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Counter-Rotating Type Power Unit Provided for Tidal Range (Toward collaboration with the wave power unit at the offshore)

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Abstract- *To cope with the warming global environments, authors have proposed the counter-rotating type hydroelectric unit. This unit may take place of the traditional bulb type turbines, and is suitable for not only the hydropower on the land but also the tidal power in the ocean. This paper discusses the effect of the runner blade number on the performances and the internal flow conditions, at the bidirectional flows. Besides, the optimum adjusting angles of the runner blades are discussed to operate at the on-cam. The runner blades were modified to get the fruitful output from not only the rising but also the falling tides at the power station with the dam/weir/sluice. Above experimental results verified that the unit with bidirectional type runners can be provided not only for the isolated but also for the grid-connected power plant.*

Keywords: Hydroelectric unit, Tidal power, Counter rotation, Tandem runners, Double rotational armature

1. INTRODUCTION

To cope with the warming global environments, the ocean power should occupy the attention of the electric power generation systems as clean and cool energy sources. That is, we should make effort to utilize effectively the large/small/mini/micro hydropower not only on the land but also on the ocean, without nature disruptions. For contributing to such demands, it is required to prepare more several types of the hydroelectric unit suitable for the individual hydro/ocean-circumstances.

The unique turbine with the counter-rotating runners has been proposed [1], and the author also have invented the counter-rotating type hydroelectric unit, which is composed of the tandem runners and the peculiar generator with the double rotational armatures [2]. In this unit, the front and the rear runners counter-drive the inner and the outer armatures of the peculiar generator, respectively, while the rotational torque is counter-balanced successfully in the runners/armatures. The unit has promising advantages that not only the output voltage is sufficiently high without supplementary equipments such as a gearbox, but also the rotational moment hardly acts on the mounting bed owing to the momentum balance. That is, it is not necessary to set rigidly the unit on the mounting bed anchored to the ground. The fundamental performances and the flow conditions around the runners have been investigated and the design data for the runners have been presented [3].

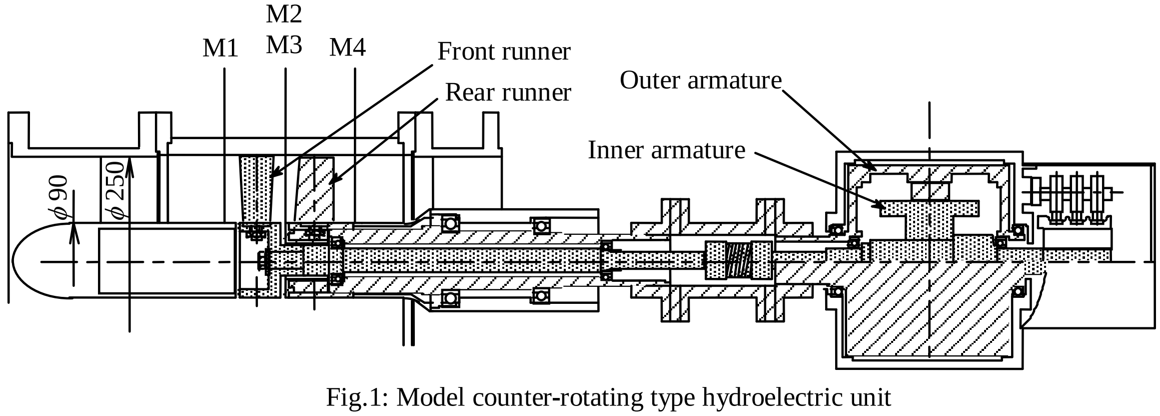


Fig.1: Model counter-rotating type hydroelectric unit

This type unit can be provided for not only the hydropower at the land but also the tidal power on the ocean, in place of the traditional bulb type turbines [4]. It is necessary to set uselessly/unfortunately a pair of the traditional type hydroelectric units whose nose and tail are replaced each other, for utilizing sufficiently the rising and the falling tidal energies. The counter-rotating type hydroelectric unit is, however, effective to both flow directions without every modifications, because the flow discharged from the rear runner is in the axial direction while the swirl-less flow attacks to the front runner. This paper discusses the effect of the runner blade number on the performances and the internal flow conditions, at the bidirectional flows. Besides, the adjusting angles of the blades are optimized to operate at the on-cam condition in response to the gradual change of the tidal head at the power station, in keeping the relative rotational speed constant to provide the unit for the grid system.

