Real-time Math Function of DL850 ScopeCorder

Etsurou Nakayama [*1] *Chiaki Yamamoto* [*1]

In recent years, energy-saving instruments including inverters have been actively developed. Researchers in R&D sections want to evaluate their prototypes in real time to enhance the development efficiency. Therefore, measuring instruments are required to have functions for not only simply recording data but also immediately calculating power values and efficiency based on the data. To meet this demand, Yokogawa has developed a unique real-time math function for the DL850 ScopeCorder, our multi-channel waveform recording instrument. This paper gives an overview of the function and its application examples.

INTRODUCTION

In recent years, energy conservation has been a hot issue and thus electric appliances and industrial equipment are required to improve energy efficiency more than ever. For example, power devices used in inverters are required to feature faster operation and higher voltages for improving efficiency. As in the case of the electronization of automobiles, multiple CPUs are used for more precise control and functional enhancement.

To develop such energy-saving devices, various measuring instruments are used for checking operation and effects. These measuring instruments record voltage, current, and other values of the target devices. However, their efficiency is evaluated based on other values such as electric power value and power efficiency, thus original data recorded by measuring instruments must be processed. In order to measure the efficiency of devices, physical quantities such as revolution speed and torque of a motor must be measured and the amount of mechanical work must be obtained. Therefore, a sensor suited for the target physical quantity is used for measurement and the physical quantity is converted into electric signals. The electric output of the sensor is not always linear with the physical quantity, so a linearizer or similar device is installed between the sensor and measuring instrument to linearize the sensor output. The physical quantity measured in this manner is an instantaneous value, so calculations such as time series integration are required to obtain the amount of mechanical work. Thus, simple measurement is not sufficient to evaluate the energy-saving efficiency of the devices; the collected data must be processed.

Conventionally, the data collected by a measuring instrument is transmitted to a PC for linearization and processing to obtain values such as electric power and power efficiency, with which the target device is evaluated. In this measuring method, however, these processes are carried out in batches, which is a bottleneck in improving the efficiency of experiments and development. Therefore, there is an increasing need for measuring instruments that can perform both measurement and data processing, and help check the efficiency of the devices being developed immediately after measurement at measurement sites.

Yokogawa already released the DL850 multi-channel high-speed waveform recording instrument shown in

*1 General Purpose T&M Center,
Yokogawa Meters & Instruments Corporation

Figure 1. To meet the needs described above, Yokogawa has developed a function for processing measured data and recording the results in real time. This paper describes this processing mechanism and gives application examples.

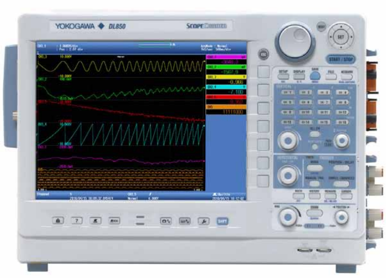

Figure 1 External view of DL850

OUTLINE OF CONFIGURATION

The DL850 is a waveform measuring and recording instrument with eight slots for input modules. Depending on the target devices, any of 17 modules for the DL850 can be selected and combined to directly connect various sensors and measure physical quantities.

Basic performance covers a sampling rate of up to 100 MS/s (M samples/second) and includes a memory capacity of up to 2 Gpts (G points). With the high-speed 100-MS/s 12-bit isolation module, the DL850 can measure the output voltage of an inverter safely and accurately in a broad bandwidth of 20 MHz and high dielectric strength voltage of 1000 V. With the 16-ch voltage input module, it can measure the voltage of up to 128 channels. In this way, a single DL850 can perform multi-channel, high-speed sampling, and long-term measurement.

Figure 2 shows a block diagram of the DL850. Input data is digitized at the A/D converter of each input module and sent to the acquisition memory via the GIGAzoom Engine® 2, which is Yokogawa's unique data processing circuit. On receiving data, the GIGAzoom Engine 2 determines whether there is any trigger, and if there is, it stores only a required portion before and after the trigger in the acquisition memory. The GIGAzoom Engine 2 also has a special engine for displaying waveforms, and thus can draw waveforms of the data in the acquisition memory at high speed. This function allows the DL850 to quickly display the waveforms of all the data even in a large memory capacity of 2 Gpts.

