Development of the "Model No.HA035" – A Small, High Accuracy, Batteryless Absolute Encoder

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1. Introduction

Machine tools, industrial robots, and equipment such as injection molding machines that support the world's manufacturing must have high precision positioning drive to create precision parts. As such, the encoder, which detects the position of the servo motor installed on machinery and equipment, is taking on an even more important role.

Currently, the primary type of detection is the battery backup method on multi turn detection on absolute encoders for servo motors. However, this method requires periodic battery replacement, thus a demand has arisen for encoders which do not require maintenance in line with the expansion of overseas markets fueled by globalization.

Machining equipment, which is best represented by machine tools, produces precision parts, and therefore requires high accuracy and smooth positioning drive. This creates a demand for servo motor encoders with even higher accuracy and resolution.

Moreover, encoders are also required to have better environmental resistance due to the diversification of equipment operating environments and improved performance.

For these reasons, Sanyo Denki decided to develop the "Model No.HA035" ("HA035") – a small, high accuracy, batteryless absolute encoder. This document describes the main specifications and features of the "HA035" and the technologies adopted to achieve these.

2. Specifications

Table 1 shows a comparison of specifications between conventional models and the new model, while Fig. 1 shows the appearance of a motor equipped with the "HA035". Up until now, Sanyo Denki has offered the "Model No.PA035" ("PA035") as our standard absolute encoder. The multi turn detection of the "PA035" adopts a battery backup method. The battery backup method supplies power from the battery even when the power supply for the device is cut off in order to detect the shaft rotations for the motor. With this method, the device will not accidentally restart even if the shaft rotates after the device has been turned off. However, this method requires periodical replacement of the battery, and although this maintenance task is extremely important, it is becoming increasingly difficult to maintain service checks with the increased number of equipment being used overseas. In addition, there are several issues, such as the fact the lithium battery used for the encoder is scarcely available overseas, export from Japan to the relevant countries is difficult and ultimately, lithium batteries are considered hazardous waste.

Fig. 1: Appearance of a motor equipped with the "Model No.HA035"

Sanyo Denki began focusing on batteryless encoders before our competitors, and commercialized the "Model No.RA035" ("RA035")[1] which uses a resolver method and the "Model No.HA062" ("HA062")[2] which uses an optical/magnetic hybrid method. Achieving high accuracy with the "RA035" was difficult, however, as it has an absolute angular accuracy of 10 minutes and a maximum resolution of 17 bits. The "HA062" also poses a problem as it has a large outer diameter and can only be mounted on motors with a flange size of 100 mm or more.

Table 1: Comparison of specifications between conventional models and the new model

Item	Conventional model			New model
	Model No.PA035	Model No.RA035	Model No.HA062	Model No.HA035
Single turn detection method	Optical	Resolver	Magnetic + optical	Optical
Single turn resolution	17 bit (20 bit)	17 bit	17 bit (20 bit)	17 bit (20 bit, 23 bit)
Absolute angular accuracy	10 minutes	10 minutes	1 minute	10 minutes (1 minute)
Multi turn backup	Battery	Batteryless		
Multi turn resolution	16 bit	14 bit, 16 bit	16 bit	
Working temperature	85°C max			105°C max
Vibration resistance	10 G	15 G	10 G	15 G
Communication method	NRZ start stop synchronization (Sanyo Denki standard format)			
Communication speed	2.5 Mbps or 4 Mbps			
Communication cables	3 pair 6 cables	2 pair 4 cables		
Installed motor flange size	40 mm or more	40 mm or more	100 mm or more	40 mm or more

The "HA035" that we have developed this time is a small, high accuracy, batteryless encoder that can be installed on our R series motors with a flange size of 40 mm or more and is being presented as the new standard encoder to replace the "PA035".

The "HA035" has an absolute angular accuracy of 1 minute and a maximum resolution of 23 bits, making it higher accuracy and higher resolution than conventional models. Moreover, it also has improved environmental resistance, with a maximum working temperature of 105°C and vibration resistance of 15 G. The "HA035" is smaller than conventional models, and can be installed on R series motors with a flange size of 40 mm or more. Communication specifications are consistent with Sanyo Denki's standard format, therefore the "HA035" is compatible with the servo amplifier used by customers up until now (SANMOTION R 3E Model and later support 23-bit resolution).

