YOKOGAWA GROUP'S INSTRUMENT TRACEABILITY AND MANAGEMENT

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It is the responsibility of instrument manufacturers to maintain the traceability of measuring instruments and testing equipment to national standards, in order to ensure the consistency and reliability of measured data. This paper discusses traceability with a focus on electrical, optical, pressure and temperature measurements. The DC voltage standard is a Zener-type standard voltage source, the DC resistance standard is a Yokogawa-manufactured standard resister, the AC voltage and AC current standards are AC/DC thermal voltage and current transfer standards, the optical power standard is a calorimeter, the optical wavelength standard is a frequency-stabilized He-Ne laser, the pressure standard is a deadweight pressure balance, and the temperature standards are a Pt-Co RTD, SPRT and R-thermocouple. Measurement traceability is maintained by means of periodical calibration.

Yokogawa Electric Corporation is an accredited calibration service provider in the categories "Electrical" and "Pressure" of the Japan Calibration Service System, a measurement law-based traceability system introduced in 1993.

INTRODUCTION

Since its foundation in 1915, the Yokogawa Group has been manufacturing and selling measuring instruments. To assure the consistency and reliability of measurements by those products, we have formulated the Group-wide traceability of measurement. In the process of manufacturing fast-advancing measuring instruments, measurements are essential. Therefore, we have been striving to develop and improve measurement standards. In response to the sweeping revision of the Measurement Law enacted in November 1993, a measurement law-based traceability system —Japan Calibration Service System (JCSS)— was established. Under this system, Yokogawa Electric Corporation is an accredited calibration service provider in the categories of "Electricity" and "Pressure." Yokogawa is also responsible for providing measurement standards to industry on behalf of the Japanese Government. This report introduces the Yokogawa Group's measurement traceability, measuring instruments management and JCSS-based calibration business.

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ENVIRONMENT OF STANDARD ROOM

In general, the performance of measuring instruments is affected by the environment where they are installed. For example, if the room temperature fluctuates, an instrument will produce different measurements after each calibration, so the reliability of the calibration is low. Sudden changes in temperature and vibration add stress to measuring instruments, causing long-term drifts and reducing their lifespan. Therefore,

Table 1 Environment of Standard Room

Factor	Temperature	Humidity	Remarks
Electricity	23°C ± 1°C	50% ± 10%	
Optics	23°C ± 2°C	50% ± 10%	Air-tight structure
Pressure	23°C ± 1°C	50% ± 10%	Vibration-proof structure
Temperature	Maintained at normal temperatures by air-conditioning		

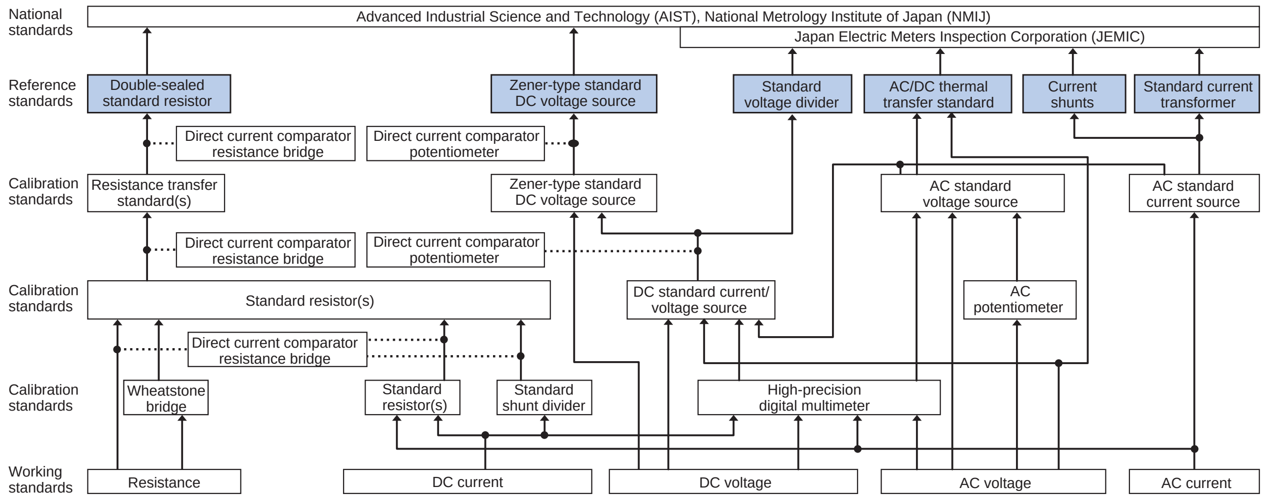


Figure 1 Traceability of Electrical Measurement

the environmental factors of the standard room are controlled to within specific limits(1). Table 1 presents the environmental factors of the standard room managed by the Yokogawa Group.

