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**DEVELOPMENT OF DAM AIR-ENERGY SYSTEM**
**FOR THE ECONOMICAL CLEAN-ENERGY MANAGEMENT**

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## 1. INTRODUCTION

In Japan, reducing dam maintenance costs is getting important and urgent, as the number of dams has been increasing. On the other hand, since water discharges of most dams in Japan are small and unstable, they can’t reduce maintenance costs by generating hydroelectric power. Therefore, it is desired to develop a new energy system as an alternative energy

Dam Air-energy System is an efficient clean energy system for dams that it can reduce the dam maintenance costs and improve the water environments by compressed air without electric power. Its significant feature is a direct energy utilization of small and unstable water discharged from dams. The originality of the system is to directly product compressed air without first producing electric power and to utilize compressed air in various uses, realizing the low cost and high performance by its simple composition of equipments.

Until now, the system has been adopted and operated in some dams such as Haneji dam and Tase dam to improve their reservoir environments, and has been planned in other dams. These achievements make big contributions to both the cost reduction in maintenances and the $CO_2$ emission reduction. In this paper, the authors describe the Dam Air-energy System through some actual performances in operation.

## 2. OUTLINE OF DAM AIR-ENERGY SYSTEM

### 2.1. Basic Outline of Dam Air-energy System

The basic flow of Dam Air-energy System (DAS) is, "compressing air → storing the compressed air (can be omitted) → using the compressed air." The direct use of compressed air produced by energy surrounding a dam as clean energy to power aeration, pumping up, cooling, and other management facilities that consume large quantities of energy can provide great environmental protection and economic benefits. (See Fg.1)

The important point is that air is a superior energy medium with three

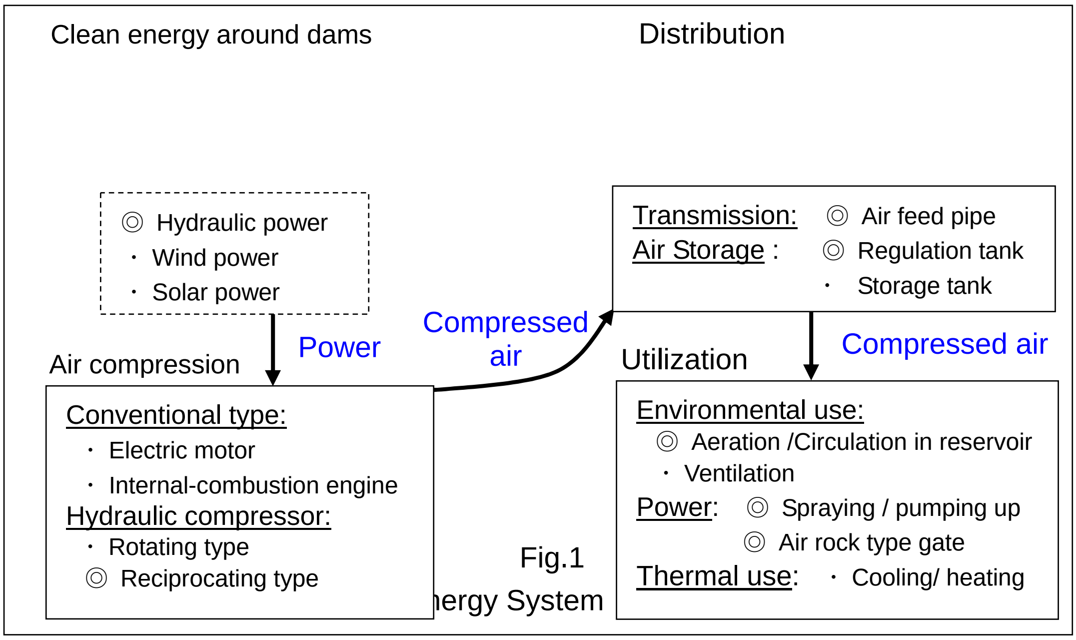


Fig.1
ergy System

functions: environmental (aeration, supplying oxygen, etc.) temperature (expansion cooling etc.) and power (pumping up, spraying, etc.). In the past, energy developed by dam was assumed to mean only the use of electric power, but the development of this system will result in multiple forms of energy.

