In 2004, JTEKT became the first in Japan to market a safety PLC (programmable logic controller), the TOYOPUC-PCS. This product, which improves machine safety, conforms to the international safety standards IEC61508 SIL3 and ISO13849-1 PL e. Since its launch, approximately 10 000 sets have been sold. The TOYOPUC-PCS features safety remote I/O communication function and is suitable for large-scale safety control on applications such as automotive production lines, but this time JTEKT has developed a new TOYOPUC-PCS-J series as a compact/low-cost safety PLC for individual machines.

Key Words: machine safety, safety PLC, compact/low-cost, international safety standard, tool-free replacement, integrated PC tools

1. Introduction

Since around the year 2000, there has been an endeavor, mainly in Europe, for systematization of safety standards. To accomplish this, manufacturers have been competing to develop and market safety control device that conforms to standards. Particularly, since the establishment of the international standard, "Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems: IEC61508" which has made it possible for safety control device through microcomputer control to be certified by a notified body, safety programmable logic controllers (hereinafter referred to as safety PLCs) as well as safety controllers have been developed and introduced one after another in the same way that machine control by relays was replaced by PLC in the past.

Furthermore, the reference standard EN954-1, which had been significant for safety control design up until now, and will be replaced by a new consistent standard ISO13849-1 (2006). In case this new standard is applied, it will become necessary to calculate the performance level (PL) of the system as a whole based on the theory of probability in addition to using the logical concepts of the conventional control structure, with even more emphasis placed on safety design than previously, which will require more labor to meet requirements. Fortunately however, employing a single device such as the safety PLC capable of constituting a safety system on its own can meet this standard comparatively easily.

JTEKT responded to this movement rapidly, developing the first safety PLC in Japan in 2004 and since selling approximately 10 000 sets of safety PLC systems mainly for automotive manufacturing machine for various types of vehicles.

Today, other domestic manufacturers have developed various types of safety PLCs or safety controllers, and the safety control device market is becoming increasingly competitive.

2. Advantages of Introducing the Safety PLC

Introduction of the safety PLC is beneficial not only in that it helps solve safety control problems caused by a conventional hard-wired system, but also that it makes safety standard compliance easy.
2. 1 Problems Regarding Hard-wired Safety Control

Hard-wired circuits using safety relays are accompanied by the following problems:
1) Complicated circuits
   Complex safety circuits bring about the following problems:
   · Machine start-up is time-consuming due to wiring errors.
   · A bigger control panel is required.
   · High wiring cost is required.
   · Tremendous time needed for design and adjustment.
2) Low machine operation rate
   When an emergency stop occurs due to an unexpected fault such as a failure of a relay, which is a limited-life part, a long time is required for recovery as the hard-wired circuits using relays need to be investigated using a tester, etc., to detect the cause of the fault.

![Logic solver
Composed of single device
Input Output
In case of safety PLC
Emergency stop button
Safety relay
Emergency stop button
Magnetic switch
Sophisticated connection of multiple devices
In case of hard wired logic
Emergency stop button
Safety relay
Safety relay
Magnetic switch
Fig. 2 Electric circuit structure

2. 2 Benefits of Safety Control Using the Safety PLC

Safety control using the safety PLC improves hard-wired circuit problems as well as offers the following benefits:
1) Simplified circuits
   While safety control electric circuits have an input-logic solver-output circuit structure as shown in Fig. 2, for the safety PLC, the logic solver portion has a simple structure made of single devices, because the logic processing is conducted using software.
2) Downsized control panel
   The simplification of electric circuits enables the entire control panel to be downsized. Figure 3 shows what effect employing a safety PLC would have on a machine tool. Since the machine in this example is comparatively large, a substantial effect can be obtained.
3) Improved machine operation rate
   The use of an electronic device in place of a mechanism mainly composed of relays results in remarkably improved reliability, and substantially improved MTBF.
4) Improved maintainability
   Faulty errors which were previously investigated by a tester can now be found with on-line monitoring using panel PCs, etc. In addition, simplified electric circuits make it easier to find the wiring of the faulty part, improving maintainability.

![State of using conventional safety relay unit
State of using safety PLC
Volume of control panel
1
Relay Safety PLC
Volume of control panel
53% reduction
Fig. 3 Control panel downsizing

Relay Safety PLC
Volume of control panel
53% reduction
5) Adaptability to safety standards

Since the SIL calculation of IEC61508 and IEC62061 or PL calculation of ISO13849-1 is made easier, it becomes easier to design machines to meet safety standards. In both the SIL and PL calculations, it is necessary to take into account all connected safety-related devices (Fig. 4).