A calorimeter, a reference standard for optical power measurement, produces different outputs when the air pressure is changing. The standard room for optical measurement is of air-tight structure, which is resistant to the effects of outside air pressure change. A deadweight pressure balance, a reference standard for pressure measurement, produces different outputs due to vibration. To restrain vibration, a 70-cm concrete layer is placed below the floor of the building on which the balance is placed.

ELECTRICAL STANDARDS

Figure 1 presents the traceability of DC resistance, DC voltage, DC current, AC voltage, and AC current.

DC Voltage and DC Current

In the past, the power source standard for DC voltage was the saturated standard cell. With advances in electronics technology, the Zener-type standard DC voltage source has now become the mainstream. Yokogawa also uses the same type, Fluke 732A, as a calibration standard. This equipment is calibrated every 12 months according to the Josephson Junction Array Voltage Standard (JJAVS) of the National Metrology Institute of Japan (NMIJ) of the National Institute of Advanced Industrial Science and Technology (AIST). The output voltage of the Zener-type standard voltage source changes over time; the results of past regular calibrations by the NMIJ indicate that the output voltage of our equipment consistently increases over time. From the past calibration values, a regression equation was determined using the method of least square to calculate estimated output voltage values for calibration.

When a small degree of calibration uncertainty is needed in the DC voltage range of 0 to 2 V, we use a Zener-type standard DC voltage source and a direct current comparator potentiometer (Guideline Instruments' Model 9930). For calibration in the range of 2 to 1000 V, a standard voltage divider (Fluke 750A) is used in addition to these two instruments. The standard voltage divider is also calibrated every 12 months by the Japan Electric Meters Inspection Corporation (JEMIC).

To calculate DC current, Ohm's law (DC current [A] = DC voltage [V] divided by DC resistance [Ω]) is employed. After flowing current through the standard resistor or the standard shunt divider and measuring the voltage generated at its two ends, the voltage value is divided by the resistance value. Hence, the traceability of DC current depends on that of DC voltage and resistance.

DC Resistance

The reference standard we use for DC resistance is a 1Ω double-sealed standard resistor (2781). Since its manganin wires are contained in a room filled with argon gas, it is efficient in terms of temperature coefficient and stability. This reference standard is calibrated by the NMIJ every 12 months.

In a setting where a 1Ω standard resistor serves as a higher-order standard, a resistance transfer standard (Haymon-type resistance transfer standard) is calibrated by a direct current comparator resistance bridge. Then 10Ω to 1MΩ calibration standard resistors are calibrated by the resistance transfer standard.

To calibrate calibration standard resistors whose resistance is 1mΩ, 10mΩ or 100mΩ i.e., below 1Ω a direct current comparator resistance bridge (Guideline Instruments' Model 6675A) is used in a setting where a 1Ω standard resistor serves as a higher-order standard. When calibrating an oil-immersed standard resistor (working standard), this resistor and a calibration standard resistor, which serves as a higher-order standard, are immersed into different oil baths whose temperatures are stable. The standard calibration resistor is immersed in an oil bath whose temperature is set at 23°C, and the calibrated resistor in an oil bath

