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Comparison of ASFM Test Result as an Alternative Measuring Method & Performance Improvement Case

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※ *Key words: Index method, Gibson method, ASFM(Acoustic Scintillation Flow Measurement)*

I. Abstract

Considering the importance of efficiency measurements in hydraulic turbines, each condition of measurement should be studied in the early stages of conceptual design for its project. As the most prominent and reasonable data for decision making of rehabilitation or improvement of turbine generating systems, and the meaningful control factor of power plant management with good quality, it should not be neglected. However, it has often been neglected in the past.

For the performance tests of hydraulic machinery discharge always represents the most difficult and important variable to measure, and its error is placed in the major part of turbine performance in comparison with other hydraulic and electric parameters. But, for the majority of turbines which were constructed 20 years ago, it is hard to find any consideration of a certain way to measure the discharge, as its priority of design factor was left behind those conditions of economy, construction, manufacturing, etc.

In this opportunity to share some experiences of hydraulic efficiency measurement, I would like to share two cases of measurement results which were performed by relative and absolute method simultaneously for the reference of each other result, and one case of efficiency improvement through the modification of turbine runners.

The lessons of the former cases are the application possibility of newly developed discharge measurement method, and properness of the comparison between the two test methods. The latter one is going to show the importance of efficiency test in turbine design.

The contents of this report contain:
+ About the public corporation ‘K-water’ in Korea
+ Comparison of Gibson and ASFM on Francis turbine
+ Comparison of Winter-Kennedy test and ASFM on tubular turbine
+ Performance improvement through the modification of turbine runner

II. About K-water (Korea Water Resources Corporation)

K-water is a state-owned public company in Korea. It has 7 regional headquarters, 46 regional offices through the country and around 4,000 employees.

Since its establishment in 1967, K-water has been implementing national water resources management policies regarding multi purpose dams including hydraulic power generation, water supply dams and regional water supply systems, and project development of hydraulic energy in domestic & overseas. It is also making a great contribution toward the development of the national economy and improving the quality of life for local people.

In commemoration of the 40th anniversary of its foundation, K-water has launched the strategic mission; Water for the Happier World and it is pursuing innovation and change, in order to become the "Best Water Partner" in the world.

With basin management, integration, specialization and automation, K-water is making efforts to provide a safe water supply for people so that all may enjoy the benefits of clean water.

With this in mind, K-water is also developing core technologies and utilizing the sharpest minds to take the initiative in water industry for the future. K-water is ready to embody the reliable image of a corporation fulfilling its duties by actively practicing sustainable, ethical and transparent management along with increasing the customer’s value.

As the increasing importance of clean energy in worldwide nowadays, K-water expends its business area in renewable energy development in domestic & oversea regions.

III. Case Studies

Case1. Comparison of ASFM Test Result with Gibson Method

1.1 Brief of Yongdam Small Hydro Pwer Pant

Yongdam small hydro in Yongdam multi-purpose dam is located in north Jella province. It was designed to use the discharge water for the improvement of water quality and environment of river as three small hydro are installed downstream of river outlet pipe. The power plant consists of 2 units of 1,150㎾ turbine and a 1,800 ㎾ turbine. The type of all turbines is horizontal Francis and their annual energy production is up to 29,500 ㎿h.

Two 1,150㎾ turbines were constructed at the time of dam construction but another 1,800㎾ unit was additionally installed after several years by a different turbine manufacturer(a domestic maker). The objective case is for the domestic turbine of 1800㎾.

1.2 The Outline of the Turbine

Turbine type	:	Horizontal Francis
Capacity (㎿)	:	1.8
Head (rated/minimum, m)	:	41.7/29.6
Flow (rated, ㎥/sec.)	:	5.21
Guaranteed turbine efficiency (%)	:	88.0
Manufacturer	:	Dae-yang, Korea

1.3 Test Coditions

1.3.1 General

The ASFM transducer of ASL Co. with 10 paths model was installed on the intake gate slot as shown in figure 1. The intake structure has 3 inlet routes for discharge through surface gate, bottom gate and safety gate, and each route make particular circulation. About the Gibson method, two separated pressure transducers were applied near the main valve of turbine. Required measuring conditions were followed by the code IEC60041.