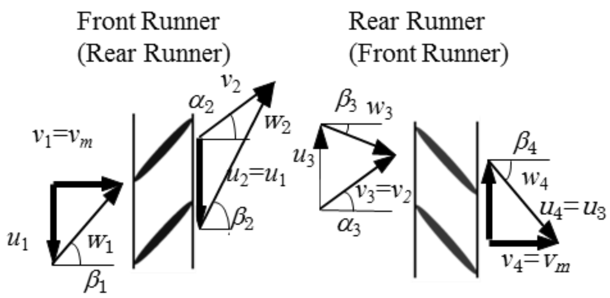


Fig.2: Velocity triangles through the axial flow type counter-rotating runners

2. MODEL POWER UNIT

2.1 Model Unit and Operating Conditions

Figure 1 shows the tentative model counter-rotating type hydroelectric unit composed of the axial flow type tandem runners and the synchronous generator with double rotational armatures. As shown in Fig. 2 (u: the rotational velocity, v: the absolute velocity, w: the relative velocity, v_m: the meridian velocity, α and β: the absolute and the relative flow angles, subscripts 1-4: the inlet and the outlet sections), the axial flow at the front runner inlet gives the rotational torque to the front runner, and swirls at the front runner outlet. Its swirling flow gives the counter-rotational torque to the rear runner, and runs out in the axial direction. It means that the angular momentum change through the front runner must coincide with the angular momentum change through the rear runner, for making the rotational torque between the armatures counter-balance. Such velocity triangles verify that these type tandem runners are suitable for not only unidirectional flow at the hydroelectric power station on the onshore but also bidirectional flows at the tidal range power station on the offshore.

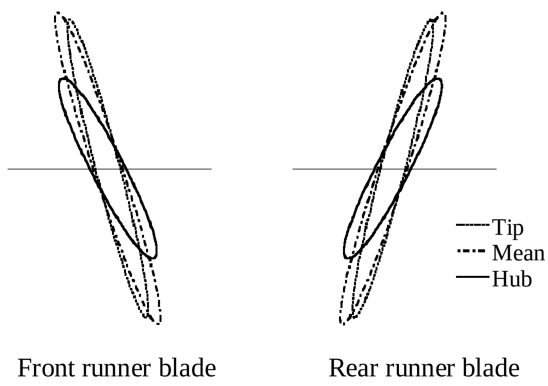


Fig.3: Cross sections of Runner Blade D

2.2 Runner Profiles

The front and the runner blade (Runner Blade D) were designed so as to work effectively at the bidirectional flows, as shown in Fig. 3, where the head H = 1.75 m and the discharge Q = 0.28 m^3/s at the relative rotational speed n_T = 1,500 min^{-1}. The blades have the symmetrical hydrofoils without the camber. The trailing edge is also the same profiles as the leading edge, and the rear blade is the same profiles as the front blade. The thickness of the blade is modeled after the NACA 0009 hydrofoils. The diameter of the runners is 245 mm with the hub diameter of 90 mm and the casing diameter 250 mm.

To know the turbine performances and the flow conditions, two type runners called Runner D34 and D43 were prepared, where D gives the blade profiles shown in Fig. 3, the numerical values give the number of the front and the rear blades in order, and the runner blades were set at the hub shown in Fig. 1.

