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# A Study of Cases of Efficiency Improvements through Efficiency Testing

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## 1. Abstract

In Korea there are 32 small hydro-power sites, having a total capacity of 46MW, currently under development. This total represents just 3.6% of the domestic potential, compared with a maximum capacity for development of 27.5%.

Focusing on increasing the utilization of small turbine resources, the national government has set a target of constructing 400 small turbines by 2011 through implementation of various support policies. Although the government is planning to increase the number of small turbines, this is just a quantitative aspect as there have been no plans established related to methods for developing or operating cutting edge small turbines from a qualitative aspect.

K-water (the Korea Water Resources Corporation) completed the construction of the Soyang River hydro-electric power plant in 1973, and has also built and operates 44 hydraulic turbines over the past 33 years. Amongst these there are 20 small turbines and this number is increasing. Performance testing on the mid- and large scale turbines (over 3000 kW) showed that among the total number of 24, 8 turbines satisfied the guaranteed efficiency criteria while 16 turbines were unable to be tested due to improper test conditions. For the 20 small turbines, only 1 turbine satisfied the performance criteria while 5 did not. Additionally, 14 turbines were unable to be tested due to improper test conditions.

As mentioned above, most of the turbine test conditions were unable to meet standardized test requirements (IEC, ISO etc.) and this situation was even worse for small turbines. Therefore, it is our hope that this paper will present some cases showing where water turbines improved their efficiency through successful testing. In addition, we will elaborate on the following to provide suitable reference data for those developing water power resources.

- ✧ Present water power generation conditions in Korea
- ✧ Summary of K-water's turbine efficiency testing
- ✧ A study of cases of efficiency improvement through efficiency testing
  - Efficiency improvements due to the adjustment of runner angles
  - Efficiency and output improvements due to the reshaping of draft tubes
  - Confirmed turbine design errors
  - Turbine rehabilitation based on operation head change

## 2. Outline of Water Power Generation in Korea

In Korea, 147 hydro-electric power units, having a total capacity of 3,879MW are classified into three groups. Among these 46 units (1,533MW) are large-scale turbines (3,000kW or more), 93 units (46MW) are small turbines (3,000kW or below) and 8 units (2,300MW) are pumping generators. A detailed listing is shown below.

- Large-scale turbines

| Owner | sites | site name |
|---|---|---|
| K-water | 11 sites, 24 units, 1,001.8㎿ | Soyang, Chungju, Hapchun, etc. |
| Public corporations | 8 sites, 22 units, 531.5㎿ | Paldang, Ganglung, Keoysan, etc. |

- Small turbines

| Owner | sites | site name |
|---|---|---|
| K-water | 11 sites, 20 units, 11.974㎿ | Yongdam, Janghung, Daegok, etc. |
| Other public corporations | 7 sites, 16 units, 7.5㎿ | Chusan, Ahnhung, Dongwha, etc. |
| Private companies | 14 sites, 57 units, 26.395㎿ | Imki, Bangwoori, Sochun, etc. |

- Pumping generators

| Owner | sites | site name |
|---|---|---|
| Public corporations | 4 sites, 8 units, 2,300 ㎿ | Sanchung, Muju, Yangyang, and Samrangjin |

## 3. Summary of K-water's Turbine Efficiency Testing

### 3.1 Methods Applied by K-water for Turbine Efficiency Measurement

#### 3.1.1 Index Method (Operating of Real-Time Efficiency Monitoring System)

The Index method is the standard relative flow measurement method. There was not a method to verify turbine efficiency utilizing absolute flow measurement until 1990. Since then K-water has applied the Index method to confirm the relative efficiency. As well, it has been applied for efficiency measurements of adjustable blade turbines. Recently, K-water has developed a real time efficiency monitoring system which utilized the Index method. As documented in the many papers previously published, the index method, when corrected by absolute flow measurement, has a high degree of accuracy and repetition. K-water has developed 'a Real-Time Efficiency Monitoring System for Pumps and Turbines' which was patented in 1999.

This system is able to provide optimum operations in real time. It can graphically present the best operation methods based on the actual operating conditions (head and output) for each individual turbine and the highest efficiency (relative efficiency or absolute efficiency) possible under real-time conditions.

