the fore wheel as compared to the after wheel.

[0029] Preferably, the pitch of the wheel blades, in particular with respect to a defined flow line of the water flow, decreases in the water flow direction. Thereby, a continuously decreasing pitch angle with respect to the plane of rotation of the wheels is preferably provided in the water flow direction. Preferably, the radius corresponding to the pitch of the wheel blades, in particular with respect to a defined flow line of the water flow, increases in the water flow direction. Thereby, a shape of the wheel blades, in particular along a defined flow line of the water flow, is preferred which corresponds to a fractional revolution of a helix with a diameter increasing in the water flow direction and/or a pitch angle decreasing in the water flow direction. These measures can also be used for a synchronization of the rotation speed of the wheels.

[0030] Preferably, the course of the wheel blades around the hub of the fore wheel is continued correspondingly by the course of the wheel blades around the hub of the after wheel, in particular with respect to the pitch of the blades and/or the corresponding pitch radius.

[0031] An advantageous combination of two or more of the above described measures is preferably applied on the turbine tube section and/or the wheels inside to simultaneously allow synchronization of the rotation speed of the wheels, a stable running of the wheels and optimization of the power output and/or turbine efficiency.

[0032] The turbine according to the invention may be also described as an "axial turbine" comprising a rotation axis of the wheels extending in the water flow direction while nonetheless allowing to exploit a change of velocity of the water flow for energy generation. Up to now, a working principle based on a velocity change of the water jet is only known from impulse turbines in which, however, the rotation axis of the wheels must be arranged perpendicular to the water flow. On the other hand, a rotation axis of the wheels extending in the water flow direction is currently only used in reaction turbines which are based, however, on a differing working principle in which the velocity of the water flow remains unchanged.

[0033] The upstream end of the turbine tube section is preferably defined as a position at which the water flow enters the fore wheel or as a position further upstream. Before the upstream end, the turbine tube section is preferably adjoined by an entry tube section through which the water flow is delivered to the turbine tube section, wherein the entry tube section preferably exhibits a narrowing diameter in the water flow direction to increase the kinetic energy of the water flow.

[0034] The downstream end of the turbine tube section is preferably defined as a position at which the water flow exits the after wheel. At the downstream end, the turbine tube section is preferably adjoined by a draft tube section that is used to recover the kinetic energy. To this purpose, the draft tube section is preferably provided with an inside diameter increasing in the water flow direction and a length adapted to recover the water flow speed downstream of the turbine to a level of the water flow speed upstream of the turbine.

[0035] According to a preferred configuration, the length of the draft tube section corresponds to a value of at most four times the diameter of the fore wheel at a leading edge at which the water flow enters the wheel. Thus, above described technical features of the turbine according to the invention can be effectively exploited to reduce the size that is necessary for the draft tube section to substantially achieve full recovery of the kinetic energy of the water flow.

[0036] A hydroelectric power plant according to the invention comprises a flowing or falling water and at least one turbine according to the foregoing description, wherein the flowing or falling water is channeled through the turbine tube section. Preferably, the hydroelectric power plant is installed in a flowing water, in particular a natural or artificial river environment.

[0037] In a preferred configuration of the power plant, the flowing or falling water exhibits a hydraulic head of at most 4 m, more preferred at most 2.5 m and most preferred 0.8 m, before entering the turbine tube section. More preferred, due to above described technical features of the turbine according to the invention allowing to employ a hydraulic head that can be substantially below 1 m, no separate fish-ladder constructions and no division of the main flow are necessary and provided in such a power plant. Moreover, such a power plant is preferably provided with a trashrack that is mainly cleaned by the residual water flow. Thus, the hydroelectric power plant can advantageously be constructed without a separate mechanical trashrack cleaning machine.

[0038] Further embodiments of the invention include a hydraulic machine having two plurality bladed wheels which rotate in opposite directions in the same rotation axis, placed on the water flow as a fore wheel and as an after wheel in a way where these wheels affect the flow of each other optimizing their functionality. Preferably, the fore wheel has more or an equal amount of blades as the after wheel. Preferably, the fore wheel has a smaller diameter than the after wheel. Preferably, the fore wheel has a different pitch and/or pitch diameter than the after wheel. Preferably, at least one or both of the wheels have a smaller leading edge diameter and a greater leaving edge diameter. Preferably, the leaving edge diameter of the fore wheel is equal to the leading edge diameter of the after wheel. Preferably, the two plurality bladed wheels have a driveable fixed connection between each other. Preferably, the machine transfers the mechanical energy outside the water flow with a shaft. Preferably, the machine is installed into a tube in a way where the water flow speed is reduced also in the bladed wheel area together with the after tube area.