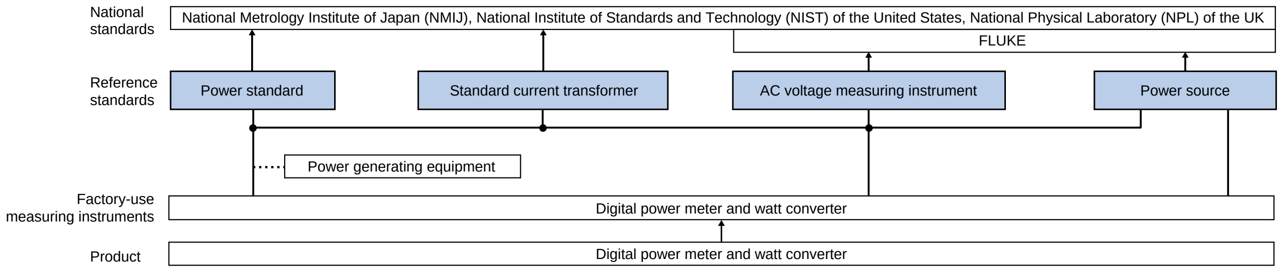


Figure 2 Newly Developed AC Power Traceability

whose temperature range is set at 20 to 30°C.

Resistances of 1MΩ to 1GΩ (working standard) are calibrated by a direct current comparator resistance bridge or a Wheatstone bridge (2768) using a standard calibration resistor as a higher-order standard.

AC Voltage and AC Current

For calibration of AC voltage, its rms value is compared with the known rms value of DC voltage using an AC/DC thermal transfer standard (Fluke 792A), which is a reference standard. This AC/DC thermal transfer standard is calibrated by the JEMIC every 12 months. The voltage range for calibration is 300 mV to 1000 V, and the frequency range for calibration is 40 Hz to 1 MHz.

For calibration of AC current, its rms value is compared with the known rms value of DC current using an AC/DC thermal transfer standard and current shunts (Fluke 792A, A40). These are also calibrated by the JEMIC every 12 months. The current range for calibration is 10 mA to 20 A, and the frequencies for calibration are 50 and 60 Hz. An AC standard current source is calibrated by an AC/DC thermal transfer standard and current shunts, a standard current transformer (2885C, CT), and a standard DC current/voltage source. It is also calibrated by the JEMIC every 36 months.

Power

In the past, a traceability system using a high-precision watt converter (2885) as a reference standard was employed to produce power meters. However, the recent drive toward energy-saving has increased the demand for highly accurate power measurement. In response, we developed the Precision Power Analyzer WT3000[2], a digital power meter whose maximum accuracy is 0.06%. It is difficult to manufacture the WT3000 to a high quality according to the traditional method, so a more accurate traceability method was needed. Figure 2 presents a new high-precision power calibration system that we have recently developed. To date, we have had to request foreign institutions to perform calibration of power standards, but in the near future (FY2006), Japan will start providing highly accurate power standards, enabling us to perform calibration of power standards here in Japan. Because the range of the calibration of foreign standard institutions is narrow, the ranges of current and voltage calibration must be widened. For this purpose, an AC voltage measuring instrument and a standard current transformer are employed.

Traceability for Unity Power Factor

Traceability at unity power factor is notable in the following three aspects: 1) Instead of the traditional method of tracing AC current and voltage, power is traced; 2) A power standard (reference standard), the long-term stability of which is greater than that of the standard watt converter, is employed; and 3) Calibration of this standard is requested to foreign power standard institutions. We carefully select a stable and low-noise combination of power generation instruments (voltage source, current source, and current/voltage phase generator).

Expansion of Current Range for Power at Unity Power Factor

We have expanded the voltage and current calibration ranges, but this paper only discusses expansion of the current range. We use a standard current transformer calibrated by the NMIJ to expand the calibration range of AC current. Figure 3 shows a procedure to calibrate a working standard using a power standard calibrated by a standard institution. The voltage, current, frequency, and power factor values (100 V, 5 A, 60 Hz, and 1, respectively) of the power standard were used as reference values for calibration. We used a standard current transformer that can change the current value on the primary side on a percentage basis and output it to the secondary side. With respect to the reference values, the factory-used measuring instrument was calibrated at

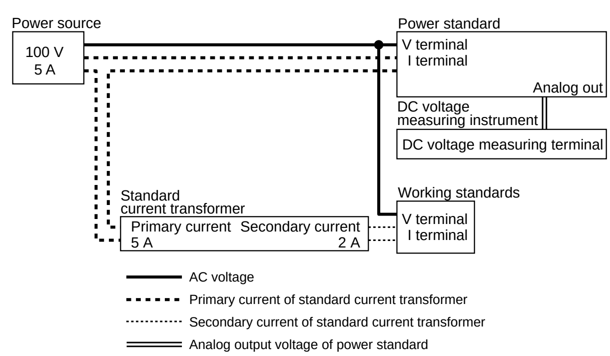


Figure 3 Parallel Block Diagram of Standard Current Transformer (Primary Current: 5 A, Secondary Current: 2 A)