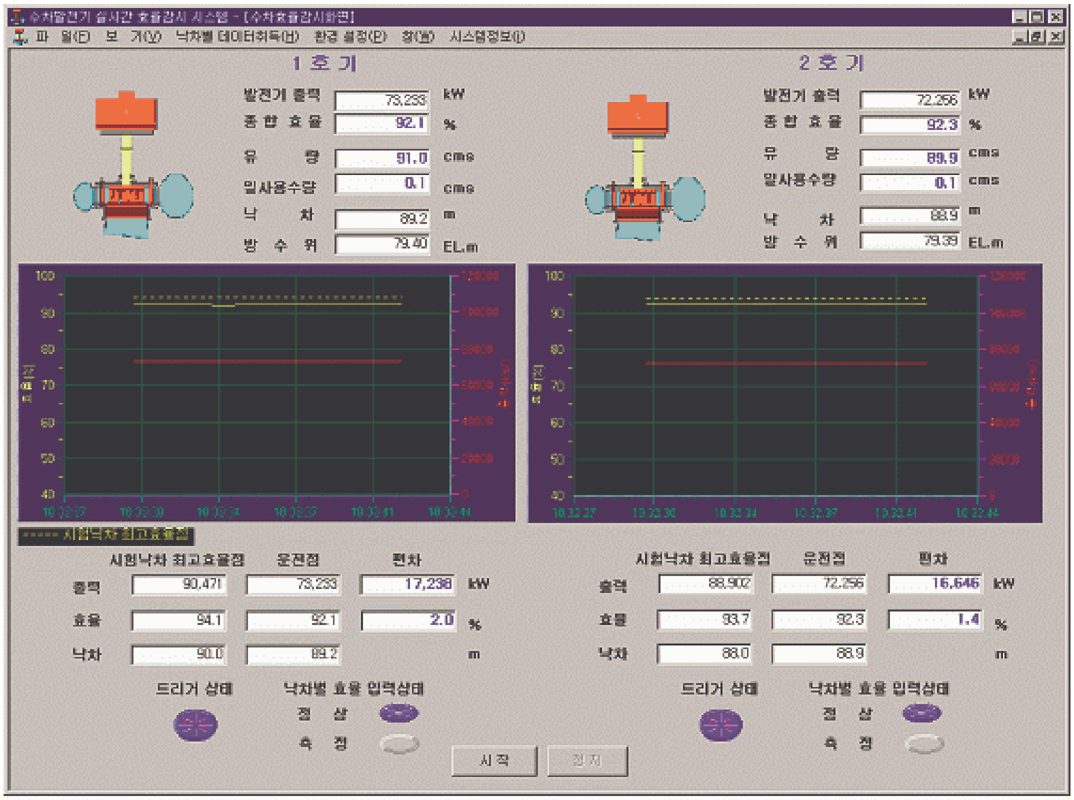


Figure 1: Real-Time Turbine Efficiency Monitoring System

Figure 1 shows the Real-Time Efficient Monitoring System which applies the index method.

### 3.1.2 Pressure Time Method

The pressure time method is K-water's first method introduced among absolute flow measurement. It’s accurate and easy to fulfill the measurement conditions. The pressure time method has been applied to small and large scale turbines since 2000 when its first application to compare the before and after the performance change of the Soyang turbines. Recently, it was applied to confirm the final performance of Yongdam 1 hydroelectric power station and domestic small scale turbines as well.

The next example is to compare the pressure diagram area (the measured flow) which meets the code (IEC41-1991) conditions (10.4.2.1-d) and cases which don't meet the conditions. The turbine type of this plant is a vertical Francis, 103 MW rated output, 90 m of rated head, and 130 CMS of rated flow. The turbine’s maximum efficiency is 93.1% and its rehabilitation was finished in 1997. The test was carried out by separate diagram method and shows how much the penstock Y-branch affects the test result. The test result is shown in the table 1 and chart 1, the maximum error range is