### 2.2. Effectiveness on Energy Use of Dam Air-energy System

Because Dam Air-energy System is not subject to the strict voltage and frequency regulation applied to produce electric power, it provides large allowance for fluctuations of the energy source. The above means that it can use hydraulic energy produced by water with a greater flow volume fluctuation range and that falls a shorter distance than in the past, making it a more effective method. Moreover, this system has also superior power conversion efficiency, because its power conversion is one less than a hydroelectric system.

Corroborative experiments conducted at Fukuji dam and Aha dam confirmed that the compressed air production and its transmission are reasonable. Haneji dam and Tase dam proved its efficiency by their actual operation.

### 2.3. Compressed Air Production

At each of the dams described below, the energy collection unit that obtains power from discharged water is driven by a waterwheel like as a hydroelectric power. The air compressor unit was a rotating system in the first Dam Air-energy System installed at Fukuji dam in 1999, and an improved type was adopted in Tase dam in 2005. On the other hand, a reciprocating compressor unit which is resistant to energy fluctuation was developed in Haneji dam in 2002.

The above equipments are simpler and more economical than conventional hydroelectric equipments, and they are available even if the hydraulic energy is too small to generate electric power. Thus, the compressed air production by Dam Air-energy System is the high rationality.

### 2.4. Compressed Air Transmission and Storage

Generally compressed air is stored in regulation tanks, preliminary tanks, and air storage tanks. The first is installed to reduce pulsation of compressed air, and the second is installed not to quickly lower the utilizing air pressure, and in this regard, both are used to stabilize air supply and have small capacity of a few cubic meters. An air storage tank on the other hand provides large air capacity for high density utilization and stabilization of energy.

To apply Dam Air-energy System, air feed pipes have some volume with a few tens of cubic meters, so that they provides a regulating function. Therefore, all that is needed is to install small manifold tanks at pipe branches. At Haneji dam, air feed pipes with length of 2km have filled the role of a pressure regulation tank.

### 2.1. History of the Development of Dam Air-energy System

The study on Dam Air-energy System started in 1997 by North Dam Office in Okinawa prefecture. The first stage in the process was the success of the hydraulic compressor and the trial of a compressed air fountain at Fukuji dam in April 1999. Continuously in Aha dam, a lower pressure hydraulic compressor was developed, and air was supplied to air spraying, aeration and air expansion cooling in March 2000.

The first full-scale system was introduced at Haneji dam in 2000, which began full operation in 2004. Further, in Tase dam in Iwate prefecture, an improved rotating type hydraulic compressor was adopted for the water conservation, and the operation of the system started from April 2007.

## 3. DAM AIR-ENERGY SYSTEM IN FUKUJI DAM

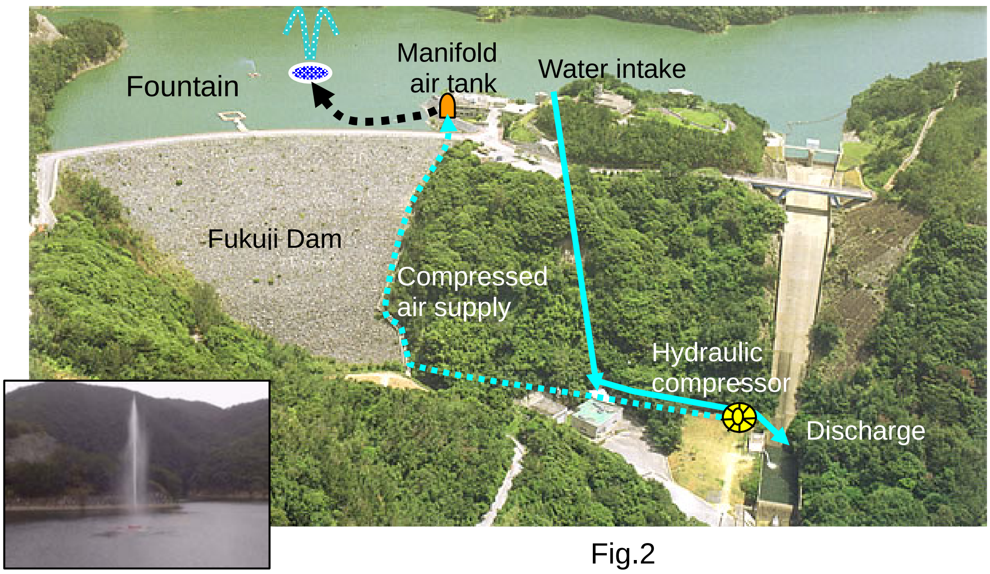
### 3.1. Installation and Operation

Energy produced by the river environmental flow (0.142 $m^3/s$) at a net head of 45m that is unused energy equivalent to 45kw when converted to electrical power, produced 4.2$Nm^3$/min of compressed air with outlet pressure of 0.69MPa.