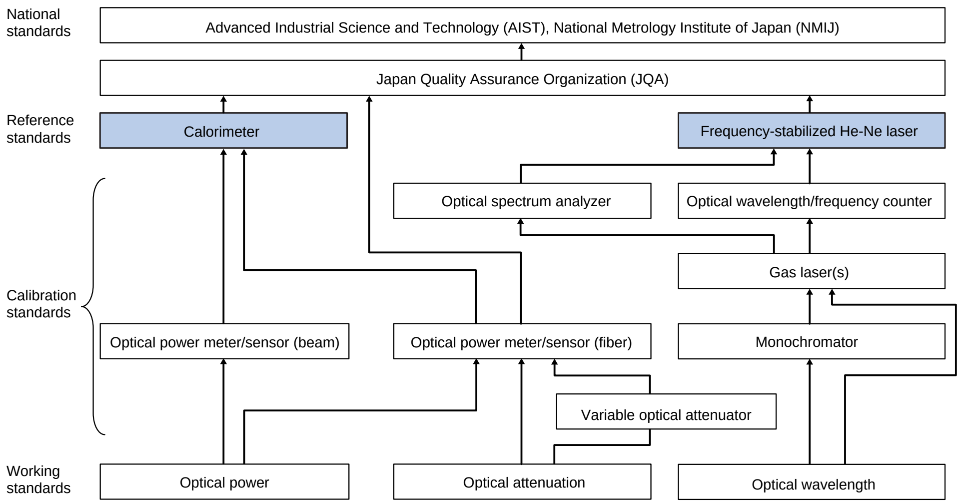


Figure 4 Traceability of Optical Standards

100 V, 2 A, 60 Hz, and a power factor of 1.

Traceability for Zero Power Factor

In this case, the power source is used as a reference standard. At zero power factor, the most uncertain element is the phase difference between current and voltage. The expanded uncertainty of the phase difference between the voltage and current of the power source used is 52 µrad (coverage factor ‘k’ = 2).

Expanded Uncertainty Added to Working Standards

According to the configuration shown in Figure 3, a working standard (digital power meter) was calibrated at 100 V, 2 A, 60 Hz, and a power factor of 1, with reference to the voltage (100 V), current (5 A), frequency (60 Hz), and power factor (1) of a power standard calibrated by the institution providing the standards. The calibration yielded an expanded uncertainty of approximately 80 ppm (k = 2). We believe that this result is not problematic for an accuracy level used to test products whose maximum accuracy is 0.06% (600 ppm).

OPTICAL STANDARDS

This section discusses the standards of fundamental quantities of optics: optical power, optical wavelength, and optical attenuation.

Optical Power

Figure 4 shows the traceability chain for optical standards. The national standard for optical power traceability is managed by the NMIJ. In accordance with its guidance, we have developed a calorimeter-type standard optical power meter (calorimeter), which employs the measurement principle of the national standard, as a reference standard. We have been providing the Japan Quality Assurance Organization (JQA) with this calorimeter, and it is being used as an optical power standard.

This calorimeter, a reference standard, is calibrated by the JQA every 12 months. The calibration range is 10 µW to 100 mW, and the wavelength range is 488 nm to 1650 nm. By taking advantage of the short-term stability of the light source outputs, an optical power meter/sensor, the equipment to be calibrated (calibration standard), is calibrated with respect to the reference standard. For calibration, light is radiated to the calibration standard and the reference standard and their readings are compared. By exchanging adapters mounted on the sensor, two types of optical power meter —beam-type and fiber-type— can be calibrated using only one sensor.

The calibration range of beam optical power meters is 10 µW (-20 dBm) to 100 mW (20 dBm), and their wavelength range is 488 nm to 1152 nm. The calibration range of fiber optical power meters is 1.25 nW (-89 dBm) to 6.3 mW (+8 dBm), and their wavelength range is 850 nm to 1650 nm.

