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RENOVATION OF HYDRAULIC RESEARCH LABORATORY

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1. FOREWORD

Fuji Electric has sequentially expanded the facilities of the hydraulic research laboratory to meet the trend of hydraulic research ever since it was built at the Kawasaki factory in 1951. The early development of a turbine with performances matched to customer's needs will become increasingly important. Labor saving and speeding up of experiments are necessary. Renovation of the research laboratory, concentrated to laboratory automation, was completed in 1989. This renovation is outlined here.

2. MODERNIZATION OF TEST FACILITY FOR MODEL TURBINE

2.1 Overview

The medium-head model test stand built in 1973 and medium-head multi-purpose model test stand built in 1978 were modernized. The former was installed for $n_s = 80 \sim 300$m-kW turbines and pump-turbines. The main modernization were replacement of aged machines with the newest ones that allow laboratory automation. For the stand in 1978, only the controller, measuring instruments, and software were changed. Since, its specifications are almost the same as those for the stand and are omitted.

2.2 Facility capacity

The capacity of the facility is almost the same as that before renovation.

Flow	: 800*l*/s
Dynamometer output power	: 400kW as a generator
Rotating speed	: 1,250~2,000 rpm
Suction head	: +8~−21m
Runner diameter	: 400~700mm

2.3 Composition of test equipment

The layout of the test equipment is shown in *Fig. 1.* The industrial work station in the control room is shown in *Fig. 2.* The upper water tank and lower water tank are arranged in a straight line so that distorted flow, pressure pulsation, etc. are not generated in the conduit to the model turbine. Since the electro-magnetic flowmeters are installed at a position of straight line with sufficient distance for the flow of each direction of the turbine and pump, the discharge that flows in or out of the model can be measured at good accuracy. The following five operation modes can be selected according to the purpose of the test.

(1) Turbine open mode
(2) Turbine close mode
(3) Pump open mode
(4) Pump closed mode
(5) Flow calibration mode

These modes can be switched automatically in a short time by operation mode selector switch at the solenoid valve panel.

2.4 Equipment in the test stand

The service pump and dynamometer thyristor static Leonard equipment, and controllers were renovated. The service pump is connected directly to a DC generator whose rotating speed is controlled by the thyristor static Leonard equipment and the rotating speed is controlled automatically according to the test head. The specifications of the pump unit are shown below.

(1) Service pump

Type	: Horizontal shaft double suction volute pump
Head	: 65m (shut-off head 78m)
Flow	: 700*l*/s (max 1,000*l*/s)
Rotating speed	: 980rpm

(2) Drive motor

Type	: Horizontal shaft DC motor
Output	: 700kW
Rotating speed	: 200~1,000rpm
Power supply	: Thyristor static Leonard equipment

The electric dynamometer performs continuous generation and motor operation in the forward/reverse rotating direction and can operate with good stability over a wide range of speeds and loads. The electric dynamometer specifications are shown below.