In the experiments, the isolated motors with the generative braking system was connected directory to the

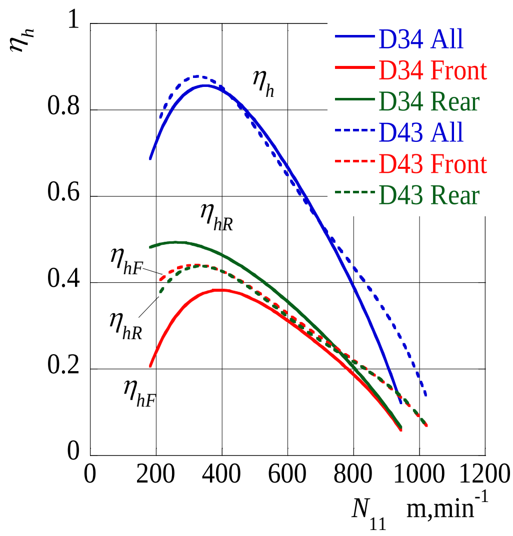


Fig. 4: Hydraulic efficiency of D34 and D44

runner, respectively, while coinciding the rotational torque of the front runner with that of the rear runner.

2.3 Turbine Performances

Figure 4 shows the hydraulic efficiencies [5] of Runners D34 and D43, where D43 means that the flow direction is changed from the direction for D34. The efficiency of the front runner η_{hF} with 4 blades (Runner D43: the thin dash line) is higher than that with 3 blades (Runner D34: the thick dash line), and the efficiency of the rear runner η_{hR} with 4 blades (Runner D34: the thick dash line) is higher than that with 3 blades (Runner D43: the thin dash line). Resultantly, the flow direction hardly affects the hydraulic efficiency η_h of the reversible/bidirectional type runners even if the front and the rear blade numbers are reasonably changed (see η_h drawn by the full lines in Fig. 4).

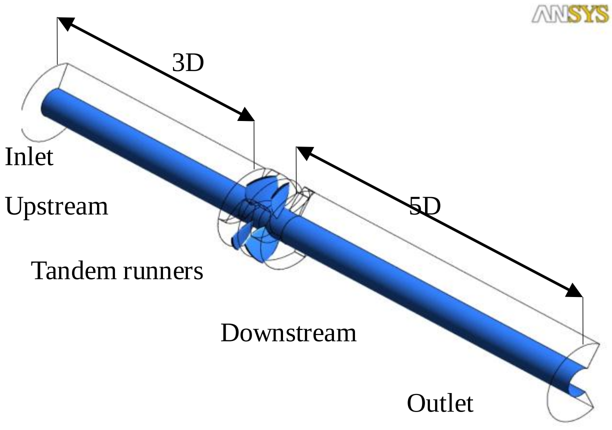
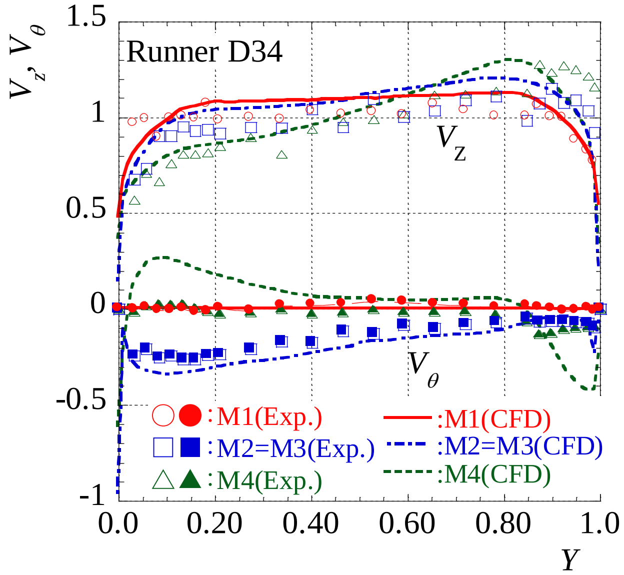
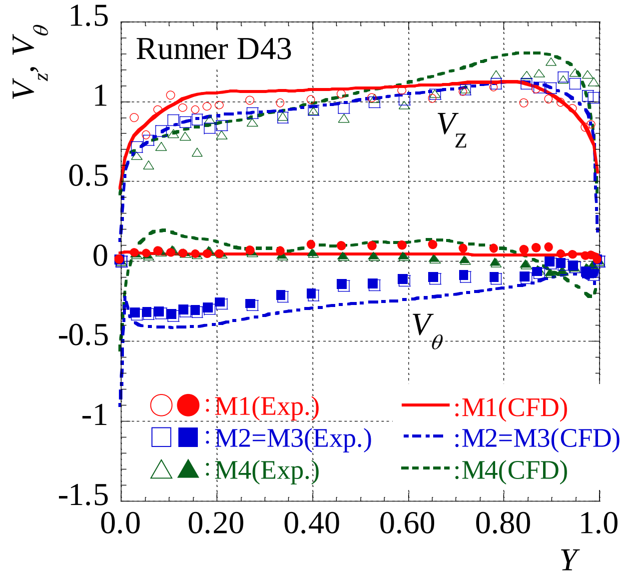