[0039] The invention is explained in more detail hereinafter by means of preferred embodiments with reference to the drawings which illustrate further properties and advantages of the invention. The figures, the description, and the claims comprise numerous features in combination that one skilled in the art may also contemplate separately and use in further appropriate combinations. In the drawings:

[0040] FIG. **1** is a longitudinal sectional view of a conventional hydraulic turbine installation;

[0041] FIG. **2** is a schematic representation of a turbine according to the invention;

[0042] FIG. **3** is a perspective view of a turbine according to the invention;

[0043] FIG. **4** is a longitudinal sectional view of a turbine according to the invention;

[0044] FIG. **5** is a frontal view of a fore wheel of the turbine shown in FIG. **3** and FIG. **4**;

[0045] FIG. **6** is a frontal view of an after wheel of the turbine shown in FIG. **3** and FIG. **4**;

[0046] FIG. **7** is a side view of the fore wheel shown in FIG. **5**;

[0047] FIG. **8** is a side view of the after wheel shown in FIG. **6**;

[0048] FIG. **9** is a frontal view of a wheel hub illustrating a preferred wheel geometry according to the invention;

[0049] FIG. **10** is a side view of the wheel hub shown in FIG. **9**; and

[0050] FIG. **11** is a vector diagram illustrating the absolute velocity, the relative velocity and the blade speed at four different positions of the wheels in the turbine shown in FIG. **2-4**.

[0051] FIG. **1** schematically shows a partial view of a conventional hydroelectric power plant. It comprises a water intake passage **2** having its inlet protected by a bar screen **5**. A screen washing system, not shown, is also provided to avoid clogging-up of bar screen **5**. Water intake passage **2** generally has a convergent shape which guides the water towards a wheel **3** of a turbine **4** of axis D. A distributor **6** is provided in water intake passage **2** upstream of turbine **4** to properly direct the water flow with respect to blades **7** of wheel **3** of turbine **4**. Turbine **4** of hydroelectric power plant generally is a Kaplan turbine, which has the shape of a helix and which generally comprises adjustable blades **7**. A draft tube **8** guides the water from the outlet of turbine **4** towards a tail race **9**. Turbine **4** can be stopped by means of the closing of distributor **6** generally equipped with movable wicket gates.

[0052] In the example of FIG. **1**, axis D of turbine **4** is substantially horizontal, but it can also be a vertical. The electric generator (not shown) is arranged in a bulb-shaped carter **1** placed in the flow. It can also be placed outside the flow.

[0053] A Kaplan-type turbine generally has an optimal efficiency for a specific rotation speed of wheel **3**. Water intake passage **2** aims at accelerating the water flow up to a velocity adapted to the optimal efficiency rotation speed of wheel **3**. The velocity of the water coming out of wheel **3** is higher than the flow velocity upstream of hydroelectric power plant. Draft tube **8** aims at slowing down the flow coming out of wheel **3** and thus enables recovering as much of the kinetic energy remaining in the flow coming out of turbine **4** as possible. Normally the draft tube **8** length is greater than 4.6 times of the diameter of wheel **3**.

[0054] Generally, a ratio K characterizing turbine **4** of a given hydroelectric power plant type is defined, corresponding to the ratio between the kinetic energy of the flow coming out of wheel **3** and the potential energy of the head. Ratio K, expressed in %, is given by the following relation:

$$K=100*V^2/2gH$$

where V is the average speed of the flow coming out of wheel **3**, g is the gravitation constant and H the head height. Ratio K is representative of the energy still contained in the flow in kinetic form when coming out of wheel **3**, divided by the energy available for the turbine, and is thus representative of the energy to be recovered by draft tube **8**.