The compressed air was fed about 1km in an air feed pipe with diameter of 50mm to power a compressed air fountain/pumping up device on the reservoir surface (operates intermittently based on a cycle of 13.5 minutes), confirming the state of the output of air energy. (See Fig.2)

### 3.2. Hydraulic Compressor (Rotating type)

The air compression system used at Fukuji Dam was a hydraulic energy type air compressor (hydraulic compressor: Fig. 3) with four units - a water wheel (reverse running pump water wheel), speed up gear, compressor (screw type), and cooler (chilled water type) - developed by combining a hydroelectric waterwheel and rotating compressor. The hydraulic compressor obtains three benefits, continuous operation, easy installation owing to its compact size, and easy maintenance, and provides superior economic benefits: cost of about 40 million yen that is 1/3 of the cost of a hydroelectric power system. The hydraulic compressor used at Aha dam is basically identical, but the air compression unit consists of two lower air pressure types (roots type and centrifugal type). The above air compressors are all rotating (vane, screw) mode.




Fountain by compressed air

Fig.2
Dam Air-energy System in Fukuji dam

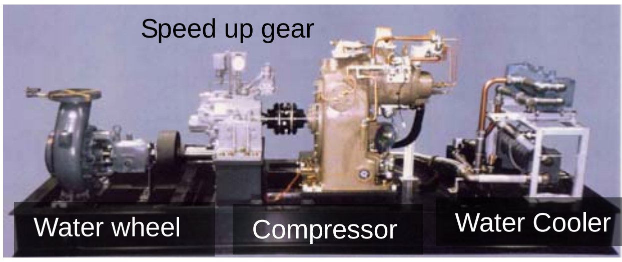



Fig. 3
Hydraulic compressor unit of Fukuji dam


Fig. 4
Dam Air-energy System in Aha dam

## 4. DAM AIR-ENERGY SYSTEM IN HANEJI DAM

The design and manufacture of a full-scale Dam Air-energy System began in 2000 in Haneji dam that was under construction at that time. Its major systems (hydraulic powered compressor, water quality improvement systems, fish transport system, etc.) were completed by 2002 and trial operation of the system began in 2003 with the first impounding. Since then, Dam Air-energy System has been in operation successfully. (See Fig. 5)

### 4.1. Installation and Operation

Energy produces compressed air at two sites by two water discharges for the river environmental including municipal water supply (maximum net head of 35.4m, maximum discharge of 0.324 $m^3$/sec) and for the agricultural water supply (maximum net head of 26.0m, maximum discharge of 0.575 $m^3$/sec despite large seasonal fluctuation). The compressed air production is 15 $Nm^3$/min and 16 $Nm^3$/min respectively with outlet air pressure of 0.49MPa (they are equivalent to 92kw and 111kw respectively converted to electrical power).

The compressed air is fed a maximum of 2km through an air feed pipe with diameter of 100mm for multiple uses: aeration and circulation inside the reservoir, pumping up, fish transport power, cooling, ventilation and so on. Fig.4 shows the outline of equipments in Haneji dam.