Fig.5: Flow region in the numerical simulation

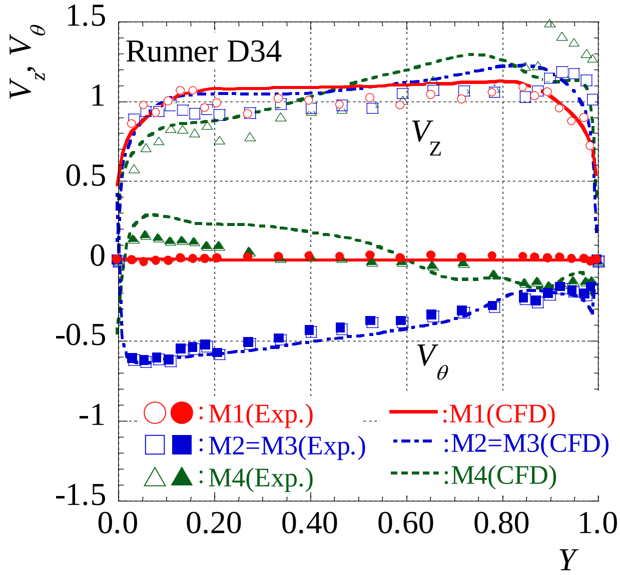


(a) RunnerD34

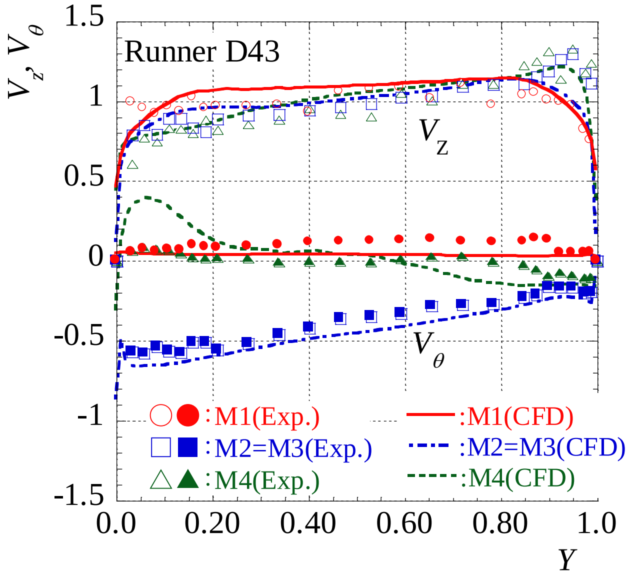


(b) RunnerD43

Fig.6: Velocity distributions around runners at the maximum output



(a) RunnerD34



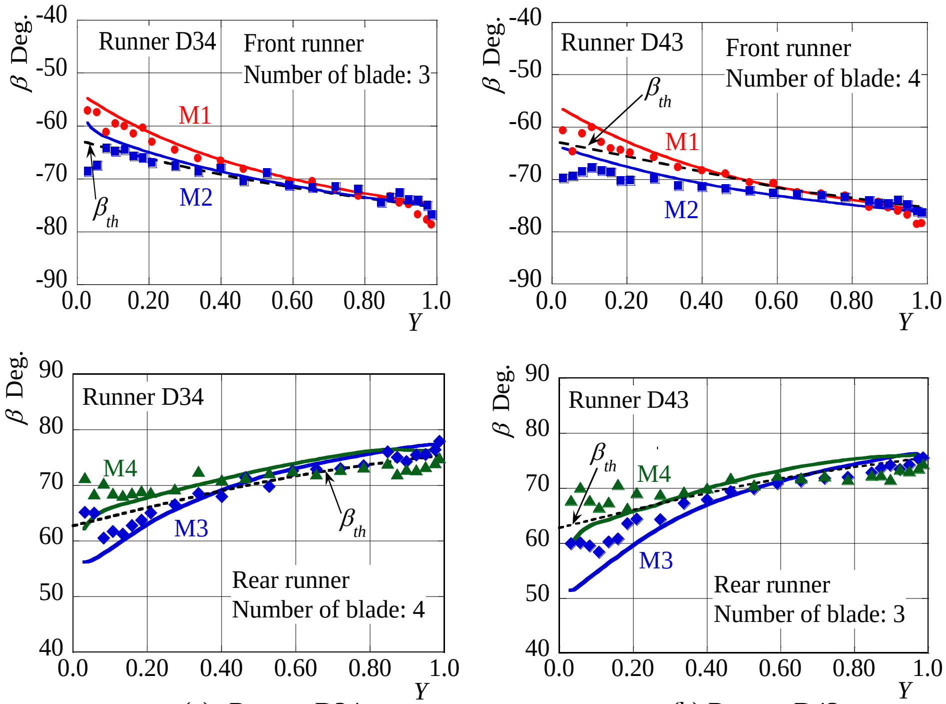
(b) RunnerD43

Fig.7: Velocity distributions around runners at the maximum efficiency

2.4 Flow Conditions around Runners

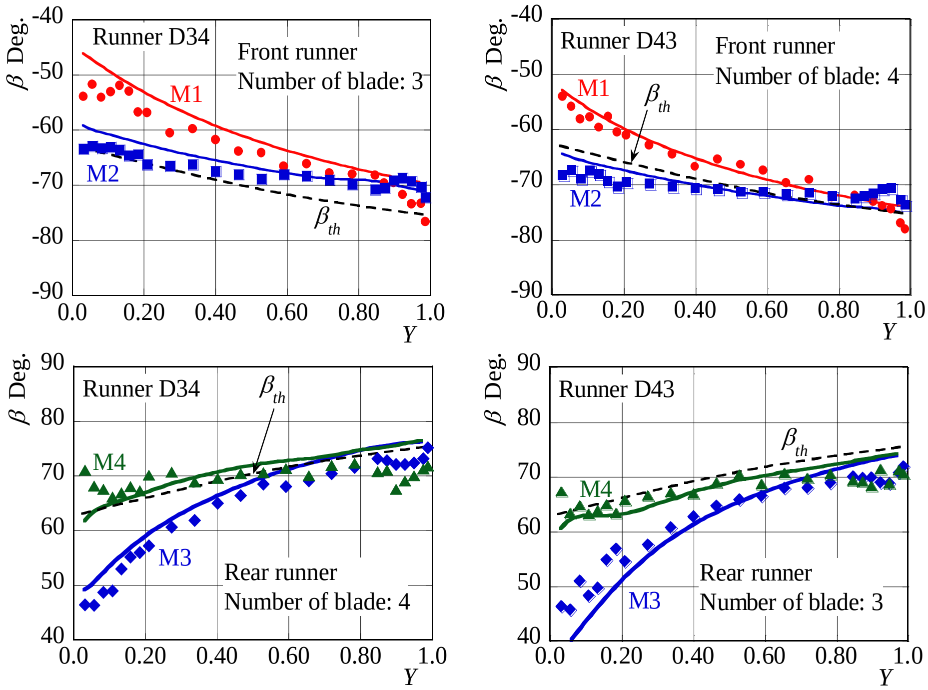
To prepare the design tool for optimizing the runner profiles, the flow conditions around the runners were simulated numerically with the commercial code ANSYS CFX-11, where the region of the simulation is shown in Fig. 5. The region from the inlet to the outlet sections was divided into the upstream (node number: 123,000), the front runner (node number: 266,000), the rear runner (node number: 352,000) and the downstream (node number: 155,000) sub-regions, and each sub-region was connected with the frozen-rotor interface.