[0055] The higher the ratio K, the greater the slowing down is to be performed. For conventional low-head Kaplan turbines, Mr. Joachim Raabe, in its work entitled "Hydro Power", indicates that ratio K is 30%, 50%, and 80% for 70-meter, 15-meter, and 2-meter heads, respectively. The high kinetic energy to be recovered in very low head turbines at the outlet of wheel **3** leads to a construction of very large draft tubes since their divergence is limited by risks of separation of the liquid vein.

[0056] The forming of water intake passage **2** and of draft tube **8** of a hydroelectric power plant thus requires the forming of large civil engineering constructions. The very high cost of such constructions considerably burdens the total cost of the plant and has strongly limited the construction of hydroelectric power plants on low heads and very low heads for which the coefficient K is particularly high.

[0057] A counter rotating double turbine according to the invention, as further described below, can especially be used efficiently as an extreme low head turbine. The main problem in known Kaplan turbines is that with low heads the turbine diameter grows rapidly. For example ~35 kW Turbine power can been reached with a flow of Q=1 m^3/s and a head of H=4 m, or Q=4 m^3/s and H=1 m, but at the same time the regular Kaplan turbine diameter grows from ~47 cm to ~133 cm. Or with a turbine power of just ~9 kW with Q=1 m^3/s and H=1 m it grows to a diameter of ~67 cm. The reason for increasing the turbine diameter is to reduce the water speed and thus cavitations on turbine. With the counter rotating double turbine according to the invention it is possible to reduce the diameter to ⅔-¾ from the original size.

[0058] As the turbine diameter is the main factor which regulates also all the surrounding structures it is the key dimension which determines if the waterpower-project is even feasible. Normally civil work cost is found out to be 5 times higher under 1.5 m head as compared to under 3 m head. In very low heads the turbine diameter easily exceeds the head height and leads to a situation where the whole turbine must be rearranged as shown in Patent CA Pat. No. 2,546,508, or the problem is solved with a matrix of turbines as shown in U.S. Pat. No. 6,281,597.

[0059] Another known problem in existing Kaplan- and Francis-type water turbines is that their efficiency curve drops relatively rapidly when the flow is not in the planned optimum. This phenomenon can be reduced with variable pitch propellers and wicket gates, but it also increases the investing costs and such a system needs also constant process surveillance. As the invention described here is not based on an optimally developed vortex like water flow, i.e. the water flow as in a conventional Kaplan turbine, but instead an axially symmetric water flow, its efficiency-curve is less reliant to the optimum water flow. This gives the invention a benefit where great flow-variances occur.

[0060] As schematically indicated in FIG. **2**, in accordance with the present invention, there is provided a water turbine comprised of the following components: two propeller-type turbine wheels **11**, **12** in a flow tube **10** rotating in counter directions. The turbines are driveable connected together with a gear to synchronize their movements. The gear transfers the mechanical energy outside the water flow tube where it is turned into an electric energy.

[0061] FIG. **3** is a perspective view of a turbine **17** according to the invention. The turbine **20** comprises a water flow tube **18** with a substantially cylindrical outer wall **19**. A flowing water with a flow direction **23** is fed into flow tube **21** at an upstream tube end **24**. Flow tube **18** is composed of an entry tube section **20** beginning at upstream tube end **24**, an intermediate turbine tube section **21**, and a subsequent draft tube section **22** leading to an downstream tube end **25**.

[0062] Entry tube section **20** is provided with an inner wall **26** with an inner diameter decreasing in the flow direction **23** in order to increase the kinetic energy of the flowing water. Turbine tube section **21** is provided with an inner wall **27** with an inner diameter increasing in the flow direction **23**, for the reasons further explained below. Thus, the kinetic energy of the flowing water is already decreased in the turbine tube section **21**. Draft tube section **22** is provided with an inner wall **28** with an inner diameter further increasing in the flow direction **23** in order to further decrease the kinetic energy of the flowing water to an upstream energy level before it enters into flow tube **18**.

[0063] With respect to water flow direction **23**, first a fore wheel **31** and subsequently an after wheel **32** are arranged inside turbine tube section **21** in immediate proximity to each other such that wheels **31**, **32** can rotate along a common rotation axis **30** extending in water flow direction **23**. Wheels **31**, **32** are from the type of the wheels of a propeller turbine. It is also conceivable, however, that wheels **31**, **32** are from the type of the wheels of a Kaplan turbine.