0.62%. This value is far less than the error range of 1.7% (IEC 41 base), which is a common uncertainty for the pressure time method. Therefore, the influence of the penstock Y-branch is negligible. This test result has significance as it allows the pressure time method to be applied widely.

| Output(㎿) | 40.8 | 61.3 | 81.6 | 101 | Ref. |
|---|---|---|---|---|---|
| before Y-branch flow(㎥/s) | 54.6 | 76.8 | 99.6 | 128.5 | constant cross section & strait penstock condition |
| after Y-branch flow(㎥/s) | 54.8 | 77.2 | 99.6 | 129.3 | varied cross section penstock condition |
| deviation | 0.37% | 0.52% | 0.00% | 0.62% | |

Table 1: Influence of the Penstock Y-branch

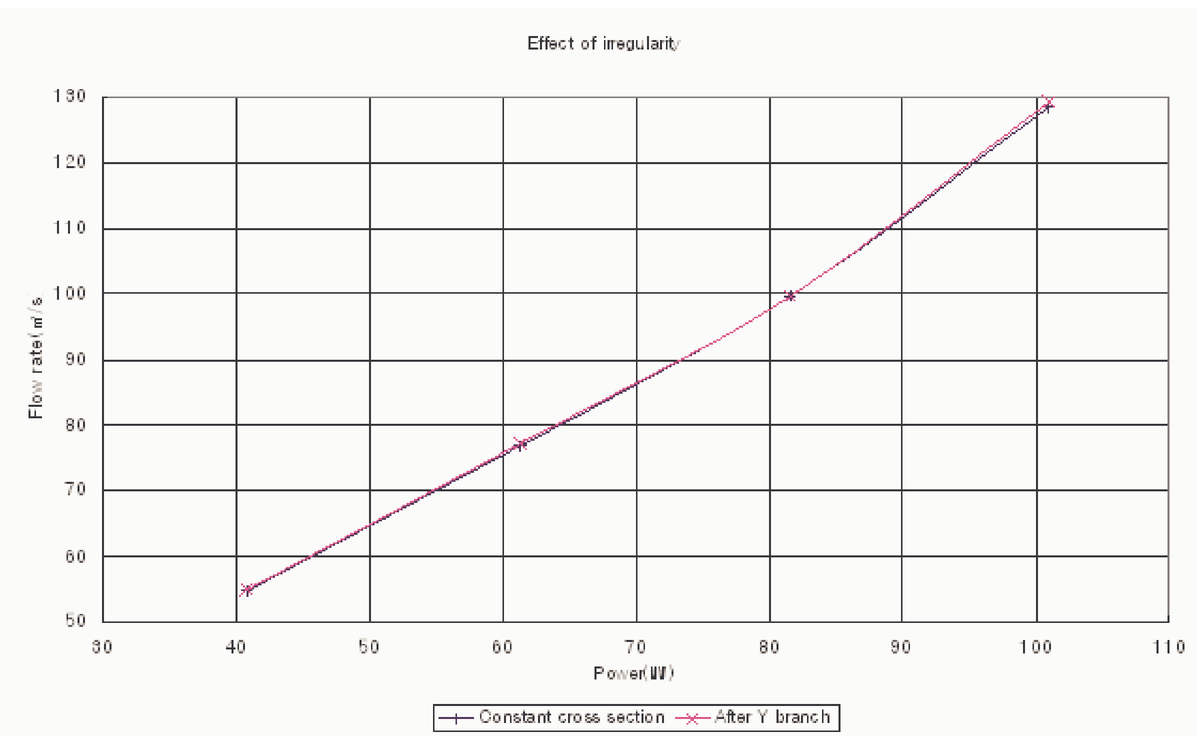


Chart 1: Test Results Chart

### 3.1.3 Thermodynamic Method

The thermodynamic method is a kind of absolute flow measuring method and it was introduced in

2003 as a complementary measure to the PTM (pressure time method) which has a weak point in that it is unable to be applied either in real-time or continuously. K-water made a special instrument (HEMS: Hydro-machine Efficiency Measuring System using thermodynamic method) to check the hydraulic efficiency of turbines in 2003 and has sold 4 units of this up to now. It contains the following sensors for acquiring signals:

| | | |
|---|---|---|
| Temperature | : | Sea-bird 3S |
| Pressure | : | Druck PTX series |
| Power | : | Yokogawa WT-130 |
| Data processing | : | Lab-View 6.0 (National Instrument). |

HEMS has been certified by Korean National Correction Center.