3. Features

3.1 A downsized batteryless system

For the conventional "RA035" and "HA062", a combination of gears was used to hold multi turn information. For this reason, downsizing was difficult due to the amount of space required for the gears, therefore the height of the "RA035" became greater and the "HA062" could only be fitted on motors with flange sizes of 100 mm or more.

On the "HA035" however, we succeeded in downsizing by newly adopting a batteryless system utilizing induced voltage with a special magnetic element. Fig. 2 shows the configuration of a batteryless system. There are only two basic components; a coil which is mounted on the circuit board and a magnet which is attached to the tip of the shaft. The basic principle of this system is that pulse-shaped voltage is induced from the coil to suit the magnet rotation, this pulse is detected and stored the data in the nonvolatile memory. The power necessary at this time is supplied from the pulse-shaped inducted voltage, therefore operation is possible without the need for an external power supply.

The coil's induced voltage is as described in Faraday's electromagnetic induction law and as expressed by Formula (1).

$$e = -\frac{d\Phi_B}{dt} \quad (1)$$

Formula (1) expresses that induced voltage is proportional to the change in the interlinked magnetic flux per unit of time, and if this magnetic flux is of the magnet, it will be proportional to the time of the magnetic flux change, or in other words, speed. For this reason, in the case of air-core coils or cores made from common materials, it is not possible to obtain a sufficient amount of induced voltage during low-speed rotation.

The "HA035" batteryless system solves this problem by using a special magnetic element in the core of the coil. Fig. 3 shows the B-H curve of the magnetic element. There is a point in the B-H curve of the magnetic element where the magnetic flux changes suddenly in relation to the magnetic field. When the magnetic field passes this change point, the magnetic flux changes suddenly, or in other words, regardless of the time of magnetic field change, the time

of magnetic flux change is minimal, therefore there will be a large amount of induced voltage. Consequently, it is possible to accurately detect shaft rotation regardless of motor speed.

The external diameter of the encoder for this batteryless system is kept minimal at ϕ35, therefore it can be installed on a motor with a flange size of 40 mm or more.

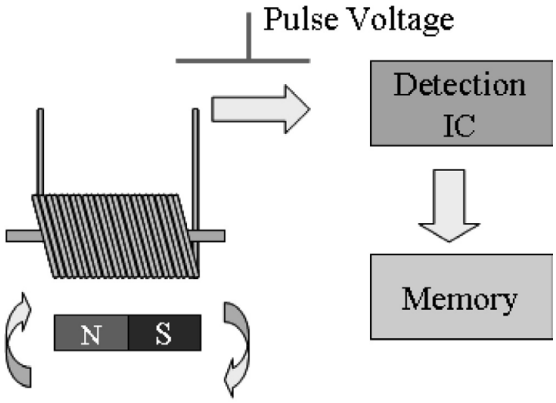

Fig. 2: The "HA035" batteryless system

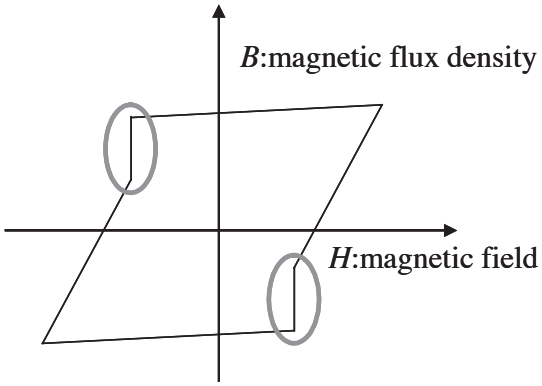

Fig. 3: B-H curve of a "HA035" magnetic element

3.2 High accuracy and high resolution

The "HA035" includes a function that measures and corrects the errors from rotary disc eccentricity and distortions in the analog waveform for each slot when assembling the encoders. This enables a high absolute angular accuracy of 60 seconds or less on the high accuracy version. Figures 4 and 5 show the measured values of absolute angular accuracy before and after correction. Normally, before correction, there is one cycle of error for one rotation, as shown in Fig. 4. The error varies depending on the individual product, however Fig. 4 shows an error of 324 seconds. Fig. 5 shows a reduction of 16 seconds due to angle correction.