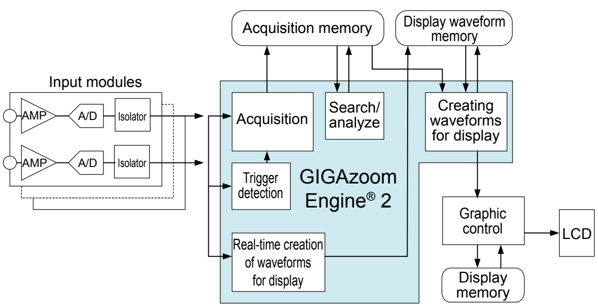

Figure 2 Block diagram of DL850

The newly developed real-time math function is provided between the input module and the GIGAzoom Engine 2. It is selectable for each channel whether the data from each input module will be stored in the acquisition memory as it is or after processing at the function. When all the data paths are assigned to the real-time math function, data of up to 16 channels can be processed simultaneously.

The features of the real-time math function in this system are as follows.

1) The data is processed before storing in the acquisition memory, so processing time is not restricted by the acquisition memory capacity. The data can be successively processed at any time.
2) The data is processed before the trigger detection circuit and the trigger is detected by using the computed result. The acquisition of data is judged based on the computed result, so the required data can be stored efficiently.
3) Routing the data enables the simultaneous acquisition of data both before and after calculation. The processed data can be routed to a channel in which no input module is inserted, and then recorded.

STRUCTURE OF MATH UNIT

The real-time math unit is configured by using a dedicated hardware math circuit for high-speed processing. Figure 3 shows a block diagram of the real-time math unit.

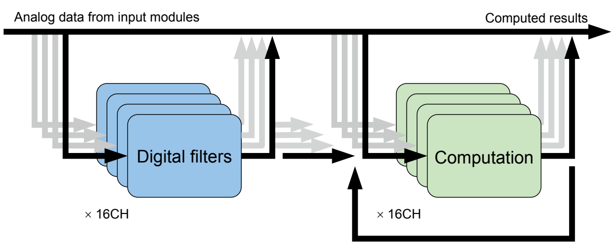

Figure 3 Structure of real-time math unit

The real-time math unit consists of two units: the digital filter unit and the calculation unit. Both units can operate independently and simultaneously perform processing for 16 channels each.

Filters in the digital filter unit can be selected from low pass, high pass, and band pass filters of a Finite Impulse Response (FIR) or Infinite Impulse Response (IIR) type, or Gaussian and moving average filters. Processing time of the digital filter is up to 1 MS/s in 16 channels at the same time, more than 10 times faster than the conventional DL750 [(1)].

At the calculation unit, a processing method can be set for each channel and is performed by using one of 28 built-in computing functions. They include fundamental functions such as four arithmetic operations, square root and logarithm, and applied functions such as electric power calculation and electrical angle calculation, and thus desired results can be acquired simply by selecting the appropriate computing functions without the need for complicated settings. Table 1 lists the computing functions. The results of the real-time calculation can be used in other calculations, and thus complicated calculation is possible by combining multiple computing functions.

Calculations are implemented in hardware, so high-speed calculations of up to 10 MS/s are possible in 16 channels at the same time, which is about 100 times faster than the conventional DL750.

Table 1 List of computing functions

Computing functions	Description
Four fundamental arithmetic operations	S1 $ S2 ($: select from among +, –, *, /)
Four arithmetic operations with coefficients	(a * S1) $ (b * S2) + c ($: select from among +, –, *, /)
Integration	Integrate every sampling data
Differentiation	Differentiate sampling data with the fifth-order Lagrange differential equation
Angle and displacement	Convert the A-phase, B-phase, and Z-phase signals of the encoder into angle and displacement
DA conversion	Convert digital data into analog quantity
Fourth-order polynomial (Poly)	a * $S1^4$ + b * $S1^3$ + c * $S1^2$ + d * S1 + e
Root mean square (Rms)	$\sqrt{}$(∑$S1^2$ / n) (n is the number of data between negative-to-positive zero crossing points)
Effective power (Power)	1 / T * ∫(S1 * S2) dt (T is the time between negative-to-positive zero crossing points)
Reactive power (Reactive Power)	Calculate reactive power by the following equation $\sqrt{}$([apparent power]^2 - [effective power]^2)
Power integration (Power Integ)	∫(S1 * S2) dt
Logarithm 1 (Log1)	a * log(S1 / S2)
Logarithm 2 (Log2)	a * log(S1)
Square root 1 (Sqrt1)	$\sqrt{}$($S1^2$ $ $S2^2$) ($: select from among +, –)
Square root 2 (Sqrt2)	$\sqrt{}$(S1)
Cos	a * cos(angle) (An encoder signal is converted into an angle)
Sin	a * sin(angle) (An encoder signal is converted into an angle)
Atan	atan(S1 / S2)
Knock Filter	Elimination filter forcing signals lower than the setting value to 0
Electrical angle	Calculate phase difference between the specified data with discrete Fourier transform
Polynomial addition and subtraction	a * ($ S1 $ S2 $ S3 $ S4) ($: select from among +, –)
Event counting	Count the number of negative-to-positive zero crossing points
Cycle time	Signal cycle time between negative-to-positive zero crossing points
Frequency	Signal frequency between negative-to-positive zero crossing points
Resolver	Convert signals from a resolver sensor into angle
IIR filter	Selectable from infinite impulse response (IIR)-type low pass, high pass, or band pass filters.
Pwm	Integrate pulse widths of pulse width modulation (PWM) waveform during a cycle time to convert into a sinusoidal wave
CAN ID	Analyze signals of CAN bus and detect a specific ID