Optical Wavelengths

We use a frequency-stabilized He-Ne laser as an optical wavelength standard. This laser is calibrated every 12 months by the JQA. The relative stability of the oscillating frequency is within $\pm 1 \times 10^{-8}$. To calibrate optical wavelength, light with a wavelength of 633 nm output from the frequency stabilized He-Ne laser is guided to a single-mode fiber by an optical fiber laser focusing unit. Then the optical light is input into the calibrated equipment: optical wavelength/frequency counter or optical spectrum analyzer. Using the calibrated optical wavelength/ frequency counter or optical spectrum analyzer, the wavelength of gas lasers is calibrated in the range of 488 nm to 1523 nm. Based on these gas lasers, the wavelengths of a monochromator and a working standard are calibrated. Monochromators are used to calibrate the responsivity of an optical power meter, and their wavelength range is 400 nm to 1700 nm.

Optical Attenuations

An optical power meter is used to calibrate optical attenuation. Outputs of a stable light source are incidented into an optical power meter via a light attenuator, the calibrated equipment. For calibration of optical attenuation, readings of the

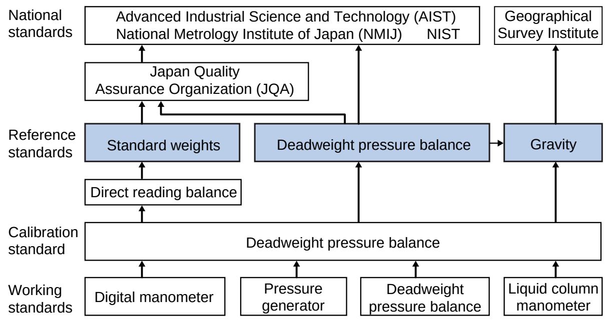


Figure 5 Pressure Traceability

optical power meter when an arbitrary value is assigned to the optical attenuator are compared with those when the optical attenuator is set to 0 dB. The calibration range is 1 dB to 60 dB, and the wavelength range is 850 nm to 1550 nm.

PRESSURE STANDARDS

Figure 5 shows the traceability for pressure. A deadweight pressure balance with high accuracy and stability is employed as a reference standard. Every 36 months, the reference standard is calibrated by the NMIJ, and the deadweight is calibrated by the JQA. Also, the reference standard is traced by the NIST.

Operating Principle of Deadweight Pressure Balances

A deadweight pressure balance is a high-precision pressure generator which is made of a piston and a cylinder and employs Pascal's law. The generated pressure is determined by the effective cross-sectional area of the piston and the mass of the weight placed on the piston as follows:

$P = W/A$

where

P : Pressure generated (Pa)
A : Effective cross-sectional area of the piston (m^2)
W: Force ($M \times g$)
M: Mass of the weight placed on the piston (kg)
g : Gravity

Corrections

To improve the accuracy of the pressure generated by the deadweight pressure balance, precision measurement of the mass and piston weights as well as correction of temperature, gravitational acceleration with respect to location, weight buoyancy, and elevation need to be conducted.

(1) Temperature Correction
The piston temperature is measured by a platinum resistance thermometer and the like (actually, the temperature of the cylinder is measured instead because the piston is revolving and cannot be measured during deadweight pressure balance operation). The effective cross-sectional area of the piston is corrected with respect to temperature coefficient. The value of the temperature coefficient is fairly large, ranging between 10 and 30 ppm/°C.

(2) Gravity Correction
To calibrate a deadweight pressure balance, the world standard gravity value, 9.80665 m/s^2, which was measured near Rishiri Island, Hokkaido in Japan (where the latitude is 45° and sea level is 0 m) is used. However, we have corrected this value with respect to the location where the deadweight pressure balance is used. The local gravity can be calculated from the map of gravity abnormality distribution (Bouguer gravity anomaly) compiled by the Geographical Survey Institute, longitude and latitude, and sea level and/or elevation. To achieve high accuracy, we use 9.79689 m/s^2, which was measured at the entrance of our Kofu Plant. This value is 0.1% smaller than the world standard gravity.

(3) Buoyancy Correction
The buoyancy of the air acting on the weight is calculated for correction.