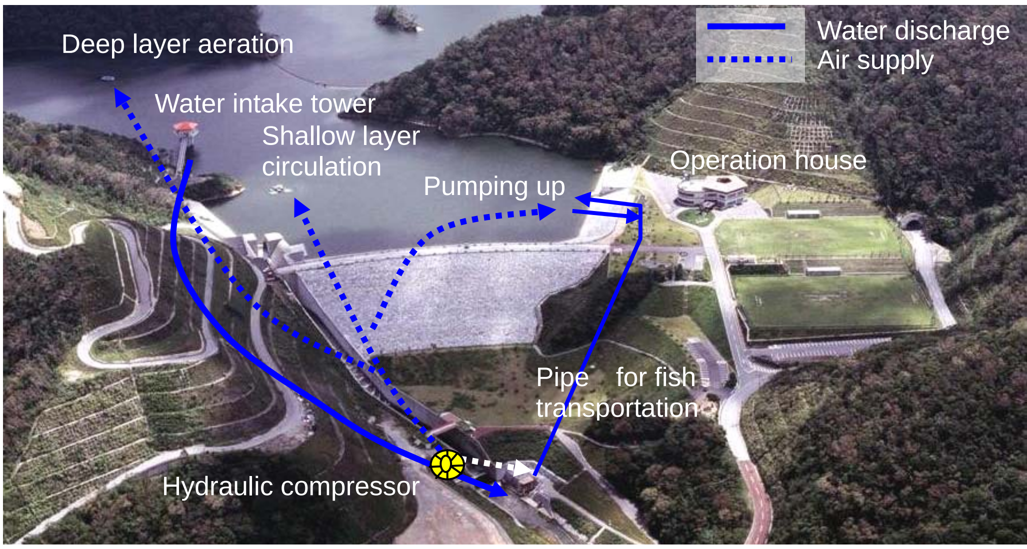





Fig. 5
Dam Air-energy System in Haneji dam

### 4.2. Hydraulic Compressor (Reciprocating Type)

For Haneji dam, a piston type compressor which is resistant to energy fluctuations was developed to deal with the characteristic highly unstable flow volume and water head, achieving the ability to compress large quantities of air: a maximum of about 30Nm$^3$/min. (equivalent to about 180kw) for two kinds of discharge systems: one for river environmental and one for agricultural use.

The five linked two-cylinder compressor units can be operated with the number of cylinders varied according to the reservoir level and the quantity discharged. (See Fig. 6)

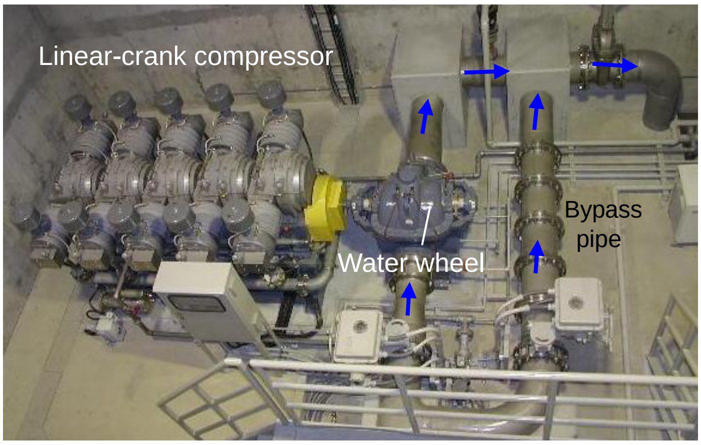


Fig.6
Hydraulic compressor room in Haneji dam

As characteristics of a reciprocating type, it can be operated in a wide range from a low rotation operation during low power to high rotation operation during high power to flexibly vary its operating characteristics: varying the compressed air production pressure for example.

### 4.3. Renewal of Hydraulic Compressor (Reciprocating Type)

The Haneji dam has employed the reciprocating (linear-crank type: details provided later) compressor developed as a prototype for the hydraulic compressor utilizing the discharged water for the benefit of river environment in two above sites. It is planned to develop the successor compressor, on the basis of the operation data up to now, to expand the application field.

For the successor compressor, it is planned to employ the V type two-cylinder (single-stage compression) reciprocating compressor which is to be resistive against energy fluctuation while proving marketability. This type of compressor is capable of producing the compressed air at a rate of 19ｍ3/min with outlet pressure of 0.49MPa at the effective head of 35.4 m while utilizing the maximum discharge rate of 0.324m$^3$/s.

### 4.4. Use of Compressed Air for Water quality improvement

Water quality improvement is the main use of compressed air. At Haneji dam, two kinds of quite large-volume aeration facilities were installed directly linked to Dam Air-energy System. One is for the deep aeration to improve DO (dissolved oxygen) from the deep to medium levels (See Fig. 7), and the other is for the shallow circulation to encourage a water cycle that prevents the growth of algae in the shallow level (See Fig. 8).

Fig.7
Deep layer aeration

Fig.8
Shallow layer circulation

## 5. DAM AIR-ENERGY SYSTEM IN TASE DAM

TASE dam is a multipurpose dam which has purposes of flood control, hydro power and irrigation water supply, and the reservoir is an available place of recreation and rest for a lot of people. However, the reservoir is sometimes attacked by the blue-green algae around from July to September since 1999 year, the deteriorating water environment has gradually affected on the use of safe water and the reservoir use. Thus, the facility construction by a water conservation project carried out in the fiscal year 2005 and 2006, and its operation started from April 2007.