[0064] Wheels **31**, **32** are each composed of a hub **33**, **34** and several blades **35**, **36**. Blades **35**, **36** are formed such that wheels **31**, **32** rotate counterwise, i.e. in a mutually opposite rotation direction, driven by the water flow in direction **23**. Fore wheel **31** has four blades **35** and after wheel **32** has three blades **36**. The shape of the outer edge **37**, **38** of blades **35**, **36** is adapted to the geometry of inner wall **27** of turbine tube section **21**, such that blades **35**, **36** can rotate in immediate proximity to inner wall **27** of turbine tube section **21**.

[0065] The position at which the water flow enters wheels **31**, **32** is subsequently denoted as the respective leading edge **39**, **40** of wheels **31**, **32**. The position at which the water flow exits wheels **31**, **32** is subsequently denoted as the respective leaving edge **41**, **42** of wheels **31**, **32**. The diameter of leaving edge **41** of fore wheel **31** corresponds to the diameter of leading edge **40** of after wheel **32**. Turbine tube section **21** ends at leaving edge **42** of after wheel **32**, at which draft tube section **22** follows. At leading edge **39** of fore wheel **31**, a hydrodynamic nose structure **29** is provided as an upstream extension of hub **33** to improve the fluid dynamics. The length of draft tube section **22** corresponds to approximately three times of the leading edge diameter **39** of fore wheel **31**.

[0066] Inside draft tube section **22**, i.e. further downstream with respect to leaving edge **42** of after wheel **32**, a gear arrangement **45** is provided. Gear arrangement **45** comprises a first gear **46** and a second gear **47** subsequently arranged around rotation axis **30** in a mutually opposing manner such that gears **46**, **47** are facing each other. Gears **46**, **47** are conical gears. An engagement gearing **48** facing rotation axis **30** is provided above rotation axis **30** in such a manner, that it engages with both other gears **46**, **47**. For this purpose, first gear **46** and second gear **47** are arranged on the downstream and upstream end of engagement gearing **48**, respectively. Engagement gearing **48** is constituted by a conical gear. Wheels **31**, **32** are connected to gears **46**, **47** each via a respective shaft **56**, **57**, as further explained below.

[0067] At its outer surface, engagement gearing **48** is fixed to a transmission shaft **51**. Transmission shaft **51** extends from engagement gearing **48** orthogonally to outer wall **19** to a region outside of flow tube **18**. For this purpose, a through hole **52** is provided in outer wall **19** of flow tube **18**. Around the position of through hole **52**, a mounting block **53** is provided by which an outer cylinder **54** is fixed on outer wall **19**. Transmission shaft **51** extends along the central axis of outer cylinder **54** to its upper end, where transmission shaft **51** is provided with a driving crank **55**. Driving crank **55** or transmission shaft **51** is connected to a power generator to produce electrical energy. The generator can be installed, for instance, inside or above or in place of outer cylinder **54**.

[0068] From FIG. **4** depicting a detailed sectional view of turbine **17** it is apparent that fore wheel **31** is connected to first gear **46** via first shaft **56** and after wheel **32** is connected to second gear **47** via second shaft **57**. The respective gears **46**, **47** are arranged inversely with respect to water flow direction **23** as compared to fore wheel **31** and after wheel **32**, i.e. first gear **46** is arranged after second gear **47** along rotational axis **30**.

[0069] Shafts **56**, **57** extend along rotation axis **30**. Second shaft **57** is a hollow shaft through which first shaft **56** concentrically extends. Via shafts **56**, **57**, gears **46**, **47** are driven to rotate in the same direction as respective wheels **31**, **32** driven by the water flow. Thus, a counterwise rotation of gears **46**, **47** is achieved through the water flow, such that gears **46**, **47** rotate in a mutually opposite direction, which is necessary to drive engagement gearing **48**. Moreover, an equivalent rotation speed of gears **46**, **47** is intrinsic for the drive of engagement gearing **48**. In this way, the rotation speeds of wheels **31**, **32** are mutually coupled by means of engagement gearing **48**. To provide the rotation speeds of wheels **31**, **32** at the desired equivalent value, the geometry of turbine tube section **21** and wheels **31**, **32** is adjusted accordingly.