* S1, S2, S3, and S4: Select data of measurement channels or computed results.

* a, b, c, d, and e: Arbitrary constants

APPLICATION EXAMPLES

Characteristic applied functions are provided for various applications. Some measurement examples using these functions are described below.

Measurement of transient power

With the power function, transient effective power for every cycle can be measured.

The power function is defined as follows.

$$\text{Effective power value} = \frac{1}{T}\int\left(\text{voltage}\cdot\text{current}\right)dt$$

T : One cycle time

It integrates instantaneous power values, which are a product of voltage and current, for one cycle to calculate an effective power value for this cycle. The calculation is repeated and the result is updated every cycle. Take as an example the voltage and current waveforms shown in Figure 4. During Period T1, which spans from a negative-to-positive zero crossing point of the voltage signal to the next point, the product of voltage and current at every sampling period Δt is integrated. The time of T1 is measured automatically, and at the end of this period the integrated result is divided by T1 and updated as the electric power value. The same process is repeated in Period T2, and at the end of this period the electric power value is updated again.

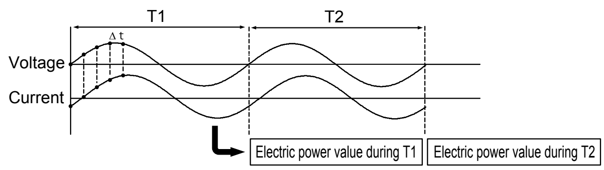

Figure 4 Calculation of effective power value

This electric power calculation is performed for every waveform cycle, so the changes in electric power can be precisely recorded even when the waveform cycle time fluctuates. For example, the waveform cycle time transiently fluctuates during the start-up of a motor, and the DL850 with this function can follow changes in the waveform cycle time and record the electric power value in real time for every waveform cycle. With the high-speed calculation of 10 MS/s, the DL850 can catch all data and calculate the electric power value of a pulse width modulation (PWM) waveform of such devices as inverters.

Figure 5 shows an example of electric power measurement at the start-up of a motor. The DL850 precisely measures changes in electric power during the start-up of a motor.

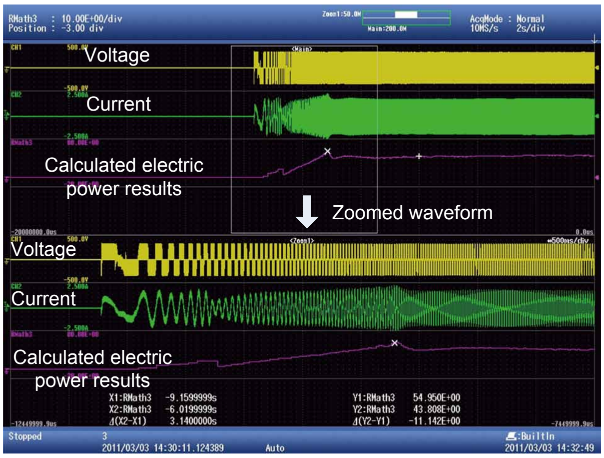

Figure 5 Example of measuring start-up of a motor

Measurement of the electrical angle of motors

To achieve energy savings when operating motors, inverters and vector control are being widely used. Torque characteristics of motors depend on the phase difference between the mechanical angle of a motor (absolute angle of the motor rotating shaft) and the electrical angle of an exciting current. Therefore, measuring the electrical angle corresponding to the mechanical angle is important for understanding motor characteristics. See Figure 6 for electrical angle. For this purpose, the DL850 provides an electrical angle function for calculating the phase difference by using the mechanical angle, a signal obtained from a rotary encoder of the motor rotating shaft.