Type	: Vertical shaft DC electric dynamometer
Output	: 400kW

Fig. 1 Medium-head model test stand

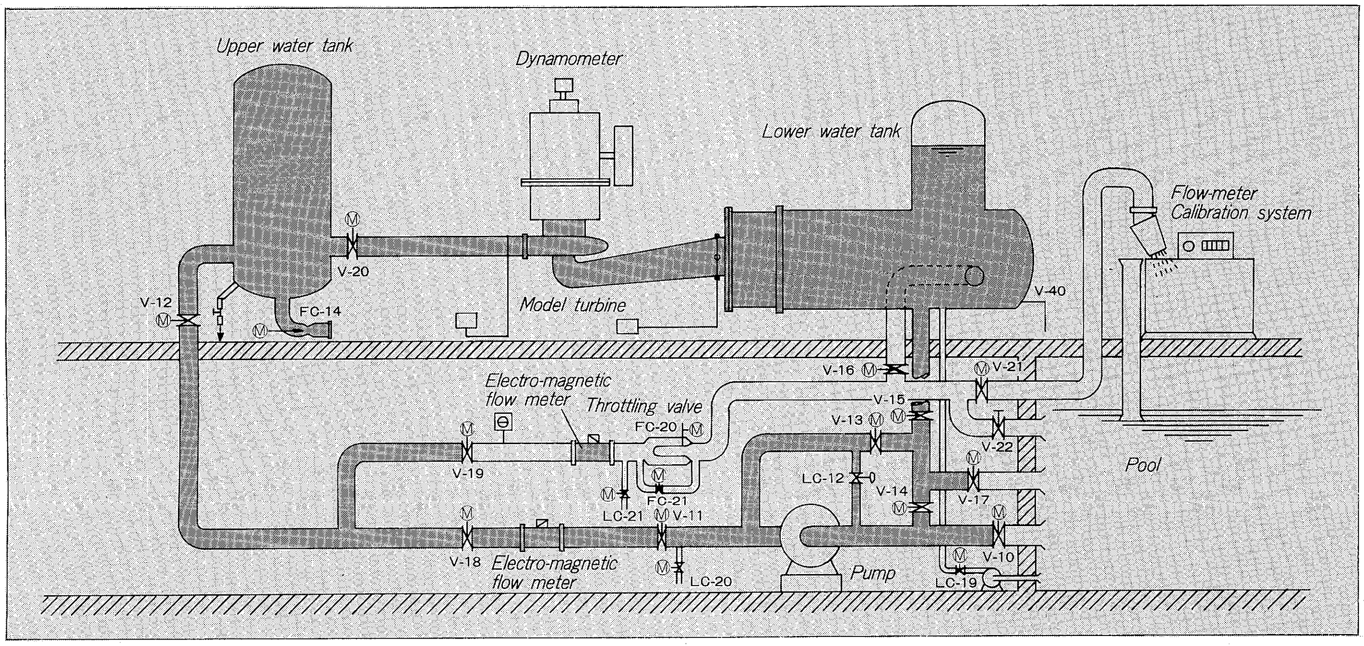
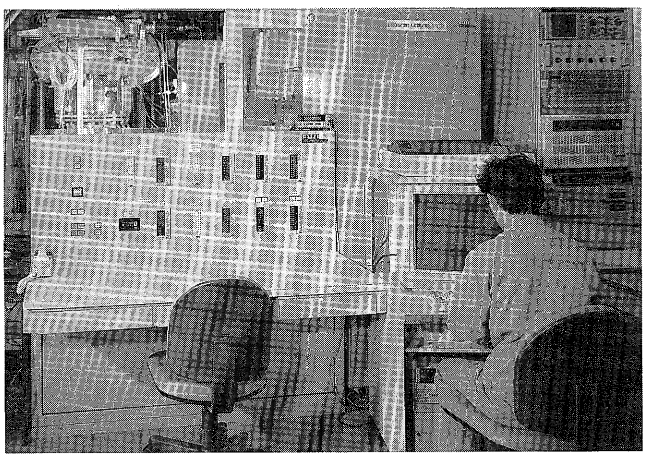


Fig. 2 Control desk and industrial work-station



Rotating speed : 1,250~2,000rpm
Power supply : Thyristor static Leonard equipment

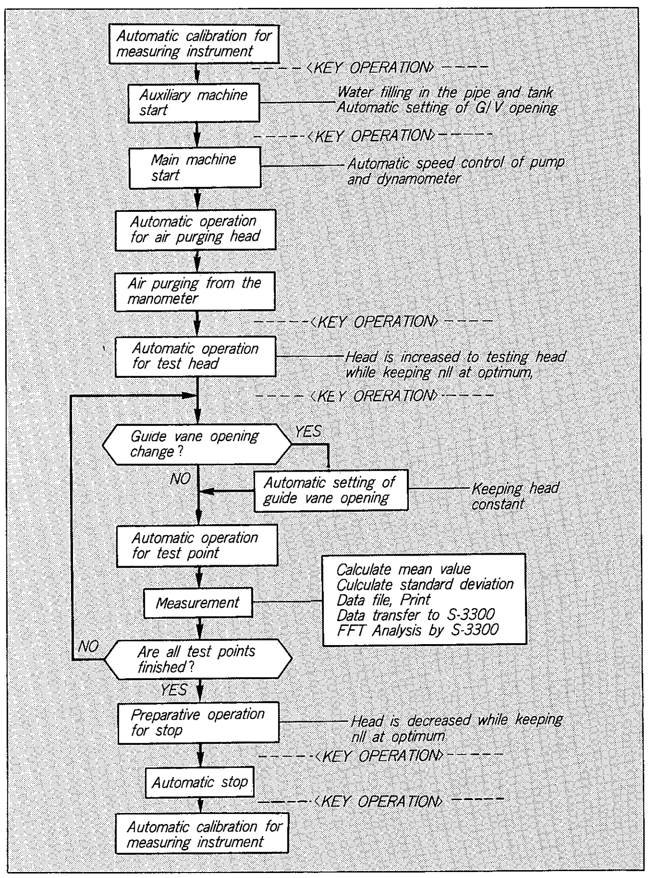
2.5 Control system for operation

By laboratory automation, complete automatic operation control is performed and the operation load of the researcher is reduced so that he can concentrate on observation and consideration of the result. The Fuji Electric newest type FC series transmitter is used as the automatic controller and the service pump and electric dynamometer are controlled by ASR control by very stable thyristor static Leonard equipment.