[0070] It becomes further apparent from FIG. **4**, that inner wall **27** of turbine tube section **21** exhibits a convex curvature along which the cross-sectional area of turbine tube section **21** widens in water flow direction **23**. Thus, the inner diameter of turbine tube section **21** increases with an increasing slope and a flow profile of inner wall **27** is provided along which the mean fluid velocity decelerates. The convex curvature of inner wall **27** extends from a position with a forward distance to leading edge **39** of fore wheel **31** to the position of leaving edge **42** of after wheel **32**. This geometry is used to synchronize the rotation speed of wheels **31**, **32**.

[0071] Draft tube section **22** following turbine tube section **21** after the position of leaving edge **42** of after wheel **32** has a diameter further increasing in water flow direction **23**. The shape of inner wall **28** of draft tube section **22** exhibits a slightly concave curvature or a substantially constant slope. The geometry and length of inner wall **28** of draft tube section

22 is designed for recovery of the kinetic energy of the water flow. Nonetheless, also the geometry of inner wall **27** of turbine tube section **21**—together with the inner arrangement of wheels **31**, **32**—largely contributes to the recovery of kinetic energy. This leads to an effective reduction of the length required for draft tube section **28**.

[0072] FIG. **5** shows a frontal view of fore wheel **31**. Fore wheel **31** comprises four blades **35***a*-**35***d* with an identical shape and equidistantly arranged around hub **33**.

[0073] FIG. **6** shows a frontal view of after wheel **32**. After wheel **32** comprises three blades **36***a*-**36***c* with an identical shape and equidistantly arranged around hub **34**. Blades **36***a*-**36***c* have a larger surface as compared to blades **35***a*-**35***d*. The diameter of fore wheel **31** at its leaving edge **41** substantially corresponds to the diameter of after wheel **32** it its leading edge **40**. The diameter of fore wheel **31** at its leading edge **39** deviates from the diameter of after wheel **32** it its leaving edge **42** by approximately 25% to 30%.

[0074] FIG. **7** shows a side view of fore wheel **31**. In the figure, a blade angle α in between outer edge **37** of blades **35** and a plane **61** orthogonal to rotation axis **30** is indicated. Blade angle α varies with the longitudinal position of orthogonal plane **61** along rotation axis **30**. This longitudinal variation of blade angle α is affected by the course **58** of blades **35** along which blades **35** extend around hub **33**, by the desired rotation direction of fore wheel **31** driven by water flow **23** and by the shape of inner wall **27** of turbine tube section **21** such that outer edges **37** of blades **35** seamlessly border onto inner wall **27**. Course **58** of blades **35** along hub **33** can be described as a partial helix winding around hub **33**, as further described below.

[0075] FIG. **8** depicts a corresponding side view of after wheel **32**, in which blade angle β in between outer edge **38** of blades **36** with respect to plane **61** orthogonal to rotation axis **30** is indicated. Blade angle β also exhibits a longitudinal variation, the amount of which being affected by the course **59** of blades **36** along hub **34**, by the desired rotation direction of after wheel **32** driven by water flow **23** and by the shape of inner wall **27** of turbine tube section **21** such that outer edges **38** of blades **36** seamlessly border onto inner wall **27**. Course **59** of blades **36** can be described as a continuation of the partial helix winding along course **58** around hub **33**. The helical course **58**, **59** of blades **35**, **36** around hubs **33**, **34** of wheels **31**, **32** is subsequently described in greater detail on the basis of a schematic illustration shown in FIGS. **9** and **10**.

[0076] The length of after wheel **32** in water flow direction **23** along which blades **36** extend exceeds the corresponding length of fore wheel **31** along which blades **35** extend. In this way, a desired pitch of the helical course **59** of blades **36** can be reached at leaving edge **42** of after wheel **32**. The blade geometry allows to compensate for the chosen lower number of blades **36** on after wheel **32** as compared to the number of blades **35** on fore wheel **31** in order to synchronize the rotation speed of the wheels.

[0077] FIG. **9** schematically shows a frontal view through a cross-sectional area **63** inside turbine tube section **21** with a cylindrical body **66** at its center. Cylinder **66** extends along rotation axis **30**. A helix **64** with a diameter increasing in water flow direction **23** winds around cylinder **66**.