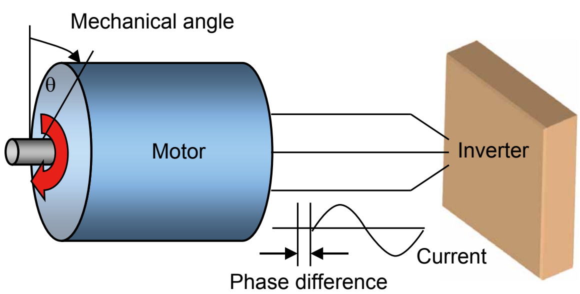

Figure 6 Measurement of electrical angle

The electrical angle function performs a discrete Fourier transform. For the fundamental frequency, the discrete Fourier transform of an exciting current waveform is calculated as follows.

$$f = \sum_{n=1}^{N} i(n)\exp\left(\frac{-j2\pi n}{N}\right)$$
$$= \sum_{n=1}^{N} i(n)\left(\cos\left(\frac{2\pi n}{N}\right) - j\sin\left(\frac{2\pi n}{N}\right)\right)$$

$i(n)$: Measured current value

N : The number of samplings per fundamental period

The fundamental frequency of an exciting current waveform is the same as that of the motor rotation. In this case, the imaginary part and the real part of the formula above can be calculated as follows: the rotation angle of the motor is measured for every sampling period, cosine and sine values of the angle are calculated, and the products of the current value at that time and the cosine and sine values are accumulated for one cycle of the motor rotation. As the fundamental frequency is that of the motor rotation, a phase difference O between the mechanical angle of the motor and the electrical angle of the exciting current is just the argument of the discrete Fourier transform equation, and therefore can be calculated by the following equation.

$$\phi = \arctan\left(\frac{\text{imaginary part}}{\text{real part}}\right)$$

This calculation is performed focusing on the fundamental frequency only on the basis of the principle of discrete Fourier transform. Therefore, the electrical angle of the fundamental frequency component can be calculated for every cycle and recorded in real time even when the current waveforms are distorted. Figure 7 shows an example of measuring electrical angle in distorted current waveforms.

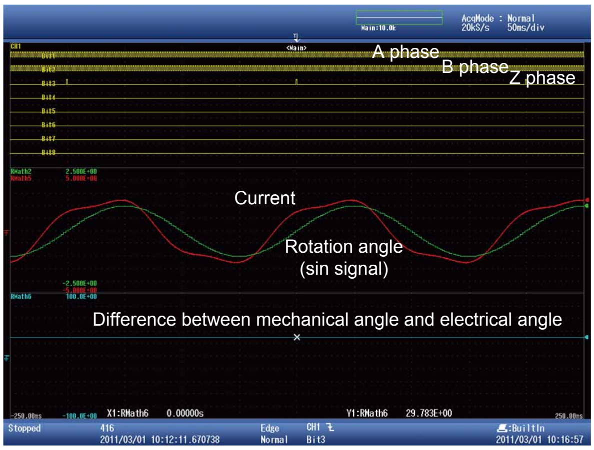

Figure 7 Example of measuring electrical angle

Displaying the measurement results of a rotating body in polar coordinates

The real-time math function enables measurement results of a rotating body to be displayed in polar coordinates in real time. For example, when measuring the wobbling of a rotating body as shown in Figure 8,

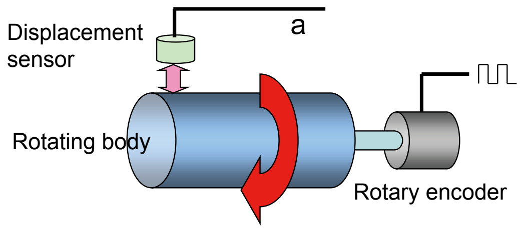

Figure 8 Measurement of wobbling of rotation

The polar coordinates are expressed by the following equation where, a is wobbling output from the displacement sensor, and θ is the angle of the rotating body.

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} a\cos\theta \\ a\sin\theta \end{pmatrix}$$

The behavior of the rotating body can be displayed in the polar coordinates in real time by using the Angle function to calculate the angle value based on the output of the rotary encoder, calculating sine and cosine values based on this value, and using the x-y display function to display each value on the coordinates.

Figure 9 shows a measurement example of the rotary displacement. You can easily understand the behavior of the rotating body which is displayed on the polar coordinates depending on the rotation angle.