### 3.1.4 Acoustic Method

In cases where the penstock is suitable to install an acoustic instrument we can apply the acoustic method. K-water, as an official flow meter correction institute, has the proper correcting instruments. Due to preliminary consideration of the design criteria, K-water has applied this method to many small turbines at the planning stage. K-water is able to test and improve the turbine efficiency due to the fruit of K-water's efforts to apply the method as described in several cases in the next chapter.

### 3.1.5 ASFM (Non-code base)

ASFM (Acoustic Scintillation Flow Measurement) was developed by the Aqflow Company, Canada, to measure the flow of low head turbines or short intake sites. K-water bought it in 2005 and applied it first to the Yongdam small turbines intake. The result show large errors due to the partial occurrence of swirl and strong turbulence at the intake. However the measured flow quantity using ASFM shows uniform deviation compared to PTM's result at the same turbine. Thus, it is still useful as a kind of reference flow quantity.

## 4. A Study of Cases of Efficiency Improvement through Efficiency Testing.

### 4.1 Efficiency Improvement Cases for Small Turbines (Buahn Small Scale Turbines)

### 4.1.1 Outline of the Site

This small-scale water turbine is located in front of the still basin at the water treatment plant site that supplies drinking and industrial water to local small cities (the area of Buahn and Gochang County). The turbine was installed using Renewable Energy Promotion Loans from the government for the first time by K-water. This turbine has utilized the surplus head of the raceway between the intake and still basin. The turbine features 193 KW of capacity, a horizontal propeller type, 1 unit and 1,522 MWh of annual electric generation.

### 4.1.2 Test Results

| | | |
|---|---|---|
| Turbine type | : | horizontal propeller |
| Capacity (MW) | : | 0.205 |
| Head (rated/maximum/minimum, m) | : | 19.7/25.7/7.5 |
| Flow (rated, CMS) | : | 1.18 |
| Guaranteed turbine efficiency (%) | : | 90.4 |
| Maker | : | Dependable Canada |
| Flow measuring method | : | Ultrasonic flow meter |
| Test purpose | : | to confirm the guaranteed performance |

Test results

When completing construction, the turbine blade angle was fixed at 17° and the test result (maximum turbine efficiency) was 82%. This value was far less than the designed and expected value. So, K-water and the maker investigated the head, flow, designed data and the condition of operation and adjusted (15°) the blade angle twice. After the adjustment, the turbine's efficiency increased by 9%, as shown in Chart 2.