[0078] FIG. **10** shows a corresponding side view of cylinder **66** and helix **64**. Cross-sectional areas **61** further upstream with respect to cross-sectional area **63** are also indicated. In addition, various flow lines **67**, **68** of the water flow inside inner wall **27** of turbine tube section **21** are indicated. The distance between flow lines **67**, **68** widens in water flow direction **23** with an increasing slope. Helix **64** winds around the most outer flow lines **68**.

[0079] Cylinder **66** serves as a schematic illustration of hub **33** of fore wheel **31** or of hub **34** of after wheel **32** or of a combination of both hubs **33**, **34** in which fore wheel **31** and after wheel **32** are directly arranged one after the other along water flow direction **23**. Helix **64** serves to illustrate the corresponding shape of blades **35**, **36** at the position of outer flow lines **68**.

[0080] More precisely, helix **64** defines a pitch line, i.e. a line that passes through the leading edge **39**, **40** and leaving edge **41**, **42** of blades **35**, **36** at the position of outer flow lines **68**. The shape of blades **35**, **36** changes accordingly at inner flow lines **67**. As already noted, the length of courses **58**, **59** of blades **35**, **36** along hub **33**, **34** of fore wheel **31** and after wheel **32** corresponds to a partial helical revolution around cylinder **66**.

[0081] Three subsequent longitudinal distances P**1**, P**2**, P**3** in flow direction **23** are indicated in FIG. **10**, each corresponding to one revolution of helix **64**. Longitudinal distances P**1**, P**2**, P**3** of the helix revolutions decrease in flow direction **23**. The corresponding radiuses R**1**, R**2**, R**3**, R**4** of the respective helix revolutions increase in flow direction **23**. Corresponding angles γ**1**, γ**2**, γ**3** between helix **64** and cross-sectional areas **61** continuously decrease in flow direction **23**.

[0082] Longitudinal distances P**1**, P**2**, P**3** define the pitch of blades **35**, **36** at outer flow lines **68**. Pitch P**1**, P**2**, P**3** is a measure of the axial fluctuation in motion of a given radial position R**1**, R**2**, R**3**, R**4** that has been covered after one complete revolution of blades **35**, **36**. Radiuses R**1**, R**2**, R**3**, R**4** are subsequently denoted as pitch radius. Angles γ**1**, γ**2**, γ**3** define the pitch angle of blades **35**, **36** at outer flow lines **68**. Pitch angles γ**1**, γ**2**, γ**3** are a measure of the pressure face of blades **35**, **36** along pitch line **64** with respect to plane of rotation **61**.

[0083] Accordingly, pitch P**1**, P**2**, P**3** of blades **35**, **36** of wheels **31**, **32** shown in FIGS. **7** and **8** continuously decreases in water flow direction **23**. Pitch radius R**1**, R**2**, R**3**, R**4** of blades **35**, **36** of wheels **31**, **32** continuously increases in water flow direction **23**. Pitch angle γ**1**, γ**2**, γ**3** of blades **35**, **36** of wheels **31**, **32** continuously decreases in water flow direction **23**.

[0084] In the vector diagram shown in FIG. **11**, a specific example of the absolute velocity, relative velocity and blade speed at two different positions of fore wheel **11**, **31** and at two different positions of after wheel **12**, **32** is illustrated.

[0085] The absolute velocity C**1** at leading edge **39** of fore wheel **31** is given by the sum of the relative velocity W**1** and the blade speed U**1** at leading edge **39** of fore wheel **31**. The absolute velocity C**2** at leaving edge **41** of fore wheel **31** is given by the sum of the relative velocity W**2** and the blade speed U**2** at leaving edge **41** of fore wheel **31**. The absolute velocity C**3** at leading edge **40** of after wheel **32** is given by the sum of relative velocity W**3** and blade speed U**3** at leading edge **40** of after wheel **32**. The absolute velocity C**4** at leaving edge **42** of after wheel **32** is given by the sum of the relative velocity W**4** and the blade speed U**4** at leaving edge **42** of after wheel **32**. The vectors are designated in a Cartesian coordinate system with an axial vector component X in water flow direction **23** and a tangential vector component Y in an orthogonal direction.