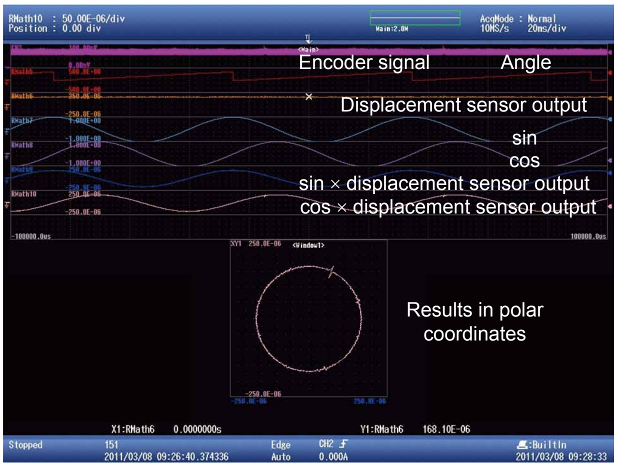

Figure 9 Example of measuring wobbling of rotation

Measurement with the resolver angle sensor

In recent years, resolvers are often used for detecting motor angles of hybrid cars and other vehicles as they are excellent in environmental resistance. As shown in Figure 10, the resolver sensor detects sinusoidal exciting voltage applied to exciting coils mounted on the rotor by using the two orthogonal sensing coils and outputting two signals (sinθ and cosθ) corresponding to the angle θ of the rotor. Exciting voltage is superimposed on the sinθ and cosθ signals, so this carrier component is removed and the angle calculation is performed. The resolver function automatically detects sinθ and cosθ signals synchronizing with the resolver exciting voltage, samples them, and calculates angle values.

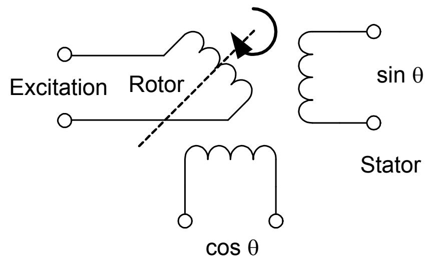

Figure 10 Resolver structure

The resolver function has a built-in tracking loop filter as shown in Figure 11. Even when some sampling data of sinθ and cosθ signals are missing, they can be interpolated.

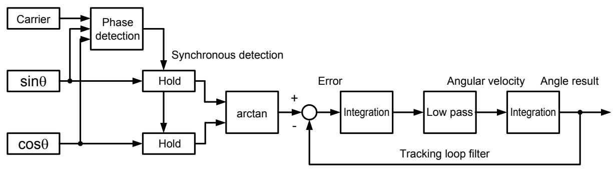

Figure 11 Block diagram of the resolver function

Figure 12 shows a measurement example of the resolver by using this function. As shown, the computed angle data is not affected by synchronous detection, and highly accurate results can be obtained without discontinuity.

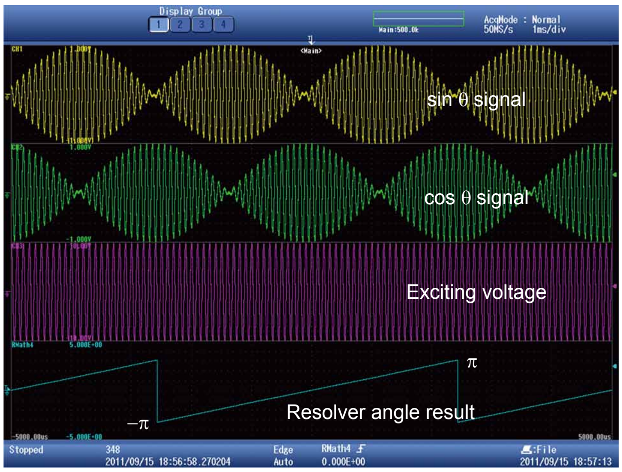

Figure 12 Example of measurement using a resolver

CONCLUSION

This paper described major features of the real-time math function, outlined the configuration, and introduced application examples. The real-time math function of the DL850 can process data and immediately show analysis results at the measuring site. The DL850 with the real-time math function is expected to improve the development efficiency of energy-saving devices as well as the efficiency of experiments and evaluations in the mechatronics and power electronics fields including automobiles, and thus help technologies develop in these fields.

REFERENCES

(1) Etsurou Nakayama, Satoru Suzuki, et al., "ScopeCorder DL750," Yokogawa Technical Report, Vol. 47, No. 3, 2003, pp. 27-30 in Japanese