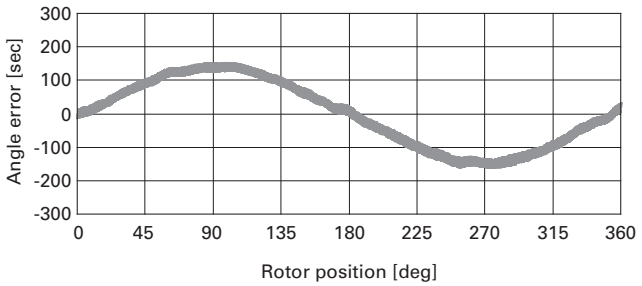

Fig. 4: Error waveform before angle correction (measured value example)

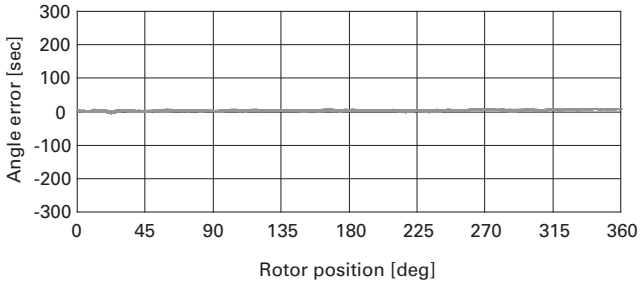

Fig. 5: Error waveform after angle correction (measured value example)

Moreover, the maximum resolution of one rotation has increased from 20 bit on the "PA035" and "HA062" (1048576 partitions) to 23 bit (8388608). In regards to 23-bit resolution, the number is so large it may be difficult to put into perspective, however if the length of the equator (40,000 km) was partitioned, 1 bit would be 4.8 meters. No doubt this level of detail is easier to comprehend. Increasing the resolution results in the refinement of position and speed detection, thus improving servo performance. Figures 6 and 7 show the respective operation waveforms with 17-bit resolution and 23-bit resolution at a fixed operation speed of 100 min^{-1}. The upper line of the figure shows the command value of the torque, while the lower line shows the error in relation to the speed command. In the case of 17-bit, the speed resolution, which is the minimum speed that can be detected, is 4.1 min^{-1}, therefore the speed error will either be -2 or +2, meaning that actual movement is not being detected. This also confirms that the torque command is pulsating. On the other hand, with 23-bit resolution, the speed resolution is significantly more refined at 0.06 min^{-1}, making it possible to detect minute speed changes, therefore minimizing changes in torque commands. This proves that by increasing the resolution, the quantization error becomes smaller, making smoother drive possible.

By achieving even higher accuracy and resolution, it is possible to contribute to better machining accuracy and improved positioning accuracy on our customers' equipment.

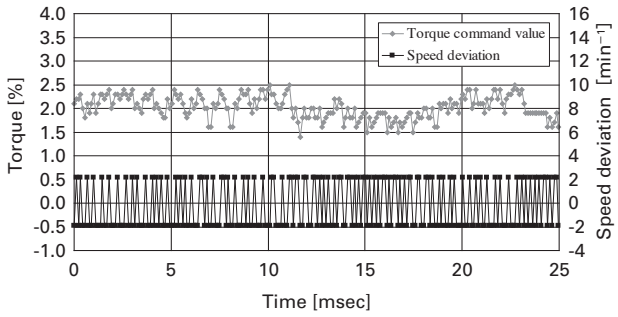

Fig. 6: Operation waveform at 17-bit resolution

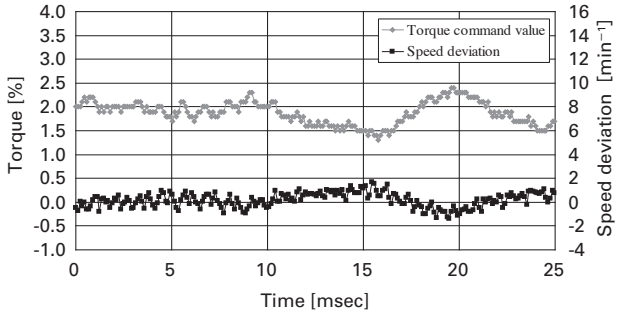

Fig. 7: Operation waveform at 23-bit resolution

3.3. Improved environment resistance characteristics

On the "HA035", the upper limit working temperature of the encoder has been increased from 85°C to 105°C. With 85°C as the upper limit working temperature of conventional encoders, the upper limit temperature of the electronic components being used was the bottleneck, however by selecting high temperature compatible components with the "HA035", temperatures of up to 105°C can be withstood. Furthermore, the encoder features a built-in temperature sensor, therefore achieving operation whilst constantly confirming encoder temperature and working as a function to set off an alarm if the upper limit temperature is reached.