[0086] Absolute velocities C**1**, C**2**, C**3**, C**4** are a measure of the speed of the incoming water flow in an absolute frame of reference. C1*m* denotes the meridian velocity at leading edge **39** of fore wheel **31** averaged over the cross sectional area of the water flow. Blade speeds U**1**, U**2**, U**3**, U**4** are a measure of the tangential velocity ω·r of blades **35**, **36** at a radial distance r, when wheels **11**, **12**, **31**, **32** rotate with rotation speed ω. Relative velocities W**1**, W**2**, W**3**, W**4** are a measure of the speed of water flow in a frame of motion relative to blade speeds U**1**, U**2**, U**3**, U**4**. Thus, relative velocities W**1**, W**2**, W**3**, W**4** are influenced by the respective angle of blades **35**, **36** of wheels **11**, **12**, **31**, **32** with respect to line **61** orthogonal to rotation axis **30**.

[0087] In common axial turbines, such as in Kaplan, Francis or propeller turbines, the velocity of the passing water jet substantially remains unchanged and only the water pressure is changed as the water jet acts on the turbine blades. Such a type of turbine is also referred to as reaction turbine.

[0088] As depicted in FIG. **11**, however, the velocity C**1**, C**2**, C**3**, C**4** of a water jet changes during its passage of turbine tube section **21** of axial turbine **17**. Turbine **17** according to the invention may therefore be regarded as an "axial impulse turbine" in which also a change of velocity of the water flow can be exploited for energy generation.

[0089] Moreover, the axial turbine loss during the water passage of the wheels and therefore the efficiency of axial turbines, in particular of current Kaplan, Francis or propeller type turbines, generally depends on approximately the square of the relative velocity W of the water flow relative to the blade speed. However, since relative velocity W**1**, W**2**, W**3**, W**4** of a water jet passing through turbine tube section **21** according to the invention is strongly reduced due to the decrease of absolute velocity C**1**, C**2**, C**3**, C**4**, the efficiency of an axial turbine **17** according to the invention can be optimized.

[0090] Subsequently, several features of turbine **17** depicted in FIG. **3**-**8** and other embodiments and advantages of the invention are summarized:

[0091] The turbine drive depicted in FIG. **3** is designated to be directly mounted to the input shaft of a generator (not shown). The drive contains a reversing mechanism **45** which has a driving shaft **51** having a conical gear **48** in constant engagement with two conical gears **46** and **47**. The gear **46** is driven by a propeller shaft **56** and the gear **47** is driven by a propeller shaft **57** in the form of a hollow shaft mounted concentrically to the shaft **56**. The shaft **56** carries a propeller **31** and the shaft **57** a propeller **32**. With the arrangement described, the propeller shafts will rotate in opposite directions. The shown arrangement can been placed after the propellers **31** and **32** as shown in FIG. **3** or it can been placed before the propellers **31**, **32**.

[0092] The after propeller **32** has a greater diameter than the fore propeller **31**, and the flow tube **10**, **18** must be formed, as schematically illustrated in FIGS. **2** and **4**, so that both propellers can function efficiently and an axially symmetric water flow can been maintained with a maximum water velocity and pressure reduction on the propellers **31**, **32**.

[0093] As water speed can be efficiently lowered already in the turbine **17** itself, it means also that the optimal draft tube **22** relative length is smaller than it is with regular turbines. The flow tube **10**, **18** can been build up tube as in the embodiment shown in FIG. **2**-**4**, or it can been a virtual tube in free water just describing the flow.

[0094] In the embodiment shown in FIG. **2**-**8**, the diameter of the fore propeller **31** is 93% of the diameter of the after propeller **32**, but depending on various factors such as head height and flow for example, the diameter of the fore propeller **31** can be also 80-97% or 60-97% or beyond of the diameter of the after propeller **32**. The fore propeller **31** can have the same or greater pitch than the after propeller **32**.

[0095] The fore propeller has more blades **35** (i.e. 4 pcs), while the after propeller has less blades **36** (i.e. 3 pcs), as shown in the embodiment in FIG. **2**-**8**.

[0096] As shown in the embodiment in FIG. **2**-**8**, the propellers leading edge has a smaller diameter than the leaving edge. This helps the turbine to reach the optimum flow tube form **10** shown in FIG. **2**-**4**.

[0097] The propellers **31**, **32** pitch P**1**, P**2**, P**3** may also vary in the blade area if there is also a difference on blade edge diameters.

[0098] From the foregoing description, numerous modifications of the turbine according to the invention and to a corresponding hydroelectric power plant are apparent to one skilled in the art without leaving the scope of protection of the invention that is solely defined by the claims.