Since the use of the safety PLC results in a structure as simple as that shown in Fig. 5, these calculations can be easily made. Figures 6 and 7 show examples of SIL calculations based on the structure shown in Fig. 5.

### Table 1 Judgment table of SIL value

<table>
<thead>
<tr>
<th>PFD</th>
<th>SIL</th>
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<tbody>
<tr>
<td>&gt;10^-4 up to &lt;10^-3</td>
<td>3</td>
</tr>
<tr>
<td>&gt;10^-3 up to &lt;10^-2</td>
<td>2</td>
</tr>
<tr>
<td>&gt;10^-2 up to &lt;10^-1</td>
<td>1</td>
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</table>

### Table 2 Judgment table of PL value

The PL of the entire system is calculated as follows: PL_{low}=c

<table>
<thead>
<tr>
<th>P_{low}</th>
<th>N_{low}</th>
<th>PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>&gt;3</td>
<td>none, not permitted</td>
</tr>
<tr>
<td>b</td>
<td>&gt;2</td>
<td>a</td>
</tr>
<tr>
<td>c</td>
<td>&gt;2</td>
<td>b</td>
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<tr>
<td>d</td>
<td>&gt;3</td>
<td>c</td>
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<tr>
<td>e</td>
<td>&gt;3</td>
<td>d</td>
</tr>
<tr>
<td>f</td>
<td>&gt;3</td>
<td>e</td>
</tr>
</tbody>
</table>

Furthermore, in the PL calculation of ISO13849-1, the safety PLC allows us to apply a high PL due to less structural devices.

In the aforementioned examples, c can be assigned for PL, but hard-wired circuits with complex device structures, if the number of structural factors at PL=c reaches 3 or more, one rank lower PL, and PL = b must be applied (Table 2).
3. Conventional TOYOPUC-PCS Problems and TOYOPUC-PCS-J Development Objectives

The TOYOPUC-PCS, Japan’s first safety PLC had the effects described above, and was developed for large scale machine which was deemed to need the safety PLC the most.

While TOYOPUC-PCS features a maximum of 2,048 safety remote I/O communication points and 24 stations, enabling large-scale safety control, reaction time is 50.5 ms, regardless of machine scale, representing extremely superior safety performance.

Thus, for centralized safety control of automotive manufacturing lines or for large-sized machine, TOYOPUC-PCS offers substantial merits in both size and cost, compared to safety relay control.

On the other hand, in regards to small-sized individual machine, safety control is still constituted based on safety relays. Therefore, there has been expectation for the development of compact, low cost safety PLCs that can be used with this category of machinery.

This is why we have developed the new safety PLC; TOYOPUC-PCS-J, which offers advantages like compactness and cost for compact individual machine, while inheriting various superior features of the conventional TOYOPUC-PCS.

4. Development Concepts

The development of TOYOPUC-PCS-J has advanced in line with the following concepts:

4.1 Downsizing

Based on the safety PLC technology established when the TOYOPUC-PCS was developed and certified, various efforts to downsize machine were made, including a review of safety requirements, achievement of a more efficient circuit structure and so on.

1) I/O-integrated CPU module and input-output-mixed I/O module

By integrating the CPU and the I/O, a module structure only 75mm wide is capable of handling the minimum unit safety control. Also, mixing the input and output circuits in the I/O structure makes module selection efficient particularly in small-scaled machine.

1) Thermal design

Even if the circuit structure is made more efficient, efforts for downsizing should always take into consideration the problem of thermal control.

The basis of thermal control consists of how well heat is dissipated and how well heat generation is restricted. In the TOYOPUC-PCS-J, the amount of heat generation in the output circuit is reduced to restrict heat generation. Each output of the safety PLC is accompanied by a read-back detection circuit to monitor individual outputs. Because TOYOPUC-PCS uses two outputs to drive the load, it is equipped with a reverse-flow-protection diode to prevent the read-back detection circuit from malfunctioning. When the load current flows through this reverse-flow-protection diode, the diode is heated.

In the TOYOPUC-PCS-J therefore, reverse-flow-protection diode is eliminated by driving the load with only one output, so as to suppress heat generation. However, this prohibits parallel connection of the load which was recognized in TOYOPUC-PCS. Also, prior to production of the device body, thermal simulation analysis was conducted to verify that heat generation was within specification.
4. 2 Improved Maintainability

While the conventional TOYOPUC-PCS requires the use of tools for replacement of the module, the TOYOPUC-PCS-J allows us to replace the module without using any tools, improving workability.

1) DIN rail mounting
   As the module is of a hook and lever linked structure which can be mounted on the DIN rail, it can be mounted and dismounted without using tools.