The velocity distributions around the runners at the maximum output and the maximum hydraulic efficiency are shown in Figs. 6 and 7, where V_Z and V_θ are the meridian and the swirling velocity components divided by the inlet mean meridian velocity, Y is the dimensionless distance measured from the hub to the casing walls, and Sections M1~M4 are referred to Fig. 1. The runner profiles scarcely affect the flow conditions irrespective of the operating conditions, and the distribution of the swirling velocity component is the free vortex type at the front runner outlet (M2) as expected in the design. Besides, the flow discharged from the rear runner runs in the axial direction in order to make the angular momentum change coincide with that through-the front runner.



(a) Runner D34 (b) Runner D43

Fig.8: Relative flow angles at the maximum output



(a) Runner D34 (b) Runner D43

Fig.9: Relative flow angles at the maximum efficiency

These figures derive the relative flow conditions as shown in Figs. 8 and 9, where β is the relative flow angle measured from the axial direction (see Fig. 2) and averaged in the tangential direction, β_{th} drawn by the thin dash line is the blade setting angle without the camber. The relative flow angles discharged from the runners are close to β_{th} at the maximum output (Fig. 8), but the flows deviate slightly from β_{th} at the maximum hydraulic efficiency (Fig. 9). The runner has to get the angular momentum change from the through flow, even if the blade has no camber. The relative flow has the positive attack angle at the leading edge and is discharged from the trailing edge along the blade camber. That is, the momentum change always accompanies with the shock loss at the leading edge.

As recognized in Figs. 6, 7, 8 and 9, the flow conditions can be predicted well with the commercial code CFD. The code may be useful to design the runners at the future steps.

3. ON-CAM OPERATION

To try the on-cam operation, Runner D33 was prepared. We can know preliminarily/conveniently the performances at the bidirectional flow conditions without every modifications, because the number of the front blade is the same as one of the rear blade. In the following experiments, the relative rotational speed was kept constant n_T = 900 min^{-1} with 8-poles for connecting the grid system having 60 Hz, irrespective of the tidal circumstances. The blade setting angles, namely the stagger angles were adjusting. The adjusting angle are measured from the axial direction, and are presented by θ_F for the front runner blade and θ_R for the rear runner blade. The experimental data are given/represented with the curves in place of the discrete points in following figures, as the performances satisfy the similarity law for the traditional hydraulic turbines.

The variable discharge performances are shown in Fig. 10, where Q_{11} is the unit discharge [$=Q/(D^2H^{1/2})$: m, m^3/s], P_{11} is the unit output [$=P/(D^3H^{3/2})$: m, kW, P: the shaft output defined by the standards/codes (IEC et al. [8])], and η_h is the hydraulic efficiency [$=P/\rho gQH$]. The performances satisfy the similarity law for the traditional hydraulic turbines, and then the experimental results are represented with the curves. The unit output P_{11} and the hydraulic efficiency η_h have the same features against the unit discharge Q_{11}, regardless of the blade adjusting angle.

The unit discharge giving the maximum hydraulic efficiency or output is at the higher discharge, with the decrease of the front or the rear blade adjusting angle. The operation at the adjusting angles (θ_F, θ_R) = (66, 75) corresponds to the operation while changing the flow direction at (θ_F, θ_R) = (75, 66), and both efficiencies are almost the same. At (θ_F, θ_R) = (84, 75) and (75, 84), the former efficiency is lower than the latter efficiency owing to the difference of the separation.

The relation between the unit relative rotational speed N_{11} [$=n_TD/H^{1/2}$: m, min^{-1}] and the unit discharge Q_{11} for each blade adjusting (θ_F, θ_R) are shown in Fig. 11, where these are derived from Fig. 10 and the hydraulic efficiency η_h on the each adjusting angle were connected at the same value. That is, Fig. 11 gives not only the on-cam hill chart for the hydraulic efficiency η_h, but also the optimum blade adjusting angle to operate the hydroelectric unit at the specified performances [6].