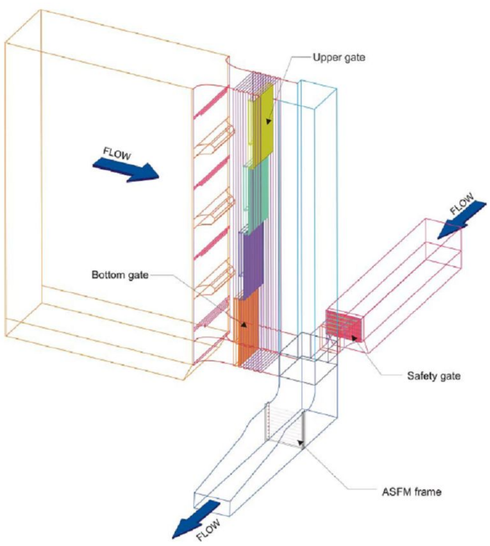

Figure 1 Intake route of discharge flow

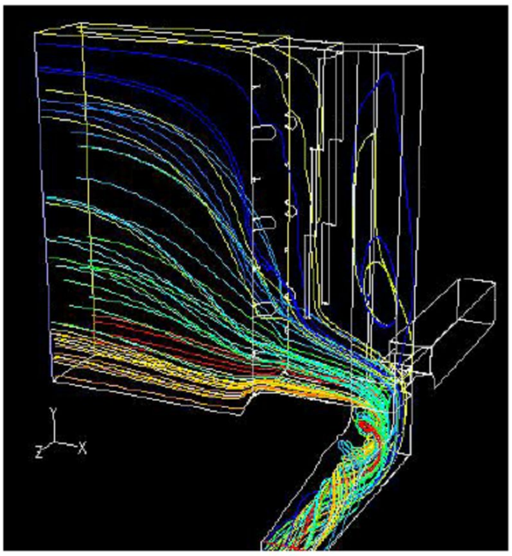

Figure 2 Stream line of Yongdam Small hydro

1.3.2. Instrumentation & Participants

Required accuracy of instrumentation and procedure of test for Gibson method were based on the code, and for the test of ASFM were performed under the manufacturer's supervision. 3 test engineers of K-water and 2 of ASL in Canada participated in the test.

Measuring Methode: Gibson & ASFM				
Test item	**Measuring device**	**Model**	**Accuracy**	**Manufacturer**
Output of Generator	Digital AC Power Meter	WT-130	0.3%	Yokogawa Japan
Static pressure of inlet	Pressure Transducer	PTX630	0.15%	DRUCK U.K.
Water level of Tailrace	Meter of Control Panel	-	-	-
Discharge	Gibson, ASFM	-	1.0%	ASL Canada
Strok of Guide vane	Stroke Transducer	-		Faster USA
Data gathering	Data Acquisition	PXI		N.I. USA

Table 2. Instrumentation of case 1

1.3.3 Operation & Physical data

*** Operation data**

Classification	**Operating Condition**
Date of test	'05. 12. 12 ~ 12. 15
Dam water level [EL. m]	248.07 – 248.08
Gate operation	Safety, bottom, and surface gate
Tailrace water level [EL. m]	205.10 – 205.13
Head net	40.9 – 41.2
Test point (Generator output)	1,505 - 1,646㎾ (4 points)

*** Physical data**

Elevation [EL. m]	207.95	Water Temp. [℃]	5.0
Altitude [。]	35.8	In/Out Pressure [10^5Pa]	4.74 / 1.28
Gravity Acc. [m/s^2]	9.797	Density of water [kg/m^3]	1,001

Table 3. Operation & physical data of case 1

1.4 Test Result

1.4.1 Discharge Calculation of ASFM

All data for the velocity and discharge were calculated from an average of 30 seconds/level of each run. The roof and floor of the intake and the sides of the frame holding the ASFM transducers define a plane surface, S, through which the flow must pass. The discharge is therefore given by the flux through S: $Q = \int V \cdot n\, da$

where the V is the velocity vector and n is the unit vector normal to the plane.

Then the discharge, Q, in terms of laterally averaged velocity v is:

$$Q = \int V(Z') \cdot \cos[\theta(Z')] \cdot L(Z')\ dz$$

where v(z') is the management of the laterally averaged velocity at elevation z', $\theta(Z')$ is the corresponding angle, L(z') is the width between the transducer faces and H is the height of the intake roof above the floor.

For the floor boundary, a simplified profile having the same discharge when integrated between the floor and the bottom transducer (at elevation 0.18m) was used in calculating discharges. A curve of the form: $Q=\left[\frac{Z}{T}\right]^{\frac{1}{x}}$ was fitted for the measured profiles between the floor and bottom transducer, the best fit was found with X = 12.