2) Securement of terminal blocks using hooks
   Gripping the hook on the wiring side of the block helps release the terminal block, so that the terminal block can be mounted and dismounted without using any tools.

4. 3 Interchangeability with TOYOPUC-PCS

Expected that some customers who have introduced TOYOPUC-PCS may introduce TOYOPUC-PCS-J, or new customers may introduce the JTEKT safety PLC series, we have taken into consideration interchangeability in the following aspects so that such customers can introduce both for lines and for individual machine with common ease.

· Maintain a performance equivalent to TOYOPUC-PCS.
· Provide programming tools with the same operability as the programming tools of Pcwin-Safe for TOYOPUC-PCS.
· Existing TOYOPUC-PCS sequence program can be diverted to TOYOPUC-PCS-J.
5. TOYOPUC-PCS-J Features

The TOYOPUC-PCS-J thus developed has the following features:

1) Downsizing

Using the TOYOPUC-PCS-J on the above-mentioned machine tool enables the space for safety devices to be drastically reduced compared to the TOYOPUC-PCS (Fig. 14).

2) Low cost

Substantial cost reduction on an individual machine basis can be expected. In the above-mentioned example of application with a machine tool, while the TOYOPUC-PCS offers only slight cost merit compared to the safety relay, the TOYOPUC-PCS-J achieves substantial device cost reduction (Fig. 15).

3) High performance

Table 3 gives a comparison of specifications between the TOYOPUC-PCS-J and the conventional TOYOPUC-PCS and their lineup, indicating that the TOYOPUC-PCS-J has a performance level equivalent to the TOYOPUC-PCS in regards to program size, memory capacity and processing speed. However, as specifications are for individual machine, the TOYOPUC-PCS has a larger number of maximum possible I/O points.

4) Supply of integrated environmental tool: Pcwin-Safe2

So that customers who have already introduced the TOYOPUC-PCS may introduce the TOYOPUC-PCS-J smoothly, or so that new customers who are planning on introducing the JTEKT safety PLC series may introduce these PLCs for line and for individual machine with common ease, we have provided integrated environment programming tools that can handle both these safety PLC series.

The PCwin-Safe2 includes the following software and utility programs:

· Certified programming tool for the TOYOPUC-PCS: PCwin-Safe
· Certified programming tool for the TOYOPUC-PCS-J: PCwin-Safe-J

The PCwin-Safe-J has the same operability as the PCwin-Safe and has been certified by a certifying agency. The program data compiled by the PCwin-Safe can be diverted to the PCwin-Safe-J through the import function.

· Support utility program for program diversion from the TOYOPUC-PCS

Fig. 14 Downsizing

Fig. 15 Cost reduction
As the import operation is supported in a wizard format, it is possible to divert a program without using a manual.

- List of related manuals
  - The list is displayed in HTML format, with an updating function for the latest data.
- Utility program for error monitoring

<table>
<thead>
<tr>
<th>Table 3 Specifications and lineup</th>
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<tr>
<td><strong>Item</strong></td>
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<tr>
<td>Program size</td>
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<td>FB program size</td>
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<tr>
<td>Comment size</td>
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<tr>
<td>Number of I/O points</td>
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<tr>
<td>Number of I/O modules (Number of slots)</td>
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<tr>
<td>Safety communication</td>
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<tr>
<td>Scanning time</td>
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<tr>
<td>(Without safety communication)</td>
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<tr>
<td>Max. reaction time (Transistor output)</td>
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<tr>
<td>(Transistor output)</td>
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<th>Item</th>
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<tbody>
<tr>
<td><strong>CPU module</strong></td>
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<tr>
<td><strong>Power source module</strong></td>
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<tr>
<td>Base</td>
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<tr>
<td>Safety communication module</td>
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<tr>
<td></td>
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<tr>
<td><strong>Input</strong></td>
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<td><strong>Output</strong></td>
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As a troubleshooting guide incorporating experiences in the field is displayed linked with the error monitoring, quick troubleshooting is possible.
6. Conclusion

Thanks to the TOYOPUC-PCS-J joining the TOYOPUC-PCS series lineup, it is now possible to make system proposals for a broad range of applications targeting automotive manufacturing machine from individual machine to lines. In addition, there is a great deal of machine in industries other than automotive where TOYOPUC-PCS-J can be applied. The TOYOPUC-PCS-J is therefore believed to be a product that can be promoted in new markets.

JTEKT, as the forerunner of the safety PLC in Japan, will provide TOYOPUC-PCS series shipment of approximately 10 000 sets that can used for more and more machine, and will contribute to the creation of a safe working environment where workers can work with peace of mind.

*1 TOYOPUC is a registered trademark of JTEKT Corporation
*2 PCwin is a registered trademark of JTEKT Corporation