As a main facility to suppress the occurrence of blue-green algae in the water, a new type aeration system by the Dam Air-energy System were adopted, because it has a superior cost performance and a good applicability to Tase dam.

### 5.1. Installation and Operation

The Dam Air-energy System is adopted to supply the compressed air to diffused aeration equipments utilizing discharging water from the dam to the lower-stream, to reduce the maintenance cost and $CO_2$ emission. (See Fig. 9)

The hydraulic compressor was prepared by two sets in consideration of the reliability and market articles. Amount of water required for operation of the compressors is a maximum of $0.44m^3/s$ ($0.22m^3/s$ x 2 set). On the other hand, the discharge water of $0.70m^3/s$ is supplied for the down-stream environmental improvement during the flood season from July to September. Therefore, $0.26m^3/s$ of the above difference is a spare for the higher reliability.

As for the Installation number of diffused aeration equipment units, after the comparison among 2 units, 3 units and 5 units, 3 units were adopted on the capability to achieve the water quality goal and the high cost performance, and 3,400 L/min x 3 units were placed with consideration of the lake water use.

Setting of air feed pipe

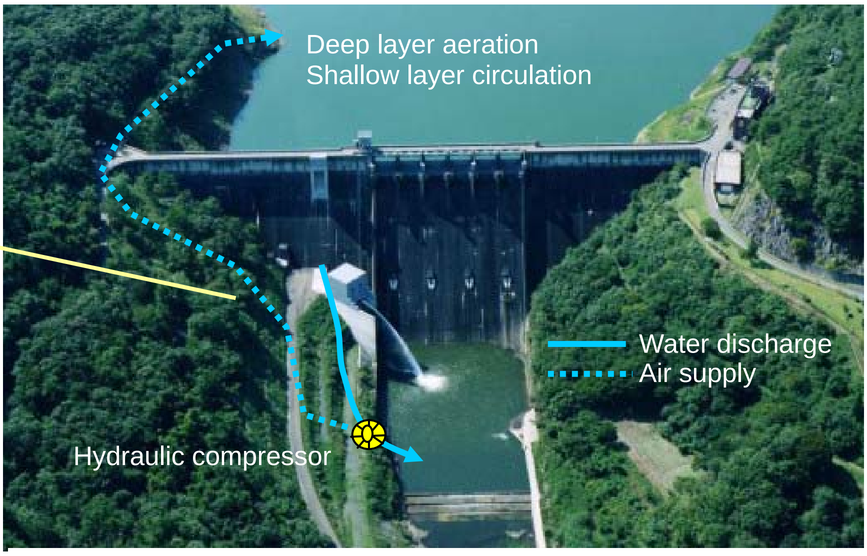



Fig. 9 Dam Air-energy System in Tase dam

## 5.2. Hydraulic Compressor (Rotating type)

### *5.2.1 Outline of the Facilities*

The hydraulic compressor of Tase dam consists of the water wheel block and the compressor as shown in Fig. 7. The water wheel block includes the reverse pumping water wheel with the single suction volute pump while the compressor block employs the screw compressor. The hydraulic compressor facilities and the aeration facilities are outlined in Tables 1 and 2 respectively.

### *5.2.2 Features of the Facilities*

The hydraulic compressor of Tase dam is characterized by securing the stable operation, against fluctuating reservoir level of the dam (fluctuating effective head), through combination of the group control of hydraulic compressors and control of the bypass pipe discharge rate. Table 3 shows the operation state for each dame reservoir level. (See Fig. 10, Fig. 11)

The both of cost-down and improvement of the maintainability are also intended by eliminating the accelerator (by coupling the water wheel shaft directly with the compressor shaft).