1.4.2 Result of ASFM

For the discharge and the standard deviation of the repeat runs, percent standard deviation of the discharge is 1.6%, the maximum 5.6%. These values are at least 4 times higher than measurement conducted at other plants, according to the ASL Co.

The results of the CFD model in the Yongdam plant show that the distribution of small-scale turbulence and flow in the intake were strongly skewed at the measurement location would produce a significant positive bias in the ASFM data. That in turn produces turbine efficiency values that are significantly low. The model results showed simulated bias up to 12%.

It may be concluded from this results that the intake gate slot at Yongdam is not well suited for this measurements because of the highly skewed distribution of turbulence and flow velocity there.

1.4.3 Comparison to Gibson Method

Considering the difference, that one is transit time averaging and another is momentary measuring, the result of those measuring method show, a large difference. As in the comparison chart based on turbine efficiency, ASFM result calculated 10~18% higher discharge than the result of the Gibson method. But, it shows good arrangement to Gibson, and the repeatability is also good. In spite of poor conditions, the measuring performance of ASFM was reliable.

For its stable data acquisition performance which was proved through this test, ASFM could be an alternative method for discharge measuring in poor & coarse test conditions.

But, the properness in skewed condition of ASFM application should be considered enough. Though it has strong points in poor condition measuring, deliberate survey will be required before the implementation such as skewed flow.

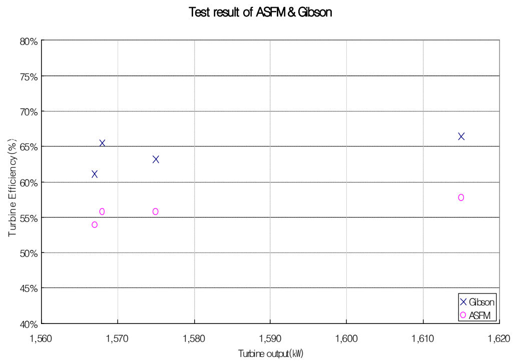

Figure 4 Efficiency of Gibson & ASFM

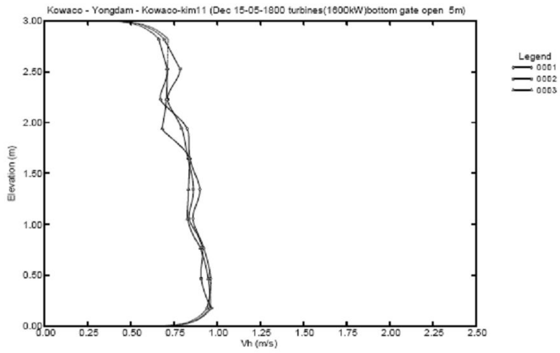

Figure 3 Velocity profile of ASFM

Case2. Comparison between Index Test and ASFM in Modernization Project

2.1 Background of Modernization Project of Namgang Hydro Power

Namgang water turbine is a dam type: Korean Electric Power Corporation (KEPCO) constructed it for exclusive supplying of power generation to the national grid in 1971. The plant was operated by KEPCO until 1998, and then K-water took over the business and dam height was increased.

Though the dam height was increased from 43m to 51m, the existing turbine was reused. During flood season, when the head is higher than the designed head, the turbine is operated by automatically adjusting the regulating gate that is installed in the down stream of the draft tube to reduce the specific energy. Regardless of reduced performance or risk of potential failure of system from its aging, Namgang hydro has been operated under optimization required conditions.

The conceptual plan of the rehabilitation is to change the turbine and auxiliary facilities to increase the efficiency or capacity of the turbine with minimized changes in related sub-structure.

Item	Existing	Alternative 1	Alternative 2
Capacity (MW)	7	7.0	11.0
Discharge (m^3/sec.)	47.5	-	75.0
Rated head (m)	16	17.5	17.5
Annual power generation (GWh)	43.16	43.16	56.91

Table 4. Nam-gang modernization plan

2.2 Test Conditions

2.2.1 The Outline of the Turbine

Turbine type	:	Horizontal Tubular
Capacity (MW)	:	7.0
Head (rated/maximum/minimum, m)	:	16.0 / 20.0 / 10.4
Flow (rated, m^3/sec.)	:	95.0