(1) Turbine operation system

Fully automatic operation by computer command up to measuring instrument calibration, test equipment starting, data acquisition operation control, and stopping in accordance with the operation order shown in *Fig. 3* is possible. When the water level and water pressure changes are large and the control range is wide such as at starting and stopping, the pressure is detected by the FC series pressure transmitter. The target test head and unit rotating speed n_{11} are input to a computer and the pressure and speed are increased automatically from starting to the

Fig. 3 Flow of automatic operation of model turbine



destination state. During the pressure boosting stage, the model rotating speed is controlled so that n_{11} becomes a specified constant value corresponding to the pressure difference between lower water tank and upper water tank. At starting and stopping, stable operation is possible by setting a hydraulically stable n_{11}.

(2) Pump operation system

The head is changed by opening or closing the outlet valve under a constant model rotating speed. A special valve capable of fine adjusting the flow with little vibration and noise is used as the adjusting valve. The operation system is the same as that of turbine operation. The pump is operated automatically by setting the model rotating speed as the specified value.

2.6 Measuring instruments

The model input power is stabilized and measuring instrument accuracy is increased by automatic control of the test stand and measurement accuracy is increased by statistical processing of acquired data. Measurements of the efficiency characteristics and other basic static performances of the model turbine and pump-turbine are detected digitally and read directly to a computer

(1) Discharge measurement equipment

At open mode measurement, the discharge can be measured directly by mass-metric absolute discharge measurement equipment. At closed operation mode, testing time is shortened by using an electro magnetic flowmeter calibrated by mass-metric method. Two electro magnetic flow meters, one for turbine test and one for pump test, are installed and a straight line sufficient to the flow of each direction is taken.

(2) Head measurement equipment

The inlet and outlet pressure heads of model turbines are measured by absolute pressure type digital quartz manometer. The pressure sensor of this meter operates on the principle that the resonant frequency of a quartz crystal resonator changes with the load (stress) applied to it (application of the piezoelectric excitation effect). The specifications of the digital quartz manometer are shown below.

Type : Absolute pressure type digital quartz manometer
Measurement range : $0 \sim 7 kg/cm^2$, $0 \sim 3 kg/cm^2$
Measurement accuracy : ±0.01% of max scale

The inlet and outlet pressure heads of model bulb turbines are measured by differential pressure type digital quartz manometer. In this case, the suction head is measured with an absolute pressure type digital quartz manometer.

Type : Differential pressure type digital quartz manometer
Measurement range : $0 \sim 1.3 kg/cm^2$, $0 \sim 0.8 kg/cm^2$

(3) Torque measurement equipment

The output generated by the runner of the model turbine is measured from the turbine torque and runner rotating speed. The force at the end of the craddle-mounted stator arm of a vertical shaft electric dynamometer directly coupled to the runner is measured by a torque meter and the turbine torque is obtained by multiplying the force by the arm length. The torque meter combines a load cell and standard weights. Of the 300kg·m measurement range, torque up to 50kg·m is measured by a high accuracy load cell (±0.02%FS) and torque exceeding this is covered by the standard weights.

(4) Rotating speed measurement equipment

The rotating speed of the model turbine is measured by counting the pulse signals generated by a rotary encoder by digital counter. A slit disk is installed to the rotating shaft of the rotary encoder. The grid portion is detected photoelectrically by rotation of the rotating shaft. Since the output generates 600 pulses/revolution, the value counted during one second by the digital counter directly indicates the rotating speed in 0.1rpm units.

3. LABORATORY AUTOMATION SYSTEM

3.1 System composition

To automate a wide range of test processing, the functions are shared by (1) data management and wall pressure pulsation and other dynamic characteristics analysis, (2) man-machine interface and measurement, and (3) operation and control. The optimum computer for each is selected and is:

(1) Super mini-computer

FACOM S-3300 (See *Fig. 4.*)

12M bytes memory, 1 MFLOPS, 1,300M bytes hard disk

(2) Industrial work station L25

1M bytes memory, 0.1 MFLOPS, 20M bytes hard disk

(3) MICREX FPK205 and 125

The system layout is shown in *Fig. 5.*

The momentary acquired values of the model turbine operation state are displayed every second on the L25 display as monitoring data. It is also sent to the MICREX via a communication line.