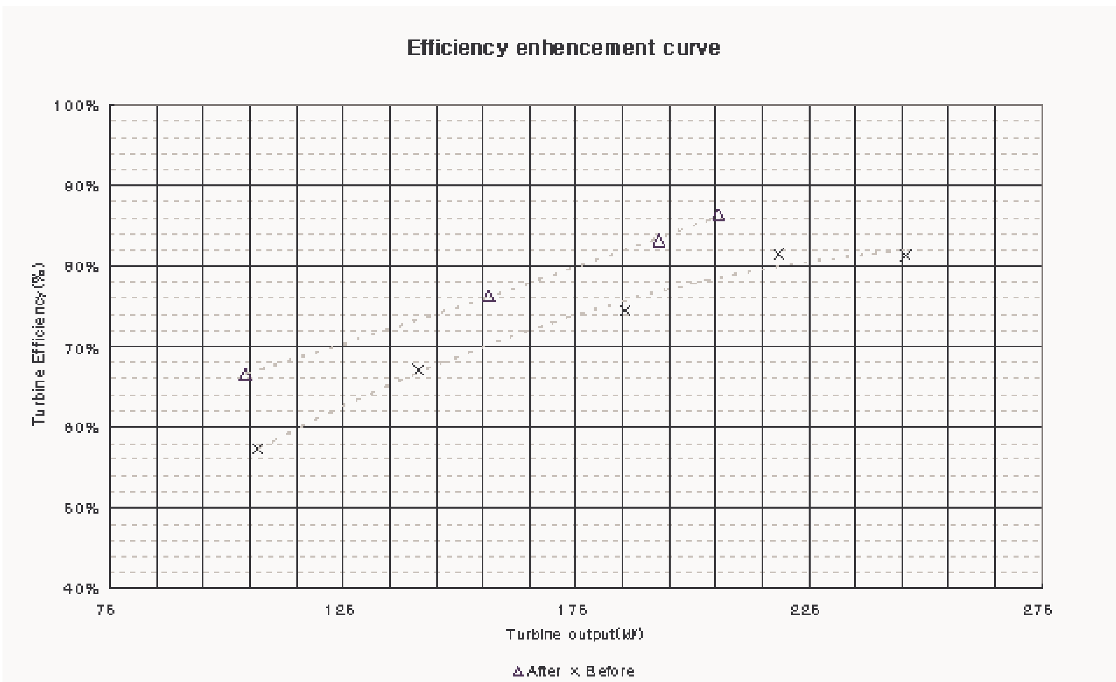


Chart 2: Efficiency Enhancement Curve

## 4.2 An Efficiency Improvement Example by Recovering Draft Tube Suction Head (Youngchun Small Turbine)

### 4.2.1 Outline of Business

This turbine use the flow which is discharged for improving water quality and the environment of the river and its source is supplied by steel conduit from the nearby dam (Imha Dam). The turbine is a horizontal Francis type and the annual generation is 5.9 GWh.

### 4.2.2 Turbine Efficiency Test Results

| | | |
|---|---|---|
| Turbine type | : | horizontal Francis |
| Capacity (MW) | : | 0.496 |
| Head (rated/maximum/minimum, m) | : | 22.45/31.67/9.92 |
| Flow (rated, CMS) | : | 2.45 |
| Guaranteed turbine efficiency (%) | : | 92.0 |
| Maker | : | Dae-yang Korea |
| Flow measuring method | : | Ultrasonic flow meter |
| Test purpose | | |
| Completing construction test | : | to confirm guaranteed performance |
| Special test | : | to investigate the cause of declining output |

### 4.2.3 Test results

#### 4.2.3.1 The Results of the Confirming Guaranteed Performance Test

There was an ultrasonic flow meter at the site, and the tests weren't carried out within rated power conditions.

The result of the turbine efficiency test was 87.8% at the available head of 18.53m and the turbine efficiency was lower then the guaranteed value.