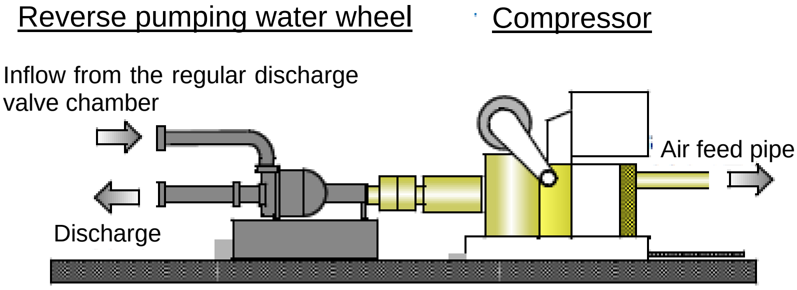


Fig.10 Outline of the hydraulic compressor

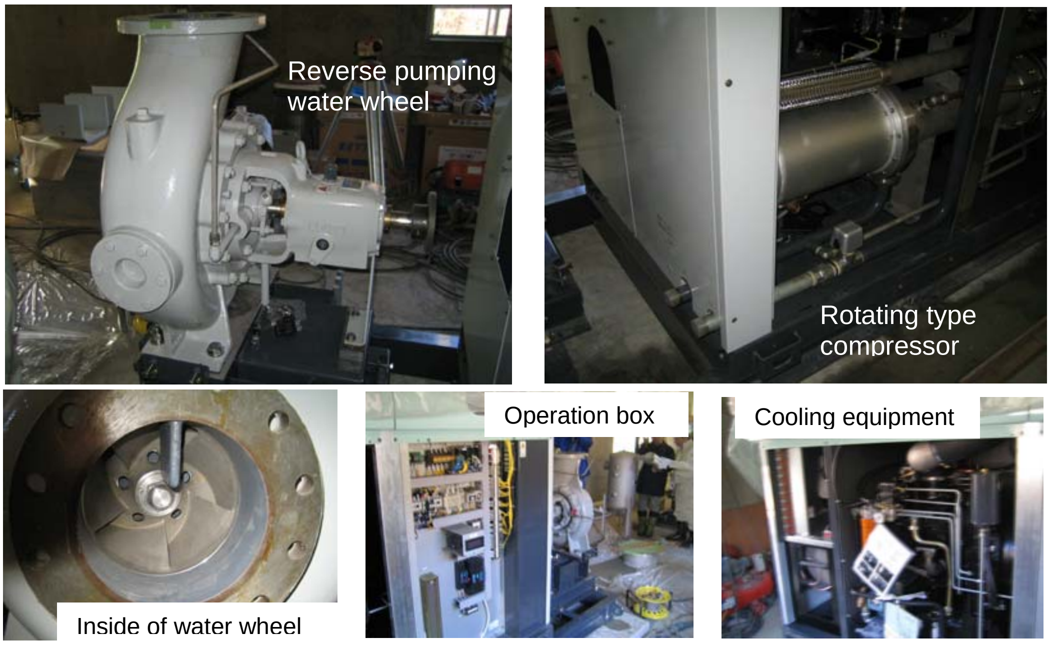



Fig.11 Installation of the hydraulic compressor in Tase dam in 2007.3.6

Table 1 Outline of aeration facilities

| | |
|---|---|
| Type | Horizontally installed diffused aeration system |
| Aeration scale | 3,400 L/min x 3 units |
| Water depth at which the diffuser tube is installed | 16 - 30 m from the surface (manually variable) |
| Diffuser tube discharge type | Porous type (120 pores/unit) |

Table 2 Outline of the hydraulic compressor facilities

| | | |
|---|---|---|
| Water wheel | Type | Reverse pumping water wheel with the single suction volute pump |
| | Size | 200 mm |
| | Recovery capacity | 55 kW (at the flow rate of 0.22 m2/s) |
| Compressor | Type | Oil-free screw compressor |
| | Discharge air flow | 8.0 m3/min |
| | Discharge capacity | 0.3 MPa |
| | Rated rotation speed | 1470 min-1 |
| | Axial output | 55 kW |
| | Cooling method | Hydraulically driven water cooling |

Table 3 Operation state by the reservoir water level with the utilization capacity

| Reservoir water level | Flow rate utilized | Unit number operated | Bypass pipe discharge rate |
|---|---|---|---|
| EL.198.5m-EL.194.0m | 0.35 $m^3/s$ | 2 | 0.32 $m^3/s$ |
| EL.194.0m-EL.192.0m | 0.38 | 2 | 0.00 |

| | | | |
|---|---|---|---|
| EL.192.0m-EL.191.0m | 0.19 | 1 | 0.00 |

### *5.2.3 Operation Record*

Table 4 shows the operation records of the hydraulic compressor and aeration facilities of Tase dam. This Table 4 shows that the stable operation is achieved.