Fig. 4 Super mini-computer

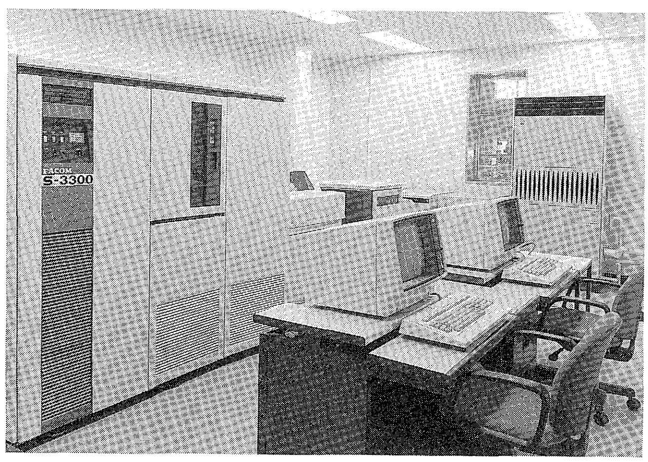


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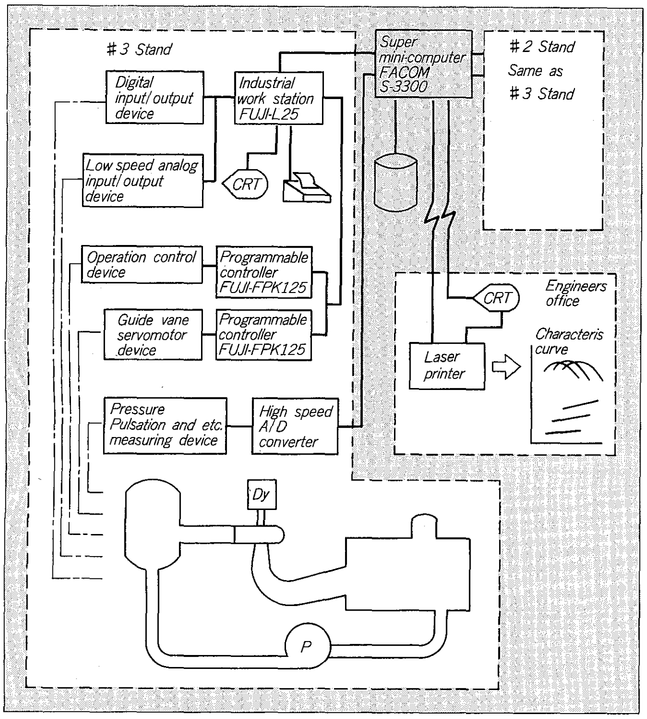
Fig. 5 Layout of automatic operation and measuring system



At calibration and automatic measurement, a corresponding graphic screen is displayed so that the test results can be seen at a glance.

The test results are sent to the S-3300 and managed by data management system. The engineer can generate test reports, design data, etc. with on-line by using a terminal. At automatic operation, detection of abnormal conditions is performed to prevent uncontrol by trouble at the equipment devices, measuring instruments, etc. If an abnormality occurred, automatic operation is halted and the abnormality information is displayed on the L25 display.

3.2 Automatic calibration

The discharge, torque, and head measurement equipment must be calibrated before and after testing and the reliability of the test results is increased. For discharge, the pump rotating speed and discharge adjusting valve opening are controlled by computer command. Fully automatic control of the mass flow measurement equipment and data acquisition is possible. Since the water filling time to the metering tank differs with the discharge, calibration accuracy is improved by matching the timing of tank water filling duration and electromagnetic flowmeter reading duration. Auto-calibration requires only one operator and saves 1/2 the time manually required. Regarding torque and head, computer control of the calibration equipment is made possible and rehooking of the dead mass for calibration, piping valve switching, data reading, computation, etc. are also automated.

3.3 Operation and control

The operation and control devices are all controlled by MICREX command. The MICREX computes the manipulated variable from the control target value sent from the L25 and 1 second monitoring data and controls the process so that the model turbine operation state becomes the target value. Consideration is given to the controlled process so that the optimum operation state is maintained and the process operates safety for the head changes especially at turbine starting and stopping or automatic setting of the guide vane opening so that the model turbine does not operate unstably. With this system, the model turbine operation state can be set automatically by only inputting the target values from the L25 keyboard. However, a special feature is that efficiency characteristics tests can be carried out fully automatically from starting to measurement, operation status modification, and stopping with start command by specifying the test range in advance. The L25 display at efficiency characteristics testing is shown in *Fig. 6*.