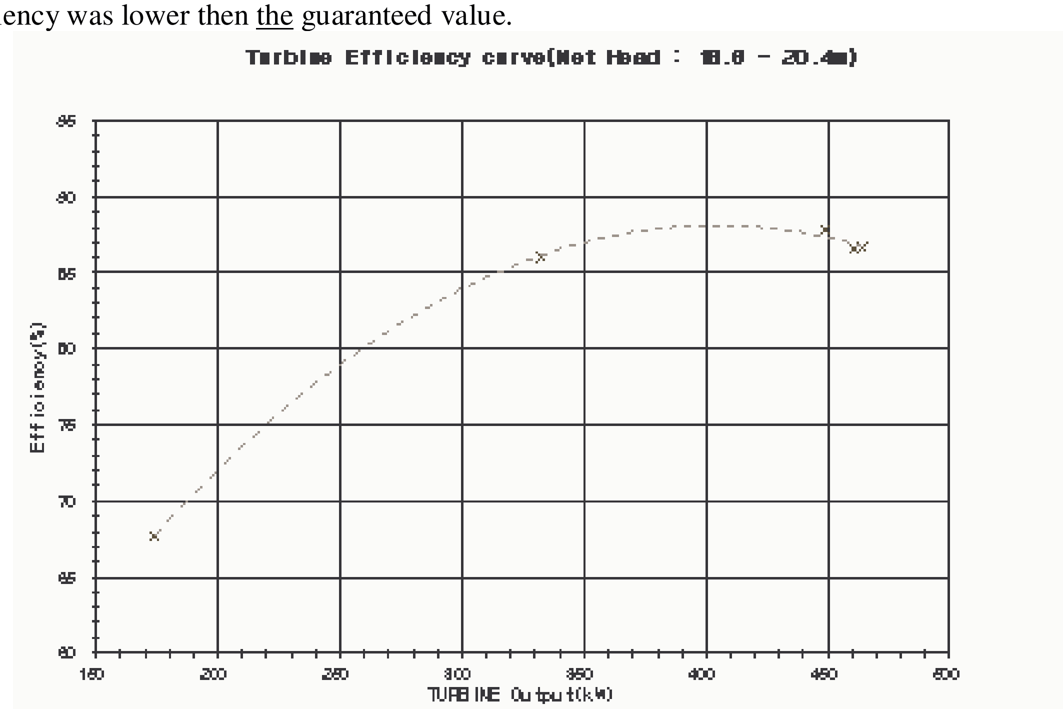


Chart 3: Youngchun #2 Turbine Efficiency Curve

#### 4.2.3.2 Power Drop test results

4 years after the construction completion. While there was no remarkable operating water level difference, but the output was notably decreased. Moreover, any defects, such as vibration, noise and/or rising temperatures, were not seen. So, K-water tested to discover what the cause was of the decreasing output. As shown in the Table 3, though the water level was raised, the output shortage was more than 100 kW. Therefore, the test team analyzed past data and finally uncovered the cause of the decreasing output. They found it was related to the recovery of the draft tube suction head.

| | Generator output (kW) | Penstock inlet pressure (mAq) | G/V opening | Water level (EL m) | Turbine output (kW) | Draft tube suction pressure (mAq) | Available head (mAq) |
|---|---|---|---|---|---|---|---|
| 2001. 8 | 218 | 22.2 | 20.9mm | 148.60 | 236.6 | -0.3 | 23.14 |
| 2003. 4 | 269 | 20.95 | 19.5mm | 146.60 | 288.6 | -3.3 | 25.01 |
| 2004. 3 | 232 | | 50% | 141.97 | | | |
| 2005.11 | 130 | | 50% | 142.40 | | | |

Table 3: Test Data

As shown in Chart 4, the generator output was reduced, while the water level rose, by the reduced available head.