(4) Elevation Correction
The pressure generated by the balance pressure is in general given by the height of the lowest point of the piston (the reference height for pressure calculation). When the reference height of the higher-order standard is different from that of the calibrated equipment, the pressure equivalent to the difference in the height is translated into an error of the calibrated value. This difference is corrected by the air density in the pipe and height difference.

Precautions on the Use of Deadweight Pressure Balances, and Their Calibration Ranges

A deadweight pressure balance is precision equipment whose piston and cylinder are approximately 1 µm apart. Since it is susceptible to condensation and dust, the measurement part uses pure nitrogen. A dust removal filter is also installed. Table 2 shows the range of calibration for a factory-use measuring instrument.

The standard room air pressure is monitored by a digital absolute manometer. The digital absolute manometer is calibrated every 6 months to confirm its normal operation.

Table 2 Calibration Range for Factory-use Measuring Instruments

Gauge pressure	0 Pa – 50 MPa
Differential pressure	200 Pa – 20 kPa
Absolute pressure	0 kPa – 200 kPa

TEMPERATURE STANDARDS

Figure 6 shows the traceability of temperature standards. Reference standards for temperature measurement are the standard platinum resistance thermometer (SPRT) and R (platinum – platinum rhodium) thermocouple. These standards are calibrated by JEMIC at 12-month intervals. When calibration is completed and Yokogawa receives the calibrated reference standards, it reproduces the state of calibration at fixed points of temperature (JEMIC's calibration points), including the triple

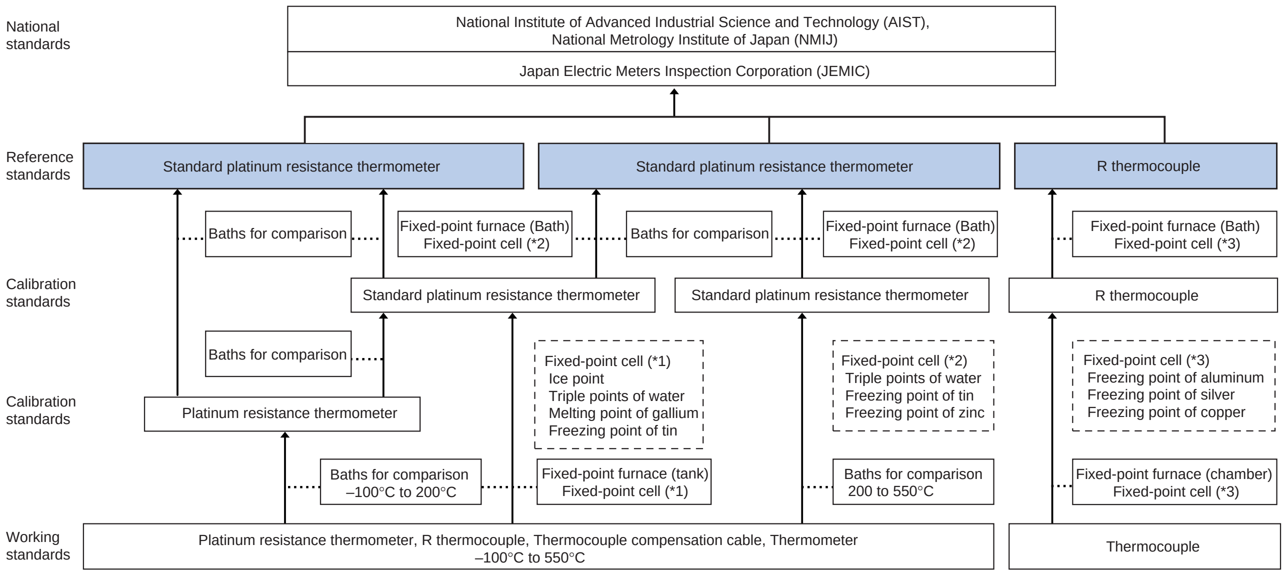


Figure 6 Traceability of Temperature Standards

points of water, the melting point of gallium, and the freezing points of tin, zinc, aluminum, silver and copper, in order to confirm deviations from the previous calibration values. Instruments subject to calibration, such as factory-use measuring instruments, are calibrated mainly using a calibration-purpose platinum resistance thermometer or a calibration-purpose standard platinum resistance thermometer across the continuous temperature range of –100°C to 550°C. At high temperatures above 550°C however, Yokogawa-owned platinum resistance thermometers cannot be used for reasons of deterioration due to oxidization. Therefore, Yokogawa uses a calibration-purpose R thermocouple instead in order to calibrate factory-use measuring instruments at the freezing points (discrete points of temperature) of aluminum, silver and copper.