1. A turbine for hydraulic power generation comprising two bladed wheels successively arranged in a turbine tube section as a fore wheel and an after wheel with respect to the water flow direction along a common rotation axis extending in the water flow direction, the wheels being configured to rotate in opposite directions driven by the water flow, wherein a first gear and a second gear are arranged along the rotation axis, wherein the first gear is connected to the fore wheel and the second gear is connected to the after wheel such that each of the first and second gear is configured to rotate around the rotation axis driven by the respective wheel, and the first gear and the second gear are connected via an engagement gearing such that the fore wheel and the after wheel are coupled to each other with respect to their rotation speed, the engagement gearing being connectable to a power generator.

2. The turbine according to claim **1**, wherein the first gear is connected to the fore wheel via a first shaft and the second gear is connected to the after wheel via a second shaft, one of the shafts being a hollow shaft and the other shaft extending concentrically through the hollow shaft along the rotation axis.

3. The turbine according to claim **1**, wherein the engagement gearing is fixed to a transmission shaft for connecting the engagement gearing to a power generator, the transmission shaft extending through an outer wall of the turbine tube section or of a tube section before or behind the turbine tube section.

4. The turbine according to claim **1**, wherein the geometry of the turbine tube section and/or the wheels is adapted such that the fore wheel and the after wheel are configured to be driven by the water flow at substantially the same rotation speed.

5. The turbine according to claim **1**, wherein the turbine tube section is provided with an inside diameter increasing in the water flow direction.

6. The turbine according to claim **5**, wherein the inside diameter of the turbine tube section increases with a slope continuously increasing from the position at which the water flow enters the fore wheel to the position at which the water flow exits the after wheel.

7. The turbine according to claim **5**, wherein the change of the inside diameter of the turbine tube section is chosen such that the water flow speed is reduced by at least 6%, more preferred by at least 20%, at the cross-sectional area at which the water flow exits the after wheel as compared to the cross-sectional area at which the water flow enters the fore wheel.

8. The turbine according to claim **1**, wherein the fore wheel or the after wheel or both have a diameter at a leading edge at which the water flow enters the wheel which is smaller as compared to the diameter at a leaving edge at which the water flow exits the respective wheel.

9. The turbine according to claim **8**, wherein the difference between the leaving edge diameter and the leading edge diameter of the after wheel is larger as compared to the difference between the leaving edge diameter and the leading edge diameter of the fore wheel.

10. The turbine according to claim **1**, wherein the leading edge diameter of the fore wheel at which the water flow enters the fore wheel is at most 97%, more preferred at most 90% and most preferred at most 80%, of the leaving edge diameter of the after wheel at which the water flow exits the after wheel.

11. The turbine according to claim **1**, wherein the fore wheel and the after wheel are arranged in immediate proximity to each other.

12. The turbine according to claim **1**, wherein the length in the water flow direction of the after wheel is different as compared to the length in the water flow direction of the fore wheel.

13. The turbine according to claim **1**, wherein the pitch of the wheel blades decreases in the water flow direction.

14. The turbine according to claim **13**, wherein the corresponding radius of the pitch of the wheel blades increases in the water flow direction.

15. The turbine according to claim **1**, wherein the wheels are arranged along the rotation axis before or after the gears with respect to the water flow direction.

16. The turbine according to claim **1**, wherein a different number of blades is provided on the fore wheel as compared to the after wheel.

17. The turbine according to claim **1**, wherein at a position at which the water flow exits the after wheel the turbine tube section is followed by a draft tube section, the draft tube section being provided with an inside diameter increasing in the water flow direction and a length adapted to recover the water flow speed downstream of the turbine to a level of the water flow speed upstream of the turbine.

18. The turbine according to claim **17**, wherein the length of the draft tube section corresponds to a value of at most four times the diameter of the fore wheel at a leading edge at which the water flow enters the wheel.

19. A hydroelectric power plant comprising a flowing or falling water and at least one turbine according to claim **1**, wherein the flowing or falling water is channeled through the turbine tube section.

20. The hydroelectric power plant according to claim **19**, wherein the flowing or falling water exhibits a hydraulic head of at most 4 m, more preferred at most 2.5 m and most preferred at most 0.8 m, before entering the turbine tube section.

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