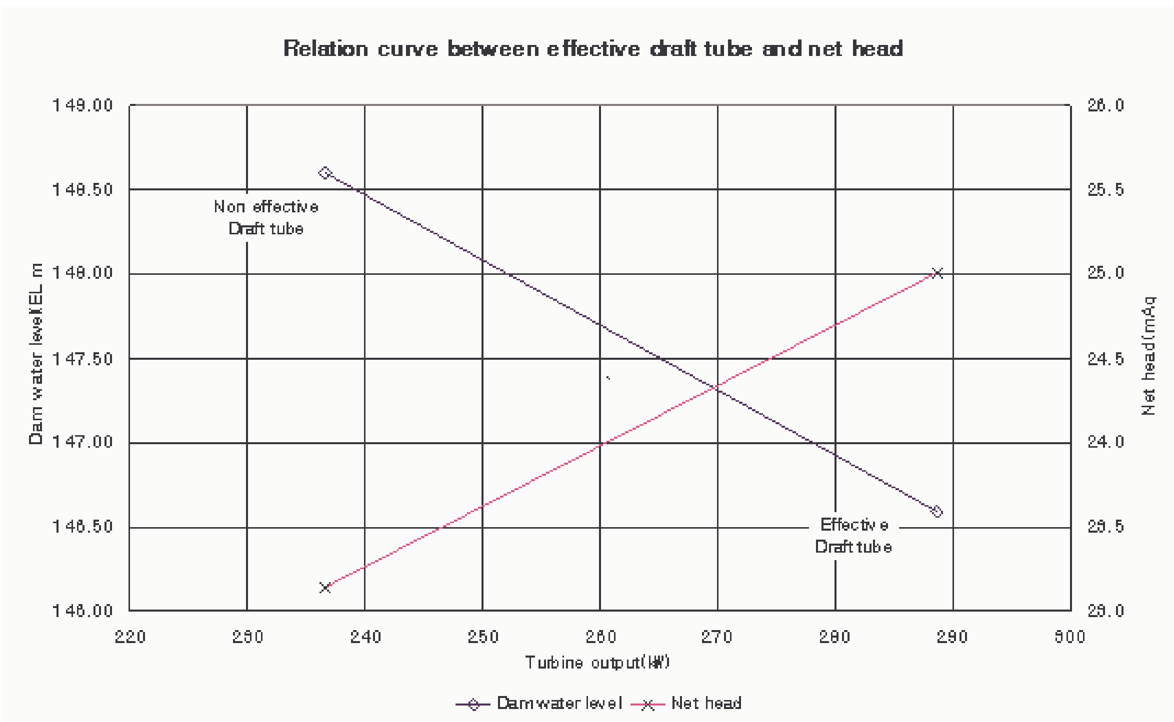


Chart 4: Suction Head Recovery Affects Output Change

The changed conditions were related to the recovery of the draft tube suction head caused by the discharge water level changes that were lowered due to the opening of the sluice gates installed at the downstream irrigation pool.

| The draft tube on the discharge water level. | Discharge through the downstream irrigation pool sluice gates. |
|---|---|

Figure 1: Draft Tube and Irrigation Pool

**4.3 Confirmed Turbine Design Error Example (Sungnam Small Turbine)**

**4.34.1 Outline of Business**

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

**4.3.2 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, CMS) | : | 2.4 |
| Guaranteed turbine efficiency (%) | : | 88.0 |
| Maker | : | Daeyang Korea |
| Flow measuring method | : | Ultrasonic flow meter |
| Test purpose | : | to confirm guaranteed performance |

**4.3.3 Test results**

As shown in the Chart 5, the turbine cannot use the designed flow; the output and efficiency were measured under guaranteed values.

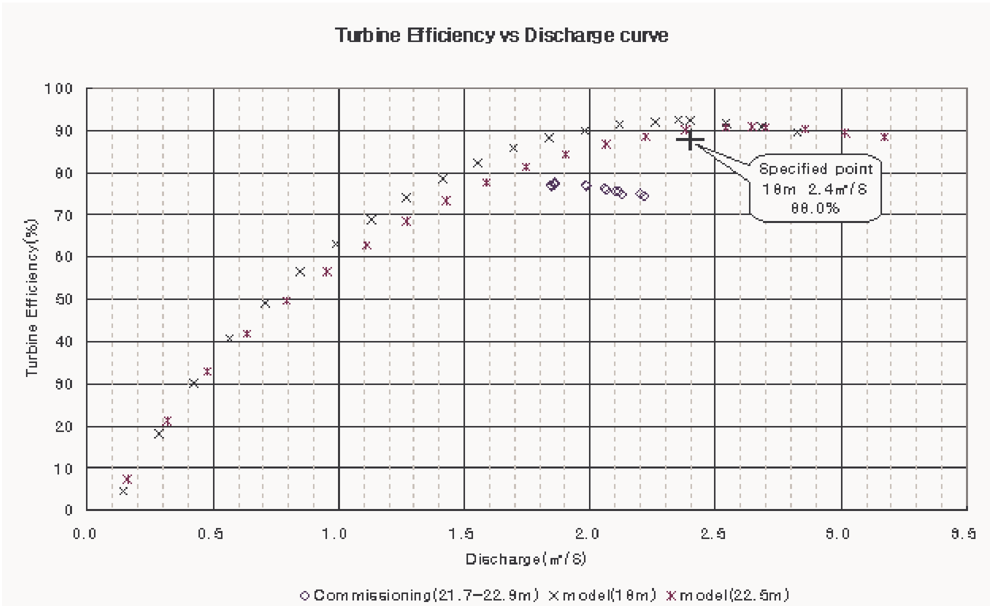


Chart 5: Turbine Efficiency and Discharge Curve

On occasion at the rated head the flow is less than the rated value. When this occurs it is necessary to check whether the runner diameter is proper or not. As a result of the investigation, the runner diameter chosen by the manufacture is 10% smaller then the calculated result from our turbine design.
The turbine shows as an optimum operating point that the flow is 20% less than the rated flow. This value coincides with the ratio of the value that is in proportion to the square of the runner diameter. This turbine is going to be changed and tested again.