Moreover, compared to the conventional optical encoder's vibration resistance of 10 G, the "HA035" has a vibration resistance of 15 G, making it equivalent to the "RA035" resolver type encoder. This was achieved through analyzing the encoder's structure and performing optimal design for the component layout and structure. In addition, we did not only perform analysis, but also conducted verifications on an actual machine.

It is necessary to consider the motor working temperature and vibration resistance, however, improving the environmental resistance of the encoder means it can be used in even harsher conditions than previously possible. This results in operation of an even shorter cycle-time than before in environments restricted by the environmental resistance of the encoder, and application on equipment with significant vibration is achievable.

3.4 A unique cover structure

Generally-speaking, encoders which use magnetic elements are easily affected by external magnetic fields. The structure to block external magnetic fields must be arranged so as not to affect the magnetic circuit of the magnetic element. In large motors with ample room, it is possible to eliminate impact by leaving enough distance, however this is difficult in small motors with limited room. Fig. 8 shows the shield cover structure of the "HA035". For the "HA035", a hole has been opened in the top of the shield cover, and cut-outs have been made in either side; resulting in a very unique cover structure. With this type of shield structure, external magnetic fields are blocked but the encoder's magnetic circuit is not affected. This unique shield cover structure ensures our customers can use the "HA035" with peace-of-mind, even in environments with external magnetic fields.

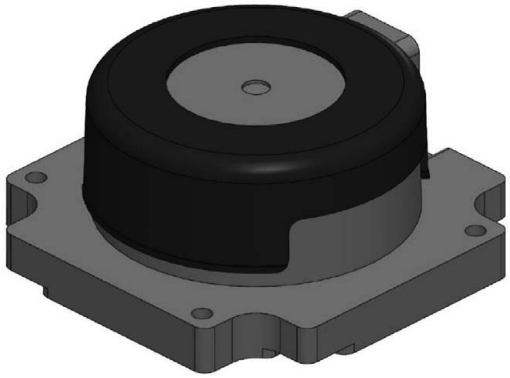

Fig. 8: The "HA035" shield cover

3.5 Highly integrated photodetector "ASIC"

On the "HA035", we have further evolved the photodiode IC technology developed in advance for the incremental encoder "Model No.PP031T" ("PP031T") [3], the highly integrated photodetector "ASIC", thus achieving comparatively higher integration. One photodiode IC such as that used on the "PP031T" was able to be equipped with a photodetector, amplifier and comparator. On the highly integrated photodetector "ASIC" used on the "HA035" this time, in addition to the analog circuit of the photodetector and amplifier, a logic circuit from the AD convertor to signal generation can be equipped on a single IC. This means that minute analog

signals do not need to pass through the pattern on a circuit board, resulting in the shortest connection within the IC and increasing strength against external noise. In addition, the number of components has been significantly reduced, achieving downsizing and reduced current consumption of the product. Finally, the ASIC has a built-in temperature sensor to protect customers' equipment from the risk of any abnormal heat that may be generated by the ASIC.

4. Conclusion

This document has described the main specifications and features of the "Model No.HA035" ("HA035") – a small, high accuracy, batteryless absolute encoder.

The "HA035" has achieved downsizing, higher accuracy, higher resolution and environmental resistance superior to conventional models through a newly-developed batteryless system utilizing induced voltage by a magnetic element.

The authors believe that planet-friendly batteryless encoders will become the norm of the future. For that reason, Sanyo Denki has made batteryless encoders the standard, ahead of our competitors. We would like to spread the "batteryless culture" around the world with the "HA035" small, high accuracy, batteryless encoder we have developed this time.

Reference

(1) Kazuhiro Makiuchi and Others: Development of the Small-size Batteryless Absolute Encoder "RA035", SANYODENKI Technical Report No.25 May 2008

(2) Yoshihiro Shoji and Others: Development of the High Precision and High Reliability Batteryless Absolute Encoder "HA062", SANYODENKI Technical Report No.33 Nov. 2012

(3) Yoshihiro Shoji and Others: Development of "PP031T" and "PP031H" Small-size Multiplier Incremental Encoders, SANYODENKI Technical Report No.28 Nov. 2009

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