Guaranteed turbine efficiency (%) : 93.0

Manufacturer : Alstom. France

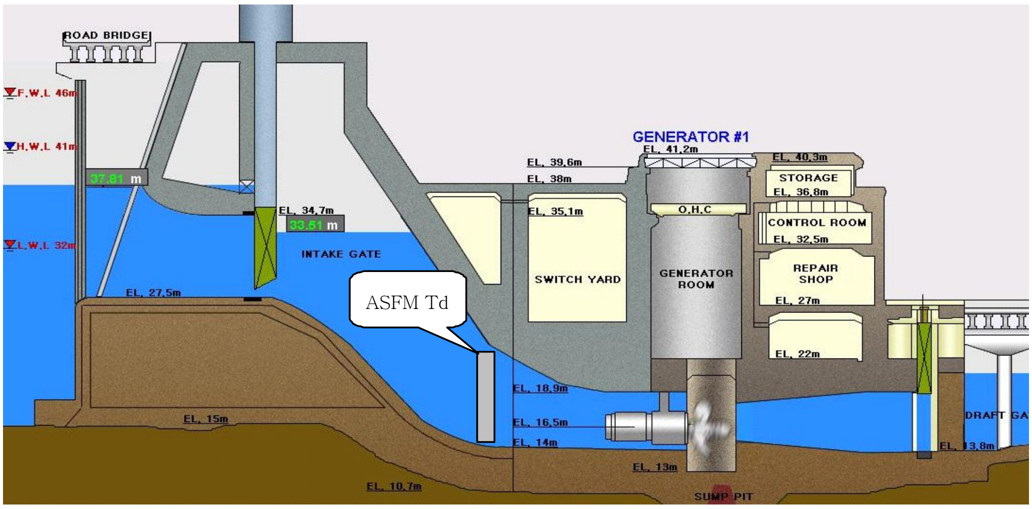

Figure 5 Power plant profile for ASFM Td. installation

2.2.2 Instrumentation

Required accuracy of Instrumentation and test procedure for index method were based on IEC60041 code, and for ASFM were followed by manufacture's guidance. Lab-view of N.I. was applied for data acquisition tool.

Measuring Methode: Index & ASFM				
Test item	**Measuring device**	**Model**	**Accuracy**	**Manufacturer**
Output of Generator	Digital AC Power Meter	WT-130	0.3%	Yokogawa Japan
Static pressure of inlet	Pressure Transducer	PTX630	0.15%	DRUCK U.K.
Water level of Tailrace	Meter of Control Panel	-	-	-
Discharge	Gibson, ASFM	-	1.0%	ASL Canada
Stroke of Guide vane	Stroke Transducer	-		Faster USA
Data gathering	Data Acquisition	PXI		N.I. USA

Table 5. Instrumentation of case 2

2.2.3 Operation & Physical data

Test conditions and physical data for two discharge measurement methods are as below. Tests were performed by 2 test engineers of K-water. Regarding the procedure for ASFM application, the frame for sensor installation and the correction of discharge calculation were supervised by ASL engineer through e-mail.

*** Operation data**

Classification	Operating Condition
Date of test	'06. 05. 16
Dam water level [EL. m]	40.42 - 40.50
Gate operation	20.40 - 20.65
Tailrace water level [EL. m]	19.61 - 20.16
Head net	3,694 - 6,860㎾ (7 points)
Test point (Generator output)	1,505 - 1,646㎾ (4 points)

* **Physical data**

Elevation [EL. m]	16.50	Water Temp. [℃]	19.5
Altitude [。]	35.15	In/Out Pressure [10^5Pa]	3.37 / 1.41
Gravity Acc. [m/s^2]	9.7974	Density of water [kg/m^3]	998.40

Table 6. Operation & physical data of case 2

2.3 Comparison of Test Results

For this case, the two test results of turbine efficiency could not get conformity as the 1st case of data comparison of Francis turbine. But regardless of bad test conditions, ASFM provided reasonable results with good repeatability. Because the ASFM showed reliable results, the same procedure of ASFM device application may be applied to a confirmation of performance guarantees after modernization, but for the confirmation of performance contract, additional study using CFD would be preceded under the agreement of each party.

2.3.1 Repeatability

Compared to the repeatability of index method data, ASFM data shows relatively poor result, but considering the detecting conditions of decreasing sectional area, coarse surface of boundary walls, and below 1 time diameter of distance from bended route, the result is sufficient. Except in 2 test points, ASFM result data are within 1% of deviation from average result of equivalent turbine output as shown in figure 7. Without the consideration that ASFM is designed for absolute discharge measuring device, it is easy to understand that test results provide good relative or reference test data.