| items | Maker proposal 1, 2 | | K-water (Turbine-pro) | |
|---|---|---|---|---|
| Design conditions | | | | |
| Rated flow (CMS) | 2.55 | 2.40 | 2.55 | 2.40 |
| Rated head (m) | 18.0 | | | |
| Minimum head (m) | 11.7 | | | |
| Maximum head (m) | 22.5 | | | |
| The calculated results | | | | |
| Speed (rpm) | 466.2 | 452.0 | 450.0 | 450.0 |
| Specific speed (m-kW) | 250.2 | 235.3 | 247.7 | 240.3 |
| Turbine output (kW) | 405.8 | 372.6 | 416.0 | 392.0 |
| Inlet diameter (mm) | 900.0 | 900.0 | 914.0 | 914.0 |
| W/G height (mm) | 229.4 | 195.0 | 226.0 | 220.0 |
| W/G circle dia. (mm) | 905 | - | 893 | 877 |
| Runner dia. (mm) | 700 | 770 | 782 | 767 |
| Choice | ○ | | | |

Table 4 : compare maker design to Turbine-pro software

### 4.4 Namgang Turbine Rehabilitation

#### 4.4.1 Outline of Namgang Site

The Namgang multi-purpose dam was constructed for protection from periodical floods in the lower reaches of the dam and the upper stream area of the Namgang River. Also, it provides stable irrigation, industrial and drinking water for nearby regions (Jinju, Sachun, Tong-young, Ko-sung and Ey-rung). Usually it supplies drinking water and river maintenance water. However, during flood seasons, it discharges most of the flow through the spillway gates into the Sachun Bay. The turbine is a bulb type, with 7000 kW of capacity, composed of 2 units, with 16 m of rated head and 41.3 GWh of annual generation.

#### 4.4.2 Rehabilitation Business Plan

The Namgang water turbine is a dam type turbine and the Korean Electric Power Company built it for exclusive use of power generation in 1971 and operated it till 1998 when K-water took over the business and increased the dam height. Though the dam height was increased from 43m to 51m the existing turbine was reused. During flood seasons, when the head is higher than designed head, the turbine is operated by automatically adjusting the regulating gate that is installed in the discharge to reduce the specific energy. The purpose of the rehabilitation is to change the turbine and auxiliary machines to increase the efficiency and capacity of the turbine without changing existing civil structures.

| Item | Existing turbine | New turbine (plan) |
|---|---|---|
| Capacity (MW) | 7 | 10.5 |
| Rated head (m) | 16 | 16:20 (25%:75%) |
| Annual power generation (GWh) | 41.3 | 58 |

Table 2: Namgang Rehabilitation Plan

#### 4.4.3 Namgang Rehabilitation Plan Items

- Turbine performance tests and site survey for evaluation.
- To investigate and analyze the operation and maintenance data.
- To test how much the turbine and generator is worn out.
- To study all the tests results and determine the turbine and generator’s condition.
- To develop an alternative plan for rehabilitation.
- To work out a detailed plan for carrying out the rehabilitation.

## 5. Conclusion

### 5.1 It Is Necessary to Check the Variable Blade’s Optimal Operating Angle.

Like the first example, that of the variable blade turbine, it is worth checking whether the operating point is as specified (and optimized) in the design or not.

### 5.2 Turbine Efficiency Test Itself Produces Good Results Towards Improving Performance.

The example of the draft tube suction head recovery states clearly the importance of overall turbine performance testing. Usually small turbines are operated by remote control and monitoring systems. Accordingly, it is necessary to periodically check the overall performance (efficiency) of the turbine.

### 5.3 Sharing Test Experiences.

Improved performances of measuring devices and sensors have also improved measuring technology. So, these improvements and technical experiences give us wider applications of test methods like PTM, thermodynamic and ultrasonic methods.
Through the experience sharing, the propagation of application makes a link with the improvement of measurement technique. In consequence, sharing technical experiences may be a cause and effect for an activity of 'IGHEM'.