Table 4 Operation record in Tase dam

| Calendar year | Number of operating days | Remarks |
|---|---|---|
| 2007 | 75 | |
| 2008 | 81 | |
| 2009 | 92 | Average for a period from 2007 to 2009 |
| average | 83 | |

Note ;
(1) The aeration facilities is operated in principle during the flood season from July 1 to September 30.
(2) The aeration facilities are not operated during discharge from the discharge equipment.

## 6. TYPE OF HYDRAULIC COMPRESSOR

### 6.1. Rotating Type

The hydraulic compressor is roughly classified into a rotating (screw) type and a reciprocating type. The former rotating-type compressor is highly marketable, abundant in product lineups, and relatively inexpensive. However, the rotating type is characterized by a narrow operation adaptability range under fluctuation of the rotation numbers of water wheel. Therefore it is essential to take into account the seasonal fluctuation of reservoir level and discharged water utilization method when determining whether or not this rotating type is to be employed.

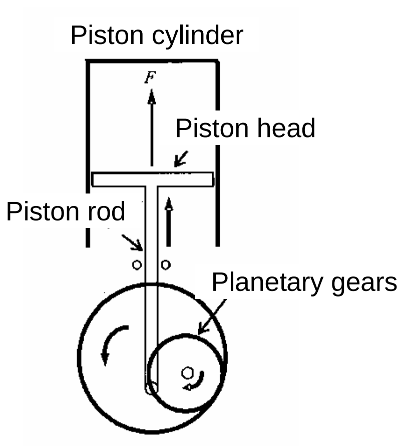



Fig.10
Linear-crank type

The rotating type hydraulic compressor has demonstrated its reliability in the previous field test with Fukuji and Aha dams and in the course of actual operation in Tase and Matsubara dams. In addition, from these successful records, many knowhow could be obtained in terms of the control and maintenance methods of rotating type hydraulic compressors.

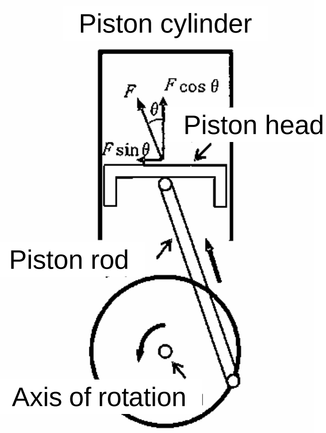



Fig.11 Piston crank type (conventional)

### 6.2. Reciprocating Type

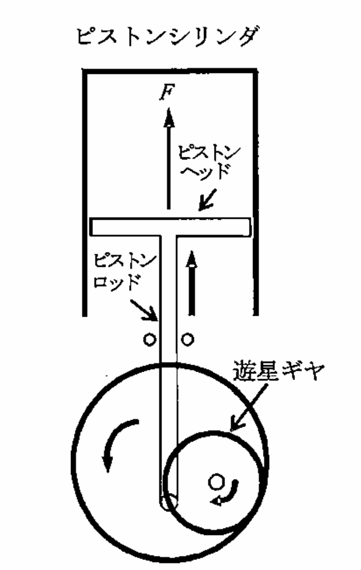
*6.2.1. Linear-crank Type*

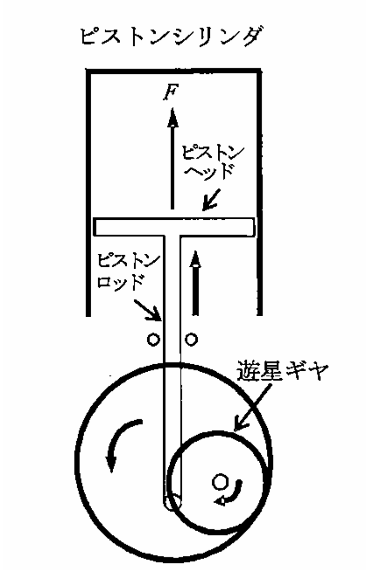
On the other hand, the reciprocating type is less available in lineups than the case with the rotating type (with reference to the range (approximately 100 kw or less) assumed for the hydraulic compressor), and is slightly more expensive.

However, this type is characterized by its wider operation adaptive range relative to fluctuation of the rotation speed of water wheel, proving superior traceability to fluctuating dam reservoir levels. In this context, this type is applicable more to the dam with substantially large fluctuation of the reservoir level. This reciprocating type includes further a linear-crank type (Fig. 8) employed in the Haneji dam and a conventional piston crank type (Fig. 10). The linear-crank type converts the motion of piston rod into the linear motion by means of planetary gears, which in turn serves to prevent wear and vibration of the piston and to improve the energy conversion efficiency.