2.3.2 Arrangement with Index Test

Without a few particular points, the efficiency curve of ASFM shows a good arrangement with index test curve as in figure 6. It keeps within 2~4% of regularity through the output range.

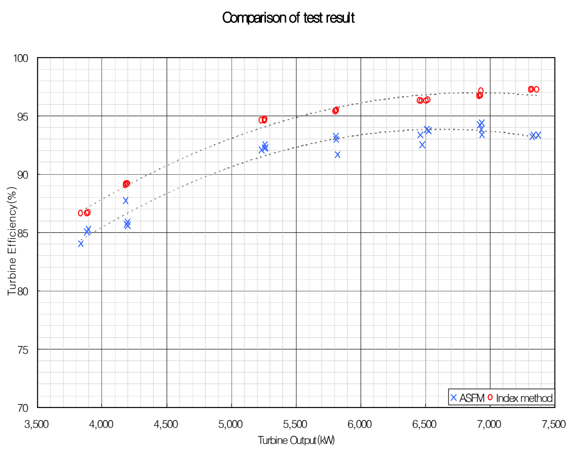

Figure 6. Efficiency curve of Index & ASFM

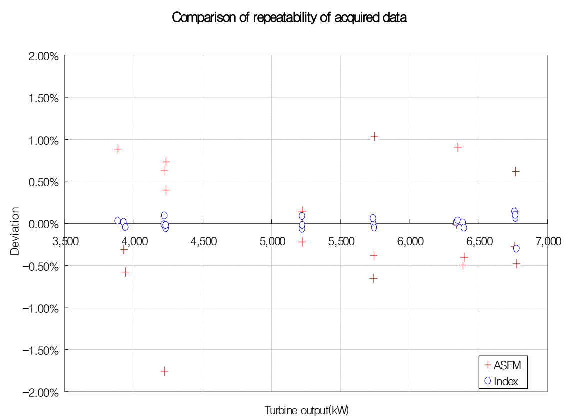

Figure 7 Repeatability of ASFM data

Case 3. Performance Improvement through the Modification of Runner.

3.1 Brief of the Objective Plant

This power plant utilized the remaining head of inflow, which flows to the water treatment plant's still basin. The turbine was built before the end of steel conduit that supplies raw water to the basin. The turbine is vertical Francis type (340kW, 1 unit) and generates 2,592 MWh annually.

3.2 The Outline of the Turbine

Turbine type	:	vertical Francis
Capacity (MW)	:	0.372
Head (rated/maximum/minimum, m)	:	18.0/22.5/11.7
Flow (rated, m^3/sec.)	:	2.4
Guaranteed turbine efficiency (%)	:	88.0
Manufacturer	:	Dae-yang. Korea

3.3 Test Results

3.3.1 The 1st Test

As shown on the chart, the turbine could not afford the design discharge, so the output and efficiency were measured under the guaranteed value.

The 1st measure for this problem was basic dimension checking of main turbine parts, using the reference data of turbine design software. In occasion at the rated head, if the flow is less than rated value, then it is necessary to check the properness of runner diameter. As the result of investigation, the chosen runner diameter of maker was 10% less than the suggested value of turbine design program. The turbine shows its optimum operating point where the flow is 20% less than rated flow. This value coincides with the ratio of the value that is in proportion to the square of the runner diameter. Details of the blade dimension are described in below table 7.

Items	**Maker proposal 1, 2**		**K-water (Turbn-pro)**	
Design conditions				
Rated flow (m^3/sec.)	2.55	2.40	2.55	2.40
Head Rated/Max./Min. (m)	18.0 / 22.5 / 11.7			
The calculated results				
Speed (rpm)	466.17	452.04	450.0	450.0
Specific speed (m-kW)	250.16	235.3	247.7	240.3
Turbine output (kW)	405.83	372.6	416.0	392.0
Inlet diameter (mm)	900.0	900.0	914	914
W/G height (mm)	229.4	195	226	220
W/G circle Dia. (mm)	905	-	893	877
Runner Dia. (mm)	700	770	782	767
Choice	○			

Table 7. Comparison of dimension

3.3.2 After Modification

After the commissioning test of December 2004, 3 series of modifications were focused on improvement of velocity profile through the flow in casing because the modification including some changes in large compartment of turbine housing may not be the best decision as an aspect of economy. But successful improvement in velocity profile through the runner blade was not easy to achieve at one time, as the domestic turbine manufacturer has not enough experience and analyzed data for hydro-turbine. Through the 3 series of trial modifications & analysis of efficiency test results, optimized blade profile was completed, and as a result of those modifications the no. of blade and discharge angle of runner outlet flow was decided properly.