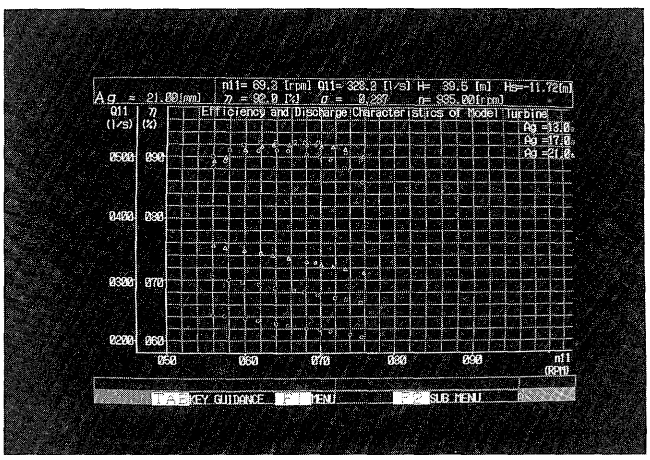
3.4 Automatic measurement

At measurement, it must be verified that the model turbine and measurement system are stable. Therefore, measurement starts after it is confirmed that the standard deviation of five consecutive one second monitoring data is within the specified value as measurement preprocessing.

Staic characteristics measurement performs the specified number of sampling within an appropriate time at each operation. Sampling check is performed in advance and statistical processing is performed and the measurement time and number of samplings are decided so that the standard deviation becomes an appropriate value. Usually, it is made 100 samplings in 20 seconds. However, when the standard deviation is large, depending on the operation conditions, adjustments are made. Besides efficiency and other basic performances, the static wall pressure distribution of each part of the model can also be measured simultaneously.

The wall pressure pulsation of each part of the model and the runner dynamic radial thrust, shaft runout, guide vane dynamic torque, and other dynamic characteristics are measured digitally from the vibration data acquisition

Fig. 6 Example of display for turbine characteristics



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equipment via an A-D converter. The amount of digital data is tremendous and is transferred to the S-3300 by GP-IB interface over a fiber-optic cable that is not easily affected by noise and FFT frequency analysis is performed.

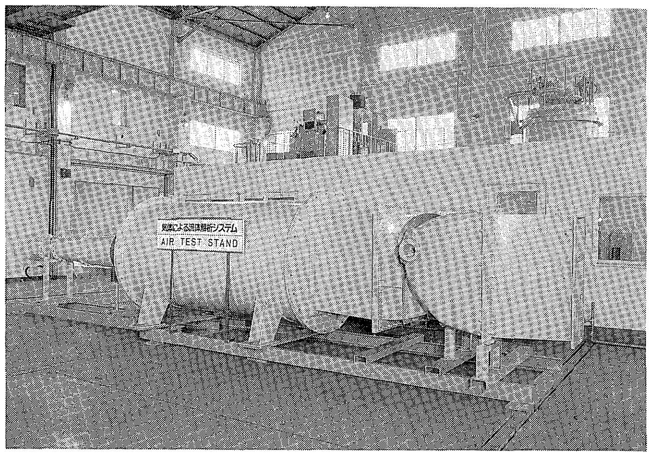
3.5 Data processing

All the test data is graphed by the S-3300 and terminal and can be output to a laser printer. Since curve fitting is also computerized, the performances of the specification points of the actual turbine can be extracted quickly and generation of test reports, design data, etc. is simple. Substantial labor-saving is achieved by also automating preparation of the hill chart of a movable vane turbine, which required considerable labor in the past, by the interpolation method.

4. AIR TEST STAND

The air test stand is shown in *Fig. 7.* Since low density air is used in tests, the working force at the model parts is small and a model can be made of plastic, etc. Therefore, modification is easy. This feature is used and optimization of each component is performed easily before testing of the complete model turbine by water. A two-focus laser velocimeter (lens diameter 150mm) is used to measure the velocity distribution of each part of the model.

Fig. 7 Air test stand



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5. CONCLUSION

Renovation of the hydraulic research laboratory has been outlined above.

From completion to the present, adjustment and testing with three types of model turbines, low specific speed Francis turbines, high specific speed Francis turbines, and high specific speed bulb turbines, have been completed. These adjustments and tests confirmed that automatic operation from starting to stopping was good. Fuji research and development capabilities have also been increased by the automation of measurement and data processing. Through this system, efforts will be put into turbine this system, efforts will be put into turbine performance development and improvement, and research will be advanced to manufacture the optimum turbines for user needs.