4. CONCLUDING REMARKS

The effect of the runner blade number on the performances and the internal flow conditions was investigated experimentally and numerically, at the bidirectional flows. Besides, the optimum adjusting angles of the runner blades are discussed to operate at the on-cam. The counter-rotating type hydroelectric unit equipped with the bidirectional type runners can be provided not only for the isolated but also for the grid-connected tidal power plant in collaboration with the ocean wave power plants [7] at offshore.

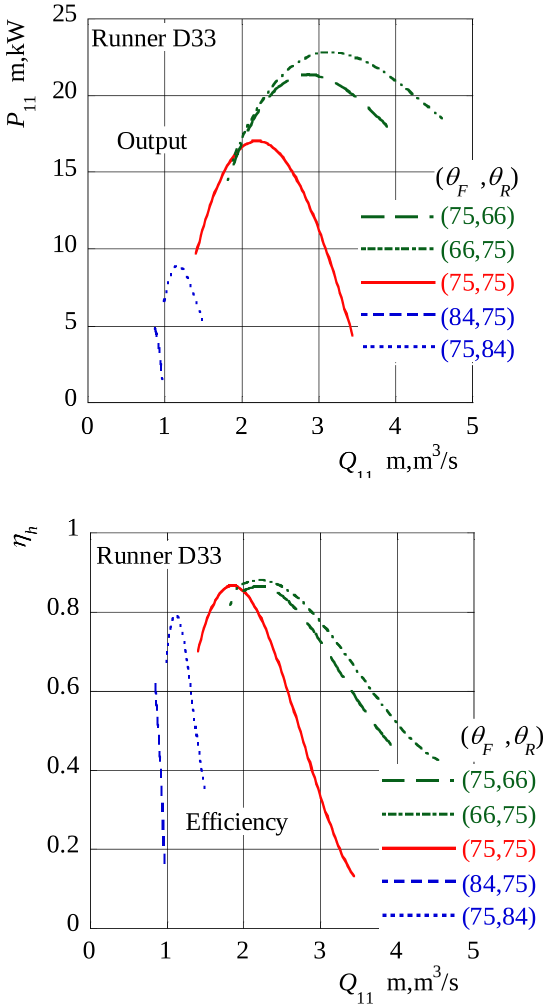


Fig.10: Outputs and efficiencies of Runner D33

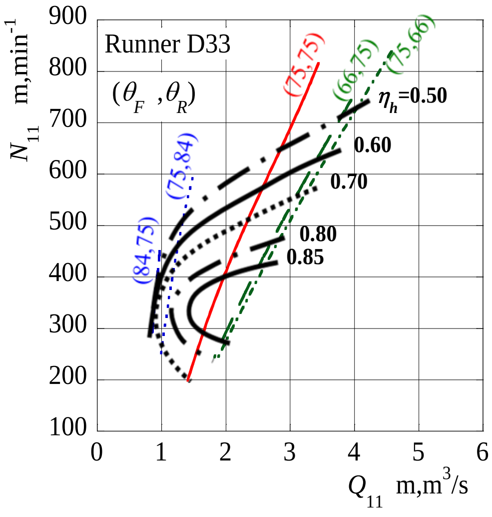


Fig.11: Optimum blade setting angles of Runner D33

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6. NOMENCLATURE

Symbol	Meaning	Unit
u	rotational velocity	(m/s)
v	absolute velocity	(m/s)
w	relative velocity	(m/s)
α	absolute flow angles	(Deg.)
β	relative flow angles	(Deg.)
β_{th}	blade setting angle	(Deg.)
H	head	(m)
Q	discharge	(m^3/s)
n_T	relative rotational speed	(min^{-1})
η_h	hydraulic efficiency	Dimentio-nless
V_Z	meridian velocity components	Dimentio-nless
V_θ	swirling velocity components	Dimentio-nless
Y	dimensionless distance measured from the hub wall	Dimentio-nless
D	diameter of runner	(m)
θ_F	stagger angles of front runner	(Deg.)
θ_R	stagger angles of rear runner	(Deg.)
Q_{11}	unit discharge	(m, m^3/s)
P_{11}	unit output	(m, kW)
N_{11}	unit relative rotational speed	(m, min^{-1})