*6.2.3 Piston-crank Type (conventional)*

When compared to the linear-crank type, the conventional one is highly marketable, guaranteeing cost merits. The conventional type features the possibility of operation appropriate to fluctuation of the compressor input power, which is enabled by switching the rotation speed and load amount (discharged air amount). This type of compressor enables flexible operation in response to fluctuating dam reservoir level (Fig. 11).



## 12. CONCLUSIONS

Dam Air-energy System is based on the direct production of compressed air and the consumption of compressed air for the dam management by utilizing the unused clean energy effectively. The system is expected to enjoy wider applications as a system extremely beneficial in terms of environment and economy in the dam operation. Its practicability has been demonstrated through several experiences, particularly in the full-scale operations. The technologies are summarized below.

### 12.1. Compressed Air Production

At Fukuji dam, a hydraulic air production system (hydraulic compressor) consisting of a water wheel (reverse pumping water wheel), accelerator, compressor (screw compressor), and cooler units was developed.

The hydraulic compressor for Haneji dam adopted the reciprocating compressor to withstand against energy fluctuation. It can produce a large quantity of compressed air (15 $Nm^3$/min, N: Normal air pressure). The air compression system at Haneji dam began full-scale operation in 2004, but a number of performance trials have confirmed its performance under a variety of conditions. At the same time, they have verified that it can provide its stipulated performance without trouble for long term operation of several months a year.

Moreover, Dam Air-energy System was operated in Matsubara dam (compressed air 3.7$Nm^3$/min×2 units) in 2005 and in Tase dam (compressed air 8.0 $Nm^3$/min×2 units) in 2007, demonstrating the performance and reliability.

### 12.2. Operation of Dam Air-energy System

As described above, the full-scale operation was made in Haneji dam in 2004 after test operation in Fukuji and Aha dams, followed by operation in Matsubara dam in 2005 and in Tase dam in 2007. Through these operations, Dam Air-energy System has proved safety and performance, demonstrating its economic efficiency and effective environmental protection. In the future, the effect of the system will be verified on the basis of long-term operation of above dams and the operation record of new dams.

### 12.3. Economic Feasibilities

Many dams require large amount of electric power for operation of their facilities, pushing up their costs. Dam Air-energy System is applicable, without using any electric power, to various facilities which use the compressed air, like as aeration, fountain, pumping and air conditioning. It can therefore contribute to reduction of the maintenance costs to a considerable degree.

Further, Dam Air-energy System also is driven by the discharge water energy, which remains with no uses to the hydraulic power generation. Namely, the system will contribute to effective utilization of unused energy.

### 12.4. Environmental Effects

Dam Air-energy System offers five types environmental effects;
(1) Utilization of unused clean energy, (2) Reduction of the power consumption and reduction of the $CO_2$ emission; the $CO_2$ emission per utility is smaller than other clean energy (solar ray, wind force), (3) Improvement of dam reservoir water quality, (4) No use of chlorofluorocarbons or other media that impact the environment in the air conditioning system, and (5) Intrinsic safety of the compressed air and free from leakage of oil and other contaminants. The aeration system will increase dissolved oxygen, improving the environment for the life.


## ACKNOWLEDGEMENT

Dam Air-energy System has been developed by Fukuji Dam, Aha dam, Haneji dam, Matsubara dam and Tase dam in Japan. The authors express sincere appreciation to all the relevant persons on these projects, and lots of cooperation of Mr. Shigemi CHIBA of Tase dam.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## SUMMARY


The Dam Air-energy System is a creative clean energy system that does not use electric power and can sharply cut dam maintenance cost and drastically improve the water environment. Its significant feature is the direct utilization of small and unstable water discharged from dams as energy. This method has been considered to be economical because of its many disadvantages: small quantity of discharge, low head and multiple fluctuations.

The development of the Dam Air-energy System started in 1998 at Fukuji dam. The first full-scale system was introduced at Haneji dam in 2000, and it began full operation in 2004. Recently, Tase dam adopted it and the operation started from 2007. Based on these experiences, we introduced how to plan and operate the air production and use the system, and it is ensured that the system makes a very significant contribution to both the economy and the environmental conservation.