As described in the table below, discharge velocity of the last turbine is decreased to 2.0 m/s from the value of commissioning test result of 5.8 m/s. Comparing to the rated head of objective turbine, its almost 8.2% of improvement in loss of turbine.

Specification	Commissioning	After modification
No. of Runner blade (ea)	12	13
Discharge angle (β2)	20.774°	7.977°
Discharge velocity (Cu2)	5.815 m/s	2.223 m/s

Table 8. Modification contents

3.3 Conclusion

The data above shows reasonable repeatability on the range of lower then 320 kW. It was hard to get a stable test condition for the limitation of basin operation and relatively low effective head.

Though the best efficiency of the final measure could not reach the value of contract point, there was a remarkable improvement in turbine efficiency. The efficiency improvement of turbine is 10% from 76% to 86%. Through the procedure of securing better turbine output and efficiency, additional improvement in pressure measuring and controlling system was made. For proper controlling of system based on exactly measured power input to turbine runner, related system should be adjusted. As a result, efficiency securing provided systemic improvement.

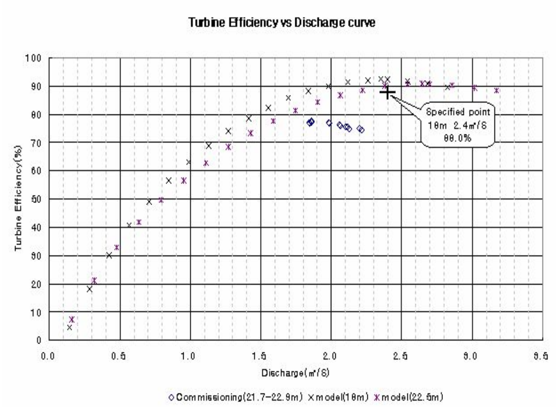

Figure 8. Efficiency curve of the 1st result

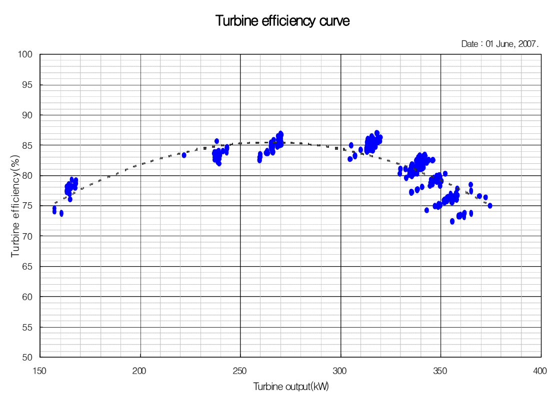

Figure 9. Efficiency curve of after modifications

IV. Conclusion

1. ASFM, as a Reliable Alternative or Reference.

Despite the poor conditions as in the cases described before, the ASFM showed reliable data with good repeatability and arrangement to the reference test result. Though neglecting the absolute value of the data, relative difference of each datum may be adopted for the analysis of turbine performance. And, with an additional CFD of the test result, it may be an occasional alternative to an absolute measuring. In personal experience, some reform measure for inconvenience of sensor & other accessory installation would be better in the developed version of this device.

2. Improvement in System through the Securing of Turbine Efficiency

The last runner modification example shows the soundness of efficiency improvement application. Elegant measuring of hydraulic energy input to the turbine is neglected as usual. Additionally, operating relationship of double regulating turbine is easily missed. But, for better productivity, the more properness in treatment will be a prerequisite. For the economy of commissioning test, inconveniences in sufficient maintenance and other priority, the importance of efficiency test for turbine system is easily neglected at initial state. However, it may have critical meaning for its performance, stability and productivity in result. Accordingly, it is meaningful to secure the overall performance based on confirming complex efficiency of system.

3. Sharing the Experience

Through developments in telecommunication technology, several unpredictable methods are able to be challenged. Recently spot-light on renewable energy leads to a 2nd boom stage of hydro plant construction. But, advanced needs for economy, convenience and time-saving are also present. In any case, the core of these changes is the will of the human engineer, through the sharing of one's tips and experience, the knowledge becomes enriched and deepens. Those things are the causes and effects for each other, and also the aim of this group.