CONTROL OF MEASURING INSTRUMENTS

Up to the previous section, we have discussed how measurement traceability is maintained by means of periodic calibration. Generally speaking, the point in time and interval of periodic calibration differ from instrument to instrument. In order to allow as many instruments as possible to remain within their effective periods of calibration, instruments must be continually sent for calibration and received back without omission. Yokogawa has established and is operating the Calibration Information Management System (CIMS) within the Yokogawa Group. Figure 7 shows the system configuration.

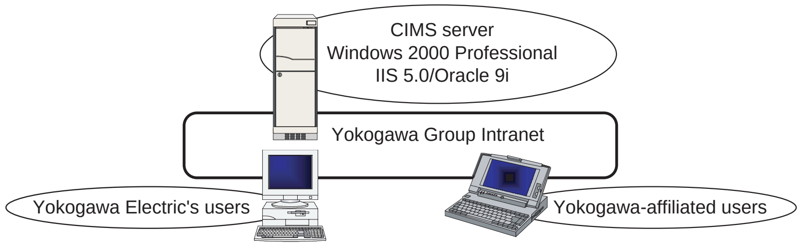
Managers in charge of measuring instruments being controlled register instrument information, such as the function, model number, serial number, calibration interval and calibration deadline, in the CIMS, instrument by instrument. According to the registered information, the CIMS sends a list of instruments whose effective periods of calibration will expire in the following month, to each manager by e-mail on the 10th day of each month. By referring to this list, measuring instrument managers simply issue calibration requests to the department in charge of calibration. With the CIMS, it is possible to effectively reduce the number of overdue instruments and the risk of forgetting to issue calibration requests.

The CIMS is accessible to anyone who is permitted to use the Yokogawa Intranet. Yokogawa Electric China Co., Ltd. in Suzhou, Jiangsu Province, P. R. China, also uses the CIMS to implement instrument control.

CALIBRATION BASED ON JAPAN CALIBRATION SERVICE SYSTEM

In November 1993, the Revised Measurement Law was put into effect and a measurement law-based traceability system called the Japan Calibration Service System (JCSS) was introduced. Consisting of the National Measurement Standards Provision System and the Calibration Laboratory Accreditation System, this traceability system has been established in order to ensure high-precision measurement in advanced industries and the reliability of quality control in industrial manufacture.

Yokogawa was accredited as a calibration service provider in the category “Electrical” in June 1995 and in the category “Pressure” in December 2000, and is now a Mutual Recognition Agreement (MRA)-based calibration service provider(3). Accredited calibration service providers are deemed to comply not only with the accreditation requirements prescribed by the Measurement Law but with the ISO/IEC17025 accreditation standard. MRA-based calibration service providers also comply with requirements prescribed by the International Laboratory Accreditation Cooperation (ILAC) and Asia Pacific Laboratory Accreditation Cooperation (APLAC) which are international and regional groups of accreditation bodies. Yokogawa supplies highly reliable measurement standards to member companies in



Note: The product and other specific names appearing in this figure are trademarks or registeredtrademarks of their respective holders.

Figure 7 CIMS System Configuration

the Yokogawa Group to enable them to produce high-quality products. In addition, Yokogawa is responsible for providing highly reliable measurement standards to the industrial world on behalf of the Japanese Government(4).

CONCLUSION

The Yokogawa Group has been creating and maintaining a family of essential measurement standards in line with the progress of measuring instruments, keeping them traceable to national standards. Reliable traceability of measurement underpins the reliability of a broad range of test and measurement data handled within the Group, and so is crucial for the production of high-quality measuring instruments. Along with the recent globalization of economic activities, ensuring the international traceability of measurement has become increasingly important as a basis for conformity assessment procedures concerning economic dealings in each country. The Yokogawa Group is committed to maintaining and improving the traceability of measurement. ◆

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